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.

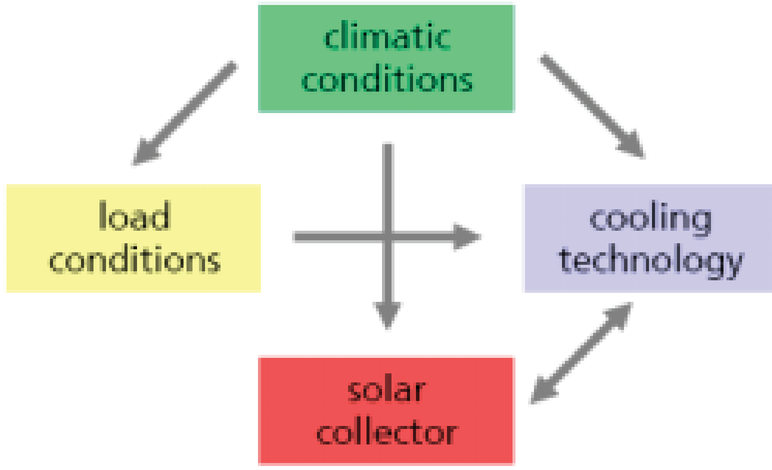

Figure 3.1 - Interaction in the design and layout of a solar-assisted air-conditioning system, to be considered in the planning phase [7].

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.

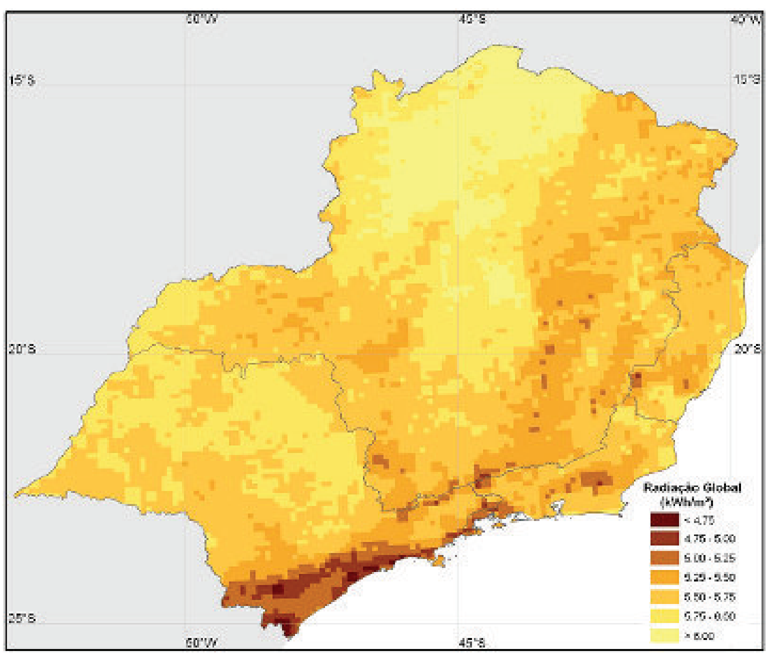

Figure 3.3 - Global solar radiation map in March 2005 provided by the model BRAZIL-SR for the south-east of Brazil [20].

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.

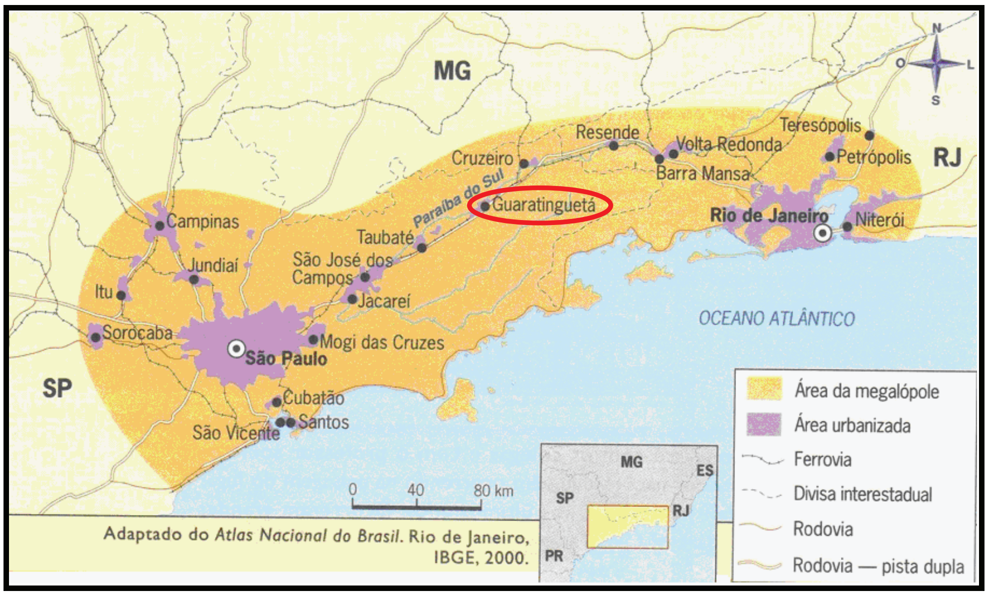

Figure 3.4 - Brazilian south-eastern Megalopolis

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.

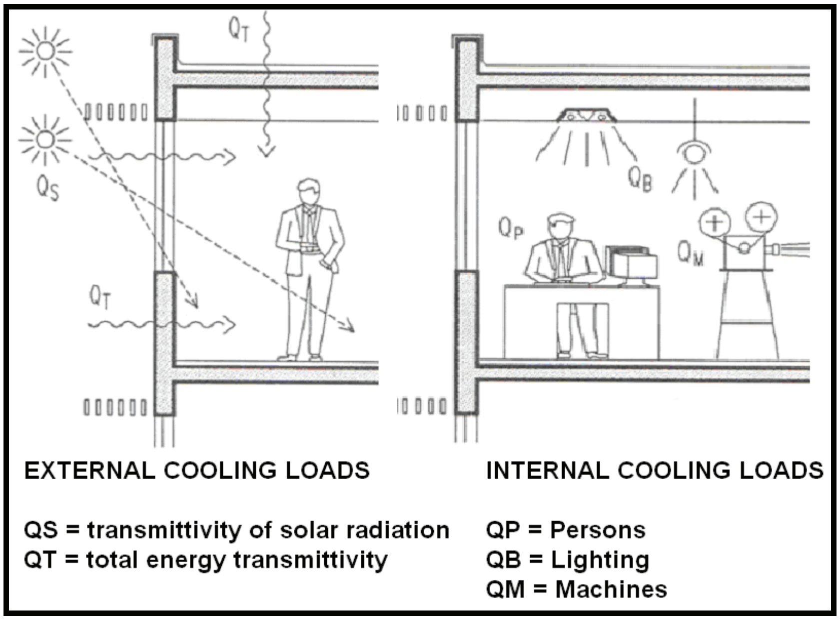

Figure 3.5 - External/internal cooling loads (modified) [21].

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:

Hygienic Air change:

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.

Internal Cooling load:

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.

Building envelope (U-Values):

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.

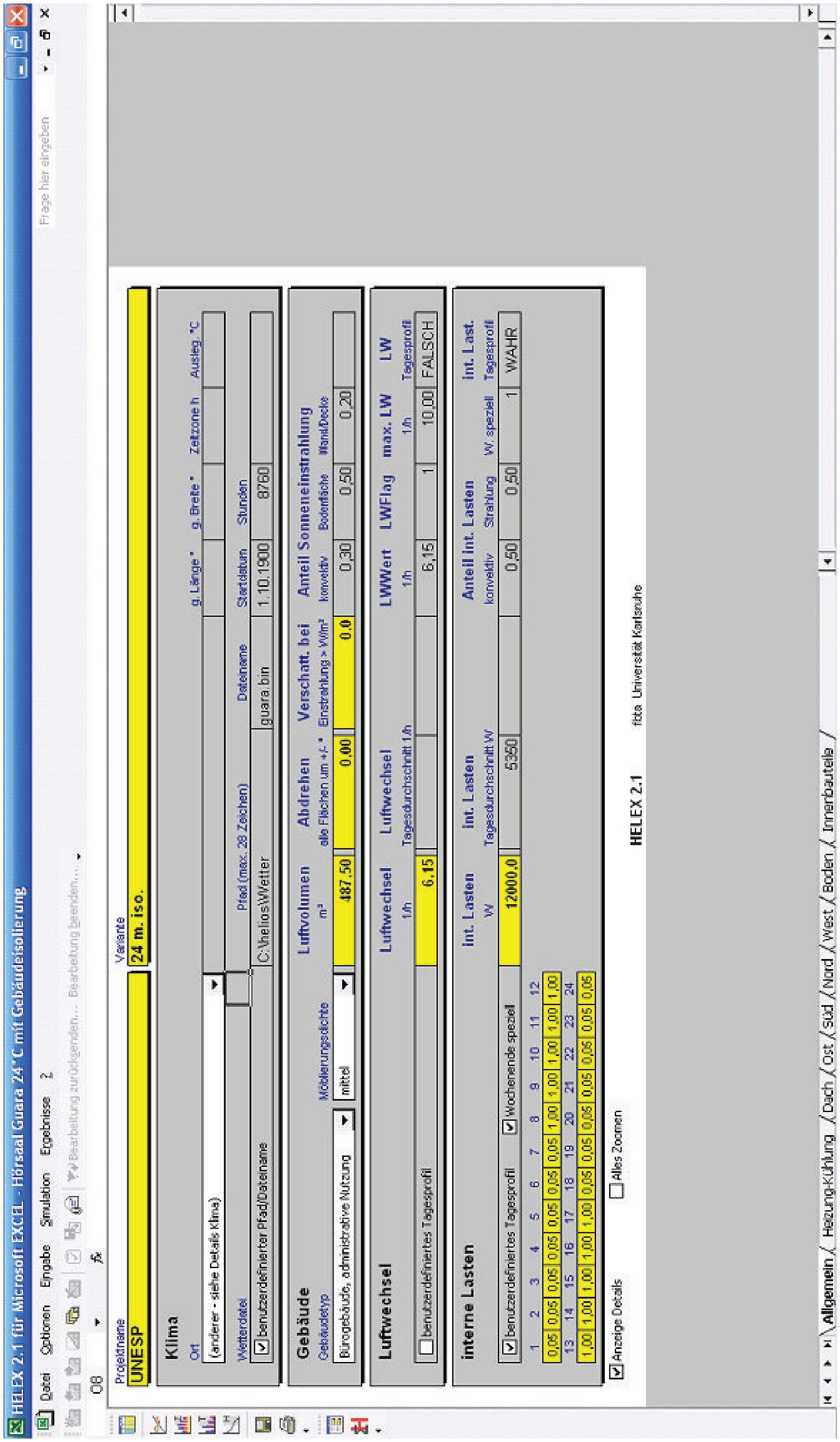

Figure 3.6 - Snapshot of HELEX 2.1 Interface

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

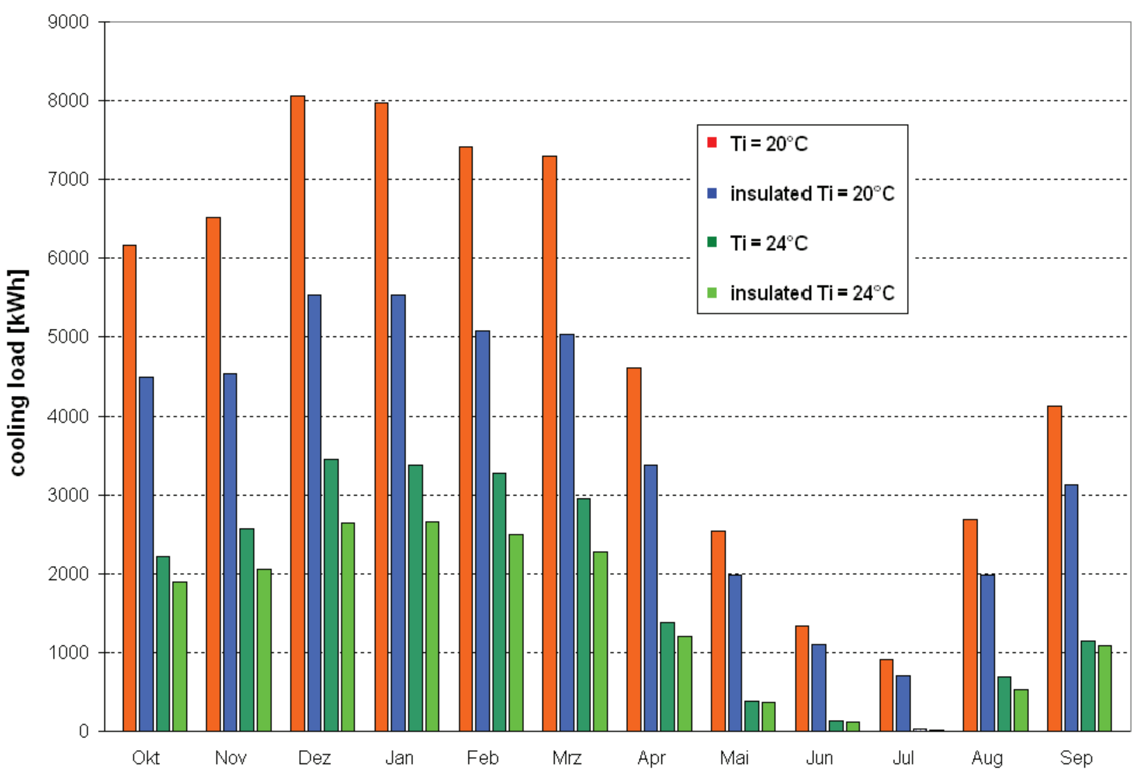

Figure 3.7 - Predicted monthly cooling load of the auditorium with and without insulation by 20℃ and 24℃ indoor air temperature.

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.

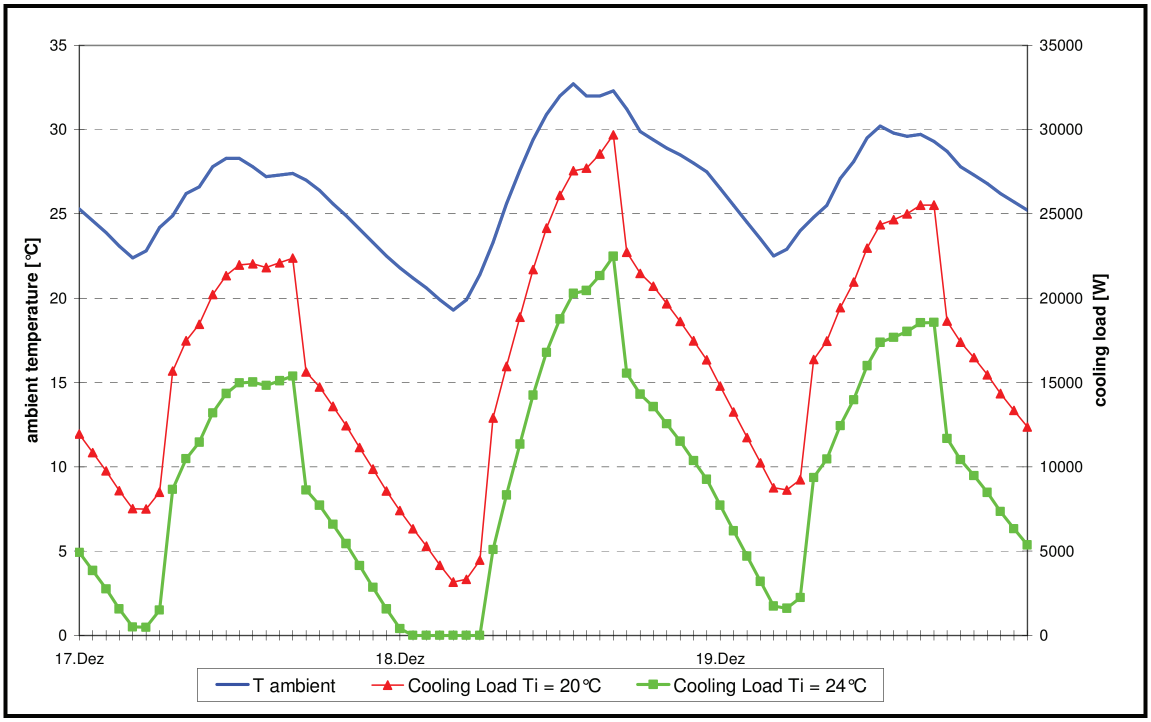

Figure 3.8 - Hourly cooling load pattern (hourly data) with Ti = 20°C and Ti = 24°C, at the predicted annual maximum ambient temperature of 32,7 °C (without insulation).

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 CO2 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 Ti = 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.

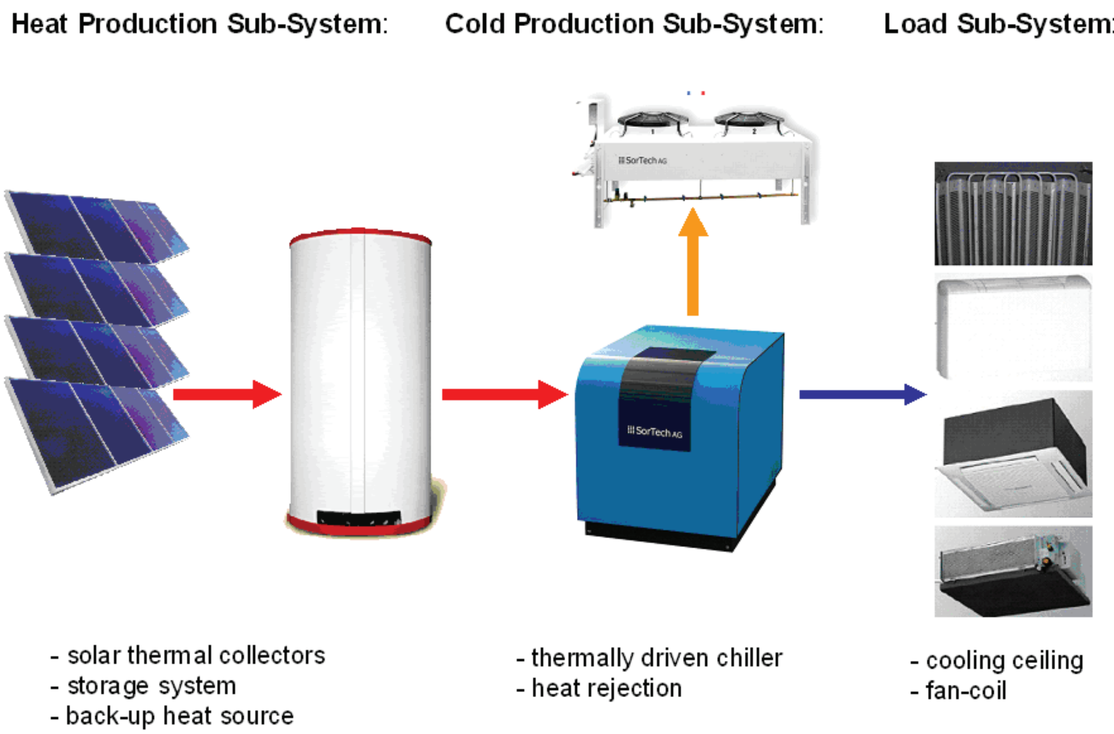

Figure 3.11 - Sub-systems and their components of a solar-assisted air-conditioning system (modified). Source: Solvis Energy Systems GmbH & CoKG

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.

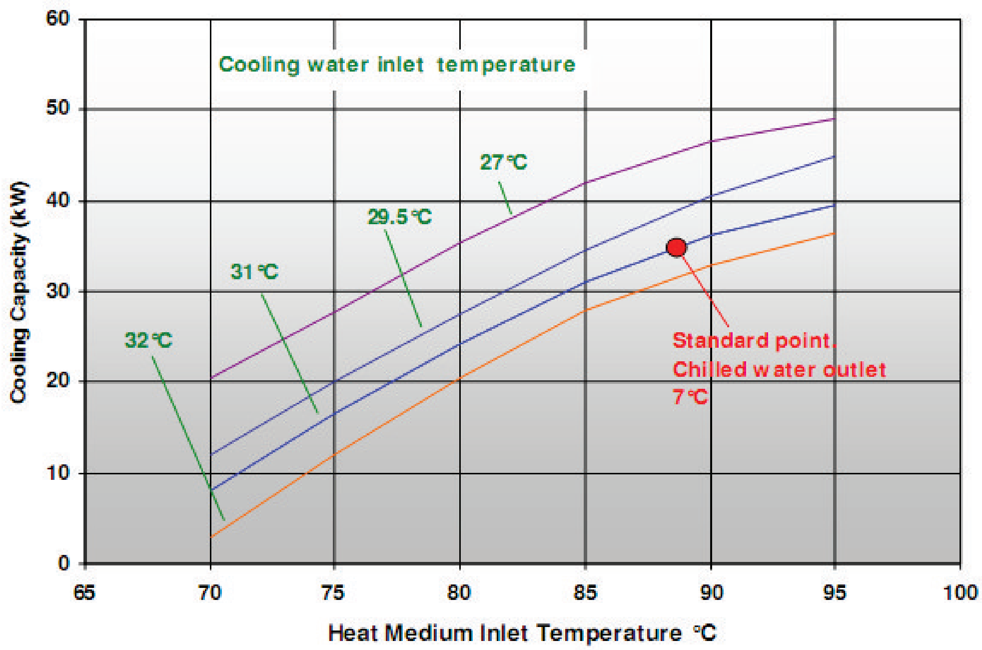

Figure 3.11 - Performance characteristics of Yazaki WFC-SC10 Absorption Chiller (Fancoil 7℃ chilled water). Source: Yazaki Energy Systems Inc.

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.

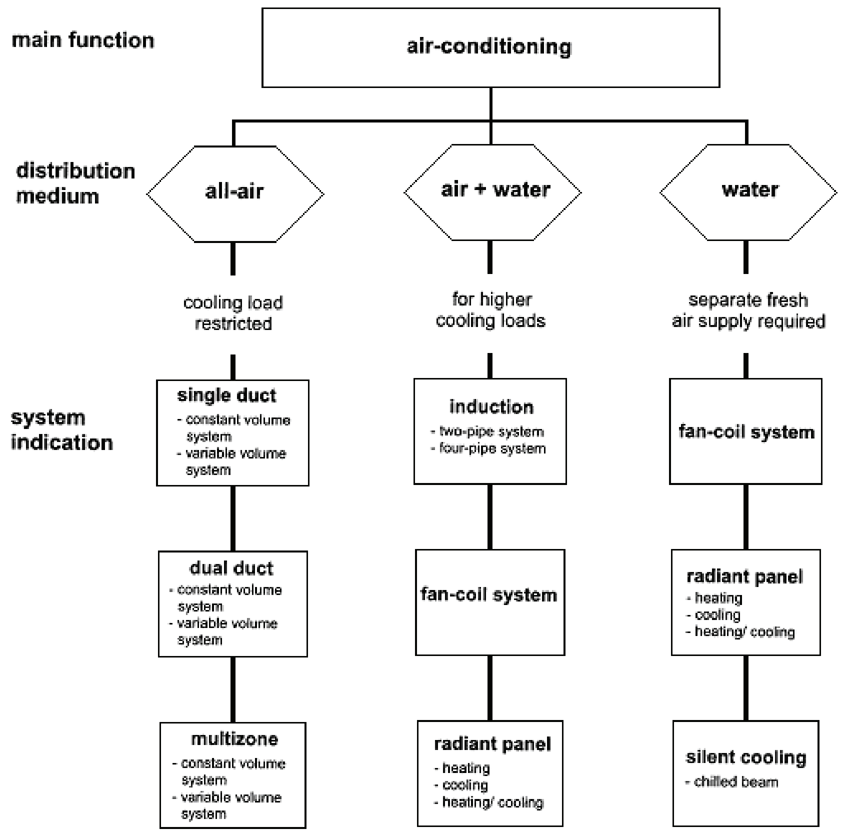

Figure 3.13 - Generic classification of centralised air-conditioning systems [10].

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.

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

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

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.

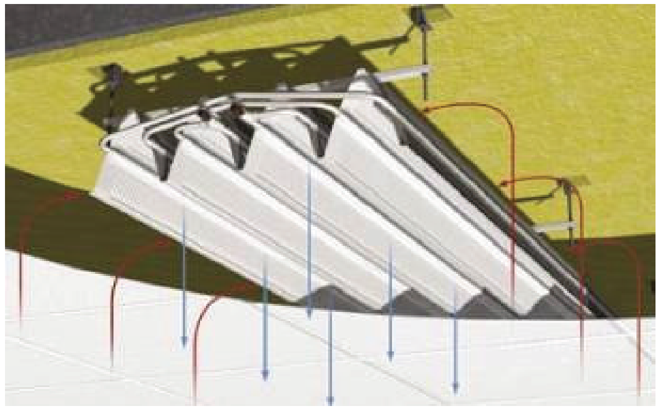

Figure 3.14 - Example of a Cooling panel Type Carat from Lindab Climate GmbH Source: Technical Data sheets

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.

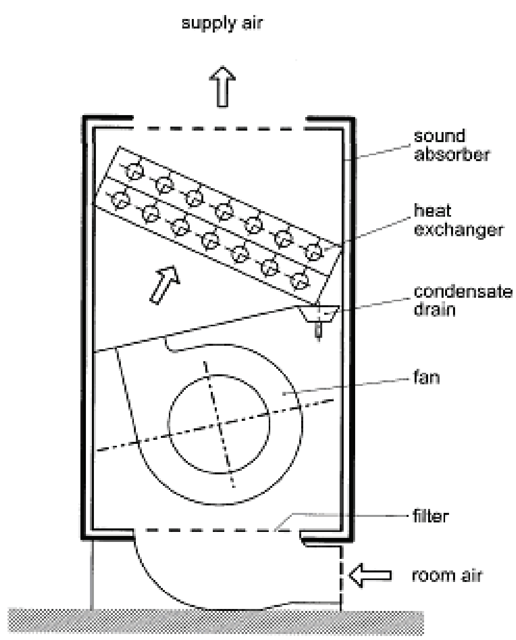

Figure 3.15 - Cross-section of a typical simple fan-coil unit with one heat exchanger for air heating/cooling [10].

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.

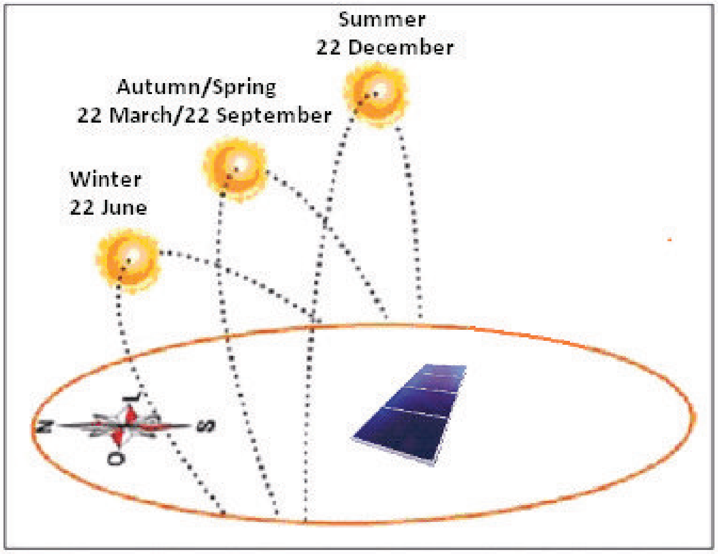

Figure 3.16 - Schematic illustration showing the inclination of the sun to the Earth surface in Guaratinguetá [28].

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.

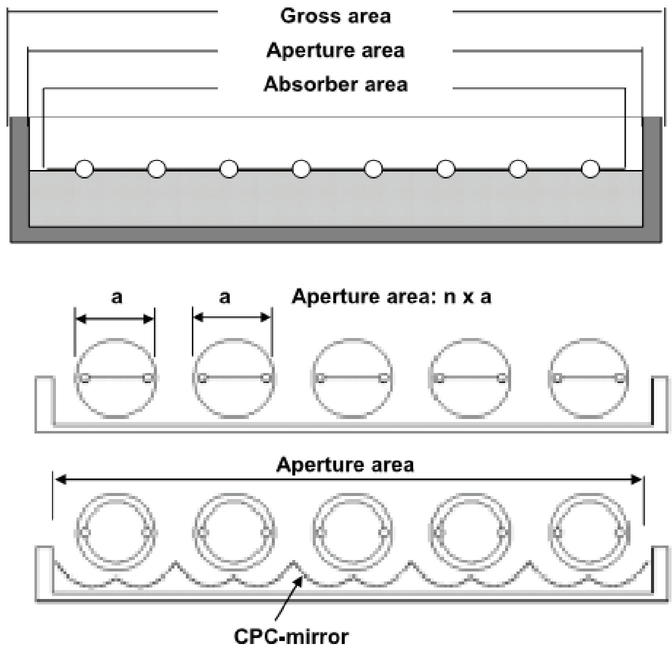

Figure 3.17 - Definition of collector's areas (to be multiplied by the length) [7]

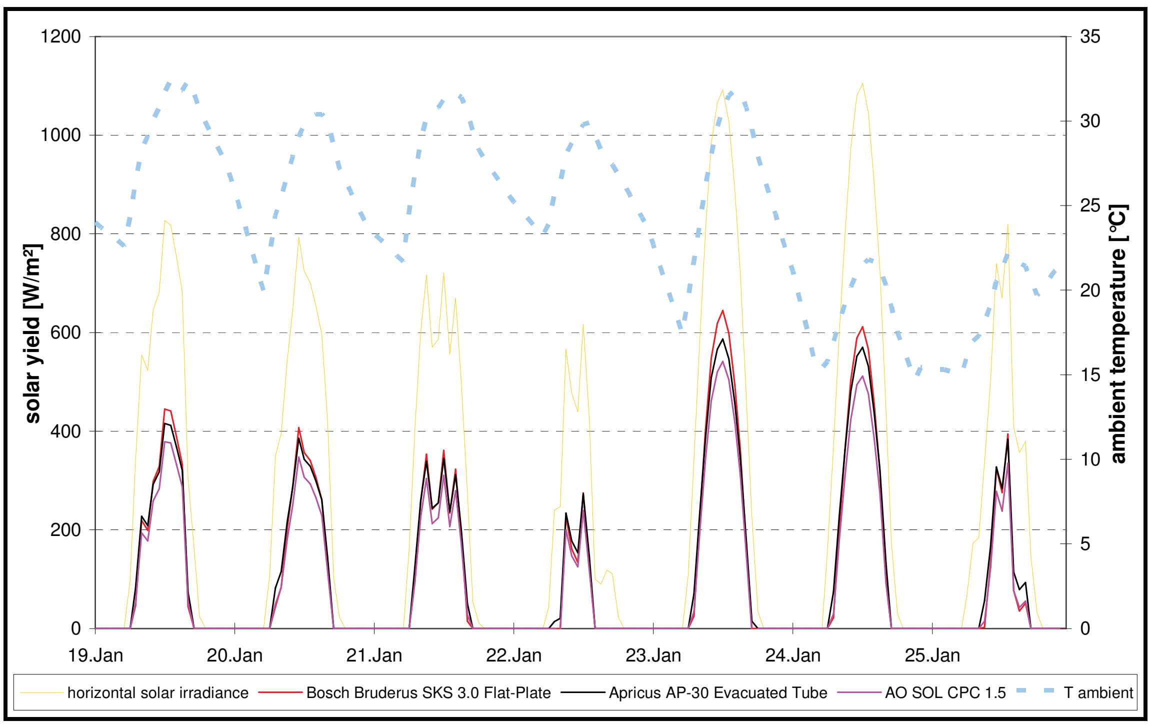

Figure 3.18 - Predicted performance of different solar collectors in Guaratinguetá during a hot summer week.

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].

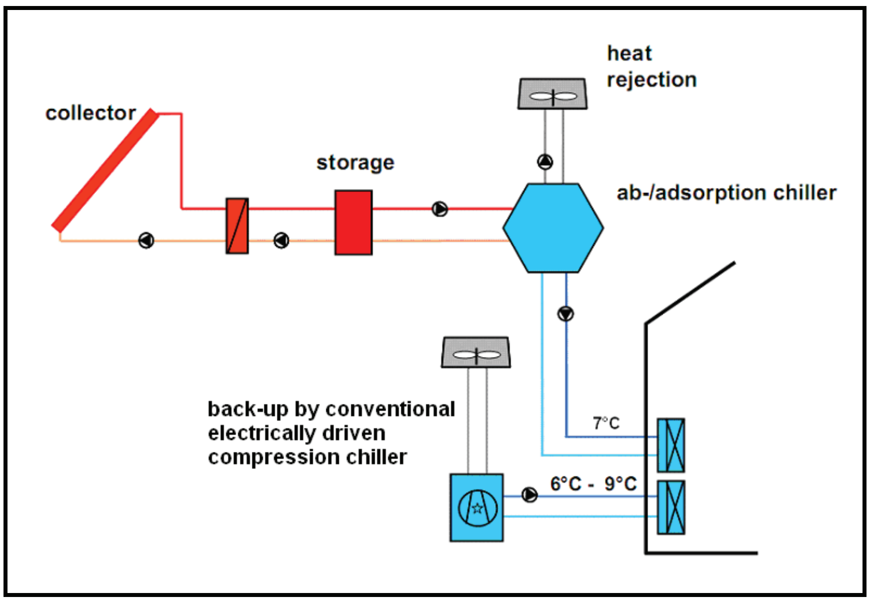

Figure 3.19 - Simplified scheme of a solar cooling system, assisted by a conventional electrically driven compression chiller. If cooling demand occurs during night, the compression chiller is operated (modified) [8].

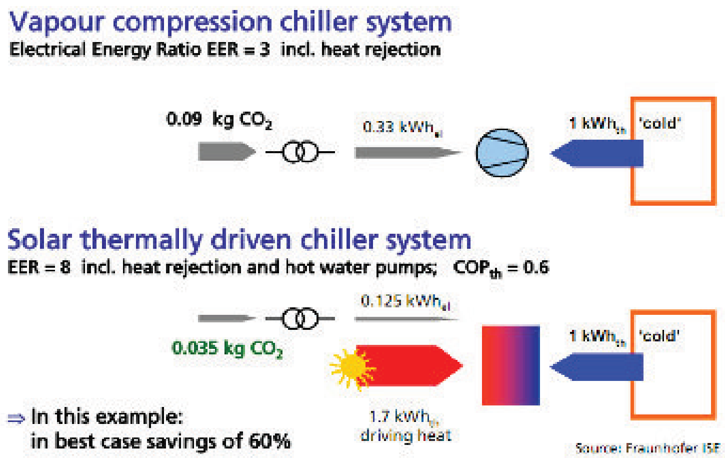

Figure 3.20a - Simple comparison of CO2 emissions of a compression chiller system and of a solar thermally driven chiller system. The conversion factor of 0.28 kg CO2 emission per kWh electricity consumed from the grid is used in this estimation [8].

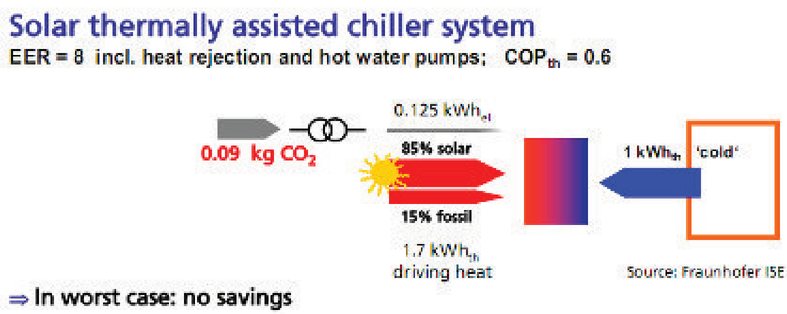

Figure 3.20b - In comparison to Figure 3.20a, 15% of the driving heat for the thermally driven chiller is based on fossil fuels, here natural gas [8].

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.

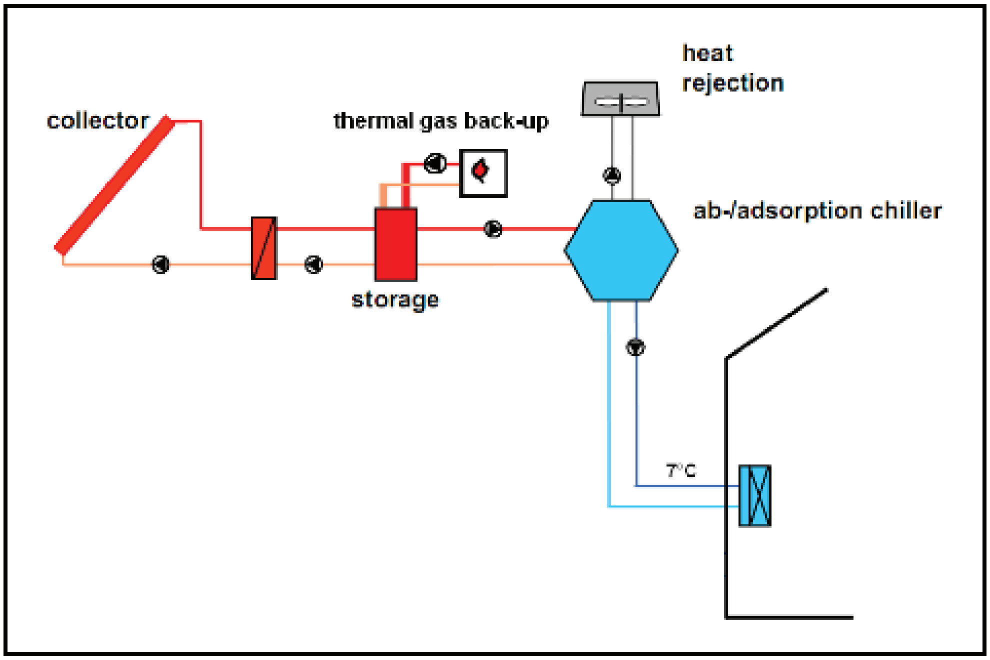

Figure 3.21 - Simplified scheme of a solar cooling system, assisted by a thermal gas back-up (modified) [8].

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 ΔT = 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.

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

with

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

$\eta_{Coll.(\Delta T, G)}$ = 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:

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

with

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

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

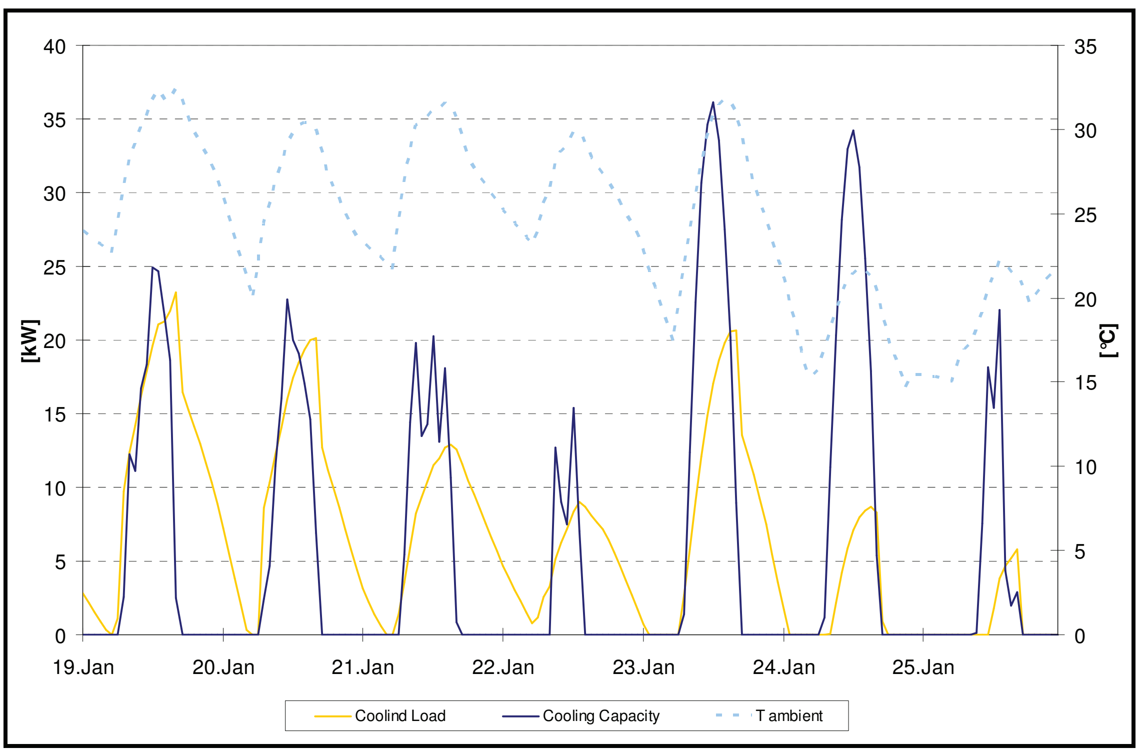

Figure 3.23 - Predicted correlation between cooling demand and cooling yield during a hot summer week in Guaratinguetá.

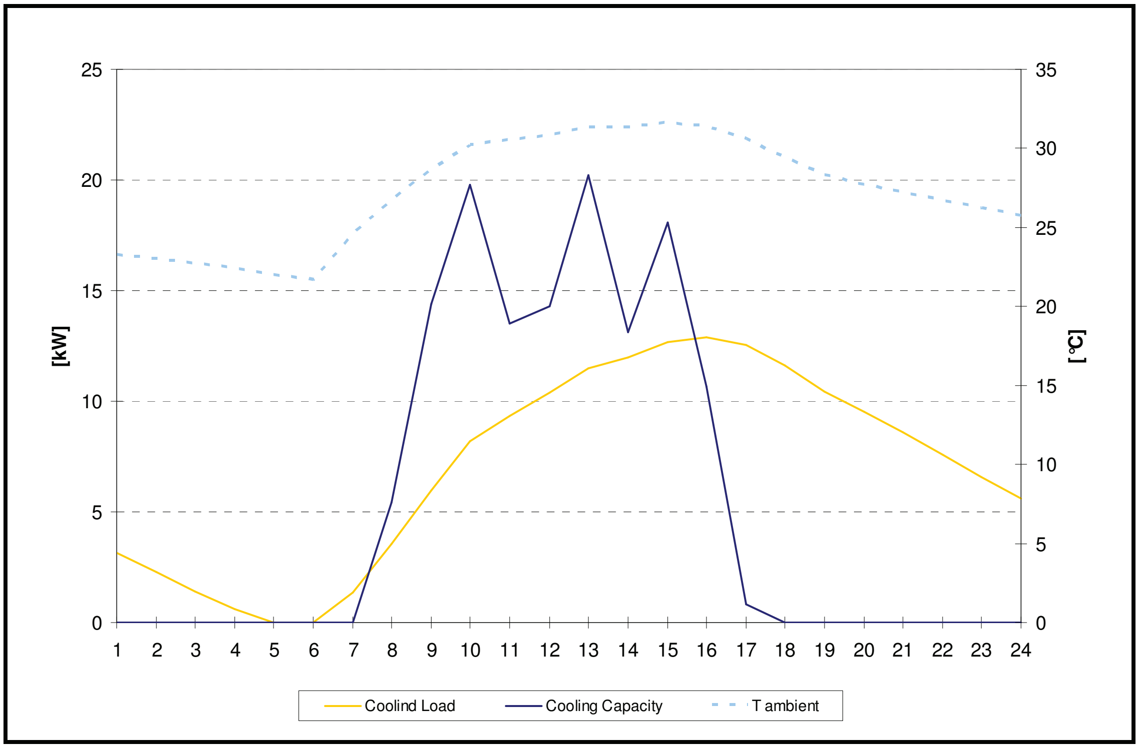

Figure 3.24 - Predicted correlation between cooling demand and cooling yield during one partly cloudy day.

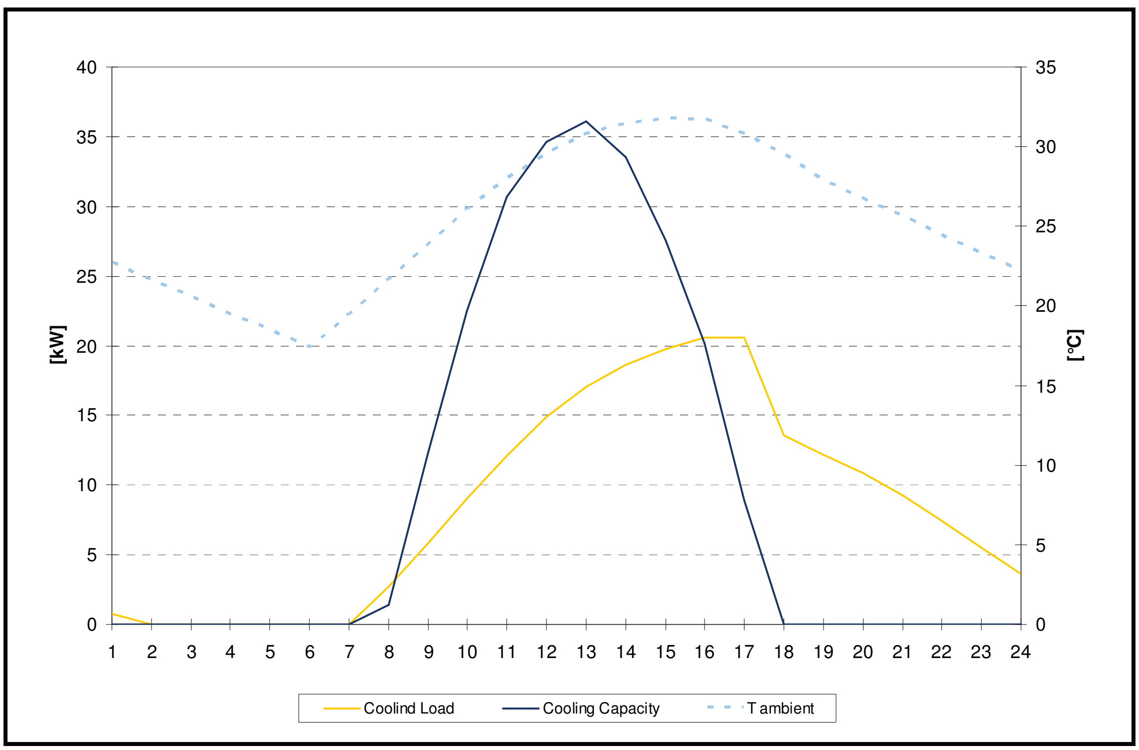

Figure 3.25 - Predicted correlation between cooling demand and cooling yield during a summer day with high solar irradiation (ca. 1100 W/m²).

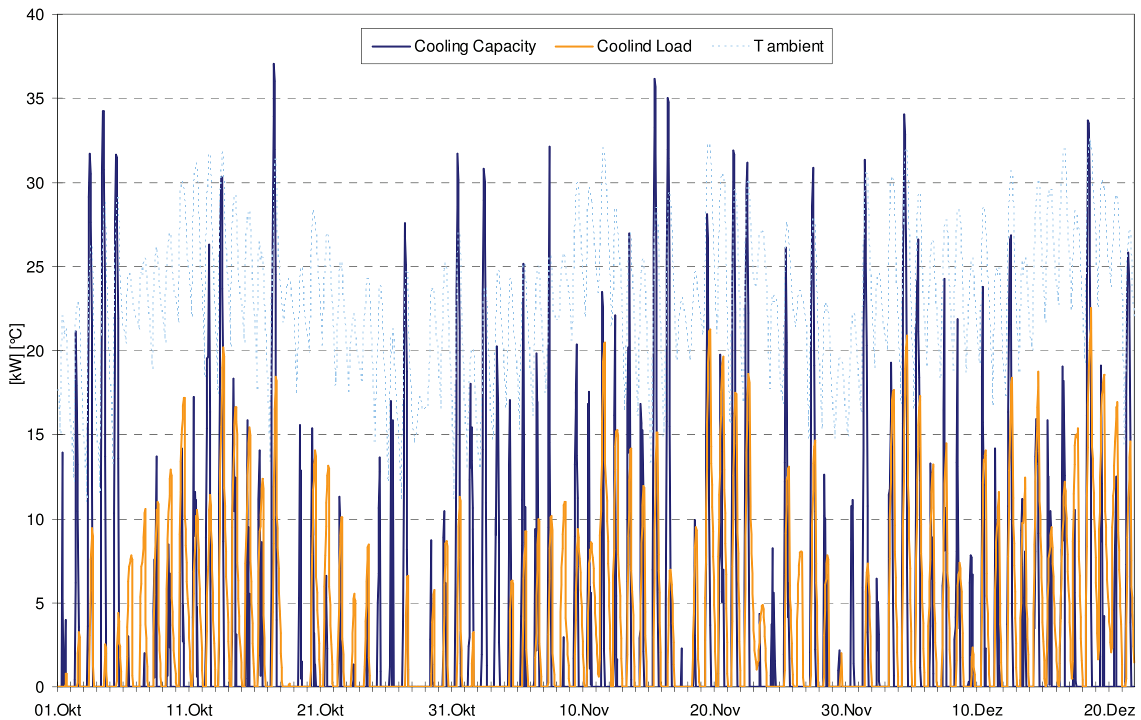

Figure 3.26 - Predicted daily demand and available yield of thermal energy during spring.

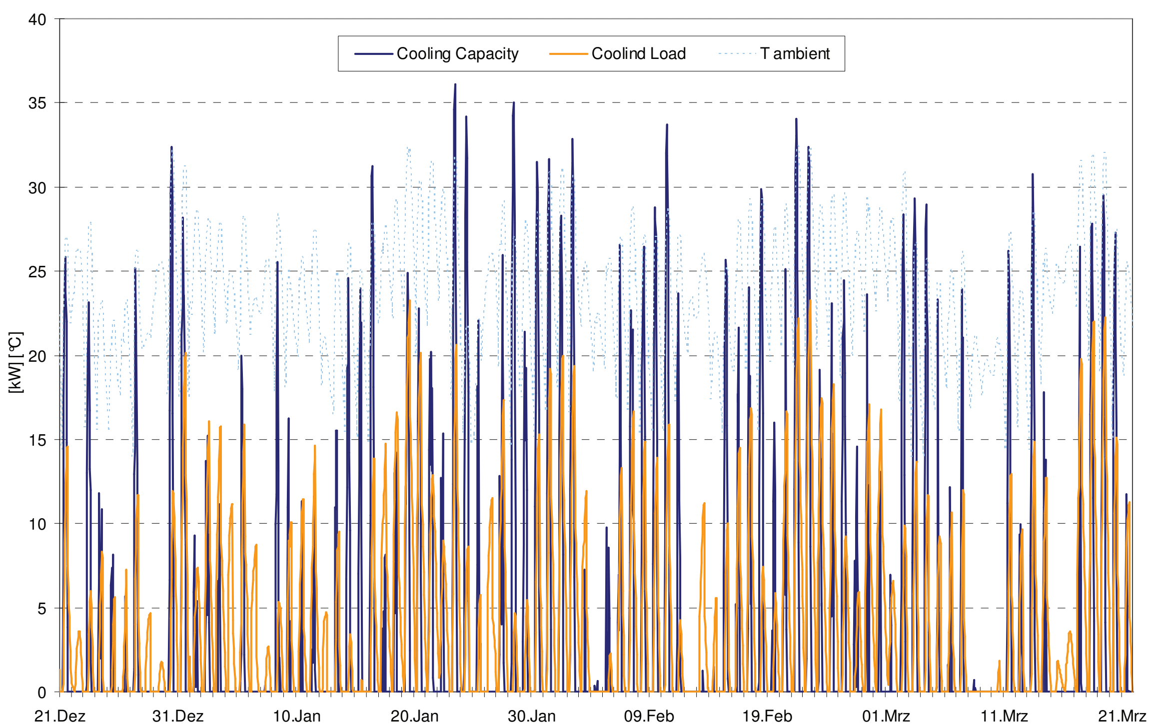

Figure 3.27 - Predicted daily demand and available yield of thermal energy during summer.

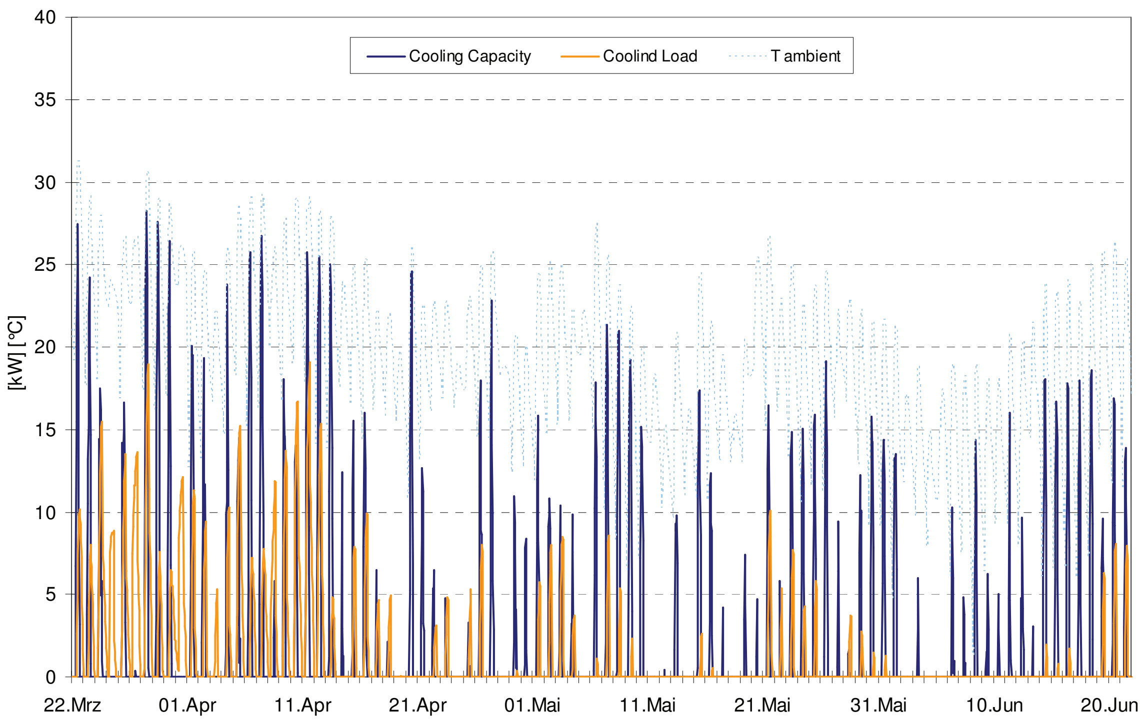

Figure 3.28 - Predicted daily demand and available yield of thermal energy during autumn.

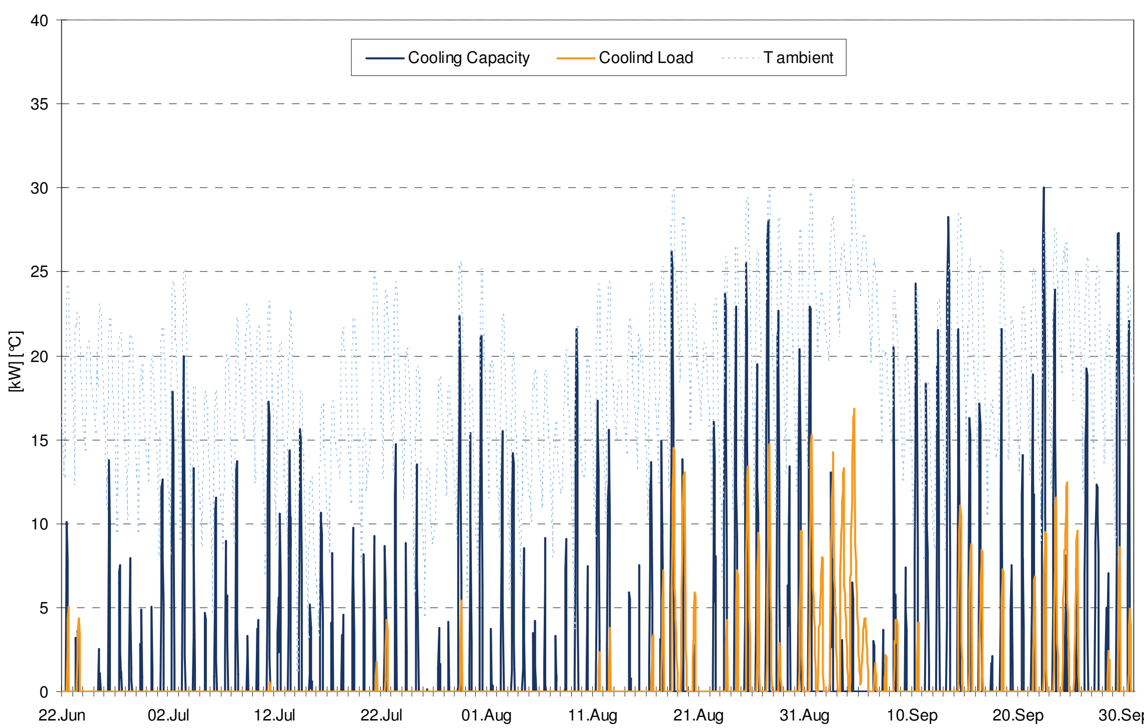

Figure 3.29 - Predicted daily demand and available yield of thermal energy during winter.

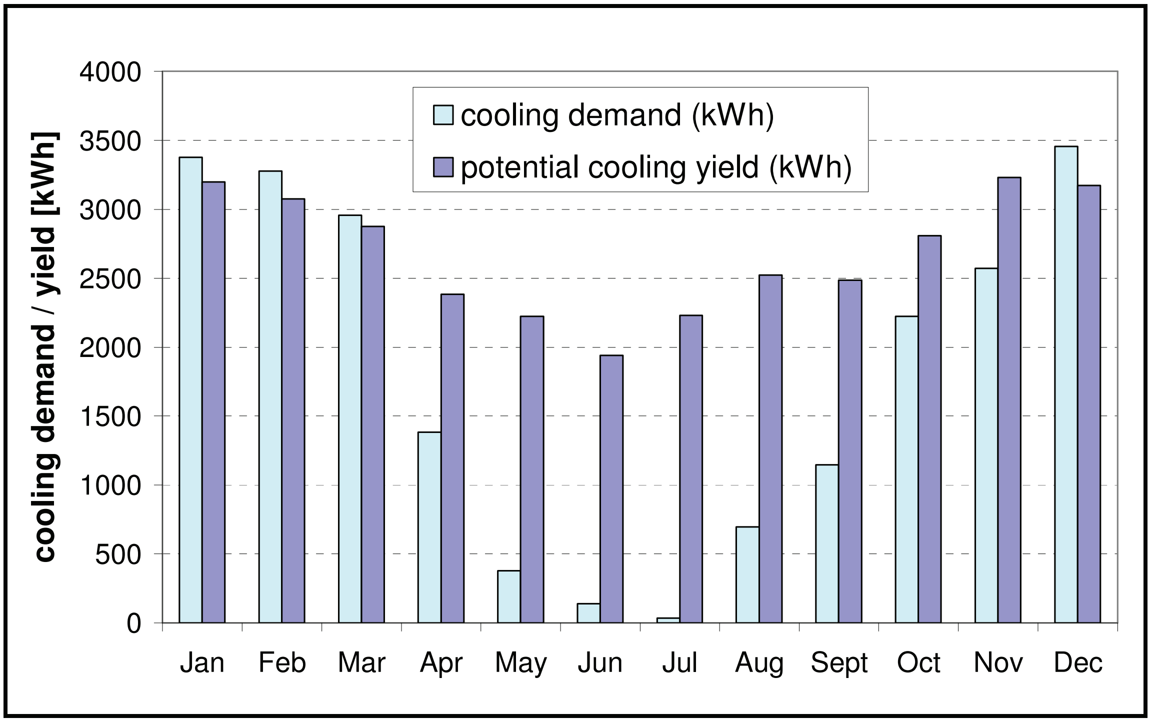

Figure 3.30 - Predicted total monthly cooling demand and available yield of thermal energy (8760 h). Solar yield is calculated with an constant daily average collector efficiency of 0,38 by 80 m² collector array and a constant Chiller COP of 0,7.

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.

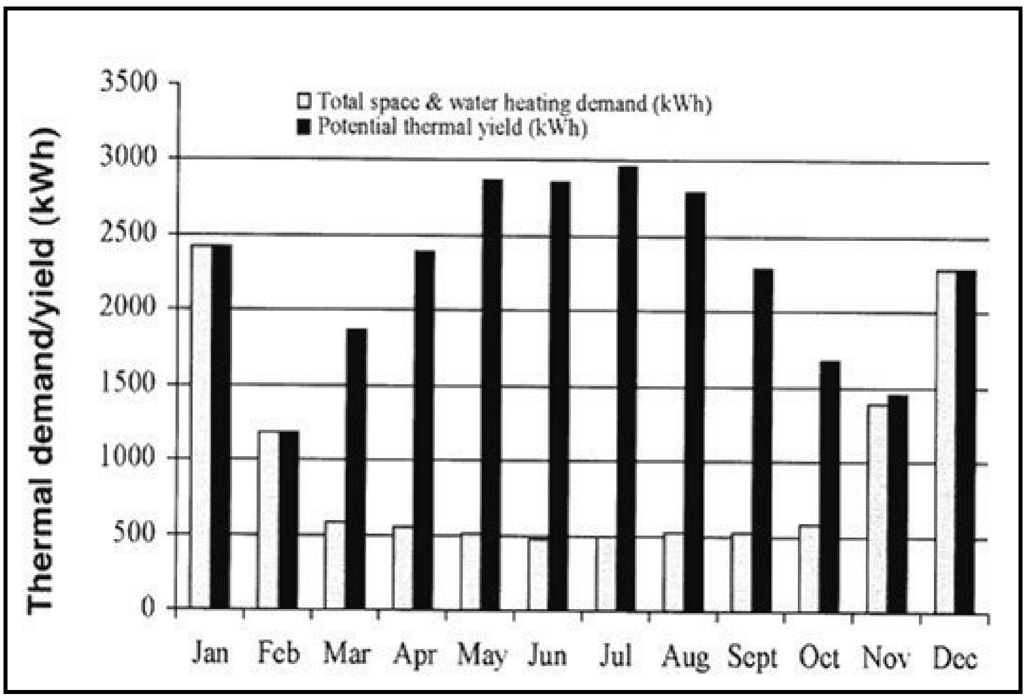

Figure 3.31 - Predicted monthly demand and available yield of thermal energy (UK, Leicestershire) [24].

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.

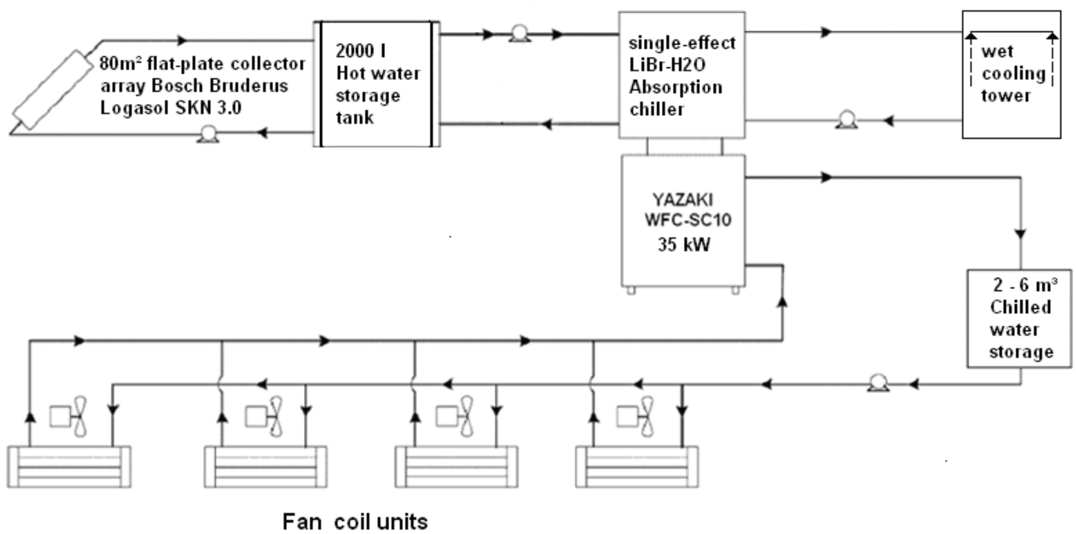

Figure 3.31 - Schematic diagram of the simulated solar-assisted air-conditioning system for the pilot-project in Guaratinguetá.

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

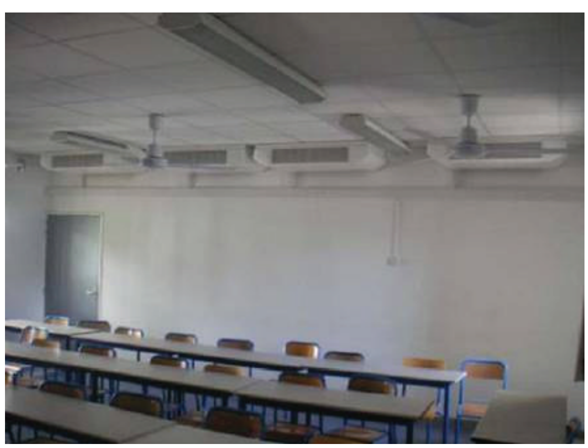

Figure 3.32 - Example of an Solar-Assisted Air-conditioning application in La Réunion, France (small island near Africa) [25]. This project was executed by Schüco International KG. At this picture the fan-coil units in the Auditorium (ca. 200 m²) are visible.

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.

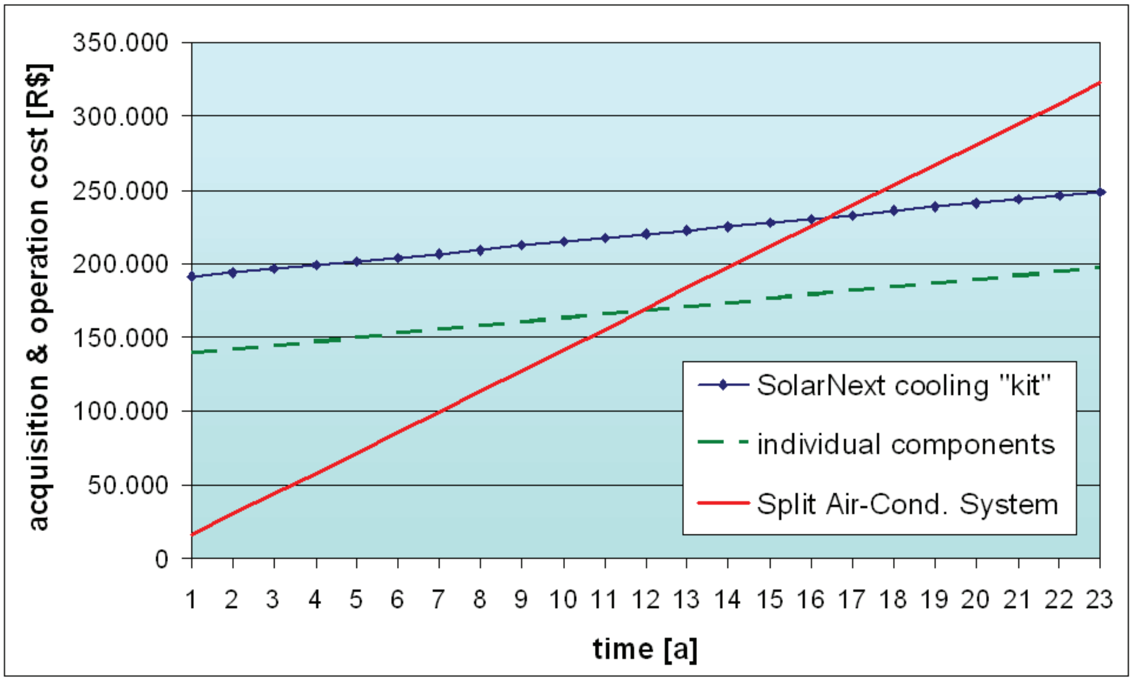

Figure 3.33 - Acquisition and operation cost of solar-assisted air-conditioning system and conventional split air-conditioning system in Guaratinguetá.

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.

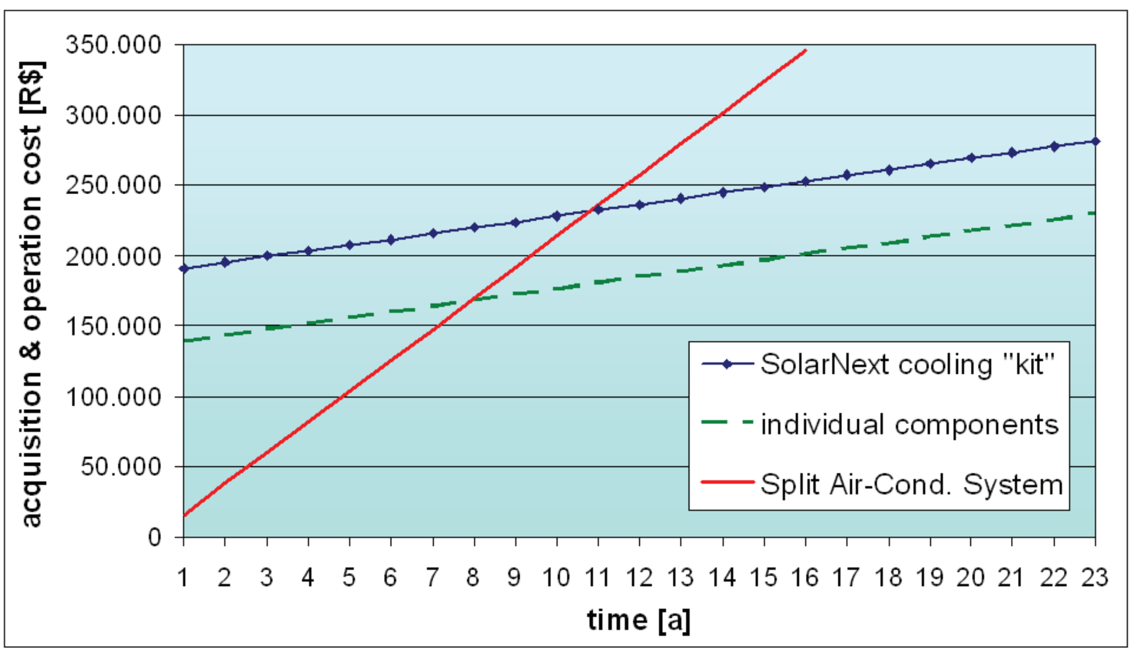

Figure 3.34 - Acquisition and operation cost of solar-assisted air-conditioning system and conventional split air-conditioning system in Minas Gerais.

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 CO_2 reduction.

To estimate the corresponding specific CO_2 emissions per kWh produced 'cold' (per 0.285 TR), a conversion factor of 0.28 kg CO_2 per kWh electricity is applied (average for the interconnected Brazilian electricity grid) [8].

The next table shows the CO_2 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 - CO_2 savings per year calculated with the conversion factor of 0.28 kg CO_2 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].