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Solar cooling technologies in Greece. An economic viability analysis

Theocharis Tsoutsos [a,*], Joanna Anagnostou [b], Colin Pritchard [b], Michalis Karagiorgas [a], Dimosthenis Agoris [a]

[a] *Centre for Renewable Energy Sources, 19th km Marathonos Avenue, GR-190 09 Pikermi, Greece*

[b] *Centre for the Study of Environmental Change and Sustainability, The University of Edinburgh, John Muir Building, The King's Buildings Mayfield Road, Edinburgh EH9 3JK, UK*

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Abstract

In Greece, during the summer, the demand for electricity greatly increases because of the extensive use of air-conditioning systems. This is a source of major problems in the country's electricity supply and contributes to an increase of the CO_2 emissions. The use of solar energy (SE) to drive cooling cycles is attractive since the cooling load is roughly in phase with SE availability. An economic evaluation of two types of solar cooling systems is made (an absorption and an adsorption system). The analyses indicated that, because of their high investment cost, these systems would be marginally competitive with standard cooling systems at present energy prices.

Keywords: Solar cooling; Solar energy economic analysis; Absorption; Adsorption

1. Introduction: cooling demand in Greece

During the summer the demand for electricity greatly increases because of the extensive use of heating ventilation air conditioning (HVAC) systems, which increase the peak electric load, causing major problems in the country's electric supply. The energy shortage is worse during 'dry' years because of the inability of the hydroelectric power stations to function. The total energy demand increases by 3–4% per year, which corresponds to a yearly increase of electric energy

* Corresponding author. Tel.: +30-210-660-3300; fax: +30-210-660-3302.
E-mail address: ttsout@cres.gr (T. Tsoutsos).

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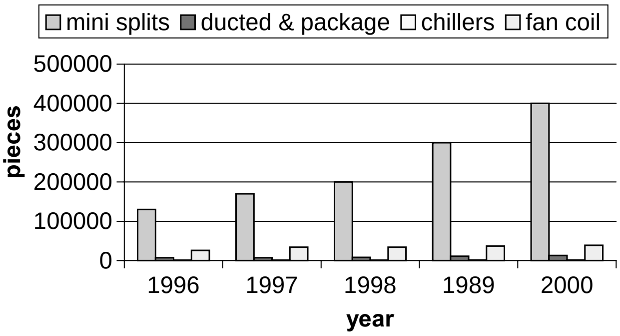

Fig. 1. Sales of HVAC units in Greece.

consumption of around 1000 GW h and implies the installation of a new thermal power generation plant of 300 MW every 18–24 months.

The energy consumed for heating and cooling of domestic premises accounts for just 7% of the country's total energy demand, but is responsible for 29% of the CO_2 emissions. Sales of mini split units tripled during the period 1996/2000 ([1], Fig. 1). In 1970 the CO_2 emissions were 22 million t/y (tonnes/year) whilst by the end of 1990s they have reached 83 million t/y, almost four times higher.

In Greece, ambient temperatures have a direct impact on the pattern of the nation's power demand. Most buildings are cooled by electrically powered, conventional, vapour compression systems [2].

The use of solar energy (SE) to drive cooling cycles for space conditioning of most buildings is an attractive concept, especially in southern European countries, since the cooling load is roughly in phase with SE availability. The cooling requirements of a building are roughly in phase with the solar incidence.

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.

2. Market conditions for solar cooling systems

At present, large-scale fossil—fuel based energy production is cheaper than the available solar alternatives [3]. However, conventional energy generation technologies, based on fossil fuel, have reached maturity leaving little room for further significant cost reduction [4].

Although a large potential market exists for solar cooling technology, existing SCS are not directly competitive with electricity-driven or gas-fired HVAC. Their high investment cost limits the possibilities for widespread application. Lowering the cost of components and improving their performance will change the situation dramatically [5]. Although it is clear what targets should be pursued in order to enable this technology to enter the market, it continues to be difficult to predict the date when these solar technologies will reach maturity.

Today the most common SC technology is based on systems using the thermal collector as thermal energy source [6]. However, in solar thermal cooling, future progress will come mainly from the chiller side, and the potential for development is considered to be large [7].

3. Available technologies for solar air conditioning

Four types of systems can accomplish solar air conditioning (SAC):

- absorption cycles,
- adsorption cycles,
- open-cycle cooling systems and
- solar mechanical processes.

There are many variations within these types: hot or cold side energy storage, continuous or intermittent process, different types of collectors, various operating temperature ranges, different control concepts etc. The integrated solar operate cooling systems are mainly of two types: absorption cooling and adsorption cooling systems.

3.1. Absorption systems

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

Most work in SAC has been based on continuous absorption cycles adapted to operation from solar collectors. One way that has proved to be financially viable when there is a cheap source of heat energy, in the temperature range of 100–200 °C, is absorption cooling. Absorption machines can also be used as retrofits in standard HVAC using chilled water. Liquid and solid ones are two types of absorption systems.

Liquid *absorption systems* use SE from thermal collectors as the driving force. Absorption refrigerators use two working substances, a refrigerant and an absorbent for that refrigerant. A lot of research has focused on the established pairs of water–ammonia (H_2O–NH_3) and lithium bromide–water (LiBr–H_2O) [8,9]. At present the market of sorption refrigeration systems is dominated by LiBr–H_2O systems, which are normally used for AC applications [10].

Second generation LiBr–H_2O absorption cooling systems are solar operated absorption refrigeration units, operating with flat-plate solar collectors that can be assembled on a common frame, having short piping length and able to be installed in restricted spaces. This type of unit is characterised by lower costs of materials and of LiBr, and is therefore considered to be a step forward towards commercial use, especially for rural or desert areas that are remote from the national electricity grids [11].

A numerical simulation of a LiBr absorption cooling system has obtained a daily collector efficiency of about 35% and a daily efficiency of the SE—cooling conversion of about 12% [12].

In the last decade, research has been focusing on solar-driven absorption refrigeration cycles with unconventional fluids, exhibiting improved behaviour. One class is ammonia–salt solutions, such as ammonia–lithium nitrate (NH_3–$LiNO_3$) and ammonia–sodium thiocyanate (NH_3–NaSCN). These systems provide certain advantages such as: lower generator temperatures (which allow operation with simple flat-plate collectors), lower evaporation temperatures in comparison with H_2O/LiBr systems and higher coefficient of performance in comparison with NH_3/H_2O systems [13].

In order to achieve the highest efficiency when converting solar radiation into cooling power, the combination of a mechanical and an absorption chiller has been used, using solar fiber-optic mini dish concentrators. A thermal cascade has been used in which the highest temperature heat is channelled to produce electricity in a gas turbine, and the intermediate-temperature heat rejection of that turbine is exploited to drive an absorption chiller [14,15].

Research has also focused on solid sorption systems, mostly used for solar refrigeration. Usually these use NH_3 as refrigerant and $SrCl_2$ as absorbent [16]. Alternatively, materials that are a mixture of $SrCl_2$ and an inactive, temperature stable material like graphite can be used [17].

3.2. Adsorption systems

Most adsorption chillers work with the silica gel–water system. They consist of two separated chambers which contain the sorption material and which are operated cyclically. Silica gel–water can be used as the adsorbent–refrigerant pair for a two-stage adsorption chiller, which can use unexploited low-temperature solar heat and may offer an attractive possibility for improving energy conservation and efficiency [19].

Their market share is significantly lower than that of absorption chillers. This type of chiller is produced in Japan; however, during the last years some machines have been installed in Europe [20].

An adsorption chiller can have application in the following markets: space cooling of offices, food industry, chemical industry, breweries, agriculture and district heating. The combination of an adsorption chiller with solar collectors offers a technically simple and energy saving solution, especially in Southern European regions such as Greece [21].

4. Economic evaluation of solar cooling systems in Greece

4.1. Economic feasibility of solar energy systems

Despite the fact that the adoption of SE technologies is recognized as a realistic response to the energy and environmental problems that are gaining the concern of the public, evaluations are often unfavourable. There is still a need for subsidy to ensure their effective penetration into the cooling market.

Critical factors that will ensure the spreading of SE systems are technological maturity and economic viability. The latter depends on many factors, including the legislation, the guidelines and the energy policy that are followed. In Greece, the financial framework for SE investments is based on:

- economic incentives for the purchase of solar collectors,
- incentives for investing in SE systems,
- subsidies for investments in oil substitution and energy saving [22,23].

4.2. Economic evaluation

Solar processes are generally characterised 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 installing the equipment, plus the operating expenses. The objective of this study was to determine the primary energy savings and respective costs for different SCS.

Several economic criteria have been proposed for evaluating and optimising SE systems, and there is no universal agreement on which should be used. For the needs of the current study, we used the following criteria:

- payback period,
- net present value (NPV).

The payback period is determined by the equation:

$$\mathrm{PB} = \frac{\log\left[\frac{C}{E}\frac{i}{100} + 1\right]}{\log\left(1 + \frac{i}{100}\right)}$$

where PB: payback period (yr), C: capital cost of installed solar cooling equipment (€), i: energy inflation (the change of energy prices relative to general inflation), E: energy saving (€/yr).

$$\mathrm{NPV} = Y\frac{1}{r-i}\left[1 - \frac{1+i}{1+r}\right]^{l} - C$$

where NPV: net present value (€), Y: yearly benefits (€/yr), r: market discount rate, i: energy inflation, L: life period (yr), C: cost of installed solar cooling equipment (€).

The yearly benefits represent an expression of the annual costs for both solar and non-solar systems to meet energy needs.

$$\text{Yearly benefits} = \text{cost of operation, maintenance and insurance of conventional system} \\ - \text{cost of operation, maintenance and insurance of solar system}$$

(In all investment costs, VAT is not included.)

The installation of equipment involves costs for labour, foundations, supports, construction expenses and other factors directly related to the erection of purchased equipment [24].

Energy savings: 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—costs of SE.

4.3. Methodology—Assumptions

4.3.1. Technological details-assumptions

Building: All calculations refer to an office building with a total volume of 5594 m^3.

For the sensible heat and moisture gains from the people working, the following assumptions were made:

- moisture gain from the people 50 g/h per person,
- a seated person generates 90 W.

For calculating the heat gains through ventilation, we assume 1 air change/h.

Table 1 shows the assumptions made during the calculations and the calculated heat gains.

Table 1
Assumptions for calculating the heat gains

U_G (W/m^2 K): common glass	5.7	
a: absorptivity	0.7	
k_1 (W/m K)(plaster)	0.46	
k_2 (W/m K)(common brick)	0.42	
k_3 (W/m K)(concrete)	0.54	
I: 24-h solar insolation (W/m^2)		
Athens	151.2	
Crete	222.6	
Solar incidence South facing: $I = I_\Theta \times \cos(37 - \theta)$		
North facing roof: $I = I_\Theta \times \sin(60)$		
Number of air changes per hour	0.5	
$1/U_w = x_1/k_1 + x_2/k_2 + x_3/k_3$ (m^2 K/W)	0.845	
$1/U_f = x_1/k_1 + x_3/k_3$ (m^2 K/W)	0.263	
	Heat gain in Athens (kW)	Heat gain in Crete (kW)
Fenestration: $Q_2 = U \times A_f \times \Delta T + Q_3 = a \times A_f \times I$	11.96	15.10
Walls: $Q_4 = U_w \times A_w \times \Delta T$	10.14	10.11
Floors: $Q_5 = U_f \times A_f \times \Delta T$	9.91	9.11
Ventilation: $Q_6 = N \times V \times \rho_{air}(h_i - h_o)$	14.15	12.07
Roof radiation: $Q_7 = (A_R/2 - X) \times a \times I_s + A_R/2 \times a \times I_N$	34.02	50.12
Photocopy machine	0.60	0.60
Lighting	0.62	0.62
People	9.00	9.00
Total gain	94.90	168.89
Climatic conditions		
Lat. (°)	35.2	37.54
Average of max August T (°C)	36.0	35.2
Indoors temperature	26.1	26.1

4.3.2. Economic assumptions

The basic assumptions that were made during the economic evaluation of the two different SCS are:

Maintenance costs: of conventional 4%, of solar: 0.1% of investment costs [18].

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 costs are assumed to be 80 €/yr.

Lifetime: 15 years.

Installation costs: 12% of the equipment cost [24].

Energy prices: electricity: 0.099 €/kW h, gas: 0.358 €/m^3.

The energy inflation and the market discount rate are taken to be 2% and 3% respectively [20], while the cost of flat-plate collectors is 171 €/m^2 [25] (in all investment costs VAT is not included).

Currency: 1 € = 0,909 $ [February 2003].

Cost of adsorption chiller: 1000 €/kW cool [21].

Firstly the investment cost for the two solar systems and for the conventional gas fired and electric driven chiller, adjusted to the desired capacity, were determined. Then the yearly benefits were calculated, as a function of the energy savings.

4.4. Alternative scenarios

The objective of the study was to determine the primary energy savings and respective costs for different SCS. The systems chosen for the economic evaluation are: an absorption type using H_2O–LiBr as working fluids, and an adsorption system using silica gel–water.

In the attempt to consider realistic scenarios for the application of the SCS we have included the latest legislation in energy taxes. According to Greek law 2601/98, enterprises that invest in SE applications will be subsidized with 40% of the investment cost of the system, independent of the area in Greece in which the investment takes place. The various scenarios, which were investigated for two geographical regions (Attiki and Crete) were:

1. commercial use in grid-connected areas,
2. commercial use in grid-connected areas-energy tax 30% on electricity; subsidies or other reduction of the investment 40%,
3. commercial use in remote areas-comparison with gas system,
4. commercial use in remote areas-energy tax 30% on gas; subsidies or other reduction of the investment: 40%.

Firstly the investment cost for the two solar systems and the conventional gas fired and electric driven chiller were determined, adjusted to the desired capacity. Then the yearly benefits were calculated, as a function of the energy savings. The maintenance costs and life period were set according to the assumptions made. Then the payback time and the NPV of the different projects were calculated.

The four different scenarios were applied for each one of the two solar systems. In the following tables all the results are analytically presented. The aggregated results of the payback period and the NPV are presented in Figs. 2–5.

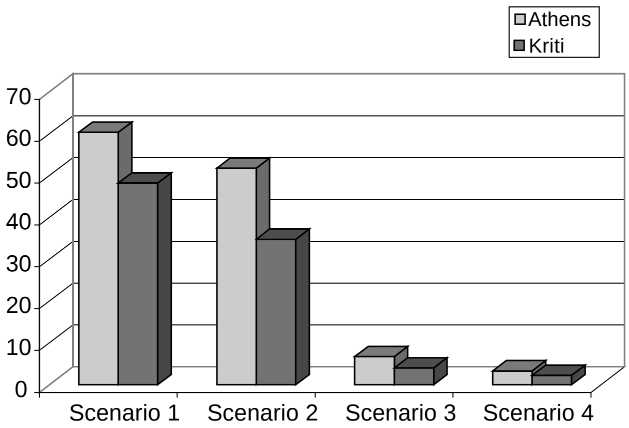

Fig. 2. Payback period for LiBr system.

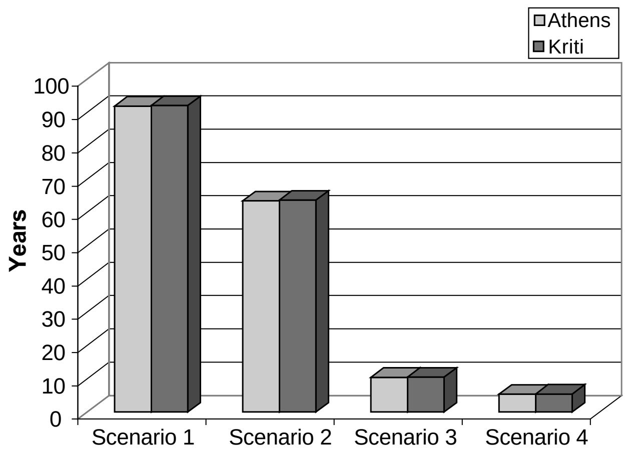

Fig. 3. Payback period for adsorption system.

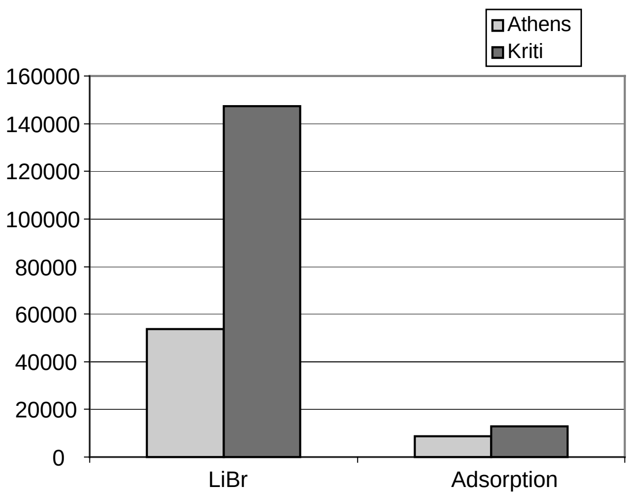

Fig. 4. Net present value for scenario 3.

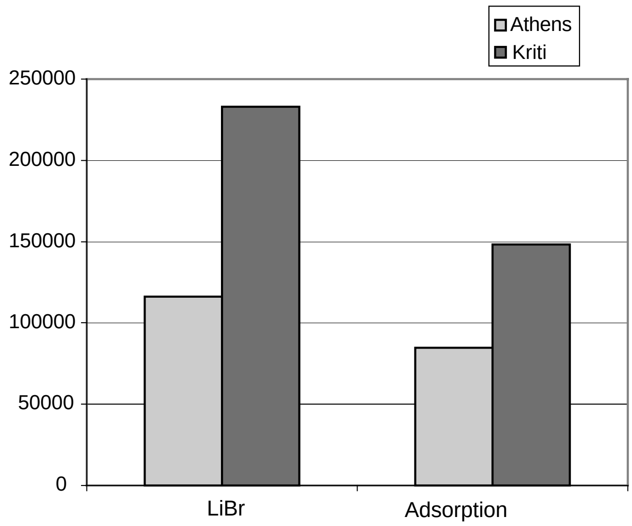

Fig. 5. Net present value for scenario 4.

4.5. Systems compared

The following systems were compared during the analysis:

(1) A LiBr absorption system, operating with large solar concentrators
The system includes:
- Collector type: ST60000-240-DLS with Evacuated Glass Absorption Tubes,
- Mountings,
- Solar Tracking,
- Temperature Regulation Package.

The cost of the system was estimated using the logarithmic relationship known as the six-tenths factor rule, since the cost of this system is similar to one of another capacity for which cost data are available. From the available data for the LiBr system, its cost capacity factor was calculated to be 0.4.

(2) Silica gel adsorption system, operating with flat-plate solar collectors
- flat-plate solar collectors: efficiency $n_{\mathrm{coll.}}$ (75 °C) = 0.55,
- adsorption chiller equipment: efficiency n_{ads} (75 °C) = 0.5,
- pumps,
- energy back up system (oil or gas).

In the case of the collectors, the cost capacity factor used was 0.6, while for the pumps it was taken to be 0.33 [24].

5. Results

5.1. Discussion

Table 2 presents a cost comparison between the cases studied and Table 3 presents the results of the various scenarios that were applied providing indices for the relevant investment.

Table 2
Cost comparison table between the cases

	Adsorption	System	LiBr	System
	Athens	Crete	Athens	Crete
Capital cost of electric a/c unit	3450	5500	3450	5500
Capital cost of gas-fired a/c unit	2400	4050	2400	4050
Capital cost of solar system (€)	94,900	168,890	43,887	55,268
Installation cost (€)	37.24	43.20	5266	6632
Annual operation + maintenance costs (€)/yr	1065	1840	518	621

Table 3
Results

	Attiki				Crete			
	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 1	Scen. 2	Scen. 3	Scen. 4
LiBr absorption system								
Payback period (yr)	60	52	7	3	48	35	4	2
NPV (€)	−43,312	−41,875	53,783	116,120	−51,298	−37,290	147,407	23,2947
Adsorption system								
Payback period (yr)	92	63	10	5	92	64	10	5
NPV (€)	−107,899	−107,899	8646	84,721	−19,5152	−122,768	12,845	148,262

In the first scenario, there is no energy tax or any investment grant and the installation of a SCS is not economically viable. The payback period exceeds the lifetime of the two systems. In the absence of subsidies, the projects could not give the investing organization a profit; therefore, the NPVs of the three projects are negative.

In the second scenario there is a double effect: an energy tax is imposed and at the same time the capital cost of the solar system is being subsidized by 40%. The systems are still not economically competitive with the conventional system driven by electricity.

For remote areas where the comparison is made with a gas-fired cooling system, the solar cooling unit appears to be more competitive. The payback period is smaller than the life period of both systems. In addition, the NPV of the LiBr system is positive for the installations in the Athens area in and Crete.

The final scenario is for use in remote areas with the double effect of the energy tax and the subsidies of 40%. Both systems are economically competitive with the conventional system and the NPV is positive.

5.2. Sensitivity analysis

Table 4 presents the results of the sensitivity analysis to carbon taxes, energy inflation and internal rate of return respectively in scenario 4. From the analysis it is apparent that there is the relatively stability in the payback period and in the NPV to Carbon Taxes and to the change to energy inflation. As it is predictable there is a major sensitivity in the energy inflation changes (e.g. from 2% to 5%, which seems to be reasonable).

Table 4
Sensitivity analysis

	Adsorption					LiBr			
	Carbon taxes (%)	Athens	% change	Crete	% change	Athens	% change	Crete	% change
Carbon taxes									
Payback period (yr)	20	5.79	+8	5.80	+8	3.56	+8	2.41	+9
	30	**5.37**		**5.38**		**3.30**		**2.23**	
	40	5.00	−7	5.01	−7	3.07	−7	2.08	−7
NPV	20	72,407	−14	126,346	−15	103,806	−9	211,032	−9
	30	**84,721**		**148,262**		**116,120**		**232,947**	
	40	97,036	+16	170,177	+15	128,435	+9	254,862	+9
Energy inflation% p.a.									
	Energy inflation (%)								
Payback period (yr)	8	4.81	−10	4.82	−10	3.11	−6	2.16	−3
	5	5.06	−6	5.07	−6	3.20	−3	2.19	−2
	2	**5.37**		**5.36**		**3.30**		**2.23**	
NPV	8	163,379	+92	287,048	+93	197,474	+70	379,255	+63
	5	119,086	+41	208,895	+41	151,663	+31	296,867	+27
	2	**84,721**		**148,262**		**116,120**		**232,947**	

6. Conclusions

The demand for AC in Greece is increasing due to the increasing demand for comfort, but also because of the higher temperatures that have occurred during the last decade. The extensive use of electrically driven compression cooling machines is responsible for an increasing peak demand of electrical power in summer, which reaches the capacity limit in several cases, especially in Athens. At the same time a lot of solar radiation is available. Therefore it is logical to utilize SE for the purpose of keeping indoor conditions during summer in a comfortable range.

Several technologies of solar assisted cooling of buildings are available in the market. Between adsorption chillers, desiccant coolers and the absorption systems the latter has the highest market penetration. The market share of adsorption systems is significantly lower. The desiccant cooling technique has the advantage of the lowest driving temperatures and therefore has a large potential for market penetration.

Economic analyses of the SCS indicate that these systems will not be competitive compared with standard cooling systems at present energy prices. The technology of solar cooling is not presently economically feasible without subsidy, mainly because of its high investment cost. However energy savings (in electricity or gas) may be realized by the integration of SE with cooling systems, so these SCS require lower costs of installation. The analysis shows that SCS are better suited to replacing conventional air-conditioners in remote areas, where there is no connection with the electricity grid and where the conventional fuel used is gas. There is a strong need both for some kind of investment incentive and also for energy tax that would help to reflect the full environmental costs of conventional fuels.

It is difficult to predict the date when these technologies will reach a competitive production cost and enter the market. However it is apparent, that the cost of RES' technologies is decreasing as they enter the mass production.

There is a need for a new perspective in valuing SE technologies. The need for new economic cost perspectives derives from the fact that these technologies have vastly divergent financial risk characteristics. These characteristics exclude externalities, distribution costs and indirect costs. Also, the unpredictability of conventional fuel prices over long periods should be taken into account. The comparison of a solar technology with one of conventional energy sources can only be made if the environmental and societal costs are included in each case, and will be strongly influenced by progress in the technology of SE capture.

References

[1] A.A. Argiriou, S. Mirasgedis, The solar thermal market in Greece—Review and perspectives, under review.
[2] W.P. Cunningham, B. Woodworth, Environmental Science, A Global Concern, McGraw-Hill, 1999.
[3] U. Chakravorty, J. Roumasset, K. Tse, Endogenous substitution among energy resources and global warming, J. Political Econ. 105 (1997) 1201.
[4] Y. Tsur, A. Zemel, Long-term perspective on the development of solar energy, Solar Energy 68 (5) (2000) 379–392.
[5] N. Best, N. Ortega, Solar refrigeration and cooling, Renew. Energy 16 (1999) 685–690.
[6] M. Karagiorgas, A. Botzios, Solar Water Heater Technology in Greece, World Renewable Energy Congress VI (WREC), Elsevier Science Ltd., 2000.
[7] A. Costa, P. Lamp, F. Ziegler, Potential of Solar Assisted Cooling in Southern Europe, in: Proceedings of Eurosun 96, Freiburg, 1996.
[8] K.E. Bett, J.S. Rowlinson, G. Saville, Thermodynamics for Chemical Engineers, The Athlone Press, London, 1992.
[9] Y.A. Cengel, M.A. Boles, Thermodynamics for Engineers, Tziola publications, Thessaloniki, 1998.
[10] P. Lamp, F. Ziegler, Review paper, European research on solar assisted AC, Elsevier Science Ltd. and IIR, 1998.
[11] M. Hammad, Y. Zurigat, Performance of a second generation solar cooling unit, Solar Energy 62 (2) (1997) 79–84.
[12] M. Izquierdo, M.E.F. Hernandez, Solar cooling in Madrid, Energetic efficiencies, Solar energy 60 (1997) 367–377.
[13] K.A. Antonopoulos, E.D. Rogdakis, Performance of solar-driven ammonia–lithium nitrate and ammonia–sodium thiocyanate absorption systems operating as coolers or heat pumps in Athens, Appl. Therm. Eng. 16 (1995) 127–147.
[14] J.M. Gordon, K.N. Choon, High efficiency solar cooling, Solar Energy 68 (1999) 23–31.
[15] D. Feuermann, J.M. Gordon, Solar fiber-optic mini-dishes: a new approach to the efficient collection of sunlight, Solar Energy 65 (2000) 159–170.
[16] A. Erhand, E. Hahne, Test and simulation of a solar powered absorption cooling machine, Solar Energy 4–6 (1997) 155–162.
[17] N.K. Bansal, J. Blumenberg, H. Kavash, J. Roettinger, Performance testing and evaluation of solid absorption solar cooling unit, Solar Energy 61 (2) (1997) 127–140.
[18] H.M. Henning, T. Erpenbeck, Integration of solar assisted open cooling cycles into building climatization systems, in: Proceedings of Eurosun 96, Freiburg, 1996.
[19] B.B. Saha, A. Akisawa, T. Kashiwagi, Solar/waste heat driven two-stage adsorption chiller, Renew. Energy 23 (2001) 93–101.
[20] H.M. Henning, T. Erpenbeck, C. Hindenburgh, C. Paulussen, Solar cooling of buildings—possible techniques, potential and international development, in: Proceedings of Eurosun 98, Freiburg, 1998.
[21] Various, Integrated Solar Conditioning Systems, A CRAFT Research feasibility study, JOR3-1022, 1998.

[22] T. Tsoutsos, Marketing solar thermal technologies: strategies in Europe, experience in Greece, Renew. Energy, vol. 26/1, Pergamon Press, 2001, pp. 33–46.
[23] M. Karagiorgas, T. Tsoutsos, R. Berkmann, The PHILOSOL project: a strategic market development of the solar thermal sector in Southern Europe, Energy Convers. Mgmt., Pergamon Press, 44 (11), 2003, pp. 1885–1901.
[24] M.S. Peters, K.D. Timmerhaus, Plant Design and Economics for Chemical Engineers, McGraw-Hill International Editions, 1994.
[25] M. Karagiorgas, A. Botzios, T. Tsoutsos, Industrial solar thermal applications in Greece. Economic evaluation, quality requirements and case studies, Renew. Sustain. Energy Rev., Pergamon Press, vol. 5/2, 2001, pp. 157–173.