Exergy Analysis of Solar Air-Conditioning Systems and their Applicability

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Strategies for a Low Carbon Built Environment

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The exergy concept

Exergy is defined as the property of the system, which gives the maximum power when it is brought to a thermodynamic equilibrium state. It is the maximum available energy.

Ex = ?H - T ?S

Exergy Analysis & Solar Cooling Systems: Analysis and Design of Innovative Systems in the Built Environment. A low- exergy heating or cooling system was defined by IEA Annex 37 as a system that allows the use of low valued energy as a source. The greatest exploitation of solar cooling potential is achieved in buildings with high thermal gains during the day and consequently high cooling load .

Cooling energy consumption

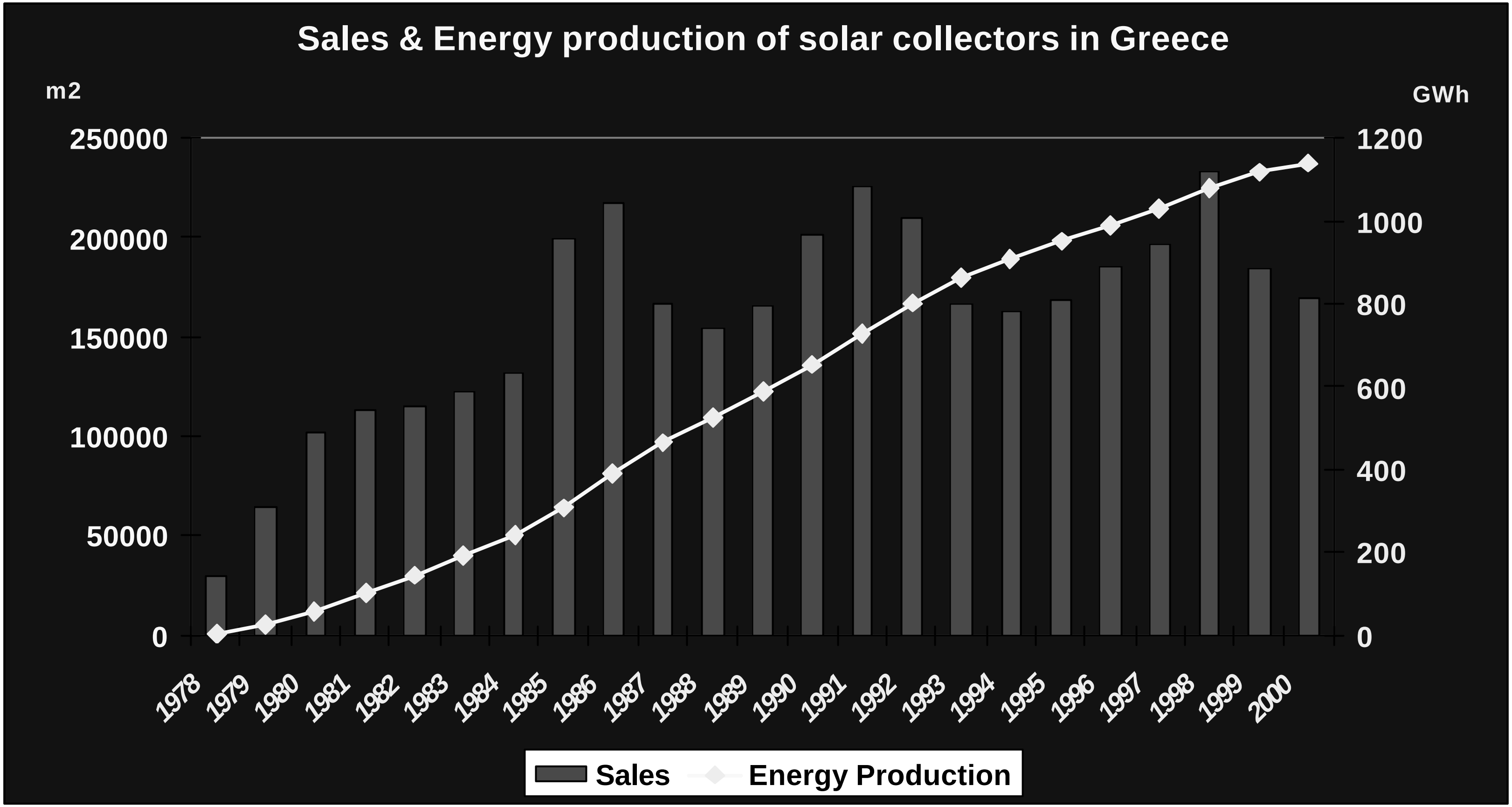
- During the last few decades energy consumption for cooling has increased dramatically in most European countries

- During the summer months the demand for electricity in Greece increases (extensive use of heating ventilation and air conditioning systems →increases 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 to heating of domestic hot water, and in limited applications for space heating and fewer for cooling.

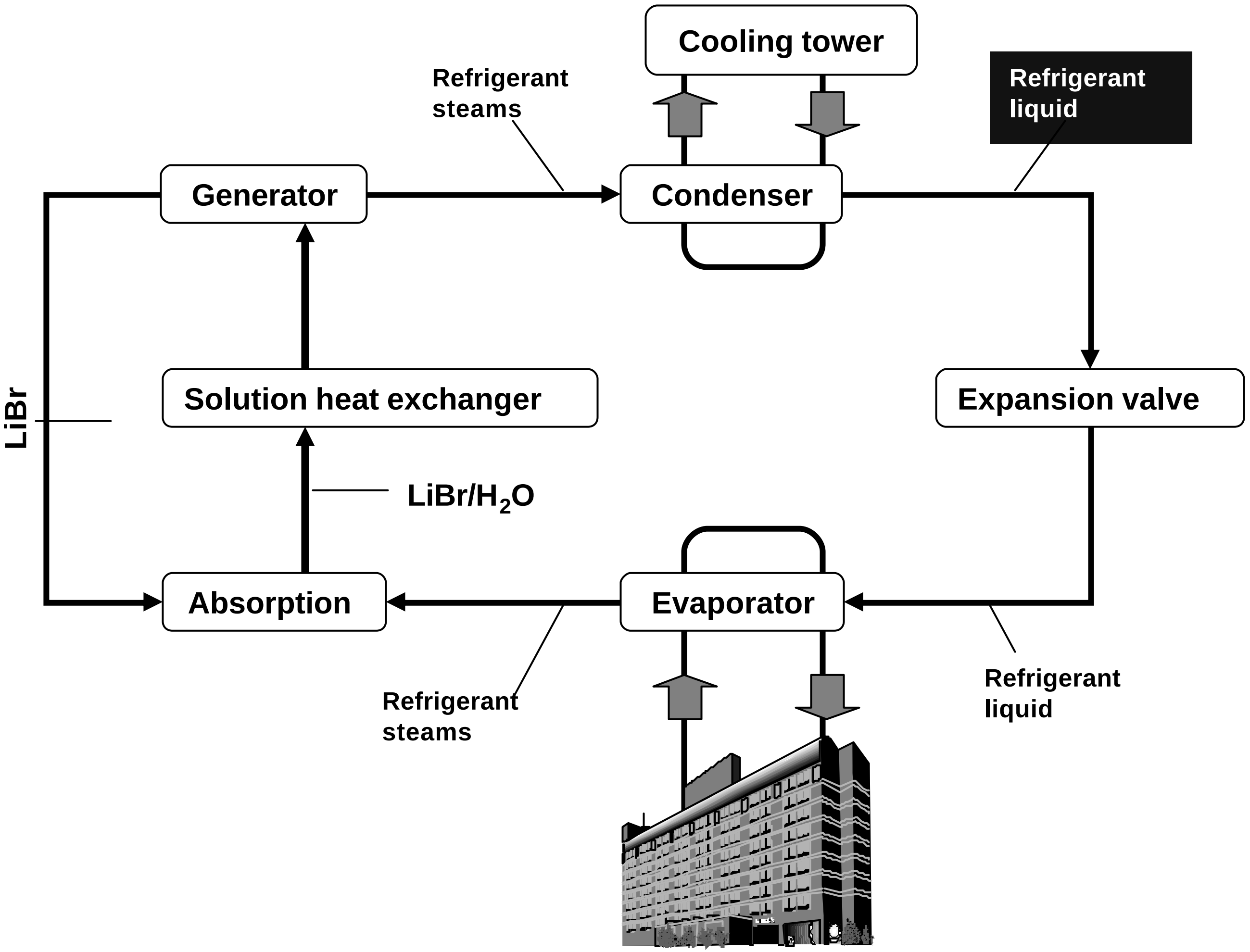
- It has been estimated that the total electric energy consumption in Greece, in 2003, for central air conditioning systems was 2909 GWh/y , whereas the per capita consumption of electricity was estimated at 371 KWh/ y

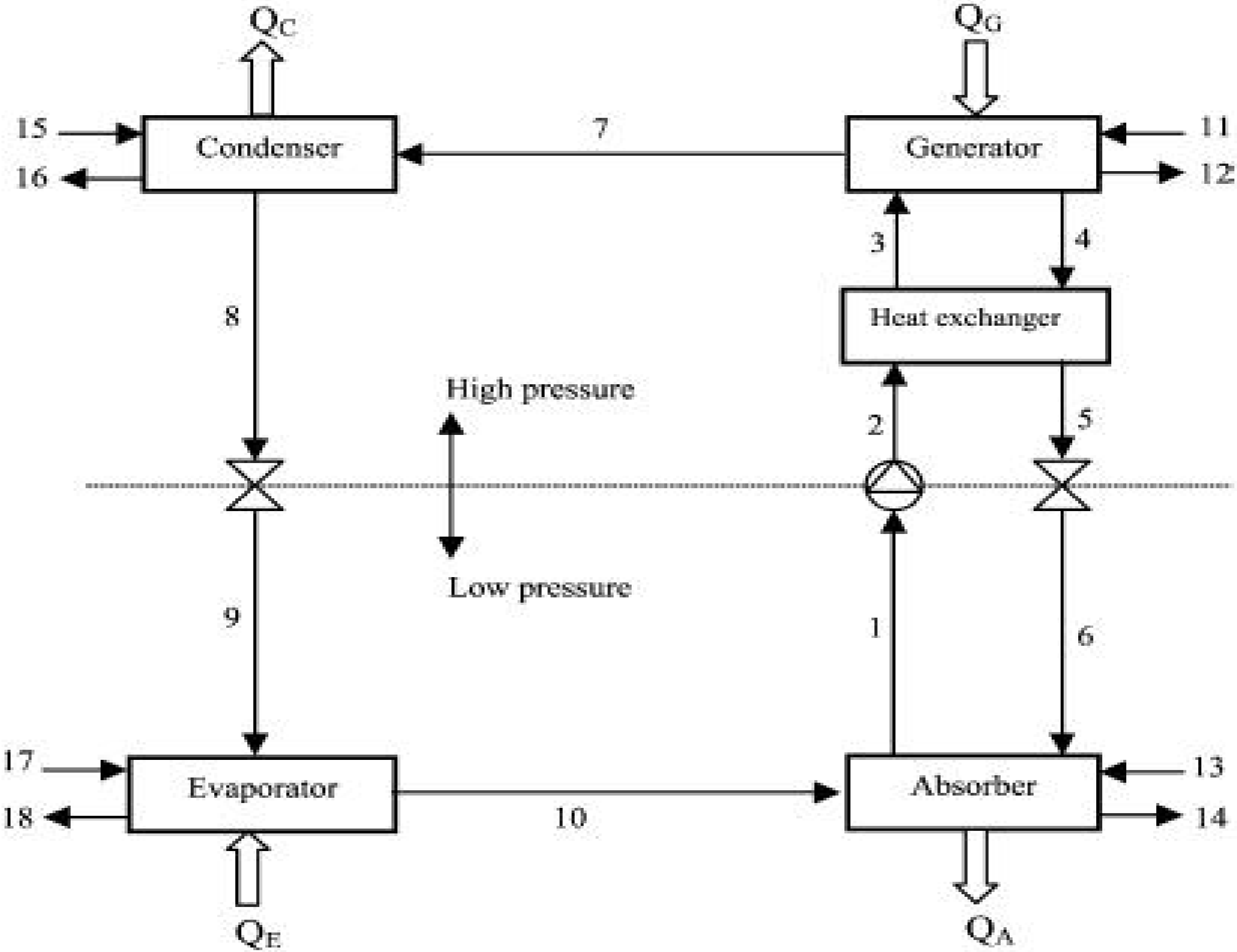
Solar Collectors in Greece



95% of the collector area installed up today : households
264 m^2/ 1,000 inhabitants

Solar Cooling System




QC
QG
15
16
Condenser
7
Generator
11
12
3
4
8
Heat exchanger
High pressure
2
5
Low pressure
9
1
6
17
18
Evaporator
10
Absorber
13
14
QE
QA

Exergy Analysis

Exergy balance of the system ? Xin = ? Xlost +? Xout (kW)

Exergy efficiency of the system

n = ? Xout / ? Xin = 1 – ? Xlost / ? Xin

Total exergy input into the absorption refrigeration cycle, in each component:

$X_{in,total} = X_{in,g} + X_{in,c} + X_{in,exv} + X_{in,e} + X_{in,a} + X_{in,she}$

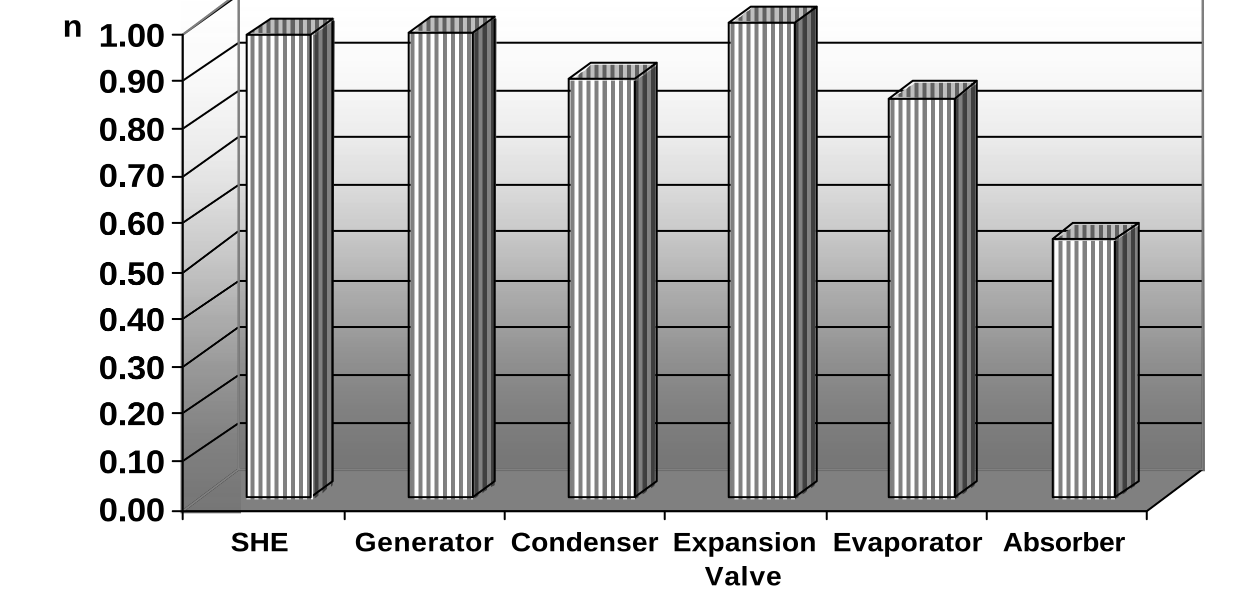
Total exergy output of the absorption refrigeration cycle :

$X_{lost,total} = X_{lost,g} + X_{lost,c} + X_{lost,exv} + X_{lost,e} + X_{lost,a} + X_{lost,she}$

g=Generator,c=Condenser, exv=Expansion Valve, e=Evaporator, a=Absorber, she=Solution Heat Exchanger

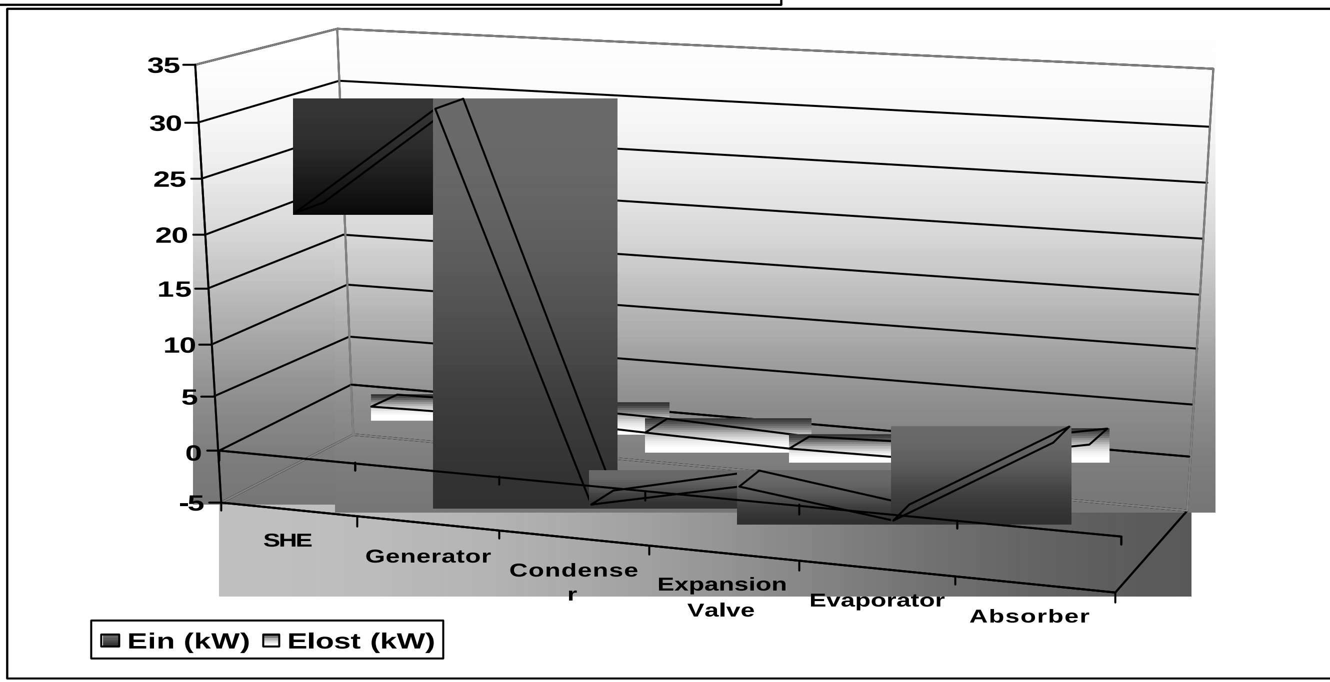
Exergy Analysis

The conditions used are the following:
Ambient temperature of ?0 = 25 ° C,
Heat exchanger efficiency e= 0.5,
Temperature of cold water ?17 = 16 ?C,
Temperature of cold water ?18 = 10 ?C,
Temperature of hot water ?11 = 100 ?C,
Mass rate of flow m7 = 0,005 kg/s



Exergy efficiency of the different solar thermal system's components

xergy inputs and xergy losses at ifferent solar thermal ystem's components



Application of solar cooling system in Greece: the case study of Igoumenitsa

A medical center located near Igoumenitsa - a city in north-western Greece with average rainfall of 1,100mm/ year- having 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 600m^2 and height of 2.8 m.

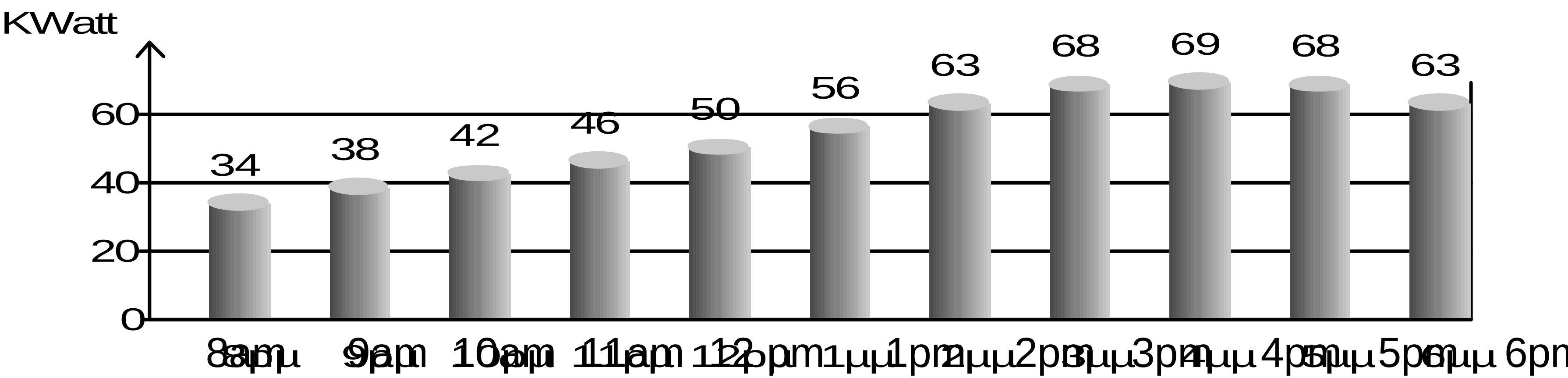
The structural components of the building consist of:

- 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

Cooling Loads

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

- internal temperature 26 ^{o}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)



Cooling loads of July 2006

Dimensioning of the System

Chiller (Yazaki type WFC-20)

- Cooling capacity: 20RT (70kW, 240,000Btu/h)
- COP: 0.7
- Temperature of water: 9 ^{0}C
- Temperature of water at the generator: 75 - 100^{0}C
- Nominal operating temperature :88^{0}C
- Temperature of water at the condenser: 29.5 ^{0}C

Cooling tower (wet type)

- Capacity : 70kW
- Rate of air flow: 130-170 m3/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 (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/m2 /d for a slope of 30^0
- Average daily collector's performance : n=0.5
- Ac= QU / n*? ⇨ Ac= 800 / 0,5*7 ⇨ Ac= 230 m2

Hot water storage tank

- 50lt/ m2 of collective area.
- V=50 * 230=11,500lt.
- H=2.0m , W=2.5m , L=2.3m

Energy Benefits

Conventional System		
Type of Energy	**Units**	**System**
Electrical energy for cooling	kWh	15,560
Price	€	1,500
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

Environmental Benefits

Gas Emissions							
? ype of energy	Quantity kg, MWh	CO_2	SO_2	CO	NO_x	Particles	Units
Oil	1 Kg	3,142	0.7	0.572	0.191	0.286	g/kg
Electric	1 MWh	850	15.5	0.18	0.05	0.8	kg/MWh
Conventional System	? . 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	? . 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

Solar Cooling System’s Cost Evaluation

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

Conclusions

The use of conventional cooling equipment has introduced several drawbacks such as high electric loads, increase of electrical energy consumption and environmental problems resulting from the use of refrigerants and electricity production.

As the rate of air-conditioned demand is expected to grow, the exploitation of solar energy, especially in South European countries, like Greece, seems to be a valuable option to mitigate the consumption of conventional fuels.

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

Thank you!

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I invite you to the conference:

International Exergy-Life Cycle Assessment and Sustainability Symposium (ELCAS)

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