Solar Air-Conditioning Systems

in small - medium scale applications

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The problem

- **Ozone layer depletion**

  CO_2 higher now than in last 400,000 years

  CO_2 emissions are expected to increase 20-fold from 1990 to 2010, only in the EU

- **IPCC predicts temperature rise of 1.5 - 5.8 degrees**

  Humans: 150,000 deaths directly attributable to climate change in 2000

  Climatic zones shifting 7 times quicker than plants can follow

- **New directives on air quality**

  2008/50/EC, *'Ambient air quality and cleaner air for Europe'*

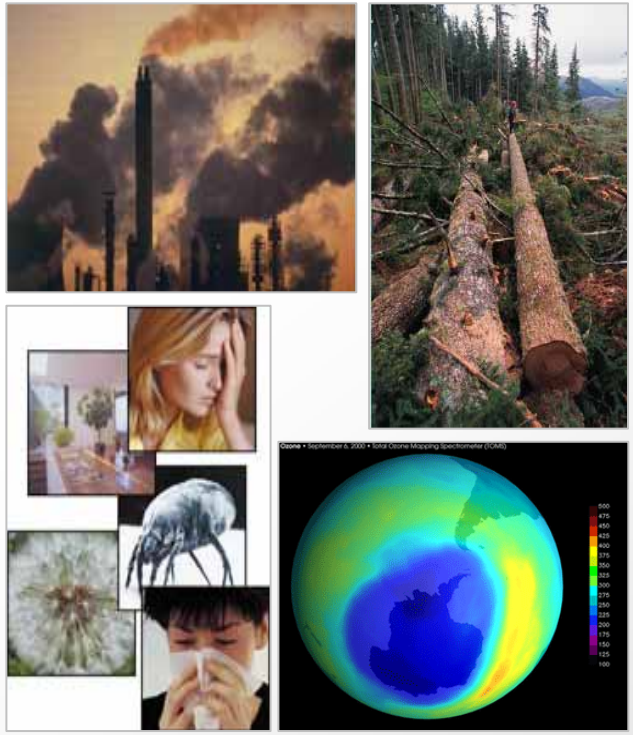
  2008/1/EC, *'Integrated pollution prevention and control'*

- **Inefficient conventional a/c units**

  - **VCS** operate at a temperature colder than the supply air dew-point temperature, so **the air is overcooled** and needs reheating before entering indoors

  - **Energy consumption** in commercial and residential buildings: **40% of Europe's energy bill**

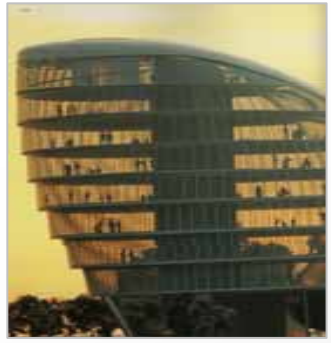
- **Global increase in air-conditioning demand**

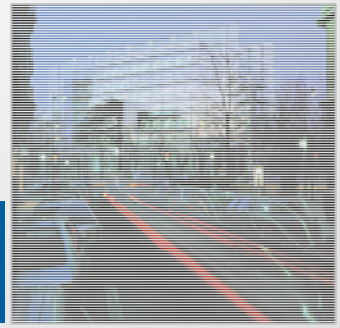


Global sales of air conditioning units, 2000-2008

	2000	2001	2002	2003	2004	2005	2006	2007	2008
Japan	7.791	8.367	7.546	7.307	7.679	7.500	7.500	7.500	7.500
Asia	13.897	16.637	17.761	23.650	26.430	28.312	30.340	32.524	34.881
Europe	1.673	1.730	1.804	2.218	2.366	2.515	2.604	2.660	2.717
M. East	2.907	2.918	3.412	4.359	4.799	5.087	5.382	5.694	6.118
N. America	12.322	11.894	12.910	13.075	12.876	12.881	12.889	12.897	12.905
S. America	2.109	1.939	2.036	2.243	2.331	2.418	2.473	2.530	2.592
Africa	664	758	700	814	850	885	915	944	978
Australia	512	593	671	712	815	825	868	913	963
Total	**41.874**	**44.834**	**46.840**	**54.379**	**58.147**	**60.422**	**62.970**	**65.663**	**68.654**

JRAIA (Japan Refrigeration and Air Conditioning Industry Association)



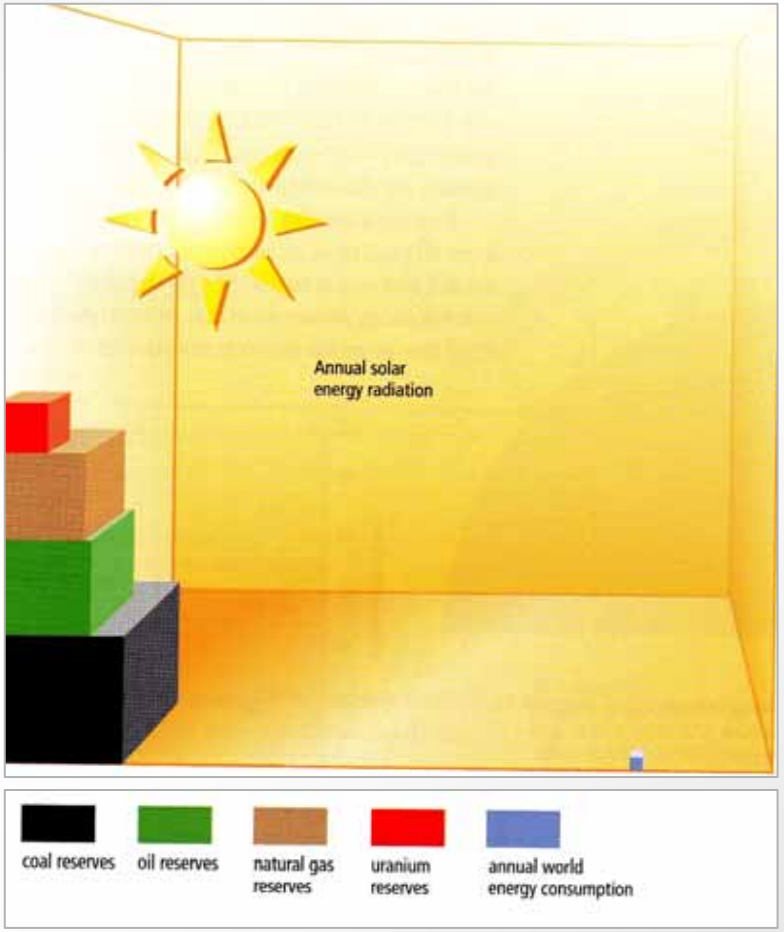


- Higher living / working standards
- Adverse outdoor conditions in urban environments
- Reduced prices of air-conditioning units
- Installed a/c has increased 5-fold in the last 20 years in Europe
- Total a/c floor space: 30 million m^2 in 1980, over 150 million m^2 in 2000.
- Annual energy use of room a/c was 6 TJ in 1990, estimated 160 TJ in 2010.

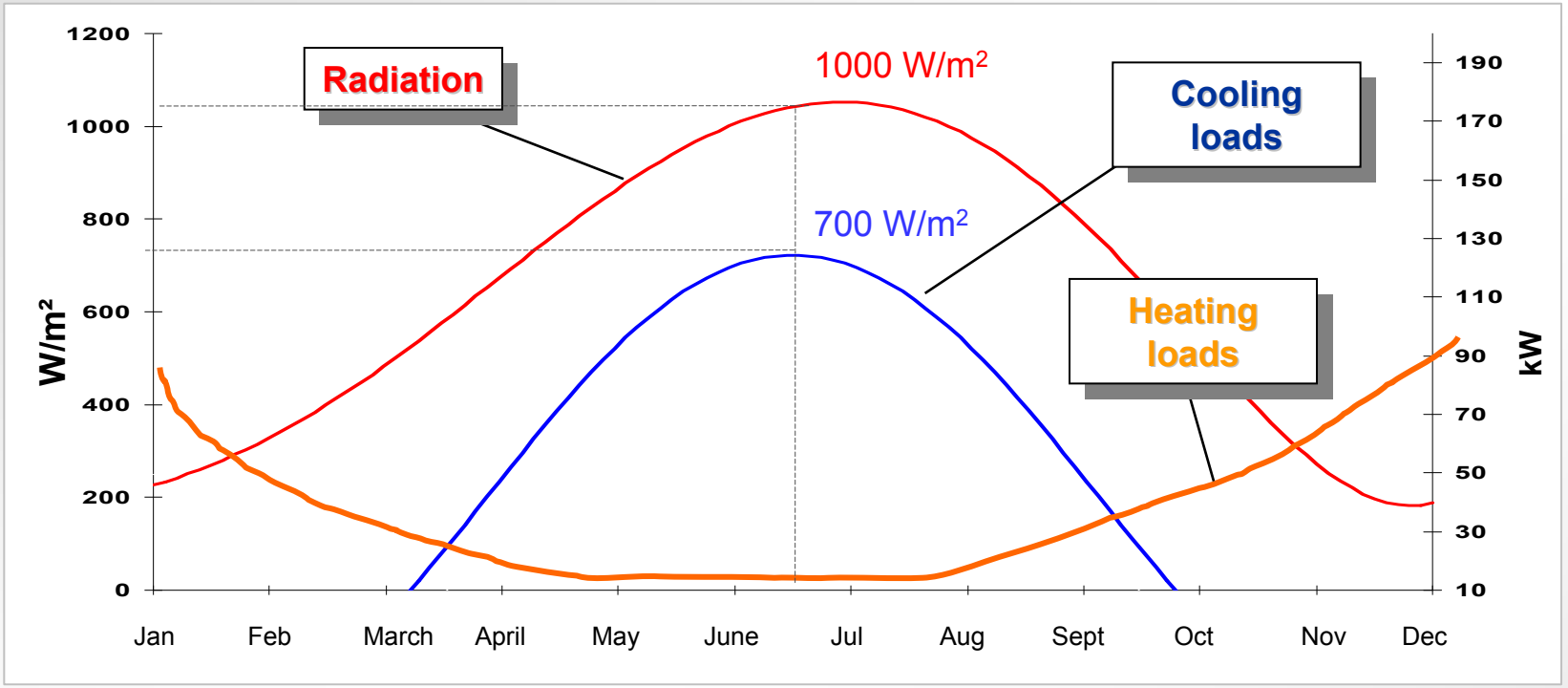
We need an a/c system that controls temperature and provides air of high quality, with high efficiency and low CO_2 emissions!

The solution : Solar-driven air-conditioning

- **Radiation** supply from sun carries a **5 billion year guarantee**
- Annually, **the sun provides 1.5*10^{18} kWh**, that is more than 10,000 times the energy that human race needs.



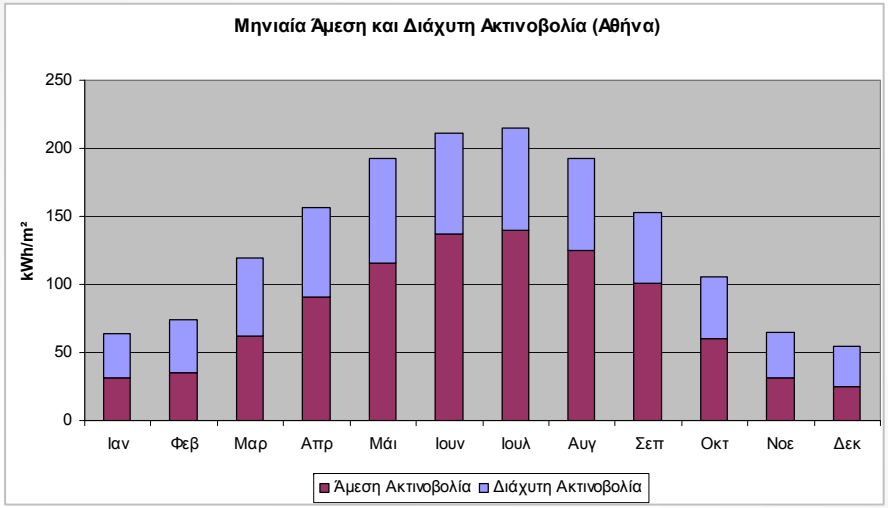
Source: *Planning & Installing Solar Thermal Systems: A guide for installers, architects & engineers*, EarthScan publications



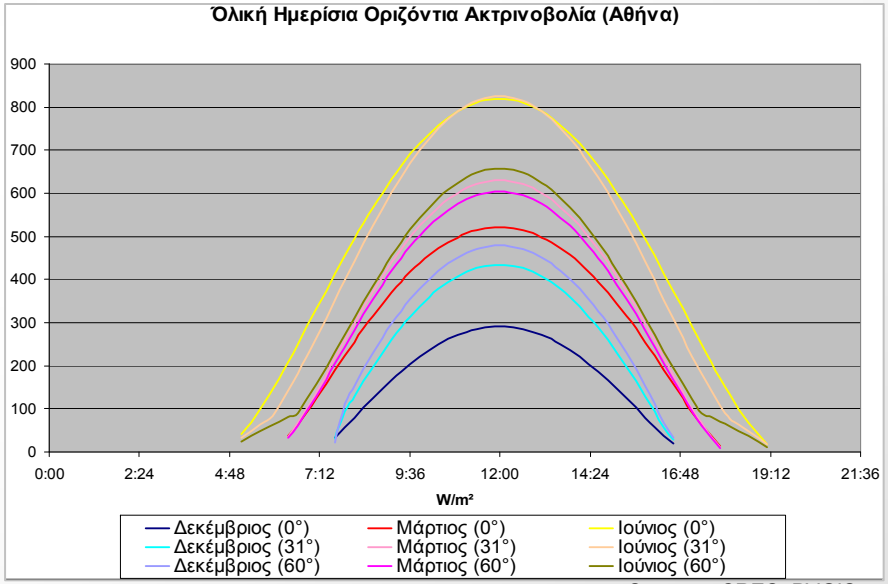
Solar radiation is in tune with air conditioning demand

Source : TECSOL for SOLAIR project

- Annual solar irradiance (sum of direct and diffuse) in Greece is approximately **1,600 kWh/m²**.
- This amount of energy, corresponds to **160 lt oil.**



- Daily solar irradiance for 3 representative dates (in winter, summer and spring) is shown in the next diagram.
- The area that receives the biggest amount of radiation has an inclination of **60⁰ in December** and **0⁰ in June**.



Source : CRES, PVGIS

Optimum collector angle: depends on the geographical location and the system's type of use.

- **Winter use**: geographical latitude of area **+ 15^0**
- **Summer use**: geographical latitude of area **- 15^0**
- **Annual use**: collector angle **= geographical latitude**

RESULTS OF INCIDENT RADIATION ON COLLECTORS (FROM TSOL)

Place: Athens

Azimuth: 0

G Inclined, Specific[kWh/m²]

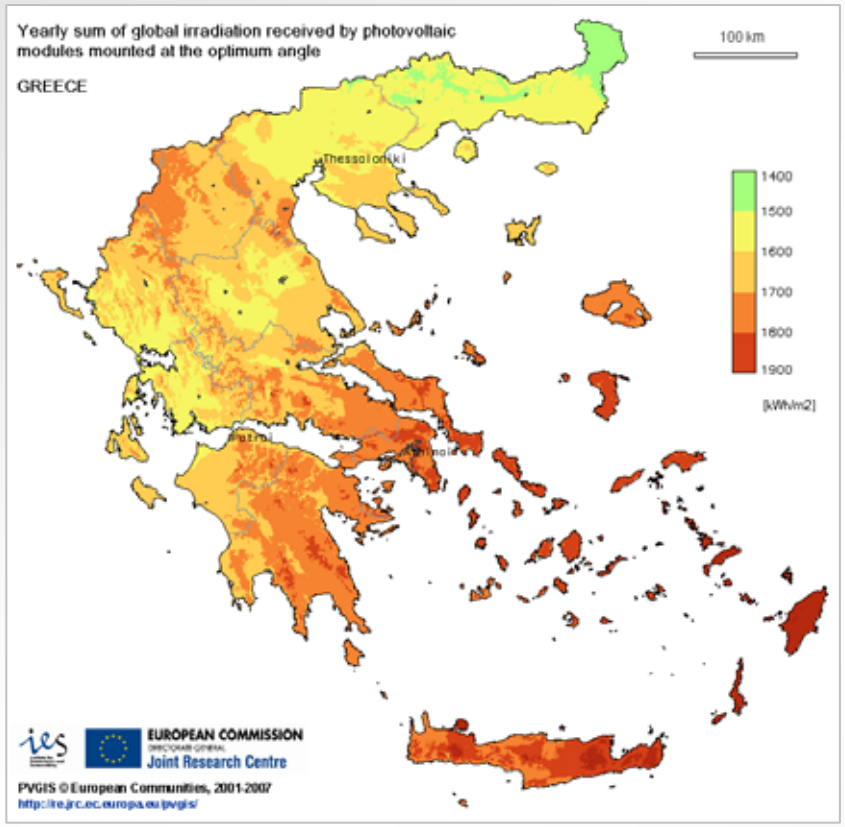
acording to collectors inclination (in degrees °)

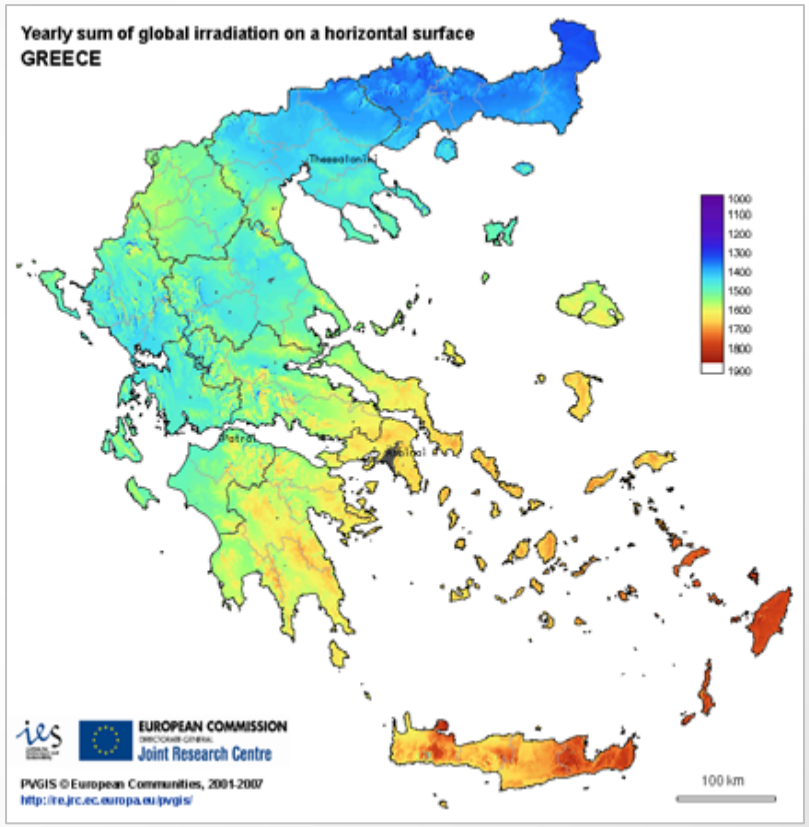
From:	To:	0	10	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
1/ 1/	1/ 2/	66	80	91	96	100	104	107	109	111	112	113	112	111	109	107	104	100
1/ 2/	1/ 3/	75	84	91	93	96	97	99	99	99	99	98	96	94	91	88	84	80
1/ 3/	1/ 4/	104	112	116	118	119	119	119	118	116	114	111	108	104	99	94	89	83
1/ 4/	1/ 5/	146	151	152	152	151	149	147	143	139	134	129	123	116	108	101	92	84
1/ 5/	1/ 6/	182	183	181	178	175	170	165	159	153	145	137	128	119	109	100	90	79
1/ 6/	1/ 7/	200	200	195	191	185	180	173	166	158	149	139	128	118	108	96	85	75
1/ 7/	1/ 8/	213	214	210	205	199	194	187	180	171	162	151	139	128	117	105	91	80
1/ 8/	1/ 9/	200	206	206	204	202	199	194	188	182	174	165	155	144	132	121	109	96
1/ 9/	1/10/	156	168	176	179	180	181	180	178	175	171	166	161	154	146	138	128	118
1/10/	1/11/	106	120	130	134	138	140	142	143	142	142	140	137	134	130	125	119	113
1/11/	1/12/	66	77	86	90	94	96	99	100	101	102	102	101	99	97	95	92	88
1/12/	1/ 1/	53	63	72	76	79	82	85	87	88	89	89	89	88	87	85	83	80
	Sum YEAR	**1567**	**1658**	**1706**	**1716**	**1718**	**1711**	**1697**	**1670**	**1635**	**1593**	**1540**	**1477**	**1409**	**1334**	**1252**	**1165**	**1075**
hotels season:	**1/4 to 1/11**	**1203**	**1242**	**1250**	**1243**	**1230**	**1213**	**1188**	**1157**	**1120**	**1077**	**1027**	**971**	**913**	**850**	**784**	**714**	**645**
heating season:	**1/11 to 1/4**	**364**	**416**	**456**	**473**	**488**	**498**	**509**	**513**	**515**	**516**	**513**	**506**	**496**	**484**	**468**	**450**	**430**
"winter":	1/12 to 1/3	194	227	254	265	275	283	291	295	298	300	300	297	293	287	280	270	260

Source : T-SOL

Energy yield

Optimum angle: 1700-1800 kWh/m^2 Horizontal surface: 1300-1400 kWh/m^2





Source : PVGIS

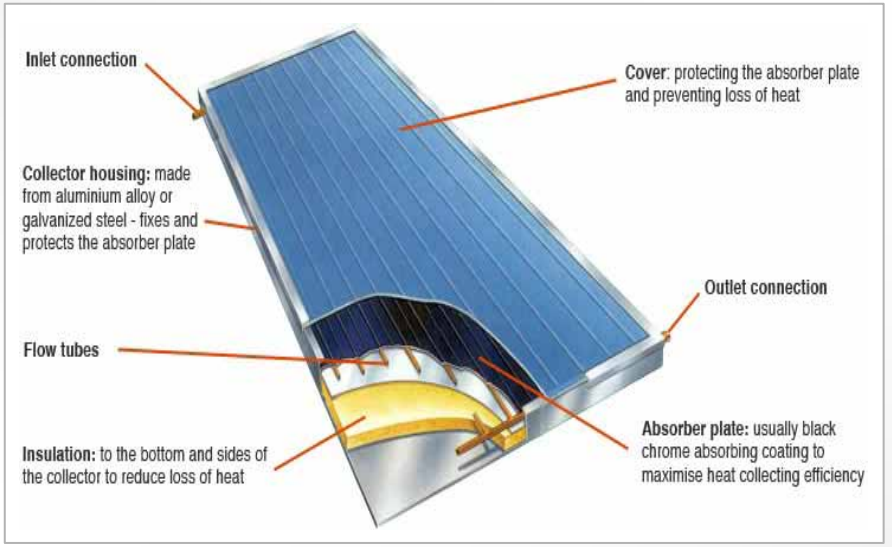
Standard flat plate collectors

Properties

- Middle cost: more expensive than unglazed, but cheaper than vacuum
- Higher operation temperature
- Thermal insulation on back & edges
- Fragile, heavier: 20-32 kg/m^2
- Absorber: black paint or spectral-selective coating (black chrome, black nickel, blue titanium)
- Spectral-selective coating: conversion of short-wave solar radiation into heat (light absorption capacity) is optimized, while thermal emissions are kept low. Absorption rate: 90-95%, emission rate 5-15%
- Stagnation temperature: 160-200^{0}C

Applications

- Space heating
- Solar air conditioning (selective coating)



Planning & Installing Solar Thermal Systems: A guide for installers, architects & engineers, EarthScan publications

Vacuum collectors

Properties

- High cost
- Minimal convection thermal losses (tube pressure < 10^{-5} bar)
- Low radiation losses
- High efficiency, even with low radiation
- Low weight
- Average annual efficiency 45-50% (with 1000kWh/m^2 irradiation, the energy yield is 450-500kWh/m^2a
- Stagnation temperature: 200-350^{0}C

Applications

- Solar air conditioning
- Industrial applications (steam generation)

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Vacuum types

- **Direct-flow**: Internal U-tube, South-oriented.

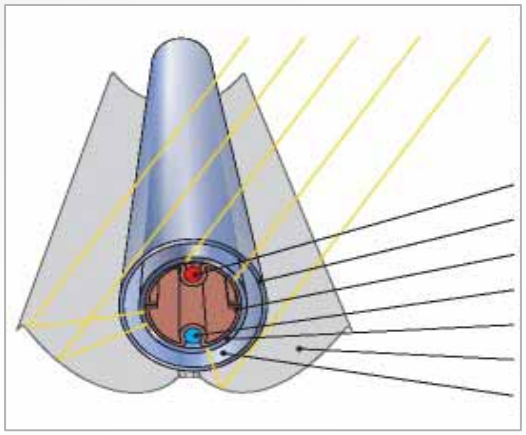
Concentrated: Double tube (external tube: absorber surface, internal tube: U-type), 2 external reflector surfaces

- Heat-pipe:

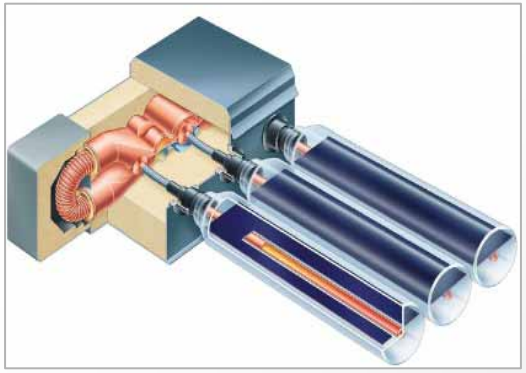
Horizontal absorber area placed inside a vacuum tube. The tube is connected to an evacuated heat pipe with a solution inside. The solution evaporates ($T_{evaporation}$=25^{0}C) and its heat is transferred through a heat exchanger in the medium.

Dry connection: the heat transfer takes place from the condenser via the tube wall to the medium, so defective tubes are replaced without emptying the solar circuit)

Wet connection: the condenser is immersed in the medium, so defective tubes are replaced by emptying the solar circuit.



Concentrated vacuum collector



Cross section of heat pipe dry connection

Cross section of heat pipe wet connection

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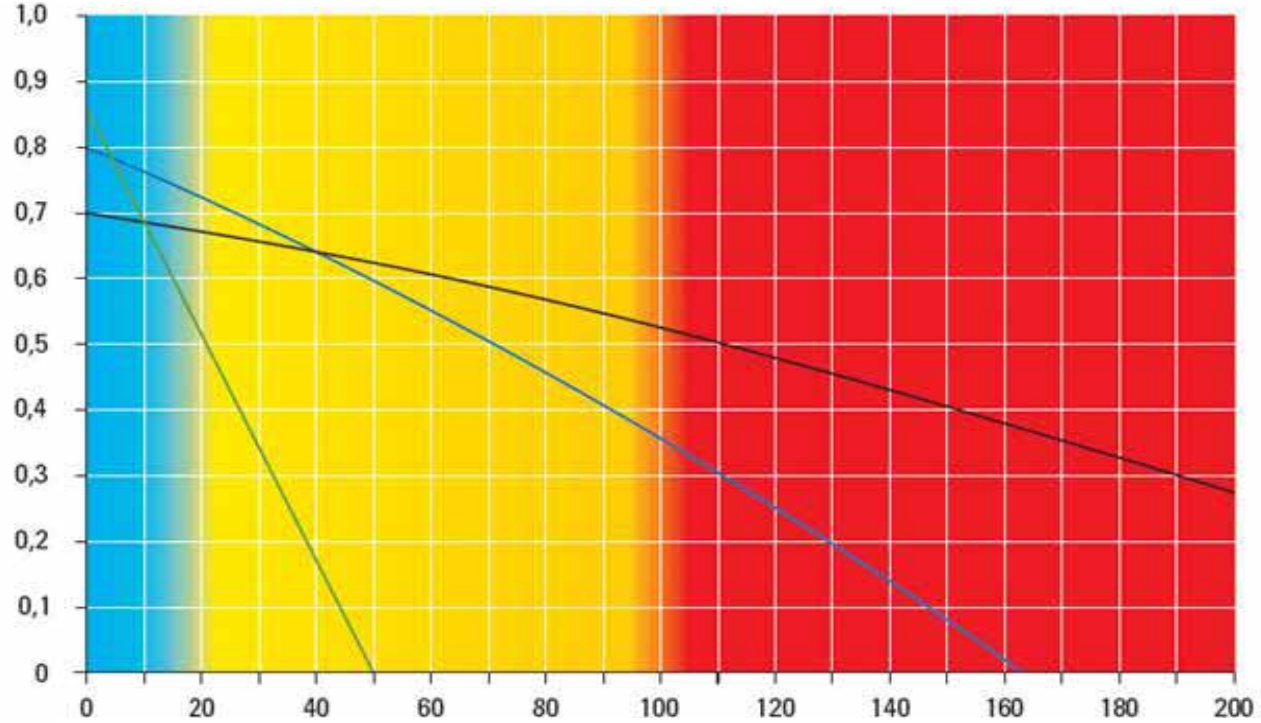
Collectors comparison

Collector type	Application	Performance (kWh/m²a)
Unglazed	Pool heating	300
Flat plate (black paint)	Pool heating, Hot water	650
Flat plate (selective coating)	Hot water, space heating, solar a/c	700
Vacuum	Solar a/c, industry	850

Performance



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Solar-driven air-conditioning systems

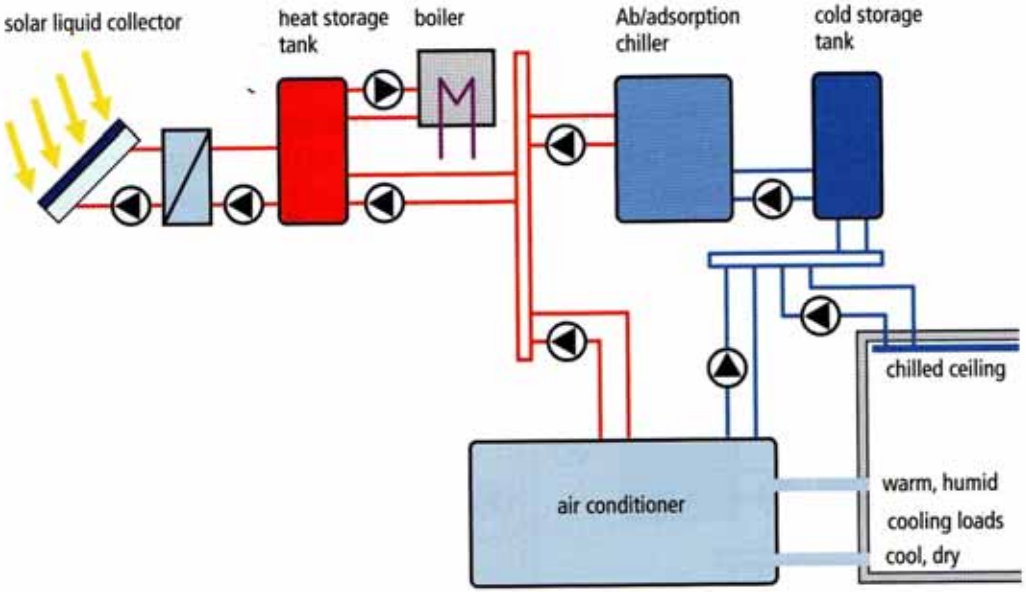
Systems

- **Open cycle DEC**

Production of air conditioned air
Dehumidification and evaporative cooling

- **Closed cycle**

Production of chilled water for space cooling through fan coil, chilled ceiling, floor heating
Absorption (liquid)
Adsorption (solid)

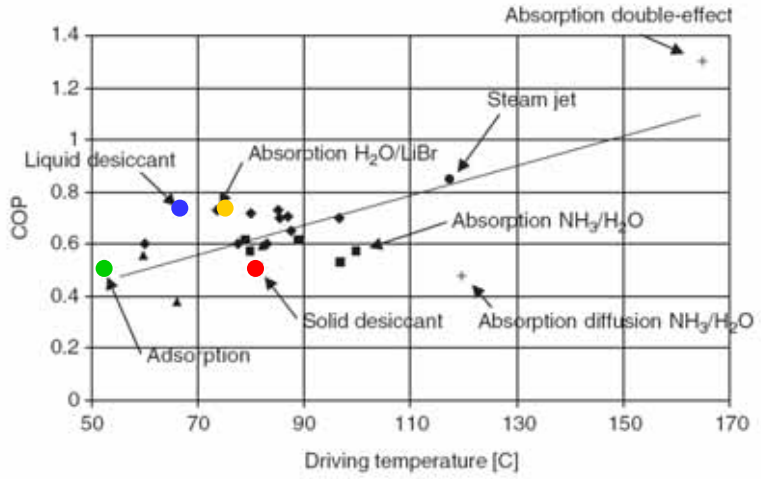


Characteristics

- ✓ Air conditioning load in tune with the solar radiation
- ✓ Solar systems can be integrated in existing air-conditioning units (fan coils, floor heating systems)
- × Small scale solar a/c systems: under research
- × Small scale chillers (<30kW): High initial cost, 2,000 €/kW.

Method	Closed cycle		Open cycle	
Refrigereant cycle	Closed refrigerant cycle		Refrigerant (water) is in contact to the atmosphere	
Principle	Chilled water		Dehumidification of air and evaporative cooling	
Phase of sorbent	solid	liquid	solid	liquid
				
Typical material pairs	water - silica gel	water - lithium bromide ammonia - water	water - silica gel, water - lithium chloride	water - calcium chloride, water - lithium chloride
Market available technology	Adsorption chiller	Absorption chiller	Desiccant cooling	Close to market introduction
Typical cooling capacity (kW cold)	50 – 430 kW	15 kW – 5 MW	20 kW – 350 kW (per module)	
Typical COP	0.5 – 0.7	0.6 – 0.75 (single effect)	0.5 – >1	> 1
Driving temperature	60 – 90 °C	80 – 110 °C	45 – 95 °C	45 – 70 °C
Solar collectors	Vacuum tubes, flat plate collectors	Vacuum tubes	Flat plate collectors, solar air collectors	Flat plate collectors, solar air collectors

Source : EU Altener Project Climasol



Efficiency – Operational temperature, 2007

Open systems

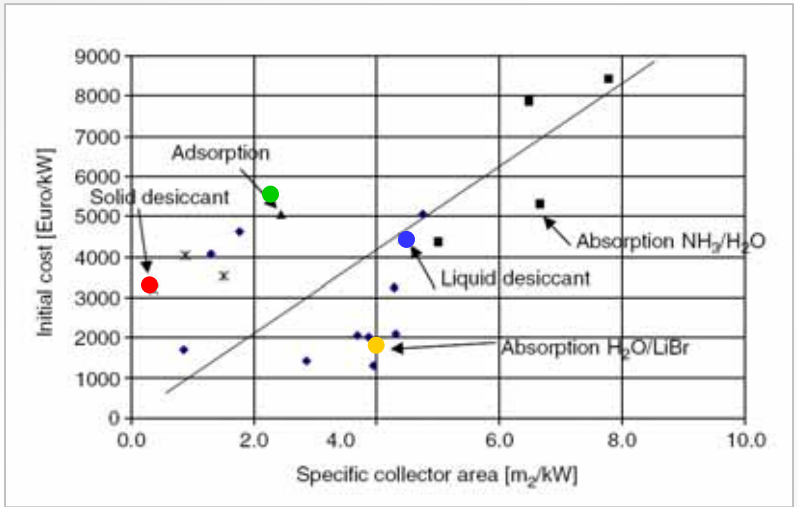
Liquid DEC: T = 60C, COP = 0.7

Solid DEC: T = 80C, COP = 0.5

Closed systems

Absorption: T = 75C, COP = 0.7

Adsorption: T = 55C, COP = 0.5



Initial cost – Collector area needed, 2007.

Open systems

Liquid DEC: 4500 €/kW, 5 m²/kW

Solid DEC: 3500 €/kW, 0.5 m²/kW

Closed systems

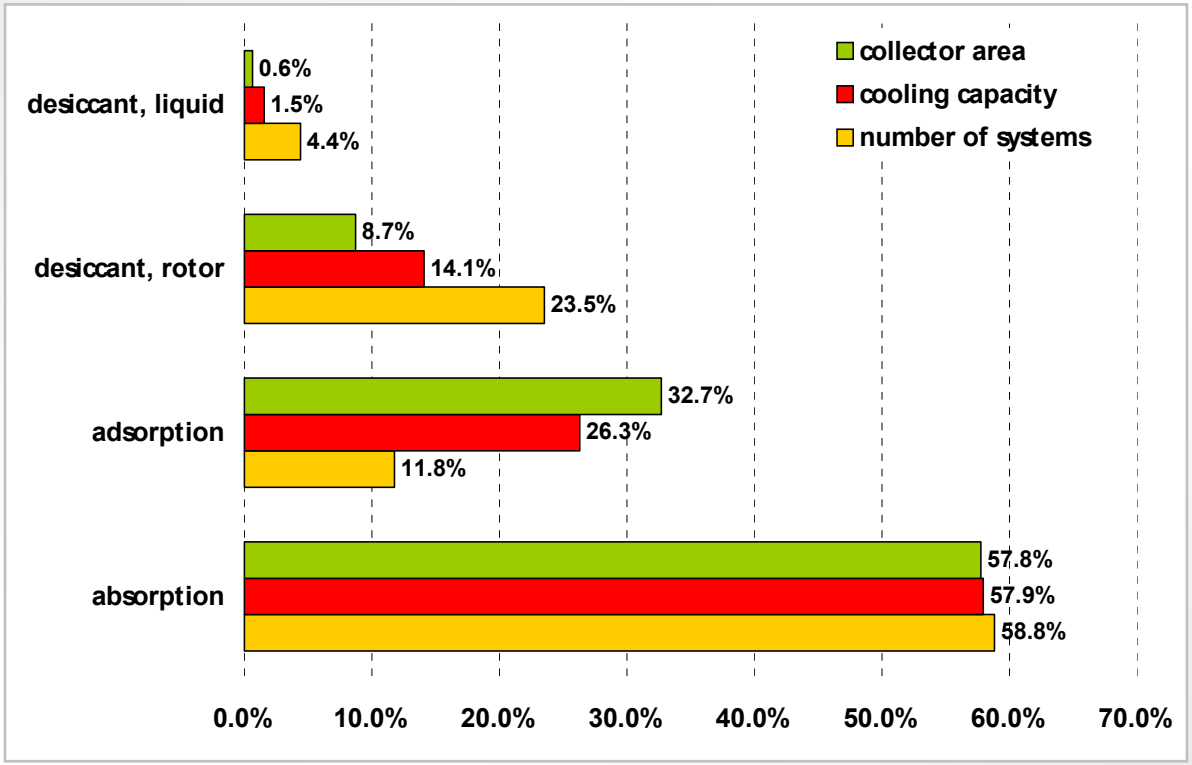
Absorption: 2000 €/kW, 4 m²/kW

Adsorption: 5500 €/kW, 2.5 m²/kW

Source : CA Balaras, G Grossman, HM Henning, *Solar Air-Conditioning in Europe - an overview*, Renewable Energy & Sustainable Energy Reviews, 11, 2007, 299-314

Solar Cooling Systems installed in Europe

- Absorption: 58%
- Solid DEC: 23%
- Adsorption: 12%
- Liquid DEC: 4%

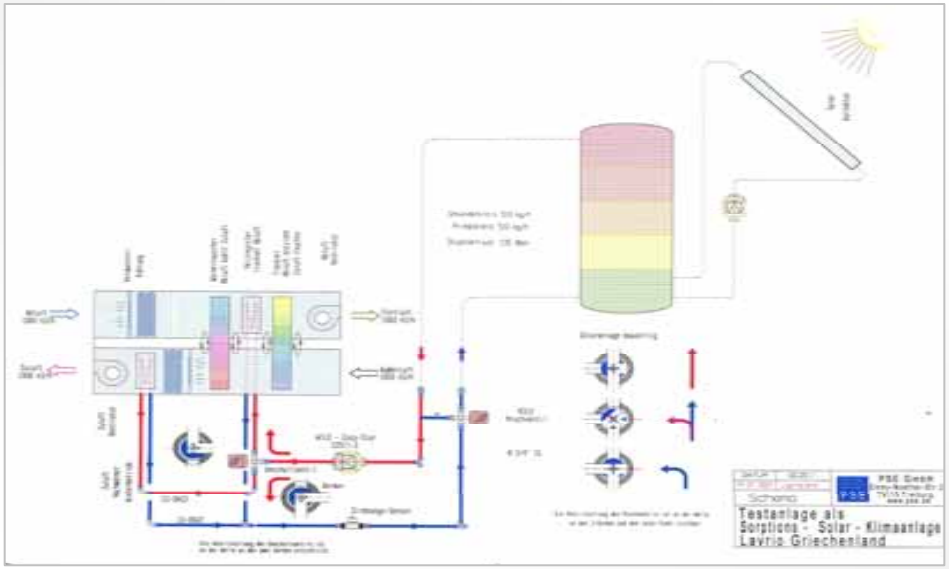


Source : HM Henning, *Solar Assisted air conditioning of buildings – an overview*, Applied Thermal Engineering, 27, 2007, 1734-1749.

CRES, demo project, Lavrio, Athens

PENA, Lavrio
Solar cooling **Solid DEC system**
Demo & research application for CRES

In operation since	2007
Air conditioned area	84m²
Collector type	10 m², Calpak flat-plate
Collector fluid	water-glycol
Operation temperature	60°C
Nominal air flow rate	1100 m³/h
Min. air volume flow rate	373 m³/h
Desiccant cooling system	solid LiCl
Brand of desiccant unit	Klingenburg

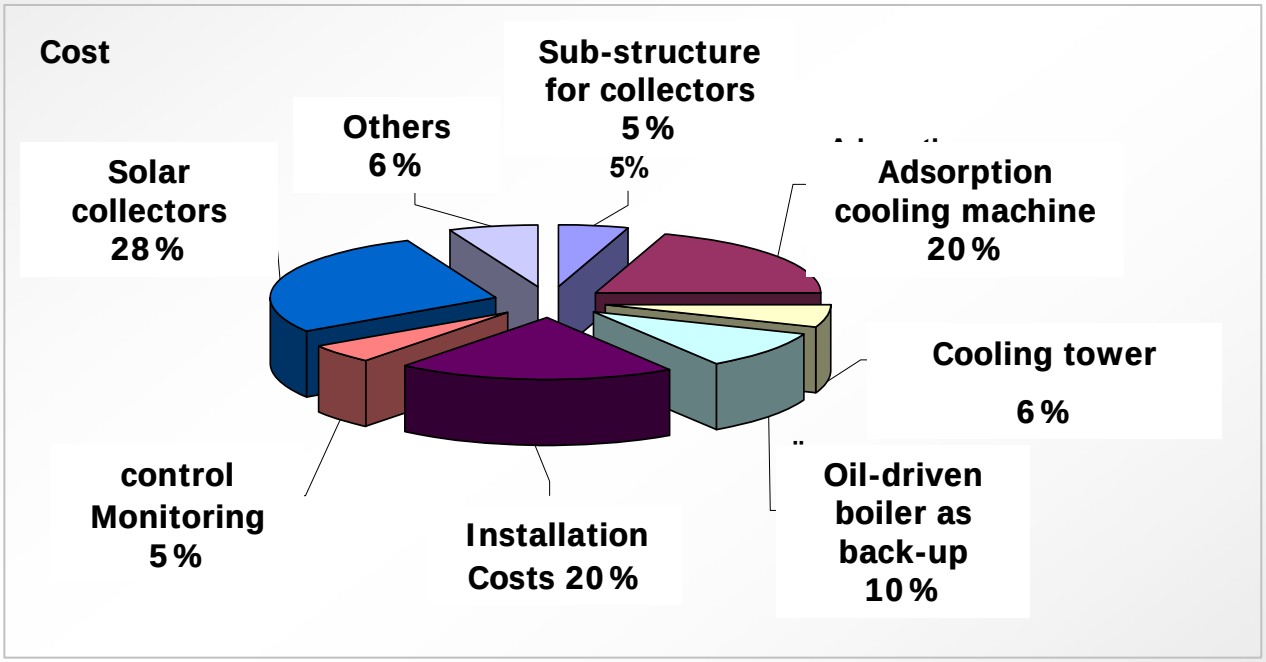


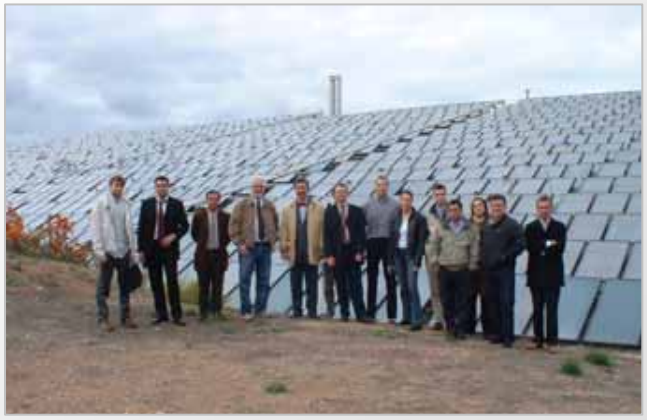
Source : CRES

SARANTIS, Industry, Inofita Viotias

Solar cooling of a production site for cosmetics
- In operation since 1999
- One of the largest installations in the world
- 2,700 m² flat plate collectors (SOLE)
- 2 **adsorption cooling** machines, with 350 kW cooling power each
- 3 compression cooling machines with 350 kW air cooling and fan-coils
- Concept: economisation of electricity (Power and Work)

Source : CRES





Rethimno Village Hotel, Crete

In operation since 20/08/00
Solar air-conditioning system, fan coils
Air-conditioned area 1000 m^2
450m^2 flat plate collectors (SOLE)
Absorption chiller LiBr, 105 kW_c
Performance: $COP_{thermal}$ =0.6,
$COP_{electrical}$=0.52
Initial cost: 146,000 € (2000)
Annual electrical energy savings:
70,000 kWh (7,000€)
Annual oil savings: 20,000 lt (8,000€)
Payback in 10 years, without incentives.
870,000 kg less CO_2 annually

Source : SOLE

Conclusions

- **Solar Cooling is not yet widespread** in Greece
  - 8% of the solar thermal market
  - lack of real incentives
- However, there is **large growth potential**, because
  - only 25% of the buildings are equipped with a solar thermal system (>90% of the owners are satisfied)
  - steady increase in demand for a/c units

Law modernization

solar cooling system project study compulsory for every large building

Financial incentives

to cover part of investment & construction costs

Thank you for your attention!

Centre for Renewable Energy Sources

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