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Past, present, future of solar cooling: Technical and economical considerations

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ABSTRACT

A large fraction of cooling demand depends on solar radiation intensity, therefore a strong attention was directed toward solar cooling immediately after the 1973 energy crisis. Whereas pilot solar cooling plants were built up and experimented, this technology never really took off. A recent survey reported something more than 1000 plants operating, a very modest number with respect the great potential of solar cooling. A review of technologies as they developed in the past, operate in the present with a forecasting for the future is here proposed to follow how the technology evolved during almost half a century regarding the solar section and the relative refrigeration equipment. The analysis allows to take stock of the situation selecting solar sections, cooling machines and their coupling which seem nowadays more suitable for wide application in the near future.

A study is proposed at the end to put together some energy evaluations in different climates and much more difficult economical evaluations to investigate whether a possible fossil fuel parity cost can be attained, if not today, in a near future.

1. Introduction

After the energy crisis of 1973 and even more after that of 1979, the interest in solar energy applications was for uses for which the demand is higher just when solar radiation is more abundant and steady. Domestic Water Heating (DWH), solar distillation of sea water or solar pumping for irrigation were considered. By sure a strong attention was immediately directed toward solar cooling. In fact a large fraction of cooling demand depends on solar radiation intensity. Many studies were produced on solar cooling since the first energy crisis of 1973 and first pilot plants were built and experimented (Ward et al., 1976, 1977). Whereas some solar energy applications concern only solar radiation collection and its transformation into heat or electricity, such as for DHW or PhotoVoltaics (PV), solar cooling greatly concerns a further transformation downstream from heat or electricity into cooling. This transformation is neither simple nor cheap.

Moreover cooling demand does not follow solar radiation course: a delay is always present in the buildings. The demand often extends to the night and to periods of poor insolation. Thus storage systems had to be provided, with technical and economical problems, in a complex system (Lazzarin, 2007a, 2007b). These problems did not only regard temperature stratification and the advantage of providing also a cold storage, but the system control and the energy cost of pumping water into often long circuits as well. The pumping energy cost on some pilot plants resulted to be even higher than the energy to drive a conventional cooling plant of similar capacity!

Nonetheless the monitoring of some pilot plants claimed appreciable results both regarding performance and reliability (Ward et al., 1978). However the high construction costs and the swinging trend of oil price prevented the development of this application even if the potential of solar energy to generate cooling is unquestionable.

Nowadays oil price is maintained at a low level, even if with unpredictable swinging. However the following points should be considered:

- the economic growth in developing countries, often in geographic locations with hot climate, produces higher comfort standards with increasing demand of space cooling;
- global warming will contribute to increase cooling demand;
- the agreements to limit greenhouse gases should promote clean applications as solar cooling;
- whereas modern buildings can be easily realised with low heating demand, it is more difficult to limit the cooling demand, reducing the incoming solar radiation, above all for buildings largely using glass;
- offices and homes are increasing the use of electric appliances with a correspondent internal heat gain that increases the cooling demand;
- the cost of the solar section in cooling plants is rapidly reducing to

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Nomenclature

Symbols

a	coefficient on the equation of thermal efficiency for solar thermal collectors
A	area (m^2)
AM	Air Mass
B	Belgium
C	cost (€, € m^{-2}, € W_p^{-1})
CdTe	cadmium telluride photovoltaics
CIGS	Copper Indium Gallium (di)Selenidephotovoltaics
CIGSS	Copper Indium Gallium Sulphur (di)Selenidephotovoltaics
CIS	Copper Indium Diselenide photovoltaics
DPB	Discounted PayBack period (y)
E	power produced by the solar thermal collectors or the PV modules or the chillers (W)
EER	Energy Efficiency Ratio
ETC	Evacuated Tube Collector
FPC	Flat Plate Collector
GaAs	gallium arsenide photovoltaics
GAX	Generator Absorber eXchange
G	global solar intensity (for non-concentrating collectors) or beam solar intensity (for concentrating collectors) (W)
HVAC	heating, ventilation, air conditioning
I	Italy
LiBr	lithium bromide
LiBr_DE	double effect lithium bromide-water absorption chiller (water cooled)
LiBr_SE	Single Effect Lithium Bromide-water absorption chiller (water cooled)
m	parameter on the equation of PV modules efficiency
NH3_Air	air cooled water-ammonia absorption chiller
NPW	Net Present Worth (€)
OSE	Overall System Efficiency
p	parameter on the equation of PV modules efficiency
PDC	Parabolic Dish Collector
PTC	Parabolic Trough Collector
PV	Photovoltaics
PV aSi	amorphous silicon photovoltaics
PV mSi	mono-crystalline silicon photovoltaics
PV pSi	poly-crystalline silicon photovoltaics
q	parameter on the equation of PV modules efficiency
r	parameter on the equation of PV modules efficiency
s	parameter on the equation of PV modules efficiency
SilGel	Silica-Gel adsorption chiller
T	temperature (°C)
u	parameter on the equation of PV modules efficiency
VC_a	air cooled vapour compression chiller
VC_w	water cooled vapour compression chiller

Greek symbols

β	tilt angle
η	efficiency

Subscripts

0	refer to the zero-loss efficiency on the equation of thermal efficiency of solar thermal collector; reference state
1	refer to the first order coefficient on the equation of thermal efficiency of solar thermal collector ($W\,m^{-2}\,K^{-1}$)
2	refer to the second order coefficient on the equation of thermal efficiency of solar thermal collector ($W\,m^{-2}\,K^{-2}$)
a	air
cell	photovoltaic cell
cool	cooling
e	electric
H_2O	water
in	inlet
inv	inverter
m	mean
out	outlet
p, peak	peak conditions (cell temperature = 25 °C, air mass = 1.5, specific radiation on tilted surface = 1000 $W\,m^{-2}$)
PV	photovoltaic modules
spec	in specific terms
system	photovoltaic modules + inverter
th	related to the solar thermal collectors
wb	wet bulb

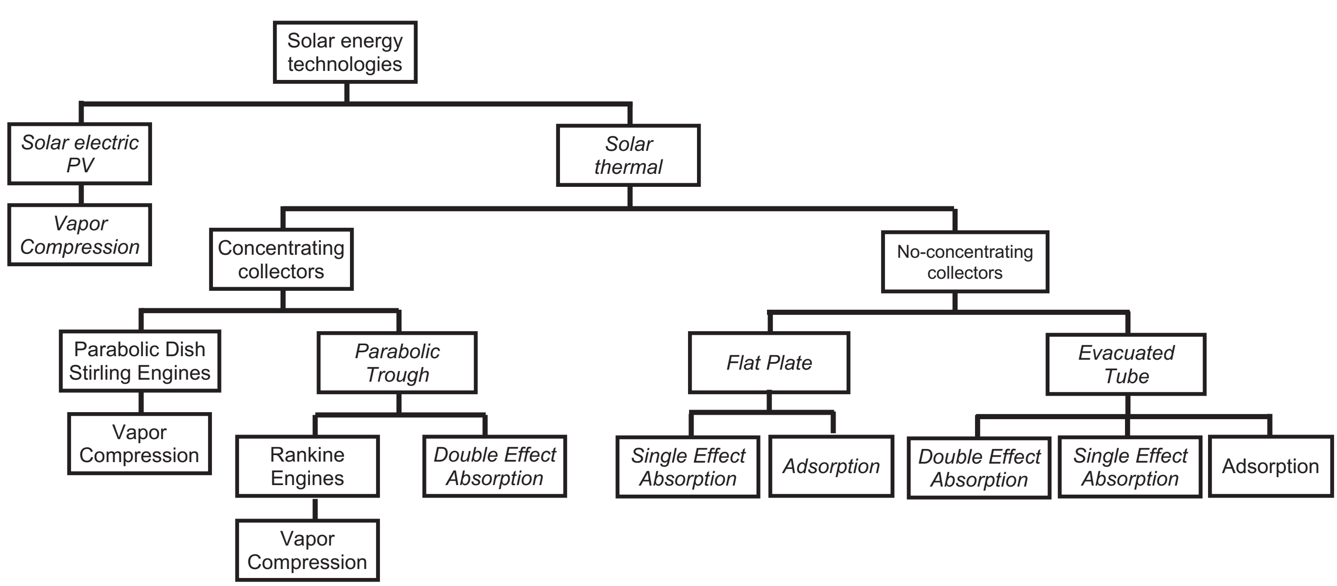

Fig. 1. Alternative routes from solar energy into cooling effect. In *italics* the technologies considered in the following energy and economic analysis.

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