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Technical and Economic Assessment of Medium Sized Solar-Assisted Air-Conditioning in Brazil

DISSERTAÇÃO DE MESTRADO

Dissertation presented to the Postgraduate Program in Urban and Environmental Engineering of the Departamento de Engenharia Civil, PUC-Rio as partial fulfillment of the requirements for the degree of Mestre m Engenharia Urbana e Ambiental (opção Profissional).

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Ever bigger machines, entailing ever bigger concentrations of economic power and exerting ever greater violence against the environment, do not represent progress: they are a denial of wisdom. Wisdom demands a new orientation of science and technology towards the organic, the gentle, the non-violent, the elegant and beautiful.

E. F. Schumacher
Small Is Beautiful: a study of economics as if people mattered

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Resumo

Till Felix Reichardt, Romanel, Celso (Orientador); Pereira, E. (Co-orientadora)**. Análise técnica e econômica de sistemas de ar-condicionado de médio porte assistido por energia solar térmica no Brasil**. Rio de Janeiro, 2010. 135 p. Dissertação de Mestrado - Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

No Brasil, devido ao clima tropical, muita energia elétrica é utilizada em sistemas de ar condicionado. Devido à excelente irradiação solar que incide na maior parte do país, existem boas condições para atender esta grande demanda de refrigeração através da utilização de sistemas de ar condicionado assistido por energia solar térmica. Nesta dissertação, as mais importantes tecnologias que utilizam a energia solar para a climatização foram verificadas quanto a sua aplicabilidade técnica e econômica no Brasil, com foco em sistemas de médio porte. Os princípios básicos para o dimensionamento de um sistema de refrigeração solar são descritos e um estudo de caso é apresentado e discutido, comparando-se um sistema de ar condicionado assistido por energia solar (auditório em Guaratinguetá, São Paulo) com um sistema tipo split convencional. No estudo deste caso, a dinâmica de simulação térmica de edifícios foi modelada utilizando o programa Helios-PC. Também se analisa como a carga térmica de resfriamento pode ser diminuída considerando-se uma temperatura adequada no interior da edificação, de acordo com as normas brasileiras de conforto térmico, como também pelo emprego de isolamento adequado na construção do edifício.

Palavras - chave

Ar condicionado solar; Coletores solares térmicos; Simulação da carga térmica de resfriamento; Eficiência energética; Estimativa econômica.

Abstract

Till Felix Reichardt, Romanel, Celso (Advisor), Pereira, Elizabeth Duarte (Co-advisor). **Technical and economic assessment of medium sized Solar-Assisted Air-Conditioning in Brazil**. Rio de Janeiro, 2010. 135 p. M.Sc. Dissertation – Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

In Brazil a lot of electrical energy is used by building air-conditioning because of the tropical climate. In many cases there is a general congruence of solar irradiation and demand for building air-conditioning and solar thermal cooling has the potential to satisfy a part of the rapidly growing cooling demand. Due to excellent solar irradiance and a high cooling demand there exists in Brazil good conditions for the use of solar-assisted air-conditioning. In this work the most important solar cooling techniques and their suitability in Brazil are discussed. The objective of the present study is to analyze the technical and economic feasibility of medium sized solar-assisted air-conditioning in Brazil. The energy saving potential of solar-thermal air-conditioning in comparison to best practical solutions in Brazil using conventional split air-conditioning systems, is shown based on a case study (auditorium in Guaratinguetá - São Paulo). The economy of solar-assisted air-conditioning is thereby discussed. The basic principles for the dimensioning of a system for solar cooling are described. The auditorium in the case study is modelled by using the dynamic thermal building simulation program Helios-PC. In this context it is, as well, demonstrated how the cooling load could be decreased by adapting the indoor temperature according to the Brazilian standards of thermal comfort and by using building insulation.

Keywords

Solar cooling air-conditioning; Solar thermal collectors; Dynamic thermal building simulation; Energy efficiency; Economic assessment.

Zusammenfassung

Till Felix Reichardt, Romanel, Celso (Betreuer); Pereira, Elizabeth Duarte (Zweitbetreuerin)**. Technical and economic assessment on medium sized Solar-Assisted Air-Conditioning in Brazil**. Rio de Janeiro, 2010. 135 S. – Abteilung Bauingenieurwesen, Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

In Brasilien wird aufgrund des tropischen Klimas, ein großer Anteil der elektrischen Energie für die Kühlung von Gebäuden verwendet. Aufgrund des stark wachsenden Klimakältebedarfs und der hervorragenden solaren Einstrahlbeding ergeben sich gute Bedingungen für den Einsatz von solarthermischer Klimakälteerzeugung. Hierbei stimmt das Angebot an solarer Einstrahlung zeitlich weitgehend mit dem Klimakältebedarf überein. In der vorliegenden Masterarbeit werden die wichtigsten Verfahren zur solaren Kälteerzeugung und ihre Eignung in Brasilien erörtert. Daraufhin wird anhand einer Fallstudie (Hörsaal in Guaratinguetá - São Paulo) überprüft, in wie weit solarthermische Klimakälteerzeugung eine energieeffiziente Alternative gegenüber Split-Kompaktklimageräten sein kann. Dabei wird anhand einer thermischen Gebäudesimulation zur Kühllastberechnung ermittelt, wie hoch der solare Deckungsgrad wäre. In diesem Kontext wird dargestellt, wie die Kühllast durch die Anpassung der Raumtemperatur an die brasilianischen Normen für thermischen Komfort und durch Gebäudeisolierung gesenkt werden könnte. Abschließend wird die Wirtschaftlichkeit von solarthermischer Klimakälteerzeugung im in Brasilien überprüft. Das thermische Verhalten des Hörsaals ist durch das dynamische Gebäudesimulationsprogramm Helios-PC abgebildet.

Schlüsselwörter

Solares Kühlen; Klimaanlage; Solarkollektoren; Dynamische Gebäudesimulation; Kühllast; Energieeffizienz; Wirtschaftlichkeitsberechnung.

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List of symbols

A	area
a_1	heat transfer coefficient
a_2	temperature depending heat transfer coefficient
COP_{Sol}	solar collector efficiency
C_w	heat capacity of water
G	solar irradiance at collector surface
h_{amb}	enthalpy ambient air
h_{supply}	enthalpy air supply
$m(t)$	water flow
m_{supply}	mass air flow
P_{el}	electric power input
Q	cooling capacity
Q_{cold}	useful cold
Q_{drive}	driving heat
Q_{reg}	external regeneration heat
t_a	ambient temperature
T_C	low temperature
T_H	high temperature
Ti	indoor temperature
t_m	average temperature solar collector
T_M	medium temperature
ΔT	temperature difference
η	efficiency factor
η_0	optical efficiency solar collector
η_{coll}	efficiency factor solar collector

List of acronyms and abbreviations

HVAC	Heating, Ventilating and Air Conditioning
IR	Infrared Radiation
Eletrobrás	Brazilian energy company with headquarters in Rio de Janeiro. The company produces and sells electricity. The majority of the share capital is held by the Brazilian government. It is the biggest energy company in Brazil as well as in Latin America.
PROCEL	Brazilian Energy Saving Program
UNESP	São Paulo State University
GTZ	German Technical Cooperation. The GTZ GmbH is an international cooperation enterprise for sustainable development with worldwide operations.
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
INMETRO	Brazilian Institute of Metrology, Standardization and Industrial Quality
INMET	Brazilian Institute of Meteorology
GREENSolar	Is the only Brazilian laboratory which is testing solar collectors for the INMETRO

DEC	Desiccant Evaporative Cooling Open cycle air-conditioning process. Central components: sorptive air dehumidification, using either solid or liquid sorption material; heat recovery unit; return (and often supply) air humidifiers. Requires separate supply and return air ducts.
COP	Coefficient of Performance Performance number of thermally driven chillers: Ratio of (cold production) / (driving heat input) Used with power units (kW/kW) to provide rated values, or with energy units (kWh/kWh) to provide the performance during longer periods.
EER	Electrical Efficiency Ratio Performance number of electrically driven compression chillers: Ratio of (cold production) / (electricity input). Used with power units (kW/kW) to provide rated values, or with energy units (kWh/kWh) to provide the performance during longer periods.

1
Introduction

The use of solar thermal energy for air-conditioning in hot and sunny climate is a promising new application of solar thermal collectors in buildings. The main advantage is that in solar air conditioning applications cooling loads and solar gains occur at the same time and on seasonal level.

In Brazil the energy demand for refrigeration and air-conditioning correspond to approximately 15 % (134 TWh/year) of the total country energy use [1].

Around 48% of energy is consumed in commercial and public buildings due to air conditioners, usually by driving electrical vapour compression chillers [2].

Solar cooling has the potential of significantly reducing the electricity consumption, contribute fossil energy saving and electrical peak load reduction. The solar array yields thermal load reduction of the building. Furthermore it contributes in a positive way the urban microclimate through absorbing the solar irradiation on the roofs. Last but not least Solar cooling decrease the ecological footprint of tropical cities due to achieving carbon emission reduction and using environmental friendly refrigerants.

Figure 1.1 shows a Hotel in Japan which is using solar energy for providing HVAC and domestic hot water. The solar array provides shading. All of the mechanical equipment is underneath the array.

Figure 1.1 - Okura Act City Hotel in Hamamatsu, Japan. This building was designed with Solar energy in mind [3].

Many of the huge agglomerations, such as Rio de Janeiro and São Paulo, are located in or at the boundaries of the inter-tropical zone and additionally in developing countries. Figure 1.2 shows a comparison of global climatic map with the population distribution.

The climatic advantages in the Tropics have led to the highest density of population highest population growth [4].

More than a third of the world's population live between the Tropic of Cancer and the Tropic of Capricorn. The Tropical belt has become the most densely populated and thus poorest region of the planet. Latin American and the Caribbean are the most urbanized regions in the World [5].

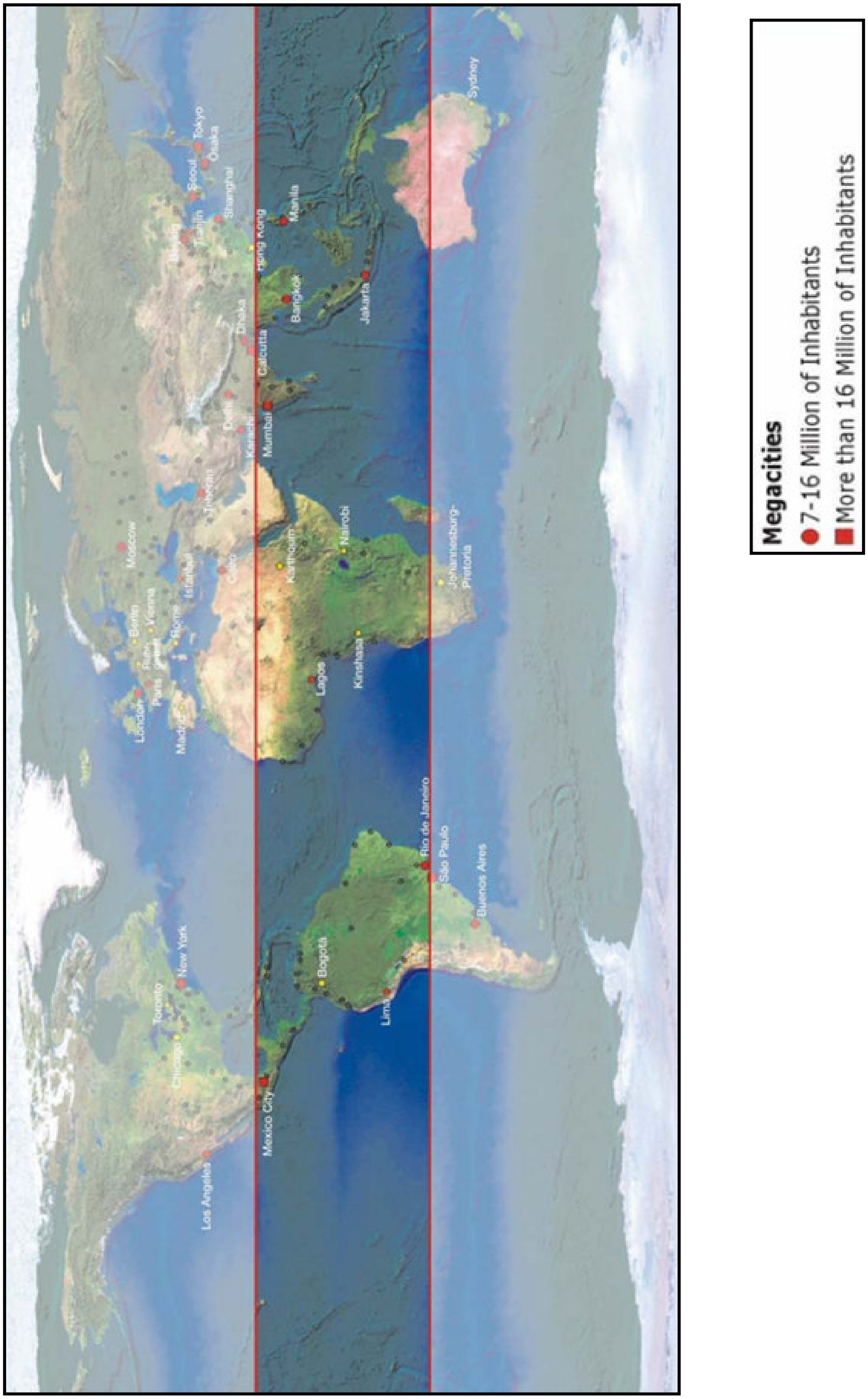


Figure 1.2 - Megacities of the tropical Belt (modified) [4].

In tropical latitudes, the impact of urban climate is associated to more negative effects on thermal comfort and the energy consumption of buildings than in the cities of the temperate climate zones, due to higher solar radiation income [6].

On the existing high temperatures in the tropical occurs an further temperature increase by the formation of the so called 'urban heat island' in created mainly by the lack of vegetation, into the environment conducted waste heat (e.g. due to the heat rejection of air-conditioning) and by the high solar radiation absorptance of urban surfaces.
Predicted climate changes due to anthropogenic emissions will cause also an increase in mean atmosphere temperatures and atmospheric IR radiation [7].
Taking all these facts into account the cooling demand increases and in future more and more buildings will be air-conditioned. For these reasons the country's energy consumption increases mostly due to in the "small" and "medium" range less-efficient applied split air-conditioners and package systems. Figure 1.3 shows a typical building in Brazil with applied split air-conditioners.

Figure 1.3 - Applied electrically driven compression air-conditioning at a commercial building in Rio de Janeiro - Brazil.

The annual growth in Brazil of the cooling and air-conditioning market in terms of capacity is expected the range of 4.5 GW/y (1.3 million TR/y) [1].

This corresponds to the sales rate of room split air-conditioners and package systems for capacities < 5 kW for South America in 2008, published by JARN [8].

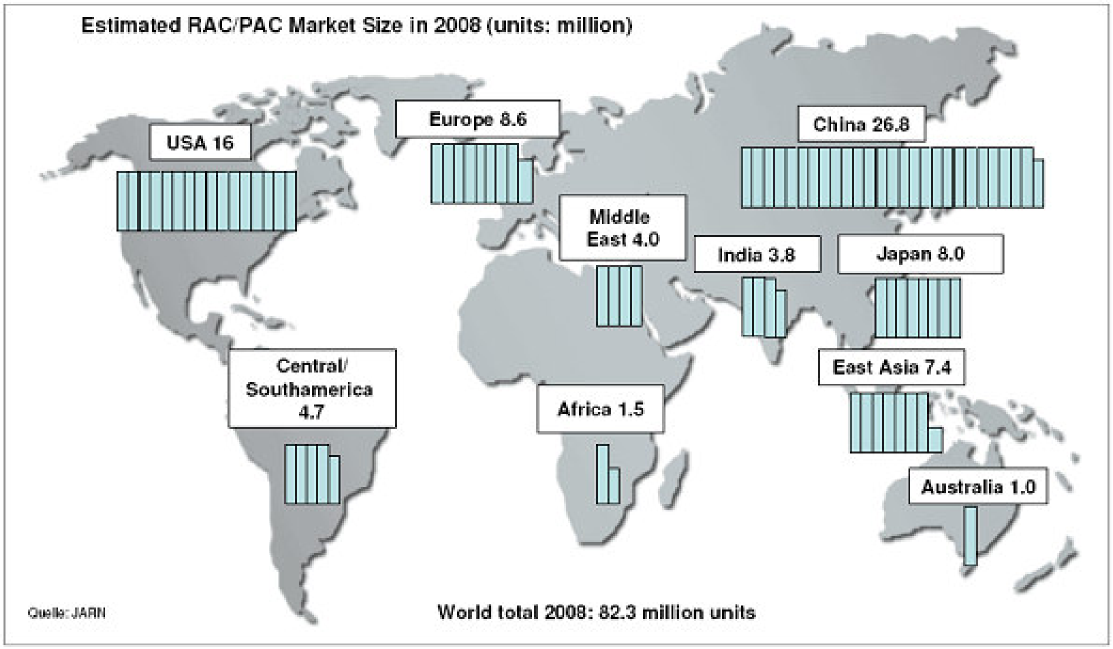


Figure 1.4 - World market sales rate in 2008 of split air-conditioners and package systems in the capacity range < 5 kW (1.42 million TR). Source: JARN

In hot and humid regions the use of free cooling techniques are limited and can not guarantee that the indoor comfort will be fulfilled all the time. To contribute a sustainable urban development in Brazil, another energy-efficient cooling technology must be implemented – the solar cooling.

By the growing environmental concerns and consistent effort in research and product development the interest in solar air-conditioning technology has increased in the last years. All over the World solar-assisted Air-Conditioning demonstration projects are showing that the technologies are mature.

Until now, there is not a pilot project for solar air-conditioning of buildings in Brazil.

The Eletrobrás/PROCEL (Brazilian electricity Conservation Program) will establish a centre for energy efficiency education in Guaratinguetá at the University UNESP (Universidade Estadual Paulista) and has the intention to equip the auditorium with a solar air-conditioning system.

The Project will be, likely realized in cooperation with the GTZ (german technical cooperation) within the framework of the GTZ energy program for the purpose supporting regenerative energies and energy efficiency in Brazil.

For the appropriate design of such a solar cooling system, the building must be simulated by using local meteorically data to determine the correlation between solar gain and cooling load.

Furthermore it must be analyzed which solar cooling technology is suitable under the specific climatic conditions and if the alternative technology can compete economically with conventional split air-conditioners.

The basis of this work is primarily a GTZ commissioned technology study "solar cooling in Brazil" developed by Fraunhofer Institute of Solar Energy Systems ISE (Germany).

The thesis is organized into the following main chapters:

The next chapter starts with a critical overview on existed solar cooling technologies and their scope regarding the climate conditions in Brazil. It describes the fundamentals of solar building cooling, function and their benefits. In these chapter will be principally discussed the use of open cycle processes (DEC) and Photovoltaic driven compression chillers in comparison to sorption chilled water systems. Summarized, it intended to give the reader an introductory technical background. It is followed a practical relevant case study.

Chapter 3 includes the main focus of this work. First it informs about the intended pilot-project in Guaratinguetá and gives some background knowledge regarding building cooling and air-conditioning. It describes the building and the energy simulation program Helios-PC which is used to simulate its thermal behaviour. The next steps in this chapter are as follows:

- Comparing of different in Brazil available solar collectors
- Simulation of Correlation Solar gain / cooling demand
- Choice and design of the appropriate solar cooling technology
- Assessment of the economically viability in comparison to conventional compressor Split Air-conditioning. Including the Assessment of two different Back-up possibilities for Solar-assisted Air-Conditioning System: a) back-up with Split Air-Conditioning b) thermally back-up with Gas
- Environmental benefits

Beside the Simulation and Design of solar cooling system it shows how the cooling demand (thermal load) of the building could be reduced by changing the indoor set temperature within the Brazilian standards (PNB-10) and by using building insulation.

Finally Chapter 4 Conclusion and Recommendations presents the results obtained and concludes the study, adding some general recommendations on solar-assisted air-conditioning.

1.1
Objective

The goal of this work is to verify if solar-assisted air-conditioning in the "medium" capacity range can already be an alternative energy saving technology for building air-conditioning in Brazil. In this context a Case Study - Auditorium in Guaratinguetá - will be done, thus the following necessary question can be answered:

- Which technology can be used and is available?
- Which is the best system for the given application under the conditions of the specific-site?
- How is the correlation between solar gain and cooling demand?
- Is the use of solar-assisted air-conditioning feasible for the building?
- Which cold distribution is suitable under the specific climatic condition (hot and humid climate)?
- Which solar collector is the most cost-effective on the Brazilian market?
- What dimensions of the solar collector area and other system components results the best energy cost performance?
- Is another ecological and economical alternative feasible for example active night-cooling?
- How can the high investment cost of solar cooling system be decreased?
- How it's possible to decrease the cooling demand of a building and hence the cooling capacity of the solar cooling system, which leads to lower investment cost?
- Which back-up system is under the local energy prices (gas/electricity) appropriate?
- Can solar assisted air conditioning already compete economically with in the "small" and "medium" cooling capacity range often applied conventional compressor Split Air-conditioning Systems?

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)

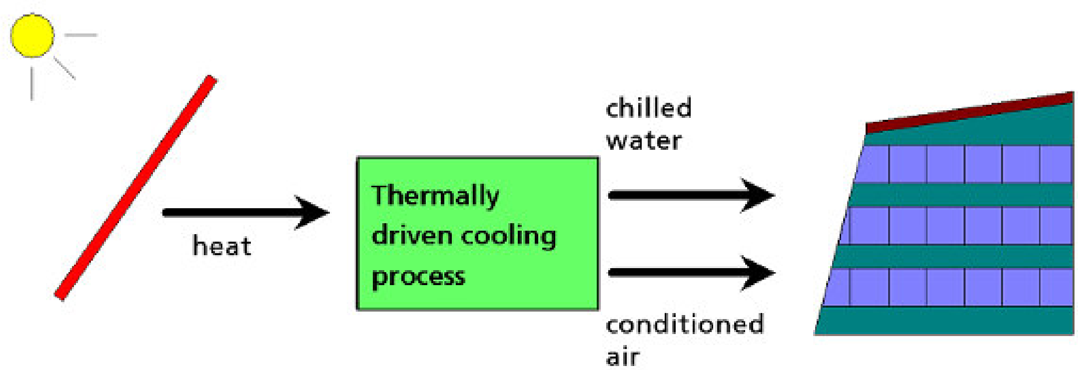


Figure 2.1 - General Scheme of the thermally driven cooling process [8].

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].

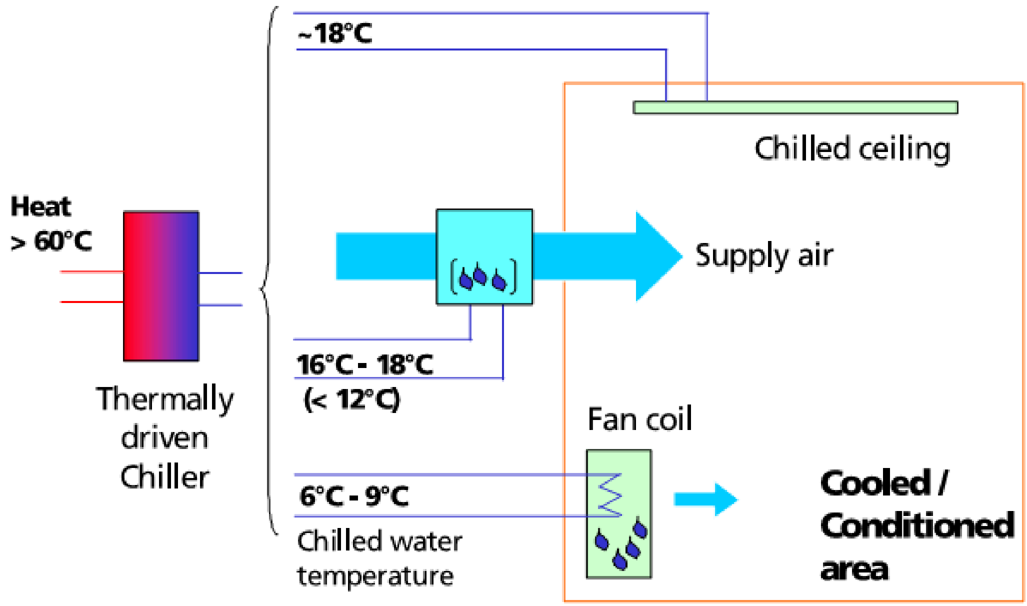


Figure 2.2 - Closed cycle system, chiller water is produced in a closed loop for different decentral application or for supply air cooling [9].

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.

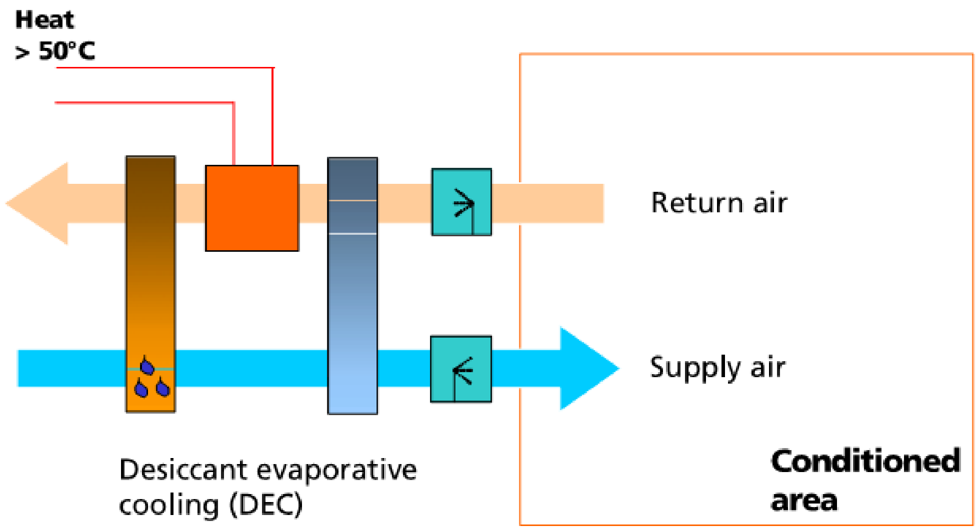


Figure 2.3 - Open sorption cycle: Supply air is directly cooled and dehumidified [8].

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.

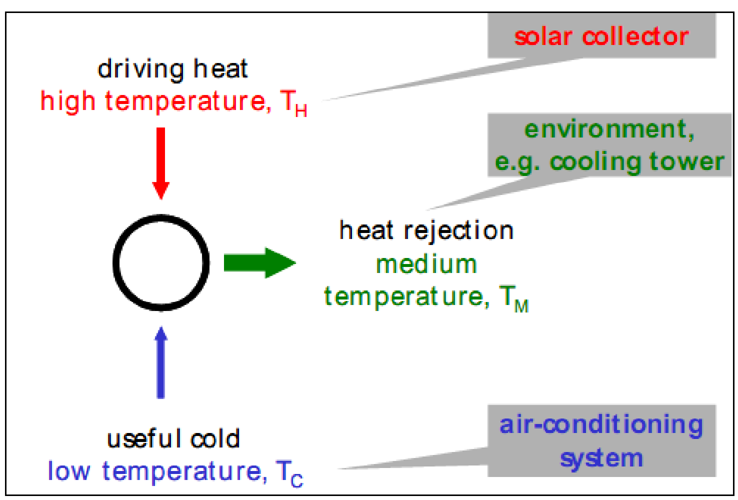


Figure 2.4 - Thermodynamic principle of thermally driven cooling [8].

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].

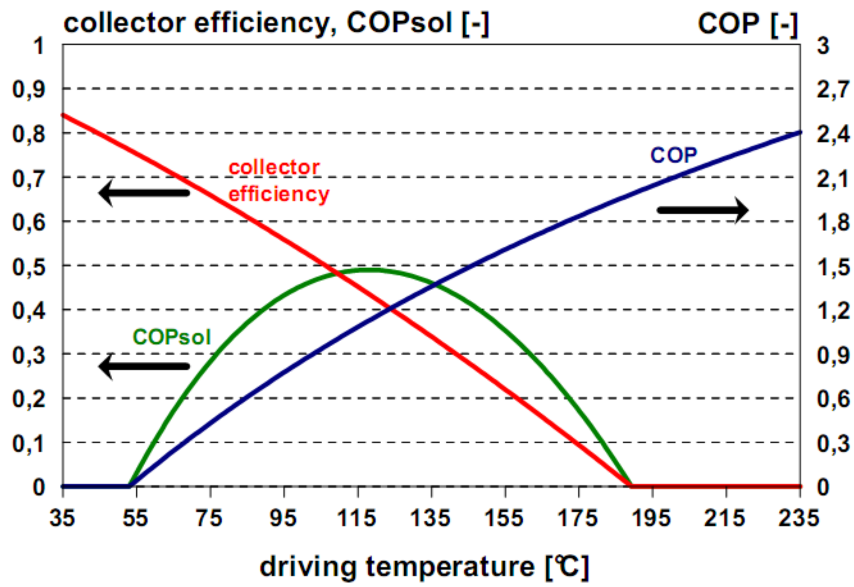


Figure 2.5 - Theoretic limit of solar thermal driven cooling processes [11].

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.

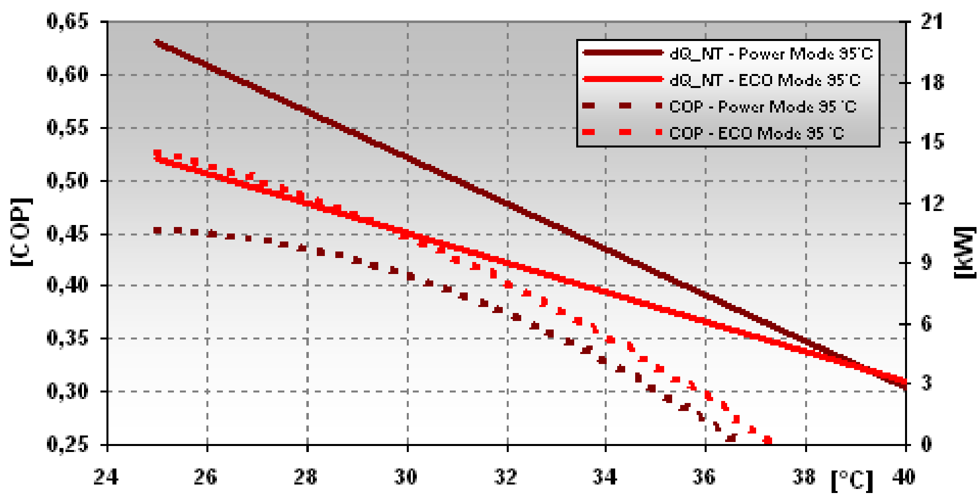


Figure 2.6 - Example manufacturer Data; COP and Cooling Power [KW] in relation to the heat rejection water temperature are shown as a function of the constant fan-coil cooling water temperature for driving a fan-coil. Source: Solvis Energy Systems GmbH&Co.KG

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.

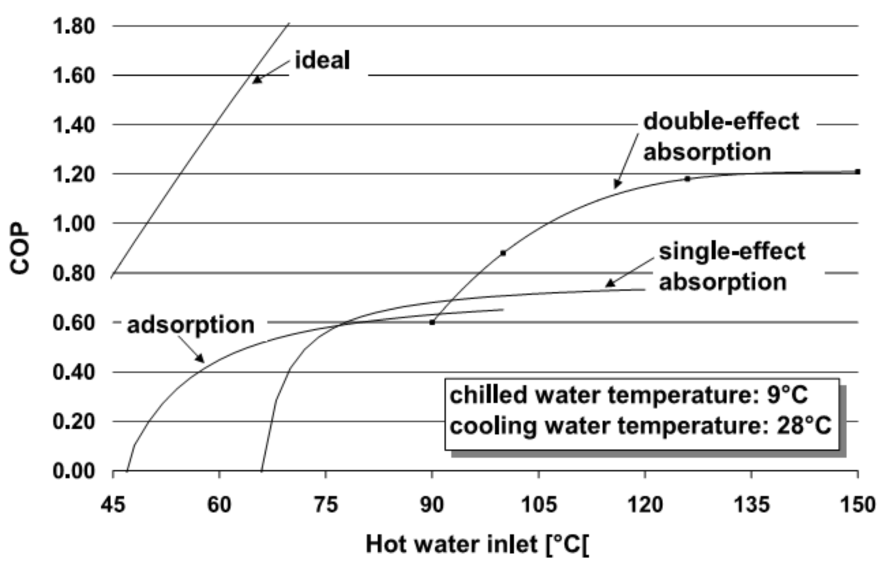


Figure 2.7 - Exemplary curves of the coefficient of performance COP for different sorption chiller technologies and the limit curve for an ideal process. The curves are shown as a function of the driving temperature and for a constant chilled and cooling water temperature [10].

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, $\dot{Q}_{reg}$:

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

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:

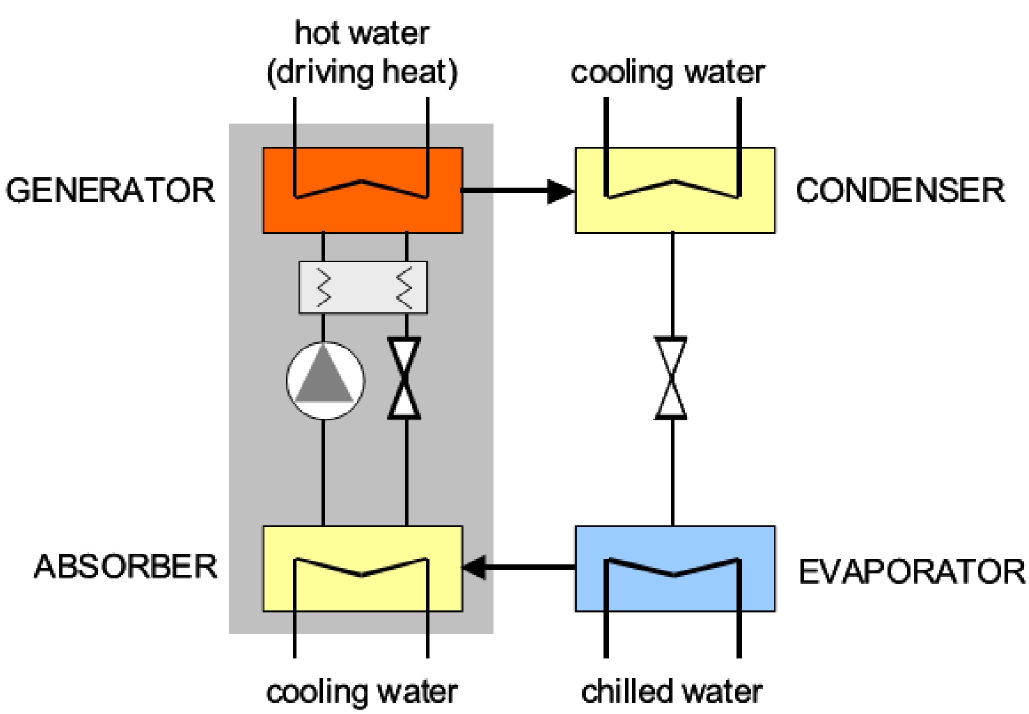


Figure 2.8 - Schematic drawing of an absorption chiller producing chilled water [8].

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

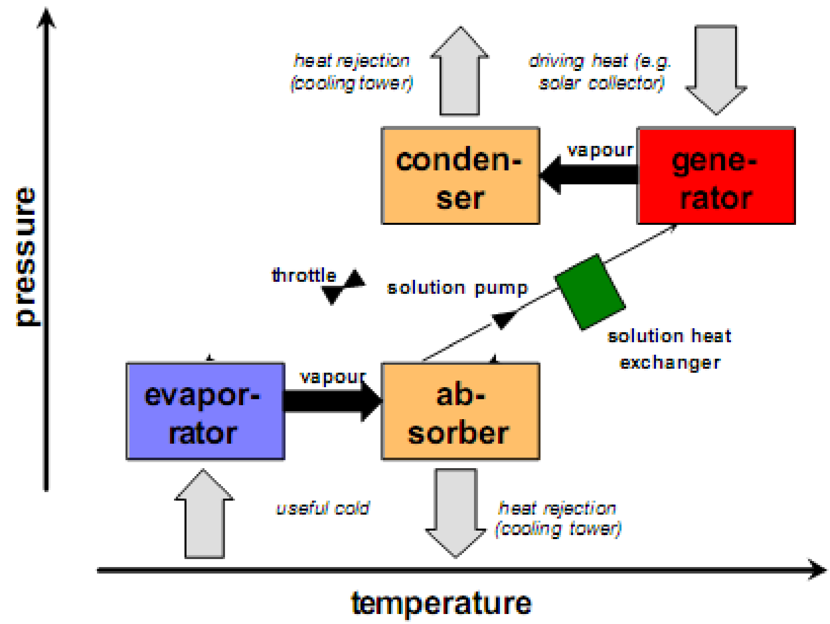


Figure 2.9 - Vapour pressure as a function of vapour temperature in an absorption Cooling cycle process [8].

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.

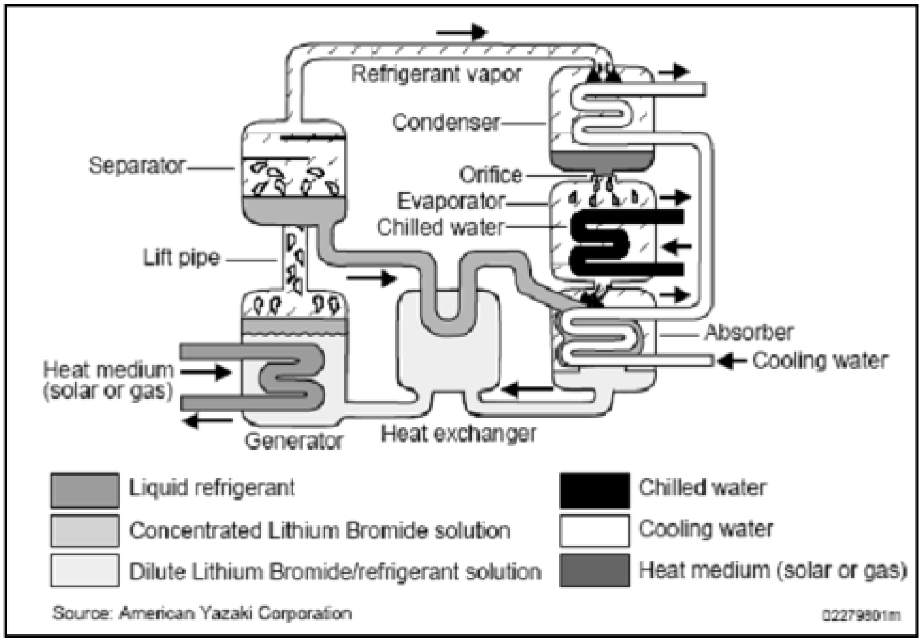


Figure 2.10 - Detail function scheme of a single-effect Absorption chiller. Source: Yazaki Energy Systems Inc.

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.

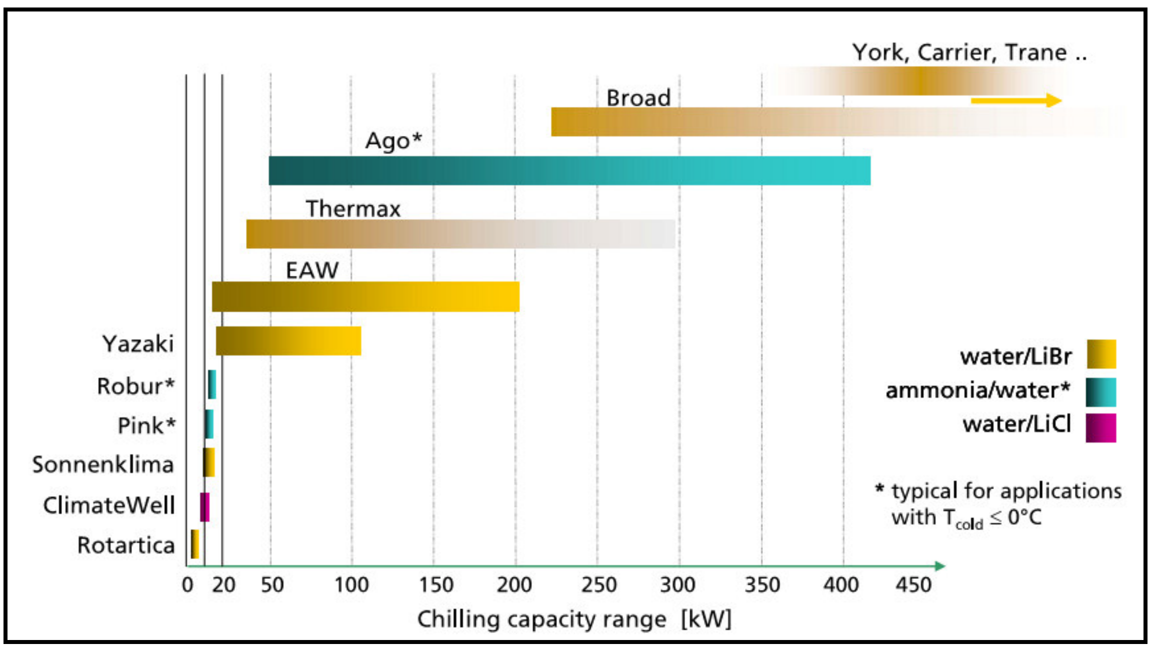


Figure 2.11 - Typical capacity range of hot water driven absorption chillers [7].
No claim to be complete.

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.

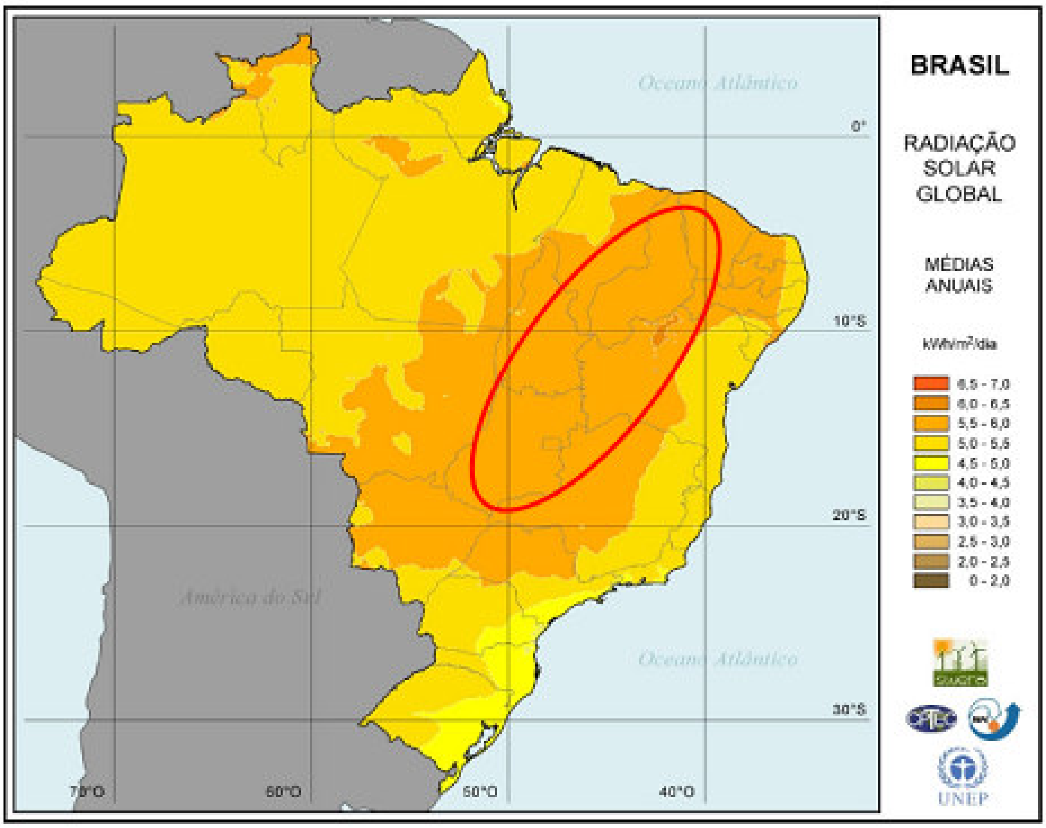


Figure 2.12 - Global solar radiation map of Brazil. In the highlighted area it makes sense to apply tracked concentration collector. Source: Atlas Brasileiro de Energia Solar

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.

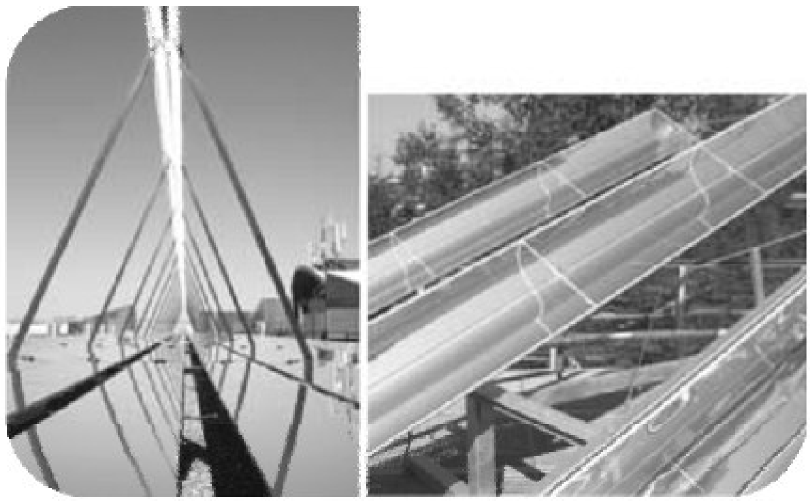


Figure 2.13 - Examples of 1-axis tracked concentration solar thermal collectors.

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.

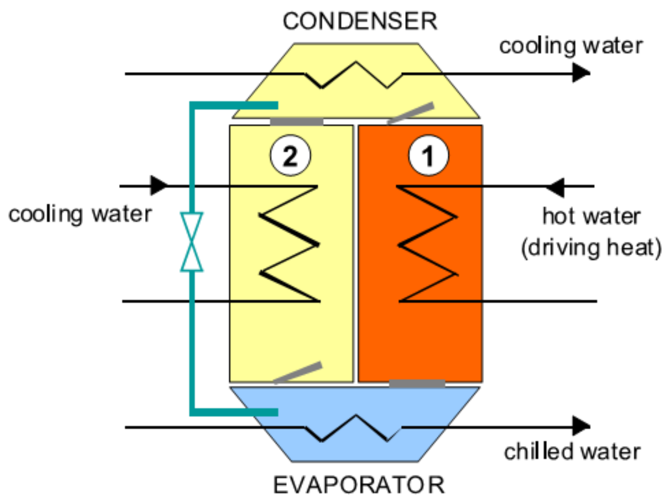


Figure 2.15 - Scheme of an adsorption chiller. They consist of two sorbent compartment 1 and 2, and the evaporator and condenser [8].

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.

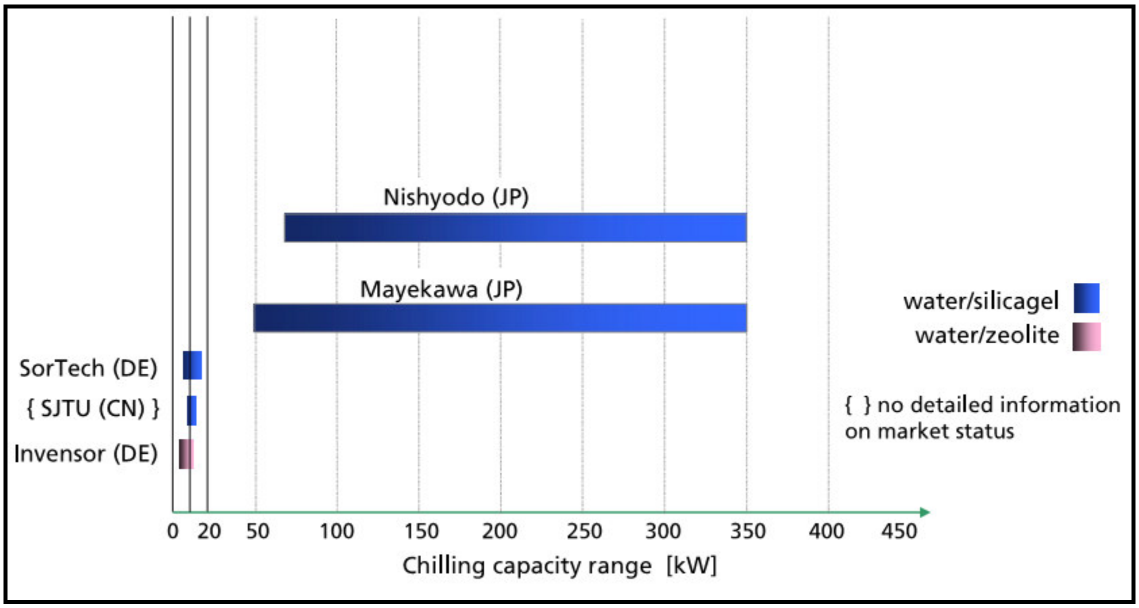


Figure 2.17 - Available adsorption chillers [7]. No claim to be complete.

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.

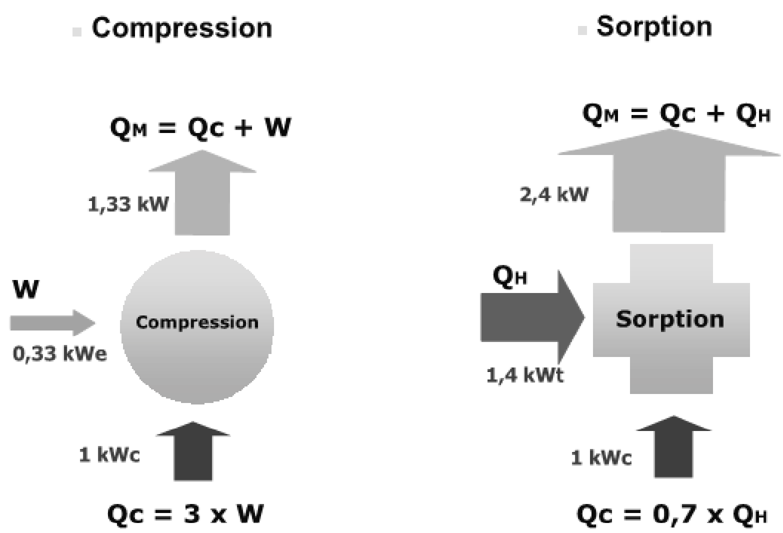


Figure 2.18 - Example on the demand for heat rejection in a conventional electrically driven compression chiller system (left) and in a (single-effect) thermally driven chiller system (right). In the comparison, the chilling capacity is 1 kW in both systems. Typical efficiency numbers have been used.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

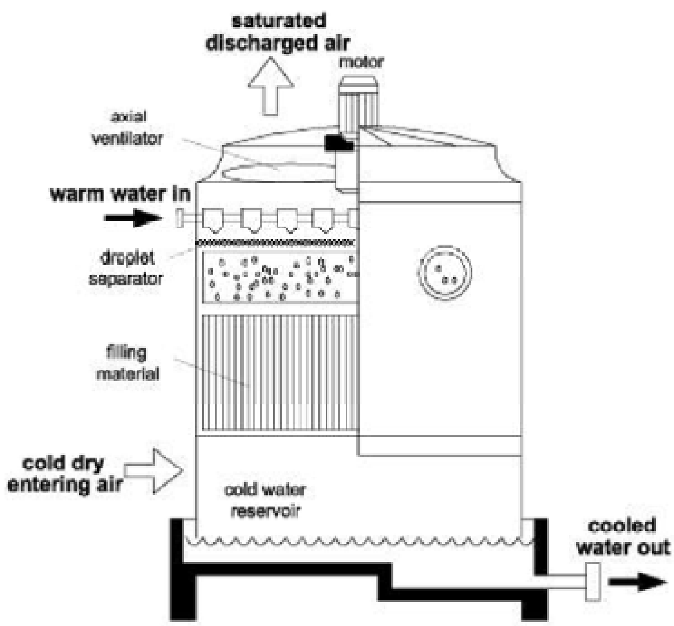


Figure 2.19 - Typical scheme of an open wet cooling tower [10].

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):

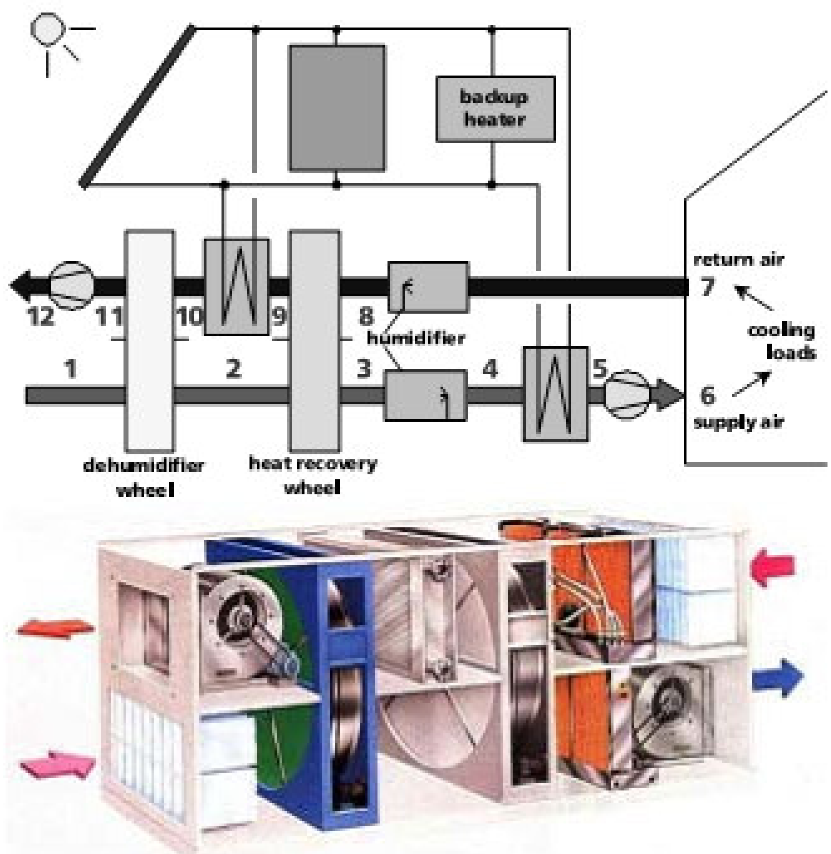


Figure 2.20 - Scheme of a solar thermally driven solid Desiccant Evaporative Cooling system (DEC), using rotating sorption and heat recovery wheels [8].

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.

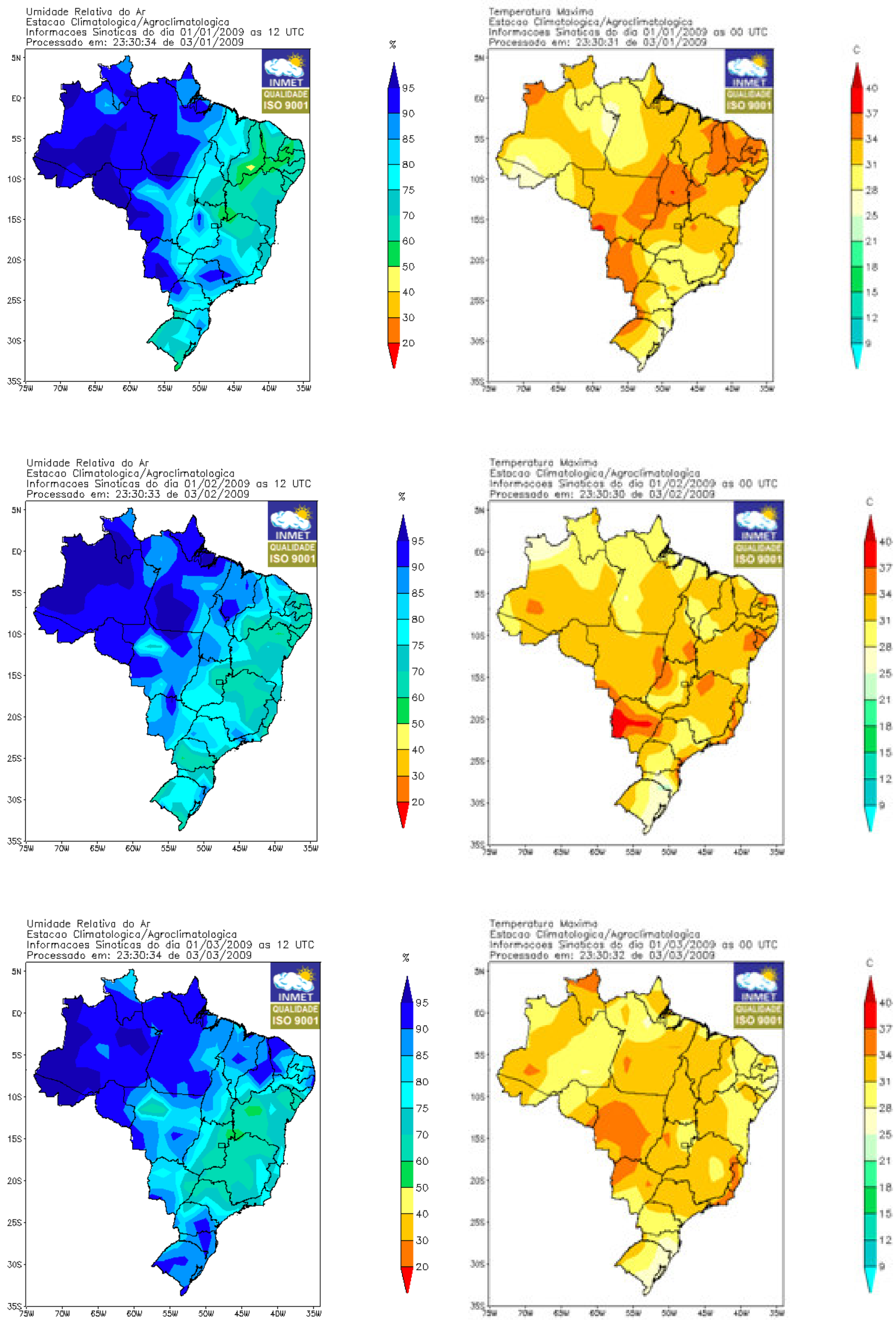


Figure 2.21 - Relative humidity of the air in relation to the maximum Temperature during the summer season 2009 from January till March chosen always the first day of the month at noon.
Source: Brazilian national institute of meteorology (www.inmet.gov.br/html/clima.php).

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].

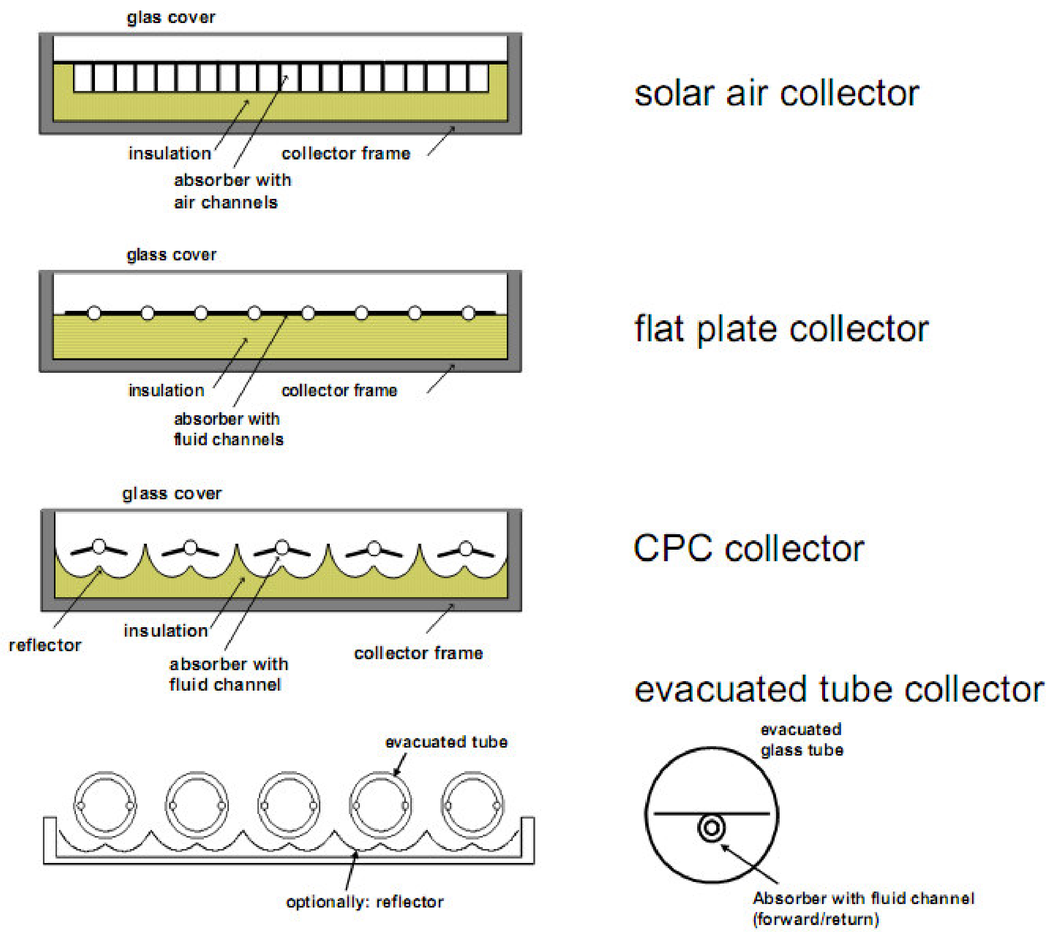


Figure 2.22 - General types of stationary solar collectors [7].

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].

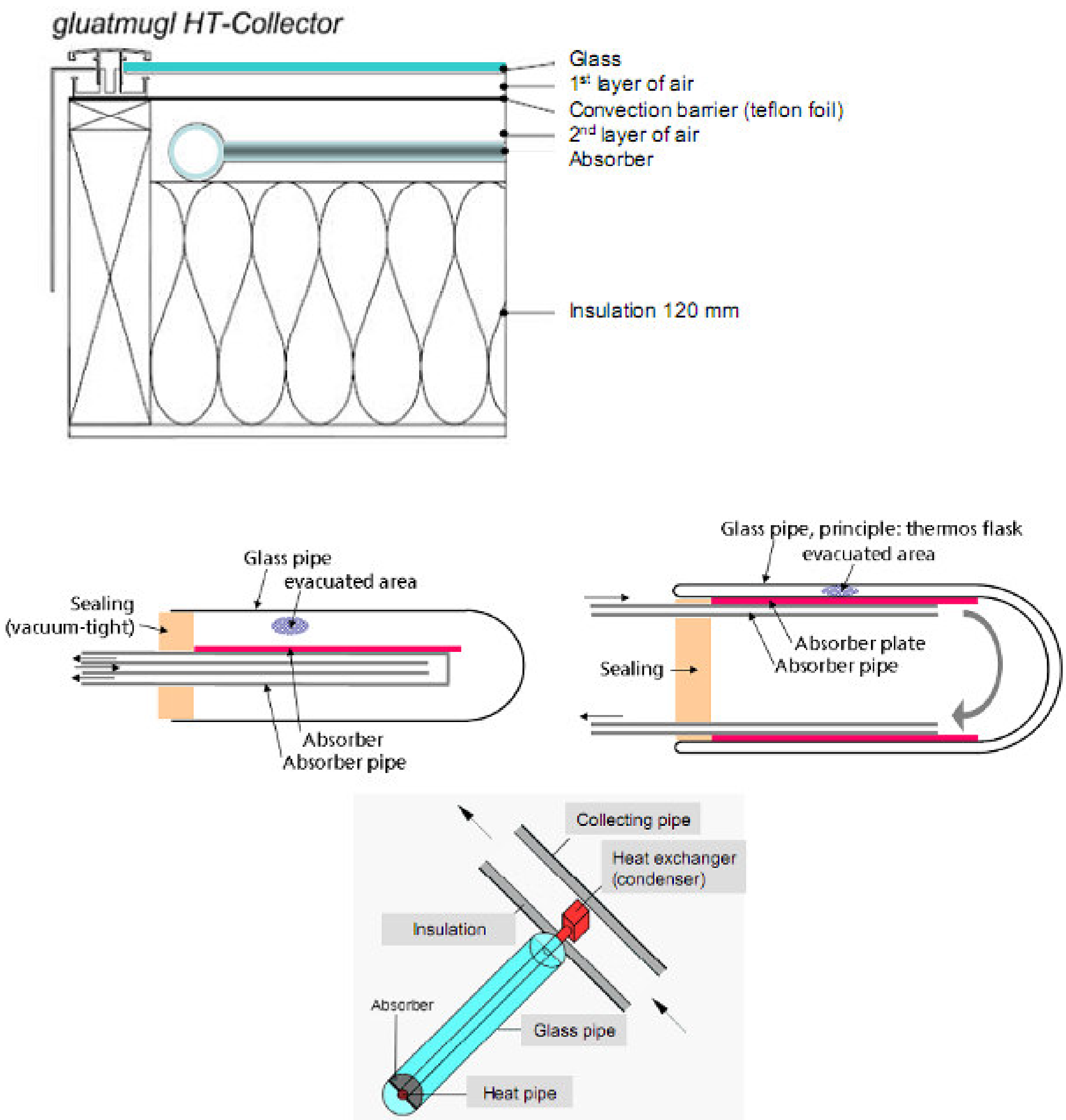


Figure 2.23 - Examples for different construction principles of stationary collectors [7].

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.

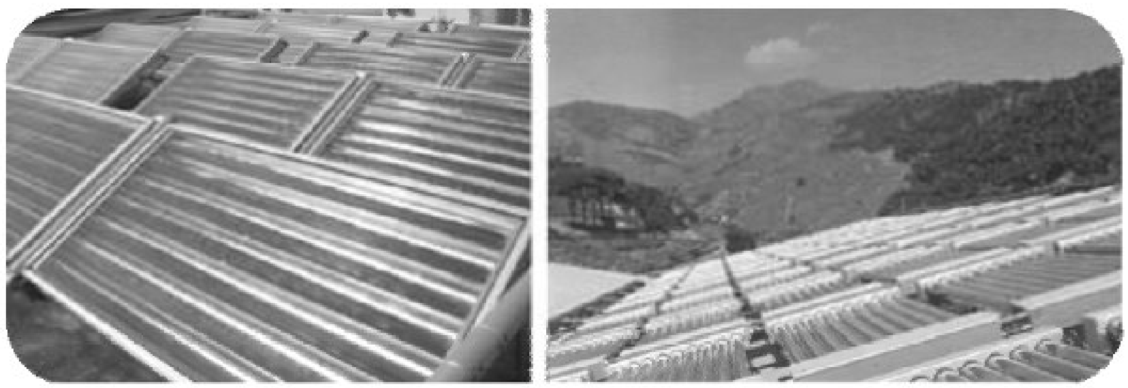


Figure 2.24 - Examples on solar collector, installed for solar cooling applications [7].

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].

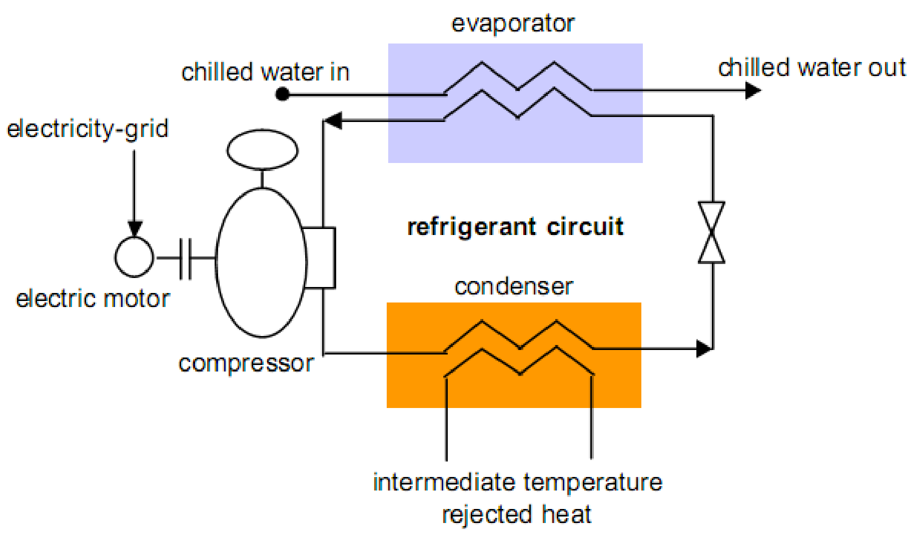


Figure 2.25 Schematic drawing of a vapour compression chiller [10].

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.

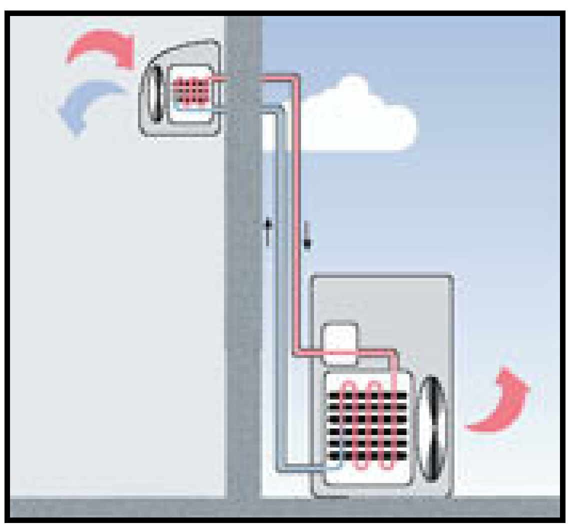


Figure 2.26 - Function scheme of a conventional electrically driven compression split air-conditioning system.

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.

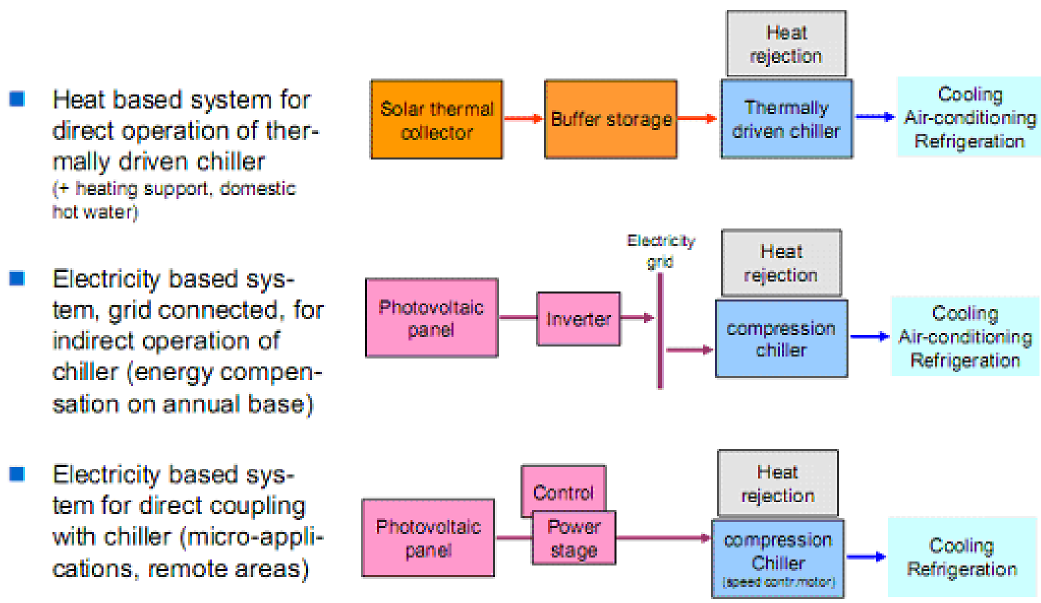


Figure 2.27 - Solar cooling possibilities [8].

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%.

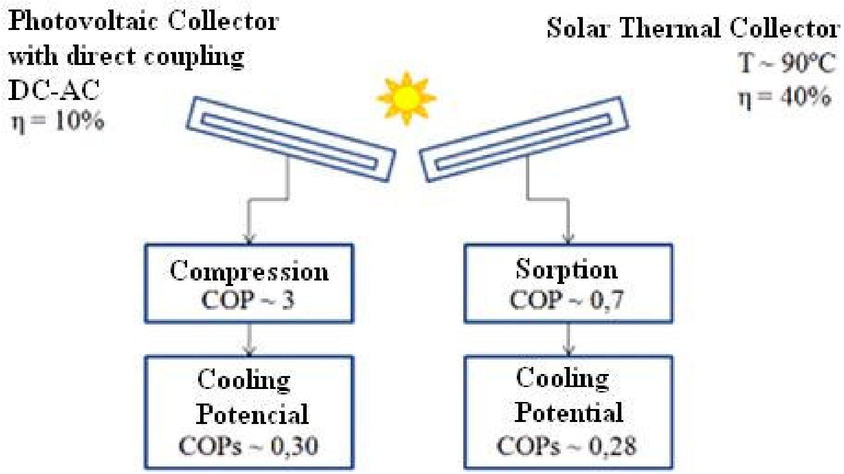


Figure 2.28 - Comparison of COP´s and efficiency between a PV direct coupling system and Solar thermal driven system [15].

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

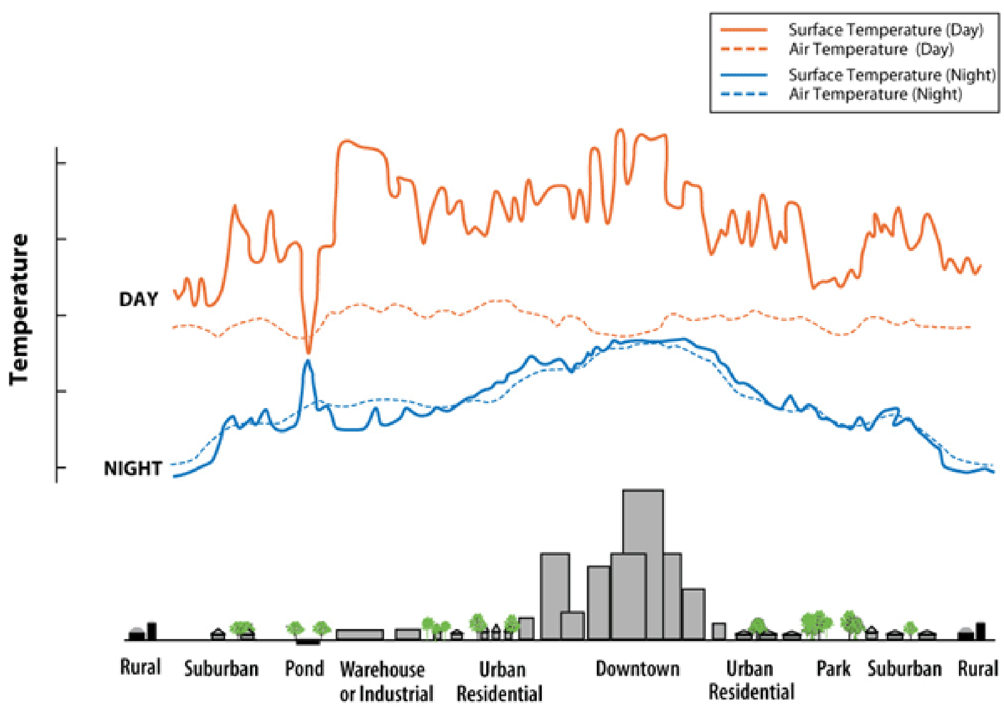


Figure 2.29 - Surface and atmospheric temperatures vary over different land use areas [16].

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.

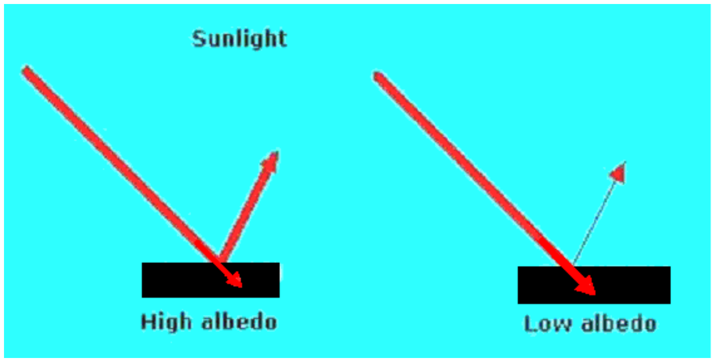


Figure 2.30 - Right: Low albedo of a solar thermal collector, only 30% is reflected; the rest is absorbed by the collector heating up the fluid. Left: PV collector transfer 60% of incident radiation to ambient air.

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.

3
Case Study

In this chapter the performance of a solar-assisted air-conditioning in relation to solar yield and building cooling is verified. This occurs on the bases of a case study. The object of the case study is the intended auditorium at the UNESP University in Guaratinguetá, which is likely to be equipped with a solar cooling system. The previous chapter is used as a technical basis for selecting the appropriate technology and their components.

At first, some background information about the project is given. Then the auditorium is designed for specific climate conditions, - and building data simulated. As well, it is shown how the cooling load (demand) through building insulation and adaptation of the indoor air temperature can be decreased. Thereafter, different collector types and as well on the Brazilian market available collectors are simulated on their suitability and the cost-benefit ratio. The chapter concludes with an assessment of the economically feasibility in comparison to conventional compressor split air-conditioning system. Because of the demand of a back-up system to cover the cooling load during cloudy days the economically feasibility calculation of two back-up system is included, too. These are a separated electric driven split air-conditioning system and a thermal gas back-up which heats up the chiller driving water. Finally, the environmental benefit of the solar-assisted air-conditioning system is demonstrated.

Figure 3.1 represents the interactions which must be considered during the planning phase of a solar cooling system.

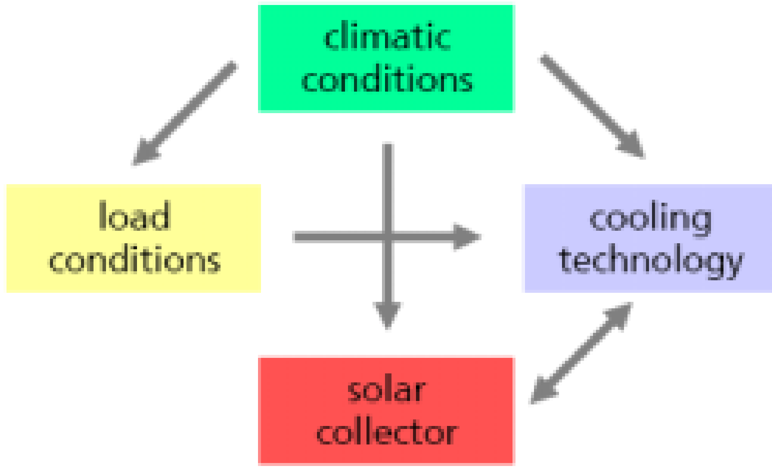


Figure 3.1 - Interaction in the design and layout of a solar-assisted air-conditioning system, to be considered in the planning phase [7].

The proper design of a solar-assisted air-conditioning system and the choice of the components interact to a high degree with the site conditions (climate conditions) and with the demand for cooling (load conditions). As one of the most cost-effective measures in the planning of an air-conditioning system is the reduction of cooling loads [7].

3.1 Background Information

It's intended to equip an auditorium of the planned centre for energy efficiency at the UNESP University in Guaratinguetá with a solar assisted air-conditioning system. The case study is used to provide the necessary theoretical base which is for the realization of such an important project. The project is likely carried out within the cooperation of the GTZ (german technical cooperation) and its main partner, the Eletrobrás and its component PROCEL (Brazilian electricity Conservation Program). The GTZ Energy program in Brazil has the task to strengthen the role of renewable energy sources and efficiency.

The Eletrobrás/PROCEL will establish a Centre of Energy Efficiency at the São Paulo State University (UNESP). In this centre, the latest architectural and technological energy saving measures will be applied. The research, training and exhibition centre has a totally area of 1.500 square meters and receive estimated up to 20.000 visitors per year. Visitors and students will be demonstrated how energy can be efficiently used in buildings. Besides the function as a "show room" it will contribute through education and research to the dissemination and development of energy saving measures in Brazil.

As part of this project the Eletrobrás/PROCEL intends, as mentioned above, the implementation of solar cooling. The pilot project will provide a clear demonstration character and will be accessible to visitors. The application at the UNESP University allows a high dissemination character and could attract the attention of decision makers, planners, building services as well as end-users.
A monitoring plan will be created to collect the key performance parameters of the pilot plant, thus a continuous monitoring can be carried out by the UNESP University. The results and experiences of the pilot project will be conveyed to the Brazilian society through publications in professional journals and lectures, events and specialist institutions.

Should the project be successfully implemented, it will show that the "new" technology reliably functions. Consequently, the pilot project can serve as a multiplier for the whole country. Partnerships between e.g. a system provider of solar-assisted air-conditioning systems, a refrigeration firm and thermal collector manufacturers could arise. Last but not least it could bring some opportunities for the development of these segments.

The time schedule of the centre for energy efficiency is as follows:

In September 2009 the project was tendered. The award of the tendering will be decided until January 2010. Around one month later the construction starts. The goal is complete the construction until the end of 2011.

For the tender, it is required a specification for the integration of a solar-assisted air-conditioning system in the auditorium (see appendix A1).

3.1.1 Location and climate conditions

Guaratinguetá is located in south-eastern Brazil. The municipality of Guaratinguetá is located in the "Vale do Rio Paraíba do Sul", in the eastern state of Sao Paulo. The region is near the Tropic of Capricorn. The municipal seat has the following geographic coordinates: 22°48'43" south latitude and 45°11'40" W, distant 237km from Rio de Janeiro and 163km from São Paulo. Elevation: 530 meters.

Figure 3.2 - Location of Guaratinguetá in Brazil within the State of São Paulo

The relative humidity varies around 70%. The climate is tropical of altitude (meaning hot and humid in the summer, hot and dry in winter).

The city is considered the hottest of the Paraíba Valley, has an average temperature of 22,6 C°.

Month	Temperature ℃	Umidity %	Pressure mb	Precipitation mm
January	25,7	69	950,5	197,7
February	26,3	63	951,4	152,1
March	25,0	69	951,9	214,2
April	22,8	68	953,8	81,7
May	20,6	70	955,1	60,6
June	18,6	68	957,0	35,2
July	18,6	66	957,9	24,4
August	20,0	63	965,5	22,8
September	21,3	64	955,2	65,8
October	23,2	65	952,6	91,4
November	24,6	68	951,5	144,9
December	24,8	71	950,3	212,9
Average	**22,6**	**67**	**953,6**	**108,6**

Table 3.1 - Monthly average climate data of Guaratinguetá 1962-1991 (modified) [19].

Figure 3.3 illustrates a global radiation map provided by the model BRAZIL-SR for the south-east of Brazil. As can be seen, the highest levels of the overall solar radiation for the month of March 2005 occur in the north of Minas Gerais with around 6 kWh/m² and the lowest, around 4.75 kWh/m², in the southern state of Sao Paulo. The solar radiation in Guaratinguetá lies with around 5.5 kWh/m² in between.

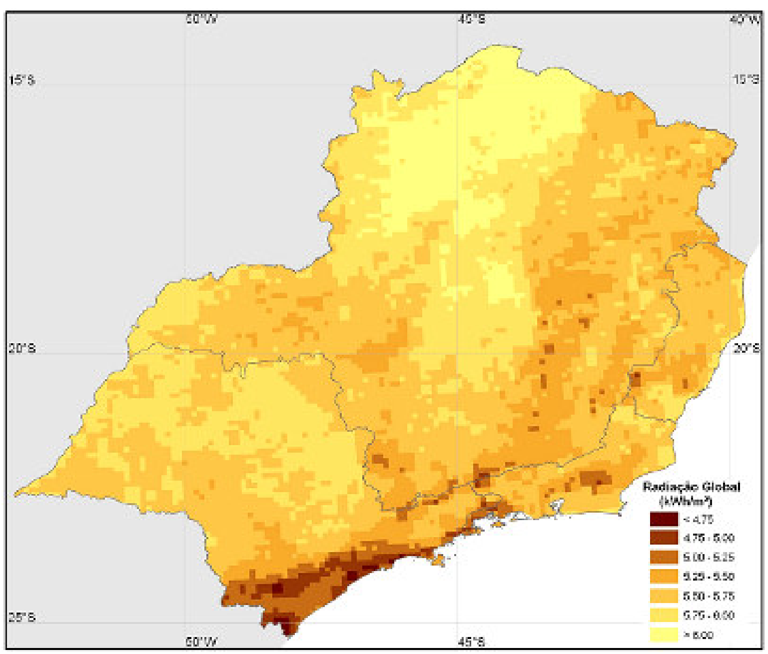


Figure 3.3 - Global solar radiation map in March 2005 provided by the model BRAZIL-SR for the south-east of Brazil [20].

Guaratinguetá has around 113.357 habitants and is one of the most important commercial and tourist cities of the Paraíba Valley. Guaratinguetá lies between the São Paulo and Rio de Janeiro in the Brazilian Megalopolis. Especially, São Paulo is growing through the Paraíba Valley along the Via Dutra Highway toward Rio de Janeiro: some people are already forecasting a megacity to be called São-Rio.

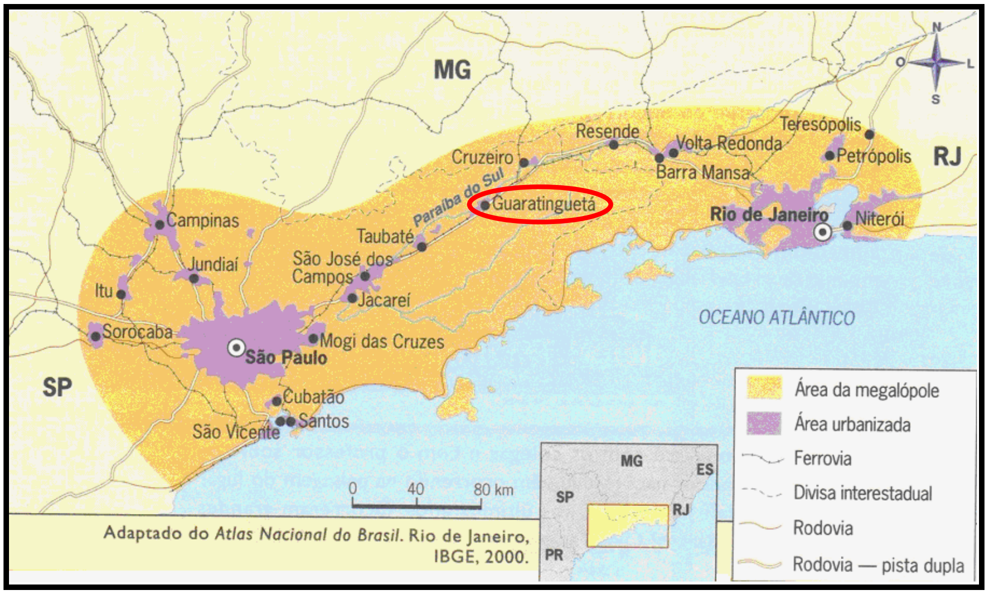


Figure 3.4 - Brazilian south-eastern Megalopolis

Therefore the pilot project, would be established in an area where the population density is the highest of Brazil, thus there exits, as well, a high dissemination potential within this region. Finally, it could contribute to their sustainable development, through minimizing CO2 emissions and avoiding hazardous refrigerants.

3.2
Simulation and design

3.2.1
The thermal load of the building

This chapter deals with the thermal behaviour of the building. It gives a statement about the maximum cooling load and how it changes due to climate change during one day or within one year. The cooling load is the amount of heat that must be dissipated from the room or building to allow a temperature which corresponds to the thermal comfort. Due to this information the solar congruence can be investigated, this means the relation between building cooling demand and cooling yield by solar irradiance. This simulation serves as basis for the technology choice and economic assessment.

The Program HELIOS-PC from Econzept Energieplannung GmbH was used for the dynamic building simulation. The thermal building simulation program HELIOS-PC was developed in the year 1992 principally by the technical University of Karlsruhe (Germany). It bases due to the user interface HELEX 2.1 for Windows on Excel macros.

Different factors have an influence of the building cooling load. A distinction is made between external and internal cooling load cooling load. The internal cooling load is the heat gain, inside the building through persons, machines and lighting. Heat gains through the windows and walls (building envelope) are called external cooling load.

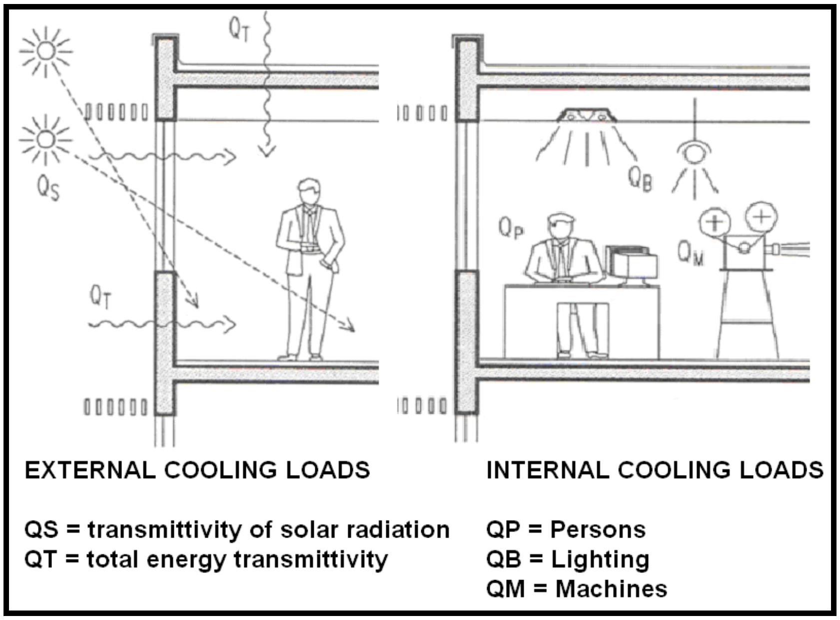


Figure 3.5 - External/internal cooling loads (modified) [21].

The specific building data which are used for the cooling load calculation are listed in the following chapter.

3.2.1.1 Simulation building data

According the Architects from PROCEL the pretended Auditorium has a Floor space of 150m² and a ceiling high of 3.25 m. It's a one floor building, thus 150 m² of free roof space for solar collectors are available. It has capacity for 100 Students. The building envelope is limited to U < 3,7 W/(m²*K) and there are no windows. During the preparation of the master theses were no further data on the building available.

Due to these appointments the necessary data's are as follows:

<u>Hygienic Air change:</u>

Because of providing sufficient air/oxygen for breathing the total volume of the auditorium must be exchanged with fresh air from the enviroment. The from outside taken air has always the condition of the present climate condition. The hygienic air change rate is 30 m³/h per person, 100 Students relate to 3000 m³/h. With an total volume of the auditorium of 487,5 m³ the hygienic air change rate is 6,15 1/h. The air change is continuous.

<u>Internal Cooling load:</u>

It's assumed that the auditorium will be fully occupied from 8 h to 17 h, during weekday. Therefore 100 Persons are present, seated and doing light work, thereby can 80 W per Person calculated, accordingly 8 kW. The lighting load is 15 W/m² by an area of 150m² the total lighting load 2,3 kW. 1,7 kW is for equipment and appliances of the auditorium e.g. Laptops. According this assumption the total internal load is 12 kW.

<u>Building envelope (U-Values):</u>

The Heat transfer U –Value is determined by the reciprocal of thermal resistances of each component of a building envelope component.

Two cases are simulated:
A: auditorium without external wall insulation: U = 3,7 W/(m²*K) and
B: auditorium with externals wall insulation U = 0,24 W/(m²*K)

The next table shows the different simulation values regarding the constructional compositions of the building envelope. It is assumed that the length of the auditorium is 15 m and the width 10 m.

		Facade area (North&South)	Facade area (East&West)	Roof	Ground floor basement
Area [m²]	-	65 (2x10x3,25)	97,5 (2x15x3,25)	150	150
Components (Materials from outside to inside)/ thicknees [cm]	A	Reinforced concrete /18	Reinforced concrete /18	Reinforced concrete /15 EPS*/ 2 light-weight concrete/ 6	Gravel-Sand /1m Reinforced concrete /18
	B	Reinforced concrete/15 with EPS*/18	Reinforced concrete /15 with EPS*/18	Reinforced concrete /15 EPS*/16 light-weight concrete/ 6	Gravel-Sand /1m EPS*/ 7 Reinforced concrete /18
Heat transfer U-values [W/(m²*K)]	A	3,7	3,7	0,96	0,59
	B	0,24	0,24	0,2	0,3

*EPS – expanded Polystyrene insulation plate

Table 3.2 - U-values of the auditorium building model

It must be mentioned that the energy transmissivity of the ground floor and roof bases one a steady soil temperature of 20°C and a average outside temperature between thermal solar collector field and the roof of 24°C. The roof of the auditorium will be almost completely covered by collector field and equipment, thus provide shading. Beside the roof shadowing, the building is unshaded and has no windows or intermediate walls.

Figure 3.6 shows the Interface-mask of thermal simulation program HELEX 2.1 from the Helios-PC Software.

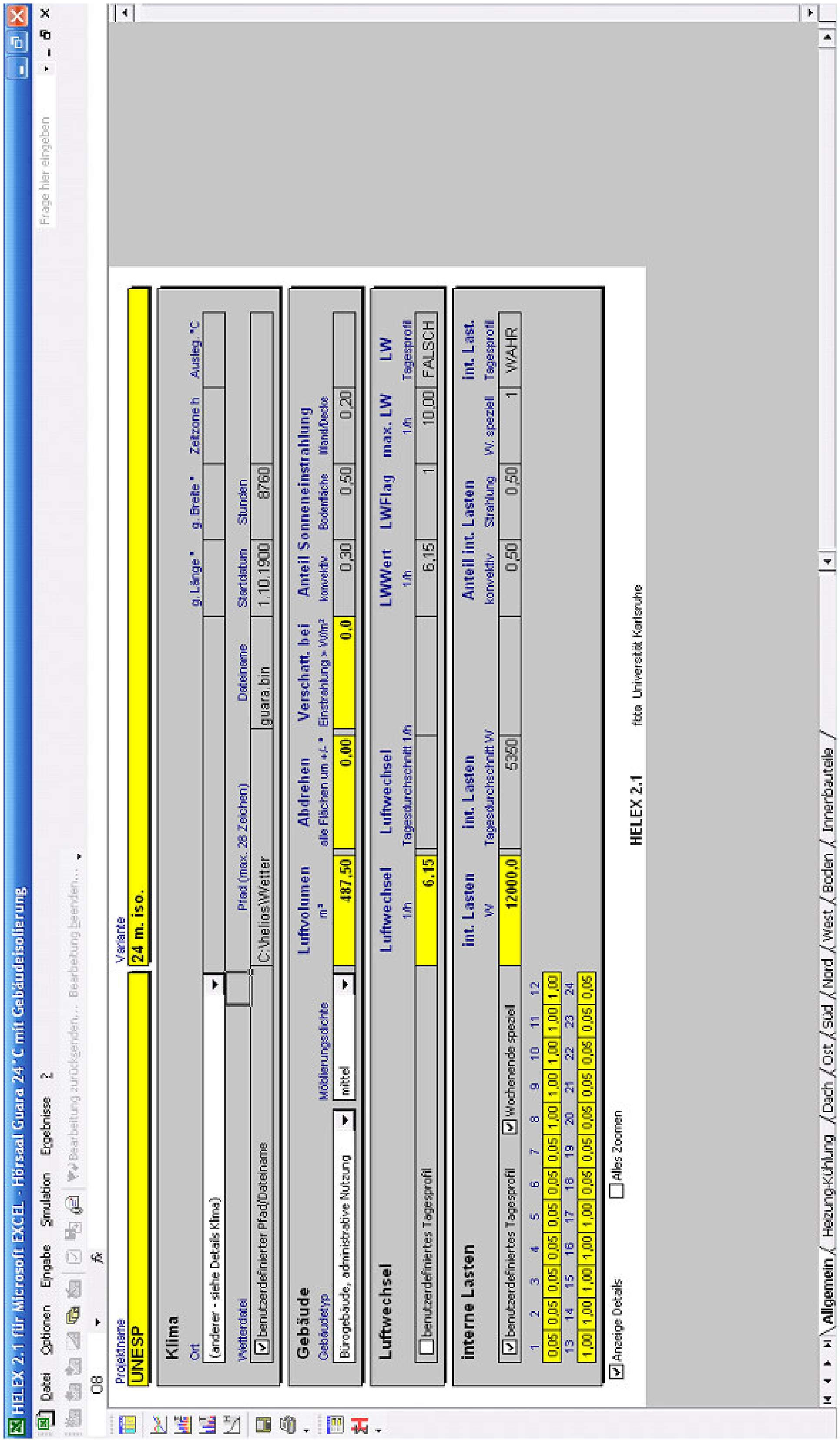


Figure 3.6 - Snapshot of HELEX 2.1 Interface

The thermal behaviour of the building will be assessed in an hourly annual, in an hourly monthly and in hourly daily simulation figures. The simulation is realized with three different indoor set point Temperatures of the auditorium. These are 20°C, 24°C and 26°C. In Brazil the air-conditioning systems are often oversized, thus the indoor temperature is all over the year 18°C - 20°C. Therefore 20°C was chosen to show how high is the cooling load and hence energy consumption in comparison to an appropriate indoor temperatures of 24°C - 26°C. This temperature range is in accordance with the Brazilian standards (PNB-10).

The indoor air temperature Ti is the most evident indicator of proper thermal comfort, the temperature should be higher on lower activity level and lighter clothing. For building cooling it is important that our body is capable to adapt to seasonal conditions. Air humidity affects the latent heat transfer from the bodies to the surrounding air. Therefore in case of higher temperatures the humidity has to be lower [7].

External Temperature	Internal Conditions		
dry-bulb temperature [°C]	dry-bulb temperature [°C]	wet-bulb temperature [°C]	relative umidity [%]
29	24,5	19,5	62,0
	25,0	19,0	56,0
	25,5	18,5	50,0
	26,0	18,0	44,0
32	25,0	20,5	66,0
	25,5	20,0	60,0
	26,0	19,5	54,0
	26,5	19,0	48,0
35	25,5	21,5	70,0
	26,0	21,0	64,0
	26,5	20,5	58,0
	27,0	20,0	52,0

Table 3.3 - Internal thermal comfort conditions regarding the ambient summer temperatures (PNB-10, Brazil) [22].

To show the energy saving potential through building insulation a simulation is realized with and with and without building insulation (U-Values see table 3.2 above). The building simulation developed by using Meteorological data from the Meteonorm 5.1 software (edition 2003). There are hourly data of the ambient temperature and horizontal global irradiation of one average year (8760 h) from Guaratinguetá available.

Meteonorm uses a database with long term monthly average measurement data from different stations. In the recent software versions there are more than 7000 meteorological stations worldwide available. If no meteorological station is available in the database for a desired site, meteorological data will be interpolated based on the data of the nearest stations. In the Meteonorm 5.1 software are the Meteorological data from the year 1971 till 2003 collected.

The next chapter show the results of the simulation.

3.2.1.2 Results of the simulation

A: without insulation				
Indoor set point temperature Ti [°C]	Maximum Cooling Load [kW]	Total annual Cooling Load [kWh]	Monthly average Cooling Load [kWh]	Monthly average Max. Specific Cooling Load [W/m²]
20	30	59.663	4972	168
24	23,3	21.639	1803	103
26	19,4	10.169	847	86

Table 3.4 - Cooling Load results without building insulation

B: with insulation				
Indoor set point temperature Ti [℃]	Maximum Cooling Load [kW]	Total annual Cooling Load [kWh]	Monthly average Cooling Load [kWh]	Monthly average Max. Specific Cooling Load [W/m²]
20	22,5	42497	3541	128
24	18	17322	1444	91
26	15,5	8981	748	69

Table 3.5 - Cooling Load results with building insulation

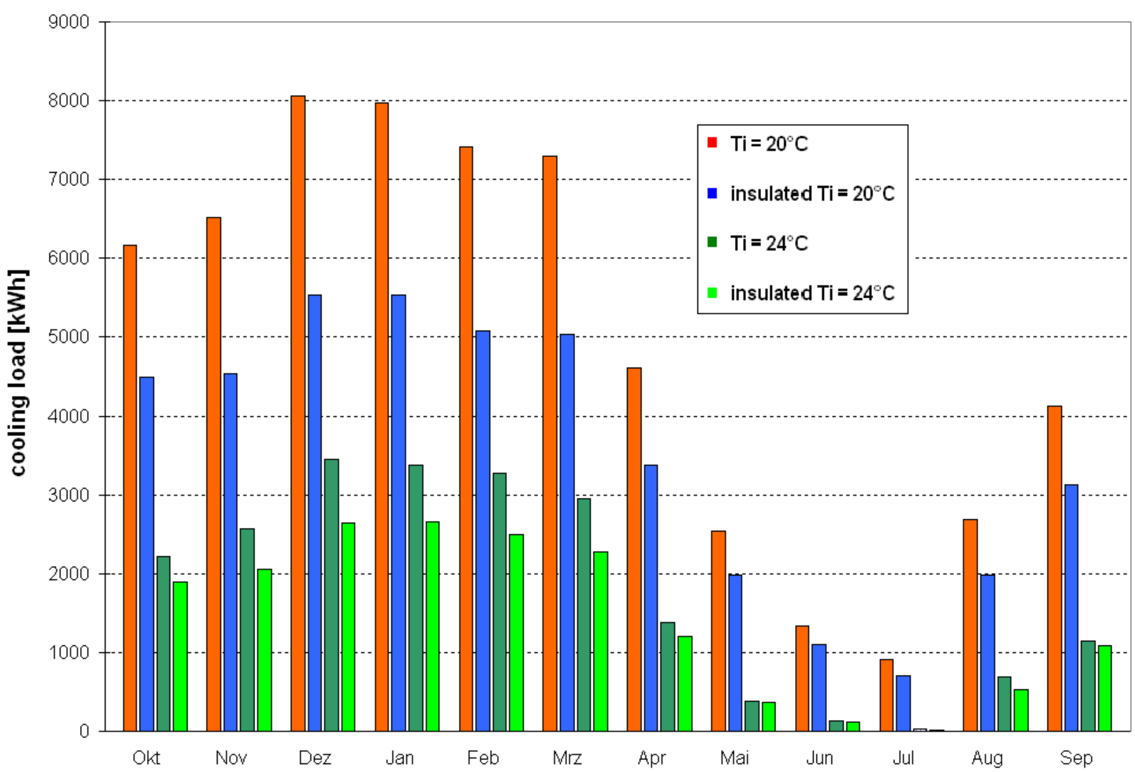


Figure 3.7 - Predicted monthly cooling load of the auditorium with and without insulation by 20℃ and 24℃ indoor air temperature.

Figure 3.8 presents the typical daily thermal behaviour of the building during summer. With an indoor air temperature of Ti = 20°C the maximum cooling Load is 30 kW and at Ti = 24°C only 23 kW. In both cases the building is without insulation. The normal cooling load range during the summer daytime is between 15 kW and 20 kW.

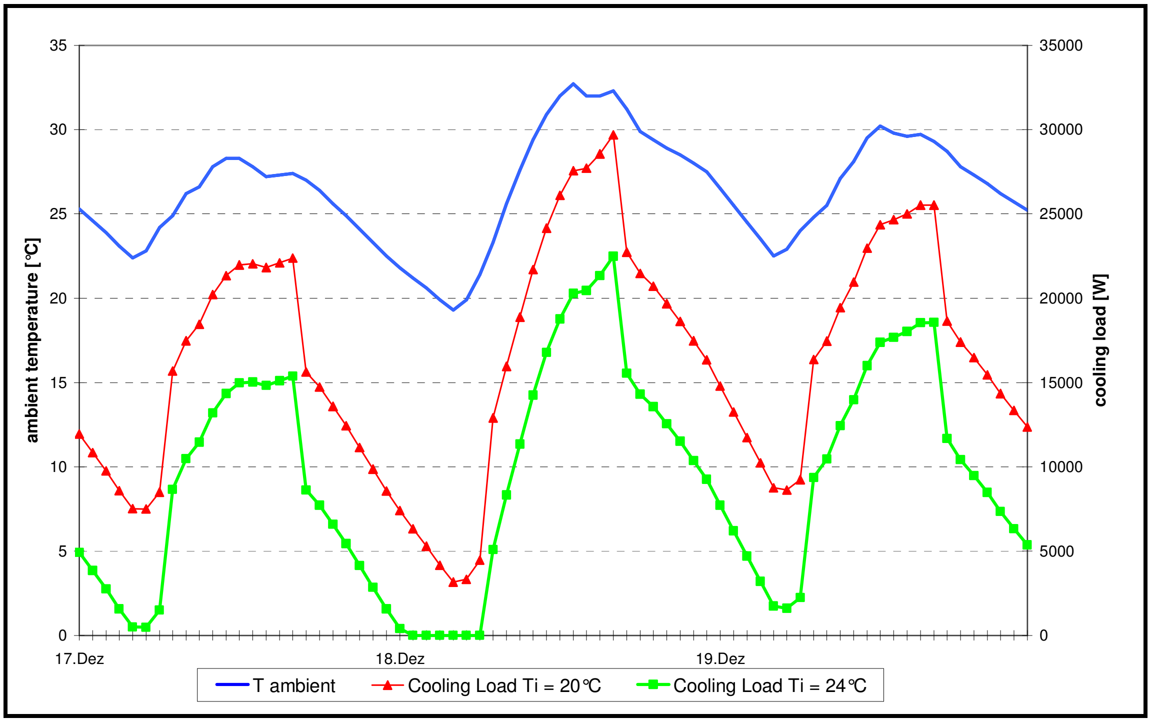


Figure 3.8 - Hourly cooling load pattern (hourly data) with Ti = 20°C and Ti = 24°C, at the predicted annual maximum ambient temperature of 32,7 °C (without insulation).

3.2.1.2.1 Conclusion

It was established that the adjustment of the indoor air temperature within the tolerance range of thermal comfort limits allows an enormous energy saving potential for air-conditioned buildings.

At an indoor air temperature of Ti = 20°C the effect of building insulation explicitly is noticeable and at 24°C and 26°C less. At this point it must be highlighted that the auditorium has, due to the shadowing effect by the collector field already a good "roof insulation", therefore, principally, the external walls have an impact. However, in Brazil a building insulation would be profitable for a long period, in the work of Carlos Gabriel Caruy (2009) payback times of two month were calculated [23].
The economic feasibility of insulation for the auditorium was not calculated, since it differ from the actual goal of this thesis. The focus of this work lies in the economic analysis of a solar-assisted air-conditioning system.

Brazil has as yet no culture to improve the thermal comfort by building insulation. Figure 3.9 is a funny room air-conditioner propaganda; it proposed that artificial cooling of open air spaces (here the beach) would represent the most ineffective use of electric energy (thus high expenses). Cooling the usually poorly insulated indoor spaces in Brazil is about the same: a highly inefficient use of energy.

Figure 3.9 - "With Springer you are the one who makes the climate" Source: Mica Advertising Postcard 2004

In this work the insulating effect was achieved principally due to 15 cm wide polystyrene insulation plates at the exterior walls. This type of isolation is mainly used for Houses in Germany. If in Brazil insulation would be applied, possible mold growth by high air humidity must be considered. Fire prevention is also always a very important point. In Brazil, natural alternative and CO_2 neutral insulation could be used e.g. coconut fibres, thus Brazilian natural recourses can be utilized.

Figure 3.10 - Insulation with EPS Polystyrene plates in Germany.
Source: www.netz-gemeinschaft.de/deetz/Tagebuch/Pict5379.jpg

Every building in Germany is insulated because of the high energy costs and winter temperatures of 3°C averagely. During winter season the outside/inside temperature difference is around $\Delta T = 17$ K. The Temperature difference ΔT in Brazil is during the summer around 10 K, which makes insulation economical.

In the next chapter the suitable air-conditioning system will be chosen, which refers to the simulated cooling load at an indoor air temperature $T_i = 24°C$ (without building insulation).

By 29°C dry-bulb ambient temperature, a building indoor dry-bulb temperature of 24°C and < 65% relative humidity lies within the tolerance range of the Brazilian thermal comfort standards.

In Brazil lot of air-conditioned buildings maintains during summer an indoor temperature of around 18-20°C. Such temperatures are resulted by an oversized air-conditioning system and do not meet to the thermal comfort standard. Refrigeration firms dimension often their systems through a rule of thumb, calculate 3,5 kW (1 TR) cooling capacity for 15 square meters space, this corresponds to a specific cooling load of 234 W/m². The Simulation has shown that by an indoor temperature of 24°C the monthly average maximum specific cooling load is only 103 W/m².

3.2.2
Selection and design of the equipment

In this chapter the appropriate technology will be chosen according the following steps:

- Selection of the proper thermally driven cooling equipment and air-conditioning system.
- Selection the proper type of solar collectors for the selected thermally driven cooling equipment.
- Sizing of the solar collector field by a thermal simulation with regard to energy and cost performance.

First of all it must be mentioned that due to the facts in sub-section 2.1.2 (Open Cycle Processes) the appropriate technology is a closed cycle (chilled water) system.

It consists of different sub- systems. According these sub-systems the next chapters are structured.

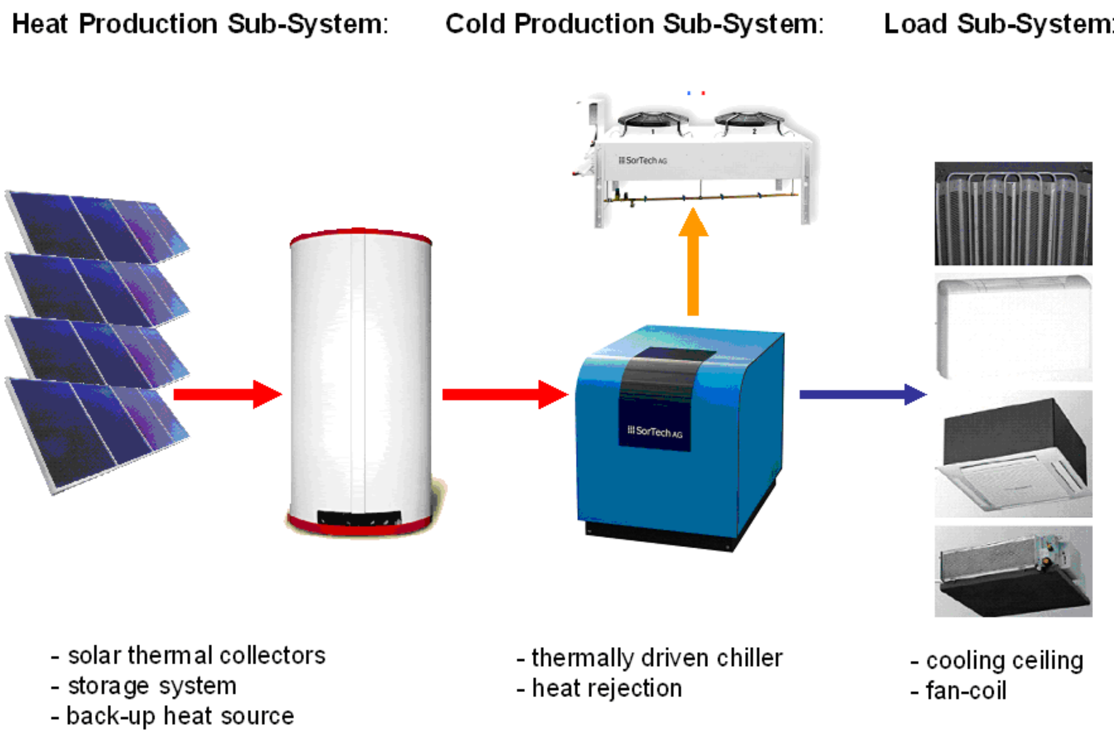


Figure 3.11 - Sub-systems and their components of a solar-assisted air-conditioning system (modified). Source: Solvis Energy Systems GmbH & CoKG

3.2.2.1
The cold production sub-system

The cooling demand peaks during the summer season is between 15 kW and 23 kW at an indoor air temperature of Ti = 24°C.

For this cooling Capacity range suits the (Yazaki WFC-SC10) 35 kW (10 TR) single-effect LiBr-H2O Absorption Chiller. This Japanese chiller is often used in solar cooling systems, because it has been for many years the smallest manufactured absorption chiller. This chiller is worldwide available.

The cooling capacity of an Absorption chiller depends on two factors Hot water driving temperature und cooling water inlet temperature. A performance curve shows their influences of the cooling capacity.

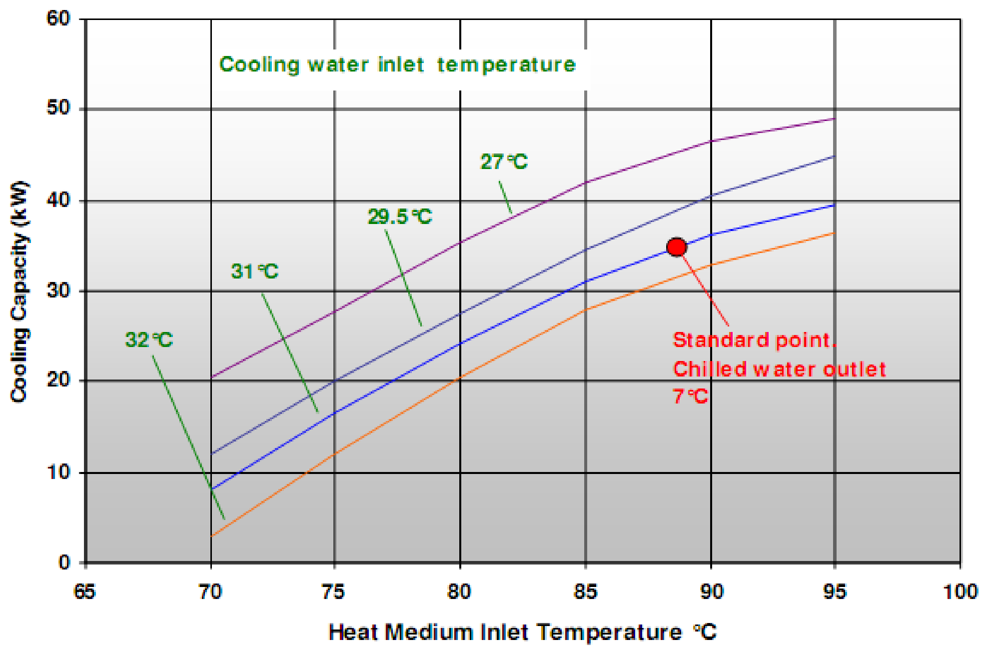


Figure 3.11 - Performance characteristics of Yazaki WFC-SC10 Absorption Chiller (Fancoil 7℃ chilled water). Source: Yazaki Energy Systems Inc.

Model	Yazaki WFC-SC10	SI unit
Cooling Capacity	35	kW
Heat Rejection – Cooling Tower Capacity	85,3	kW
COP	0,7	-
Cold water temperature in/out (chiller)	12,5 - 7,0	℃
Chilled water flow	5,508	m3/h
Hot water temperature in/out (min. 75 ° C, max. 95 ° C)	88 - 83	℃
Hot water flow (min. 75 ° C, max. 95 ° C)	8,64	m3/h
Cooling water temperature in/out (chiller)	31 - 35	℃
Cooling water flow	18,36	m3/h

Table 3.6 - Technical data of the Yazaki WFC-SC10 Absorption Chiller. Source: Yazaki Energy Systems Inc.

Further Technical data and information see appendix A2.

A COP of 0,7 and a capacity of 35 kW is reached by the chiller operation point at 88°C hot water inlet temperature and 31°C cooling water in inlet temperature. The performance of the collector field regarding the hot water driving temperatures is shown in the sub-section III.2.2.3 Heat production sub-system.

In Guaratinguetá the average relative humidity is around 70%. The cooling water temperatures in relation to the dry-bulb air temperatures are as follows:

dry-bulb air temperature [°C]	**wet-bulb air temperature [°C]**	**cooling water temperature (wet-bulb temperature + 5 K) [°C]**
24	20	25
26	21,8	26,8
28	23,6	28,6
30	25,5	30,5
32	27,3	32,3

Table 3.7 - Cooling water temperature in relation to dry-bulb ambient air temperature and relative humidity of 70%.

The maximum cooling demand is normally during a dry-bulb temperature of 32°C. Due to this temperature the cooling water temperatures is around 32°C. The advantage of the chosen chiller is that at this cooling water temperature and a hot water temperature of only 82°C the chiller capacity is still 23 kW which meets the maximum cooling demand at 24°C indoor dry-bulb air temperature.

The suitable wet cooling tower is available at the Brazilian company International Refrigeração Ltda (www.internationalrefrigeracao.com.br). The Model F-32 must be chosen for the Yazaki WFC-SC10 cooling water demand.

Capacidade Média em m³/h			
Modelo	Temperatura de Bulbo Úmido		
	25,6 °C	26,5 °C	27 °C
F-08	5	4,4	3,9
F-10	5,5	4,8	4,3
F-12	9	7,6	6,8
F-15	9,6	8,4	7,5
F-20	14	12	10,8
F-25	17,6	15	13,9
F-32	32	25	22,7
F-40	35	28,5	24,8
F-45	44	37,5	33
F-55	55	44,5	40,5
F-75	64,5	53	47
F-90	73	60	54
F-105	101	79	70
F-120	128	109	96
F-150	136	117	102
F-180	158	142	118

Note: Temperature de Bulbo Úmido means wet-bulb temperature

Figure 3.12 - Technical data wet cooling tower from the Brazilian company Internacional Refrigeração Ltda.

3.2.2.2
The load sub-system – air-conditioning equipment

By the Chiller generated cold water load must distributed inside the building. The cooling medium is water at 7°C for fan-coil operation or the second modus is water with 18°C for the option to use a cooling ceiling.

To give a general overview of the generic classification of central Air-conditioning system figure 3.14 is shown. Table 3.7 lists specific cooling capacities of the different air- conditioning system. The maximum specific cooling load of the building is 155 W/m² (23,3 kW) . This energy must be brought into the building. According to the table for the auditorium only a fan-coil system is recommended. A cooling ceiling can not be applied because it doesn't bring the necessary cooling load into building, as well not if the ceiling is 100% covered.

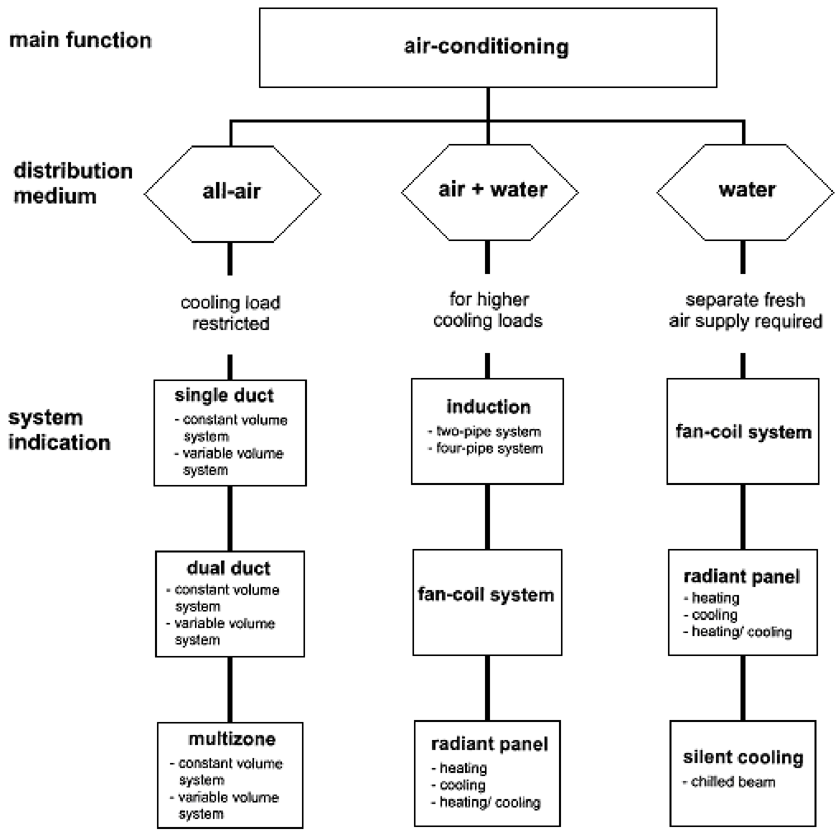


Figure 3.13 - Generic classification of centralised air-conditioning systems [10].

Air-Conditioning system		Ventilation rate	Room height in m $\Delta T = T_{room} - T_{supply}$ (draught-free conditions)				
	System type	air change per hour [h^{-1}]	2.4 T = 6°C	2.7 8°C	3.0 10°C	3.5 12°C	4.0 15°C
A	All-air systems	3	15	20	30	40	60
"		4	20	30	40	55	80
"		5	25	35	50	70	100
"		6*	30	45	60	85	120
B	Displacement ventilation	approx. 8	30	30	30	**	**
C	Induction/ fan-coil	10	50	75	100	140	200
D	Chilled ceiling	-	60	60	60	60	60
E	Chilled floor	-	20	20	20	20	20
F	Pure displacement	250	800	900	1	1.15	1.35
A	+ D	2	70	75	80	90	100
"	"	3	75	80	90	100	120
"	"	4	80	90	100	115	140
"	"	6	85	100	100	140	180
B	+ D	approx. 8	80	80	80	**	**
C	+ D	10	90	100	100	140	200

Table 3.8 - Specific (max. possible) cooling capacities (W/m²) of different air-conditioning systems (see figure 3.14 above) [10]. *At higher ventilation rates **Values not known

For cooling loads higher than 45 W/m² it must be chosen: air cooling based on minimum required fresh air quantity (e.g. 30 to 50 m³/h per person) and secondary cooling (water-based); e.g. system C (fan-coil) or A + D. The aim is to save costs for ducting and energy for transportation of air and to avoid possible draughts when introducing too much air into the room. Possible draught can be avoided by using, for example, high-induction air outlets in the wall or swirl outlets in a ceiling [10].

In tropical climate conditions the specific cooling capacity of a cooling ceiling is as well limited, due to the high relative humidity. At a relative humidity of 70 - 80% only cold water of about 20°C can be used as medium, since temperatures ≤18°C falls below the dew point and create condensation at cooling panel. For safety the water temperature in the cooling panels must be is always 2 K above the dew point temperature. Therefore, ΔT is limited to 4 K at an indoor temperature of 24°C. The maximum flow rate of cooling panel, here type Carat H-84, is around 0.5 l/s. Due to a following calculation the possible cooling capacity can be determined.

$$Q = m(t) \cdot C_w \cdot \Delta T \qquad \text{(Eq. 3.1)}$$

$Q = 0,5 l/s \cdot 4186,8 Ws/kgK \cdot 4K = 8,3 kW$

C_w – heat capacity of water

The maximum cooling load could of the auditorium could be only 8,3 kW, this means the specific cooling at 150m² would be 55 W/m². As well, this calculation demonstrates the limitation of active night-cooling applications within the tropics. Active night-cooling exploit the colder night air temperatures to cool water due to e.g. a wet cooling tower. During the day the stored chilled water circulates through a cooling ceiling.

It must be added that the water temperature is limited by relative humidity and temperature of the ambient air. The water temperature depends on wet-bulb temperature +3-5 K. In tropical cities the relative humidity goes up to 80 - 90% at night and only at the day it decreases to 60 -70%, however at an high air temperature, hence to potential to cool the water till 15-20°C does not often exist.

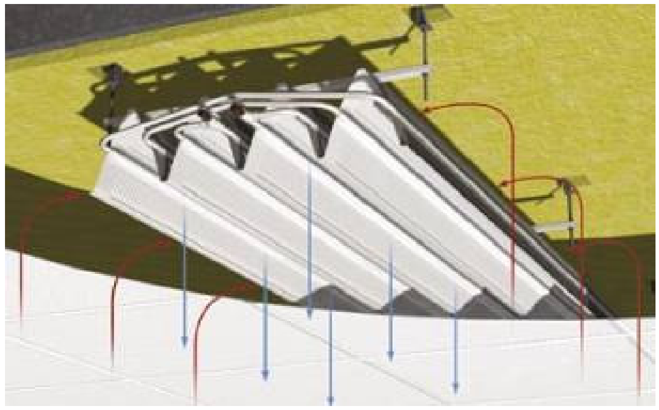


Figure 3.14 - Example of a Cooling panel Type Carat from Lindab Climate GmbH Source: Technical Data sheets

In Germany cooling ceilings are often applied due to lower noise emissions and no energy consumption, despite higher investment costs. Only during 3% of annual operation hours condensation occurs. Through an alarm system which stops the water circulation condensation drops are avoided.

For the case study four Fan coil units were chosen; Model aquaris silent SP 50/51 from Schako Air distribution KG (www.schako.com). In Brazil fan-coils are a standard product and applied in conventional air-conditioning systems.

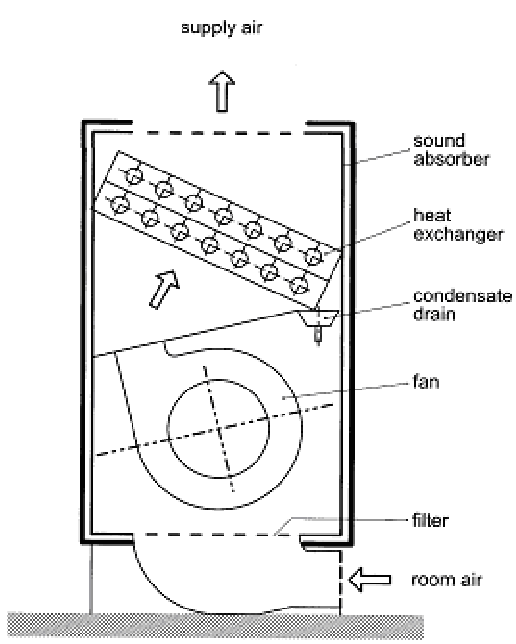


Figure 3.15 - Cross-section of a typical simple fan-coil unit with one heat exchanger for air heating/cooling [10].

3.2.2.3
Heat production sub-system

This chapter deals with the heat production sub-system. The hot water driving temperature is provided principally by the thermal solar collector field. During cloudy days a thermal driven Back-up system can be used, which heats up the hot water storage due to a gas burner. Another way to secure the thermal comfort is to apply a conventional electric driven Back-up system. In this chapter both types are compared.

3.2.2.3.1
Thermal solar collector comparison

To find out the performance-cost relation of different collectors, it is important to simulate these under the specific climate conditions.

The collector's manufacturers usually specify only the maximum point of the collector performance. This point is rather of theoretical importance. A simulation with the specific hourly data at side tells us more about reality behaviour and suitability.

To simulate the behaviour of the collector the solar efficiency equation is applied (see sub-section 2.1.3 Solar thermal Collector Equation 2.1). The Simulation depends on the hourly global irradiation, the hourly ambient air temperature and the average collector hot water temperature. The hourly values are from the Meteonorm database.

As average collector hot water temperature tm (average between input and output temperature) were 85°C chosen. Because the operation point of the Chiller is at 88°C inlet temperature (collector output Temperature) and at around 83°C at the outlet (collector input temperature). Thus results a ΔT, between average ambient air temperature of ta = 25°C und average collector hot water temperature of tm = 85°C, of 60 K.

To simulate the solar irradiance G at the collector surface it is chosen the horizontal global irradiance, which is composed of diffuse and direct radiation. In summer, the highest solar yield is reached due to a horizontal position of the collector. As well during the summer season the highest cooling demand occurs.

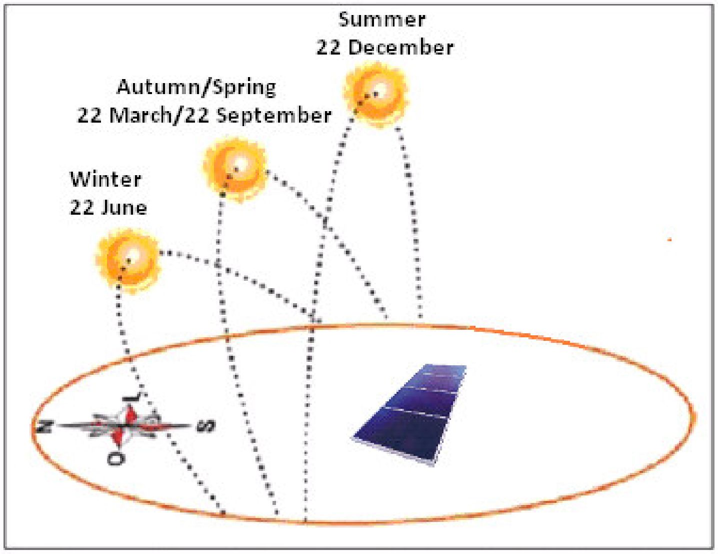


Figure 3.16 - Schematic illustration showing the inclination of the sun to the Earth surface in Guaratinguetá [28].

Table 3.9 shows the characteristics and costs of the on Brazilian market available and for solar-assisted air-conditioning applications useful collectors:

Collector Type	Evacuated tube	stationary CPC* (without vacuum)	Flat-plate (selective coating)	Flat-plate (selective coating)
Supplier	Apricus Solar Co., Ltd/ Fibratec	AO SOL, Lda	BOSCH GmbH	Cumulus S.A. Ind. Com.
Model	AP-30	CPC AO SOL 1.5	Bruderus Logasol SKN 3.0	CSC Premium 200
Aperture area of a single module [m²]	2,82	2,38	2,256	-
Gross area of a single module [m²]	4,14	2,69	2,398	1,95
Price of a single module [R$]	4081 Source: Fibratec Unasol Energias Renováveis Brazil		1050,28 Source: Bosch Brazil	1148 Source: Quali Tek Aquecedores, Rio de Janeiro
η_0 conversion factor [-]	0,656 (aperture area)	0,628 (aperture area)	0,770 (aperture area)	0,755** (gross area)

a_1 heat transfer coefficient [W/(m²K)]	2,063 (aperture area)	1,47 (aperture area)	3,681 (aperture area)	4,717** (gross area)
a_2 Temperature depending heat transfer coefficient [W/(m²K²)]	0,006 (aperture area)	0,0220 (aperture area)	0,0173 (aperture area)	not available**
η (ΔT=60K and G=500W/m²)	0,37	0,29	0,32	0,19 Equation 2.6
η (ΔT=60K and G=1000 W/m²)	0,51	0,46	0,55	0,47 Equation 2.6
Specific costs €/m² (R$/m²) area referred to the collector gross area.	985,75 R$/m²	223 €/m² (conversion factor 2.7 R$/€) 602,1 R$/m²	437,98 R$/m²	574 R$/m²

*source of the data [10].

** according GREEN Solar PUC-Minas (Prof. Elizabeth Duarte Pereira) the a_2-value of the Cumulus CSC Premium 200 Collector is negative and thus only the Equation 2.6 (see sub-section 3.1.3) can be applied. The INMETRO/PROCEL test procedure the efficiency values are referring to the gross area of the collectors.

Table 3.9 - Characteristic values and cost of solar collector typologies.

Except the CPC collector all collectors are available in Brazil. Through inside information the CPC collector will be at the Brazilian market in near future. The efficiency values are taken from the each collector test report according EN 12975-2:2006. The test reports are in the appendix A3. The Cumulus CSC Premium 200 Collector was tested according the Brazilian procedure, hence there is no a_2-Value and the referring collector area is the cross area, instead according EN standard the aperture area. Therefore this collector can not be exactly compared with the others. Nevertheless, the existing efficiency values and specific cost demonstrates that this collector can not compete with the, as well economic, Bosch Bruderus Logasol SKN 3.0 Collector. Because of that the Cumulus collector is not in Simulation.

It must be mentioned that the collector's efficiency-values have to be referred to same collector area. If not, they can not be compared.

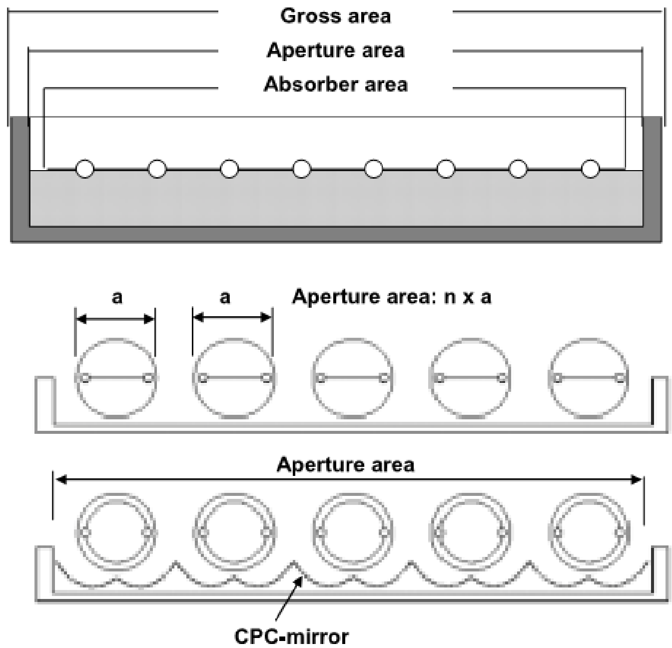


Figure 3.17 - Definition of collector’s areas (to be multiplied by the length) [7]

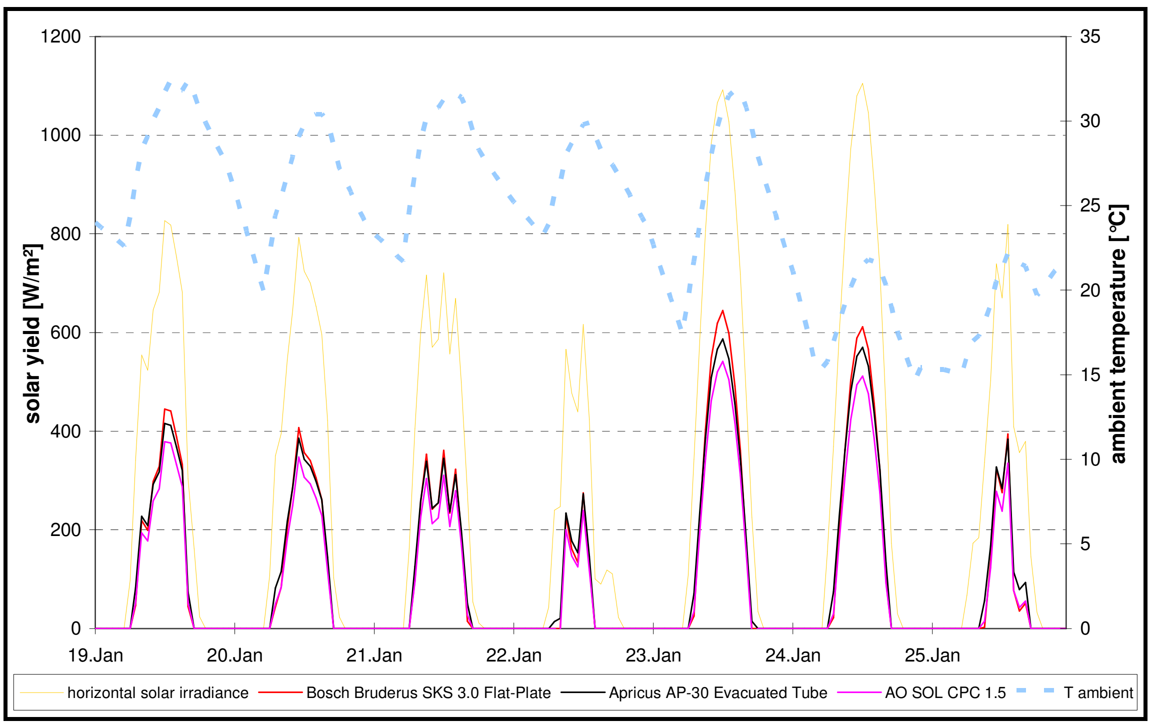


Figure 3.18 - Predicted performance of different solar collectors in Guaratinguetá during a hot summer week.

The simulation demonstrates that the Bosch Bruderus SKN 3.0 Flat-Plate collector at high solar irradiance and ambient temperature reaches the best result. At lower ambient temperatures and solar irradiance the collector is equal to the Apricus AP-30 Evacuated Tube collector, which costs the double.
Therefore the Bosch Bruderus SKN 3.0 Collector has the best performance-cost relation of all simulated collectors and thus highly recommendable for the solar-assisted air-conditioning project in Guaratinguetá.

3.2.2.3.2 Back-up and hot water storage

The main purpose of the storage in a solar-assisted air-conditioning system is to overcome mismatches between solar gains and cooling loads. The most common application is the integration of a hot water buffer tank in the heating cycle of the thermally driven cooling equipment [10].

Another form is to store the excess cooling power in a cold storage unit.
There is one company, SolarNext AG, who offers for the pilot-project the appropriate cold production sub-system including storage system. The offered solar cooling 'kit' from the company SolarNext AG (see Appendix A4) contains 2000 litre cold water storage and a 2000 litre hot water storage. The hot water flow (min. 75 °C, max. 95°C) driving the chiller at 8,64 m³/h and the cold water flow 5,5 m³/h. Due to an rough estimation, a capacity of 15-20 kW can be maintained within 2 hours. Provided that, the hot water tank has a total water temperature of 95°C and the cold water tank of 7°C.

A solar cooling system can not cover cooling loads during very cloudy days or at night, thus a back-up system is necessary.

3.2.2.3.2.1
Electrically driven compression chiller back-up

For the auditorium in Guaratinguetá the back-up system consists of four split air conditioning system with a total capacity of 35 kW (10 TR). There is no central air conditioning system with one compression chiller foreseen.

In any case, the back-up system should be NOT a fossil fueled heat source, as this option causes disadvantages in primary energy consumption and in greenhouse gas emissions, compared to a conventional compression chiller based solution. Thus, a non-regenerative based back-up system, where necessary, should consist of an electrically driven compression chiller, as shown in the example sketch of Figure below [8].

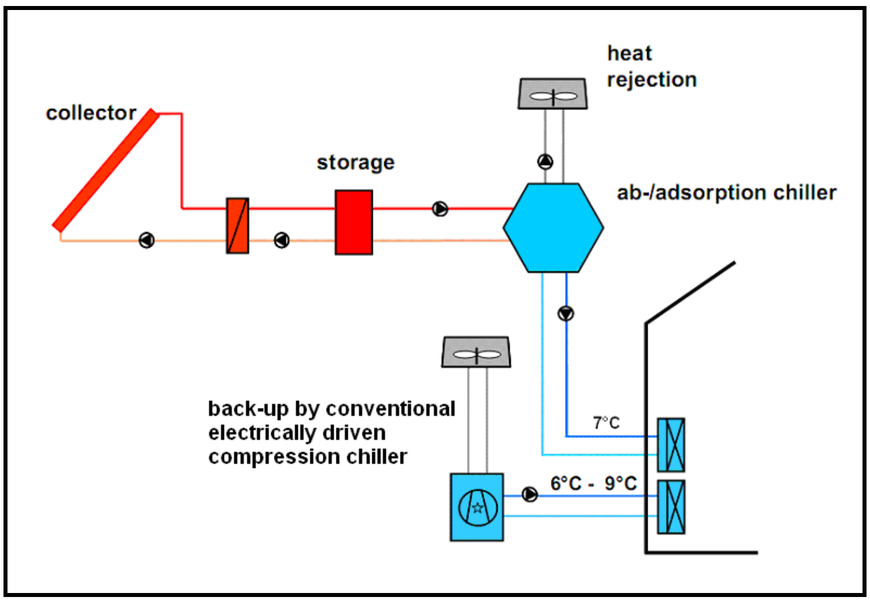


Figure 3.19 - Simplified scheme of a solar cooling system, assisted by a conventional electrically driven compression chiller. If cooling demand occurs during night, the compression chiller is operated (modified) [8].

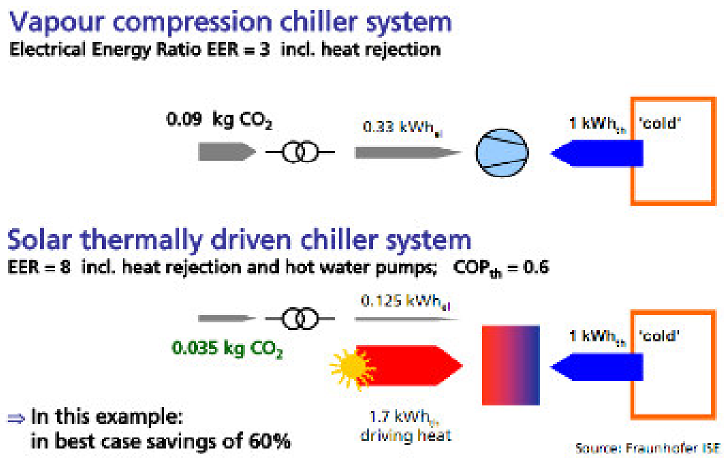


Figure 3.20a - Simple comparison of CO2 emissions of a compression chiller system and of a solar thermally driven chiller system. The conversion factor of 0.28 kg CO2 emission per kWh electricity consumed from the grid is used in this estimation [8].

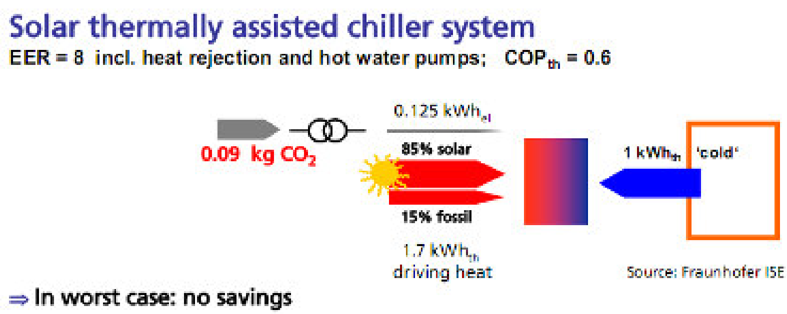


Figure 3.20b - In comparison to Figure 3.20a, 15% of the driving heat for the thermally driven chiller is based on fossil fuels, here natural gas [8].

The conversion factor of 0.28 kg CO2 per kWh electricity consumed from the grid is used in this estimation. Furthermore: gas boiler efficiency 0.9, 0.2 kg CO2 emission per kWh heat from the boiler. With this small share of fossil fuels on the heat input, the CO2 emission have already increased to the emission level of the conventional system (figure 3.20a) [8].

3.2.2.3.2.2
Thermal gas driven back-up

Because of economical reasons a thermally gas driven back-up must be evaluated. In Brazil the gas prices are lower than in Europe and because of the recently founded “pre salt” reserves the prevision is very promising. Therefore a gas driven back-up could be an alternative to Conventional electrically driven compression chiller back-up.

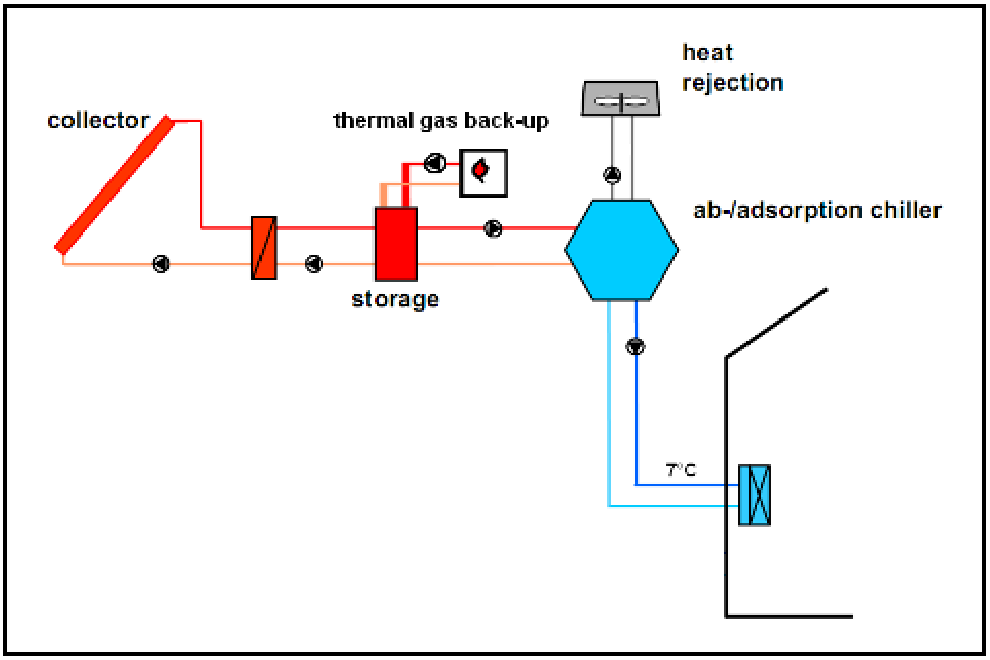


Figure 3.21 - Simplified scheme of a solar cooling system, assisted by a thermal gas back-up (modified) [8].

Before the economical feasibility calculation can be done, the gas demand must be calculated:

The Yazaki WFC-SC10 absorption chiller needs a hot water flow of 8,64 m³/h for 35 kW cooling capacity . The necessary Temperature elevation is ΔT 5 K (88°C chiller inlet and 83°C Chiller outlet). This results a energy demand of 50 kW (50 kW*COP 0,7 = 35kW or $Q = m(t) * Cw\ \ \Delta T = 2{,}4$ l/s * 4186,8 Ws/kgK * 5K = 50 kW). A efficient gas-fired burner has an efficiency of 98%, to facilitate the calculation 100% are assumed. The Energy demand for one day (9 h from 8 till 17 o'clock) is 450 kWh (9h*50kW).

The assumed calorific value for domestic gas is 11 kWh/m³, thus the consumption is 41 m³/day (450 kWh/11 kWh/m³). Hence 1257 m³ in one month (30 days).

The domestic gas supplier in Guaratinguetá is the Comgas company from São Paulo. 1 m³ domestic natural gas cost according a price table from 29.05.2009 (www.comgas.com.br/tarifas.asp) 6,14 R$/m³ incl. taxes. As yet there is no domestic gas supply in Guaratinguetá, thus gas cylinders must be applied. The specific cost is assumed with 7 R$/m³. Therefore the totally cost for driving a 35 KW absorption one month is 8800 R$ (7 R$/m³*1257 m³).

In comparison a 35 kW (35kW / 2.57 COP = 13,6 kW) Split air conditioning system consumes at the same time 3672 kWh with an electricity tariff in Guaratinguetá of 0,38 R$/kWh incl. taxes. Source, information February 2008 ANEEL (national electric energy agency - www.aneel.gov.br/area.cfm?idArea=532). This price was recently confirmed by the Edp Bandeirante Energia company. It must be mentioned that the Brazilian ICMS tax for residential (mono-phase) tariff about 200 kWh/month energy consumption is 25 % and not 12%.

Finally, the cost for driving one month a electric driven 35 kW split air-conditioning system is 1395 R$ (3672 kWh*0,38 R$/kWh). Because of this result a thermal back up system is until now not economically advantageous. The cost for maintaining the cooling capacity of 35 kW due to heating up the driving water for an single-stage absorption chiller is around 6 times higher than to generate the same cooling capacity with an electric driven split air- conditioning system. It must be added that the investment cost of a 35 kW split air-conditioning system is estimated only the half than a 50 kW gas-fired system including water tank. Normally, the gas burner is directly mounted at the water storage tank.

3.2.2.4
Design and performance of the complete system

According to the technical analyses the appropriate system consists of the Bosch Bruderus Logasol SKN 3.0 collector and the Yazaki WFC-SC10 (35 kW) single-stage absorption chiller. These are principal components and the main cost driver of the acquisition.

First system providers are on the market, offering system sets with appropriate selected system components. The SolarNext (Germany) company had offered a complete solar cooling “kit” including the Yazaki WFC-SC10 chiller (quotation see appendix A4). The advantage of a complete set is that the most important components are already selected, such as heat rejection system, pumps, valves, storages and special developed control unit etc. Therefore the planning costs decrease, due to higher standardisation. Another benefit is that the components are fitting ideal together e.g. electricity consumption of the heat rejection system is minimized due to a special controller. SolarNext offers a complete package for the application in Guaratinguetá including commissioning in Brazil, but except the collector system and cold distribution (load sub-system).

In the next step the collector area (A) must be calculated. For a first rough estimation the following equation is applied.

$$A = \frac{Q_{Cold}}{\eta_{\mathrm{Coll.}(\Delta T,\, G)} \cdot G \cdot COP} \qquad \text{(Eq. 3.2)}$$

with

Q_{Cold} = 35.000 W (max. cooling capacity)

$\eta_{\mathrm{Coll.}(\Delta T,\, G)}$ = 0,55 (with ΔT = 60 K and G = 1100 W/m²)

G = 1100 W/m² (max. solar irradiance at collector surface)

COP = 0,7

the collector area is 83m² ~ 80m²

With these 80 m² collector field the correlation between building cooling load (demand) and the cooling capacity (yield) will be simulated and the economic viability calculation is done in chapter 3.2.3.

In the Excel sheet the cold capacity is calculated by the following equation:

$$Q_{Cold} = \eta \cdot G \cdot A \cdot COP \qquad \text{(Eq. 3.3)}$$

with

$$\eta = \eta_0 - a_1 \frac{t_m - t_a}{G} - a_2 \frac{(t_m - t_a)^2}{G} \qquad \text{(Eq. 2.6)}$$

It is assumed that the COP is constant at 0,7, which accords to the chiller operation point at 88°C water inlet temperature and 31°C cooling water temperature. Therefore the in collector efficiency equation assumed Collector average water temperature (tm) is 85°C (88°C in / ca. 83°C out). The ambient temperature (ta) and solar irradiance (G) is applied hourly.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**HELEX 2.1**		UNESP 24 o. iso										
2	fbta Universität Karlsruhe		ALLGEMEIN										
3	Serie	1900	Ti	Cooling Load	G	Ta	ηApricus		ηCPC		ηBOSCH		Cooling Capacity
4	date	hour	[C]	[W]	[W/m²]	[C]		Q Apricus 1m²		Q CPC 1m²		Q Bosch 1m²	Q Bosch 80m² * 0,7 Chiller [W]
2741	33261	1	24	744	0	22,7	0,00	0	0,00	0	0,00	0	0
2742	23.Jan	2	23,8	0	0	21,6	0,00	0	0,00	0	0,00	0	0
2743		3	23,41	0	0	20,6	0,00	0	0,00	0	0,00	0	0
2744		4	22,96	0	0	19,5	0,00	0	0,00	0	0,00	0	0
2745		5	22,5	0	0	18,5	0,00	0	0,00	0	0,00	0	0
2746		6	22	0	0	17,4	0,00	0	0,00	0	0,00	0	0
2747		7	22,37	0	108	19,5	0,00	0	0,00	0	0,00	0	0
2748		8	24	2.688	343	21,7	0,21	70	0,10	34	0,07	25	1.405
2749		9	24	5.809	583	23,9	0,40	234	0,33	194	0,38	221	12.349
2750		10	24	9.070	806	26,1	0,48	386	0,43	343	0,50	403	22.551
2751		11	24	12.125	983	28	0,52	508	0,47	462	0,56	548	30.682
2752		12	24	14.853	1065	29,6	0,53	566	0,49	520	0,58	618	34.632
2753		13	24	17.060	1092	30,8	0,54	587	0,50	541	0,59	645	36.104
2754		14	24	18.637	1028	31,5	0,53	547	0,49	504	0,58	599	33.522
2755		15	24	19.789	887	31,8	0,51	455	0,47	417	0,55	491	27.518
2756		16	24	20.584	718	31,7	0,48	344	0,43	310	0,50	361	20.206
2757		17	24	20.625	462	30,8	0,38	174	0,32	146	0,35	160	8.938
2758		18	24	13.583	225	29,5	0,06	15	-0,04	-8	0,00	0	0
2759		19	24	12.167	34	27,9	0,00	0	0,00	0	0,00	0	0
2760		20	24	10.863	0	26,7	0,00	0	0,00	0	0,00	0	0
2761		21	24	9.281	0	25,6	0,00	0	0,00	0	0,00	0	0
2762		22	24	7.471	0	24,5	0,00	0	0,00	0	0,00	0	0
2763		23	24	5.486	0	23,3	0,00	0	0,00	0	0,00	0	0
2764		24	24	3.585	0	22,2	0,00	0	0,00	0	0,00	0	0

Figure 3.22 - Snapshot of generic spreadsheet

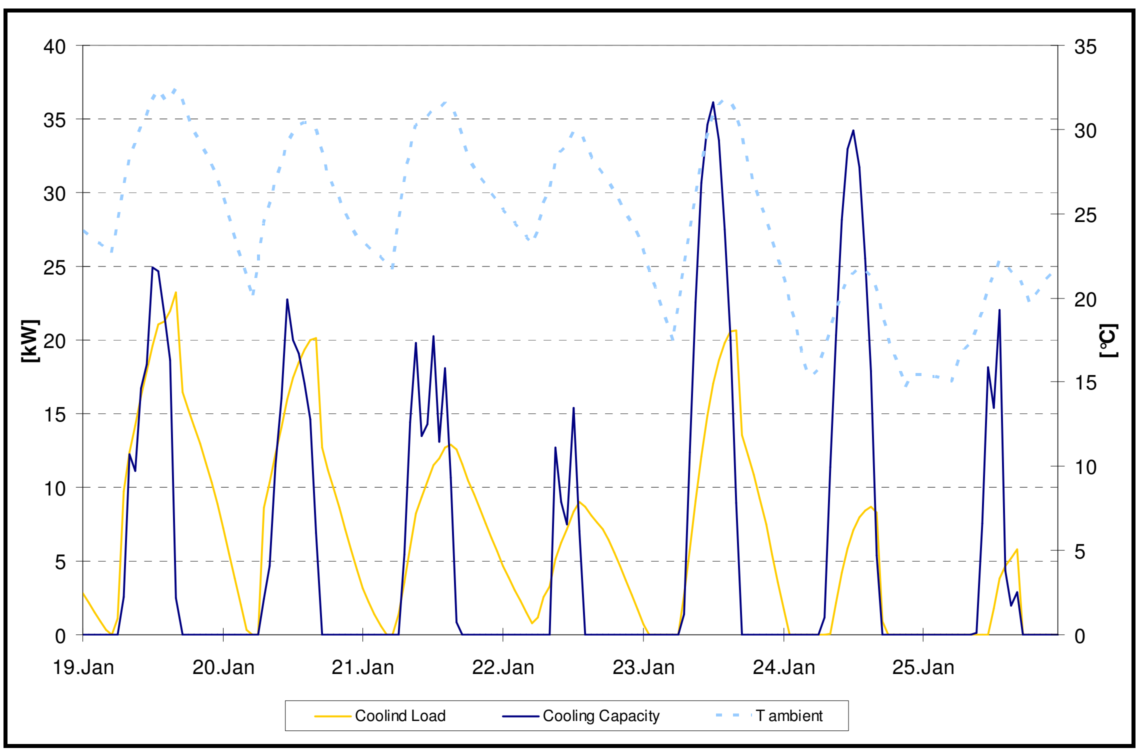


Figure 3.23 - Predicted correlation between cooling demand and cooling yield during a hot summer week in Guaratinguetá.

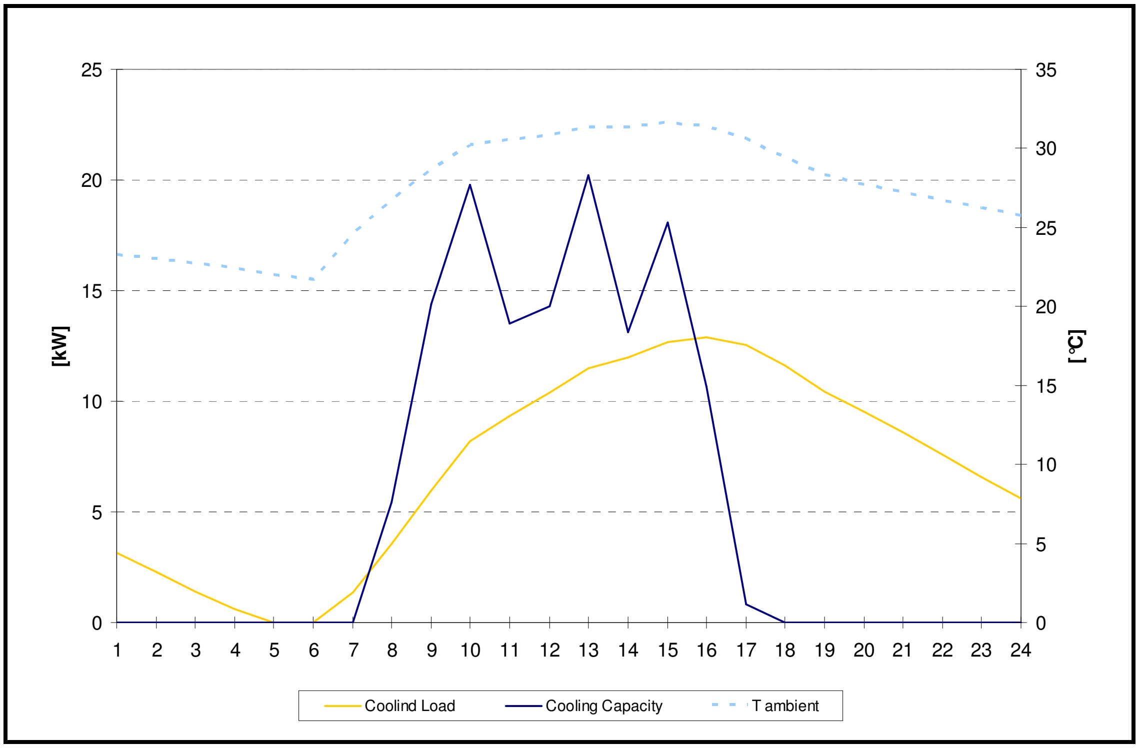


Figure 3.24 - Predicted correlation between cooling demand and cooling yield during one partly cloudy day.

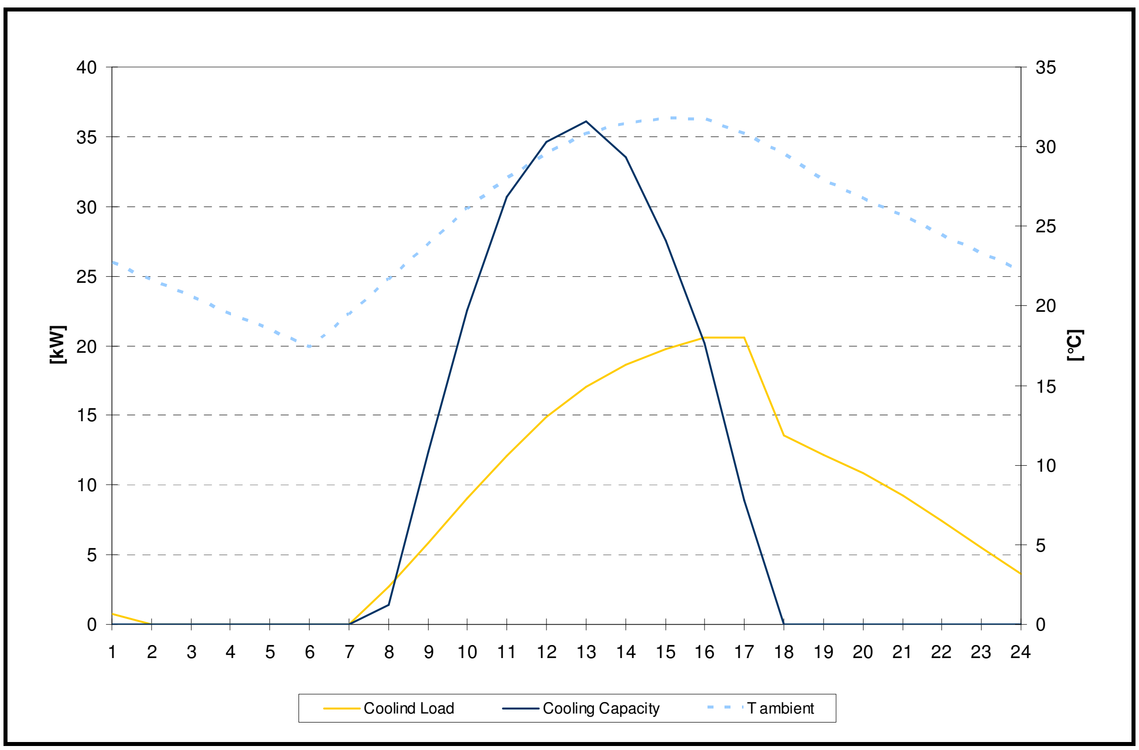


Figure 3.25 - Predicted correlation between cooling demand and cooling yield during a summer day with high solar irradiation (ca. 1100 W/m²).

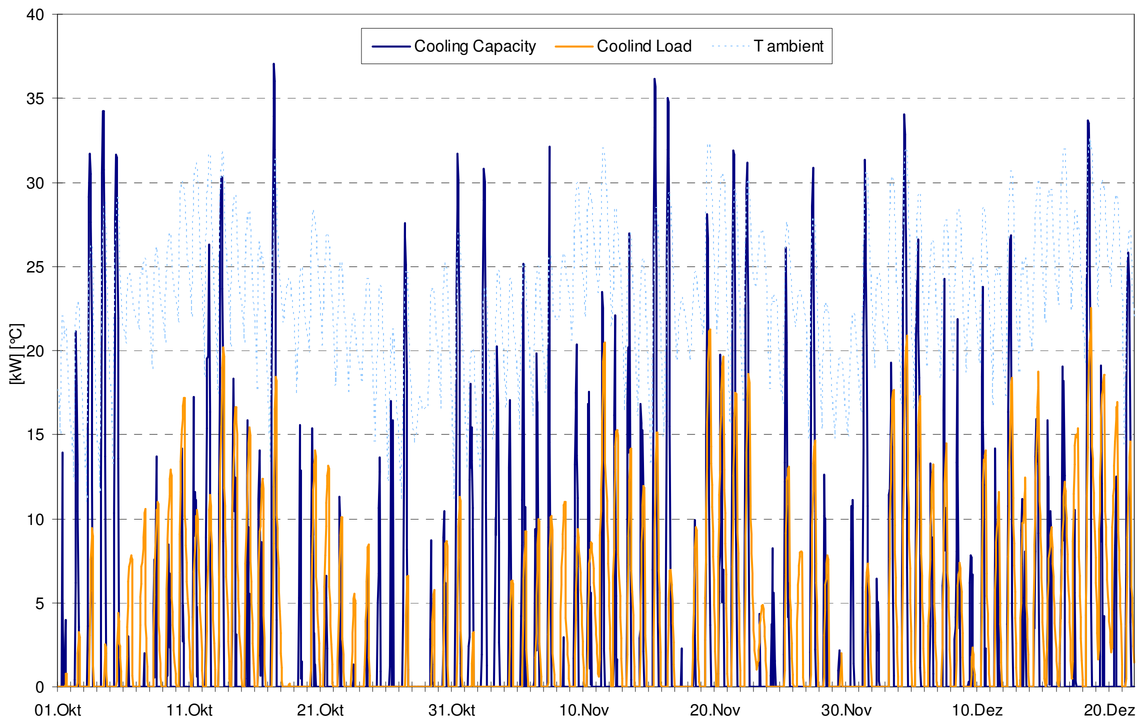


Figure 3.26 - Predicted daily demand and available yield of thermal energy during spring.

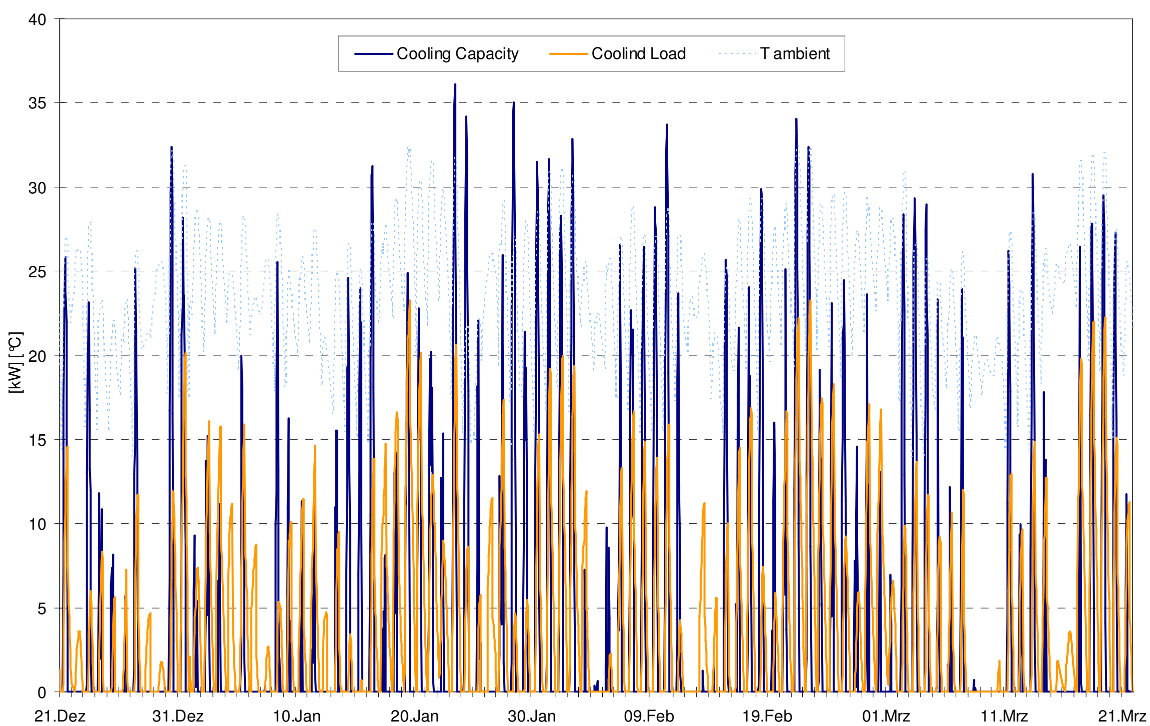


Figure 3.27 - Predicted daily demand and available yield of thermal energy during summer.

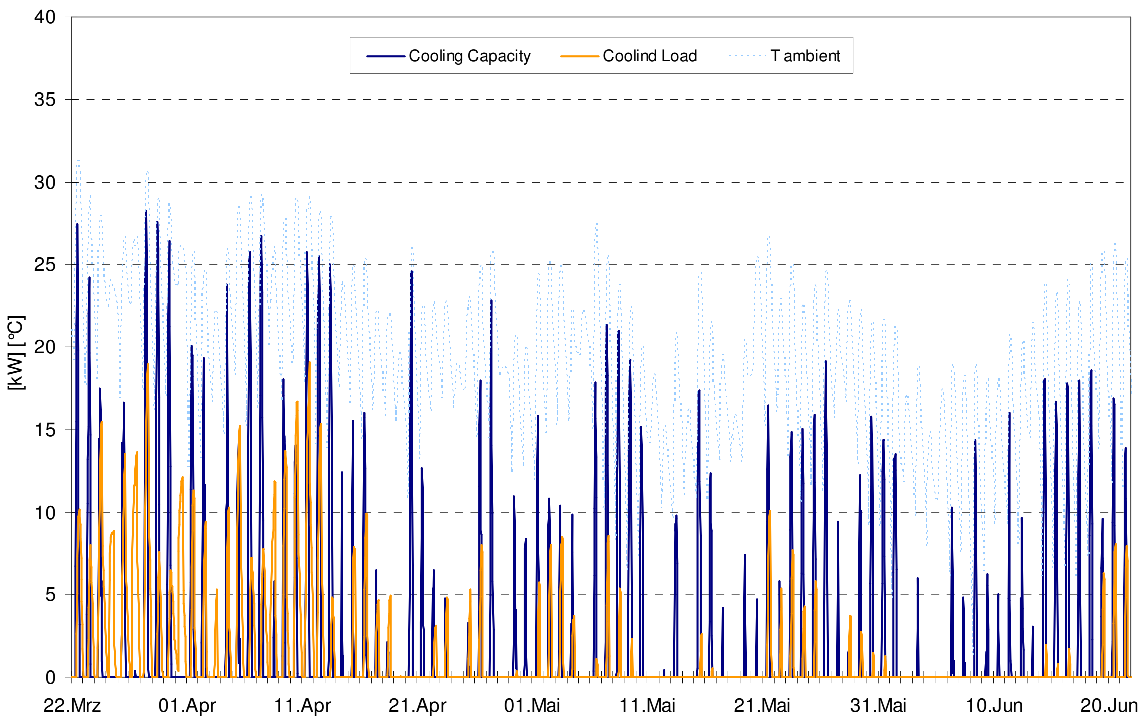


Figure 3.28 - Predicted daily demand and available yield of thermal energy during autumn.

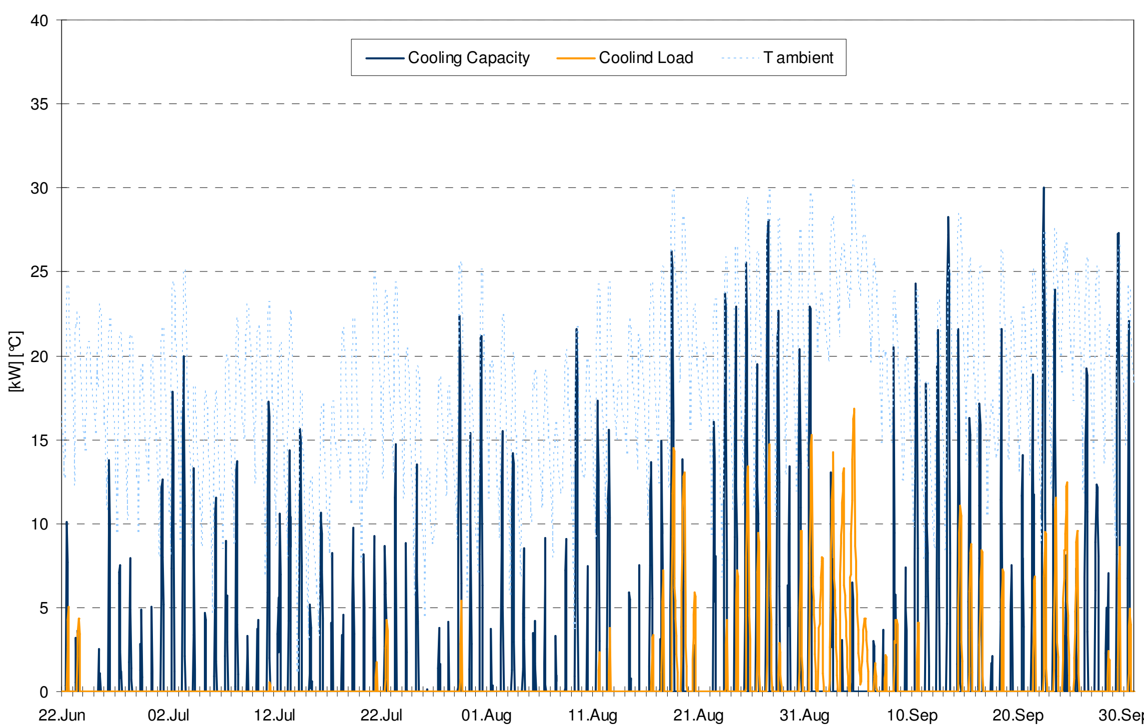


Figure 3.29 - Predicted daily demand and available yield of thermal energy during winter.

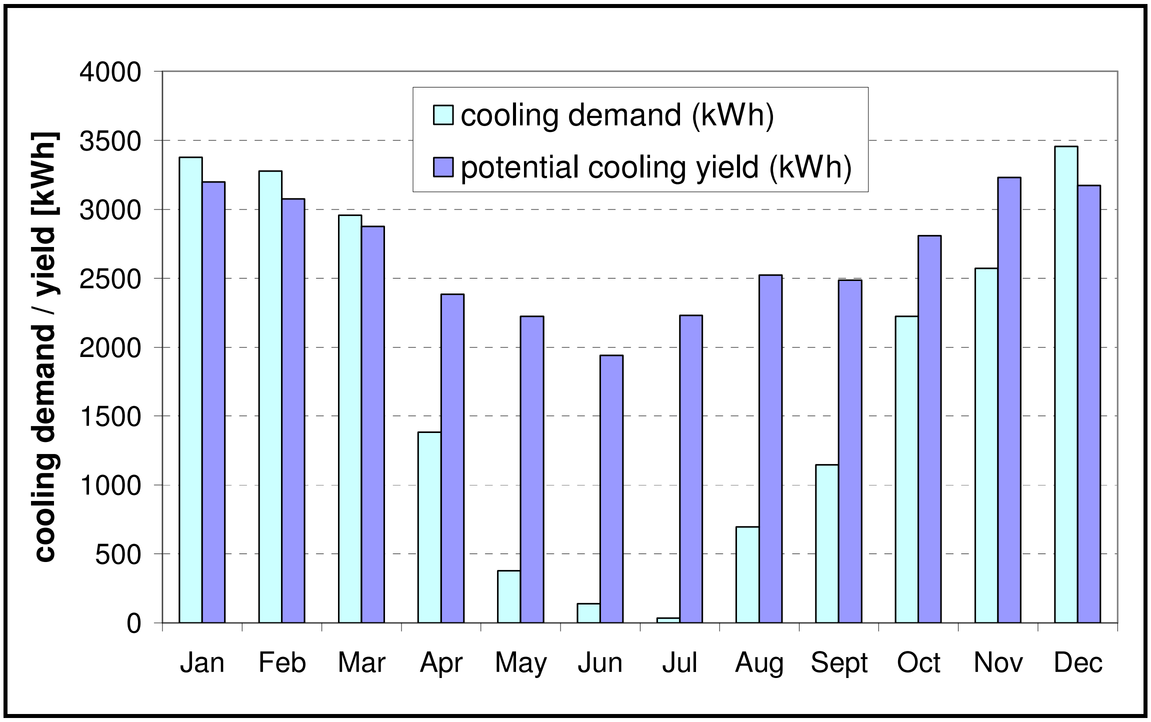


Figure 3.30 - Predicted total monthly cooling demand and available yield of thermal energy (8760 h). Solar yield is calculated with an constant daily average collector efficiency of 0,38 by 80 m² collector array and a constant Chiller COP of 0,7.

3.2.2.4.1 Conclusion

The figures have showed that the solar congruence regarding the cooling demand is in general good. At night the building cooling load is often higher than the cooling capacity and at noon the cooling capacity is around twice as much the demand, around 30 kW - 35 kW (see figure 3.26). With such a cooling capacity the auditorium could be air-conditioned until 20°C indoor temperature.

To utilize the excess thermal energy (hot/cold water) which occurs by an indoor temperature of 24°C at noon, the storage system must be on these thermal energy amount adapted. The SolarNext Solar Cooling Company recommends a 6000 l cold water tank to secure the thermal comfort 24 h at a hot summer day with maximum solar irradiance (see figure 3.25). Another way to adapt the solar irradiance gradient is by positioning the solar collectors slightly more into the west, thus the cooling demand would be more concordant to the solar yield.

Due to a rough evaluation of solar yield/demand correlation it was investigated that in around 30 days/year the sun not covers the cooling demand. Hence at these days the back-up system must run to secure the thermal comfort.

During spring and summer the solar yield and the building cooling demand is very congruence; only during their winter and autumn is more cooling power generated than needed. At June and July is an artificial cooling due to a cooling machine not necessary; at this time the free ventilation of 3000 m³/h is sufficient to compensate the internal cooling load of 12 kW. During this time the ambient air temperature at daytime is often below 24°C.

At the winter season it makes sense to utilise the thermal solar energy for water heating. The hot water can be used for taking shower, cooking or washing machines. At the UNESP University it could supply the refectory dishwashers.

Finally, it must be pointed out, that in comparison to normally solar thermal application for space and water heating in Europe the solar coverage is considerably superior.

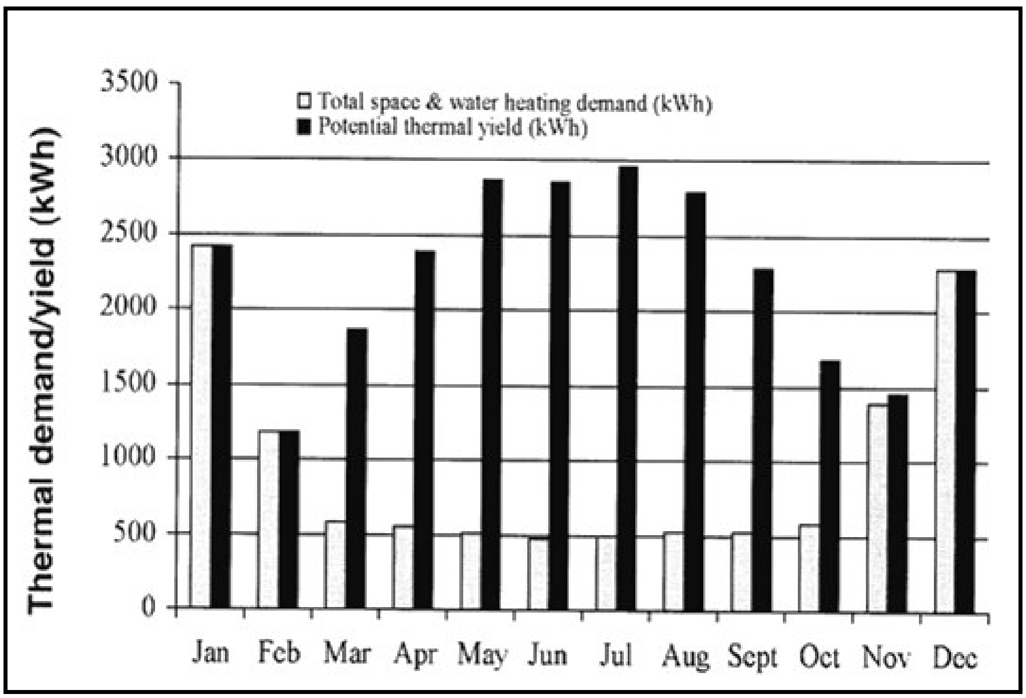


Figure 3.31 - Predicted monthly demand and available yield of thermal energy (UK, Leicestershire) [24].

The next figure shows a schematic diagram of the simulated solar-assisted air-conditioning system for the pilot-project in Guaratinguetá. It notices that a lot of pumps must be applied, as well, that the whole system is more complex than a conventional Split Air-Conditioning System. The pumps and mainly the cooling tower system consuming electric energy in the same way. In the next chapter will be investigated whether a solar-assisted air-conditioning system is under specific electricity cost in Brazil economic feasible.

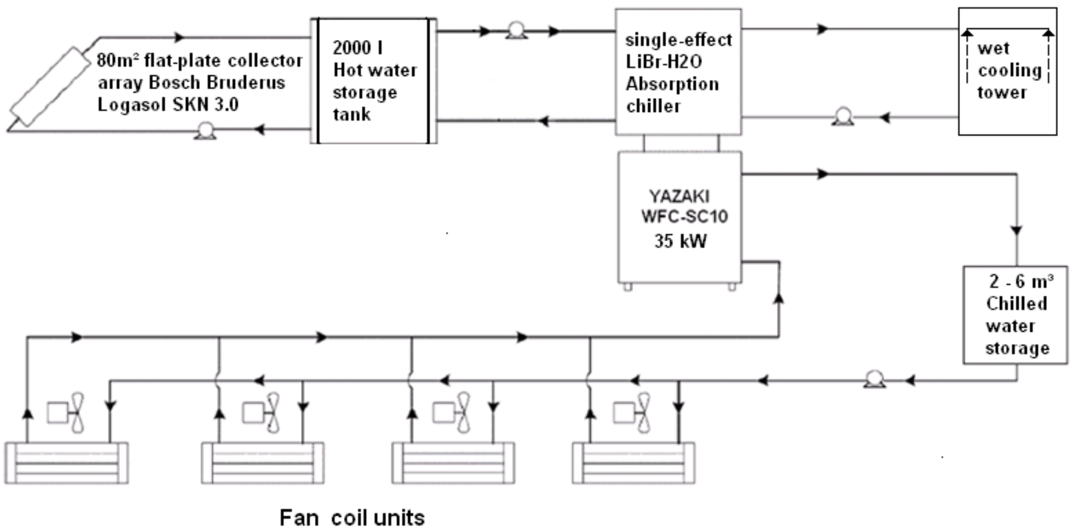


Figure 3.31 - Schematic diagram of the simulated solar-assisted air-conditioning system for the pilot-project in Guaratinguetá.

Note: The author does not recommend one of the mentioned brands.

Figure 3.32 - Example of an Solar-Assisted Air-conditioning application in La Réunion, France (small island near Africa) [25]. This project was executed by Schüco International KG. At this picture the fan-coil units in the Auditorium (ca. 200 m²) are visible.

3.2.3 Economic assessment

3.2.3.1 Acquisition and operation cost calculation

Before the economic feasibility can be calculated the Acquisition and operation cost must be investigated. Below are actual cost tables (Tables 3.10 e 3.11) for the applicable solar-assisted air-conditioning system and Split Air condition system (data base 2009). It must be mentioned that under real conditions the COP decreases, because of higher ambient air temperatures in summer estimated 10% and degradation through on-off controlling.

The on-off types of controls are generally used in small-capacity units to maintain the desired indoor temperatures and regulate capacity. For real systems using such controls, it can be said that a pure steady state does not exist. Judge et al. (1996) reported that on-off cycling of the system degrades the coefficient of performance (COP) of the system to values below 75% of the steady-state values. Thus, the transient characteristics are equally as important as the steady-state performance from the point of actual energy efficiency of the systems [26].

The Electrolux Split Air-conditioner is labelled with energy-efficient class A (PROCEL). The total cooling capacity of these four Split-conditioners is max. 35 kW (10 TR). This capacity was specified by two consulted refrigeration firms Frygeltec Refrigeração Ltda and Benco Ltda. This value meet the thumb rule calculate 1 TR (3.5 kW) for 15 m² room space (auditorium 150 m²). It is assumed that the Split System runs daily 9 hours.

Cost calculations are without installation, planning and maintenance cost because of no data base in Brazil. The installation cost can differ according to the site conditions to a high degree. Certainly they are higher than for the conventional system. The maintenance - and engineering cost are estimated higher, too. On the other side a compressor unit of the conventional split air-conditioner has an average lifetime of only 8 to 12 years by full use and a solar-assisted air-conditioning plant of 20 years minimum.

ACQUISITION COST [R$]			SPECIFIC COST [R$ per kW cooling capacity]	
Component	A: complete solar cooling "kit"	B: individual comp.	A:	B:
Flate Plate collectors, 80 m² Bosch Bruderus Logasol SKN 3.0	37.234 (13.790 €)	37.234 (13.790 €)	1.064	1.064
SolarNext chillii ® Cooling Kit WFC35, incl.: 1 x Yazaki WFC-SC10 Absorption chiller 1 x wet cooling tower with auto accessories filling and emptying, and fan speed control 1 x hot water pump 1 x cooling water pump 1 x chillii ® System Controller HC incl. Temperature Sensors 1 x cold storage 2000 l without Insulation 1 set of sensors f. Chilled water storage 1 x pump f. cold distribution with accessories 1 x hot water storage 2000 l with insulation 1 set of sensors f. hot water storage 2 x changeover valve with actuator	126.700 (46.926 €)	18.225 (6.750 €) estimated price for all these comp. except: chiller, cooling tower and controller	3.620	
1 x pump f. solar collector cuircit	945 (350 €)	945 (350 €)		
4 x fan coil unit	10.268 (3840 €)	10.268 (3840 €)	293	293
Yazaki WFC-SC10 35 kW Absorption Chiller		43.501 (16.700 €)		1.242
wet cooling-tower F-32 Refrigeracao International		7.370 (2.729 €)		211
SolarNext chillii ® System Controller H		5.624 (2.083 €)		
4 x Split Air-conditioner back-up* Electrolux SPLIT SE 30 F (30.000 BTU / 8,8 kW)	16.000 (5.926 €)	16.000 (5.926 €)	457 (169 €/KW)	457 (169 €/KW)
TOTAL	191.147 (70.772 €)	139.167 (52.178 €)	5.461 (2.022 €/KW)	3.976 (1473 €/KW)

Table 3.10 - Acquisition and specific costs per kW cooling capacity for two different system combinations.

Notes: a) Conversion factor 2,7 R$/€; b) * In accordance with PROCEL, as Back-up was chosen a split-conditioning system, because of the possibility to compare both systems by checking actual measuring data; c) A includes a complete cooling "kit" available by SolarNext AG company in Germany; d) B includes the acquisition prices for individual ordered components as the wet cooling tower, directly from a Brazilian company and the chiller directly from Yazaki, Japan. At last the controller device from SolarNext, too.

ELECTRICITY CONSUMPTION & OPERATION COST		
Component	solar-assisted air-conditioning system	conventional split air-conditioning system
4 x water pumps	360 W	
wet cooling-tower fan	280 W	
Yazaki WFC-SC10 35 kW Absorption Chiller	210 W	
4 x fan coil units	480 W	
4 x Split Air-conditioner Electrolux SPLIT SE 30 F (30.000 BTU / 8,8 kW)**		13.600 W
TOTAL	1.330 W	13.600 W
1 Month (30 days x 9 h)	359 kWh	3.672 kWh
9 Months	3232 kWh	33.048 kWh
TOTAL 10 Months operating (1 year) *	with 1 Month split-air conditioning back-up 6.904 kWh	36.720 kWh
Operation Cost (1 year) by 0,38 R$/kWh (Guaratingueta Edp Bandeirante Energia)	2.624 R$	13.954 R$
Operation Cost (1 year) by 0,598 R$/kWh (Minas Gerais -Cemig)	4.106 R$	21.959 R$

Table 3.11 - Comparison of electricity consumption and operation cost of a solar-assisted air-conditioning system and electrically driven compression vapour split air conditioning system.

Notes: a) * During two month there exists no cooling demand; b) ** The cooling capacity is 8,8 kW by each Split Air conditioner; c) The electricity consumption of each Split is 3.396 kW, according technical data, thus resulting a theoretical COP of 2,6.

3.2.3.2 Economic feasibility

The next two figures show the difference acquisition cost and cost developing. Beside the shown cost development due to the specific electricity cost in Guaratinguetá, it is presented the cost gradient through a higher electric energy price, which exists for example in Minas Gerais, where, as well, very good solar irradiance occurs.

There are no interest rates of the investment capital or maintenance cost considered, as well, no intended possible public subsidies and electricity cost elevation. Regarding the interest rates must be mentioned the following point. If there is a interest rate of only 1,5 % per year of the investment cost of 191.147 R$ the payback-time would be 5 years longer. This means a payback time of around 21 years, thus the system would not bring an income during the system lifespan. The usual interest rate of such a credit in Brazil around 8,5 % per year. Hence it is essential to become a credit with a very low interest rate, lower than 1,5 % per year.

In Brazil, as yet there is no subsidy or tax relief for those who exploit renewable energy. However, the Brazilian government just discussed a law (Lei 630/03) which pretends a financially support. In Germany there are several solar thermal energy incentives. For example the Reconstruction Loan Corporation (KfW) pays 30% of the solar cooling system investment, if the collector array is bigger than 40 m².

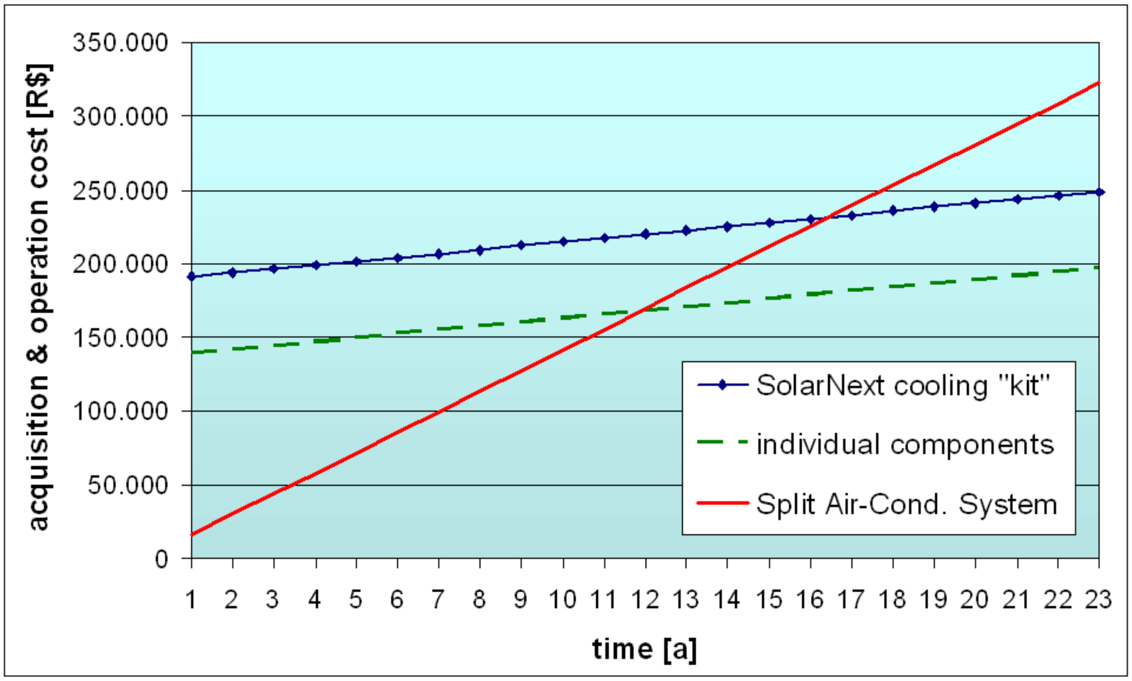


Figure 3.33 - Acquisition and operation cost of solar-assisted air-conditioning system and conventional split air-conditioning system in Guaratinguetá.

Note: Operation cost are calculated with an electric price of 0,38 R$/kWh which is the price in Guaratinguetá by supplier EDP-Bandeirante Energia SA.

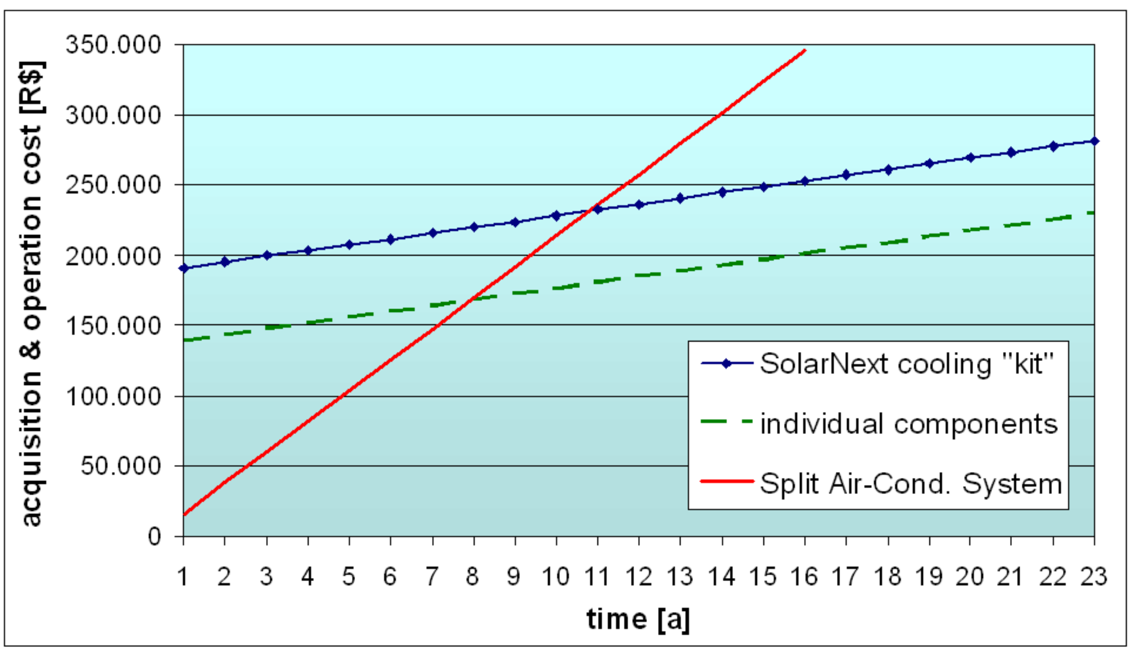


Figure 3.34 - Acquisition and operation cost of solar-assisted air-conditioning system and conventional split air-conditioning system in Minas Gerais.

Note: Operation cost are calculated with an electric price of 0,60 R$/kWh which is the price in the Brazilian State of Minas Gerais by CEMIG (companhia energética de Minas Gerais).

An important definition to evaluate the economic feasibility is the meaning of “critical operation time”. Below “critical operation time” is understood the time as from the solar-assisted air-conditioning system in relation to acquisition and operation cost is cheaper than the conventional system. If the solar cooling system within the lifetime (here 20 years) will be longer in operation than the critical operation time, the firstly high cost of acquisition pays off.

3.2.4 Environmental benefits

The main motivation of solar cooling technology implementation and replacing the conventional system is that they have a lower environmental impact. Any primary energy savings result in CO2 reduction.

To estimate the corresponding specific CO2 emissions per kWh produced ‘cold’ (per 0.285 TR), a conversion factor of 0.28 kg CO2 per kWh electricity is applied (average for the interconnected Brazilian electricity grid) [8].

The next table shows the CO2 savings per year.

Electricity consumption per year [kWh]		CO2-emissions [kg]
Solar assisted system	6.904*	1933 (1,9 tons)
Split Air-conditioning	36.720	10282 (10,3 tons)
CO2 Savings per year		8349 (8,3 tons)

*The calculation includes 1 month back-up operation by a split air-conditioning system.

Table 3.12 - CO2 savings per year calculated with the conversion factor of 0.28 kg CO2 per kWh electricity

In addition to the CO2 savings, the usage of environmentally refrigerants must be pointed out. They have no ozone-depleting or global warming potential. In the conventional systems are often used the R-134a as refrigerant.

A negative point is the water consumption of the wet cooling-tower. However, the water amount is very small in this case only 50 litres per day. This water could be collected by rain and therefore it causes no negative environmental impact. In order to complete the environmental impact evaluation of solar-assisted air-conditioning system a complete life cycle analyses should be carried out, but this would go beyond the scope.

3.2.5 Conclusion

This chapter has demonstrated that the acquisition cost of solar-assisted air-conditioning is very high in comparison to the conventional system. By contrast the running costs are significant lower, only 0,038 kWh electricity is sufficient to generate1 kWh cooling power. To secure this cost it is important to apply always high-efficient pumps and fans, the pumps and cooling tower fan should be speed regulated.

Generally, in all calculated cases the solar cooling low operation cost compensate the higher investment cost in a long term, especially in Minas Gerais at a higher electricity price. The case study shows that solar cooling systems can be a alternative option against electric split chillers, especially in areas with significant cooling demand (high internal cooling load), solar irradiance, and electric prices. As electric rates increase, solar cooling will become an even more economically attractive option for building owners.

But, it must be mentioned if in Guaratinguetá on the high investment cost an interest rate more than 1,5 % would be added, there would be no cost savings during operation yield. Thus it is important that a financial support exists, for example through low-interest credits or direct investment grant. As well, must be highlighted that that the economic feasibility is only given for buildings where the cooling demand mostly occurs during the day.

The Payback times are 11 years with the higher SolarNext solar cooling “kit” investment cost and the electricity cost in Minas Gerais and 16 years Payback due to the lower electricity cost in Guaratinguetá.

In the onsite energy market for privately-owned buildings, paybacks of two to three years are desirable; five to seven years are sometimes acceptable, and anything over ten years is not economic. Payback periods for publicly owned buildings (e.g. institutions such as schools, municipal buildings, federal government buildings, jails, etc.) might be extended longer than for privately-owned buildings [27].

4
Conclusion and recommendations

The study has shown that for the pilot-project in Guaratinguetá the following appropriate and cost-effective solar cooling technology can be applied:

- A closed chilled water cycle system with an integrated (Yazaki WFC-SC10) 35 kW (10 TR) single-effect LiBr-H2O Absorption Chiller and a wet-cooling tower.

- The cold distribution inside the auditorium by four fan coil units. A cooling ceiling is not suitable because it brings nit the sufficient cooling capacity into the building.

- A collector array of 80 m² with Bosch Bruderus Logasol SKN 3.0 (Flat-Plate) has the best performance-cost relation.

- As back-up system should a conventional electrically driven compression split air-conditioning system applied, because heating up the water with gas for driving the single-effect absorption chiller causes six times higher operation cost. Consequently, a thermal gas back-up can not be recommended due to the gas prices in the necessary consumption range and as well due to the negative CO2 balance.

Therewith the congruence between solar gain and cooling demand is good, thus less collector surface is necessary and the investment cost decreases, it's important to clarify in advance which indoor set point temperatures are applicable for the cooling demand calculation. According the Brazilian thermal comfort standard (PNB-10) is 24°C indoor temperature by 29°C ambient temperature well sufficient. With an indoor set temperature of 24°C, the cooling load can be reduced in contrast to an indoor temperature of 20°C for more than half.

It was noted that it is important to verify before dimensioning of a solar cooling system, or generally of a conventional air-conditioning system, too, which cooling demand is really necessary and how it can be reduced through alternative ways, such as, shading measures, (night-) cooling with outside air, building insulation or decreasing (lighting etc.) the internal load.

Through the case study was the economic feasibility of the specified solar-assisted air-conditioning checked and compared with a conventional electrically driven compression split air-conditioning system. It turned out, that the low operation cost can compensate the higher investment cost within the solar cooling system life time of minimum 20 years.

In Guaratinguetá this happens after 12 years with a "tropicalizated" system in which the components are provided individually mostly by the Brazilian market, and after about 16 years by an application of a complete solar "kit" from SolarNext AG, Germany (without solar collectors). In Minas Gerais would yield payback times of 8 and 11 years since there is the price of electricity 60% higher than in Guaratinguetá.

Consequently, solar assisted air-conditioning can compete with Split-Air conditioning system, but only under the following conditions:

- No minor electricity prices than in Guaratinguetá (0,38R$/kWh)
- Cooling demand only during daytime thus application for offices, universities or schools etc. Cinemas are not recommendable.
- Efficient pumps and fans applied
- Financial support for the acquisition through low-interest credits or direct investment grant.

Finally, it must be mentioned that the payback periods are very high for privately-owned buildings. On the other side private companies e.g. hotels could use this technology to do “eco-facade/green marketing”. Solar air-conditioning is a renewable energy technology with an enormous marketing potential. It makes the Sun generate chilled water.

By the demonstration project validation could be made against the simulation data by checking actually measured data. A solar cooling pilot project could fill many of the existent knowledge gaps, confirm the technical and economical feasibility and perhaps become a precursor for a general implementation.

A Pilot-Project is the first step to disseminate this for Brazil “new” environmental friendly technology. It must be made sure that quality of planning and installation has a high level to ensure to later reliability of the system. A market barrier of the implementation is not only the high investment cost, as well, a lack of knowledge. Therefore it’s important to realize the first project in cooperation with experienced firms. Hereby a know-how transfer to Brazilian companies who pretends to deal with solar cooling is elementary. As well, a simple pre-design software tool for Brazil must be introduced, thus local companies can dimension their systems. This program should also consider the economic feasibility by the individual local energy prices.

Last but not least, a recommendation regarding “solar cooling” integration in high buildings. In Tropical Cities sufficient roof area for providing a whole skyscraper with solar air-conditioning is often not given. Through a rough estimation can be said that only for two stores enough roof space exists. Hence it is recommendable to use an electrically driven compression central chiller to cover the latent cooling loads and use a solar cooling system in side-stream to cover the highest cooling loads during the day. Thus extra capacity generated by the sun occurs only when the load is the greatest, and the energy source to drive it has no recurring cost.

The energy source is somewhat coincident with the greatest load, providing a sensible means of Peak Shaving, keeping the electric chillers in their most efficient mode during the hottest period of the day. And if the solar collectors are placed on the roof, they will provide a reduced cooling load by shading the roof [3].

The next figure shows clearly that that most efficient mode of an electric chiller lies between 25% and 75% of full load. If the chiller runs at full load it will waste more energy kW per Tons of Refrigeration.

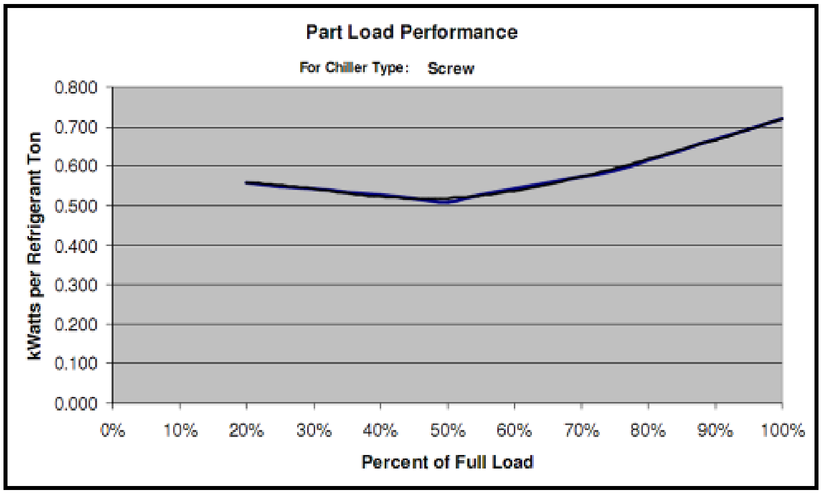


Figure 4.1 - Typical electric driven screw chiller power curve [3].

Brazil receives solar energy in the order of 10^13 MWh per year, which is about 50.000 times the country's annual consumption of electricity. But, despite of this optimum solar radiation condition, as yet only a small part of this energy is used. The most electrical energy is generated by large-scale central hydropower plants, whose sustainability is doubtful. The power supply is through the centrality of power generation very interference-prone, which had showed the recently black-out from 10. November 2009. As well, a lot of energy is wasted due to long way energy transmission for example from Itaipu to São Paulo.

In future the Brazilian government intends to secure the country's electricity supply by more nuclear power and fossil-fuelled thermal power stations.

Energy efficiency measures like solar cooling implementation can contribute to less electric energy consumption. Certainly, it does not solve the country's energy problem, but if the whole country cooling demand would be supplied by solar cooling systems more or less one large-scale power plant could be avoided.

Solar cooling technology is a way to provide building air-conditioning by using local regenerative sun energy. The main advantage is that the cooling load and solar gain occurs at the same time, an at least at seasonal level, which is by other regenerative energies often not the case. From central power plants used primary energy can be saved and CO2 emissions can be minimized. Through a solar cooling pilot Project in Guaratinguetá 8,3 tons CO2 could be saved per year and it could open the way for a general application of this environmental technology in Brazil.

References

[1] Revista Brasil Energia (June 2005) http://www.energiahoje.com/brasilenergia/noticiario/2005/06/01/268315/comgas-quer-avancar-sobre-o-segmento-de-ar-refrigerado.html

[2] Lamberts, R. Energy Efficiency in Buildings in Brazil (March 1999): Towards a Standard. Report presented to the International Energy Initiative. Florianópolis: Núcleo de Pesquisa em Construção - Universidade Federal de Santa Catarina.

[3] Presentation "Effective Solar Chilled Water" (June 2009) by Bud Leavell Yazaki Energy Systems Inc. Plano, Texas

[4] Kraas, F. (2003): Megacities as Global Risk Areas. (Petermanns Geographische Mitteilungen 147 (4): 6-15.

[5] Un-Habitat (2001): Cities in a Globalizing World - Global Report on Human Settlements

[6] Spangenberg, J. (2004): Improvement of urban climate in tropical metropolis, Master´s Thesis - University of Applied Sciences Cologne (Institute for Technologies in the Tropics)

[7] Solair (2009): Requirements on the design and configuration of small and medium sized solar air-conditioning applications - Guidelines

[8] Fraunhofer Institute for Solar Energy Systems ISE (2009): Solar cooling in Brazil - Technology study

[9] ASHRAE Terminology of HVAC&R, ASHRAE, Inc., Atlanta, 1991

[10] Henning, H. (2007) Solar-Assisted Air-Conditioning in Buildings - A Handbook for Planners

[11] SOLATERM Project Report (September 2007) - Potential Analysis for a New Generation of Solar Thermal Systems in the Southern Mediterranean Countries

[12] Barja, G. (2006): A cogeração e sua inserção ao sistema elétrica, Dissertação de Mestrado – Universidade de Brasília

[13] M. Filippi, G. Mutani, M. Perina (2001): The use of natural or artificial lakes and ponds in HVAC Plant in Italy - 6th European Conference Solar Energy in Architecture and Urban Planning

[14] P. Bourdoukan, E. Wurtz, P. Joubert and M. Spérandio (2008): Sensitivity Analysis Of A Desiccant Wheel, Université de La Rochelle (LEPTIAB) and Université de Savoie (Campus Scientifique)

[15] Riffel, D. (2008): Estudo Teórico e Experimental da Dinâmica e da Otimização de Refrigeradores Térmicos por Adsorção, Tese de Doutorado - Universidade Federal da Paraíba

[16] Environmental Protect Agency (EPA) ww.epa.gov/hiri/about/index.htm

[17] Akbari, H. (2005): Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation - Lawrence Berkeley National Laboratory

[18] Meunier, F. (2007): Oasis effect to mitigate heat island - 22nd IIR International Congress of Refrigeration

[19] Lima, J. & Silva, E (2000): Climatologia na região de Guaratinguetá São Paulo (Brasil) - XXVII Congresso Interamericano de Engenharia Sanitária e Ambiental

[20] S. Silva, R. Guarnieri, F. Martins e E. Pereira (2007): Comparação de estimativas de radiação solar fornecidas por interpolação kriging de dados de

superfície e por modelo físico alimentado com dados de satélite - Instituto Nacional de Pesquisas Espaciais (INPE) Divisão de Clima e Meio Ambiente (CPTEC)

[21] Kuchta-Schrader, C. (2004): Passive Kühlung http://www4.architektur.tu-darmstadt.de/powerhouse/db/248,id_30,s_Papers.fb15

[22] Hagel, A. (2005): Análise computacional da demanda energética de climatização de edifício, projeto de graduação - Universidade de Brasília

[23] Caruy, C. (2009): ABRALISO Economia de energia elétrica através de isolamento das envoltórias em edifícios climatizados artificialmente - 6° Congresso Brasileiro de Eficiência Energética São Paulo

[24] N.Shankland, K. Lomas, H. Eppel and B. Certmell (2001): Renewable Energy technologies for low-energy public building - 6th European Conference Solar Energy in Architecture and Urban Planning

[25] Köln, H. (2008): Entwicklung von Paketlösungen für solare Kühlung - 5. Symposium "Solares Kühlen in der Praxis"

[26] Report in HVAC&R (May 2009): Transient characteristics of split air-conditioning systems using R-22 and R-410A as refrigerants

[27] Hinrichs, D. (2006): Technical and economic assessment of solar thermal absorption cooling systems in small commercial buildings - Sentech, Inc.

[28] Cunha, C. (2009): Aquecimento Solar - ABRAVA

Appendix

A1
Specification for the auditorium

Rio de Janeiro, 04/09/2009

Especificação de requisitos para a integração de um sistema de climatização solar no auditório do novo núcleo de eficiência energética da UNESP

Por Dipl.-Ing. (FH) Till Felix Reichardt

1. Introdução

Conforme reunião na Eletrobrás - Rio de Janeiro, junto com a GTZ, realizada no dia 19 de agosto de 2009 foram apresentadas as especificações de requisitos para a integração de um sistema de climatização solar no auditório do núcleo de eficiência energética da UNESP – Guaratinguetá/SP.

A GTZ Brasil e a Eletrobrás/PROCEL são parceiros no programa ProFREE (Programa de Fontes Renováveis de Energia e Eficiência Energética) da GTZ que fortalece a Eficiência Energética e o uso de energias renováveis em prédios públicos.

O aproveitamento da energia térmica para converter calor em frio é uma tecnologia que vem crescendo na Europa. A Agência Internacional de Energia (IEA) tem vários projetos envolvendo energia solar para fins de climatização e mostra que a tecnologia está madura para ser utilizada comercialmente. Nos países de clima tropical, como o Brasil, nos quais a demanda de resfriamento coincide com os períodos de maior intensidade de radiação solar, a implementação da climatização solar tende a ser uma realidade em futuro próximo.

1.1 Centro de Educação para Eficiência Energética

O Centro de Educação para Eficiência Energética em Guaratinguetá no Estado de São Paulo pretende utilizar conceitos arquitetônicos e tecnológicos que exemplifiquem o uso eficiente e inteligente da energia, demonstrando aos visitantes que o planejamento de uma obra pode ser ecologicamente correto.

Para oferecer condições de funcionalidade no espaço físico onde deverá ser instalada a sede do Centro de Educação para Eficiência Energética, serão feitos vários investimentos visando à obtenção de produto final com as características listadas a seguir:

1. Área total do Centro de Educação: até 1500 m²;

2. Auditório ou Sala de Projeção: Área destinada à realização de eventos variados, tais como palestras, encontros, capacitações etc. Capacidade para cerca de 100 pessoas. Área aproximada: 150m^2;

3. Biblioteca: Área aproximada de 50m^2. Abrigará o acervo bibliográfico sobre educação, de maneira geral, energia, meio ambiente, eficiência energética, de maneira específica. Além de apoio aos pesquisadores, a biblioteca tem a função de divulgar e disponibilizar materiais sobre o tema da Eficiência Energética;

4. Área de trabalho para professores e pesquisadores: Salas destinadas a abrigar professores e pesquisadores envolvidos com as pesquisas do Centro de Educação. Composto por 5 salas de aproximadamente 50m^2, devendo abrigar, em geral, 2 pesquisadores por sala. Com previsão de sistema de rede wireless;

5. Laboratório de Desenvolvimento: Espaço no qual serão alocadas as estações de trabalho (móveis, computadores e softwares). Este laboratório abrigará programadores, alunos, bolsistas, pesquisadores e professores envolvidos com o desenvolvimento de softwares e materiais didáticos relacionados ao Centro de Educação. Área prevista de aproximadamente 200m^2. Com previsão de uso de rede wireless;

6. Laboratório de Hardware: Laboratório para desenvolvimento de equipamentos e dispositivos elétrico/eletrônicos relacionados aos objetivos do Centro de Educação. O laboratório tem como objetivo criar um ambiente adequado com ferramentas para o desenvolvimento dos dispositivos. Área de aproximadamente 100m^2. Com previsão de rede wireless;

7. Laboratórios eletromecânico: laboratório destinado a elaboração de equipamentos, maquetes, equipamentos eletromecânicos para demonstrações relacionadas à produção, transmissão e utilização da energia. Área aproximada de 100m^2.

8. Hall de exposições: Área destinada a exposições e de divulgação dos objetivos do Centro de Educação e suas atividades. Área de cerca de 400m^2;

9. Sanitários: 2 conjuntos (masculino/feminino) sendo a área total deles de cerca de 60m^2;

10. Copa e área de serviços gerais: aproximadamente 50m^2;

11. Recepção do Centro: Com uma área de aproximadamente 40m^2, tem a função de realizar a triagem e orientação dos visitantes, bem como abrigar as funções administrativas do Centro de Educação.

12. Corredores, escada e espaços funcionais: aproximadamente 100 m^2.

1.2 Demanda de resfriamento e ar condicionado no Brasil

Os sistemas de resfriamento e ar condicionado (R&AC) são responsáveis por um elevado e crescente consumo de energia elétrica, sendo essa uma tendência mundial. Na Europa, por exemplo, o crescimento esperado é de 50% ao ano, nos próximos 15 anos (EECCAC, 2003).

No Brasil, a mesma tendência pode ser observada. De acordo com a ABRAVA (2006), equipamentos de ar condicionado respondem por cerca de 40% da eletricidade consumida em um edifício comercial. Esse percentual chega a 50% nos aeroportos brasileiros, segundo dados divulgados pela INFRAERO (2006).

O Jornal Mercantil (2008) divulga um crescimento para o setor de 12% ao ano. Os dados acima mostram a importância, tanto do ponto de vista energético, quanto econômico, dos sistemas de condicionamento de ar no país. Considerando o impacto desses sistemas na matriz energética nacional e o crescente custo da energia elétrica, o uso combinado de fontes térmicas para fins de climatização pode ser uma alternativa estratégica e economicamente viável.

2. Aplicação de climatização solar no auditório da UNESP/Guaratinguetá

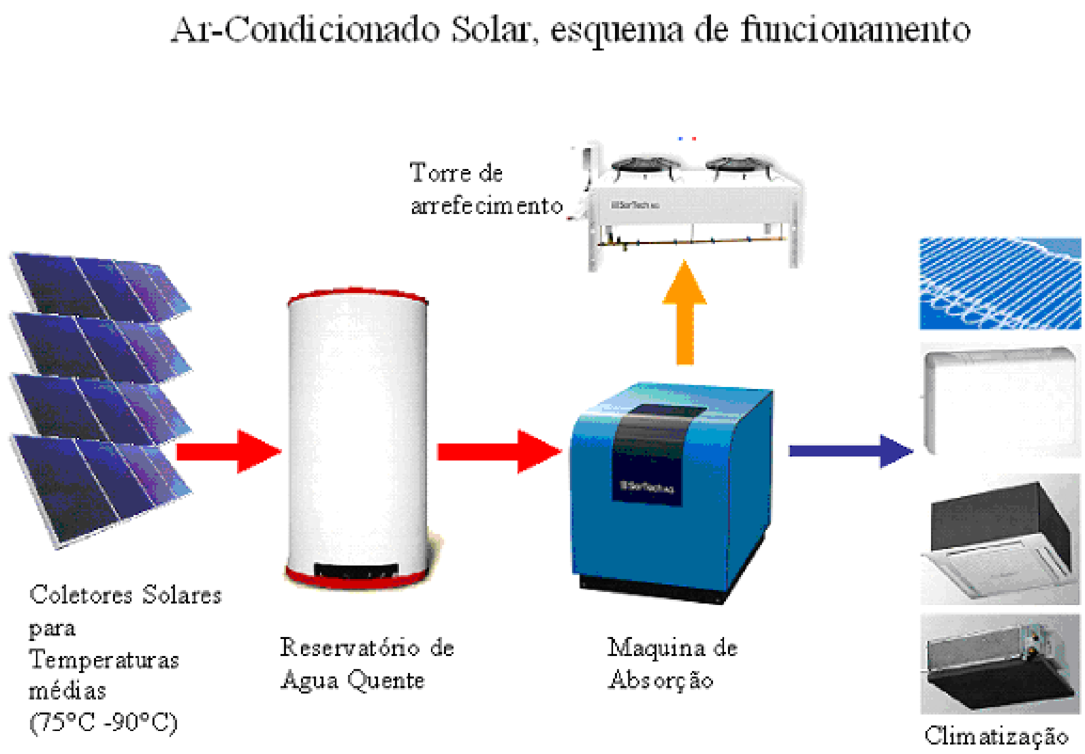
PROCEL avalia incluir no planejamento da obra do núcleo de eficiência energética um sistema de climatização solar, sendo esse o primeiro projeto piloto no Brasil.

Está prevista climatização do auditório com energia solar térmica. O auditório tem uma capacidade para cerca de 100 pessoas e uma área aproximada de 150 m^2. Para uma sala de 150m² estima-se uma potência de ar condicionado de aproximadamente 30 kW (8 TR). É importante ressaltar que, com mais detalhes sobre a carga térmica do auditório, é possível realizar cálculos para definir um valor mais preciso. Nesse momento do projeto os dados não estão disponíveis.

O sistema apropriado seria de ciclo fechado com uma máquina de absorção movida a energia solar térmica obtida de coletores para temperaturas médias entre 75°C - 90°C. Essas coletares são disponíveis no mercado brasileiro. Também esse sistema pode ser utilizado em todas as regiões climáticas do Brasil. Além disso já existem empresas com experiência que oferecem sistemas compactos para a climatização, destinados a edifícios de pequeno e médio portes, com uma potência de resfriamento desde 7 kW (2.5 TR) até 70 kW (20 TR).

O ciclo de absorção é de simples efeito (single effect chiller), utilizando o par água-brometo de lítio (H2O-LiBr) como refrigerante e absorvente. A máquina de absorção necessita no mínimo de 80°C de água quente na entrada para gerar o frio. Para o abastecimento da água frio (6°C – 9°C) no auditório, recomenda-se um sistema de ar condicionado cm "fan-coil". Durante a tese de mestrado será investigado qual o sistema mais apropriado. Como sistema back-up foi proposto originalmente um sistema de ar-condicionado convencional (compressor elétrico).

Os seguintes esquemas explicam o funcionamento do sistema (fonte: Solvis GmbH&CoKG, modificado):



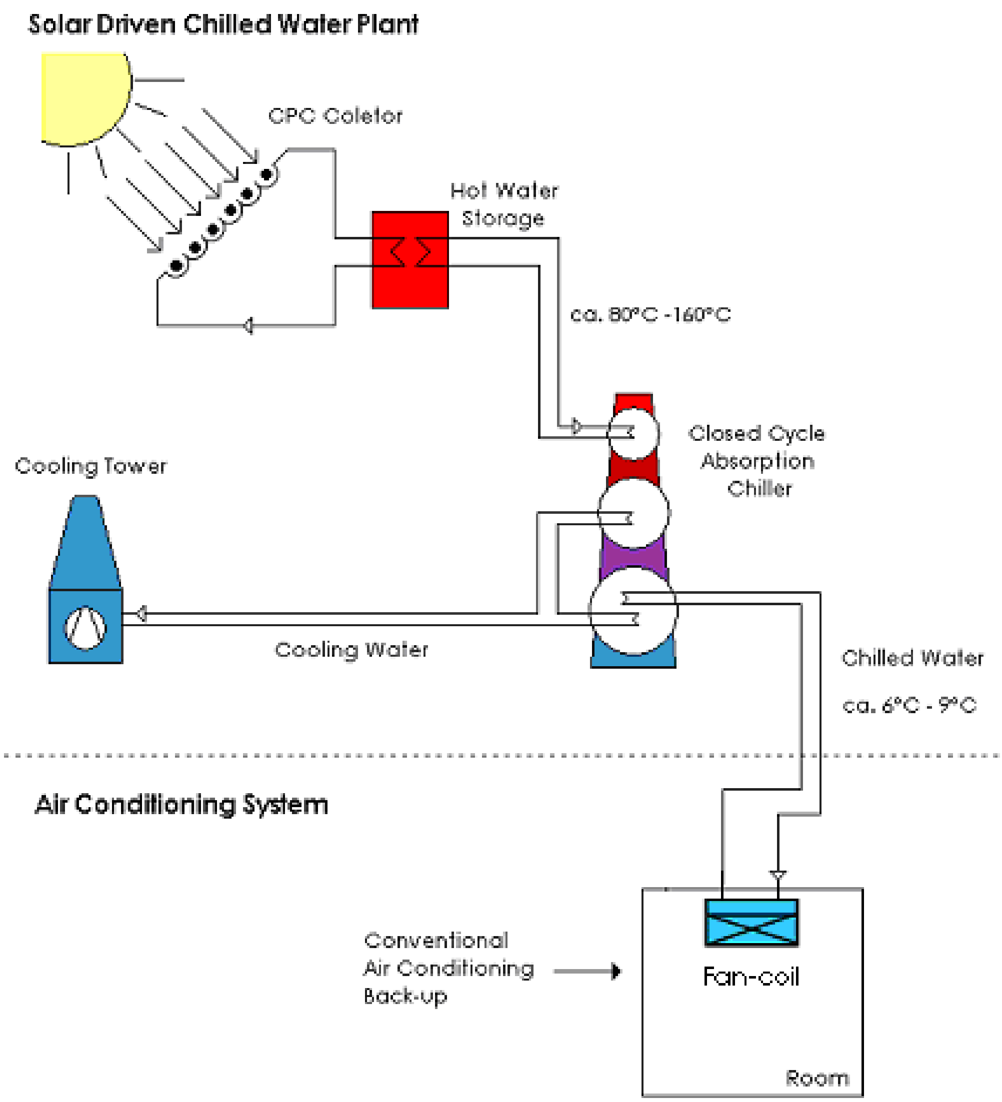


Figura 1: Sistema de ciclo fechado com uma máquina de absorção movido pela energia solar térmica. Fonte: Innovative Systems for Solar Air Conditioning of Buildings Dr. W. Kessling (modificado).

3. Especificação de requisitos

Este capítulo trata das especificações de requisitos para a integração de um sistema de climatização solar no auditório, como descrito a seguir:

- teto do prédio
- o espaço físico
- sistema hidráulico

3.1 Recomendações para o teto do prédio:

- Área necessária para a instalação dos coletores: 125 m² (inclusive o espaço necessário entre os coletores.)
- O teto deve suportar o peso de todos os coletores solares no total de 2,6 toneladas. O peso foi estimado considerando-se o coletor plano CPC da empresa AoSol e o coletor plano da empresa Schüco.
- O teto tem que dispor de acesso para instalação, inspeção e manutenção
- O teto deve ser preferencialmente plano. Se inclinado, no máximo de 20° e direcionado para o Norte geográfico, com uma área de 125 m².
- O teto deve ser livre de sombras dos outros prédios ou de vegetação.

Para uma aplicação de climatização solar, a demanda da energia solar para resfriamento do auditório acontecerá principalmente no verão, portanto os coletores devem ser inclinados para receber os raios nessa época. Por isso recomenda-se um teto plano.

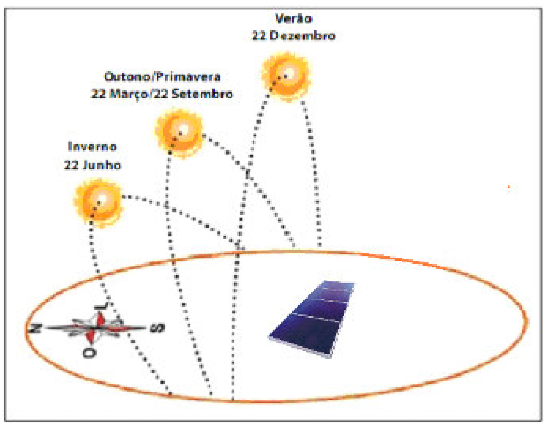


Figura 2: Ilustração esquemática mostrando a inclinação dos raios solares em relação à superfície da Terra para a cidade de São Paulo (modificado). Fonte: Abrava

Se o teto não estiver de acordo com as recomendações:

- É necessário determinar se os coletores serão instalados diretamente sobre as telhas, apoiados em suportes inclinados instalados na laje, ou uma instalação especial ao lado do prédio deveria ser executada.

Essa segunda alternativa demandaria mais custos e seria visualmente menos atrativa.

Figura 3: Coletores apoiados em suporte inclinados Fonte: Abrava.

3.2 Recomendações para o sala de máquinas no prédio

Necessita-se de um espaço separado, com entrada individual para os componentes do sistema, como:

- maquina de absorção: ~1300mm x 1060mm x 2030mm
- 2 reservatórios para água quente de 2000l
- reservatório para água fria de 6000l
- sistema de controle: ~ 352mm x 285mm x 96mm
- 3 bombas d´água

Recomenda-se um espaço de 20 m² (4 m x 5 m x altura min. 2.5 m) com fornecimento de água, energia elétrica (210V, 60Hz, 3 fases) e sistema de drenagem.

3.3 Recomendações para o sistema hidráulico / elétrico

Para instalação dos sistemas hidráulico e elétrico serão necessárias três diferentes tubulações:

- Para interligar a máquina de absorção e o reservatório até o teto, onde serão instalados os coletores, serão necessários dois tubos de cobre com 40mm de diâmetro que, junto com seus isolamentos, resultam em um diâmetro total individual de 80 mm. Portanto, recomenda-se um canal de 200 mm x 120 mm para ser embutido no prédio. A distância não deve ser mais que 50 m.
- Para interligar a máquina de absorção até a torre de arrefecimento recomenda-se um canal de 200 mm x 120 mm. É importante ressaltar que a torre de arrefecimento deve ser localizada ao ar livre e abastecida com água (tubo PVC 1/2”) e energia elétrica (210V, 60Hz, 3 fases). Dimensões e peso aproximados da torre de arrefecimento: 4125 x 1145 x 950 mm e 340 kg.
- O último canal de tubos da máquina de absorção até o auditório tem a função de abastecer o auditório com água fria para a climatização pelo teto de resfriamento (cooling ceiling). Recomenda-se 200 mm x 120 mm.

As distâncias entre a sala de máquinas, teto com os coletores e auditório devem ser as menores possíveis.

4. Procedimento

A especificação de requisitos para a integração de um sistema de climatização solar no auditório deve ser encaminhada aos arquitetos da Eletrobrás responsáveis pela licitação. A conclusão da dissertação de mestrado esta prevista para o mês de janeiro de 2010, devendo incluir os seguintes pontos de estudo e discussão:

1. Análise dos fatores e respectivos custos
   1.1 Verificar se é possível integrar componentes do mercado brasileiro
2. Estratégia para baixar os custos do investimento
3. Desenvolver um sistema para o auditório na UNESP
   3.1 Dimensionamento e custos
4. Cálculos sobre o tempo de amortização e comparação com um sistema convencional (compressor elétrico)
   4.1 Comparação de um sistema solar com um back-up convencional e com um sistema de back-up a gás.

O orientador da dissertação é o Professor Celso Romanel da PUC do Rio de Janeiro, pertencente ao Departamento de Engenharia Civil. A co-Orientadora é a Professora Elizabeth Pereira, da PUC de Minas Gerais, e afiliada ao GREEN (Centro Brasileiro para Desenvolvimento da Energia Solar Térmica).

5. Agradecimentos

Agradeço as empresas Schüco International KG , Solarnext AG e Solvis GmbH pelo apoio técnico. Ao PROCEL pela colaboração e à GTZ do Rio de Janeiro pela orientação técnica.

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Andreas Nieters (Andreas.Nieters@gtz.de)

A2
Technical Data and Information

YAZAKI

WFC-SC 10 & -SH 10

Specifications:

Water Fired Chiller absorption type with H_2O/LiBr

System functionality provides cooling

Heating with an automatic change over control mode (SH model only)

Utilizing Hot Water

Model	Production
WFC-SC10	Chilled Water
WFC-SH10	Chilled & Heating Water

ITEM			MODEL	WFC-SH10	WFC-SC10
Cooling Capacity			kW	35.2	
Heating Capacity			kW	48.7	-
Chilled Water and Hot Water	Chilled Water Temperature	Inlet	℃	12.5	
		Outlet	℃	7.0	
	Hot Water Temperature	Inlet	℃	47.4	-
		Outlet	℃	55.0	-
	Evaporator Pressure Loss(Max) *3		kPa	56.1	
	Max Operating Pressure		kPa	588	
	Rated Water Flow		L/sec	1.52	
			m^3/hr	5.47	
	Water Retention Volume		L	17	
Cooling Water	Heat Rejection		kW	85.4	
	Cooling Water Temperature	Inlet	℃	31.0	
		Outlet	℃	35.0	
	Abs.&Cond.Pressure Loss(Max) *3		kPa	85.3	
	Max Operating Pressure		kPa	588	
	Rated Water Flow		L/sec	5.1	
			m^3/hr	18.4	
	Water Retention Volume		L	66	
Heat Medium	Heat Input		kW	50.2	
	Heat Medium Temperature	Inlet	℃	88	
		Outlet	℃	83	
		Inlet Limit	℃	70 - 95	
	Generator. Pressure Loss(Max) *3		kPa	90.4	
	Max Operating Pressure		kPa	588	
	Rated Water Flow		L/sec	2.4	
			m^3/hr	8.64	
	Water Retention Volume		L	21	
Electrical	Power Source			400V 50Hz 3ph.	
	Consumption *1		W	210	
Control				On – Off	
Dimension	Width		mm	760 (855)	
	Depth		mm	970	
	Height *2		mm	1,900 (1,983)	
Piping	Chilled Water		A	40	
	Cooling Water		A	50	
	Heat Medium		A	40	
Weight	Dry Weight		kg	500	
	Operating Weight		kg	600	

*1. Power consumption of Chiller Only.(excluding recirculating pumps and cooling tower fan)
*2. Dimension in( ) include fixed plate and eye bolt.
*3. Specification are subject to change without prior notice.
*. The table shows standard operating condition (i.e. 88 ℃ heat medium inlet temperature)

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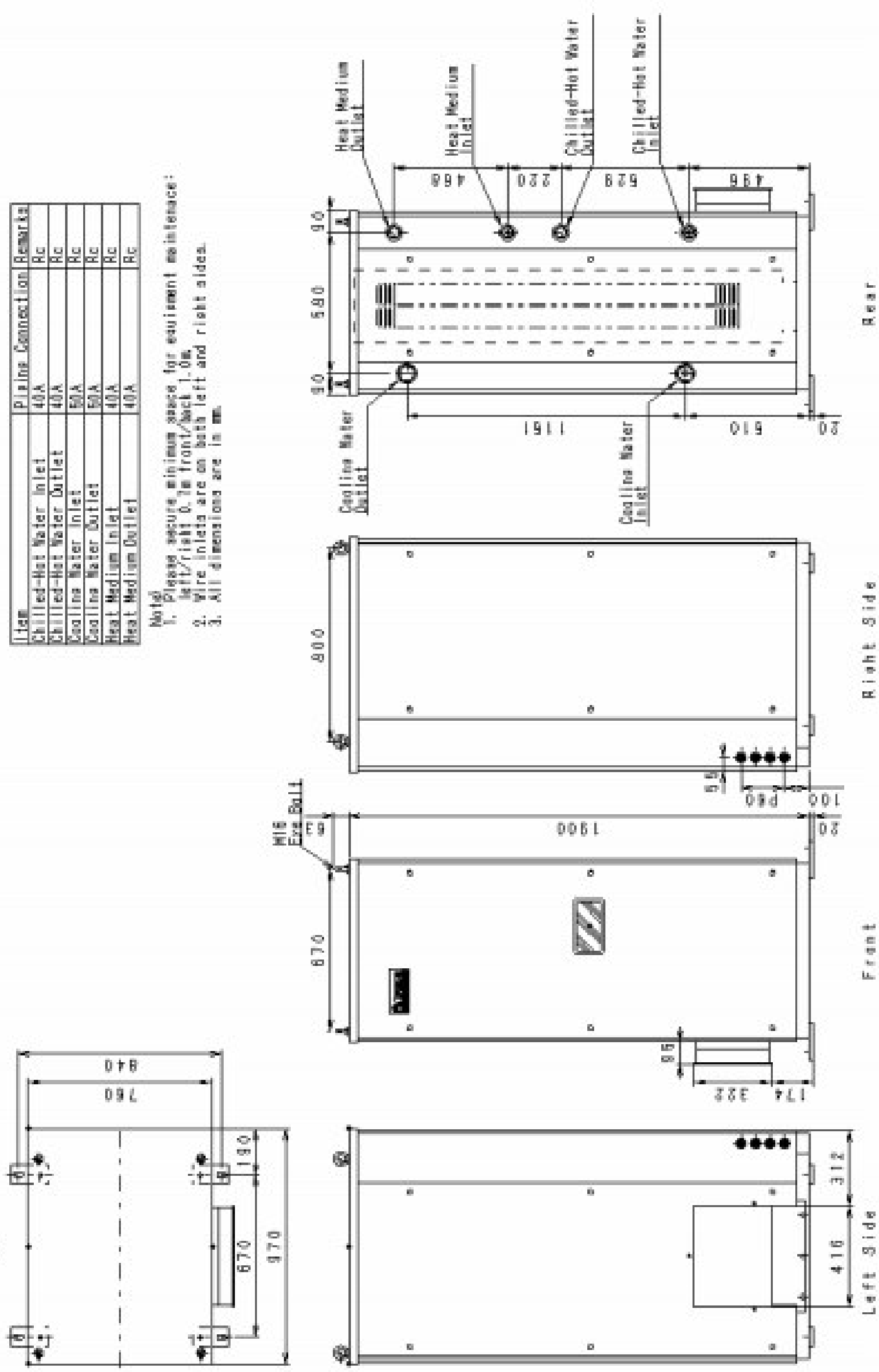

Item	Piping Connection	Remarks
Chilled-Hot Water Inlet	40A	Rc
Chilled-Hot Water Outlet	40A	Rc
Cooling Water Inlet	50A	Rc
Cooling Water Outlet	50A	Rc
Heat Medium Inlet	40A	Rc
Heat Medium Outlet	40A	Rc

Note)
1. Please secure minimum space for equipment maintenace:
   left/right 0.7m front/back 1.0m.
2. Wire inlets are on both left and right sides.
3. All dimensions are in mm.

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A3
Solar collector Test certificates

Fraunhofer Institut Solare Energiesysteme

1 Überblick über die Ergebnisse

1.1 Vorbemerkung

Die Leistungsprüfung wurde nach EN 12975 durchgeführt. Es wurden alle Kriterien für den Mindestertragsnachweis (Zertifikat über 525 kwh/m²a) für die deutsche Förderung erreicht. Der Mindestertragsnachweis wurde für den Kollektor Logasol SKN 3.0 erstellt.

1.2 Ermittelte Leistungsparameter

Die ermittelten Parameter beziehen sich auf die folgenden Flächen:

Aperturfläche von 2.256 m²:	Absorberfläche von 2.228 m²:
$\eta_{0a} = 0.770$	$\eta_{0A} = 0.780$
$a_{1a} = 3.681\ W/m^2K$	$a_{1A} = 3.727\ W/m^2K$
$a_{2a} = 0.0173\ W/m^2K^2$	$a_{2A} = 0.0175\ W/m^2K^2$

Energieertrag pro Kollektormodul [W]:

$t_m - t_a$ [K]	400 [W/m²]	700 [W/m²]	1000 [W/m²]
10	608	1129	1650
30	411	932	1453
50	182	703	1224

1.3 Einstrahlwinkelkorrekturfaktor - IAM

IAM bei $\theta = 50°$ = 0.911

1.4 Durchgeführte Prüfungen

Anlieferungsdatum:	11.09.2006	
Prüfung	Datum	Ergebnis
Ermittlung der Leistungsparameter	18.-19.09.2006	durchgeführt
Ermittlung des IAM	02.-06.11.2006	durchgeführt
Ermittlung der Kapazität:	15.11.2006	ermittelt

1.5 Gesamtergebnis

Der Kollektor hat alle Prüfungen bestanden. Während der Messung traten keine Besonderheiten auf.

KTB Nr. 2006-28 : Leistungsmessung nach EN 12975-2:2006 Seite 3 von 15
BBT Thermotechnik GmbH-Buderus, Logasol SKN 3.0
16. November 2006, Fraunhofer-ISE, Heidenhofstraße 2, D-79110 Freiburg

FORSCHUNGS- UND TESTZENTRUM FÜR SOLARANLAGEN
Institut für Thermodynamik und Wärmetechnik
Universität Stuttgart
Professor Dr. Dr.-Ing. habil. H. Müller-Steinhagen

in Kooperation mit

Prüfbericht
Zuverlässigkeit, Dauerhaftigkeit und Wärmeleistung eines Sonnenkollektors

Test Report
Durability, Reliability and Thermal Performance of a Solar Collector

nach EN 12975-2: 2006
according to EN 12975-2:2006

Prüfbericht-Nr.: 07COL553
Test Report No.: 07COL553

Stuttgart, den 30.05.2007
Stuttgart, May 30th, 2007

Auftraggeber: *client:*	**Apricus Solar Co., Ltd** **402 Building 8 East** **Pukou New & High Tech** **Development Zone** **Nanjing, China, 210061**
Hersteller: *manufacturer:*	**Apricus Solar Co., Ltd**
Typ: *brand name:*	**AP-30**
Herstelljahr: *year of production:*	**2007**

Institut für Thermodynamik und Wärmetechnik (ITW) • Pfaffenwaldring 6 • 70550 Stuttgart
Tel. 0049(0)711/685-63536 • Fax 0049(0)711/685-63503 • e-mail: tzs@itw.uni-stuttgart.de

Prüfbericht-Nr. / *test report no.:* 07COL553
Datum / *date:* 30.05.2007

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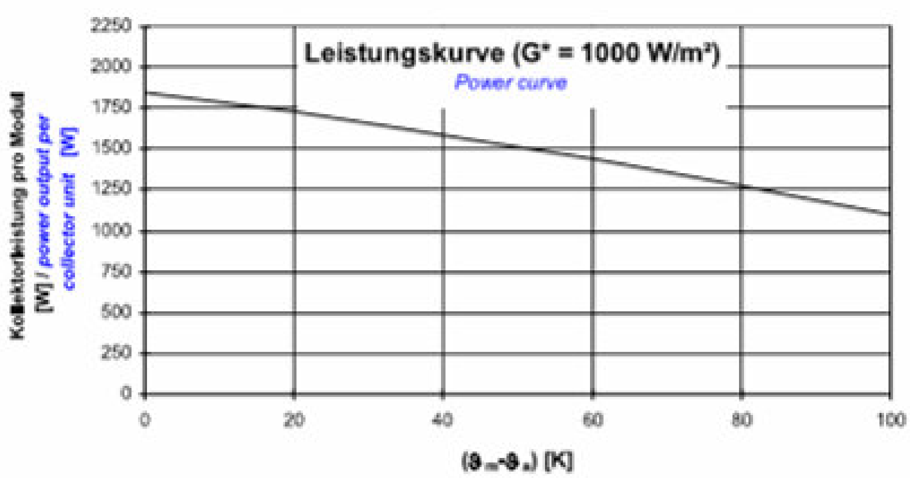
11 Prüfergebnisse Wärmeleistung

Test Results Thermal Performance

Bestimmung der Kollektorleistung:
Determination of power per collector unit:

$$\dot{Q} = A \cdot G^* \left(\eta_0 - a_1 \frac{(\vartheta_m - \vartheta_a)}{G^*} - a_2 \frac{(\vartheta_m - \vartheta_a)^2}{G^*} \right)$$

Konversionsfaktor η_0 [-] *conversion factor*	0.656
Wärmedurchgangskoeffizient a_1 [W/(m²K)] *heat transfer coefficient*	2.063
temperaturabhängiger Wärmedurchgangskoeffizient a_2 [W/(m²K²)] *temperature depending heat transfer coefficient*	0.006
Einfallswinkel-Korrekturfaktor $K_\theta(50°)$ [-] *incidence angle modifier*	s. Seite 17 *see page 17*
flächenbezogene Wärmekapazität c [kJ/(m²K)] *area related heat capacity*	44.890
Volumenstrom [l/(m²h)] *volume flow rate*	65
Aperturfläche pro Kollektormodul A [m²] *aperture area per collector unit*	2.82
Peakleistung [W_{peak}] pro Kollektormodul (G^* = 1000 W/m², $(\vartheta_m-\vartheta_a)$= 0) *peak power [$W_{peak}$] per collector unit ($G^*$ = 1000 W/m², $(\vartheta_m-\vartheta_a)$ = 0)*	1850



INSTITUTO NACIONAL DE METROLOGIA, NORMALIZAÇÃO E QUALIDADE INDUSTRIAL

INMETRO

PROGRAMA BRASILEIRO DE ETIQUETAGEM

1 - COLETORES SOLARES

CLASSES	INDICE BANHO / ACOPLADO	INDICE PISCINA	BANHO TOTAL	BANHO %	ACOPLADO TOTAL	ACOPLADO %	PISCINA TOTAL	PISCINA %	TOTAL (B+A+P)	
A	Pme > 77,0	P_{me} > 95,0	90	62,1	0	0,0	43	58,1	133	Mais Eficiente
B	77,0 >= Pme > 71,0	95,0 >= P_{me} > 87,0	43	29,7	1	50,0	26	35,1	70	
C	71,0 >= P_{me} > 61,0	87,0 >= P_{me} > 79,0	10	6,9	1	50,0	2	2,7	13	
D	61,0 >= P_{me} > 51,0	79,0 >= P_{me} > 71,0	1	0,7	0	0,0	2	2,7	3	
E	51,0 >= P_{me} > 41,0	71,0 >= P_{me} > 63,0	1	0,7	0	0,0	1	1,4	2	Menos Eficiente
			145		2		74		221	

APLICAÇÃO: BANHO

17/03/08

1	2	3	4		5	6		7	8	9	10	11	12
FABRICANTE	MARCA	MODELO	PRESSÃO DE FUNCIONAMENTO		ÁREA EXTERNA DO COLETOR	PRODUÇÃO MÉDIA MENSAL DE ENERGIA: Por Coletor	Por m² (Especifica)	EFICIÊNCIA ENERGÉTICA MÉDIA	CLASSIFICAÇÃO	MATERIAL SUPERFÍCIE ABSORVEDORA	$F_r(\tau\alpha)_n$	F_rU_L	SELO PROCEL (1)
			(kPa)	(mca)	(m^2)	(kWh/mês)	(kWh/mês.m^2)	(%)					
ALBACETE	ALBACETE	PSL-1	400	40,8	1,02	61,6	60,4	44,6	D	ALUMÍNIO	0,593	5,564	
APARELHOS TÉRMICOS TECNOSOL	TECNOSOL	TSOL 1.5	400,0	40,8	1,42	101,8	71,7	52,0	B	ALUMÍNIO	0,673	6,143	
AQUECEMAX	AQUECE MAIS	LMPV 1.0	392	40,0	1,01	72,4	71,7	51,5	B	ALUMÍNIO	0,707	7,441	
		LMPV 1.2	392,0	40,0	1,21	92,6	76,5	55,5	B	ALUMÍNIO	0,719	6,513	
		LMPV 1.5	392,0	40,0	1,52	116,3	76,5	55,5	B	ALUMÍNIO	0,719	6,513	
		LMPV 1.8	392,0	40,0	1,82	139,2	76,5	55,5	B	ALUMÍNIO	0,719	6,513	
		LMPV 2.0	392,0	40,0	2,01	149,7	74,5	54,0	B	ALUMÍNIO	0,696	6,182	
BOSCH	BUDERUS	SKE 2.0	600,0	61,2	2,37	198,6	83,8	59,9	A	COBRE	0,711	4,016	SIM
		SKN 3.0	600,0	61,2	2,37	210,0	88,6	63,2	A	COBRE	0,743	3,933	SIM
		SKS 4.0	1000,0	102,0	2,37	205,7	86,8	62,0	A	COBRE	0,794	4,539	SIM
BOTEGA	BOTEGA	BELOSOL	20,0	2,0	0,79	33,0	41,8	39,1	E	PVC	0,958	28,342	
CONTINI & PORTO	THERMOTINI	CSV16	392,0	40,0	1,56	111,7	71,6	51,0	B	ALUMÍNIO	0,678	6,039	
COLSOL	COLSOL	PL100RE	400,0	40,8	1,00	82,0	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM
		PL130RE	400,0	40,8	1,30	106,6	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM
		PL150RE	400,0	40,8	1,50	123,0	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM
		PL200RE	400,0	40,8	1,92	157,4	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM

APLICAÇÃO: BANHO

17/03/08

1	2	3	4		5	6		7	8	9	10	11	12
FABRICANTE	MARCA	MODELO	PRESSÃO DE FUNCIONAMENTO		ÁREA EXTERNA DO COLETOR	PRODUÇÃO MÉDIA MENSAL DE ENERGIA: Por Coletor	Por m² (Especifica)	EFICIÊNCIA ENERGÉTICA MÉDIA	FAIXA DE CLASSIFICAÇÃO	MATERIAL SUPERFÍCIE ABSORVEDORA	$F_r(\tau\alpha)_n$	F_rU_L	SELO PROCEL (1)
			(kPa)	(mca)	(m^2)	(kWh/mês)	(kWh/mês.m^2)	(%)					
AQUECEMAX	AQUECEMAIS	LMPV 1.2	392,0	40,0	1,21	92,6	76,5	55,5	B	ALUMÍNIO	0,719	6,513	
		LMPV 1.5	392,0	40,0	1,52	116,3	76,5	55,5	B	ALUMÍNIO	0,719	6,513	
		LMPV 1.8	392,0	40,0	1,82	139,2	76,5	55,5	B	ALUMÍNIO	0,719	6,513	
		LMPV 2.0	392,0	40,0	2,01	149,7	74,5	54,0	B	ALUMÍNIO	0,696	6,182	
BOTEGA	BOTEGA	BELOSOL	20,0	2,0	0,79	33,0	41,8	39,1	E	PVC	0,958	28,342	
CONTINI & PORTO	THERMOTINI	CSV16	392,0	40,0	1,56	111,7	71,6	51,0	B	ALUMÍNIO	0,678	6,039	
COLSOL	COLSOL	PL100RE	400,0	40,8	1,00	82,0	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM
		PL130RE	400,0	40,8	1,30	106,6	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM
		PL150RE	400,0	40,8	1,50	123,0	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM
		PL200RE	400,0	40,8	1,92	157,4	82,0	58,8	A	ALUMÍNIO	0,759	7,199	SIM
CUMULUS	CSC SUPER	100	400,0	40,8	1,00	73,6	73,6	53,7	B	COBRE	0,717	7,227	
		140	400,0	40,8	1,42	106,8	75,2	54,7	B	COBRE	0,709	6,527	
		200	400,0	40,8	1,95	146,6	75,2	54,7	B	COBRE	0,709	6,527	
	CSC PREMIUM	100	400,0	40,8	1,00	87,1	87,1	62,4	A	COBRE	0,755	4,716	SIM
		140	400,0	40,8	1,42	123,7	87,1	62,4	A	COBRE	0,755	4,716	SIM
		200	400,0	40,8	1,95	169,8	87,1	62,4	A	COBRE	0,755	4,716	SIM
	CSA SUNPOP	140	400,0	40,8	1,42	93,2	65,6	48,1	C	ALUMÍNIO	0,646	6,979	
		200	400,0	40,8	1,95	127,9	65,6	48,1	C	ALUMÍNIO	0,646	6,979	

A4
Quotations

SOLARNEXT

SolarNext AG, Nordstraße 10, D-83253 Rimsting

GTZ mbH
Hr. Till Reichardt
Av. Rio Branco 174, 28° Andar -

Centro - 20040-004 - Rio de Janeiro
Brazil

Seite:	1
Kunden Nr.:	07006
Bearbeiter:	SEH
Bestellnr.:	126
Steuernr.:	156 115 80514
USt-IdNr.:	DE211610335
Datum:	01.10.2009

Angebot Nr. 8332

Sehr geehrter Herr Reichardt,
gerne bieten wir Ihnen wie folgt an:

Pos	Menge	Art.-Nr	Text	Einzelpreis EUR	Gesamtpreis EUR
1	1 Stk.	WFC35_B1H1M1456	chillii® Cooling Kit WFC35 1 Stk. Yazaki Aroace WFC-SC10 Absorptionskältemaschine 1 Stk. Nasskühlturm m. Zubehör für automatische Befüllung und Entleerung, sowie Drehzahlregelung Lüfter 1 Stk. Heisswasserversorgungspumpe 1 Stk. Kühlwasserpumpe 1 Stk. chillii® System Controller HC incl. Temperatursensoren	40.249,00	40.249,00
2	1 Stk.	WFC35_LT12_2000	Erweiterung Kaltwasserspeicher 2000l bestehend aus: 1 Stk. Kaltwasserspeicher 2000ltr., ohne Dämmung 1 Set Sensoren f. Kaltwasserspeicher 1 Stk. Pumpe Kältekreis mit Zubehör	2.891,65	2.891,65
3	1 Stk.	WFC35_HT2_2000	Erweiterung Wärmespeicher 2000l bestehend aus: 1 Stk. Pufferspeicher 2000ltr., mit Dämmung 1 Set Sensoren f. Pufferspeicher 2 Stk. Umschaltventil mit Stellantrieb	3.786,13	3.786,13
4	1 Stk.	Service_com	Inbetriebnahme der Kältemaschine Tagespauschale zzgl. Fahrt- und Übernachtungskosten falls notwendig. Sollte sich die Inbetriebnahme aufgrund fehlerhafter Systemtechnik (Hydraulik, Regelung) verzögern, so müssen wir zusätzliche Kosten in Rechnung stellen.	980,00	980,00
A	1	Service_sv	Alternativposition	500,00	(500,00)
Zwischensumme					47.906,78

SolarNext AG Nordstraße 10 D-83253 Rimsting / Chiemsee
Tel.: +49 8051 6888-400 Fax: +49 8051 6888-490 info@solarnext.de www.solarnext.de
Vorstand: Frank Molter Aufsichtsrat: David Walker (Vorsitz), Dr. Urs Hasler (Stellvertreter), Karl Schmid
Bankverbindung: Hypovereinsbank München BLZ: 70020270 Kto.-Nr. 2423669

Angebot Nr. 8332 vom 01.10.2009 Seite: 2

Pos	Menge	Art.-Nr	Text	Einzelpreis EUR	Gesamtpreis EUR
Übertrag					**47.906,78**
			Ortstermin nach Bedarf, zzgl. Reisekosten		
Gesamt Netto					47.906,78
zzgl. 19,00 % USt. auf				47.906,78	9.102,29
Gesamtbetrag					**57.009,07**

Angebotsgültigkeit: 8 Wochen

Es gelten unsere Allgemeinen Geschäftsbedingungen.

Mit freundlichen Grüßen
SolarNext AG

i.A. Sebastian Hauke
Solar Cooling Division