Energy and Buildings 42 (2010) 265–272

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Design of a solar absorption cooling system in a Greek hospital

T. Tsoutsos [a,*], E. Aloumpi [a], Z. Gkouskos [a], M. Karagiorgas [b]

[a] Department of Environmental Engineering, Technical University of Crete, Chania, Greece
[b] Department of Pedagogical Mechanical Engineers, ASPETE, Ktima Makrykosta, N. Iraklio, Greece

ARTICLE INFO

Article history:
Received 2 April 2009
Received in revised form 3 September 2009
Accepted 4 September 2009

Keywords:
Solar energy
Solar cooling
Solar collectors
Chillers

ABSTRACT

Air conditioning of buildings is responsible for a large percentage of the greenhouse and ozone depletion effect, as refrigerant harmful gases are released into the atmosphere from conventional cooling systems. The need to implement advanced new concepts in building air conditioning systems is more crucial than ever today.

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

Amongst cooling technologies, absorption cooling seems to have a promising market potential.

In this paper, the performance and economic evaluation of a solar heating and cooling system of a hospital in Crete, is studied using the transient simulation program (TRNSYS). The meteorological year file exploited the hourly weather data where produced by 30-year statistical process. The required data were obtained by Hellenic National Meteorological Service.

The objective of this study is to simulate a complete system comprised of a solar collector, a storage tank, a backup heat source, a water cooling tower and a LiBr-H_2O absorption chiller. The exploitation of the results of the simulation provided the optimum sizing of the system.

1. Introduction

During the last years a spectacular increase of the number of the installed air conditioning systems in buildings is observed. The dominant practice is that air conditioning applications rely exclusively on electrical energy while the exploitation of solar energy is mainly for domestic hot water, with few applications on space heating and very limited on space cooling [1].

Greek electricity utility often faces blackout situations on hot summer days, due to overloaded distribution networks. Such peaks, occurring only for a few weeks a year, cannot be covered at a reasonable cost, if one tries to apply a rational tariff system, as the investments needed in infrastructure are unjustified. Thus, in order to face the summer load peaks, without affecting the demand side, new power generation plants should be built, close to the consumption location [2].

The use of solar energy is an attractive concept that can be used to drive cooling cycles for space conditioning of most buildings. Passive [3] and active solar cooling systems (SCS) have the advantage of using absolutely harmless working fluids such as water, or salt solution being energy efficient and environmentally safe. They can be used either as stand-alone systems or with conventional air conditioning (AC), to improve the indoor air quality of all types of buildings. The main goal is to utilize "zero emissions" technologies in order to reduce energy consumption as well as the CO_2 emissions [4].

Several thermally driven AC technologies are market available by today, which enable the use of solar thermal energy for this application. Based on current technologies, i.e., market available thermally driven cooling devices and market available solar collectors, solar assisted air conditioning can lead to remarkable primary energy savings, if the systems are properly designed [5,6].

Till 2007 there were 81 installed large scale SCS, including systems which are currently not in operation. 73 installations are located in Europe, 7 in Asia, China in particular and 1 in America (Mexico). 60% of these installations are dedicated to office buildings, 10% to factories, 15% to laboratories and education centers, 6% to hotels and the left percentage to buildings with different final use (hospitals, canteen, sport center, etc.). The overall cooling capacity of the solar thermally driven chillers amounts to 9 MW; 31% of it is installed in Spain, 18% in Germany and 12% in Greece [7].

The Greek islands in general, constitute a special case due to both increased temperatures as well as their isolated power grids.

* Corresponding author. Tel.: +30 2821037825; fax: +30 2821037846.
E-mail address: theocharis.tsoutsos@enveng.tuc.gr (T. Tsoutsos).

0378-7788/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2009.09.002

Therefore, sustainable energy solutions should be adopted in wide scale.

The solar absorption cooling is using the process of attracting and holding moisture by desiccants.

As the hot and humid process air passes through the desiccant wheel, the moisture is removed by the desiccant, and its temperature increases. The temperature of this process air, which is now hotter and drier, is reduced to the desired comfort conditions; the warm and humid return air from the conditioned space is further heated up to the required regeneration temperature of the desiccant and this regeneration stream of air is passed through the desiccant wheel to remove the moisture from the desiccant [8].

Wide-ranging studies of different aspects of absorption system, such as performance simulations and experimental test results, have been reported. Amongst the various types of continuous absorption SCS, LiBr–H_2O and H_2O–NH_3 are the major working pairs employed in these systems. It is reported that LiBr–H_2O has a higher coefficient of performance (COP) than that of the other working fluids [9].

For various reasons, LiBr–H_2O system is considered to be better suited for most solar absorption air conditioning applications, and it will be the only combination examined here [10].

The objective of this work is to simulate a complete system comprised of a solar collector, a storage tank, a backup heat source, a water cooling tower and a LiBr–H_2O absorption chiller. This system aims to cover a fraction of the total cooling and heating energy demands of a hospital in Crete, throughout the year. During the process specialized software was used.

The optimization parameters were: collector plate area, collector plate slope angle, volume of hot water storage tank, nominal power of absorption chiller, cooling tower and backup heat source; the criteria to optimize is the solar fraction for cooling, for heating as well as the overall solar fraction.

2. Methodology

2.1. Software description

Transient System Simulation Program (TRNSYS) v.15 was used to simulate the building, in order to calculate its demands in terms of cooling and heating energy required in combination with two smaller programs: SimCad and Prebid.

Solar Air Conditioning in Europe (SACE) program was used for the feasibility study of the solar assisted air conditioning system [11]. Both of these programs require the weather values of a typical meteorological year (TMY), obtained through the "Meteonorm" software.

2.2. Steps of the applied methodology

The methodology is composed of the following steps [12,13]:

(i) Collection of the required meteorological data of the examined area.

These data concern the solar radiation, the relative humidity and both the strength and the direction of wind. Average monthly weather values of a TMY, were obtained through the "Meteonorm" program.

(ii) Study of the maximum, minimum and average heating and cooling energy demands of the building, for determining the technical characteristics of the system.

In order to maintain stable humidity and temperature conditions within the building, the heating and cooling loads should be calculated. These depend on a great number of parameters, such as:

- size and geometrical characteristics of the building
- orientation
- construction materials
- activity
- internal sources of heating
- ventilation
- infiltration
- lighting
- desired values of indoor temperature and humidity, during summer and winter
- meteorological conditions

(iii) Selection of the solar cooling technology to be applied.

The procedure adopted to select the optimum SAC technology depends on several building parameters (e.g. construction materials, geometry, orientation). The selected technology is also chosen taken into account the type of the AC installation (decentralized or not) and the climate conditions (moderate or extreme) [14].

(iv) Sizing study of the solar assisted air conditioning

The results of TRNSYS are inserted in SACE and the process of the output shows the feasibility or not of the system application in a specific building.

(v) Carry out studies on optimized solutions for the solar fraction by varying the technical characteristics that mainly concern the:

- solar collector surface
- absorption chiller power
- boiler power
- water tank volume
- cooling tower type and power

(vi) Economical evaluation of optimized solutions

Solar processes are generally characterized by high investment and low operating cost. Thus the basic economic problem is one of comparing an initial known investment with estimated future operating savings. The cost of any energy delivery process includes all the items of hardware and labour that are involved in the installation of the equipment, plus the operating expenses. It is vital to determine the primary energy savings and relevant costs for different SCS. Several economic criteria have been proposed for evaluating and optimizing SE systems, and there is no universal agreement on which should be used [15].

The installation of equipment involves costs for labour, foundations, supports, construction expenses and other factors directly related to the erection of purchased equipment [16].

To be considered effective, a solar system must be able under sustained conditions to match the cooling output of a conventional system, while using less electricity or fossil fuel. This saving can be estimated only if a basis for comparison is defined. The appropriate basis is the conventional vapour compression chiller. Energy saving is the cost of the conventional energy minus the costs of SE.

(vii) Optimization of the system and final remarks

As a final proposal is chosen the optimized solution which optimizes both environmental and economic benefits.

3. Application – results

3.1. Meteorological data

The National Meteorological Service of Greece provided the meteorological data, for the city of Sitia covering a time span of at least 30 years. After their processing, the average monthly values were calculated as well as the maximum–minimum values, where it was considered necessary. From these averages, maximum and

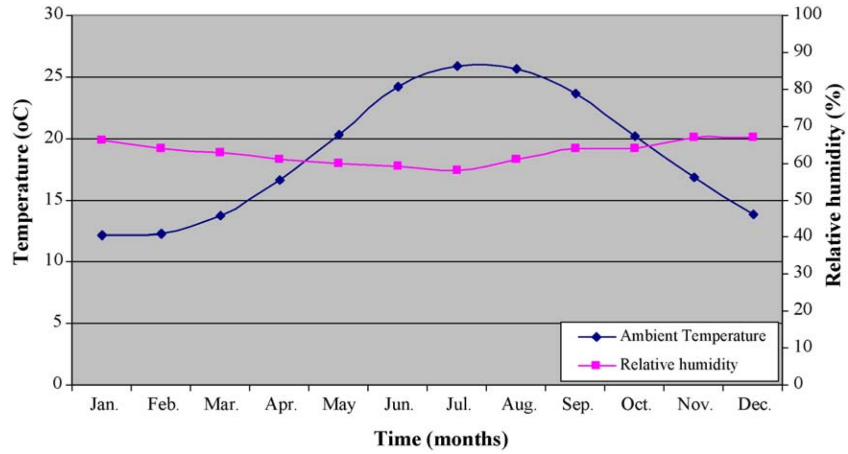

Fig. 1. Variability of ambient mean monthly temperature and mean monthly relative humidity (Sitia, Crete).

minimum values, assisted by the "Meteonorm" program, three TMY were created respectively.

In Fig. 1 the variability of ambient temperature and relative humidity and in Fig. 2 the monthly solar radiation on horizontal surface are demonstrated.

3.2. Building's profile

The building studied is part of the facilities of the General Hospital of Sitia. The Hospital consists of eight buildings connected to each other. Building B is the one studied shown in Fig. 3. Building B has an overall surface of 1.250 m^2 and consists of three areas. It accommodates the maternity clinic on the ground floor, the cardiology and the pathology clinic on the first floor and the pediatric clinic on the second floor. This building was selected due to the priority of the management of the General Hospital, to the problems in the existing conventional AC system, and to its operation as clinic.

Knowledge of the materials of the building is necessary to conduct the simulation of the thermal behavior of the building and is used as inputs in Prebid software. The construction materials are shown in Table 1 and simulation is presented in Fig. 4. The

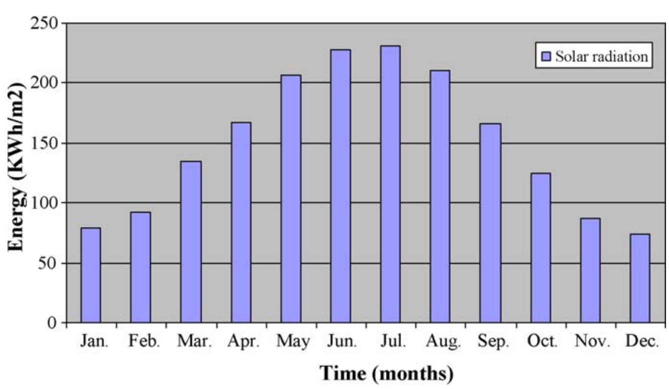

Fig. 2. Monthly solar radiation on horizontal surface in situ (Sitia, Crete).

Table 1
Construction materials of the building.

Type	Construction materials	Total thickness (cm)
Ground floor	Concrete (20 cm), polyethylene (1 cm)	21
1st floor	Concrete (20 cm), polyethylene (1 cm)	21
2nd floor	Concrete (20 cm), polyethylene (1 cm)	21
Roof	Tar, bitumen cloth, lightweight concrete (0.50 cm), bitumen, stones	60
External walls	Brick (10 cm), roof mator, brick (10 cm), plaster	30
Internal walls	Brick (10 cm), plaster	11

Fig. 3. General Hospital of Sitia.

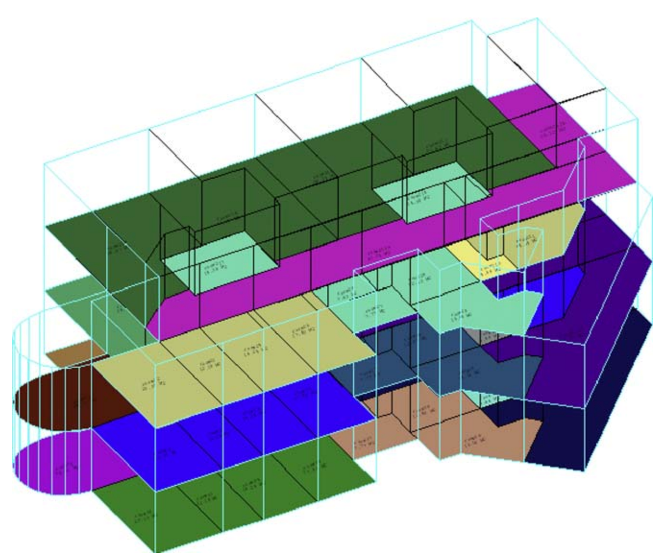

Fig. 4. Profile of the building was created in SimCad.

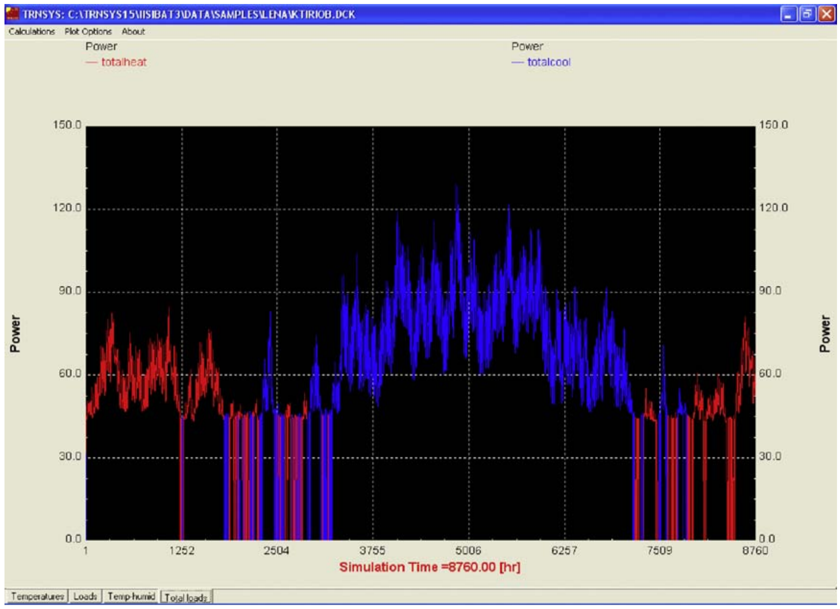

Fig. 5. Heating and cooling loads (kW) on hourly base.

information needed for every thermal zone of the ground floor, the 1st and 2nd floor of the building concern the volume and the surface of the rooms.

3.3. Determining parameters of simulation

(i) Absorption of solar radiation by the walls

The color of the external walls of the building is brown and the radiation absorption factor is 0.82.

(ii) Ventilation

The ventilation per individual has been determined according to a Technical Directive of the Technical Chamber of Greece [16]. The values of ventilation of every thermal zone were chosen to be the mean values of the suggested range.

(iii) Infiltration

The infiltration of the air was calculated by TRNSYS according to the orientation of the building, the open surfaces and the meteorological data of the area (especially the direction and the intensity of wind).

(iv) Internal sources of heat

The lighting of the building includes fluorescent lamps of 32 W and common lamps of 75 W. Depending on the use of each room of the building, certain categories of Prebid software were selected. These categories refer to people who are seated at rest (patients) and those who are seated while doing very light work (nurses and doctors in offices).

The computers that are installed in the building have a power of 230 W and are equipped with colored monitors.

On the first floor of the building there is monitor of 2.5 kW and an ultrasound device of 1.5 kW.

(v) Hours of operation

The building operates 24 h a day, all year.

(vi) Humidity and temperature

The operational values of humidity and temperature during the summer and the winter were determined according to values provided from the Technical Chamber of Greece. The thermal energy simulation of the building was carried out in TRNSYS software.

3.4. Required load for cooling and heating

The required energy for cooling and heating was calculated according to the outputs of TRNSYS. Solar collectors will be installed in an area next to the building. Therefore, the required

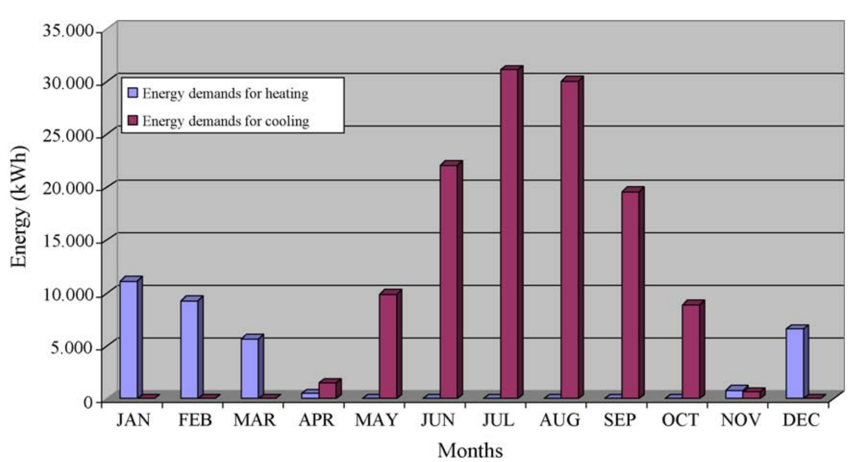

Fig. 6. Heating and cooling energy on monthly base.

energy for cooling and heating was calculated without having to take into account an installation on the roof of the building.

Fig. 5 depicts the total cooling loads (blue) and the total heating loads (red). Axis y is power (kW) and axis x is time (h).

Fig. 6 depicts the energy demands of cooling and heating as these were calculated in TRNSYS. It is obvious that the annual required energy of heating is 34.205 kWh and the annual required energy of cooling is 123.911 kWh.

3.5. Required power of cooling and heating system

In order to define the power of the chiller and the backup boiler, the assumption that the percentage of 1% of the maximum cooling and heating loads cannot be covered by them, was made.

This means that the power of the chiller and the backup boiler is the 31st value of the first highest hourly cooling and heating loads respectively (since the total values are 3.100). In the first case the hourly cooling loads have been calculated in TRNSYS using the TMY file which includes the mean maximum cooling loads (period of summer). The power of the cooling system is calculated to be 121 kW. In the case of the backup boiler the TMY file includes the mean minimum heating loads (period of winter). The power of the heating system is calculated to be 87 kW.

The accepted value of the summer cooling period is represented as 1%. This means that the power of the cooling system will be the 31st value of the first highest hourly cooling loads which were calculated in TRNSYS. In order to calculate the power of the cooling system, a second simulation of the building was conducted. The difference from the first is that in this case the TMY file which includes the maximum cooling and heating loads (period of summer) was used. The power of the cooling system is calculated to be 121 kW.

In order to calculate the power of the heating system, a third simulation of the building was conducted. In this case the TMY file which includes the minimum cooling and heating loads (period of winter) was used. The power of the heating system is calculated to be 87 kW.

3.6. Technology of the solar air conditioning system

The used SCS is a closed system and includes an absorption chiller with a working fluid of LiBr–H_2O. This system was chosen as:

- There are no duct networks in the building and as a result an open system cannot be used.

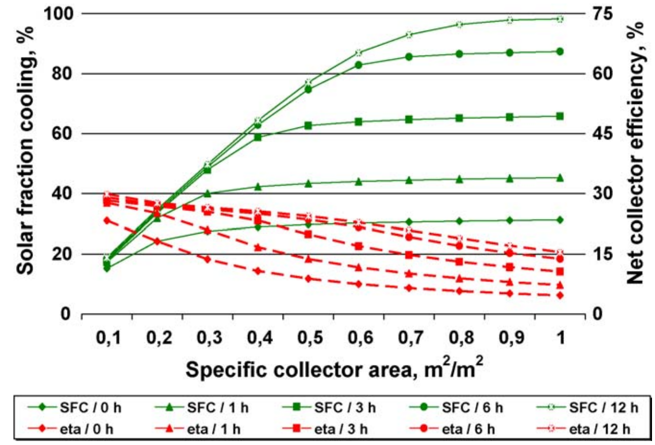

Fig. 7. Effect of specific collector area on solar fraction cooling and net collector efficiency.

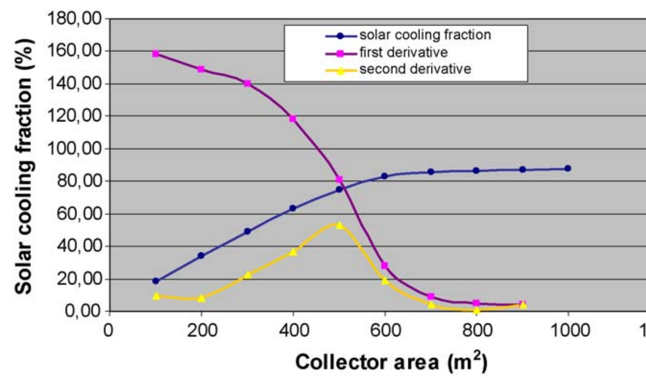

Fig. 8. Defining the optimum collector area.

- The absorption chiller in combination with the working fluid of LiBr–H_2O has a higher COP than that of the working fluid of H_2O–NH_3 [17].
- The LiBr–H_2O has a lower cost and better performance than the H_2O–NH_3. For these reasons, the LiBr–H_2O system is considered to be better suited for most solar absorption air conditioning applications [18].

Table 2
Alternative scenarios.

	Conventional	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Collector area (m^2)	0	200	200	500	500
Solar fraction cooling (%)	0	34.05	34.05	74.73	74.73
Electricity for cooling (%)	100	0	65.95	0	25.27
Fossil fuel for cooling (%)	0	65.95	0	25.27	0
Solar fraction heating (%)	0	36.58	36.58	70.78	70.78
Electricity for heating (%)	0	0	0	0	0
Fossil fuel for heating (%)	100	63.42	63.42	29.22	29.22

Table 3
Characteristics of the solar air conditioning system of the four scenarios.

Equipment	Type	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Chiller	Compression	–	50 kW	–	50 kW
	Absor. LiBr–H_2O	121 kW	70 kW	121 kW	70 kW
Solar collector	Selective	200 m^2	200 m^2	500 m^2	500 m^2
Storage tank	Hot water	5 m^3	5 m^3	15 m^3	15 m^3
Cooling tower	Open	280 kW	170 kW	280 kW	170 kW
Auxill. system	Pre-heater	175 kW (ad. power: 88 kW)	87 kW	175 kW (ad. power: 88 kW)	87 kW

3.7. Equipment and operation parameters

In order to select the appropriate solar collector type, four different types were examined. A flat selective collector was selected due to its lower cost per kW. The optimum slope angle was calculated to be 10–15° with South orientation, since it was given priority for the maximum performance during summertime.The absorption chiller that was used is a WFC chiller produced by YAZAKI.

The optimum operational temperature of the system is the one which optimizes the efficiency of the absorption chiller and the efficiency of the solar collectors simultaneously (90 °C).

Solar collectors will be installed in an area next to the building as the roof of the building is covered by stones for insulation but also because some solar collectors, used to provide hot water, are already installed next to the Hospital.

3.8. Feasibility study

The estimation of the optimal surface of solar collectors as well as the solar cooling fraction was performed through SACE software.

In Fig. 7 the solar cooling fraction as well as the net efficiency of the collector depending on the specific collector area appears.

Table 4
Financial data.

	Cost
Equipment	
Absorption chiller LiBr–H_2O (COP = 0.7)	400 €/kW (2004)
Compression chiller (COP = 2.5)	310 €/kW (2004)
Selective solar collector	180 €/m^2 (2008)
Pre-heater (n = 85%)	50 €/kW (2008)
Cooling tower	50 €/kW (2004)
Storage tank	600 €/m^3 (2004)
Cost of energy	
Electricity	0.25 €/kWh (2008)
Oil	1.200 €/t (2008)

3.9. Alternative scenarios

Four alternative scenarios have been studied, in which there are different solar heating and cooling fractions. The first scenario has been conducted according to Fig. 7. The collector area is the one that corresponds to the section of the two lines of the diagram (the solar fraction cooling line and the net collector line) and is 200 m^2.

This scenario functions with a low solar fraction in comparison to the second scenario that functions with the highest solar fraction.

Table 5
Results of annual energy balance for system design.

Annual energy requirements	Conventional	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual total electricity consumption (kWh)	49.564	1.700	33.687	2.200	14.025
Annual electricity consumption of the compression chiller (kWh)	49.564	–	32.687	–	12.525
Annual required heat for cooling (kWh)	–	177.016	60.274	177.016	132.284
Annual required heat for heating (kWh)	34.205	34.205	34.205	34.205	34.205
Total annual heat (kWh)	34.205	211.221	94.479	211.221	166.489
Annual heat from 2nd heat source (fossil fuel) (kWh)	34.205	138.435	21.693	54.727	9.995
Annual amount of fossil heat source (primary energy) (kWh)	40.241	162.865	25.521	64.385	11.759
Annual radiation on collector (kWh)	–	385.800	385.800	964.500	964.500
Annual heat produced by solar collector (kWh)	–	127.584	127.584	318.960	318.960
Annual overall cooling production (kWh)	123.911	123.911	123.911	123.911	123.911
Annual cooling production by compression (kWh)	123.911	–	81.719	–	31.312

Table 6
Investment, operation cost and payback time.

	Conventional	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Investment cost (€)					
Absorption chiller	–	48.400	28.000	48.400	28.000
Compression chiller	31.000	–	15.500	–	15.500
Solar collectors	–	36.000	36.000	90.000	90.000
Storage tank	–	3.000	9.000	3.000	9.000
Pre-heater	4.350	8.750	4.350	8.750	4.350
Cooling tower	–	14.000	8.500	14.000	8.500
Total equipment cost	35.350	110.150	101.350	164.150	155.350
Installation cost	4.242	13.218	12.162	19.698	18.642
Total investment cost without funding subsidies	39.592	123.368	113.512	183.848	173.992
Funding (%)	–	40	40	40	40
Total investment cost wit funding subsidies	–	74.021	68.107	110.309	104.395
Annual operational cost					
Cost of maintenance	1.500	1.234	1.135	1.838	1.740
Annual electricity cost	12.391	425	8.422	550	3.506
Annual heat cost (fossil fuel)	4.200	16.995	2.663	6.718	1.227
Total annual cost	18.091	18.654	12.220	9.106	6.473
Total annual savings	–	−563	5.871	8.985	11.618
Payback time (year)					
Payback time without funding subsidies	–	<0	12.6	16.0	11.5
Payback time with funding subsidies	–	<0	7.6	9.6	6.9

Table 7
Environmental benefits.

Environmental benefits	Conventional	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Saved electricity (kWh)	–	47.864	15.877	47.364	35.539
CO_2 savings due to electricity savings (kg)	–	50.855	16.869	50.324	37.760
Saved fossil fuel energy for heat (kWh)	–	−122.624	14.720	−24.144	28.482
CO_2 savings due to heat (fossil fuel) savings (kg)	–	−33.476	−4.018	−6.591	7.775
Overall primary energy savings (kWh)	–	−7.713	49.912	90.267	113.581
Total CO_2 savings (kg)	–	17.379	12.851	43.733	45.535
Working fluid in the solar air conditioning system	–	LiBr–H_2O	LiBr–H_2O	LiBr–H_2O	LiBr–H_2O
Working fluid in the conventional AC system	R-407c		R-407c		R-407c

Table 8
Comparative table for the hospital situated in three different locations and climates.

Equipment	Type	Sitia	Athens	Thessaloniki	Basel
Chiller	Compression	50 kW	50 kW	45 kW	35 kW
	Absor. LiBr–H_2O	70 kW	80 kW	70 kW	50 kW
Solar collector	Selective	500 m^2	600 m^2	600 m^2	700 m^2
Storage tank	Hot water	15 m^3	25 m^3	25 m^3	30 m^3
Auxill. system	Pre-heater	87 kW	91 kW	140 kW	166 kW
Solar fraction cooling (%)	–	74.73	31.70	27.17	17.89
Solar fraction heating (%)	–	70.78	16.57	8.71	5.33
Solar fraction total (%)	–	74.27	28.10	20.53	11.78

In order to find the appropriate collector area in which the highest solar fraction is achieved, it is necessary to use Fig. 8 which depicts the solar fraction cooling versus the collector area. It is observed that the appropriate collector area is 500 m^2.

In Table 2 the four alternative scenarios and the conventional scenario are presented. The characteristics of the solar air conditioning system of all scenarios are presented in the Table 3.

The four scenarios are not only compared to each other but also to the conventional system, in order to evaluate their function and choose the one that optimizes the financial and environmental benefits.

The basic assumptions made during the economic evaluation are:

- Maintenance costs: conventional 2%, of solar: 1% of investment costs [11].
- Operating costs associated with a solar process include the cost of electricity for operation of pumps, interest charges on funds borrowed to purchase the equipment and others. The operation cost is connected to the specific characteristics of the system.
- Installation costs: 12% of the equipment cost [15].
- The energy inflation is taken to be 2% [18].

In Table 4, some necessary financial data are presented.

In Tables 5–7 there is a description of the financial study and a study of the environmental benefits of each scenario.

Several simulations, following the previous procedure, were performed for the same building situated in three different locations and climates: Athens (central Greece), Thessaloniki (North Greece), and Basel (Switzerland). The specifications of these SCS are presented in the Table 8. An optimization of the solar collector size and other system parameters was also performed.

4. Conclusions

The fourth scenario is the one which optimizes the financial and environmental benefits. This scenario functions with the highest solar fraction and has a solar fraction cooling of 74.23% and the solar fraction heating is 70.78%. The number of solar collectors necessary to cover the surface of 500 m^2 is 179. The solar air conditioning system that is used is a closed system and includes an absorption chiller of 70 kW with a working fluid of LiBr–H_2O. In the case that the absorption chiller cannot provide the required energy for cooling, a compression chiller of 50 kW is used in addition. The system includes an auxiliary pre-heater (fossil fuel) of 87 kW.

A great advantage of this scenario is that it offers the highest environmental benefits. The investment cost without funding subsidies is 173.992 € with a payback time of 11.5 years. In the case that there is a funding of 40%, the investment cost decreases in 104.395 € with a payback time of 6.9 years.

It is observed that the investment cost is quite high. However, this is compensated by the highest environmental benefits, the lower payback time and the highest total annual savings.

The efficiency of an SCS is higher in Crete (the most south amongst the locations examined), but there are environmental gains (in CO_2 emissions) even in N. Europe. However, the payback period for such installations in N. Europe can still be considered high.

The application of the solar air conditioning system has several advantages compared to the conventional air conditioning system.

The major benefit is that this technology is environmentally friendly and contributes to a significant decrease of the CO_2 emissions which cause the green house effect. Also, the total annual savings of the operation of the system are quite considerable. Another benefit is that there are great electricity and fossil fuel savings. This is important as the reservoirs of fossil fuels are decreasing resulting to their very high prices. Taking that into account, the application of such systems should dominate the future market. This could result in the widespread application of these systems provided that experts who study and apply these systems gain more experience and specialization in their installation.

Acknowledgments

This study has been supported by the IEE Programme of the European Commission, Directorate General TREN, through the project Removal of non-technological barriers to Solar Cooling technology across Southern European Islands (SOLCO, contract no: EIE/06/116)

References

[1] K. Mamounis, A. Dimoudi, Solar cooling potential in tourist complexes in the North Aegean, in: Proceedings of Passive and Low Energy Cooling for the Built Environment, International Conference, Santorini, Greece, (2005), pp. 669–675.

[2] A.M. Papadopoulos, S. Oxizidis, N. Kyriakis, Perspectives of solar cooling in view of the developments in the air-conditioning sector, Renewable and Sustainable Energy Reviews 7 (5) (2003) 419–438.

[3] M. Santamouris, K. Pavlou, A. Synnefa, K. Niachou, D. Kolokotsa, Recent progress on passive cooling techniques: Advanced technological developments to improve survivability levels in low-income households, Energy and Buildings 39 (7) (2007) 859–866.

[4] T. Tsoutsos, M. Karagiorgas, The development of solar air conditioning in Greece, in: Proceedings of the 8th Conference for Renewable Energy Sources, Thessaloniki, Greece, 2006.

[5] H.M. Henning, Solar assisted air conditioning of buildings – an overview, Applied Thermal Engineering 27 (10) (2007) 1734–1749.

[6] A. Argiriou, C.A. Balaras, S. Kontoyiannidis, E. Michel, Numerical simulation and performance assessment of a low capacity solar assisted absorption heat pump coupled with a sub-floor system, Solar Energy 79 (3) (2005) 290–301.

[7] W. Sparber, A. Napolitano, P. Melograno, Overview on worldwide installed solar cooling systems, in: Proceedings of 2nd Solar Cooling Conference, Tarragona Costa Dorada, Spain, 2007.

[8] G.A. Florides, S.A. Kalogirou, S.A. Tassou, L.C. Wrobel, Modeling and simulation of absorption solar cooling system for Cyprus, Solar Energy 72 (1) (2002) 43–51.

[9] C.A. Balaras, G. Grossman, H.M. Henning, C.A. Infante Ferreira, E. Podesser, W. Lei, E. Wiemken, Solar air conditioning in Europe – an overview, Renewable and Sustainable Energy Reviews 11 (2) (2007) 299–314.

[10] Z.F. Li, K. Sumathy, Simulation of a solar absorption air conditioning system, Energy Conversion and Management 42 (3) (2001) 313–327.

[11] Various, SACE – Solar air conditioning in Europe, Delft University of Technology, NNE5-2001-00025, Energy's Programme (1998–2002), 2003.

[12] G. Zidianakis, T. Tsoutsos, N. Zografakis, Simulation of a solar absorption cooling system, in: Proceedings of 2nd PALENC Conference, Crete, Greece, 2007.

[13] T. Tsoutsos, M. Karagiorgas, G. Zidianakis, V. Drosou, A. Aidonis, Z. Gouskos, C. Moeses, Development of the applications of solar thermal cooling systems in Greece and Cyprus, Fresenius Environmental Bulletin, June 2009.

[14] Various, Climasol, http://raee.org/climatisationsolaire/gb/documents.htm, 2005.

[15] M. Peters, K. Timmerhaus, R. West, Plant Design and Economics for Chemical Engineers, fourth ed., McGraw-Hill International Editions, 1991. Exclusive rights by McGraw-Hill Book Co - Singapore, ISBN 0-07-100871-3.

[16] Technical Chamber of Greece, Installations in buildings: data for the estimation of air conditioning loads, Technical Directive. T.D.T.C.G. 2425/86, 2005.

[17] T. Tsoutsos, J. Anagnostou, C. Pritchard, M. Karagiorgas, D. Agoris, Solar cooling technologies in Greece, an economic viability analysis, Applied Thermal Engineering 23 (11) (2003) 1427–1439.

[18] M. Balghouthi, M.H. Chahbani, A. Guizani, Feasibility of solar absorption air conditioning in Tunisia, Building and Environment 43 (9) (2008) 1459–1470.