Solar Air-conditioning Systems Impact on the Built Environment – A Thermodynamic Approach

1. *Introduction*

Energy consumption in European domestic and tertiary sectors represents about 40% of the annual EU-15 final energy use and about a third of greenhouse gas emissions. Among these, about two-thirds are concentrated in residential sector, the remaining part in commercial building. The household sector represents about 70% of total energy consumption in buildings sector [1]. During the last few decades energy consumption for cooling has increased dramatically in most European countries. The main reasons for the increasing energy demand for summer air- conditioning are the increased thermal loads, increased living standards and comfort demands in conjunction with architectural characteristics and trends.

During the summer the demand for electricity in Greece increases due to the extensive use of heating ventilation and air conditioning systems, which increase the peak electric load, causing major problems in the electric supply. In the current practice, air conditioning is exclusively based in the use of electric energy, while the use of solar energy is limited at heating of domestic hot water and in limited applications for space heating and fewer for cooling. It has been estimated that the total energy consumption in Greece, in 2003, for central air conditioning systems was 2909 GWh/y [2], whereas the per capita consumption was estimated at 371 KWh/ y [3]. The extensive use of electrically driven compression cooling equipment is responsible for an increase of greenhouse gases emissions, due to the energy production or to the leakage of the cooling fluids; intensifying the cycle of climate change. The latter is of great significance, especially in the case of public buildings.

The energy behavior of the public buildings in Greece varies according to the building's age and its structural components [4]. Public buildings that have been constructed until 1940 are characterized by heavy structural components, lack of central heating, high energy consumption rates and satisfactory conditions of thermal comfort especially during the summer months. The majority of public buildings in Greece have been constructed during the period 1940-1980 (before 1973); these constructions are characterized by reinforced concrete, lack of thermal insulation, they usually have a central heating system, high energy consumption rates and medium thermal comfort. The energy behavior of the public buildings in Greece has significantly been improved, during the past 20 years, mainly due to the use of thermal insulation. In 1980 the buildings adsorbed 22% of total energy consumption; while in 1994 the absorbed energy came up to 30.9% [5].This increase can be attributed to the increase in the use of electrical energy. Taken into consideration the fact that the energy consumption in public buildings will be greater than 50 kWh/ m ^{2}, coming up to a total of 250 kWh/ m^2; it is obvious the need for rational energy use so as to avoid the economic as well as environmental impacts. For this reason the development of trendsetting technologies for reliable, affordable and environmentally friendly energy is vital.

The use of solar energy to drive cooling cycles for space conditioning of most buildings constitutes an attractive concept, since the cooling load coincides generally with solar energy availability and therefore cooling requirements of a building are roughly in phase with solar incidence. Solar cooling systems have the advantage of using harmless working fluids such as water, or solutions of certain salts. They are energy efficient and environmentally safe. They can be used, either as stand-alone systems or with conventional air conditioning, to improve the indoor air –quality of all types of buildings. The main goal is to utilize "zero emission" technologies to reduce energy consumption and CO_2 emissions.

The continuous increase in the price of energies, associated with support systems set up by the majority of governments has made it possible for a significant solar thermal sector growth. In particular, the solar energy market in the EU presented significant growth (+12%); still at 1.089 MW_{th} of newly installed capacity it remains below what would be needed to reach EU's target for 2010: 70,000 MW_{th} of solar thermal capacity (100 million m^2). The solar thermal capacity in operation reached 9,525 MW_{th} at the end of 2004, which provides 8,164 MW_{th} of clean energy. As far as Greece is concerned, 151 MW_{th} of new solar thermal capacity were installed in 2004 – an increase of 34% compared to 2003. For 2005 a continuation of the pre-2004 trend is expected, with sales in the area of 119 MW_{th} [6].

Today approximately 120 solar thermal assisted cooling systems are presently installed worldwide, with a total cooling capacity estimated at 10MW [7,8].Their specific collector is ~ $3m^2$/ Kw for water chillers or 10 m^2 per 1000 m^3/h of air volume flow in desiccant systems. Most of the systems have been installed in Germany, Spain as well as Greece [9].About 69% of theses systems use absorption chillers whereas about 10% of them adsorption chillers. Furthermore, in about 19% of the installations a solid desiccant cooling system is installed. It should be noted that their primary energy savings potential is between 30-60%; however these potentials are often unrealizable with the current systems, due to sub-optimal design, installation, and operation. Although a precise statement on the economic situation of a solar assisted air conditioning system depends on the specific system, in general the annual cost (the complete cost including capital cost, operation and maintenance costs etc) of a solar assisted air conditioning system are currently above the annual cost of a conventional system.

In the context of this paper, the potential for solar applications, mainly for solar cooling are investigated for a medical center in Northern-Western Greece. To be more specific, an exergy analysis is applied, to a solar air conditioning system, so as to analyze the performance of a cycle driven by solar energy. Additionally, an environmental and an economic evaluation of the solar cooling installation in the medical center are presented in this study. The environmental benefits of such a system outweigh the conventional ones. The results are of great significance, as they are indicative of the application prospects in the Greek market.

2. *Solar Cooling*

Solar air conditioning refers to any air conditioning system that uses solar power. This can be done through passive solar, photovoltaic conversion or solar thermal energy conversion. Specifically, solar cooling technologies use solar thermal energy provided through solar collectors to power thermally driven cooling machines. A solar cooling installation consists of a typical solar thermal system made up of solar collectors, storage tank, control unit, pipes and pumps and a thermally driven cooling machine. A conventional energy source functions as auxiliary, mainly for the periods when the cooling load is not covered by the produced energy by the collectors. The schematic installation for the provision of solar air conditioning is presented in Figure 1 [10].

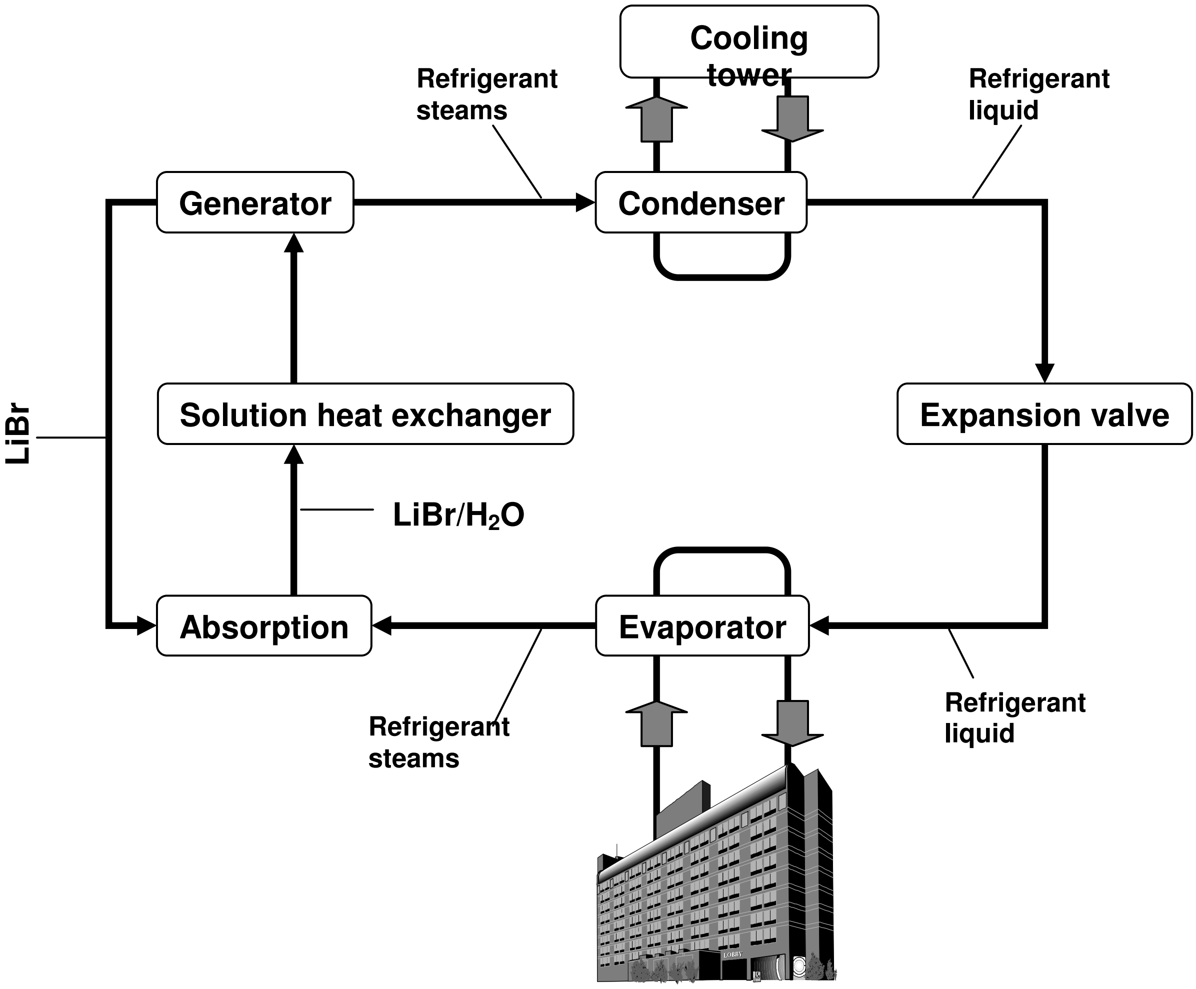

Figure 1: Schematic installation for the provision of solar air conditioning using as refrigerant water [10]

The basic principle for production of cold by heat is based on the evaporation technique. The basic advantage of solar cooling is, that the greater heat exists the more cooling is produced, advantage that is excellently synchronized with the requirements for summer cooling in buildings. In Table 1, the basic operations characteristics of the main solar cooling techniques are summarized.

Method	Closed		Open	
Cooling cycle	Closed circulation of cooling means		Cooling means in contact with the atmosphere	
Principle of method	Cold water production		Air humidification +evaporative cooling	
Absorption mean	**Solid**	**Liquid**	**Solid**	**Liquid**
Cooling/absorption mean	water/silica gel NH3/ salt	H2O/ LiBr, NH3/H2O	H2O/ silica gel, H2O/ LiCl, cellulose	H2O/CaCl, H2O/ LiCl
Available techniques	Cooling adsorption machines	Cooling absorption machines	Air-conditioning based on absorption (ABA)	----
Available power (KW)	70-1050 kW	50 kW-5MW (A) 250 Kw-5MW (B)	30-350 kW (per unit)	----
Coefficient of performance COP	0.3 – 0.7	0.6 -0.75 (A) 1.0- 1.20 (B)	0.5-1.0	>1.0
Driving Temperature	60-90 ^{0}C	80-110 ^{0}C (A) 140-160 ^{0}C (B)	45-95 ^{0}C	45-95 ^{0}C
Solar Collector	Vacuum tube, flat plate collector	Vacuum tube, flat plate selective collector	Flat plate collector, air collector	Flat plate collector, air collector

Table 1: Characteristics of solar cooling techniques [11]

A classification is presented based on the type of thermal cycle –either open or closed- and absorption medium. The types of thermal cycles are distinguished to:

- **closed systems:** thermally driven chillers that provide chilled water, which is either used in air handling units to supply conditioned air or that is distributed via a chilled water network to the designated rooms to operate decentralized room installations. These systems usually use cooling towers or similar equipment to reject heat. The market available machines for this purpose are the absorption chillers.
- **open systems:** they allow complete air conditioning by supplying cooled and dehumidified air according to the comfort conditions. The "refrigerant" is always water, since it is in direct contact with the atmosphere. Most common systems are desiccant cooling systems using a rotating dehumidification wheel with solid sorbent.

The greatest exploitation of solar cooling potential is achieved in buildings with high thermal gains during the day and consequently high cooling load. The efficiency of the solar air conditioning installation depends on the type of used solar collectors (flat collectors or vacuum tubes or vacuum collectors), the size of solar field, the cooling load (type of building and use, local climatic conditions) as well as the used cooling and air-conditioning technique. Most collectors used in solar cooling systems are the high efficiency collectors available in the market today (usually double-glazed flat plate collectors or evacuated tube collectors).So as to achieve energy savings, solar cooling installations should achieve a minimum cover of about 20% of the load (in absorption and open air cycle cooling based on absorption) and of about 30% (in absorption cooling) [11].

It should also be mentioned that a key figure to characterize the energy performance of a cooling machine is the **C**oefficient **o**f **P**erformance (COP). For thermally driven air- conditioning systems, the $COP_{thermal}$, is the ration of the thermal cooling output and the driving heat input, and is defined as follows: $COP_{thermal} = Q_{cold} / Q_{heat,}$ Q_{cold} is the heat flux extracted at a low temperature and Q_{heat} is the driving heat flux supplied to cooling equipment. For an electrically driven vapour compression chiller, the COP_{conv} is defined as the required input for production of cooling energy: $COP_{conv} = Q_{cold} /Q_{electric}$. The COP values of conventional chillers and thermally driven cooling machines cannot be directly compared since the quality of the energy input is different.

3. Exergy Analysis

Exergy is a concept that shows the quality of energy and matter, in addition to what has been consumed in the course of energy transfer or conversion steps. The concept of 'exergy' provides us with further understanding of 'how a system works' by pinpointing the subsystems where energy is degraded. Understanding exergy consumption principles will lead will lead to a better understanding of resource and environment issues. The exergy analysis can indicate the locations and causes of inefficiency in a process or system accurately. For instance, in the case of electricity generation in a thermal power plant, exergy losses are associated primarily with internal combustion and heat transfer components. For this reason, in order to improve the efficiency, more consideration should be paid on the improvement of those processes. If only the energy analysis is applied, heat rejected by condensers accounts for the major energy losses [12].

A low- exergy heating or cooling system was defined by IEA Annex 37 [13] as a system that allows the use of low- valued energy as a source. For instance, hot or cold supply temperatures in a forced air system that allows the use of low-valued energy as forced air system should be as close as possible to the desired room temperature. In addition, the first and second thermodynamic laws have been applied to the analysis of absorption systems for heating and cooling [14]. A packaged single-zone air-conditioning unit with a dehumidifier was analyzed, and found that its exergy efficiency was 1.8- 6.3% [15]. Furthermore an experimental open-cycle desiccant cooling system was analyzed and it was shown that the desiccant wheel has the greatest percentage of total exergy destruction followed by the heating system [16]. In addition, the first and second thermodynamic laws have been applied to the analysis of absorption systems for heating and cooling. The exergy performance of a district heating system was analyzed and it was found that if the heating is provided by renewable energy sources or waste energy instead of using electric boiler or heaters, the fossil fuel consumption and emissions can be reduced significantly [17].

As a fundamental measure of the thermodynamic deviation of a considered system from its environment, exergy is equal to the maximum amount of work the system can perform when brought into thermodynamic equilibrium with its reference environment. From the thermodynamic point of view exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Unlike energy, exergy is not subject to a conservation law with the exception of ideal or reversible processes. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process. The total exergy coming into a system, due to heat and mass flow is given from the following equation:

$$X_{in} = \sum m_i\, x_i - \sum Q\, (1 - T_0/T)_i + \sum W \qquad (1)$$

The entropy production at a process where the temperature of the environment is T_0 results to the destruction of exergy:

$$\sum X_{lost} = \sum T_0\, S_{gen} = T_o\, [(m(s_2 - s_1) - Q/T)]\ (kW) \qquad (2)$$, where

s is the entropy (kJ/Kg K), h is the enthalpy (kJ/ KG)

The exergy balance for a system is given by the following equation:

$$\sum X_{in} = \sum X_{lost} + \sum X_{out}\ (kW) \qquad (3)$$

The exergy efficiency of the system is given by the following equation:

$$n = \sum X_{out} / \sum X_{in} = 1 - \sum X_{lost} / \sum X_{in} \qquad (4)$$

A typical water- lithium bromide absorption refrigeration system is illustrated in Figure 2 [18].

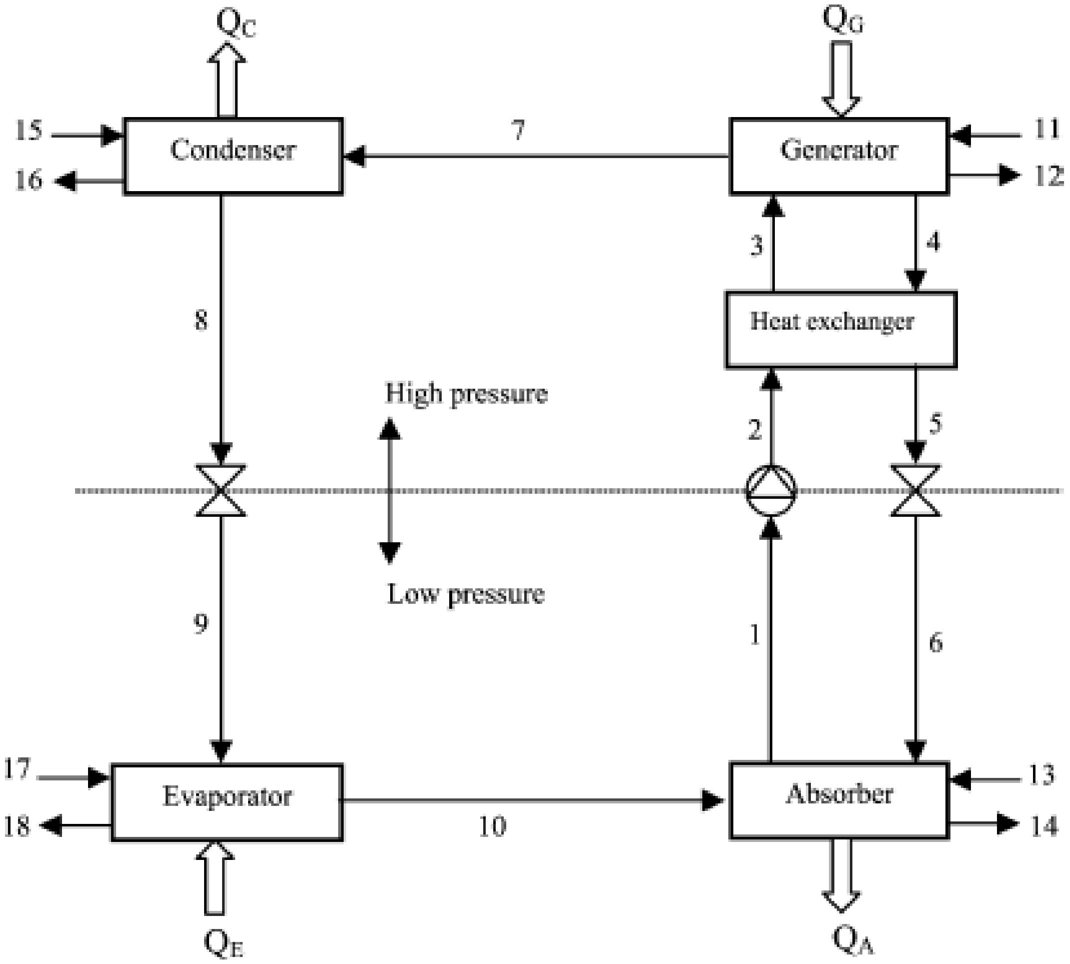

Figure 2: Schematic diagram of the water-lithium bromide solar thermal system [18]

The system includes a generator, absorber, evaporator, pump, expansion valves, solution heat exchanger and refrigerant heat exchanger. Mass balance equations for components of the absorber chiller can be written as follows:

$m_1 = m_2 = m_3$

$m_4 = m_5 = m_6$

$m_7 = m_8 = m_9 = m_{10}$

$m_{11} = m_{12}$

$m_{13} = m_{14} = m_{15} = m_{16}$

$m_{17} = m_{18}$

Based on the following assumptions, the energy equilibrium equation is calculated (eq.5): the system is considered to operate at a steady state, the work coming from the solution pump is negligible and the heat losses to the environment are also negligible.

$$Q_C + Q_A = Q_G + Q_E \quad (5),\quad \text{where}$$

Q_G = input generator heat coming from the hot water
Q_C = waste condensation heat
Q_E = evaporation input heat
Q_A = waste absorption heat

Based on Fig. 2 the following equations are calculated:

$Q_G = m_4 h_4 + m_7 h_7 - m_3 h_3 = m_{11} (h_{11} - h_{12})$
$Q_C = m_7 h_7 - m_8 h_8 = m_{15} (h_{16} - h_{15})$
$Q_E = m_{10} h_{10} - m_9 h_9 = m_{17} (h_{17} - h_{18})$
$Q_A = m_{10} h_{10} + m_6 h_6 - m_1 h_1 = m_{13} (h_{14} - h_{13})$

Based on equations (1) and (2) the incoming exergy X_{in} as well as the destroyed exergy X_{lost} are calculated, for each part of the solar absorber chiller, as follows:

- ***Generator***

$X_{in,G} = m_3 x_3 + m_{11} x_{11} - Q_G (1 - T_O / T_G)$
where $x_i = (h_i - h_o) - T_O (s_i - s_O)$
$X_{lost,G} = To (m_4 s_4 + m_7 s_7 - m_3 s_3 + m_{11} s_{12} - m_{11} s_{11} - Q_G / T_G)$

- ***Condenser***

$X_{in,c} = m_7 x_7 + m_{15} x_{15} - m_{15} x_{16} + Q_C (1 - T_O / T_C)$
$X_{lost,C} = To (m_{15} s_{16} - m_{15} s_{15} - m_7 s_7 + Q_C / T_C)$

- ***Expansion Valve***

$X_{in,EXV} = m_8 x_8$
$X_{lost,EXV} = To (m_9 s_9 - m_8 s_8)$

- ***Evaporator***

$X_{in,E} = m_9 x_9 + m_{17} x_{17} - Q_E (1 - T_O / T_E)$
$X_{lost,E} = To (m_9 s_{10} - m_9 s_9 + m_{17} s_{18} - m_{17} s_{17} - Q_E / T_E)$

- ***Absorber***

$X_{in,A} = m_{10} x_{10} + m_6 x_6 + m_{13} x_{13} + Q_A (1 - T_O / T_A)$
$X_{lost,A} = To (m_1 s_1 + m_{13} s_{14} - m_{10} s_{10} - m_6 s_6 - m_{13} s_{13} + Q_A / T_A)$

- ***Pump***

The power of the solution pump is small; thereby the exergy transformation is negligible.

- ***Solution heat exchanger***

$X_{in,SHE} = m_2 x_2 + m_4 x_4$
$X_{lost,SHE} = To (m_3 s_3 + m_5 s_5 - m_4 s_4 - m_2 s_2)$

The total exergy input into the absorption refrigeration cycle equals to the sum of exergy inputs in each component, therefore:

$$X_{in,total} = X_{in,G} + X_{in,c} + X_{in,EXV} + X_{in,E} + X_{in,A} + X_{in,SHE} \quad (6)$$

The total exergy output of the absorption refrigeration cycle equals to the sum of exergy outputs in each component, therefore:

$$X_{lost,total} = X_{lost,G} + X_{lost,c} + X_{lost,EXV} + X_{lost,E} + X_{lost,A} + X_{lost,SHE} \quad (7)$$

In this paper the exergy analysis for each one of the components of the solar thermal system is based on the following conditions: ambient temperature of $T_0 = 25$ ℃, heat exchanger efficiency $\varepsilon = 0.5$, temperature of cold water $T_{17} = 16$ °C, temperature of cold water $T_{18} = 10$ °C, temperature of hot water $T_{11} = 100$ °C, mass rate of flow $m_7 = 0{,}005$ kg/s.Using theses parameters a computer simulation calculates the thermodynamic properties (T, X, m, h, s) of each state point of the cycle, heat transfer rates of components, pump work rate and performance parameters of the system under study are calculated.

Calculation results are presented in Fig. 3 and Fig. 4-5 [18]. The analysis shows how exergy is consumed in the course of energy conversion and heat transfer processes. It is concluded that exergy destructions occur significantly in generator and in absorber.

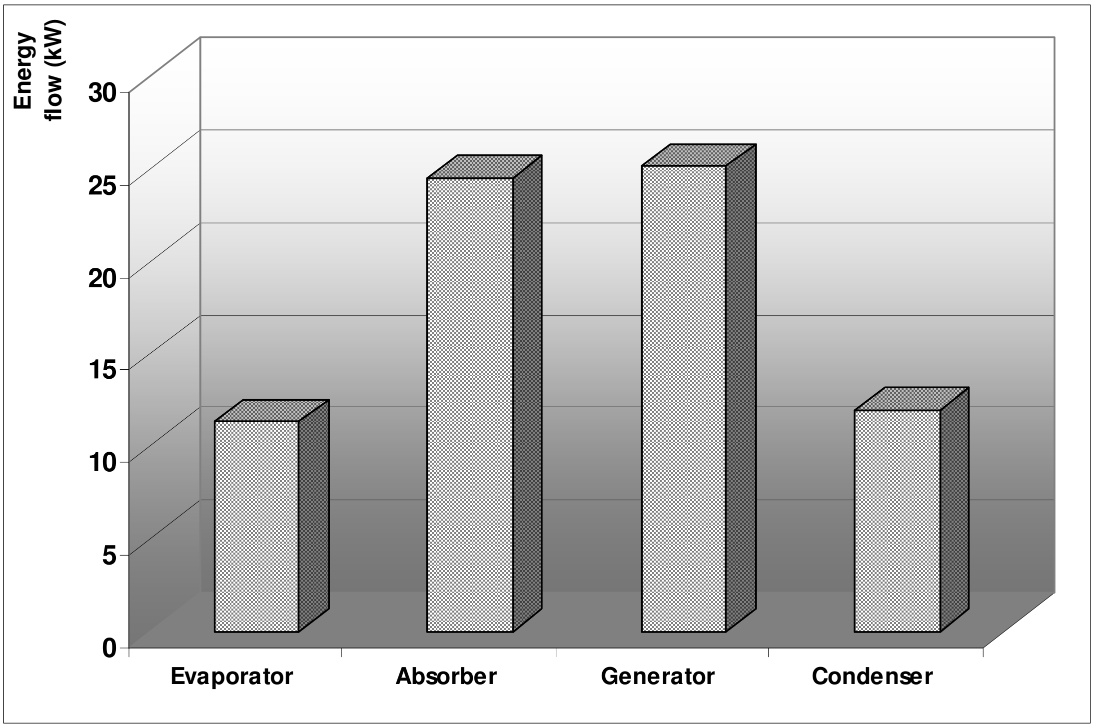

Figure 3: Energy flow at different solar thermal system's components [18]

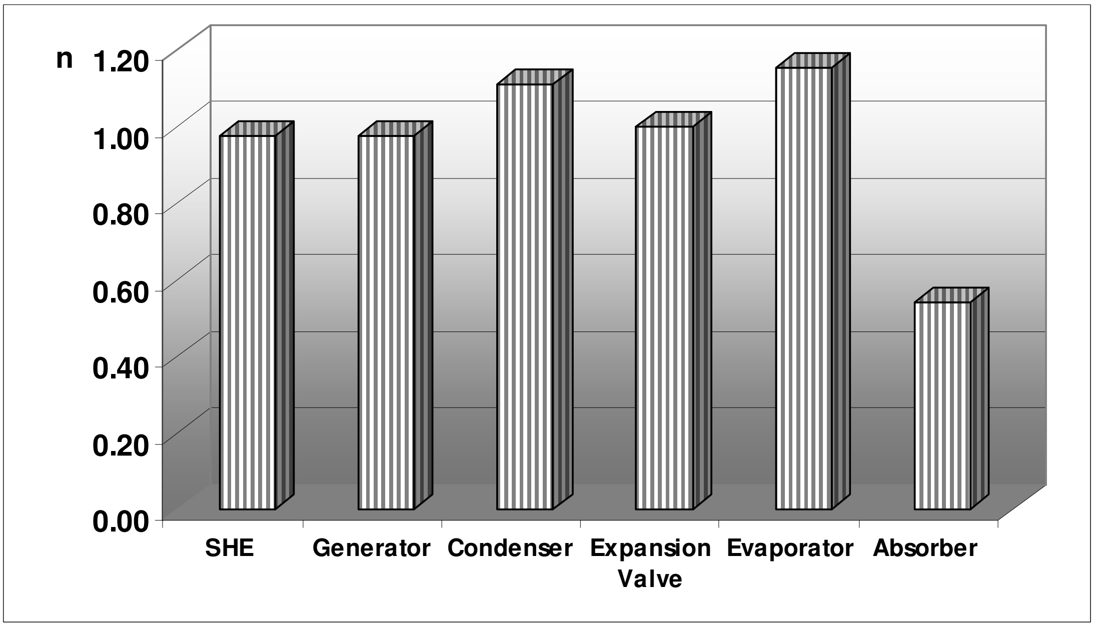

Figure 4: Exergy efficiency of the different solar thermal system's components [18]

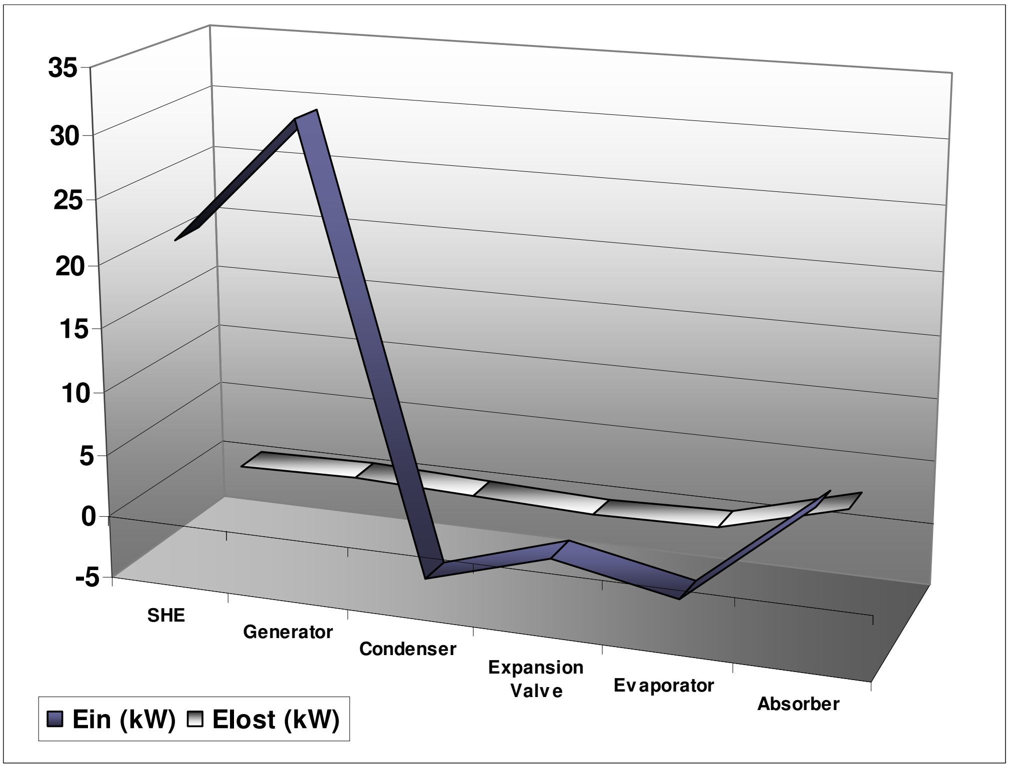

Figure 5: Exergy inputs and exergy losses at different solar thermal system's components [18]

It is obvious that the condenser and evaporator heat loads and exergy losses are less than those of the generator and absorber. This is due to the heat of mixing in the solution, which is not present in pure fluids. The irreversibilities of the system reduce not only the coefficient of performance (COP), but also the system's exergetic efficiency. This is due to the incomplete mass and heat transfer within the system's components, as well as to the mixture of losses and their recycling.

The results show that the cooling and heating COP of the system increase slightly when increasing the heat source temperature. However, the exergetic efficiency of the system decreases when increasing the heat source temperature for both cooling and heating applications, due to increased irreversibilities.

4. Application of Solar Air- Conditioning System in Greece

A medical center located near Igoumenitsa, a city in north-western Greece is used as a case study for a solar driven air-conditioning system. The medical center has units for the treatment of patients, offices, labs and auxiliary spaces. The building was designed in 1984 and consists of a ground floor area of 1,240m^2 and height of 3.60 m and a basement area of 600 m^2 and height of 2.8 m. The structural components of the building consist of:

- double casing external walls with insulation 4cm, K= 0.55 kcal/ m$^{2\,0}$C
- internal walls : 10cm, K= 1.5 kcal/ m$^{2\,0}$C
- insulated roof, K= 0,47 kcal/ m$^{2\,0}$C
- marble insulated floor 5cm, K= 0.52kcal/ m$^{2\,0}$C
- aluminum window frames, K= 0.52kcal/ m$^{2\,0}$C
- sunlight protection of the building consisting of open-colored walls and internal curtain

As far as the climate conditions of the region are concerned it is noticed that the average rainfall in Igoumenitsa is around 1,100 mm. In 2006, the town had 124.2 rainy days, the period from May to September had 23,3 rainy days. The average relative humidity in 2006 was about 70% with a minimum value during the months of July- August, in the order of 60%. The prevailing wind direction is southeast and for short periods northwest. The last 25 years, the lowest temperature was -9°C and the highest was 43°C. Igumenitsa area has total annual sunshine radiation of 1697 kWh/ m^2 at a 30^0 surface. The highest monthly value of 206 kWh/ m^2 was observed in August.

The building is provided with central heating with a steel 120,000 Kcal/ h powered boiler. A system of two pipes feeds the FCU units that are lying in the ground. The auxiliary rooms (storehouses and archive room) are not heated. As the building needs for hot water are small, an electric-powered water heater of 80lt is used. Despite the fact that a FCU heating system is available, a central cooling system was never installed. During the last years and in conjunction with the change to the climate conditions split units were installed. For this reason spaces such as the waiting room, corridors, kitchen, storehouses as well as toilets are not being cooled. Totally, 35 units of total power 288,000Btu/h (1x 18,000 Btu/h, 26x 9,000 Btu/h, 3x12,000 Btu/h) suitable for 30 spaces were installed.

The calculation of the building's cooling loads took into consideration the following:

- internal temperature 26 ^{0}C
- internal humid 50%
- climatic data for the city of Igoumenitsa
- calculation method : Carrier
- checking times: 08:00 – 18:00
- reporting months: 5 (May- September)

It should be noticed that in order to make a comparative data assessment the calculations of the cooling loads were performed only for the spaces that are already cooled. The calculation of the cooling loads was performed using the software ADAPT- FCALC of the company 4M [19]. Figure 6, presents the calculated cooling loads for the month of July 2006.

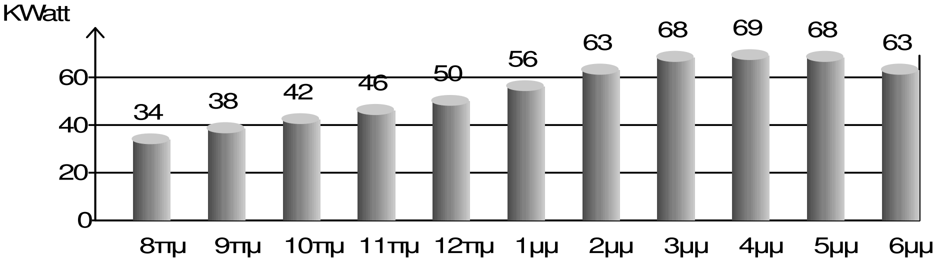

Figure 6: Cooling loads of the building as they were calculated on 23th of July 2006

The solar thermal system used in this building consists of a water lithium bromide absorption chiller (consisting of an evaporator, a compressor, a condenser and a valve), a cooling tower refrigeration, a solar field collector, a hot-cold water storage tank, piping and fittings, a control system as well as a backup system. The collectors are placed at the roof in series. A typical distance of the series is 1.5 times bigger than the height of the collector [20]. In many cases of solar thermal cooling hot- cold water storage tank of 50-100 lt/m^2 is used [21]. Dimensioning of the system was based on the following:

- ***Chiller***
  - In order to cover the calculated cooling needs of 69KW of the medical center a solar chiller of Yazaki type WFC-20 was selected [22]

  - Cooling capacity: 20RT (70kW, 240,000Btu/h)
  - COP: 0.7
  - Temperature of water: 9° C
  - Temperature of water at the generator: 75 - 100° C
  - Nominal operating temperature :88° C
  - Temperature of water at the condenser: 29.5° C
- ***Cooling tower***
  - Capacity : 70kW
  - With respect to the heat transfer mechanism employed, the wet type (open) of cooling tower was selected
  - Rate of air flow: 130-170 m^3/h per kW of cooling capacity
  - Electrical consumption: 6-10 W per kW of cooling capacity for axial fans and 10-20 W per kW of cooling load for radial fans.
- ***Solar thermal collector field***
  - Type of collector: Flat Plate Collector
  - Collector's azimuth: 0°
  - Collector's slope :30° (Latitude: 39,53°)
  - Average daily radiation for the month of July 2006: H=7 $kWh/m^2/d$ for a slope of 30°
  - Average daily collector's performance : n=0.5

The performance of a solar thermal collector is given as follows:

$$n=Q_U/A_c{}^*H \qquad (8)$$

(Q_U = collector's useful solar energy, Ac = collector's area)

For the dimensioning of the solar collector system, a daily energy cooling demand of Q_{th}=560 kWh/d and o peak load of 70k W were taken into consideration. Thereby, the collector's area is deduced from the following equations :

$$COP= Q_{th}/Q_U \Rightarrow Q_U= 560 / 0.7 \Rightarrow Q_U = 800\ kWh/d \qquad (9)$$

From (1) and (2): $A_c= Q_U / n^*H \Rightarrow A_c= 800 / 0,5^*7 \Rightarrow A_c= 230\ m^2$

- ***Hot water storage tank***

  Dimensioning of the hot water storage tank is made for 50lt/ m^2 of collective area. Therefore, the needed volume is: V=50 * 230=11,500lt. The hot water storage tank with the following dimensions : H=2.0m , W=2.5m , L=2.3m can be placed at the basement, as the height of the basement is 2.80m.

5. Economic Evaluation and Energy and Environmental Benefits

Solar air- conditioning systems have the main purpose of replacing fossil fuel based systems so as to attain a primary energy saving, in terms of economic vitality. In this context, the resource to solar energy for air-conditioning represents a suitable choice not only to reduce the final energy consumption but also to significantly reduce greenhouse gases. Especially in the case of Mediterranean climates, which are characterized by high cooling demand during the summer solar air conditioning can play a crucial role in the promotion of sustainability. For this reason the under study solar air conditioning system is evaluated not only economically but also environmentally both for the winter and summer period.

Winter Period

For a solar field collector of 230 m^2 with an average efficiency of n= 0.5 the useful thermal load during the winter period, based both on the climatic data of the region and equ.10 is presented in Table 2.

$$n= Q_U /A_c*H \qquad (10)$$

Month	H (kWh/m^2)	Q_U (kWh)
November	82	9,430
December	61	7,015
January	68	7,280
February	81	9,315
March	125	14,375
Total	**417**	**47,955**

H = monthly solar radiation in a surface of 30°

Table 2: Useful thermal load coming from solar collectors during the winter period of 2006

During the winter period of 2005/2006 the building's oil consumption came up to 13,850lt costing 8,310€. Based on equ.11 this result to 137,026 kWh.

$$E = V * Hu * \rho \qquad (11)$$

(V=volume of consumed oil in lt, Hu=11, 92 kWh/kg lower calorific value of oil, ρ=0, 83 kg/lt specific oil weight)

Thus the solar collectors fields can cover the energy needs of the building at a percentage of: (47,955/137,026) * 100% = 35%. Based on the aforementioned it is obvious that 47,955 kWh of heating and 8,310 *0.35= 2,908€ are saved with the use of solar collectors.

Summer Period

Based on the data, which are presented in Table 3 and concern the electricity consumption as well as the energy costs [23], it is assumed an average energy consumption of 4100kWh for air conditioning. If these needs are covered with solar thermal energy, then a reduction of 15,560 kWh and of 1500.54 € per year can be achieved (Table 4).

Month	kWh	Price (€)	Month	kWh	Price (€)
January	5,640	533.09	**July**	10,200	999.60
February	4,760	449.84	**August**	8,950	859.20
March	3,960	374.84	**September**	5,050	494.90
April	4,080	385.94	**October**	4,500	441.00
May	4,120	390.15	**November**	6,160	607.68
June	7,760	729.44	**December**	7,360	725.54

Table 3: Annual electricity consumption and energy costs [23]

Month	Total KWh	Cooling kWh	Total Price(€)	Cooling Price (€)
June	7,760	3,660	729.44	344.04
July	10,200	6,100	999.60	597.80
August	8,950	4,850	859.20	465.60
September	5,050	950	494.90	93.10
Total	**31,960**	**15.560**	**3,083.14**	**1,500.54**

Table 4: Comparison of total electrical energy consumption and cooling consumption for the summer period of 2006

Furthermore, an environmental analysis was performed on the basis of the energy savings achieved by replacing conventional energy systems with a solar installation and the resulted reduction of pollutant emissions was calculated. The economic results of the comparison between the use of a solar installation in the medical center compared to the use of a conventional are presented in Table 5 .The energy savings are associated with a reduction of pollutant emissions, which are quantified in Table 6.

Conventional System		
Type of Energy	**Units**	**System**
Electrical energy for cooling	kWh	15,560
Price	€	1,500.54
Oil used for heating	lt (kg)	13,850 (11,495)
Price of oil	€	8,310
Solar System		
Electrical energy for cooling*	kWh	177.00
Price	€	16.85
Oil used for heating	lt (kg)	9,002 (7,472)
Price of oil	€	5,401

* The estimation of electrical consumption of the solar system was based on the following:
Installed cooling capacity: 288,000 Btu/h (84 kW)
Total hours of cooling: 15,560 / 84 = 185 h
Electrical consumption of chiller: 185*0.26 = 48 kWh
Electrical consumption of cooling tower 185*(10W*70) = 129. 5 kWh

Table 5: Overall economic evaluation both of conventional and solar systems

Gas Emissions							
Type of energy	**Quantity kg, MWh**	**CO_2**	**SO_2**	**CO**	**NO_x**	**Particles**	**Units**
Oil	1	3,142	0.7	0.572	0.191	0.286	g/kg
Electric	1	850	15.5	0.18	0.05	0.8	kg/MWh
Conventional System		**A. Overall emissions of conventional system**					
Oil	11,495	36,117	8.04	6.57	2.19	3.28	kg/year
Electric (cooling)	15.56	13,226	241.18	2.80	0.77	12.45	kg/year
Solar System		**B. Overall emissions of solar system**					
Oil	7,472	23,477	5.23	4.27	1.42	2.136	kg/year
Electric (cooling)	0.177	150	2.74	0.03	0.008	0.14	kg/year

Table 6: Overall environmental evaluation both of conventional and solar systems

Based on the economic data within the project ALTENER [24] it is deduced that the investment cost of a solar thermal system – as the one described in this study having a capacity of 70 kW, AB absorption technology and a collector area of 291m^2 - comes up to 600€/m^2. It should be mentioned that the cost of distribution is not calculated, as it is the same with the cost of a conventional system. The payback time of such a system as well as the cost of a solar thermal system are summarized in Table 7.

Price of energy saving per year	4,409 €
Cost of solar thermal system	138,000 €
Difference between cost of solar system – conventional system	107,640 €
Payback time	24 years
Payback time having a 50% subsidy	12 years

Table 7: Estimation of the cost of a solar thermal system and its payback time

6. Conclusions

The use of conventional cooling equipment has introduced several drawbacks such as frequent peak electric loads, increase of electrical energy consumption and environmental problems resulting from the use of refrigerants and the increase of installed electric power generation. As the rate of air-conditioned demand is expected to grow, the exploitation of solar energy, especially in South European countries, like Greece, during the hot season, seems to be a valuable option to mitigate the consumption of conventional fuels due to the cooling requirements. Solar air conditioning systems can be a reasonable alternative to conventional air-conditioning systems. No long- term intermediate storage is necessary. The sun can provide a substantial part of the energy needed for air-conditioning. This can help to reduce primary energy consumption.

The most common technology of solar thermal cooling is absorption chiller. The configurations considered are: single and double-effect cycles using water/LiBr as working pair and the advanced cycles using ammonia/water as working fluid. Each of systems is coupled with the more suitable low to medium temperature solar field to supply thermal energy. In the case study of the medical center in Igoumenitsa, the technology of a single-effect cycle water lithium bromide absorption chiller was considered. The solar in Greece constitutes an important application field of the use of solar thermal energy, because the sunshine of the region is at very high levels.

The thermodynamically analysis of solar thermal systems with the method of exergy allows the identification of the components where exergy is destructed; the minimization of the system's exergy losses will lead to the optimization of the coefficient of the system's performance (COP).

It is vital that such an innovative cooling method be viable from an economic point of view; nevertheless the technical effort in the implementation of a solar thermal air conditioning system is higher compared to the implementation of a conventional system. This results from the complete additional solar thermal installation on the one hand, and from increased requirements on the re-cooling installations, since the thermally driven chillers usually need higher amounts of heat to be re-cooled. Additionally, some of the components costs are still high. In general, the annual cost, i.e., the complete cost including investment, operation and maintenance costs of a solar thermal system are currently above the annual cost of a conventional system using an electric vapour compression chiller [24]. In the examined case study of the medical center in Igoumenitsa for the cooling production of 70kW the cost of the solar thermal system comes up to 138,000 €, having a difference of 107,640 € compared to the cost of a conventional system. The payback time of the solar thermal system is 24 years. However, economic motives through national and European programs with subsidies reaching 40-50% can reduce the long payback time to the half.

As it was realized by the examined case study in the present work, the use of thermal solar systems in the medical center of Igoumenitsa can create environmental profits as a significant reduction of pollutants emissions is noticed. What is more, the use of solar thermal systems is expected to reduce the peak electricity load, especially during summer. Solar cooling can decrease the electricity peak loads during summertime, thus resulting to important savings and remarkable environmental benefits.

Given that Greece, has been committed, according to the objective that has been placed by the Community Directive 2001/77/EC to increase the rate of production of energy from renewable energy sources to 20% the use of solar thermal systems is of great interest. However, a strategy including information dissemination regarding the new energy technologies as well as the existing effective financing mechanisms should be realized, in order to promote their application. In conclusion, the results presented in this study constitute a preliminary step towards the assessment of applicability of solar thermal cooling technologies in Greece; nevertheless for an extensive analysis, other aspects such as level of commercial maturity, economic potential, and presence of technological barriers and so on, must be deeply investigated.

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