# BETWEEN THE SOLAR REFRIGERATION AND THE SOLAR PHOTOVOLTAIC

**Lara ISSA, Nazih MOUBAYED**

*Lebanese University, Faculty of Engineering 1, nmoubayed@ieee.org*

***Abstract*** **– The human consumption of electrical energy became dangerous for the environment and it is necessary to reconsider our resources notably while making appear the part of the renewable one. Recent researches bring us to note that the renewable resources (coming from the sun, the terrestrial core and from the phenomena of tides) are enormous, often comfortably available for our long-term needs. In fact, with the increase of fossil fuel consumption worldwide, it is becoming even more urgent to find ways of using the renewable energy. One of the renewable energy plans is producing electricity directly from sun energy. Thus, photovoltaic panels are used. The produced energy is connected to a set of batteries in order to be stored and then used at any time (day or night). Another way is by using the sun energy indirectly for different applications. Some of these applications are heating and cooling. Solar panels are also used but the global conversion system is different from that which produces electricity. In this paper, the tow strategies in using sun energy directly from solar PV and indirectly as solar thermal energy are respectively treated. A comparison between these tow different strategies is discussed. Conclusions are finally given.**

***Keywords***: *Renewable energy, solar thermal, solar photovoltaic, adsorption, comparison study.*

## 1. INTRODUCTION

Lebanon that is located 33°54′N 35°32′E has no known fossil resources; all energy needs are met with imports of petroleum products. Therefore, Lebanon as government and as individuals needs to improve the utilization of renewable energies, with particular the solar energy, as one can capture a great amount of energy [1]. It should be noted that the average of daily isolation varies between 2.4 and 7 $KWh/m^2$ [2]. A promising way to use this energy is in cooling, especially that, the months with the peak demand for cooling coincide with the high solar energy availability, and the peak demand in the world is in the places that have a big need for cooling and lack of electricity providers such deserts [3]. Until now, solar systems are mostly limited to heating purposes and it may sound rather strange to use the sun energy to cooling goals, one have the ability to reduce the cost of the electricity bills; we can find the energy independence and preserve the future of the planet by using renewable energy [4].

Two ways are available to use this energy:

- the photovoltaic cells in producing electricity that can be used to feed the cooling system [5].
- the direct use of the sunlight for cooling system based on adsorption [6].

In order to know which system is the more efficient, a comparison is needed. Thus, this paper is organized as follows. Section 2 presents the photovoltaic energy. Section 3 is devoted to explain the adsorption system. A comparison between these two kinds of applications is discussed in section 4. Finally, conclusion is given in section 5.

## 2. PHOTOVOLTAIC SYSTEM

### 2.1. Photovoltaic cells brief history

The first discovery of the photoelectric effect was in 1839 by Edmund Becquerel, a nineteen year old French physicist. He found that certain materials would produce small amounts of electric current when exposed to light. The first solar cell has been developed in USA in 1950 [7].

### 2.2. Conversion principles

Photovoltaic panels are arrays of cells containing a solar photovoltaic material that converts solar radiation into direct current electricity; the photovoltaic effect refers to photons of light knocking electrons into a higher state of energy to create electricity. They transfer their energy to electrons that will immediately put in motion in a given direction, creating a continuous electrical current [8].

### 2.3. Photovoltaic panels

A PV Array is made up of PV modules, which are environmentally-sealed collections of PV Cells. The most common PV module is 5-to-25 square feet in size and weighs about 3-4 lbs/ft2. Often sets of four or more smaller modules are framed or attached together by struts in what is called a panel. They can be installed on fixed supports (Fig. 1) on the ground or on mobile devices tracking the sun, called trackers, in which case the electrical output increases by about 50% compared to a fixed [9].

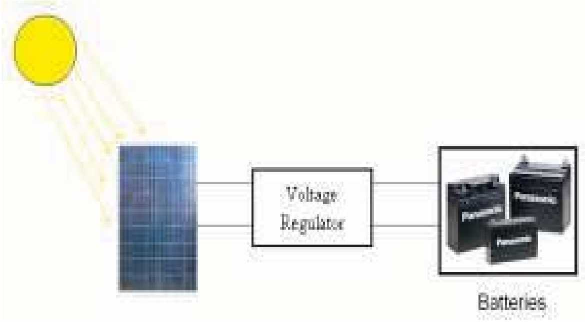


Figure 1: Photovoltaic panels.

PV systems produce power in proportion to the intensity of sunlight striking the solar array surface that vary through a day (depending on the position of the sun and the angle that the radiation strike the panel) as well as day to day and month to month, then, the actual output of a solar power system can vary substantial.

### 2.4. Factors that could affect the output

- *Standard Test Conditions:*
Solar modules produce DC electricity. The dc output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25ºC; solar irradiance (intensity) = 1 kW/m$^2$ and solar spectrum as filtered by passing through 1.5 thickness of atmosphere [10].

- *Temperature:*
Module output power reduces as module temperature increases. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50-75$^0$C. For crystalline modules, a typical temperature reduction factor recommended is 89% or 0.89 [11].

- *Dirt and dust:*
Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. A typical annual dust reduction factor to use is 93% or 0.93 [12].

-*Mismatch and wiring losses:*
The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and amounts to at least a 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses is 95% or 0.95 [13].

- *DC to AC conversion losses:*
The DC power generated by the solar module must be converted into common household AC power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Modern inverters commonly used in residential PV power systems have peak efficiencies of 92-94% indicated by their manufacturers, but these again are measured under well-controlled factory conditions. Actual field conditions usually result in overall DC-to-AC conversion efficiencies of about 88-92%, with 90% or 0.90 a reasonable compromise [10].

### 2.5. PV system with backup batteries

Conservative estimate of the annual energy expected from a typical PV system, taking into account the various factors discussed above. These values are for annual kWh produced from a 1-kilowatt (1kW) STC DC array, as a simple and easy guide. If the system includes battery backup the output may be reduced further by 6-10% due to battery effects (Fig. 2). This type of system incorporates energy storage in the form of a battery to keep “critical load” in this case air conditioner operating during a utility outage. When an outage occurs the unit disconnects from the utility and powers specific circuits in the home. If the outage occurs during daylight hours, the PV array is able to assist the battery in supplying the house loads. If the outage occurs at night, the battery supplies the load. The amount of time critical loads can operate depends on the amount of power they consume and the energy stored in the battery system. A typical backup battery system may provide about 8kWh of energy storage at an 8-hour discharge rate, which means that the battery will operate a 1-kW load for 8 hours [10].
Another system could be found the Grid-Interactive Only (No Battery Backup). This type of system only operates when the utility is available. Since we are using this system to feed an air conditioner or a freezer depending on the use of the cooling a high consumption is needed.

## 3. ADSORPTION SYSTEM

### 3.1. Introduction

Solar-assisted cooling for air-conditioning and refrigeration systems is gaining in interest as they have reached the near-market stage of development. This thermally driven process is more complex, being based on a thermo-chemical sorption process. A liquid or gas can either be attached to a solid, porous material (adsorption) or absorbed by another liquid or solid material (absorption).

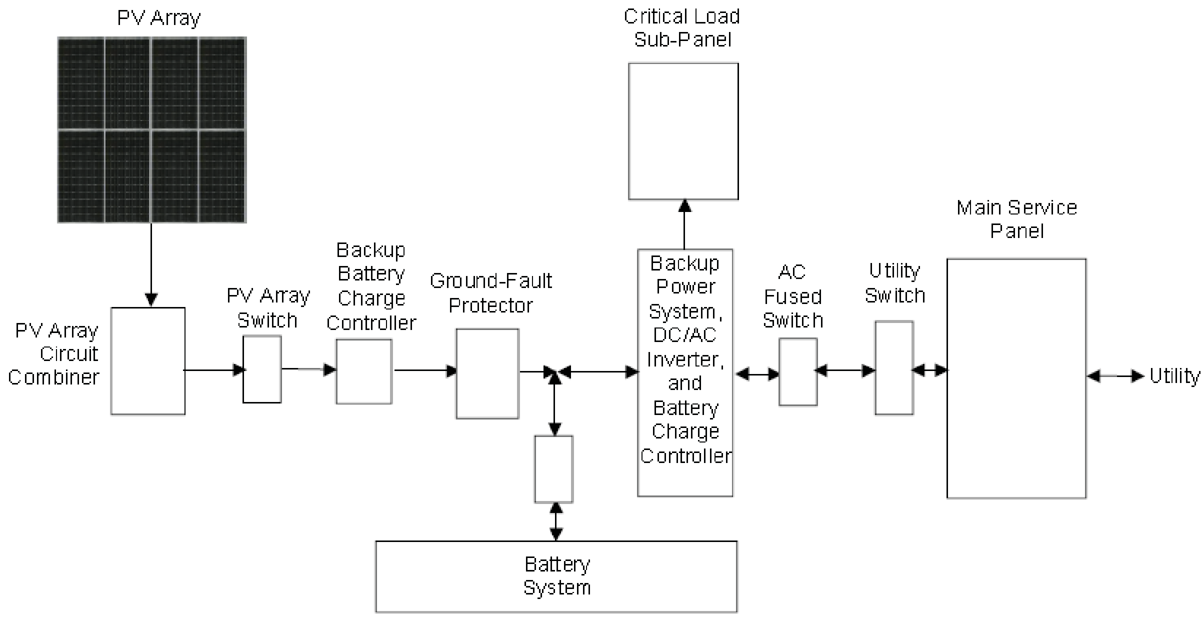


Figure 2: Grid-Interactive with battery backup [10].

Closed systems including both adsorption and absorption chillers can be used for central or decentralized conditioning. Open cooling cycles use desiccant and evaporative cooling systems that directly condition air [14].

### 3.2. Adsorption cycle phases

The conventional adsorption cycle has been presented extensively in the literature and it mainly includes two phases [15]:

1. Adsorbent cooling with adsorption process, which results in refrigerant evaporation inside the evaporator and, thus, in the desired refrigeration effect. At this phase, the sensible heat and the adsorption heat are consumed by a cooling medium, which is usually water or air.
2. Adsorbent heating with desorption process, also called generation, which results in refrigerant condensation at the condenser and heat release into the environment. The heat necessary for the generation process can be supplied by a low-grade heat source, such as solar energy, waste heat, etc.

The adsorption cycle is best understood with reference to the ***p-T-x*** (pressure-temperature-concentration) diagram of figure 3 [16] :

with:

$T_{a1}$ = temperature at start of adsorption,
$T_{a2}$ = temperature at end of adsorption,
***Te*** = evaporating temperature,
***Tc*** = condensing temperature,
$T_{g1}$ = temperature at start of generation,
$T_{g2}$ = temperature at end of generation.

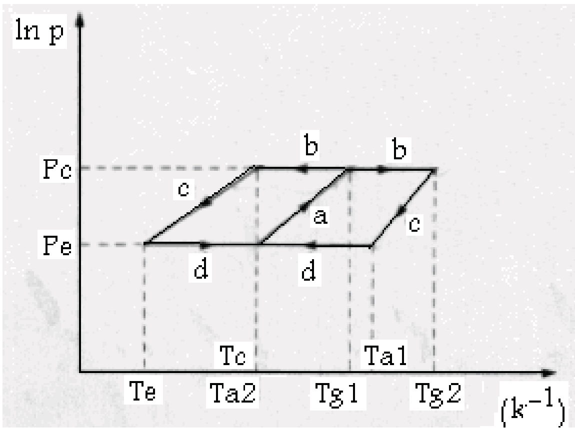


Figure 3: p-T-x diagram of a simple adsorption cycle.

The processes involved are as follows [16]:

1. Starting in the morning with the valve open and at ambient temperature of about 30ºC ***(Ta₂)*** the rich concentration adsorbent in the generator/absorber is heated by solar energy until the pressure reaches a level that enables refrigerant to desorbed and be condensed in an air or water cooled condenser.
2. Refrigerant is driven off at constant pressure. The adsorbent becoming more and more dilute until the maximum cycle temperature of about 100°C ***($Tg_2$)*** is reached. The condensed liquid is collected in a receiver.
3. The valve is shut, and the adsorbent cools and reduces its pressure. At some stage of the evening or night, its pressure will be the saturated vapor pressure of refrigerant at -10°C, ***(Te)*** which is sufficiently low for ice production.

**4.** The valve is now opened, and the liquid refrigerant starts to boil in the evaporator. Initially the refrigerant within the evaporator and receiver simply cools itself, but having dropped below 0°C it can start to freeze water. Adsorption is completed by the following morning, completing the cycle. During this process heat is released in the absorber and so the generator/absorber must be cooled be ambient temperature air or water.

### 3.3. Adsorption process

The process of adsorption involves separation of a substance from one phase accompanied by its accumulation or concentration at the surface of another. The adsorbing phase is the adsorbent, and the material concentrated or adsorbed at the surface of that phase is the adsorbate. It is caused mainly by van der Waals forces and electrostatic forces between adsorbate molecules and the atoms which compose the adsorbent surface. It is a reversible process by which a fluid molecule is fixed onto a solid matrix, typically a surface or a porous material. When the molecule is fixed, it loses some energy: adsorption is exothermic. Moreover, the thermodynamic equilibrium is divariant. This divariant equilibrium can be described by the set of isosters in the Clapeyron diagram [17].
Adsorbents are mostly micro porous, high specific surface materials (200 - 2000 $m^2/g$).Most commonly used: Alumina (drying), Silica gel (drying), Zeolite molecular sieves (gas & liquid separations, drying), Active carbon (gas & liquid separations, guard beds), Carbon molecular sieves [18].

### 3.4. Thermodynamics of adsorption cycles

Consider the ***p-T-x*** diagram of figure 3. ***Te*** depends on the application; air conditioning, ice making, deep freeze, etc (Table 1). ***Tc*** is a heat rejection temperature and should be as near to ambient as heat transfer and economics will allow. ***Ta2*** should be as low as possible so that the strong concentration is as high as possible—this maximizes the concentration change in desorption, thus minimizing the quantity of charcoal that must be wastefully heated and cooled with the adsorbed refrigerant. ***Ta2*** *is* also limited by ambient temperature and heat transfer considerations. Although ***Ta2*** is not necessarily equal to ***Tc*** (different heat exchangers may be used and the ambient temperature may change between adsorption and desorption). It is useful to consider the simple case where they are equal [16],[19]. The values of $Tg_2$ are normally within 2 to $5^oC$ of the results for detailed calculations on specific pairs. Given that $T_{g1}$ is the temperature at the start of generation and that in practice $T_{g2}$ will be at least 10°C higher (probably more) the importance of keeping $Ta_2$ low can be seen [20],[21].

Heat rejection from the condenser and adsorber should be as close to ambient as possible to avoid excessively high solar collection temperatures. The assumption that $T_{a2} = Tc$, is reasonable in many circumstances but may not be true for a diurnal cycle in a climate with large diurnal temperature variations. The maximum cycle temperature $T_{g2}$ is not fixed by the above relationships but is a design variable that must be optimized. The higher $T_{g2}$, the more refrigerant is driven off and so the greater the cooling effect per Unit mass of adsorbent. However, progressively fewer refrigerants is desorbed as the temperature rises, and the extra heat input is mainly used in sensible heating of adsorbent and refrigerant, rather than in desorption [19]. Table 2 represents the performance of adsorption systens for different applications.

| Application | Ambiente Temperature | Te ºC | $T_{a2}$ ºC | $T_{g1}$ ºC |
|---|---|---|---|---|
| Freezing | Moderate | -20 | 25 | 79 |
| | Hot | -20 | 45 | 126 |
| Ice Making | Moderate | -10 | 25 | 65 |
| | Hot | -10 | 45 | 112 |
| Air Conditionning | Moderate | 5 | 25 | 46 |
| | Hot | 5 | 45 | 91 |

Table 1: Typical cycle Temperature [16].

## 4. COMPARISION

Adsorption systems have the benefits of energy saving if powered by solar energy, simpler control, no vibration and lower operation costs. Adsorption refrigerants present the advantage of being able to be powered by a large range of heat source temperature, starting at 50 $^0$C and going up to 500 $^0$C, and could use plus the solar energy wasted heat of any source. The latter kind of system does not need a liquid pump or rectifier for the refrigerant, does not present corrosion problems due to the working pairs normally used, less sensitive to shocks and to the installation position. These last two features make it suitable for applications in locomotives, busses, boats and spacecrafts. Although, adsorption systems present all the benefits listed above, they usually also have the drawbacks of low COP and low specific cooling power (SCP). However, these inconvenient can be overcome by the intensification of the heat and mass transfer properties of the working pairs and by a better heat management during the adsorption cycle. Thus, most research on this kind of system is related to the evaluation of the adsorption and physical-chemical of the working pairs, to the development of predictive models of their behavior in different working conditions, and the study of the different kinds of cycles. Numerical and experimental studies have been carried out, but the costs of these systems still make them non-competitive for commercialization.

| Application | Heat source temperature or insolation | Working Pair | COP | SCP or ice production | Year |
|---|---|---|---|---|---|
| Ice making | 20 $MJm^{-2}day^{-1}$ | AC-Methanol | 0.12 | 6 kg $day^{-1}$ $m^{-2}$ | 1986 |
| Ice making | 105 °C | AC- $NH_3$ | 0.10 | 35 W $kg^{-1}$ | 1997 |
| Ice making | 18.1 – 19.2 $MJm^{-2}day^{-1}$ | AC-Methanol | 0.12 - 0.14 | 5.0 – 6.0 kg $day^{-1}$ $m^{-2}$ | 2002 |
| Ice making | 17 – 20 $MJm^{-2}day^{-1}$ | AC-Methanol | 0.13 - 0.15 | 6.0 – 7.0 kg $day^{-1}$ $m^{-2}$ | 2004 |
| Ice making | 15.4 $MJm^{-2}day^{-1}$ | Silica gel-water | [1]0.16 | 2.05 MJ $day^{-1}$ $m^{-2}$ | 2004 |
| Ice making | 20 $MJm^{-2}day^{-1}$ | AC+blackened steel-Methanol | 0.16 | [2]9.4 kg $day^{-1}$ $m^{-2}$ | 2004 |
| Ice making | <120 °C | AC-Methanol | 0.18 | 27 W $kg^{-1}$ | 2005 |
| Ice making | <120 °C | AC+$CaCl_2$-$NH_3$ | 0.41 | [3]731 W $kg^{-1}$ | 2005 |
| Chilled water | 55 °C | Silica gel-Water | 0.36 | 3.2 kW $Unit^{-1}$ | 2001 |
| Chilled water | 100 °C | AC-Methanol | 0.4 | 73.1 W $kg^{-1}$ | 2001 |
| Chilled water | 65 °C | Silica gel-Water | 0.28 | 12.0 kW $Unit^{-1}$ | 2003 |
| Chilled water | 75 – 95 °C | Silica gel-Water | 0.35-0.60 | 15.0 $kWm^{-3}$ | 2004 |
| Chilled water | 80 – 95 °C | Silica gel-Water | 0.3-0.6 | [5]20 $Wkg^{-1}$ | 2004 |
| Chilled water | 80 °C | Silica gel-Water | 0.33-0.5 | 91.7-171.8 W $kg^{-1}$ | 2005 |
| Air conditioning | 232 °C | AC-$NH_3$ | 0.42-1.19 | [6]NA | 1996 |
| Air conditioning | 204 °C | Zeolite-Water | 0.6-1.6 | 36-144 W $kg^{-1}$ | 1988 |
| Air conditioning | 230 °C | Zeolite-Water | 0.41 | 97 W $kg^{-1}$ | 1999 |
| Air conditioning | 310 °C | Zeolite-Water | 0.38 | 25.7 W $kg^{-1}$ | 2000 |
| Air conditioning | 100 °C | AC-$NH_3$ | 0.2 | 600 W $kg^{-1}$ | 2003 |
| Air conditioning | 230 – 300 °C | Zeolite-Water | 0.20 - 0.21 | 21.4 – 30 W $kg^{-1}$ | 2004 |

[1] Average value obtained during 30 days of continuous operation.
[2]. Based on the area of the adsorber, which was different from the area of the reflector panels.
[3]. The SCP is based on the mass of $CaCl_2$ inside one adsorbent bed and on the adsorption time.
[4] To be published in International Journal of Refrigeration.
[5] At generation temperature of 95 °C.
[6] Not informed.

Where:
SCP is the Specific Cooling Power,
COP is the Coefficient Of Performance.

Table 2 : Performance of adsorption systems for different applications [19].

Advantages of adsorption chillers are:

- Applicable in most climates,
- Much cheaper than photovoltaic solar conventional air conditioners.

The disadvantages of this approach are:

- For acceptable system efficiencies, the water needs to be heated in an expensive high performance (usually concentrating collector), not a conventional flat plate collector,
- A maximum of only about 50% energy use reduction is feasible,
- Currently only available for commercial buildings,
- Other greenhouse gas reduction approaches are much cheaper per tonne of $CO_2$ saved.

A solar photovoltaic array (solar cells) can be connected to a conventional air conditioner, (although typically a particularly efficient design is chosen). This one requires enormous power [22]. All existing types of conventional air conditioners are actually only solar assist air conditioners. Based on published researches, solar power contributes about 10-20% of the used power. In addition, if an efficient approach is proposed, the energy use might be 30% less than the energy used for a conventional air conditioner.

Advantages of this approach are:

- Applicable in most climates,

The disadvantages of this approach are:

- Solar cells are way too expensive to provide a 100% solar powered design for a conventional home,
- Generally this is pure tokenism,
- Other greenhouse gas reduction approaches are much cheaper per tonne of $CO_2$ saved.

## 5. CONCLUSION

Solar energy offers an economical, ecological, green alternative to fossil and nuclear power plants. It is clean and produces no air or water pollution. In this paper, solar chillers and solar PV systems are presented, discussed and compared. In worldwide, the adsorption technology has not been widely applied and needs more efforts to give reliability and to reduce costs that can compete with conventional cooling technologies. In Lebanon, researchers are started to develop this technology which is recently introduced in some universities. In Lebanon, the investment in installation of photovoltaic systems in order to produce electricity is very high regarding the actual price of kWh paid to the state.

## References


[1] *Possibilité et vision de la production de l'énergie des sources d'énergie renouvelables dans les pays d'ESCWA*. Rapport interne des Nations Unies, vol. 3, (2001).

[2] Olgyay A & V, *Solar control and shading devices*, Book, Princeton (1976).

[3] Höfker, G, *Desiccant Cooling with Solar Energy*. PhD thesis. De Montfort University Leicester, 2001.

[4] C. Cromer, *Solar Pool Heating: A Question and Answer Primer*, Solar Today 9(3): pp 32-34, May/June, 1995.

[5] Astier S., *L'électricité photovoltaïque connectée au réseau : une énergie en plein essor*, La Revue 3EI, n° 39, 32-45 (2004).

[6] H. Schweiger et al., *The Potential of Solar Heat for Industrial Processes*, POSHIP Project, Final Report, 2001.

[7] Web site: *http://www.schoolgen.co.nz/se/pv_history.aspx*.

[8] Web site: *http://en.wikipedia.org/wiki/Photovoltaics.*

[9] Web site: *http://megaquest.us/GlobalRealEstate.html.*

[10] California Energy Commission, *A guide to photovoltaic (PV) system design and installation*, Consultant report, June 2001.

[11] Web site: *http://xihesolar.com/NewsView.Asp?ID=21.*

[12] Web site: *http://www.consol.ws/builder-resources/.*

[13] Web site: *http://syllabusforpvsolarinstaller.blogspot.com/.*

[14] Solar cooling project (ProEcoPolyNet), *Network for the promotion of RTD results in the field of Eco-building technologies, small polygeneration and renewable heating and cooling technologies for buildings*, Berliner Energie Agentur GmbH (BEA), 2004.

[15] F. Poyelle, J.J. Guilleminot and F. Meunier, Experimental tests and predictive model of an adsorptive air conditioning unit, Ind. Eng. Chem. Res. **38** (1999), pp. 298–309.

[16] Duardo D. Sagredo PE, *Design And Construction Of A Solar Energy Refrigeration System Using Vacuum Concentric Tubes With Adsorption*, (LACCEI'2004), 2-4 June 2004, Miami, Florida, USA

[17] Web site: *http://www.aquatechnologies.com/.*

[18] Web site: *http://ias.vub.ac.be/.*

[19] R.E. Critoph, *Performance limitations of adsorption cycles for solar cooling*, Solar Energy, Volume 41, Issue 1, 1988, Pages 21-31.

[20] IEA 2006. Barriers to technology diffusion: the case of solar thermal technologies. International Energy Agency, OECD/IEA, Paris, 2006.

[21] IEA 2007a: Renewables for Heating and cooling – Untapped Potential, IEA, Paris 2007.

[22] Sun & Wind Energy 2007. Sun & Wind Energy, international issue 4/2007, Bielefeld 2007.