

A REVIEW OF SOLAR ASSISTED COOLING TECHNIQUES

A. Syed¹, G. G. Maidment¹, J. F. Missenden¹, R. M. Tozer^{1,2}

¹South Bank University, Centre for Air-conditioning and Refrigeration Research, 103 Borough Road, SE1 OAA, London, United Kingdom.

²Waterman Gore – M&E Consulting Engineers, Versailles Court, 3 Paris Garden, SE1 8ND, London, United Kingdom.

ABSTRACT

This paper provides a review of recent developments and future prospects in the field of solar cooling systems from their applications in air-conditioning and refrigeration. 20 solar-thermal cooling system combinations based on 5 thermal/ PV cooling cycle technologies and 3 collector types have been identified with respect to 4 cooling temperature ranges. These are liquid and solid based systems in open or closed cycle configurations, from absorption to Rankine heat engine technologies powered by heat derived from flat-plate to concentrating collectors. The 4 operating temperature ranges used are 12 to 20°C, 4 to 12°C, -17 to 0°C and -40 to -20°C for high and low temperature air-conditioning and high to medium and medium to low temperature refrigeration applications, respectively. The systems have been compared using the Solar Coefficient of Performance (SCOP); this combines the solar collection efficiency with the efficiency of the cooling cycle.

The review indicates that in the 12 to 20°C application temperature range, the PV-Compression unit achieves the highest SCOP of approximately 1.1. PV-Compression also competes with double-effect absorption at 4 to 12°C with a SCOP of 0.79-0.60. The same system is also the preferred choice for cold storage and ice-making applications at -17 to 0°C, 0.523-0.350. Moreover, for deep-freezing at -40 to -20°C, the suitability of PV-Compression and single effect-NH₃/H₂O, 0.259-0.215; 0.230-0.129, respectively has been shown.

The comparative results have been used to allow the best systems to be selected for each application.

KEYWORDS

Solar, Sorption, Cooling, Desiccant, Systems, Cycles, Coefficient of Performance.

1.0 INTRODUCTION

Present day air-conditioning and refrigeration of buildings make a significant contribution to the greenhouse effect directly through the leakage of refrigerant greenhouse gases. They also contribute indirectly through the emission of CO₂, which results from the burning of fossil fuels in the production of electricity. This is used to power mechanical compression refrigeration cycles, which dominate the HVAC&R market both in the UK and overseas. In the UK alone, building air-conditioning systems contribute 10-20% of greenhouse gases [1]. This percentage is much higher for developing countries where more than half the world's population resides. These locations receive plentiful solar radiation, which is coincident with the need for cooling. This has been the single most important motive for sustained research in the field of solar cooling over three decades. However, interest in solar powered cooling for buildings was first shown during the energy crisis of the 1970s when a number of demonstration projects involving single-effect absorption cycles for cold generation were conducted in the United States [2, 3, 4]. This research trend continued throughout the early part of the 1980s in Central America & the Middle East [5, 6]. Although technical potential was shown with lower than expected cycle COPs of 0.75-0.52 and 0.512-0.352 for LiBr/H₂O and NH₃/H₂O systems respectively, these systems failed to

establish significant global market share of cooling systems. Additionally, this was due to their high initial costs of approximately 4:1, as a fraction of the cost of investing in a compression chiller of the same cooling capacity which resulted in longer than acceptable payback periods of 13.5 years [7]. This technical/ economic drawback was the reason for a shift in theoretical as well as experimental research trend towards alternative heat driven cooling systems and novel sorption refrigerants utilising existing solar energy collection/ conversion technologies after the mid-1980s.

Present day research should aim to resolve this long-standing technical/ economic problem which evolved as a result of adhoc system applications and lack of industry standards against which solar cooling system can be rated.

As such, this paper presents a generic framework for the classification of 20 solar cooling technologies and their efficiency comparisons.

2.0 OVERVIEW OF RESEARCH IN SOLAR HEAT POWERED CYCLES

Solar energy can be used to drive directly three thermodynamic cooling systems based on desiccant, absorption and adsorption cycles. In addition, it can be

used to power indirectly two secondary cooling cycles of Rankine vapour compression and photovoltaic vapour compression by thermo-electric conversion. In each of the thermodynamic systems, heat from the Sun is converted into cooling by increasing the temperature and pressure of a binary mixture of refrigerant and sorbent. This process is conventionally achieved in a compressor of a mechanical compression refrigeration system, which is present in the thermo-electric systems. The processes of condensation and evaporation are common to both types of cycles, which differ only in the number of heat exchangers required for regenerating the sorbent/ refrigerant in heat powered cycles. These systems have been reported in independent investigations:-

2.1 Desiccant Systems

Three system types (two solid and one liquid) of open cycle solar desiccant air-conditioning have been reported. These use evaporative cooling with desiccant dehumidification. The original concept was applied to the Pennington Cycle, which uses a rotating wheel embedded with solid desiccant silica gel to transfer the latent heat of vaporisation of incoming fresh air to the moist exhaust air, which is responsible for regenerating the sorbent. The second type of solid system, in which a fixed bed of desiccant is present, works on the same principle of sequential dehumidification and heat transfer cooling. Experimental investigations on this type of system have been carried out in two independent studies by Lu et al. [8, 9] and Pesaran and Wipke [10]. Their systems showed thermal COPs not exceeding 1.0. However, these systems have been shown to be inferior to the liquid desiccant system in which the processes of cooling and dehumidification occur simultaneously resulting in a COP of 1.2 to provide cooling at 25°C, determined from a simulation study at absorber temperature of 40°C and humidity ratio of 0.026kg H₂O/kg dry air [11]. Higher COPs of over 2.0 may be expected from liquid desiccant systems according to laboratory tests carried out at ambient temperature of 35°C and 40% RH [12]. All three systems are commercially available and can be economically applied to low temperature flat-plate collectors (solid systems) and evacuated tube collectors (liquid systems) for heat source temperatures in the range of 70 to 50°C and not exceeding 110°C, for solid and liquid systems, respectively.

2.2 Absorption Systems

Eleven system types in open and closed configurations have been reported to belong to liquid/vapour and solid/vapour states of sorbent/ refrigerant pairs. The performance of these systems have been studied extensively by earlier investigators whose studies show that their cycle COP falls in the range of 1.460-0.152 [13, 14].

2.2.1 Liquid Systems

These can be further subdivided into closed cycles and open cycles. Of the former type, the single-effect system for the supply of chilled water (LiBr/H₂O) or a range of

refrigeration temperatures down to -40°C (NH₃/H₂O) has been researched significantly more than the other system types [15]. The main emphasis of earlier investigations was to demonstrate the integration of low-medium temperature (70 to 130°C) flat plate collectors or more efficient evacuated tube collectors with improved COPs of cooling systems [16]. Open cycle systems using LiCl/H₂O have been thoroughly reviewed by Hawlander who stated that the most important component for efficient performance of the system is the collector/ regenerator [17].

2.2.2 Solid Systems

Contrary to desiccant systems, the three known solid absorption systems are only found in closed cycle configuration. Research in these technologies has been active since 1985 when the first CaCl₂/NH₃ ice-maker was experimentally demonstrated by Illoeje in Nigeria [18]. Since then, a number of units based on SrCl₂/NH₃ and chemical reaction-SrCl₂/NH₃ [19, 20] have been designed and tested with success. The main difference between the solid and liquid system types is that these do not require a pump for circulating the refrigerant through the evaporator and condenser, hence are only available in small capacities not exceeding 0.46kW for the Chemical Reaction unit.

2.3 Adsorption Systems

Similar in operating characteristics to the solid absorption systems, the *adsorption* (solid sorption) systems work intermittently in two processes namely, desorption/*adsorption*. Four units have been demonstrated to date utilising low-high temperature heat (60 to 154°C) of non-concentrating as well as concentrating collector types [21, 22]. The Silica-gel water is the only *adsorption* water chiller commercially available. Generally, their COPs are the lowest of all known solar cooling systems, at 0.600-0.019.

2.4 Rankine- Compression System

This system consists of a Rankine power cycle driven by solar heat, which produces shaft power to drive high efficiency mechanical compression cycle that produces cooling. The Rankine cycle with the preferred Rankine drive at conventional electric motor speed to power the compressors of the vapour compression chiller utilises R113 at temperatures ≤ 204°C, Toluene ≤ 371°C and Steam >371°C [23]. Therefore only Organic Rankine Cycle Engines (ORCE) that provide ≤ 1MW of electrical power have been driven by low temperature heat of solar collectors. Expected system performance for combined Rankine/vapour system is 0.8-0.6 at 93 to 77°C for use with flat-plate or ETC collectors and extend ≤1.2-1.0 at 149°C for use with CPC collectors. However thermal COP of 0.7-0.6 (vapour cycle COP=5-3) was actually achieved for three installations [24]. Recent developments in ejector compression systems (ECS) for solar tri-generation (CCHP) applications by Oliveira et al. [25] has created an opportunity to realise low installation costs. However, achieved COPs as low as 0.14 may render these systems unattractive, although

theoretical COP of 0.3 has been obtained by Huang et al. [26].

2.5 Photovoltaic- Compression Systems

The process of direct conversion of solar insolation into AC current which is subsequently converted to DC through an inverter to power mechanical chillers that provide cooling cannot be referred to as a solar-thermal cooling cycle. However, the ratio of capital cost of PV: solar absorption cooling is estimated at approximately 1:8 which makes this technology presently an attractive option for solar air-conditioning. Results of two Joule Projects have shown promise in air-conditioning and cold storage. In the first case, a 1kW (COP=4-2.5) prototype air-conditioner was built and connected to a 1.2kW output array of PV cells activated by threshold insolation of 450W/m² [27]. Two cold storage prototypes were built and tested in Spain. Results show that their operation has been satisfactory over a range of climatic conditions and a variety of foodstuffs [28].

3.0 CLASSIFICATION AND COMPARISON OF SYSTEMS

Historically, solar cooling systems have been classified on the basis of a triad scheme of resource-technology-use to identify 19 combinations based on 7 solar collector technologies, 8 cooling technologies and 3 operating temperature ranges [29, 30]. This was done through a survey using a questionnaire to suggest only the viable options. From this, the degree of development of each option was evaluated. The same method for assessing the viability of solar systems was adopted in a later study with a limited scope [31]. The present study classifies the systems based on the following factors:-

1. Process type.
2. Sorbent phase.
3. Cycle configuration.
4. Cooling cycles.
5. Market availability.

These factors that distinguish between the various forms of solar cooling systems are given in Table 1. The 20 solar cooling cycles contained in Table 1 were then compared on the basis of their attainable Solar Coefficient of Performance (SCOP) at the specified application temperatures and presented in Figure 1. The data pertaining to this has been derived by evaluating the cycle COPs using established correlations that relate the desorption and application temperatures at specified cooling water temperatures for a number of known technologies. This data is presented in Table 2. In addition, a computer software has been used to derive the COP of the vapour compression cycle using a model of a semi-hermetic reciprocating compressor [Bitzer, 2000] with R134a. This is able to predict the refrigeration effect and power input to the compressor by varying the evaporating temperature at fixed condensing temperature (40°C). Where such detailed information was unavailable, general values were used from cases of applied systems. Similarly, the solar collector efficiencies were evaluated for various collector inlet temperatures at peak conditions.

Table 1- Classification criteria for solar cooling units.

Process Type	Phase	Cycle Config.	Unit Type	Market Avail.
Desiccant	Solid	Open	Fixed bed/Silica gel	Current
			Rotating/Silica gel	Current
	Liquid	Open	Spray-LiBr	Current
Absorption	Liquid	Closed	LiBr	Future
			SE-LiBr/H ₂ O	Current
			DE-LiBr/H ₂ O	Future
			SE/DL-H ₂ O/H ₂ O-LiBr	Future
			2S-LiBr/H ₂ O	Future
			Diffusion-NH ₃ /H ₂ O+H ₂	Future
			1S-NH ₃ /H ₂ O	Future
			SE-NH ₃ /H ₂ O	Current
	Solid	Closed	Chemical Reaction-SrCl ₂ /NH ₃	Future
			SrCl ₂ /NH ₃	Future
			CaCl ₂ /NH ₃	Future
Adsorption	Solid	Closed	Active C/NH ₃	Future
			Zeolite/H ₂ O	Future
			Silica gel/H ₂ O	Current
			Active C-CH ₃ OH	Future
Rankine-Comp.	Liquid	Closed	R-11/R-12/R141b	Future
PV Comp.	Liquid	Closed	Mono-crystalline Silicon/R134a	Future

3.1 Results and Discussion

Solar cooling systems are specified on the basis of available solar collector temperatures. Therefore the solar collectors are specified according to the required process desorption temperatures. Typical percentage collector efficiencies are 32.6-12.6%, 52.5-54% and 55-45% for inlet temperatures of 27 to 77°C, 47 to 187°C and 67 to 160°C for flat plate, evacuated tube (ETC) and concentrating parabolic collectors (CPC), respectively [32]. However, specific values of collector efficiencies are calculated from the Hottel-Whiller equation for flat plate/ETC and CPC absorbers given in equations 1 and 2, respectively [33]:-

$$\eta_{\text{flat plate/ETC}} = F_R(\tau\alpha) - F_R U_L (T_f - T_a) / I_T \quad (1)$$

$$\eta_{\text{CPC}} = F_R / N_s \{ (\tau\alpha) - U_L (T_f - T_a) \} \quad (2)$$

$$\text{where } F_R = m C_p / U_L [1 - \exp(-U_L F' / m C_p)]. \quad (3)$$

$$(\tau\alpha) = I_{\text{bt}}(\tau\alpha)_b + I_{\text{dt}}(\tau\alpha)_d / I_T \quad (4)$$

$$F' = R_{\text{ra}} / (R_{\text{fr}} + R_{\text{ra}}); \text{ where } \quad (5)$$

$R_{\text{ra}} = 1/U_L$ and R_{fr} is the thermal resistance between the working fluid and the receiver surface conduits of the CPC. Equations 3 to 5 give the heat removal factor, transmittance - absorptance product and collector efficiency factor, which were used in the calculation of the CPC collector efficiency.

Table 2 gives the source and data format used in used to calculate the COP values for each of the 20 cooling cycles.

4.0 GENERIC SYSTEM TYPES

Although no overall comparison of all available solar cooling systems was made, Ileri in his study suggested that system comparison based on their energetic COPs (rather than exergetic COP) is valid and sufficient in the case of systems with similar operating temperature ranges differing only in working fluid pairs [34]. The present study has compared the system SCOP data based on 4 operating temperature ranges for 5 applications as follows:-

1. 12 to 20°C for direct cooling of supply air stream (high temperature air-conditioning).
2. 4 to 12°C for providing chilled water (low temperature air-conditioning)
3. -17 to 0°C for ice making/ cold storage (high-medium temperature refrigeration)
4. -40 to 0°C for ice making/ cold storage and deep-freezing (high to low temperature refrigeration).

Generally, higher solar COPs are achieved by systems operating at higher temperatures as compared to low temperature applications as shown in Figure 1.

4.1 High temperature air-conditioning systems

10 systems (7 closed and 3 open cycle) occupy the category of 12 to 20°C for air-conditioning application. Direct comparison of their attainable SCOPs show that the PV- Vapour Compression system attains the highest SCOP of 1.102 at 20°C. Generally, liquid systems perform better than solid systems for the same application because the former require lower driving temperatures for desorption as well as lower specific solution flow rates, f , that the latter, due to continuous versus intermittent operations for the two system types, respectively. However, it has been shown that for identical boundary conditions, the theoretical minimum driving temperature for liquid absorption and solid sorption systems are nearly identical [35].

4.2 Low temperature air-conditioning systems

Figure 2 also shows the attainable SCOPs for 11 units in the 4 to 12°C range for low temperature air-conditioning applications. These systems mainly consist of closed cycles with the exception to the open cycle LiBr chiller. The PV- Compression system attains the highest SCOP of 0.79 at 12°C which is followed closely by the liquid double-effect absorption system at 0.70 (12°C).

4.3 High to medium temperature refrigeration systems

In the first of two temperature ranges for refrigeration systems, 8 units occupy the -17 to 0°C range for ice-making and cold storage applications. Again, the PV-compression system shows highest SCOPs at 0.523-0.350, followed by the single-stage $\text{NH}_3/\text{H}_2\text{O}$ (0.316-0.293) and single-effect $\text{NH}_3/\text{H}_2\text{O}$ (0.294-0.252) systems, and finally the solid sorption systems.

4.4 Medium to low temperature refrigeration systems

As an extension to the previous application temperature range of cooling systems, two deep-freezers have been identified that can provide temperatures as low as -40 to -20°C. These are the SE- $\text{NH}_3/\text{H}_2\text{O}$ and PV-Compression units with SCOPs ranging between 0.181-0.129 (at -40 to -20°C) and 0.314-0.226 (at -30 to -20°C), respectively.

5.0 CONCLUSIONS

This paper presents a framework for classification and comparison of 20 presently available and forthcoming technology options for solar air-conditioning, ice making and deep-freezing depending on the required application temperatures.

The predicted performance parameters of the cycle COP and solar collector efficiencies (based on the required desorption temperatures) produce system specific solar cooling COPs. Backed by cases of operational equipment as well as experimental projects throughout the world, these values offer a benchmark for assessment of solar cooling schemes at any location.

The results indicate that the preferred choice of system types for low temperature water chilling (4 to 12°C), high temperature direct cooling of supply air (12 to 20°C), high to medium temperature refrigeration (cold storage/ ice making, -17 to 0°C) and medium to low temperature refrigeration (-40 to -20°C), respectively are:-

1. PV- Compression.
2. Double-effect absorption (LiBr/ H_2O).
3. Single-effect absorption ($\text{NH}_3/\text{H}_2\text{O}$).

6.0 FURTHER WORK

It would be of interest to compare the exergetic COP (EXCOP) of the various sorption systems with the mechanical compression system at the given cooling temperatures. From this to assess the relative economic rank of the alternatives based on a detailed life cycle cost analysis with different qualities of primary energy sources for auxiliary backup. This is because the prices of energy sources are proportional at a much closer degree to the exergy content than their energy content.

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8.0 NOMENCLATURE

η	Collector efficiency	dimensionless
$(\tau\alpha)$	Transmittance – absorptance product	dimensionless
C_p	Fluid specific heat capacity	kJ/kgK
F'	Fin efficiency factor	dimensionless
F_R	Overall collector heat removal efficiency factor	dimensionless
I_{bt}	Incident beam radiation	Wm ⁻²
I_{dt}	Incident diffuse radiation	Wm ⁻²
I_T	Total incident radiation on flat surface	Wm ⁻²
m	Mass flow rate	kg/s
N_s	Number of identical collectors mounted in series	
R_{ra}	Thermal resistance between receiver and ambient air	dimensionless
T_a	Ambient dry-bulb temperature	K
T_i	Collector inlet temperature	K
U_L	Overall heat loss coefficient	Wm ⁻²

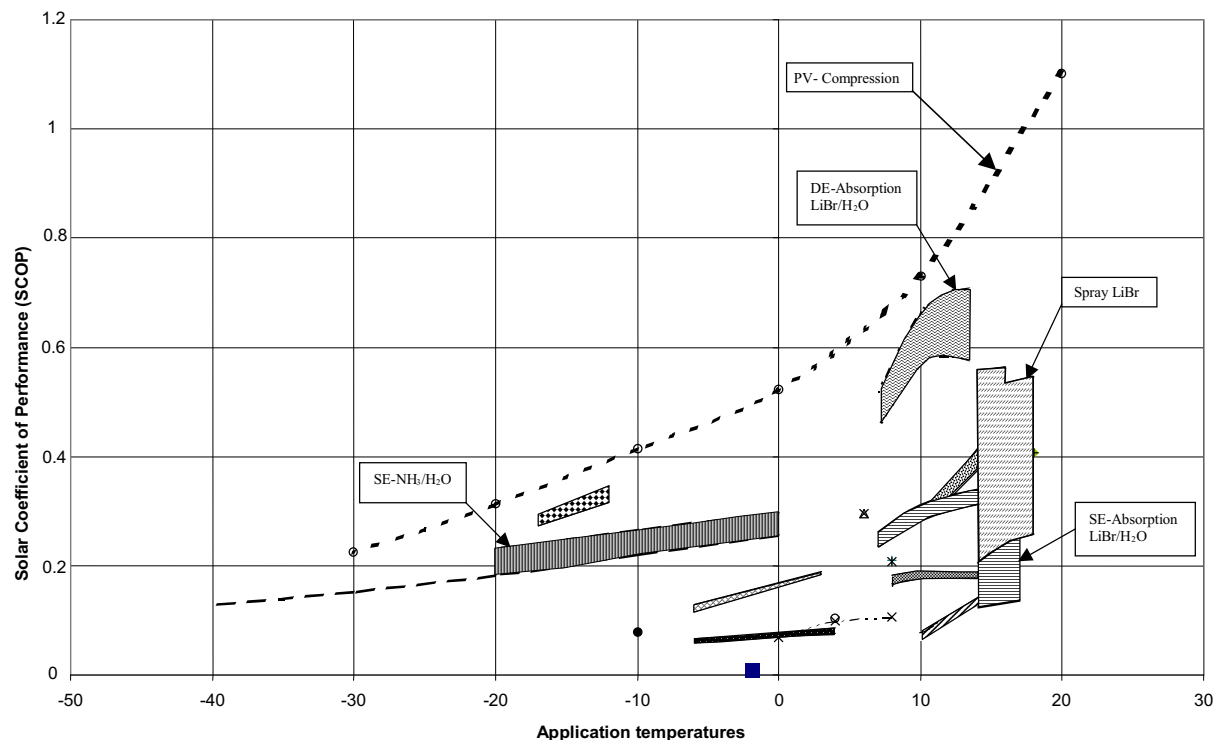


Figure 1- Performance comparison of liquid and solid solar cooling systems based on four application temperature ranges.

Table 2- Efficiency comparison of solar cooling schemes based on required application temperatures.

* Data obtained through use of software.

** General values taken from case studies.

*** Specific values taken from graphs.

Assumptions:1. Ambient dry-bulb temperature, $T_a = 303\text{K}$.2. Average incident solar radiation = 850Wm^{-2} .3. Collector inlet water temperature, $T_{f,in}$ is $30\text{K} < T_{\text{desorption}}$.4. Solar incidence angle, $i > 0$.

App Temps (°C)	Desorp Temps (°C)	Collector Inlet Temps (°C)	Cycle COP	Cycle Type	Collector Efficiency	Collector Type	Data Source
20	N/A	N/A	6.89*	Vapour Compression	0.16-0.15	PV	Green (2001) ^{1A} ;
18	70-50	65	1.0-0.6**	Fixed bed-Silica gel	0.234	Flat Plate	IEA Annex 24 ^{2A} ;
18	70-50	65	1.0-0.6**	Fixed bed-Silica gel	0.507	ETC	IEA Annex 24;
18	70-50	65	1.0-0.6**	Rotary-Silica gel	0.234	Flat Plate	IEA Annex 24
18	70-50	65	1.0-0.6**	Rotary-Silica gel	0.507	ETC	IEA Annex 24
18	68	63	1.07***	Spray-LiBr	0.240	Flat Plate	Ahmed (1997) ^{3A}
18	68	63	1.07***	Spray-LiBr	0.509	ETC	Ahmed (1997)
17	75	70	0.625***	Single Effect-LiBr/H ₂ O	0.218	Flat Plate	IEA Annex 24
17	75	70	0.625***	Single Effect-LiBr/H ₂ O	0.498	ETC	IEA Annex 24
17	75	70	0.625***	Single Effect-LiBr/H ₂ O	0.530	CPC	IEA Annex 24
16	69	64	0.320**	Ch. React.-SrCl ₂ /NH ₃	0.222	Flat Plate	Nahrendorf et al (1998) ^{4A}
16	69	64	0.320**	Ch. React.-SrCl ₂ /NH ₃	0.499	ETC	Nahrendorf et al (1998)
16	69	64	0.320**	Ch. React.-SrCl ₂ /NH ₃	0.535	CPC	Nahrendorf et al (1998)
16	72	67	1.06***	Spray-LiBr	0.226	Flat Plate	Ahmed (1997)
16	72	67	1.06***	Spray-LiBr	0.503	ETC	Ahmed (1997)
16	72	67	1.06***	Spray-LiBr	0.532	CPC	Ahmed (1997)
15	76	71	1.05***	Spray-LiBr	0.212	Flat Plate	Ahmed (1997)
14	80	75	1.04***	Spray-LiBr	0.196	Flat Plate	Ahmed (1997)
14	80	75	1.04***	Spray-LiBr	0.490	ETC	Ahmed (1997)
14	80	75	1.06***	Spray-LiBr	0.528	CPC	Ahmed (1997)
14	80	75	0.64***	Single Effect-LiBr/H ₂ O	0.196	Flat Plate	IEA Annex 24
14	80	75	0.64***	Single Effect-LiBr/H ₂ O	0.490	ETC	IEA Annex 24
14	80	75	0.64***	Single Effect-LiBr/H ₂ O	0.528	CPC	IEA Annex 24
14	75	70	0.356***	2 Stg. LiBr/H ₂ O	0.218	Flat Plate	Cheng et al (1991) ^{5A}
14	75	70	0.356***	2 Stg. LiBr/H ₂ O	0.498	ETC	Cheng et al (1991)
14	75	70	0.356***	2 Stg. LiBr/H ₂ O	0.530	CPC	Cheng et al (1991)
14	93	88	0.80**	Rankine	0.469	ETC	Barber (1979) ^{6A}
14	93	88	0.80**	Rankine	0.518	CPC	Barber (1979)
13.5	140	135	1.46***	Double Effect-LiBr/H ₂ O	0.395	ETC	Wardono & Nelson (1996) ^{7A}
13.5	140	135	1.46***	Double Effect-LiBr/H ₂ O	0.487	CPC	Wardono & Nelson (1996)
12	127	123	1.413***	Double Effect-LiBr/H ₂ O	0.413	ETC	Wardono & Nelson (1996)
12	127	123	1.413***	Double Effect-LiBr/H ₂ O	0.495	CPC	Wardono & Nelson (1996)
12	75	70	0.356**	2 Stg. LiBr/H ₂ O	0.218	Flat Plate	Cheng et al (1991)
12	75	70	0.356**	2 Stg. LiBr/H ₂ O	0.498	ETC	Cheng et al (1991)
12	75	70	0.356**	2 Stg. LiBr/H ₂ O	0.530	CPC	Cheng et al (1991)
11	77	72	0.60**	Rankine	0.210	Flat Plate	Barber (1979)
11	77	72	0.60**	Rankine	0.494	ETC	Barber (1979)
11	77	72	0.60**	Rankine	0.529	CPC	Barber (1979)
10	80	75	0.360**	2 Stg. LiBr/H ₂ O	0.196	Flat Plate	Cheng et al (1991)
10	80	75	0.360**	2 Stg. LiBr/H ₂ O	0.490	ETC	Cheng et al (1991)
10	80	75	0.360**	2 Stg. LiBr/H ₂ O	0.528	CPC	Cheng et al (1991)
10	90	85	0.60***	Single Effect-LiBr/H ₂ O	0.474	ETC	IEA Annex 24
10	90	85	0.60***	Single Effect-LiBr/H ₂ O	0.520	CPC	IEA Annex 24
10	95	90	0.150**	Ch. React.-SrCl ₂ /NH ₃	0.465	ETC	Nahrendorf et al (1998)
10	95	90	0.150**	Ch. React.-SrCl ₂ /NH ₃	0.517	CPC	Nahrendorf et al (1998)
10	120	115	1.325***	Double Effect-LiBr/H ₂ O	0.430	ETC	Wardono & Nelson (1996)
10	120	115	1.325***	Double Effect-LiBr/H ₂ O	0.500	CPC	Wardono & Nelson (1996)
	N/A	N/A	4.57*	Vapour Compression	0.16-0.15	PV	Green (2001)
8	70	65	0.450***	Open Cycle-LiBr	0.234	Flat Plate	Hellman & Grossman (1995) ^{8A}
8	70	65	0.450***	Open Cycle-LiBr	0.507	ETC	Hellman & Grossman (1995)

8	86	81	0.350**	2 Stg. 2 Fld.-LiBr-NH ₃	0.480	ETC	Cheng et al (1991)
8	86	81	0.350**	2 Stg. 2 Fld.-LiBr-NH ₃	0.523	CPC	Cheng et al (1991)
8	95	90	0.40**	SE/DL-H ₂ O-H ₂ O/LiBr	0.465	ETC	Schweigler et al (1996) ^{9A}
8	95	90	0.40**	SE/DL-H ₂ O-H ₂ O/LiBr	0.518	CPC	Schweigler et al (1996)
7	100	95	0.510***	Single Effect-LiBr/H ₂ O	0.458	ETC	IEA Annex 24
7	100	95	0.510***	Single Effect-LiBr/H ₂ O	0.513	CPC	IEA Annex 24
7	110	105	1.025***	Double Effect-LiBr/H ₂ O	0.442	ETC	Wardono & Nelson (1996)
7	110	105	1.025***	Double Effect-LiBr/H ₂ O	0.508	CPC	Wardono & Nelson (1996)
6	130-70	125	0.60**	Silica gel/ H ₂ O	0.410	ETC	IEA Annex 24
6	130-70	125	0.60**	Silica gel/ H ₂ O	0.493	CPC	IEA Annex 24
6	130-70	125	0.60**	Zeolite/H ₂ O	0.410	ETC	IEA Annex 24
6	130-70	125	0.60**	Zeolite/H ₂ O	0.493	CPC	IEA Annex 24
4	44	39	0.30***	Open Cycle-LiBr	0.325	Flat Plate	Hellman & Grossman (1995)
4	105	100	0.204**	Diffus.-Absorp.NH ₃ /H ₂ O	0.450	ETC	Gutierrez (1998) ^{10A}
4	105	100	0.204**	Diffus.-Absorp.NH ₃ /H ₂ O	0.510	CPC	Gutierrez (1998)
4	110	105	0.170**	Activated Carbon/ NH ₃	0.442	ETC	Telto & Critoph (1999) ^{11A}
4	110	105	0.170**	Activated Carbon/ NH ₃	0.508	CPC	Telto & Critoph (1999)
3	84	79	0.385**	CaCl ₂ /NH ₃	0.480	ETC	Iloje (1985) ^{12A}
3	84	79	0.385**	CaCl ₂ /NH ₃	0.527	CPC	Iloje (1985)
0	40	35	0.200***	Open Cycle-LiBr	0.340	Flat Plate	Hellman & Grossman (1995)
0	110	105	0.580***	Single Effect-NH ₃ /H ₂ O	0.442	ETC	IEA Annex 24
0	110	105	0.580***	Single Effect-NH ₃ /H ₂ O	0.508	CPC	IEA Annex 24
0	N/A	N/A	3.27*	Vapour Compression	0.16-0.15	PV	Green (2001)
-2	150	145	0.019**	Activated Carbon/ CH ₃ OH	0.378	ETC	Headley et al (1979) ^{13A}
-2	150	145	0.019**	Activated Carbon/ CH ₃ OH	0.480	CPC	Headley et al (1979)
-6	99	94	0.251**	CaCl ₂ /NH ₃	0.458	ETC	Iloje (1985)
-6	99	94	0.251**	CaCl ₂ /NH ₃	0.514	CPC	Iloje (1985)
-6	117	112	0.130**	Activated Carbon/ NH ₃	0.437	ETC	Telto & Critoph (1999)
-6	117	112	0.130**	Activated Carbon/ NH ₃	0.503	CPC	Telto & Critoph (1999)
-10	130	125	0.540***	Single Effect-NH ₃ /H ₂ O	0.410	ETC	IEA Annex 24
-10	130	125	0.540***	Single Effect-NH ₃ /H ₂ O	0.493	CPC	IEA Annex 24
-10	103	98	0.152**	SrCl ₂ /NH ₃	0.453	ETC	Erhard & Hahne (1997) ^{14A}
-10	103	98	0.152**	SrCl ₂ /NH ₃	0.512	CPC	Erhard & Hahne (1997)
-10	N/A	N/A	2.59*	Vapour Compression	0.16-0.15	PV	Green (2001)
-12	90	85	0.667**	1Stage-NH ₃ /H ₂ O	0.474	ETC	Staicovici (1986) ^{15A}
-12	90	85	0.667**	1Stage-NH ₃ /H ₂ O	0.520	CPC	Staicovici (1986)
-17	80	75	0.555**	1Stage-NH ₃ /H ₂ O	0.196	Flat Plate	Staicovici (1986)
-17	80	75	0.555**	1Stage-NH ₃ /H ₂ O	0.490	ETC	Staicovici (1986)
-17	80	75	0.555**	1Stage-NH ₃ /H ₂ O	0.528	CPC	Staicovici (1986)
-20	150	145	0.480***	Single Effect-NH ₃ /H ₂ O	0.378	ETC	IEA Annex 24
-20	150	145	0.480***	Single Effect-NH ₃ /H ₂ O	0.480	CPC	IEA Annex 24
-20	N/A	N/A	1.96*	Vapour Compression	0.16-0.15	PV	Green (2001)
-30	N/A	N/A	1.41*	Vapour Compression	0.16-0.15	PV	Green (2001)
-30	170	165	0.440***	Single Effect-NH ₃ /H ₂ O	0.238	ETC	IEA Annex 24
-40	180	175	0.390***	Single Effect-NH ₃ /H ₂ O	0.330	ETC	IEA Annex 24