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Solar Cooling for Industry and Commerce (SCIC)

Study on the Solar Cooling Potential in Jordan

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On behalf of

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)
Programmbüro Internationale Klimaschutzinitiative
Potsdamer Platz 10, 10785 Berlin
E-Mail: programmbuero@programmbuero-klima.de
Phone: +49 (0)30 408 190 - 218
Fax: +49 (0)30 408 190 – 303
Internet: www.international-climate-initiative.com

Authors

Dietram Oppelt
Maria Martin
Tobias März
Mohamad El-Nass
Elke Zimmermann

Editors
Dieter Rothenberger
Marion Geiss

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Executive Summary

Energy demand is increasing worldwide, and the Hashemite Kingdom of Jordan is following this trend. Between 2004 and 2009, its energy consumption increased by about 50%, leading to higher CO_2 emissions. Increasing cooling needs contribute significantly and increasingly to the growing energy demand. Cooling needs are rising mainly due to improved living standards and rising global temperatures combined with higher frequency of heat waves. Air conditioning is especially important in countries like Jordan with a hot and dry climate in summer. Jordan meets the most of its electricity needs by conventional sources, with renewable energy contributing only 1% of the total.

As Jordan imports most of its primary energy, increasing the share of renewable energy will help to make the country more economically independent. Furthermore, Jordan´s electricity rates are subsidized heavily by the government, which it can less and less afford to do. As a result, the rates are expected to rise drastically over the coming years. Renewable energy sources like wind or solar power will thus become an attractive alternative. The Jordanian government is supporting their expansion and aims to increase the renewable energy share to 10% by 2020. The share of buildings with solar thermal systems for domestic room and water heating in particular is supposed to rise from a current 15% to 30%[1] . The Renewable Energy and Energy Efficiency Law, which was introduced in March 2012, regulates and encourages the use of renewable sources.

The climate in Jordan is very well suited for the exploitation of solar power. So far, solar thermal energy is almost exclusively used for heating and warm water supply. However, it can also be used to provide air conditioning, particularly through the application of sorption technologies. Solar cooling takes advantage of the fact that the peak cooling need in summer correlates with the highest solar irradiation. Solar cooling systems consume around 25% of the electric power of conventional systems, which means that up to 75% of electricity can be saved.

Despite the advantageous natural conditions, solar cooling has not yet penetrated the market in Jordan and several barriers hinder its further introduction into the Jordanian market. The main concerns are high investment costs related to insufficient economies of scale and the amount of roof space needed for the solar system. However, once the technology becomes more established, the market is expected to grow and the component costs are expected to decrease. As solar cooling systems are complex and consist of several components that have to fit to each other, the systems have to be designed carefully. For the installation of a well running and economical system, expert knowledge is required and customized solutions for the respective sites are needed. Systems become more economical when synergies can be exploited, for instance by using the solar thermal system for cooling, heating and a hot water supply.

The market potential for solar cooling in Jordan is mainly limited by the missing availability of different system types or components. The availability however is expected to increase due to a rising demand, if economic and technical feasibility of solar cooling systems can successfully be demonstrated. Two scenarios for the introduction of solar thermal cooling technology were investigated, one with conservative assumptions and one assuming a very high market penetration due to shortage of resources, rising energy prices and a continued phase-out of fluorinated refrigerants. This leads to penetration rates of 12 and 60%, respectively. Compared to a BAU scenario without the introduction of solar cooling systems, this correlates to possible emission reductions of 0.92 and 3.74 Mt CO_2eq per annum in 2050, respectively.

For a higher penetration rate of solar thermal cooling systems for commercial application in Jordan, the systems have to prove robustness, acceptable costs and need to be compatible with existing water heating systems. The best way to achieve this is to use small, single-step systems with non-concentrating solar collectors. For certain research purposes or when the available rooftop area is small and therefore high space efficiency is needed, double-step absorption machines using concentrating solar systems can be an interesting option. However, due to the increased complexity, the latter combination is normally only feasible for systems of 500-1000 kW or higher.

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[1] Salman Zafar, 2012

1 | Introduction

1.1 | Energy demand for AC

This study provides an overview on the current status and the potential for solar thermal cooling in Jordan. The Middle East and Northern Africa (MENA) region follows the worldwide trend of a continuously increasing demand of both primary energy and electricity for cooling purposes (Figure 1). Currently this energy demand is mainly covered by the use of fossil fuels (International Energy Agency, 2005). In the face of both global warming and limited conventional energy sources, the future challenge will be to find ways of meeting the growing cooling demand by renewable energy means. Current practices have to be dramatically redirected over the coming years if conventional energy sources are to be replaced by renewable ones.

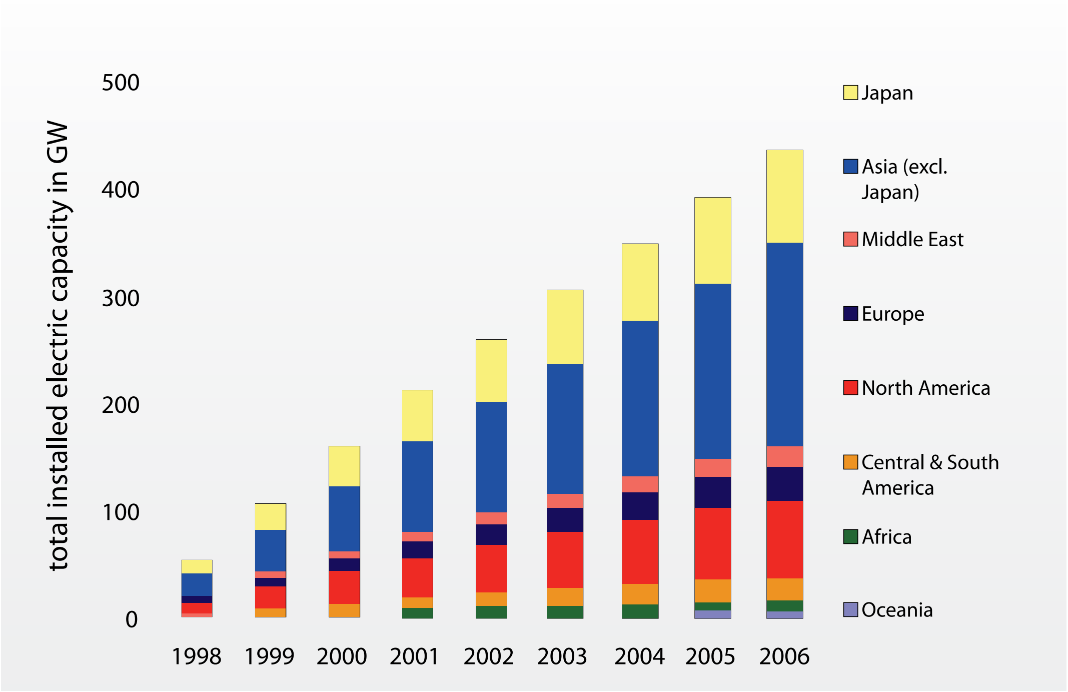

Figure 1: Installed cooling power world-wide. Source: Herkel, 2009

Jordan follows the global and regional trend of increasing energy demand for air conditioning. Among the electricity consumption, the share for residential and commercial air conditioning is strongly increasing due to growing living standards and the hot and often humid climatic conditions (see detailed outline in chapter 4.1.1).

Figures 2 and 3 illustrate a future scenario for the growing demand for commercial air conditioning in Jordan and the resulting CO_2 emissions, respectively. The calculations on which the graphs are based are given in detail in section 4.6.

1 | Introduction

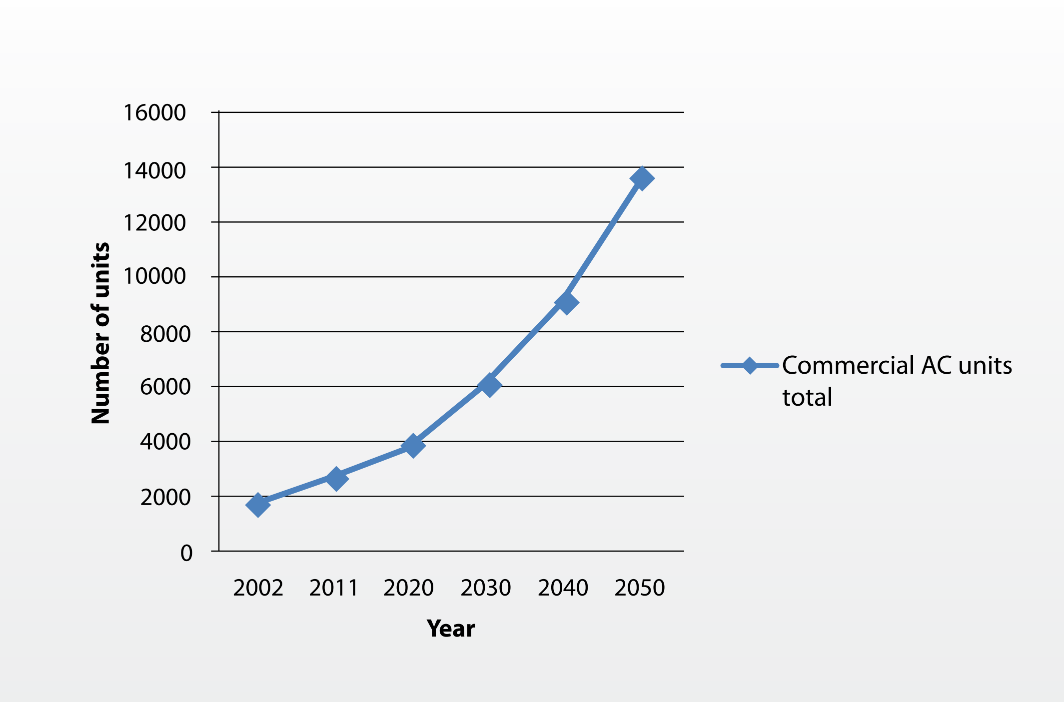

Figure 2: Estimated number of chiller units in Jordan in total.

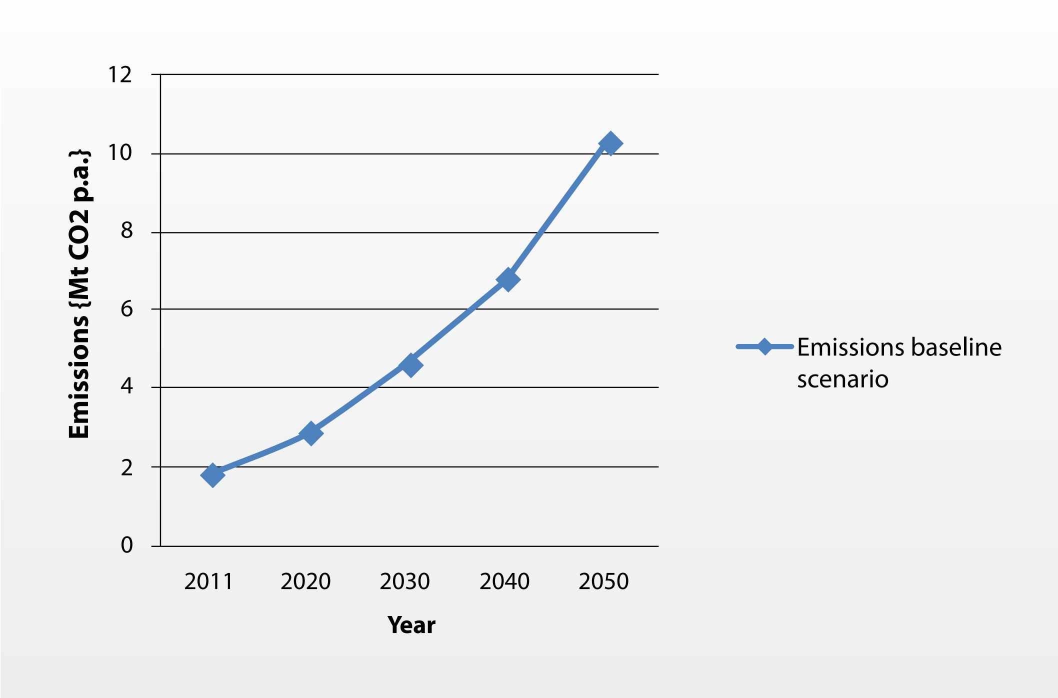

Figure 3: Estimated emissions from chiller units in the baseline scenario.

1 | Introduction

1.2 | Energy supply in Jordan

Energy and electricity consumption are on the rise in Jordan, with electricity consumption having increased by 46% between 2004 and 2009 (Source: IEA statistical data; more recent IEA data is difficult to access).

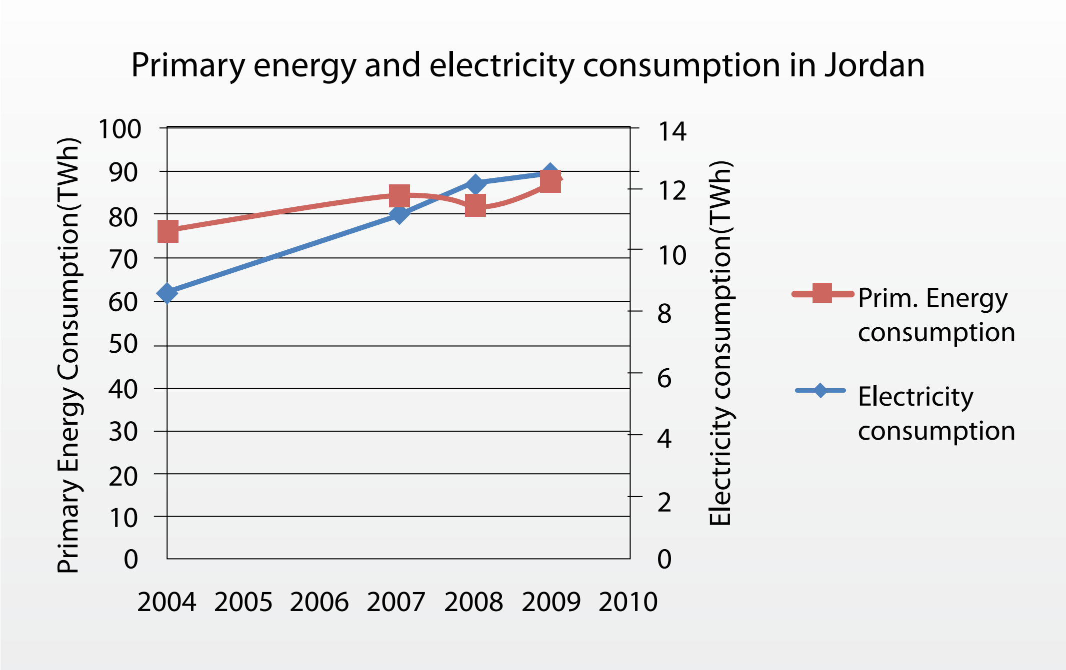

Figure 4: Development of primary energy and electricity consumption in Jordan

At the same time, Jordan has almost no domestic fossil energy sources and covers virtually all of its energy needs via oil and gas imports from Egypt. With Egyptian domestic consumption on the rise, imports will be less secure for Jordan in the years to come. Also, in 2011 and 2012, there were frequent disruptions of the Egypt-Jordan gas supply as militants blew up the pipeline, leading to high additional costs to the government as it purchased oil on the market to maintain power generation in the country. The government has therefore started working to increase the share of renewable energy sources.

Jordan targets to substantially increase the renewable energy contribution to the Kingdom's energy mix by 2020. The targets for renewable electricity (mainly wind and solar) were set to increase from the current 1% to 10% and for solar thermal from 15%[2] to 30% (Zafar, 2012).

Current electricity rates are still highly subsidized (average usage rates of 73 fils / kWh against generation costs of 192 fils[3]). The state budget suffers severely from these subsidies and electricity price increases are likely for the future. In the commercial sector the highest electricity prices are currently faced by banks and telecommunications companies with over 200 fils / kWh (Annex I, Table AI 3). Other commercial sectors, hotels and industries receive subsidized electricity rates below 130 fils / kWh (Annex I, Table AI.1 - AI.2).

From this data, it is clear that the government has a strong incentive to tackle the increase on the demand side and develop both energy efficiency and alternative energy options such as solar thermal systems for air conditioning.

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[2] Refers to the current use of solar thermal room and water heating (no. of buildings)

[3] Source: nuqudy.com, 31/1/2012; in USc/kWh approx 10 vs 27 US/c kWh).

1 | Introduction

1.3 | Role of solar thermal cooling in Jordan

Compared to conventional air conditioning (A/C) by electric compression systems, the use of solar thermal cooling systems has been negligible so far. This is mainly due to existing barriers for the deployment of solar thermal cooling systems. Key barriers are the high investment costs for the technology, the lack of economies of scale and the relatively high free roof space requirements. The required technologies are not widely available in Jordan and there are limited installation and operating experiences in Jordan.

With a wider deployment it can be expected that equipment costs will further decrease in the future. The favorable solar conditions in Jordan will allow for higher efficiency compared e.g. to Europe. Compared to renewable energy used for electricity generation, solar thermal cooling has the advantage of directly covering energy needs without posing additional challenges to the national grid which induce further costs to the utility and/or the consumer.

Jordan has excellent direct solar irradiation (DNI) reaching well over 2,000 kWh per square meter per annum and a global hemispheric irradiation (GHI) reaching around 2,000 kWh/m²/a (Figure 5) compared to values of 1,000-1,800 kWh/m²/a across Europe for both DNI and GHI.

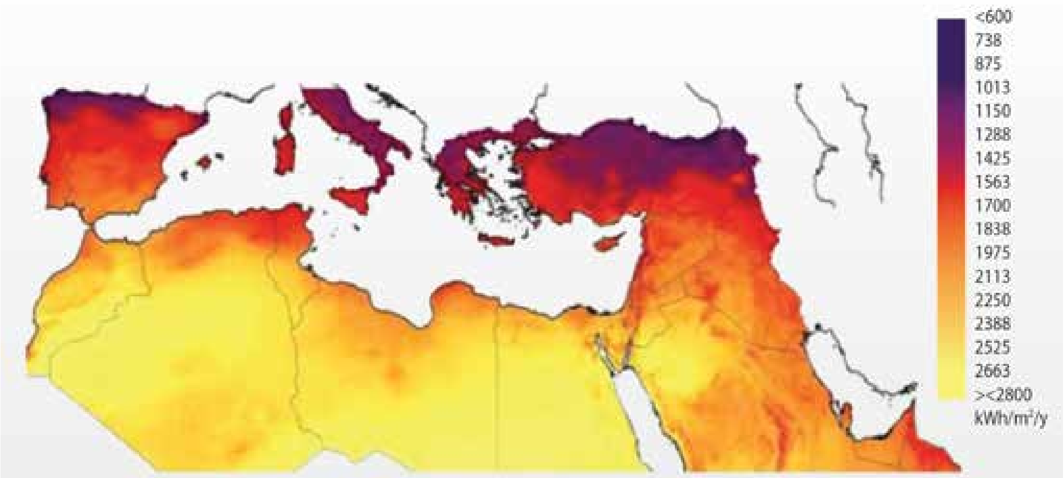

Figure 5: Direct Normal Irradiation (DNI) in the MENA region. Source: (Trieb, 2007).

1.4 | Solar thermal cooling market and costs

Solar thermal cooling is still a niche market worldwide. Although absorption and other thermal cooling systems are technically fairly simple, standardized economic dimensioning and standard component manufacturing are still only in the emerging stage. Sufficient standardization and deployment are basic requirements if solar cooling systems shall be competitive compared to conventional cooling systems. The IEA roadmap on solar heating and cooling from 2012 roughly indicates investment costs of solar thermal cooling between 1,600 and 3,200 USD per kW of installed cooling power. According to Henning (2010), solar thermal cooling costs are “two to five times higher than for conventional solutions”. Higher costs of solar cooling stem from the solar equipment, but also from the integration and control parts, which are more complex compared to those of conventional chillers and which are not yet standardized. Further cost information is given in chapter 2.4.

The higher investment cost, of course, has to be seen in relation to the operational costs which are considerably lower (mostly through the energy consumption, which is a fraction of that of conventional systems). If cost competitiveness for solar cooling will be achieved in the future, it will be through the lifetime costs as the investment costs for solar collector and heat medium circuit will hardly drop below those of a conventional compressor system.

1 | Introduction

The actual design of a system depends strongly on the local conditions at a chosen site such as the specific cooling needs, the solar irradiation and the available options for the heat rejection. Moreover, only if the available space for collectors (mostly on a roof) is sufficient, can thermal cooling systems supply cooling with a capacity that covers a significant part of the cooling load of a building. To decrease system costs it will be important to develop increasingly customized technology options which fit to the specific local conditions of a region or country. With increasing scales however, it can be expected that component costs can be decreased. The competitiveness of solar cooling will further improve with rising electricity prices and can be further supported by financial government incentives.

Another important aspect is the co-utilization of the solar hot water for other domestic purposes. This is an important economic co-benefit of solar thermal cooling systems that has to be taken into account when comparing it against conventional cooling systems; either as an additional gain, or, if solar collectors for water heating are already installed at a certain site, by excluding the solar collector from the investment costs. With the increasing share of solar thermal systems for heating and hot water supply in Jordan (installation target to increase from currently 15% to 30% as mentioned in section 1.2), there is a growing potential for synergetic systems where the use of hot water for heating and cooling can be combined. Hot water requirements typically decrease during the summer months and excess hot water can be used for cooling purposes. However, solar cooling systems depend on a certain driving temperature which not all domestic solar collectors provide, so the feasibility of this co-use depends on a case-to-case analysis.

1.5 | Outline of the study

The focus of this study is to investigate the **potential for solar (thermal) cooling in Jordan** in particular for commercial applications covering mostly Central Air Conditioning (CAC) systems through central chillers.

The study provides an overview of the relevant **system components** including:

- solar equipment
- cooling machine
- energy storage equipment
- auxiliary systems

Some tentative numbers are given on costs, and a market overview is also presented.

The study then analyzes the potential for solar (thermal) cooling in Jordan specifically, discussing climate conditions, existing relevant regulations, potential barriers and the potential for local manufacturing of components and provision of services. Furthermore, an estimate is made on the market potential for solar cooling in Jordan.

Finally, for illustration, two main technology combinations are outlined and discussed:

- The combination of highly efficient solar cooling systems with CSP (concentrated solar power) which achieve high area efficiencies
- Widely available single-step solar cooling systems utilizing non-concentrating solar systems to supply economical cooling power

2 | Background on Solar Cooling Technologies

2.1 | Overview Solar Cooling Systems

The utilization of solar power for cooling purposes can be done in different ways. The two most important combinations are generating electricity by photovoltaic (PV) panels and using the electricity to run an electric compressor, and using solar radiation to generate heat and utilize it to drive a thermal chiller unit.

In the first case, solar PV panels generate electricity which in turn drives a conventional electric compression system. In off-grid systems, a battery needs to be used in order to cover time periods with low or no sunshine. However, in systems connected to the grid, battery storage makes no technical or economical sense; in these cases, electricity is consumed from the grid by the cooling system and fed into the grid by the PV panels. The (renewable) generation of electricity and the electricity consumption by the cooling system are therefore practically de-coupled. This case (and the very most of Jordan is grid-connected) is therefore not of further analytical interest and has not been considered in this study.

In the second case, thermal solar collectors generate hot water, and the hot water is used to drive a thermal refrigeration cycle. In this case, no electricity is generated, but the hot water produced in periods without cooling needs can be used for building heating and domestic hot water needs, most importantly during the winter. Cooling systems driven by solar thermal collectors, compared to PV solar collectors, are still more complex, less standardized, less developed and currently more expensive compared to the PV case.

However, this also brings the potential of this technology: Higher deployment and standardization will bring down prices, and the combination with hot water generation brings interesting synergies. This highlights the development potential of solar thermal cooling systems in Jordan. As Jordan already has a relatively high number of solar thermal systems installed, compared to PV solar, the development of solar thermal cooling systems looks promising.
For a comparison (especially economical) between PV-compressor and solar thermal chilling technologies, see (Ziegler, 2009).

The following chart (Figure 6) provides an overview of the combinations between solar and cooling systems.

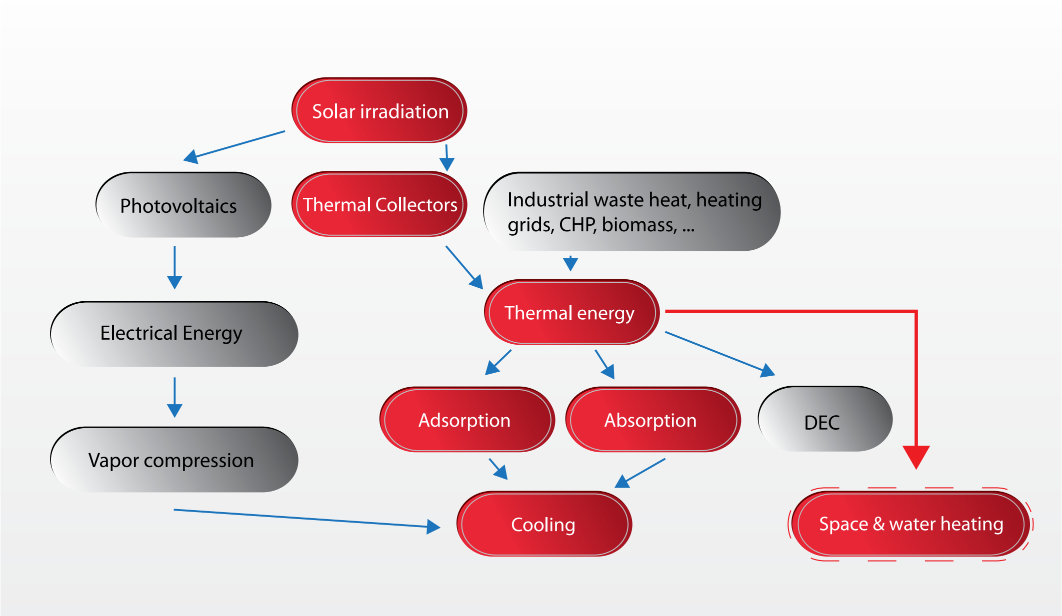

Figure 6: Schematic overview of cooling systems. Adapted from: Ziegler, 2011..

2 | Background on Solar Cooling Technologies

On the thermal energy side, there are more or less four types of collectors capturing solar energy which are potentially suitable for thermal cooling:

- Flat Plate Collectors (FPCs),
- Evacuated Tube Collectors (ETCs),
- Parabolic Trough Collectors (PTC) and
- Fresnel Collectors (FCs).

For the creation of cold, there are several different types of cooling methods[4] :

- Absorption,
- Adsorption,
- Desiccant cooling.

The most common type is absorption cooling which typically runs on one of two different pairs of sorbent and refrigerant:

- Lithium bromide with water (water as the refrigerant) or
- Water with ammonia (ammonia as the refrigerant).

Principally, all of the different cooling methods and collector types can be combined, however, certain combinations are not favorable from the technological and economical point of view. This is discussed further in Chapter 5.

The overall primary energy consumption and the carbon emissions reduction potential of the solar cooling system depend strongly on the following factors:

- COP (Coefficient of Performance) of the sorption technology
- Share of (primary) energy consumption of the auxiliary system components (pumps etc.)
- If back-up gas firing is used, the annual fossil power share (influenced by the available rooftop area and economic considerations)

2.2 | Overview Solar Systems

The solar collector part of the system is where the irradiation energy from the sun is gathered in the form of thermal energy which is then used to drive the chiller. Different types of collectors are available, which are presented below.

2.2.1 | Flat Plate Collectors

Figure 7: Flat Plate Collector. Source: Jiangsu Sunpower Solar Technology Co., Ltd.

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[4] There are some other types of thermal cooling, which are not commercially available in the power range of interest and have other disadvantages; they are therefore not considered within this study: evaporative cooling (high water usage) and ejector cooling (poor performance, low development).

Flat plate collectors (FPC) are the simplest and cheapest form of solar collectors. They are flat, usually rectangular panels that consist of a transparent cover that allows solar irradiation to enter but reduces heat losses, a dark flat-plate absorber including the tubing system and a heat insulating back-structure. The absorber consists of a thin absorber sheet (thermally stable polymers, aluminum, steel or copper, to which either a matt black or a selective coating is applied) and a grid or coil of fluid tubing where the heat transfer fluid (HTF) circulates. For certain applications, flooded absorbers are used where the air or water flows through the whole collector area between two metal sheets.

Solar radiation passes through the transparent cover and heats up the absorber, the heat is then transported away in the heat transfer fluid (HTF).

The advantage of FPCs is their low price (starting at around 100 $ per m²) and robustness. Disadvantages originating from their simplicity are relatively high heat losses which lead to limited output temperatures and low efficiencies in terms of output power per collector area. The temperature range achieved by FPCs is around 50-80 °C (Clausen, 2007); for higher temperatures, the thermal losses become prohibitively high. The achieved temperature is thus on the lower end of the range achieved by solar collector systems and FPCs are therefore most commonly used for heating up domestic hot water. For solar cooling purposes, the temperature reached with FPCs is suitable for running open cycles where the air is cooled directly and low input temperatures are suitable, or for adsorption cooling systems with low input temperatures. The temperature needed to run absorption machines (single-step) is a bit higher, so their combination with FPCs can be a challenge and not all models of FPCs deliver the necessary temperature. In general, in order to achieve satisfying COPs and minimize space requirements, FPCs with low heat losses and high efficiencies should be selected for solar cooling systems.

2.2.2 | Evacuated Tube Collectors

Figure 8: Evacuated Tube Collector. Source: selfio.de

Evacuated Tube Collectors (ETCs) use a vacuum around the absorber in order to achieve a high thermal insulation and lower heat losses and come in the form of tubes. They consist of parallel lines of two concentric glass tubes with a vacuum in between them, and the absorber running in their center. The absorber (using selective coating) can either be a U-tube containing the HTF directly or a "heat pipe" which is a hermetically closed tube with a fluid inside which delivers the gathered heat to the circulating HTF in the header tube on the top; these heat pipes have the advantage that they can be changed without the need for draining the system. Often, semi-parabolic reflectors are used behind the tubes in order to focus additional solar radiation onto the tubes (compound parabolic collector, CPC).

Solar irradiation hits the tube directly or is reflected onto it by the absorber and heats up the HTF or, in the case of heat pipes, heats up the intrinsic fluid of the heat pipes, which continuously evaporates and condenses again, leaving the thermal energy with the HTF in the header pipe ("manifold").

ETCs have a better insulation than FPCs and therefore can achieve higher temperatures. They also normally have a higher (per-area) efficiency than FPCs (see also Figure 9). The advantages come at a higher cost and a somewhat lower robustness. Especially, losses of the vacuum can be a problem; in this case, the affected tube has to be changed. However, necessary replacement rates are low in modern systems.

ETCs are usually operated to achieve temperatures between 80° to 150°C (Clausen, 2007); Temperatures above this range lead to high losses. They are therefore used for domestic heating and hot water, but also for industrial purposes (Delorme et al., 2004). As for solar cooling, their achievable outlet temperature makes them principally suitable for adsorption and single- or double-effect absorption processes. However, their utilization with double-step machines is a challenge as the temperatures required here are at the upper end of the ETC temperature range which can consequently lead to low COPs and cooling power during times where solar radiation is low.

Figure 9 shows collector efficiencies at different temperatures and the corresponding suitable cooling systems. ("Solar air collector" is a simple collector design which is not mentioned here as it operates at a low output temperature and has little commercial importance.)

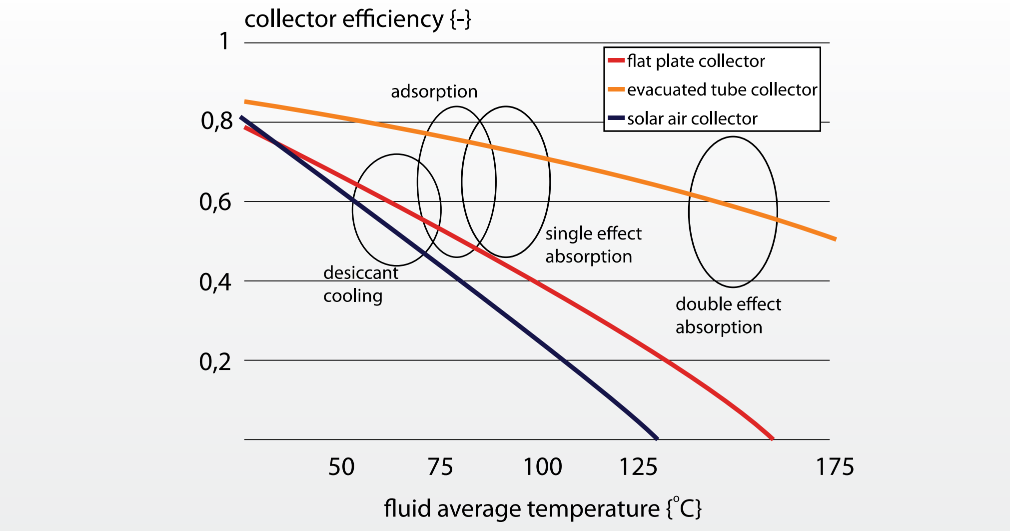

Figure 9: Collector efficiencies against temperature and suitable cooling systems. Ambient temperature 25°C, solar radiation 800 W/m². Source: (Henning, 2000).

2.2.3 | Parabolic Trough Collectors

Parabolic trough collectors (PTCs) also use evacuated tubes as their radiation receiver, however they use reflectors which are much bigger in size to reflect incoming sun radiation onto the receiver. The reflector needs an accurate parabolic shape and must track the sun during the day in order to ensure that the incoming light hits the tube. The tubes themselves are therefore only a small portion of the material and costs, and the largest amount goes to the reflectors and their backing structure as well as the tracking system. In contrast to FPCs and

ETCs, they depend mostly on the direct normal irradiation (DNI), which makes them unsuitable for areas where a covered sky is common, such as in Central Europe, and more suitable for areas with clear skies and a high direct irradiation such as the Middle East.

The advantage of this system is that it can achieve high temperatures (up to 400°C and more) at relatively low heat losses, which is why it is mostly used for electricity generation by means of a steam turbine cycle, which requires high temperatures. Disadvantages are a high relative cost and the high complexity of the system leading to substantial maintenance and control requirements. Commercial applications are therefore rarely below the MW range which would disqualify them for cooling of singular buildings; however, some providers offer relatively "low-tech" models suitable for smaller output power ratings (see table in Chapter 3.1 Overview of Potential Suppliers Worldwide).

A sensible utilization of the temperature delivered by PTCs can be achieved by double- or triple-step absorption machines; for all other systems, the higher complexity and cost of PTCs compared to FPCs and ETCs is not justified.

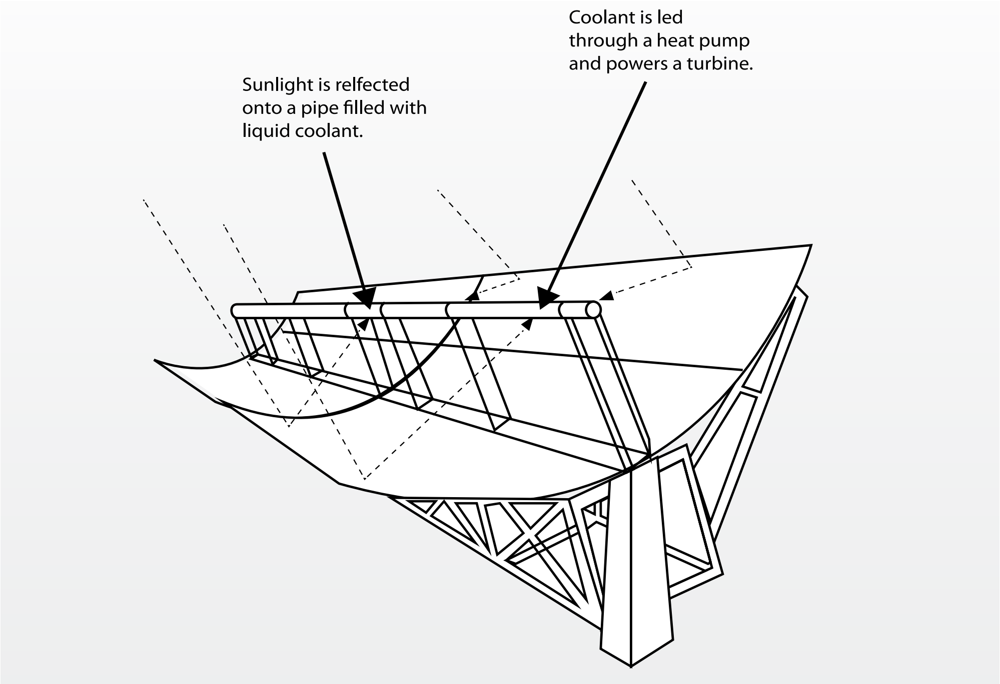

Figure 10: Parabolic Trough Collector. Source: Gayle Brooke.

2.2.4 | Fresnel Collectors

Fresnel Collectors (FCs) are similar to PTCs in system and size and also run on direct irradiation. However, instead of a complete parabolic shape, they use long lines of rectangular flat (or only slightly bent) mirrors which track the sun during the day and focus the irradiation onto a receiver running several meters above the mirror lines. In this design, the absorber tube is fixed and does not have to move as in the case of the PTCs, and the moveable parts (here only the mirrors) are minimized.

The advantage of FCs is that the system is simpler and cheaper than PTCs,though achieved efficiencies are lower. Furthermore, the effective area of the collector depends on the sun's incident angle, meaning the output power varies strongly during the day with a pronounced peak at noon and much lower outputs in the morning and afternoon.

The temperature range of FCs implemented so far is somewhat lower than that of PTCs. Their application in solar cooling is similar to PTCs: Double- or triple-step absorption machines can be a sensible match; for all other systems, the simpler collectors are preferable.

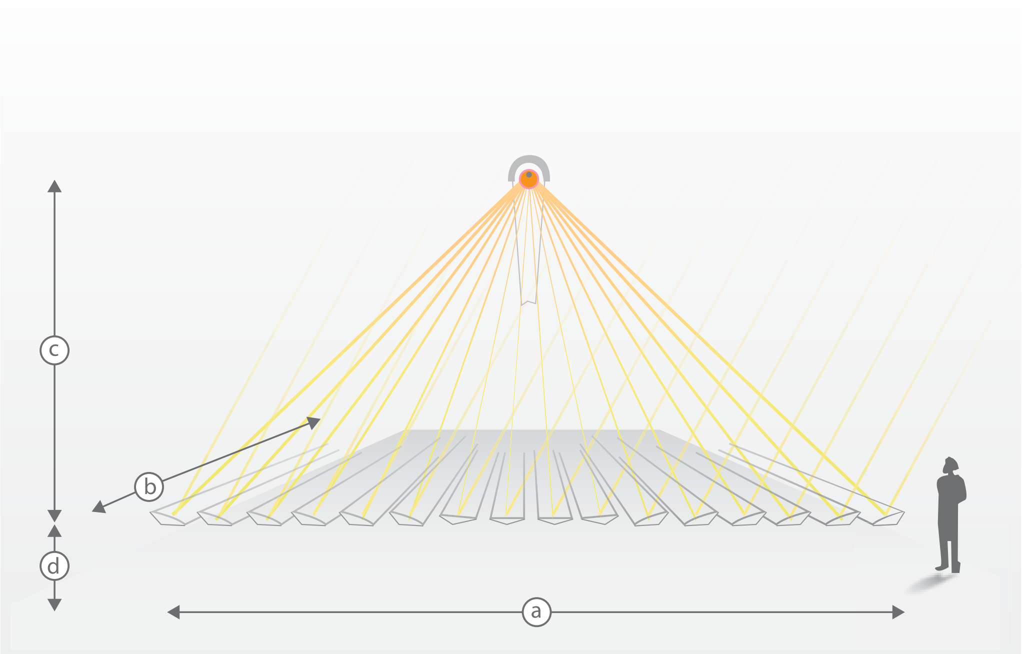

Figure 11: Schematic drawing of a Fresnel collector. Source: Novatec Biosol.

2.2.5 | Summary Solar Collectors

Overall, the characteristics of the different collector types are summarized in Table 1:

Table 1: Characteristics of different solar collectors (for solar cooling purposes

Type	Typical Temperatures	Advantages	Disadvantages	Suitable cooling applications	Robustness, simplicity, potential for local production	Efficiency, achievable temperatures, need for maintenance
Flat Collector	Up to 80 °C	Cheap, robust, no moving parts	Temperature low for cooling systems	Direct air cooling	↑	↓
Vacuum Tube	Up to 130 °C	Robust, no moving parts	Temperatures limited	Single-effect absorption		
Fresnel	Up to 450 °C	High temperatures	Need for O&M	Single- and multi-effect absorption		
Parabolic	Up to 450 °C	High temperatures and efficiencies	Significant O&M	Single- and multi-effect absorption		

2.3 | Overview Cooling Systems

Solar cooling technologies were developed and deployed for practical use since the 1970s. Larger absorption machines (larger than 50 kW) have already reached a significant market and track record in non-solar applications. In particular smaller systems are still at the earlier stage of development.

Absorption and adsorption cooling systems are the most important commercially available types of thermal cooling applications in combination with solar thermal power. Desiccant evaporative cooling (DEC) works without a chemical refrigerant, targets humidification or dehumidification besides cooling, and is so far little used in commercial applications; it is not further discussed in this study.

Any thermal cooling system is comprised of several important elements. One such element is the heat rejection system, which is bigger for thermal cooling systems than for compression systems and which requires specific considerations especially in hot climate regions, where heat rejection to the environment is more difficult to achieve. Another important element is a storage system for thermal energy to provide cooling in periods without sunshine, given that solar irradiation varies throughout the year and fluctuates within individual days. An alternative is a back-up supply of thermal energy via a gas burner, but as the deployment of fossil fuel power backup system negatively affects the greenhouse gas (GHG) emission profile of the system, a storage system is preferred wherever feasible. These two important system elements (heat rejection, storage) are also presented in the following chapters.

A system and its main components are schematically illustrated in Figure 12.

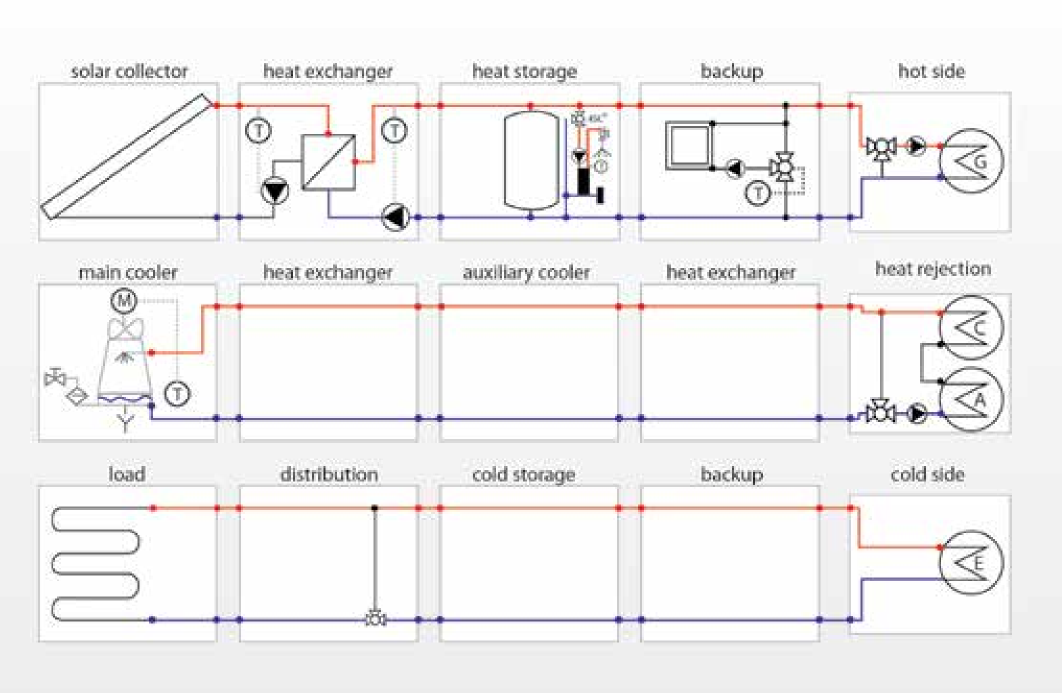

Figure 12: Schematic drawing of standardized system typology for solar thermal chillers. Taken from: Becker et al., 2009.

The efficiency of cooling machines is quantified using the coefficient of performance (COP). The COP is defined as the ratio between the useful thermal energy in form of cold and the invested energy in form of heat or electricity. As thermal heat and electricity are two entirely different forms of energy with different exergies, the comparison of electric and thermal COPs is subject to different interpretations and should be avoided. Actual thermal COPs of installed systems are usually in the range of 0.4 up to 1.2 for current technology and depend strongly on the working temperatures (output temperature of solar system, input and output temperature of the cooling system, cooling temperature and ambient temperature); they are thus not always really comparable either. Another differentiation between electrical COPs is between the COP of the cooling cycle itself and that of the whole system (COSP or COP_sys), where the latter accounts for all of the peripheral or ancillary energy such as for pumps, controls, fans and so on, and is therefore of a lower value. For thermal systems, the electrical COP always refers to the system as a whole (including pumps etc.). Furthermore, COPs are given as instantaneous values and average values (e.g., seasonal CO(S)P or seasonal performance factor, SPF), where the averaged, seasonal values account for both very good (sunny) conditions and those when the conditions lead to poor operation. The COPs given in the following chapters are thermal COPs (achieved cooling energy in relation to invested heat), instantaneous in most cases, and refer to typical systems implemented so far.

2.3.1 | Cooling Cycles: Absorption

Absorption cooling systems are widely used globally. They use a liquid refrigerant-sorbent pair enclosed in a hermetic system. The cooling effect is achieved in the same way as in a compressor system: An evaporating liquid (the refrigerant) draws thermal energy from its surroundings. However, the recovery of the vapour to its liquid state, where it can be evaporated again, is done by a sophisticated chain of phase changes at different refrigerant/sorbent compositions, temperatures and pressures, using an external thermal energy supply.

The simplest design for absorption machines is single-effect; in Germany mostly single-effect systems are deployed as they only require modest input temperatures which can be achieved with FPCs or ETCs without the requirement of high direct solar irradiation. Double-effect systems use two evaporators in sequence for energy recovery, require higher input temperatures and achieve higher COPs. Triple-effect systems with even higher COPs are under development (i.e. Kawasaki, Thermax, Broad). Commercial absorption machines show the widest range of rated cooling power output, starting at several kW_{th} and going up to the MW_{th} range. Double- and triple-effect machines start above $100kW_{th}$. For single-effect machines, the needed input temperature is between 80 and 110°C, and the achieved COP lies between 0.6 and 0.8. Double-effect systems need higher driving temperatures, usually larger than 140°C; in turn, they achieve COPs up to 1.2 (ESTIF, 2006).

Virtually all absorption machines work with one of two different pairs of sorbent and refrigerant, either lithium bromide in combination with water (refrigerant) or water in combination with ammonia (refrigerant). Water as a refrigerant has the advantage of safety in case of leakage and slightly higher COPs for temperatures above 3°C, whereas ammonia has the advantage of low evaporation temperatures and can be used for cooling down to around -20°C which is why it is often used for industrial refrigeration and freezing purposes. For normal building a/c and other applications above 0°C, lithium bromide systems are mostly used. All absorption machines are closed systems, so there is no intended loss of refrigerant or sorbent.

Advantages of absorption machines are the biggest market availability compared to the alternatives, tentatively lower specific costs and a high range of output power ratings (cold production).

2 | Background on Solar Cooling Technologies

2.3.2 | Cooling Cycles: Adsorption

Adsorption cooling uses a similar process as absorption, but the adsorbent is a solid substance whereas absorbents are liquids. As the solid adsorbent is static and cannot flow through a tube system like liquid substances, two adsorbent compartments are needed for continuous operation; in one compartment, the adsorbent adsorbs the refrigerant, drawing heat from the surroundings of the refrigerant reservoir; in the other compartment, the adsorbent-refrigerant system is "recovered" or "regenerated" using external thermal heat; then compartments are switched for continuous operation.

Adsorption units comprise a minor share of sorption machines produced so far and market prices therefore tend to be rather high (ESTIF, 2006). Most presently available machines are of the lower cooling power range of several tens of kW_{th}, but there is at least one supplier from the US offering machines up to more than 100 kW. One large advantage of adsorption systems is that they can operate at relatively low temperatures of 55 to 80°C. Other advantages are that for material property reasons, adsorption chillers are an easier match for dry cooling (see 2.3.3) than absorption machines and that they are very robust. COPs achieved are up to around 0.6. Disadvantages are the mentioned low availability and the rather high price, as well as high weight and volume. The allowable water input temperatures for adsorption chillers are lower, particularly when compared with double-step absorption chillers. Accordingly, achievable system efficiencies are also lower.

Table 2 provides an overview of typical parameters of the different cooling systems.

Table 2 Overview of thermal cooling technologies. Source: (ESTIF, 2006).

method	closed cycle		open cycle	
refrigerant 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 - 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)	adsorption chiller : 50 - 430 kW	absorption chiller 15 kW - 5 MW	20 kW - 350kW (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

For a decision which type will best suit the needs of actual projects in Jordan, technical and financial quotes for specific site specifications from various manufacturers will have to be analyzed.

2 | Background on Solar Cooling Technologies

2.3.3 | Heat Rejection Systems

Every cooling machine generates waste heat; more than the amount of the energy which is removed to create the cold. For thermal cooling machines, this amount is considerably higher than for compression machines and can be a multiple of the useful cooling energy. Some of this heat can be used for heating or domestic hot water (DHW), but a significant amount usually has to be rejected into the surroundings. This process also consumes a significant amount of the ancillary power for pumping, driving of fans etc.

Heat rejection systems are mainly divided into wet cooling (using the heat consumption of evaporating water), dry cooling (using the temperature difference to the ambient air or ground) and hybrid systems.

Please note that the cooling temperatures of the heat rejection systems which are mentioned in the following are different from those of the chiller system. High cooling temperatures of the heat rejection system can affect the COP of the overall system.

The following overview of heat rejection systems is mainly based on Krause et al., 2010 and Jaehnig et al., 2010.

Wet or evaporative cooling

Figure 13: Wet cooling tower, Hungary. GEA, 2004

Wet or evaporative cooling towers work with the evaporation of water, whereby the latent heat of the water is used to remove (some of) the rejected heat and the water vapour is released into ambient air. Heat is rejected from the condenser to a flow of water. This warm water is then sprayed onto packing material (used to increase surface area) within a vertical cylinder which is open to the atmosphere (the cooling tower). The flow of air across the surface of the water encourages evaporation of the water. As the water evaporates it removes heat from the (liquid) water which reduces its temperature. The water is then returned to the condenser with a lower temperature.

Wet cooling systems have the advantage that they can provide lower water temperatures than dry coolers, have lower investment costs and require less space. Disadvantages are hygienic problems (cultivation of legionella bacteria), high water consumption and high maintenance needs (blow down of solids in the cooling tower).

Water consumption in existing solar cooling plants has ranged from 0.5 to 2 liters per kWh of dissipated heat (some even higher), though it is not clear whether these values refer to dissipated heat in the cooled building or in the heat rejection cycle. They correspond to either 0.5 to 2 liters per kWh of cooling directly or to 1.5 to 6 liters per kWh of cooling with an assumed COP of 0.5 for the two cases respectively (Jaehnig and Thuer, 2011).

As water is scarce in Jordan, wet cooling is not a sustainable solution in this country; it is even forbidden in most cases. Utilization of waste water could be an option in certain cases, but basic water treatment would most probably be necessary in order to protect the equipment.

Dry cooling

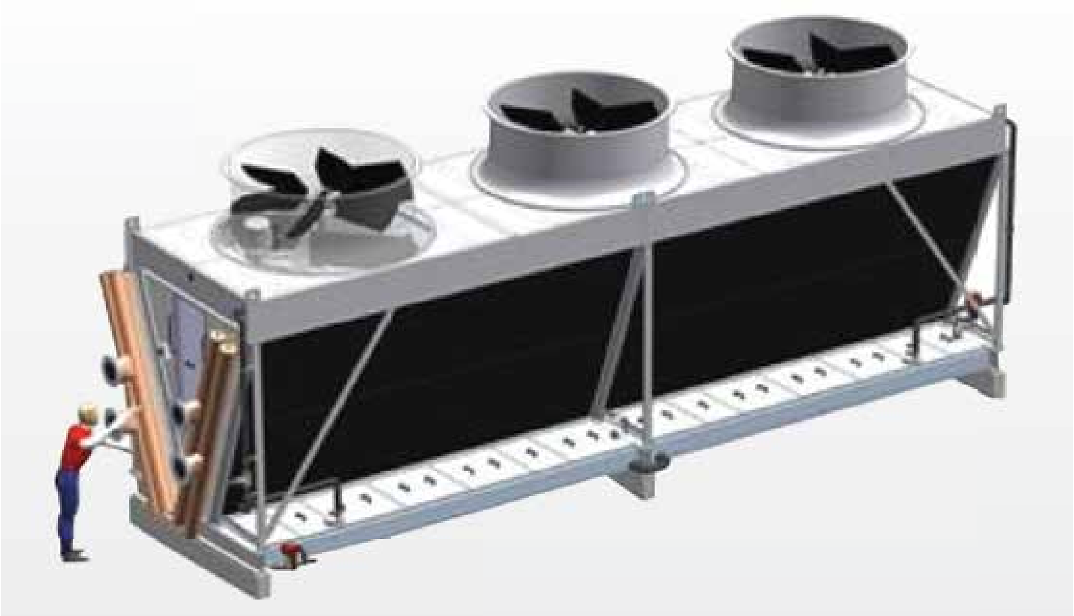

Figure 14: Hybrid dry cooler, Jaeggi Hybridtechnologie Ltd. The outside appearance is similar to dry coolers.

In dry coolers, the heat transfer liquid (typically water) is cooled via finned-tube heat exchangers that reject heat to the surrounding air. Fans are used to ensure the needed air flow and heat evacuation. The heat transfer liquid circulates in a closed circuit. Dry coolers have lower operation and maintenance costs than wet cooling towers and avoid water consumption. Their physical volume and space requirements per unit of cooling capacity are higher than for wet cooling systems, and investment costs are therefore higher as well (roughly two times the costs of wet cooling for big installations, see e.g. Zhai and Rubin, 2010). Their main drawback is that they can cool down the HTF only to the dry bulb temperature of the ambient air, which is higher than the wet bulb temperature that represents the limit for cooling towers. This comparatively high return temperature poses a challenge to the chiller (especially if it is of absorption type) and can lead to lower chiller efficiencies.

Furthermore, the fans needed for circulating the air cause significantly higher parasitic electricity consumption than wet cooling systems.

Due to the water situation in Jordan, dry cooling is the standard cooling method for thermal systems in the country, and its drawbacks have to be minimized by sensible design and dimensioning.

Ground cooling

Ground cooling systems are an alternative to dry cooling, using the ground as a heat sink instead of the ambient air, but not all locations lend themselves well for this application as it depends heavily on the ground composition or, more specifically, its thermal conductivity. Heat can either be rejected through vertical boreholes or horizontal tubes laid into the ground. Due to the ground temperature typically being lower than daytime surface air temperatures, it has lower energy consumption than the wet or dry cooling and achieves lower cooling temperatures. The main drawback is the high investment cost.

Ground cooling would be an interesting option for solar cooling systems in Jordan; however, due to higher investment costs and extensive ground works that are necessary for the installation, suitable application sites will be scarce except in non-urban areas. Ground cooling could be an interesting option for systems that are installed at universities where often free ground space is available and this specific form of cooling could be an interesting object for technical monitoring.

Hybrid cooling systems

In order to combine the advantages of wet systems with the water consumption advantages of dry systems, the two can be combined in different manners:

- The air used for dry cooling can be pre-cooled before entering the actual heat exchanger by evaporation of water sprayed onto it. This leads to an air temperature cooler than the ambient and thus lower temperatures can be achieved. This is an interesting option for regions with high ambient temperatures, but it has the disadvantage that impurities from the water used for pre-cooling can deposit on the surfaces of the cooler, causing higher maintenance needs and costs.
- Hybrid dry coolers are a combination of dry and wet cooling taking place in the same heat exchanger. When the weather is relatively cold, the cooler acts like a dry cooler described above. When temperatures are higher, water is circulated and flows over the surface of the heat exchangers. As air passes over the heat exchangers, the water evaporates and draws heat from the fins.

These hybrid systems can cool down to the lower temperatures of wet cooling, but show significantly lower water consumption than wet cooling systems (depending on the operating conditions). They are therefore principally an interesting option for solar cooling systems in Jordan; however, high investment costs and little standardization may make their application less attractive.

Other forms of cooling

In countries with abundant water, ground water, rivers or lakes are also used for the rejection of heat. Due to water scarcity in Jordan, these options are not discussed further here.

2.3.4 | Overview Storage Systems

As both the incoming sun radiation and the cooling demand fluctuate, storage systems are used to help matching demand and supply and avoid occurrence of cooling power shortage or the need for conventional back-up systems which require mains electricity. In regions with high incoming solar radiation (as it is the case in Jordan), a storage capacity of two to four hours is usually necessary for covering at least the cooling needs during the day (International Energy Agency, 2010).

In solar collector systems, thermal energy is typically stored in a storage medium, which can buffer the thermal energy generation peak around noon to use the energy later on, compensate passing clouds etc. Storage is also often applied on the cold side of a chiller system, where it can compensate fluctuations on the cooling demand side.

The simplest and most frequent method to store thermal energy is insulated tanks that can take up the heat transfer fluid (HTF) and release it at a later point in time. This can be done both on the solar, hot side of the system (hot HTF tanks) and on the cooling side (cold HTF tanks). Components are fairly standard and many suppliers are available. More sophisticated methods of storing thermal energy like phase-change materials etc. are used for other applications, but they all feature the disadvantage of high costs, and their advantages (higher efficiency, higher energy density etc.) are of little relevance for solar cooling applications.

So for regular air cooling and even refrigeration applications, the utilization of hot and cold HTF (usually water) tanks is the most practical and economical option. These would most probably be the storage systems applied in solar thermal cooling in Jordan. Their dimensioning will depend on the specific location and needs (load profiles, solar resources etc.).

2.3.5 | System planning and component selection

Assuming that the auxiliaries (pumps, fans, control etc.) will typically require at least some 25% of the electric power consumed by a comparable conventional compression cooling system, energy (=electricity) savings of 75% maximum can be reached. This applies if solar is the only power source of the air conditioning system; however, if for economic or reliability reasons fossil fuel co-firing is used, the achievable primary energy reduction quickly decreases and can even become negative if the thermal COP of the sorption machine is low and the fossil fuel burner is used frequently. It is therefore essential to dimension the solar and storage system in a way that it covers at least 80% of the required cooling demand throughout the year (see Figure 15). For COPs below 1.0 (all single-step machines), this share should be even higher, ideally above 90%, in order to achieve sensible energy savings.

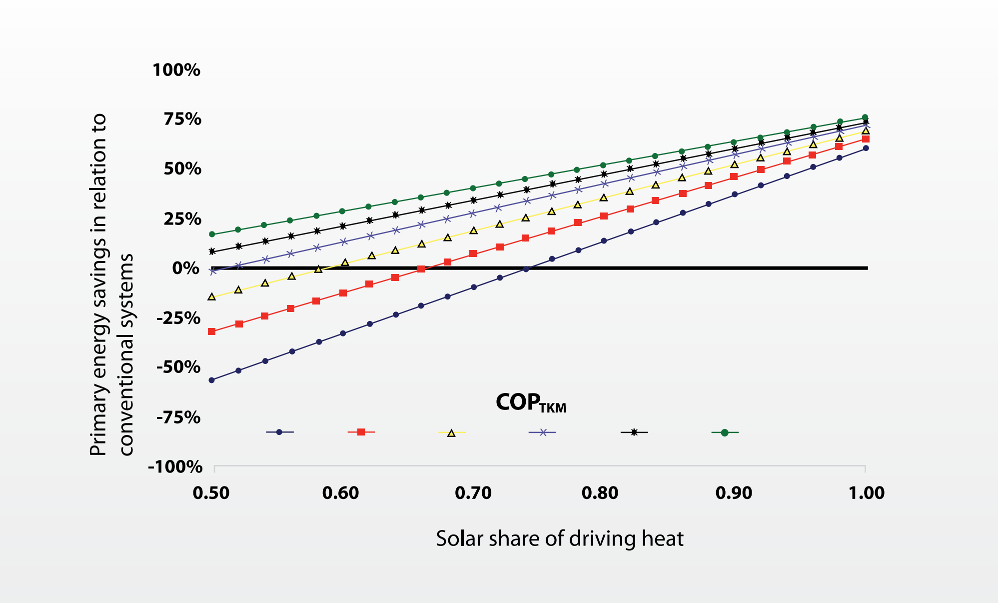

Figure 15: Primary energy savings vs. solar share of thermal energy input. Source: Herkel, 2009

The selection of the chiller model (including its COP) and the solar coverage ratio (by dimensioning of the solar field and storage size) are the key determinants for the primary energy saving and CO_2 reduction. At the same time, they can strongly affect the economics of the system; so sometimes a suitable compromise has to be found between emission savings and incremental costs. Finding a suitable and efficient heat rejection system is also crucial as it can harshly affect the COP as well.

A comparison of which collector-chiller combinations are suitable under which conditions is done in chapter 5 on the base of a detailed analysis of two actual design options.

2.4 | Costs of solar cooling system components

This section provides a rough overview of costs of solar cooling system components. However, as systems are not standardized and available analysis is limited and not standardized either, this overview is bound to be very tentative and therefore has to be treated as a rough estimate.

Sources for the figures given are Preisler et al., 2008, an analysis by AiguaSol (AiguaSol, 2009), a general market research for the prices of solar collectors and a roadmap on solar cooling and heating (International Energy Agency, 2012).

Cost shares

One important factor is the share of costs by different system components. Components or subsystems are accounted differently in different analyses (especially on “auxiliaries” or “solar collector”) and often some uncertainties remain on whether secondary costs as planning, installation, contingencies etc. have been considered or not. Table 3 gives a synthesis of the Rococo project (Preisler et al., 2008), an actual case from France cited in the same project report and the AiguaSol analysis paper (AiguaSol, 2009).

Table 3: Cost shares of solar cooling systems’ components

Component	Typical share of total costs	Sample share of costs (∑ 100%)
Chiller	15-20%	18%
Control	5-10%	8%
Auxiliaries	8-15%	14%
Solar Collector	30-45%	42%
Heat rejection	<10%	8%
Design & Planning	app. 10%	10%
Total		100%

Component costs

For the most important components of a solar cooling system, typical cost ranges have been assessed for solar cooling components. They are summarized in Table 4. The numbers for the solar collector are competitive market prices.

2 | Background on Solar Cooling Technologies

Table 4: Typical component cost ranges

Component	Price	Source
Solar Collector – Flat Panels	200 € / m^2 aperture area	Market price
Solar Collector – Evacuated Tube	300 € / m^2 aperture area	Market price
Chiller	350-500 € / kW cold production	Aiguasol, 2009; TU Berlin
Cooling tower (wet)	40-80 € / kW heat rejection	AiguaSol, 2009
Storage, hot	2000-3000 € / m^3	AiguaSol, 2009
Storage, cold	1600-2400 € / m^3	AiguaSol, 2009

Costs for a typical solar cooling system

For illustration, the cost distribution for an actual system is given, based on the component costs from the AiguaSol analysis. Note that it is not clear from the report whether components referring to the balance of plant are missing in the costs, or whether it is considered within the solar collector auxiliaries.

Resulting cost assumptions for a system with $100kW_{th}$ cooling power (app. 30TR) are shown in Table 5.

Table 5: Cost listing for a solar cooling system with 100kWth cooling power (app. 30TR), based on AiguaSol, 2009.

Component	Cost (€)
Solar Collector	129,000
Chiller	50,000
Cooling Tower	20,000
Hot storage	30,000
Cold storage	12,000
Control, Elect., Monitoring	50,000
Design&Planning	34,920
Total	325,920
Total per kW	3,259

Total cost per kW

As can be seen from the cost distribution above, the presented system costs result in specific costs of about 3,300 € per kW of cooling. The roadmap on solar heating and cooling (International Energy Agency, 2012) gives a range of 1,600 to 3,200 US$ per kW of cooling for big systems; however, no sources are mentioned for these numbers and compared to data from the Rococo project (Preisler et al., 2008), this range seems very optimistic.

3 | Background on the Solar Cooling Market

Solar thermal cooling is still a young and developing market. In 2010, approximately 600 solar cooling systems were installed worldwide – above 500 of them in Europe (Weiss and Mauthner, 2012). The average capacity of systems that were analyzed by Fraunhofer ISE was about 50 kW_{th} of cooling power (thermal power extracted in form of cold) and the average collector area about 130 m^2 (Herkel, 2009). Key market installations are in Germany and Spain (each about one third of the market and the remainder of the world with the remaining third). 70% of assessed cooling machines were absorption type, 20% DEC and 10% adsorption (Herkel, 2009).

When compared to conventional compression-based cooling, one important issue is that most manufacturers of components are specialised in either the solar or the chiller part, but seldom in both. The different components also have different development stages and track-records: whereas solar flat plates and evacuated tubes are standardised components sold on big world-markets, Concentrated Solar Power (CSP) systems are only standardised and sold in big scales for electricity generation in the MW range and are not yet produced in big numbers for heating and cooling purposes. Thermal chillers have significant markets in the industrial range above 100 kW, but not so for smaller capacities, and for operating chillers by solar thermal energy, adaptations are needed to the traditionally gas-driven models. Heat rejection and storage systems are easily available, but have to be dimensioned specifically to the needs of a given system. It is easy to understand that the control of such a diverse system with components from different suppliers is also a complex task that often has to be custom-made which consumes time and money.

3.1 | Overview of Potential Suppliers Worldwide

3.1.1 | Analysis of International and EU technology providers

In the following, an overview of the International and European suppliers that sell either solar systems or cooling systems is given, with a particular focus on German companies (as Germany is one of the countries with the most installed solar cooling systems). Jordanian companies are included as well. Companies from other countries are mentioned when certain systems are not available on the German or European market.

On the solar side, there are many companies on the market for flat plate and evacuated tube systems. These systems are often used for heating or for warm water supply on a smaller, residential scale. CSP systems that have higher output temperatures are less common, especially on the residential market. They are more complex and thus more difficult to handle. Often CSP systems have a higher specific weight and only a few are suitable for acceptable loads on rooftops.

Compared to conventional cooling systems even in Europe solar systems for solar cooling, and absorption and adsorption systems, are still a niche market but the systems are getting more common.

As it is still a niche market there are only a few companies that deliver these kind of systems. For the improvement of solar cooling technologies further R&D will be required. Thus, also research institutes and universities are working on the technology and developing and improving systems.

When planning a solar cooling unit, it is important, that the solar system matches the cooling system, i.e. the temperatures delivered have to fit to the needed temperatures for the cooling cycle. Additionally, other components (e.g. storage tanks) are needed to complete the set-up. Thus, it is complicated and time-consuming for interested consumers to put a whole solar

3 | Background on the Solar Cooling Market

cooling system together on their own, starting from single components. To simplify this process, there are companies focussing on system integration and on planning of the set-up.

Table 6 provides an overview of suitable companies[5] with track record for building systems or providing components for solar cooling.

More information about the companies can be found in Annex IV.

Table 6: Overview of companies supplying solar, cooling and/or complete systems. (Cooling capacity is given in kW)

Scope	Collectors				Cooling System					Complete Systems		Engineering
					Absorption				Adsorption			
Company	Flat plate	Evacuated tube	Fresnel	Parabolic trough	Single step NH3/H2O	Single step H2O/LiBr	Double step	Triple step	Adsorption	Residen-tial	Commercial	
KBB (D)	■											
ökoTech (AT)	■											
Schüco (D)	■											
Stiebel-Eltron (D)	■											
Wagner Solar (D)	■											
Buderus (D)	■	■										
GreenOneTec (AT)	■	■										
Solvis (D)	■	■										
Viessmann (D)	■	■										
Paradigma (D)		■										
Solarfocus (AT)		■										
Sunda (D)		■										
Industrial Solar (D)			■									
Novatec Biosol (D)			■									
PSE AG (D)			■									
Solarlite (D)				■								
Solitem (D)				■								
AGO (D)					50 - 1000							
Pink (AT)					10						■	
Robur (D)					15 - 90							
Solarice (D)					25 - 40							
BS Nova / TU Berlin (D)						15; 54						
EAW (D)						15 - 200						
Yazaki (J)						17 - 105	105 - 700					
Broad (CHN)							23 - 11.630					
Kawasaki (J)							281 - 9.142					
Thermax (IND)					175 - 1050							
ECO-MAX (USA)									35 - 1100			
Invensor (D)									4 - 22	■		
Sortech (D)									8; 15			
Climatewell (SE)										■	■	
MEI (JOR)	■	■							10 - 20	■	■	
Mustakbal (JOR)	■	■								■	■	
SolarNext (D)											■	
Sopogy (USA)											■	
Solid (AT)												■

Technology providers: non-concentrating solar systems (flat plate and evacuated tube collectors)

The market in this sector started to develop in the 1970s, where small start-ups as well as established European companies (e.g. Bosch Buderus, Viessmann) started to sell solar thermal systems.

These were mainly used for heating and for warm water supply. Up to now, there are few companies active across different regions and the market is segmented. Regionally, often smaller producers dominate. However, the market is expected to expand, mainly as a growing segment of the heating technology branch.

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[5] The listed companies only represent a selection and it should be noted that the list is not complete

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3 | Background on the Solar Cooling Market

Technology providers: concentrating solar power systems

At the moment, there are not many CSP systems installed globally, but the market has been growing in recent years. Commercially, mainly parabolic trough collectors are used, which have a share of around 94% of the CSP market. Linear Fresnel collectors are to a lesser degree commercialised but there are few good reference examples for the use of linear Fresnel collectors with solar cooling.

CSP mainly deployed in regions with high direct solar irradiation. Right now, the main markets are in the USA and in Spain. High direct irradiation makes the MENA region a potentially suitable market for further penetration of CSP systems.

Most CSP providers are focusing on concentrated solar for electricity production only (without producing steam targeted as input for cooling machines). Key differences in the system layout are that CSP for cooling systems are specialized for

- high steam output per m^2 solar covered
- minimum weight for solar system (as most cooling system are required for urban areas with no or limited space availability but on rooftops)
- precise temperature control as input requirement for the absorption machine.

Technology providers: absorption / adsorption systems

Most systems available in the market today are single step absorption units with the pair lithium-bromide and water. Most of these systems are used in Germany where absorption systems are used in combination with relatively low temperature hot water resources from district heating systems or FPCs/ ETC collectors. In Germany there is an industry association, the Green Chiller Association[6], to represent the joint interests of absorption suppliers and research institutes.

Due to the lacking direct irradiation CSPs are less suitable in Germany but more common in other countries, particularly, Spain, India, China and Japan. Leading suppliers there are Thermax (India), Broad (China) and Kawasaki and Yasaki (Japan) with double or triple step absorption units. Adsorption systems are significantly less common. Adsorption systems are significantly less common. There are only few technology providers present in Europe, such as SorTech and Invensor (both from Germany).

Technology providers: research institutes / universities working with absorption / adsorption systems

There are several research institutes working on this topic. The dominating countries here are Germany and Spain. In Germany, amongst others Fraunhofer ISE, ILK Dresden, Hft Stuttgart and Fh Gelsenkirchen are active in the field.

Most of the projects are still in the development phase, with different absorption and adsorption systems being researched. The ILK Dresden is developing absorption systems working with H_2O/LiBr and NH_3/H_2O. Their focus includes the cooling systems in complex energy systems. The Fraunhofer ISE makes concept studies, consults with planers and carries out pilot projects, especially in a smaller power range. The ZAE Bayern has together with industrial partners developed a two-step absorption chiller with 90 kW in a pilot project. In the follow-up project, they are going to develop a two-step chiller with a larger cooling capacity (250 kW). The TU Berlin has developed market-ready absorption chillers with H_2O/LiBr in capacity ranges of 50 kW and 160 kW working very efficiently at low temperatures. They already installed model systems and one chiller is now built commercially by an industrial partner.

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[6] See www.greenchiller.de

3 | Background on the Solar Cooling Market

Technology providers: System Integrators

There are a few companies worldwide offering complete solar cooling solutions. These System Integrators have specialized on system solutions optimizing both solar and cooling components.

The services typically include the EPC (engineering, procurement and construction) of both the solar and cooling systems.

The system integrators can be classified by those more focusing on the residential side (smaller than 100 kW thermal capacity, typically 10 kW) or on the commercial side (above 100 kW thermal output).

Typically, larger systems (> 100-200 kW) are tailored to the needs of the customer, smaller systems (<100 kW) are prefabricated and sold as standard systems.

There are several companies focusing on the smaller market. The market leader here is Climatewell (Sweden).

Most of the system integrators have their core competence in solar systems which are optimized to work with absorption machines. Examples of companies with core competencies in providing solar cooling installations for commercial buildings are Industrial Solar from Freiburg, Germany, and Solid from Austria. Novatec Biosol (Germany), which is a larger player in Germany for CSP / electricity also claims on its website competence on solar cooling for commercial applications.

4 | Potential for Solar Cooling in Jordan

4.1 Climatic Conditions in Jordan

4.1.1 | General Overview

Jordan is situated 80 km to the east of the Mediterranean Sea between latitudes 29° 11' N – 32° 42' and longitudes 34° 54' – 38° 15' E, with an area 89,329 km^2.

The relief of Jordan is extremely of diverse nature. The eastern shore of Jordan River – the western part of the country – which is called the Ghor or the Jordan valley represents the world deepest rift. This low land is stretching from north to south revealing areas 200 – 400 m below sea level.

To the east of the Ghor the terrain extends abruptly upward comprising the hilly region. The elevation of this highland reaches approximately 1,150 m above sea level in Ras Muneef. But the southern part of the country is higher than that, it reaches 1,854 m above sea level at Um Al-Dami Mountain near the southern border.

The hilly land slopes down eastward form a semi-desert plateau called the Badia region. The area of the Badia region is approximately 75% of the total area of the country with elevation between 500 – 1,200 m above sea level.

Deep valleys cross the northern and southern heights create rain-fed floods during winter.

Such diversity of topography within a small country leads to great differences in climate.

Climate in Jordan

The climate of Jordan is predominantly of the Mediterranean type. It is marked by sharp seasonal variations in both temperature and precipitation. Summers are hot and dry while winteres are cool wet. . Summer starts around middle of May and winter starts around mid of November, with two short transitional periods in between.

The climate of Jordan can be divided into 4 main types according to the topography of the country, which has distinct longitudinal zones despite its small area:

1) Hilly regions: cool dry summer and cold wet winter characterize the climate in these re gions with good amount of rainfall.
2) The Ghor: very hot summer and warm winter characterize the climate in these regions with rainfall amount around 77 - 392 mm.
3) The Badia: very hot dry summer and cold winter characterize the climate in these regions with very little precipitation and clear sky during most of the year.
4) The Gulf of Aqaba: very hot summer and warm winter characterize the climate in this re gion with extremely little amount of precipitation.

Temperature

The temperature in Jordan varies by location and seasons. The temperature in the hilly regions experience cold weather with temperatures below 0°C. The summer temperature can reach temperatures above 30°C (as monthly average temperatures).

Humidity

During the winter season the relative humidity is generally above 80%. But during January and February (the coldest and wettest months), the relative humidity still reaches up to 90%. In the hilly region, the daily average relative humidity still reaches about 70% during this period. While in the Jordan Valley average relative humidity is 65%, in the Badia region and Aqaba area the relative humidity is much lower and the daily average is about 60%.

During the summer season the relative humidity is generally low. In the hilly region the air is much drier and the daily average relative humidity is about 35%, Amman is located in such a climate. During this season the relative humidity has a wide range especially between day and night on the whole relative humidity at night is high about 90%. During daytime, the relative humidity is about 40%.

a) **Amman** is located in a hilly area in northern east part of Jordan with big difference in elevation from 700 to 1,100 m above sea level. It spans over an area of 19 hills. Amman has a semi-arid climate. Winter is cold with high humidity. It has an average temperature of 10°C (it can reach as low as -7.5°C) and an average relative humidity above 60%. Winter usually spans from late November till late March. Spring is relatively short. It stays until late May with an average temperature of 16° C. Summer is long and dry. It stays till mid-October with average temperature of 25° C but with high differences between day and night. It may reach more than 40° C (sometimes 44° C) during the day and less than 18° C during night. Mean sunshine hours range from 12.5 hours/day during summer to 6.5 hours/day during winter. Mean daily global solar radiation ranges from 2800 Jul/Cm^2 during summer to 1000 Jul/Cm^2 during winter.

b) **Zarqa** is located northeast of Amman with elevation of 620 m above sea level. Zarqa has a desert climate with a hot and dry summer and low precipitation during winter. Temperature ranges from 10° C to 25° C. Humidity is between 42% and 68% all over the year.

c) **Irbid** is located in northern Jordan at 620 m above sea level. It's the second largest city in population in Jordan. It has an average temperature of 10°C during winter with relative humidity of 70%. Winter is from December till mid-March. Average temperature in spring is about 16° C. Summer spans till mid of October. It has average temperature and humidity of 25° C and 60%, respectively. Mean daily global solar radiation is between 2800 Jul/Cm^2 in summer and 1000 Jul/Cm^2 in winter. Mean sunshine hours are 5.5 hours/day in winter and 12 hours/day in summer. Temperature difference between day and night is about 13° C.

d) **Aqaba** is in south of Jordan on the Red Sea. It's the only port in Jordan. Aqaba has a desert climate with a warm winter and a hot dry summer. During winter, temperature is mostly above 15° C. In summer, temperature is usually above 32° C. Humidity is about 55% during winter, and 36% during summer. Aqaba has mean daily global solar radiation of 2800 Jul/Cm^2 in summer, and 1300 Jul/Cm^2 in winter. Mean sunshine hours range from 7 hours/day to 12 hours/day.

e) **Dead Sea** is located in the Middle West of Jordan with elevation of 400 m below sea level. It's the hottest area in Jordan with average temperature above 35° C during summer and about 18° C during winter. Humidity ranges between 40% and 60% all over the year. Mean daily global solar radiation ranges between 1000 Jul/Cm^2 and 2700 Jul/Cm^2 and mean sunshine hours are between 6 hours/day and 11.5 hours/day.

4.1.2 | Air Conditioning Needs

To calculate the air condition needs of a particular location in Jordan, the concept of cooling degree days is a suitable method. Degree days are essentially a simplified representation of hourly outside air-temperature data. Cooling degree days are a measure of to what extent (in degrees), and for how long (in days), outside air temperature was higher than the desired room air temperature (e.g. 20 or 25°C). The degree days can then further be used to estimate the cooling load or for calculations relating to the energy consumption required to cool buildings. In the same way, heating degree days result from the product of temperature deviation (lower temperature, degrees) and its duration (days) compared to the desired room air temperature.

Therefore, in order to get a rough idea, the number of months within one year where air conditioning (or heating respectively) is used already gives a good overview on the general situation of cooling needs in the country (see Table 7).

Table 7: Number of cooling months and heating degree days in different cities in Jordan

Region	No. of cooling months / year	No. of Heating degree days/year
Dead Sea	9	1.5
Aqaba	9	2
Irbid	5.5	5
Amman	5.5	5
Zarqa	6.5	4.5

4.2 Regulations and Incentive Schemes

In March 2012, Renewable Energy and Energy Efficiency Law was released. The law aims to regulate and encourage the renewable energy and energy efficiency sectors.

Some of the important points in the law[7] :

- Allow producing and selling electricity to the grid from renewable energy sources
- Custom exemption for renewable energy and energy efficiency equipment
- Establishment of Jordan Renewable Energy and Energy Efficiency Fund (JREEEF)

JREEEF can give a big step forward in introducing solar cooling since it can be an important source for funding these projects as renewable energy projects. Funding options are under preparation.

But in concept, solar cooling projects can be funded through JREEEF, either by soft loans, grants, or covering part of the project costs. The introduced tax exemption for renewable energy technologies has an effect on the overall cost of procurement.

Jordan Renewable Energy and Energy Efficiency Fund

Under the regulations of the Renewable Energy and Energy Efficiency Law that was issued in March 2012, a fund to be known as Renewable Energy and Energy Efficiency Fund will be established in the Ministry of Energy and Mineral Resources (MEMR).

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[7] For the full details about the law, please visit the website: http://www.memr.gov.jo/LinkClick.aspx?fileticket=1uZNgYBo-co%3D&tabid=36

The fund aims to provide the funding necessary for the exploitation of Renewable Energy Sources and the rationalization of energy consumption including small Renewable Energy Facilities.

The Fund will be managed by a Committee called (Management Committee of the Fund) under the Chairmanship of the Minister.

The financial resources of the Fund shall consist of the following:

1) The amounts allocated in the general budget.
2) The fund's revenues and investment proceeds.
3) Aids, gifts, donations and grants subject to the approval of the Council of Ministers if they are from non-Jordanian sources.
4) The percentage determined by the Council of Ministers from the proceeds of the sale of certified emission reductions credits (carbon) for energy projects.
5) Any other resources approved by the Council of Ministers.

The fund is under establishment right now. A director was appointed. Experts will be hired to put a plan and a time frame for establishing the fund, under the instructions of the law.

One of the bylaws which were issued under the Renewable Energy and Energy Efficiency law is "The Bylaw on Regulating Procedures and Means of Conserving Energy and Improving Its Efficiency"

One important point in the bylaw:

No work permit shall be granted until after submitting a proof of installation of a Solar Water Heater (SWH) for any of the following, subject to abundant of the technical conditions allowing the same, according to the inspection conducted by the competent official authorities:

1) Buildings exceeding (250) square meters in area.
2) Apartments exceeding (150) square meters in area.
3) Offices exceeding (100) square meters in area in commercial buildings.

Provisions of this article shall come into force as of 1/4/2013[8] .

This bylaw can be linked to solar cooling in a way that in the future, if new buildings implement solar water heaters and have excess heat, the collectors can be linked to an absorption/ adsorption chiller.

4.3 Barriers and Options

In the following, the most important barriers and options to overcome the barriers for the introduction of solar cooling technology on the Jordan market are introduced. Barriers are obstacles that hinder the introduction of new technologies. Options are ways to overcome the barriers and allow a wider diffusion of the solar cooling technologies in the market.

4.3.1 | Technical barriers

The main aspect here is the difficulty regarding the right determination of the best suitable solar cooling system for a certain application.

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[8] For more details, the bylaw can be found in the link: http://www.memr.gov.jo/LinkClick.aspx?fileticket=7xnTASsmwyY%3d&tabid=254

Table 8 provides a list of the most important technical barriers relevant for the market in Jordan and possible options to remove the barriers:

Table 8: Technical barriers and options for Jordan

Barriers	Options to Overcome the Barriers
Heat rejection challenges due to high ambient temperatures and water shortage	• Utilization of dry or hybrid cooling • Utilization of ground cooling
Limitations in available rooftop size	• Make clear how much rooftop space (in combination with a recommended solar system type) is needed for specific cooling needs • Utilization of CSP and double-step absorption machines for higher spatial efficiency (subject to budget availability) • Combine solar cooling with conventional cooling systems
Poor matching of cooling demand with solar energy affects system efficiency	• Identify typical load profiles and match with standardized system dimensioning options. • Identify and integrate especially hot water needs in order to get a high overall efficiency.
Non-standardized components can create issues during selection, commissioning and operation	• Identify suppliers worldwide; develop standards for components where suitable • Definition of model cases with a list of corresponding component suppliers • Identify suitable, qualified suppliers in Jordan • Capacity building measures where necessary
Ancillary energy consumption and co-firing harm the overall primary energy savings	• Use a high solar share and little or no co-firing for system design to minimize fossil fuel consumption • Use highly efficient ancillary parts to minimize electricity consumption

4.3.2 | Component supply and availability

Here, the main points to be considered are:

- difficulties in sourcing equipment from usual suppliers as there was no demand before (solar flat plates are available, but it is more difficult to find absorption systems)
- no availability of complete "packages", components from different sources have to be connected
- poor availability of systems for certain cooling capacities

Ways to overcome these difficulties include sourcing of missing components by working with existing distributors / suppliers, who can start to stock the desired components, developing new components or adapting the production line. Also importation channels can be developed or a distribution infrastructure could be set up. For the available components, it is helpful to set up a database of producers in order to link them with each other and for giving possible customers a good overview. Awareness-raising may also help or the introduction of incentive and/or disincentive schemes for possible customers by national policies.

4.3.1 | Commercial barriers

Commercial barriers refer to the fact that higher investment costs are implied for solar thermal cooling systems than for conventional systems in a comparable size, which can lead to higher investment costs (often around 2 to 5 times higher).

In order to bridge the time period until the technology becomes cheaper, this barrier can be overcome by incentive schemes such as subsidies covering parts of the investment costs or disincentive schemes for conventional systems. Demonstrating the well functioning of the systems and their commercial viability over several years can help in the long-term.

On the other hand, the operational costs of solar cooling systems are lower (if the systems is well designed and operated), so another possibility is to provide and spread tools that show when and in which cases solar cooling is financially attractive, especially emphasizing their lower lifetime costs, and by providing guidance documentation on best practice for the use of solar cooling equipment.

4.3.2 | Market barriers

Here, the following aspects have to be considered:

- missing awareness of the new technology
- no familiarity with the technology and thus hesitation to work with it
- competing conventional systems are already widespread and are more convenient / easy to handle

These problems can be addressed by dissemination of information about the technology, their advantages and availability. It can help to indicate in which cases solar cooling systems offer financial benefits. In case of the absence of national strategies, an integrated development plan could be developed. In general, the industry involvement should be stimulated and local engineering with the new technologies encouraged.

4.3.3 | Information resources

This barrier refers to

- limited availability of technical data, guidelines or instructions
- missing training and /or lack of expertise for technicians and engineers on solar cooling systems
- limited appreciation of technical and safety aspects
- poor performance by not sufficiently qualified technicians

This barrier can be overcome by working with authorities to roll out awareness programmes or introduce a labelling scheme. Also the development of interest groups and the implementation of train-the-trainers schemes can help. If the technicians have no experience with the system or no knowledge about it, it will be good to implement demonstration projects. There, they can have practical training on the system and get familiar with the technology. It is critical to adopt dedicated training that is specific to the solar cooling technology. If no design and selection guides are available, new tools should be developed to assist with the design, selection, installation and monitoring. It should be targeted specifically to single stakeholder groups. Thus, important messages can be presented in a way that is most relevant to the group and enhance the appeal of solar cooling systems.

4.3.4 | Regulatory and quasi-regulatory barriers

Legislation and certain standards can impose barriers, e.g. if they

- ban the use of flammable and / or higher toxicity refrigerants (e.g. ammonia) in buildings
- or regulate the construction features of the refrigerating systems.
- The absence of supportive legislation is a barrier for solar cooling systems, as there is no motivation for the industry to introduce them and there is no “push” to put effort into overcoming the hurdles.

These barriers can be overcome by governmental interventions that facilitate the introduction of the new technologies. Legislation and standards can also help to improve the cost-effectiveness of the technology. Some interventions are already initiated by the Renewable Energy and Energy Efficiency law (s. section 4.2). This includes custom exemptions for renewable energies and the establishment of a fund, which will targets to cover loans, grants and can partly pay for costs of renewable energy projects. Other possibilities could include loans from a national bank for the installation of solar cooling systems with good conditions and a low interest rate. The (initially) higher investment costs for solar cooling systems could be lowered by an upfront payment as high as the discounted amount of money that solar cooling systems save over their lifetime by not receiving subsidized electricity from the grid. Preferential tax treatment for solar cooling system producers may also help to stimulate investments.

4.3.5 | Psychological and sociological aspects

Psychological or sociological aspects include

- personal perceptions
- prejudices of key players (such as installers or end users)
- natural resistance to change
- missing awareness of global warming
- resentments against higher upfront costs

These feelings can be overcome by promoting the new idea via information, demonstrating successful projects or national campaigns, which give a positive image to the new technology. Further support will also come from the introduction of several (successful) demonstration projects which provide case studies and good quality data. Furthermore, the endorsement by key figures will assist the new systems. Authorities can develop incentive schemes to support the purchase of alternative solar cooling systems.

4.3.6 | Summary: Barriers and Mainstreaming of Solar Cooling Technologies

From the barriers introduced above that have to be taken into consideration when introducing solar cooling systems in Jordan, the most important ones are summarized in Table 9:

Table 9: Overview of main barriers and options for Jordan

Barriers	Options to Overcome the Barriers
Right technical collection	• Publication of guidelines for technicians and political decision makers, which helps to choose the right technology combination (e.g. concerning roof top size, cooling needs) • Matching of the system to the particular situation • Well-chosen, appropriate design • Matching of the different components to each other • Implement functioning, well designed pilot projects that can help disseminate suitable designs and technologies
Market development	• Stimulation of the market by spreading information about the technology and their advantages so that local suppliers invest in it • Information of suppliers and consumers about the potential financial benefit of the technology
Higher investment costs	• Support by more active policy through legislations including loans, tax exemptions, subsidies or preferential tax treatment until lower technology costs are reached • Give potential customers detailed information about the amortisation times for solar cooling systems
Lack of awareness	• Highlight the possible benefits (financial savings, environmental protection) for decision-makers and end-users • Description of different available solar cooling options for different scenarios (different systems for different cooling needs, possibility of using excess heat)
Lack of capacities	• Support local technicians to understand and work with the new systems through training • Development of training material

4.4.2 | Capacity Development Needs

The assessment of the market and previous projects in the field of Solar Cooling in Jordan reveals that the local market for sustainable cooling features both, potential and needs in developing capacities. Although capabilities for production of sorption machines exist, such machines have been produced so far only at an experimental state. Implementation of first solar cooling systems for buildings has not been very successful so far. Research partnerships and technology transfers are potential ways to enable the Jordanian industry to produce its own sorption chillers locally. This possibly would reduce technology cost.

With regard to solar collectors, local companies have experience in their design and installation. However, knowledge on the coupling to sorption machines needs to be developed. As for production, technology cooperations with foreign flat plate producers could strengthen capacities to locally produce flat panels suitable for solar cooling applications. For evacuated tube systems, the world market is already very competitive and the establishment of local production would be very difficult. Implemented solar cooling projects in Jordan reveal shortcomings in the field of operation and maintenance. It is expected that twinning projects and offering training at the pilot project sites will improve the capacities.

4.6 | Overview of Market Potential

A high future market penetration is crucial for achieving a significant emission reduction by the deployment of solar cooling in Jordan. In this chapter, the main constraints for a large-scale deployment of solar cooling technologies in Jordan are introduced. An estimation of the penetration rate after the introduction of solar cooling systems in Jordan is given, defined as the maximum market potential of the new technology. Finally, an estimation of the emission reduction potential corresponding to the estimated market potential of solar cooling is given (for simplicity we consider only single step absorption systems).

4.6.1 | Main constraints on the market potential

There are different limitations to the new solar cooling technology resulting from safety concerns, costs and availability of the systems and/or system requirements. All these limiting factors have to be considered when estimating the market potential of solar cooling technologies.

In the following, two scenarios are projected. The first is a conservative estimate (CE) about the market penetration of solar cooling technologies in Jordan and the second is a best case estimate (BE) scenario, assuming that scarcity of resources, rising energy prices and the continued phase-out of HCFC refrigerants will increase the market penetration drastically.

It must be noted here that there is no generally accepted methodology for the determination of penetration rates, and that the rates are subjective and with uncertainties. Evidently, it is not possible to precisely forecast and quantify the technical development in the coming years. The penetration rates rely on the best knowledge of experts. Furthermore, the penetration rates will also fluctuate depending on the building and the kind of system needed. For instance, if excess heat is available no – or less – solar systems are needed, which will decrease payback time and consequently increase the market potential.

Safety constraints

The application of refrigerants is generally controlled by national regulations, such as those dealing with the use of hazardous substances in buildings.

In absorption systems, one can either use ammonia or water as refrigerant. Ammonia has a low flammability but a high toxicity, and thus safety is a concern for these systems. However, ammonia systems have still advantages compared to conventional compression systems (lower pressures, no moving parts). Consequently, in regional and international safety standards, ammonia sorption systems are treated differently to compression systems. In sorption systems, higher quantities of refrigerant are permitted compared to compression systems with similar specifications, in which only little or no ammonia is allowed. If water is used as refrigerant, safety is not an issue. If we assume that about 1/3 of the absorption systems use ammonia and that half of the customers thus have concerns regarding the new systems, we can estimate that the safety constraint is about 15% for both scenarios.

Cost constraints / payback time

Cost is a crucial point when calculating the penetration rate of solar cooling systems, as they still have higher capital costs than conventional systems. However, when regarding the costs over the entire lifetime of the systems, solar cooling systems are cheaper as they require less energy than conventional systems. This is especially interesting in Jordan, where the energy prices rise quickly at the moment.

Thus, for estimating the cost constraint, one should consider the payback time, which is the period until the point in time where the costs for the conventional chiller plus its energy costs equal the higher investment costs for the absorption chillers plus its lower energy costs. After this point in time, cost savings are realized from using a solar cooling system. Payback time is estimated to be 10 years at present based on calculations made on other projects in the region[9] , which leads to a constraint of payback time of approximately 45% in 2020 for the CE scenario and about 40% for the BE scenario. This constraint will decrease with time, as the capital costs for solar cooling systems will decrease due to a wider dissemination of the systems. The decline will depend on the dissemination of the technology. For the CE scenario, we assume that in 2050 the constraint will still be 30% whereas in the BE scenario with a wider dissemination it will be reduced to 10%.

Availability

Solar cooling systems are still not a very common technology and not many different system types are available. Furthermore, not many people might be informed about their existence and advantages. When customers decide to make a bigger acquisition, such as an AC system, they prefer in general to be able to choose between different systems. Thus, people tend to buy a conventional system where they have more possibilities to pick from. This is a big constraint for solar cooling systems right now, estimated to be about 95 % in 2020 for the CE scenario and about 80% for the BE scenario. However, if the technology gets promoted accordingly, this constraint will decrease heavily with time. The technology will become further known, more people will demand it and the market will increase. Thus, we assume in 2050 that this constraint will decrease to 88% in the CE and to 60% in the BE scenario.

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[9] See e.g. http://www.afedonline.org/eeh/Eng/F.pdf, Case Study 5

System requirements and design

The biggest constraint here is the space needed for solar panels on the roof top, which should be preferably in a non-shaded area. However, this is a larger constraint for residential than for commercial buildings, especially for people living in apartments, who might have no roof access at all. For commercial buildings, such as hotels, factories or public buildings, more roof space is available and this leads to a constant constraint of about 60% for the CE scenario. For the BE scenario we assume that the solar panels will become more efficient and that the further development of the cooling systems will lead to a better COP. Thus, less panels are needed to achieve the same amount of cooling which in turn decreases this constraint to 40% in the BE scenario for 2050.

Maximum potential penetration rate

The maximum potential penetration rate can now be estimated as

$$1 - \max\{i\},$$

with “i” representing the constraint. For our case, the amount of the constraints as mentioned above and the resulting maximum penetration rates are summarized in Table 10.

Table 10: Estimated constraints and resulting maximum penetration rate for today and the future for the CE and the BE scenarios.

Year	Constraints [%]								Maximum penetration rate [%]	
	Safety		Costs / payback time		Availability		System requirements / space for solar panels		CE	BE
	CE	BE	CE	BE	CE	BE	CE	BE		
2011[10]	-	-	-	-	-	-	-	-	0	0
2020	15	15	45	40	95	80	60	60	5	20
2030	15	15	40	30	92	75	60	55	8	25
2040	15	15	35	20	90	55	60	50	10	45
2050	15	15	30	10	88	40	60	40	12	60

It can be seen from the table that the biggest constraint which determines the maximum penetration rates is system availability for the CE scenario. As the estimations given here are based on a business-as-usual situation, this constraint can be further decreased by specific interventions like spreading information about solar cooling systems and their advantages compared to conventional systems, or incentive schemes that can help to attract both potential suppliers’ and customers’ interest in this kind of systems. If availability issues can be overcome, penetration rates up to 60% can be reached according to these estimations in the BE scenario, and the biggest remaining constraint then will be the needed space for solar panels.

4.6.2 | Estimation of emission reductions

For estimating the possible emission reductions with the introduction of solar cooling systems, we start with the number for R-22 chillers in Jordan, which was about 1800 (Jordan Ministry of Environment) in 2002. We assume that all chillers are running on R-22 in 2002 and thus this is the total number of chillers. For estimating the number of chillers today and in the future, it is

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[10] 2011 is assumed as the baseline year with a penetration rate of 0% of AC systems.

4 | Potential for Solar Cooling in Jordan

supposed that the relative increase in chillers is the same as the relative increase in the GDP in the MENA region.

For a typical chiller, a COP of 3.5 and 3500 operating hours p.a. are assumed, furthermore a rated electrical capacity of 0.23 MW and a refrigerant charge of 304 kg with an annual leakage rate of 10%. Furthermore, it is assumed that after a lifetime of 20 years the whole charge of a chiller is emitted. The electricity emission factor in Jordan is 0.566 tCO2/MWh . With these numbers, we can calculate the indirect, direct and thus total emissions per chiller p.a., which are 645 t CO2eq. Next, the baseline emissions without the introduction of solar cooling systems were calculated until 2050 as number of chillers times emissions per chiller.

The reduced emissions in the solar cooling scenario can be calculated using the penetration rates estimated above and assuming that solar cooling systems have about 25% of the electricity consumption of the baseline R-22 system.

Finally, the emission reductions can be given as the difference between the baseline emissions and the emissions in the solar cooling scenario.

The numbers are summarized in table 11 and 12.

Table 11: Emissions in the BAU scenario and in the conservative estimate scenario with the introduction of solar cooling systems as well as resulting emission reductions.

CE Scenario						
Year	2002	2011	2020	2030	2040	2050
MENA GDP growth rates p.a. [12,13]	4.1% (2010-20)	4.1% (2010-20)	4.1% (2010-20)	4.60% (2020-30)	4.1% (2030-50)	4.1% (2030-50)
Number of Chillers (with R-22)	1,800[14]	2,714	3,897	6,110	9,132	13,648
Emissions in baseline [$MtCO_2eq$/year]	[not considered]	1.75	2.86	4.60	6.78	10.29
Emissions of conventional chiller in solar cooling scenario (penetration rates see above) [MtCO2eq/year]	[not considered]	1.75	2.76	4.35	6.21	9.19
Emissions of solar cooling chiller in solar cooling scenario (penetration rates see above) [MtCO2eq/year]	[not considered]	0	0.02	0.06	0.10	0.19
Emission reductions [MtCO2eq/year]	[not considered]	0	0.08	0.19	0.47	0.92

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[11] IEA statistics, CO2 Emissions from fuel Combustions, IEA, 2012, available under http://www.iea.org/co2highlights/co2highlights.pdf

[12] Index Mundi Country Data Jordan; http://www.indexmundi.com/g/g.aspx?c=jo&v=67

[13] Chateau et al., 2011.

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Table 12: Emissions in the BAU scenario and in the best case estimate scenario with the introduction of solar cooling systems as well as resulting emission reductions.

BE scenario						
Year	2002	2011	2020	2030	2040	2050
MENA GDP growth rates p.a.[15,16]	4.1% (2010-20)	4.1% (2010-20)	4.1% (2010-20)	4.60% (2020-30)	4.1% (2030-50)	4.1% (2030-50)
Number of Chillers (with R-22)	1,800[17]	2,714	3,118	4,583	5,022	5,459
Emissions in baseline [$MtCO_2eq$/year]	[not considered]	1.75	2.86	4.60	6.78	10.29
Emissions of conventional chiller in solar cooling scenario (penetration rates see above) [$MtCO_2eq$/year]	[not considered]	1.75	2.46	3.82	4.48	5.63
Emissions of solar cooling chiller in solar cooling scenario (penetration rates see above) [$MtCO_2eq$/year]	[not considered]	0	0.09	0.17	0.47	0.93
Emission reductions [$MtCO_2eq$/year]	[not considered]	0	0.31	0.60	1.84	3.74

The emissions for the different scenarios are also illustrated in Figure 17:

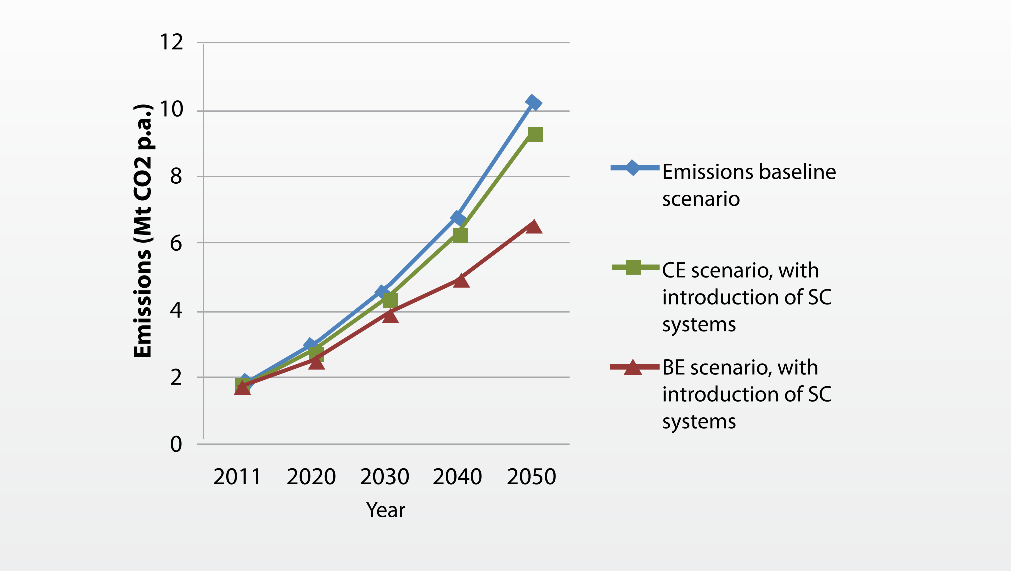

Figure 17: Emission growth for the baseline scenario without introduction of solar cooling, and for the scenario with introduction of solar cooling.

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[14] Jordan Ministry of Environment

[15] Index Mundi Country Data Jordan; http://www.indexmundi.com/g/g.aspx?c=jo&v=67

[16] Chateau et al., 2011.

[17] Jordan Ministry of Environment

5 | Typical design cases for Solar Cooling in Jordan

As technical showcases and as a base for discussion, two concrete designs for solar cooling systems are presented in the following. These cases are rough estimates with the purpose to give an idea of the various parameters of such a system; they do not substitute the actual planning and design of a system. Their size/output power has been chosen rather small, but big enough so that economically sensible components are available for the respective technology.

The two designs represent two basic combinations between solar collectors and absorption machines: (1) Concentrated Solar Power (CSP, in this case Fresnel) delivers higher temperatures and can suitably be combined with a double-step absorption machine, thus featuring higher efficiencies, but also higher costs. On the other hand, (2) non- or low-concentrating collectors (in this case evacuated tubes, ETC) which are economic and easy to handle are combined with a single-step absorption machine, featuring lower costs, but lower efficiencies as well. This latter design utilizes standard solar collectors used for heating water which are already common in Jordan and is thus a good option to use the excess heat generated by an already installed system during the summer months. An adsorption machine could also be considered instead of the single-step absorption machine. Their basic characteristics are similar, with certain differences in part-load behavior, feeding temperatures etc. Desiccant cooling and other concepts have not been considered here due to their low standardization and development for commercial applications.

Both cases are designed for reaching 100% solar cooling (no fossil co-firing). However, the designs presented here are rough and the share of cooling needs that can be covered by the systems has to be analyzed in more detail. Also, the usage of fossil co-firing (with a low annual share of the total) could still be necessary as a back-up. In-depth feasibility studies are needed to provide more evidence.

The different components for the systems displayed here are taken from specific suppliers in order to avail actual component data and give an illustrative example. However, the same components are available from various suppliers.

An overview of the advantages and disadvantages of the two setups is given after the presentation of the latter.

Remark: The examples are for illustration only. Given values can easily vary by factor two when an actual design is done based on actual solar irradiation, cooling needs profiles, etc. Specifically, the specific space requirements are subject to the preferences and methodology in designing and can vary significantly – in the cases presented here they are very high due to the goal of achieving 100% solar share and safety factors.

5.1 | Design Case I: CSP and Absorption

In this case, a Yazaki double-effect absorption machine with 200 kW$_{th}$ thermal output in form of chilled water is coupled to an Industrial Solar Fresnel collector. With a COP of around 1.0, input heat flow is also 200 kWth, delivered by steam of 175 °C at 8 bar. Electric consumption depends mostly on the heat rejection system and the type of pumps and fans used. Therefore it can only be calculated based on a detailed design specification.

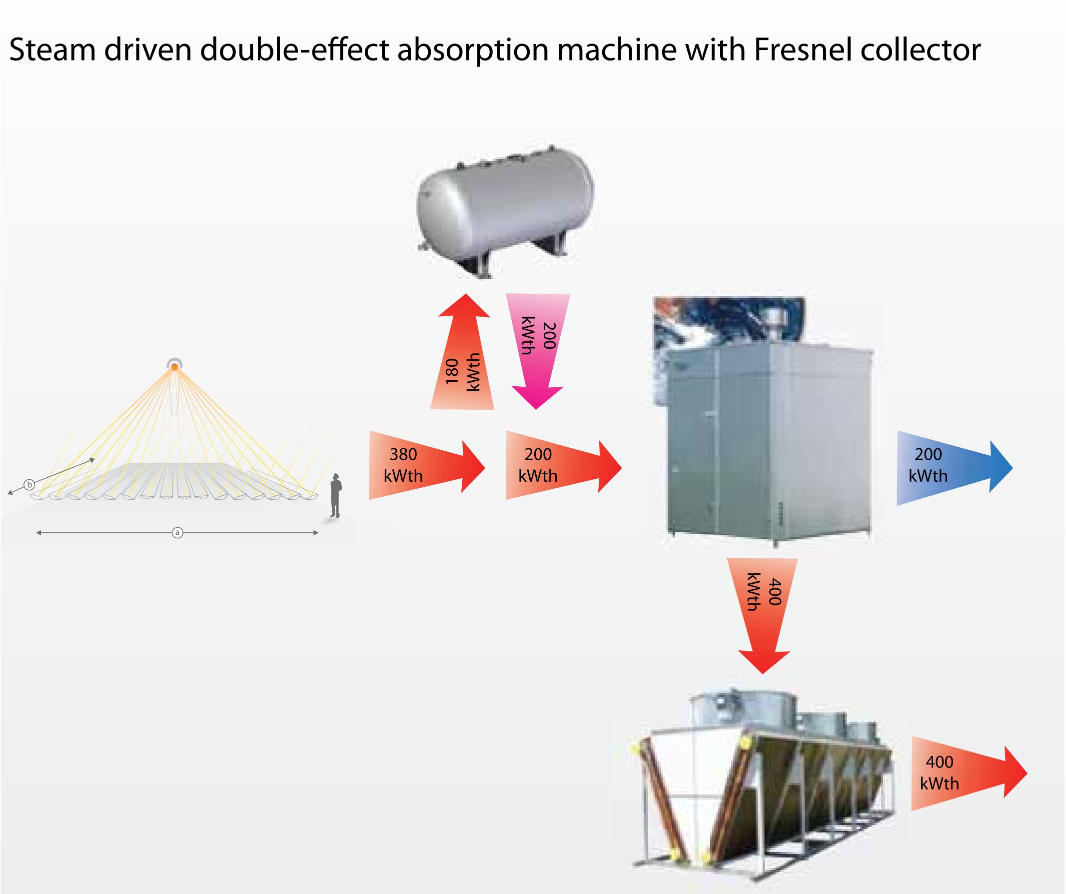

Figure 18: Sketch of a CSP-double-step system design

As the thermal power delivered by the Fresnel collector varies strongly throughout the day, a considerable amount of storage and additional solar field is required. Therefore, a solar multiple of two is assumed (relation between thermal output under peak conditions and thermal input required by the chiller). This number, as well as the storage size, has to be calculated exactly based on available solar irradiation on-site and parameters of the actually employed collector.

Technical adaptation of the standard units is necessary in the following fields:

- The steam parameters are taken from a similar Thermax double-effect machine as the Yazaki machine is designed for gas firing (but Yazaki gives much more specifics otherwise compared to Thermax). If the Yazaki machine is to be used, it would have to be redesigned for steam firing.
- Total heat rejection amounts to 380 kWth, which is designed to be by water cooling both in Thermax and Yazaki machines. An adaptation to dry cooling systems has to be done.
- A pressure storage tank for steam has to be ordered from a specialized supplier.

Table 13: Basic data of application case 1

Absorption machine		**Solar field**	
Cooling power	200 kW_{th}	Solar output power, peak	418 kW_{th}
Input heat flow	200 kW_{th}	Solar multiple	2
Steam parameters	175 °C, 8 bar	Modules	2 lines of 16 = 32
Heat rejection	380 kW_{th}	Dimensions	65 m x 15 m x 4.5 m (L x W x H) = 2,000 m^2
Specific area requirements per cooling power	5.1 m^2 per kW_{th}	Storage	4.5 h, 900 kW_{th}

The Fresnel collector can be substituted by a **Parabolic Trough Collector** (PTC), resulting typically in higher costs per square meter, but also higher efficiencies and possible temperatures. The output of PTCs is more stable throughout the day, so the solar multiple could be decreased, resulting in cost reductions. Whether the savings outweigh the higher costs depends on the offers by the specific suppliers. In any case it is important to mention that these PTCs would be different from those used in CSP power plants for electric generation, which have high-precision and are only economically feasible for big installations.

Potentially, even an **evacuated tubes collector** could be feasible to use at this temperature and pressure. This would have to be clarified in a more detailed technical analysis.

Double-effect absorption machines are available from a number of other producers in Japan, China and India.

5.2 Design Case II: Evacuated Tubes (alternatively flat plates) and Absorption (alternatively adsorption)

In this case, a Yazaki single-effect absorption machine with 100 kW_{th} thermal output in form of chilled water is coupled to an evacuated tube collector field. The COP of 0.66 is still acceptable and leads to an input heat flow of 150 kW_{th}, delivered by hot water at 88 °C. Again, electric consumption depends mostly on the heat rejection system and cannot be calculated without a more specific design.

Figure 19: Sketch of an ETC-single-step system design

The solar multiple and storage amount here are less as the thermal output of ETCs varies less throughout the day. These numbers however have to be re-calculated depending on on-site irradiation and collector parameters. FPCs' output power varies more than that of ETCs and would require a higher solar multiple and storage.

Technical adaptation of the standard units is necessary for the following:

- Total heat rejection amounts to 255 kWth, which is designed to be by water cooling both in Thermax and Yazaki machines. An adaptation to dry cooling systems has to be done.

5 | Typical design cases for Solar Cooling in Jordan

Table 14: Basic data of application case 2

Absorption machine	Solar field		
Cooling power	100 kW_{th}	Solar output power, peak	194 kW_{th}
Input heat flow	150 kW_{th}	Solar multiple	1.3
Hot water temperature	88 °C	Modules	357 panels of 2.4 m^2 each
Heat rejection	255 kW_{th}	Dimensions	40 m x 20 m (L x W) = 800m^2
Specific area requirements per cooling power	8.5 m^2 per kW_{th}	Storage	2.5 h, 375 kWth (5-10 m^3 of water with ΔT= 30-60 K)

The evacuated tubes collector can be substituted by **a flat plate collector** if the latter one is suitable for the necessary temperature range (here 88 °C). Higher heat losses and probably higher solar multiple and storage then have to be compensated by cheaper investment costs for economic feasibility.

Single-effect machines are available by a big number of suppliers in Europe and Asia. Here the Yazaki model has been taken for the sake of a parallelism to the double-effect design.

5.3 Comparison of Design Case I and II:

From the features of the two designs above, the following comparison can be derived:

Table 15: Pros and Cons of the two system design variations (CSP-double / ETC-single)

Design	CSP & Double-Step	ETC & Single-Step
Robustness (leading to lower maintenance)	Depending on solar collector and control	High
Standard components	No (fresnel collector, parabolic); double-effect machine	Yes
Area requirements	Lower	Higher (can be reduced by using CPC-type ETCs)
Price considerations (per kW output power)	Price higher in the beginning, but potential for cost reductions in the future	Price lower due to standardized, less complex components
Compatibility with existing solar thermal collectors for water heating	No	Yes (parameters have to match; not all existing systems are suitable)

From this comparison, the situation presents itself as follows: For the first systems in the country, where robustness, relatively low costs and integration with existing solar water heating systems are desired, single-step machines with ETC or FPC are more suitable. For specific locations where the available free rooftop area is small and high space-efficiency is desired, or where the aim is to gain experience with technologies that have a cost reduction potential for the future, the double-step machine with CSP could be the more interesting option.

6 | Way forward

In this document, the potential for solar thermal cooling has been analyzed from different perspectives, both for Jordan and in general. The technology has a good potential in Jordan due to the high incoming solar irradiation and Jordan´s considerable cooling needs. Another appeal to explore renewable energy sources in Jordan is caused by the expected rising electricity rates and Jordan´s momentary dependence on imported primary electricity.

From an environmental perspective, CO_2 emissions can be reduced quite substantially because the systems have low electricity consumption and because environmentally friendly refrigerants are used instead of conventional ones with a high global warming potential. In an optimistic best case scenario it is assumed that in 2050 3.74 Mt CO_2eq can be saved by the introduction of solar cooling systems in Jordan. This corresponds to about 35% of the emissions in a baseline scenario assuming a continued use of conventional systems.Solar thermal cooling is still a new and emerging technology with relatively high investment costs, low standardisation and small market scales. These hindrances need to be overcome before a market can start to develop and the technology can spread. In order to achieve this, a high diffusion of the solar cooling technology has to be sought by addressing the fields listed in the following.

- The barrier of higher investment costs of solar cooling systems compared to conventional technologies can be approached by a more active policy support through loans, tax exemptions, subsidies or preferential tax treatment for investors.. Raising electricity prices to a level where they cover generation costs would also favour solar cooling, where payback times will shorten through the increased energy bill saving. From growing implementation, progress can then be expected in terms of efficiency and reliability of the technology, growing scales and standardization of systems. This will ultimately lead to further cost and price reductions.

- To establish well working systems, the best fitting technology has to be adapted to the specific sites. The system has to match the particular situation by a well-chosen, appropriate design and the different components have to harmonize with each other. The publication of guidelines for technicians and political decision makers will help to make the best choices.

- The technical capacities in the country can be improved by training of technicians, engineers, architects and planners. This will help to build up local expertise, which will be further supported by successful pilot projects in the country. A technology transfer with international companies that are experts in the field will also increase the know-how in the country. Emerging local manufacturing and standardization will then lead to an increased local benefit.

- For a market development, it is important to spread the information about the technology and their advantages. Right now, there is often a lack of awareness by decision makers and / or end-users. Potential producers need to know about the different options for covering their solar cooling needs. Pre-defined model cases for typical commercial applications such as supermarkets or hotels can help to illustrate the different possibilities. Well working pilot projects will increase the reputation of solar cooling.

If the above mentioned points are addressed correctly and thus the barriers for the introduction of solar cooling in Jordan are reduced, the diffusion of the technology in Jordan can be achieved. This will have various benefits for the country, such as independence of importing electricity from other countries and will also help to reduce CO_2 emissions. Jordan could take a leading role in distributing the new technology to other countries in the region.

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Annex I: Information of electricity tariffs for various sectors

Table AI 1: The standard tariffs for households[18]

Consumption [kWh / month]	Tariff [fils / kWh]
1 – 160	33
161 – 300	72
301 – 500	86
501 – 600	114
601 – 750	141
751 – 1000	168
More than 1000	235

Table AI 2: Tariffs for different industries[18] (directly supplied through the 132 kV network via substations)

Industry	Day tariff [fils / kWh]	Night tariff [fils / kWh]
Mining and Quarrying	220	164
Principal Consumers	94	76

There is also a small industry tariff, including agriculture from 57 - 63 fils / kWh.

Table AI 3: Tariffs for different commercial users[18]

Type	Consumption 1- 2000 kWh per month	Consumption above 2000 kWh per month
Standard commercial users	91	127
Banks	227	265
Telecommunications	227	265

Hotels have a standard tariff of 127 fils / kWh. Four Stars and above hotels have a tariff of 116 fils / kWh (day) and 102 fils / kWh (night).

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[18] http://www.erc.gov.jo/English/RegulatoryDocuments/Documents/Electricity%20Tariff%20from%205%206.2012.pdf, year 2012

Annex II: Weather station locations

Table AII 1: Locations of the different weather stations in Jordan

Station	WMO No	Elevation [m]	Latitude N	Longitude E
Baqura	40253	-170	32° 38'	35° 37'
Wadi El-Rayyan	40256	-200	32° 24'	35° 35'
Deir Alla	40285	-224	32° 13'	35° 37'
University Farm		-230	32° 10'	35° 37'
Ghor Safi	40296	-350	32° 10'	35° 28'
Aqaba Airport	40340	51	31° 02'	35° 00'
Irbid	40255	616	29° 33'	35° 51'
Ramtha	40252	590	32° 33'	35° 59'
Ras Muneef	40257	1150	32° 30'	35° 45'
Salt	40268	796	32° 02'	35° 44'
Jordan University		980	32° 01'	35° 53'
Swaileh	40269	1050	32° 00'	35° 54'
Amman Airport	40270	780	31° 59'	35° 59'
Roman Amph./ Amman		750	31° 57'	35° 57'
Q.A.I. Airport	40272	722	31° 43'	35° 59'
Madaba		785	31° 43'	35° 48'
Er-Rabbah	40292	920	31° 16'	35° 45'
Mu'tah University		1105	31° 03'	35° 42'
Alhasan/Tafileh	40298	1200	30° 47'	35° 43'
Shoubak	40300	1365	30° 31'	35° 32'
Wadi Mousa	40313	1115	30° 19'	35° 28'
Ma'an	40310	1069	30° 10'	35° 47'
Mafraq	40265	686	32° 22'	36° 15'
Al Al-Bayt University	40266	686	32° 21'	36° 15'
Wadi Dhulail	40267	580	32° 09'	36° 17'
Zarqa Refinery		555	32° 05'	36° 07'
Azraq South	40288	521	31° 50'	36° 49'
Safawi (H-5)	40260	672	32° 12'	37° 08'
Rwaished (H4)	40250	683	32° 30'	38° 12'
Qatraneh	40275	768	31° 15'	36° 07'
Al Jafer	40305	865	30° 17'	36° 09'

Annex III: Temperature data[19]

Table AIII 1: Mean air temperature

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	13,3	14,1	16,5	20,7	24,8	28,0	30,0	30,3	28,8	25,2	19,9	14,9	**22,2**	1967	2000
2	Wadi El-Rayyan	13,1	13,9	16,4	2,8	25,0	28,4	30,3	30,7	28,9	25,2	19,5	14,6	**22,2**	1961	2000
3	Deir Alla	14,8	15,6	17,9	22,2	26,2	29,4	31,0	31,5	29,9	26,9	21,7	16,6	**23,6**	1952	2000
4	University Farm	13,7	14,6	17,2	22,9	27,3	30,5	32,6	32,6	30,8	26,7	20,9	16,2	**23,8**	1986	2000
5	Ghor Safi	15,9	17,0	20,0	24,5	28,5	31,5	33,6	33,5	31,5	27,7	22,0	17,2	**25,2**	1975	2000
6	Aqaba Airport	14,7	16,2	19,3	23,8	27,9	31,0	32,3	32,3	29,9	26,3	21,0	16,1	**24,2**	1959	2000
7	Irbed	8,9	9,7	12,1	16,4	20,6	23,7	25,1	25,5	24,0	20,9	15,5	10,7	**17,8**	1955	2000
8	Ramtha	8,4	9,3	11,4	16,4	20,4	23,1	24,7	25,3	23,4	20,3	14,8	10,3	**17,3**	1976	2000
9	Ras Muneef	5,2	5,9	8,3	13,2	17,4	19,8	21,5	21,7	20,6	17,7	12,0	7,3	**14,2**	1977	2000
10	Salt	7,8	7,8	10,0	15,5	20,3	22,6	24,4	24,6	23,1	20,4	14,7	10,3	**16,8**	1992	2000
11	Jordan University	6,4	7,4	10,1	14,5	18,8	21,3	21,5	23,5	22,1	18,8	13,0	8,3	**15,6**	1960	2000
12	Swaileh	6,5	6,8	9,3	15,0	19,3	21,7	24,4	23,7	22,1	18,6	13,3	8,5	**15,7**	1985	2000
13	Amman Airport	8,0	9,0	11,7	16,1	20,7	23,7	23,5	25,5	23,6	20,4	14,9	9,8	**17,4**	1923	2000
14	Roman Amph./ Amman	9,1	10,0	12,9	17,7	22,0	25,0	25,3	26,6	25,2	21,7	15,8	10,8	**18,6**	1974	2000
15	Q.A.I. Airport	7,2	8,3	10,8	15,4	19,1	21,5	26,6	23,1	21,7	18,5	13,1	8,7	**15,9**	1971	2000
16	Madaba	7,8	8,9	11,4	15,9	20,1	22,8	23,1	24,5	23,0	19,8	14,3	9,3	**16,9**	1970	2000
17	Er-Rabbah	7,7	8,4	10,9	15,0	19,0	21,9	24,6	23,5	21,9	19,1	14,2	9,5	**16,2**	1961	2000
18	Mu'tah University	6,5	6,7	9,5	15,2	19,4	21,9	23,5	23,8	22,2	18,7	13,3	8,7	**15,8**	1986	2000
19	Alhasan/Tafileh	6,5	7,4	10,0	14,8	18,9	21,7	23,6	23,6	22,0	18,4	12,9	8,6	**15,7**	1973	2000
20	Shoubak	4,0	4,8	7,6	11,9	15,4	18,4	20,3	20,2	18,2	14,8	9,7	5,8	**12,6**	1960	2000
21	Wadi Mousa	7,8	8,0	10,7	16,2	20,2	22,5	23,9	23,9	22,1	18,9	13,9	9,5	**16,5**	1984	2000
22	Ma'an	7,6	9,0	12,0	17,0	21,1	24,2	25,7	25,8	23,9	19,7	13,6	9,2	**17,4**	1960	2000
23	Mafraq	7,4	8,7	11,4	15,9	20,1	22,8	24,4	24,4	22,8	19,3	13,6	8,9	**16,6**	1953	2000
24	Al Al-Bayt University	7,9	8,4	10,4	16,3	21,4	23,2	25,5	25,3	23,2	19,1	14,1	9,8	**17,1**	1995	2000
25	Wadi Dhulail	7,7	9,2	12,2	17,0	21,4	24,2	26,0	26,1	24,4	20,1	13,9	9,2	**17,6**	1968	2000
26	Zarqa Refinery	8,7	10,1	12,9	17,8	22,0	24,7	25,6	26,0	24,6	20,8	14,5	10,0	**18,1**	1966	2000
27	Azraq South	8,9	10,3	13,6	19,2	23,7	26,6	28,3	28,5	26,6	21,9	15,1	10,3	**19,4**	1981	2000
28	Safawi (H-5)	7,9	9,7	13,1	18,3	23,2	26,7	28,7	28,5	26,5	21,7	14,8	9,6	**19,1**	1964	2000
29	Rwaished (H4)	7,9	9,6	13,1	18,3	23,1	26,6	28,7	28,5	26,0	21,0	14,4	9,5	**18,9**	1961	2000
30	Qatraneh	8,0	8,8	11,6	16,7	20,8	23,1	24,9	24,9	23,1	19,3	14,0	9,5	**17,1**	1984	2000
31	Al Jafer	7,7	9,2	12,7	17,8	22,0	25,0	26,6	26,8	24,8	20,3	14,1	9,1	**18,0**	1965	2000

Table AIII 2: Mean maximum air temperature

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	13,3	14,1	16,5	20,7	24,8	28,0	30,0	30,3	28,8	25,2	19,9	14,9	**22,2**	1967	2000
2	Wadi El-Rayyan	13,1	13,9	16,4	2,8	25,0	28,4	30,3	30,7	28,9	25,2	19,5	14,6	**22,2**	1961	2000
3	Deir Alla	14,8	15,6	17,9	22,2	26,2	29,4	31,0	31,5	29,9	26,9	21,7	16,6	**23,6**	1952	2000
4	University Farm	13,7	14,6	17,2	22,9	27,3	30,5	32,6	32,6	30,8	26,7	20,9	16,2	**23,8**	1986	2000
5	Ghor Safi	15,9	17,0	20,0	24,5	28,5	31,5	33,6	33,5	31,5	27,7	22,0	17,2	**25,2**	1975	2000
6	Aqaba Airport	14,7	16,2	19,3	23,8	27,9	31,0	32,3	32,3	29,9	26,3	21,0	16,1	**24,2**	1959	2000
7	Irbed	8,9	9,7	12,1	16,4	20,6	23,7	25,1	25,5	24,0	20,9	15,5	10,7	**17,8**	1955	2000
8	Ramtha	8,4	9,3	11,4	16,4	20,4	23,1	24,7	25,3	23,4	20,3	14,8	10,3	**17,3**	1976	2000
9	Ras Muneef	5,2	5,9	8,3	13,2	17,4	19,8	21,5	21,7	20,6	17,7	12,0	7,3	**14,2**	1977	2000
10	Salt	7,8	7,8	10,0	15,5	20,3	22,6	24,4	24,6	23,1	20,4	14,7	10,3	**16,8**	1992	2000
11	Jordan University	6,4	7,4	10,1	14,5	18,8	21,3	21,5	23,5	22,1	18,8	13,0	8,3	**15,6**	1960	2000
12	Swaileh	6,5	6,8	9,3	15,0	19,3	21,7	24,4	23,7	22,1	18,6	13,3	8,5	**15,7**	1985	2000
13	Amman Airport	8,0	9,0	11,7	16,1	20,7	23,7	23,5	25,5	23,6	20,4	14,9	9,8	**17,4**	1923	2000
14	Roman Amph./ Amman	9,1	10,0	12,9	17,7	22,0	25,0	25,3	26,6	25,2	21,7	15,8	10,8	**18,6**	1974	2000
15	Q.A.I. Airport	7,2	8,3	10,8	15,4	19,1	21,5	26,6	23,1	21,7	18,5	13,1	8,7	**15,9**	1971	2000
16	Madaba	7,8	8,9	11,4	15,9	20,1	22,8	23,1	24,5	23,0	19,8	14,3	9,3	**16,9**	1970	2000
17	Er-Rabbah	7,7	8,4	10,9	15,0	19,0	21,9	24,6	23,5	21,9	19,1	14,2	9,5	**16,2**	1961	2000
18	Mu'tah University	6,5	6,7	9,5	15,2	19,4	21,9	23,5	23,8	22,2	18,7	13,3	8,7	**15,8**	1986	2000
19	Alhasan/Tafileh	6,5	7,4	10,0	14,8	18,9	21,7	23,6	23,6	22,0	18,4	12,9	8,6	**15,7**	1973	2000
20	Shoubak	4,0	4,8	7,6	11,9	15,4	18,4	20,3	20,2	18,2	14,8	9,7	5,8	**12,6**	1960	2000
21	Wadi Mousa	7,8	8,0	10,7	16,2	20,2	22,5	23,9	23,9	22,1	18,9	13,9	9,5	**16,5**	1984	2000
22	Ma'an	7,6	9,0	12,0	17,0	21,1	24,2	25,7	25,8	23,9	19,7	13,6	9,2	**17,4**	1960	2000
23	Mafraq	7,4	8,7	11,4	15,9	20,1	22,8	24,4	24,4	22,8	19,3	13,6	8,9	**16,6**	1953	2000
24	Al Al-Bayt University	7,9	8,4	10,4	16,3	21,4	23,2	25,5	25,3	23,2	19,1	14,1	9,8	**17,1**	1995	2000
25	Wadi Dhulail	7,7	9,2	12,2	17,0	21,4	24,2	26,0	26,1	24,4	20,1	13,9	9,2	**17,6**	1968	2000
26	Zarqa Refinery	8,7	10,1	12,9	17,8	22,0	24,7	25,6	26,0	24,6	20,8	14,5	10,0	**18,1**	1966	2000
27	Azraq South	8,9	10,3	13,6	19,2	23,7	26,6	28,3	28,5	26,6	21,9	15,1	10,3	**19,4**	1981	2000
28	Safawi (H-5)	7,9	9,7	13,1	18,3	23,2	26,7	28,7	28,5	26,5	21,7	14,8	9,6	**19,1**	1964	2000
29	Rwaished (H4)	7,9	9,6	13,1	18,3	23,1	26,6	28,7	28,5	26,0	21,0	14,4	9,5	**18,9**	1961	2000
30	Qatraneh	8,0	8,8	11,6	16,7	20,8	23,1	24,9	24,9	23,1	19,3	14,0	9,5	**17,1**	1984	2000
31	Al Jafer	7,7	9,2	12,7	17,8	22,0	25,0	26,6	26,8	24,8	20,3	14,1	9,1	**18,0**	1965	2000

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[19] Data from weather service Jordan

Annexes

Table AIII 3: Mean minimum air temperature

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	8,4	8,5	10,2	13,2	16,8	20,5	23,1	23,6	21,7	18,1	13,9	10,0	**15,7**	1967	2000
2	Wadi El-Rayyan	7,2	7,5	9,3	12,6	16,6	20,0	22,6	23,2	21,2	17,3	12,3	8,7	**14,9**	1961	2000
3	Deir Alla	10,6	10,8	12,3	15,3	18,5	21,4	23,4	24,1	23,0	20,6	16,8	12,5	**17,4**	1952	2000
4	University Farm	8,9	9,2	11,6	15,3	19,7	23,0	25,5	25,7	24,0	20,3	15,1	11,3	**17,5**	1986	2000
5	Ghor Safi	10,8	11,7	14,5	18,5	21,9	24,8	26,9	27,3	26,0	22,4	16,6	11,9	**19,4**	1975	2000
6	Aqaba Airport	8,9	10,1	12,9	17,0	20,7	23,6	25,1	25,3	23,3	19,9	14,9	10,3	**17,7**	1959	2000
7	Irbed	4,9	5,4	7,3	10,6	14,1	17,4	19,2	19,6	18,2	15,1	10,0	6,4	**12,4**	1955	2000
8	Ramtha	3,9	4,3	5,7	9,3	12,5	15,3	17,3	17,7	16,1	13,4	9,2	5,6	**10,9**	1976	2000
9	Ras Muneef	2,5	2,8	4,7	8,7	12,5	14,6	16,4	16,4	15,5	13,4	8,6	4,5	**10,1**	1977	2000
10	Salt	5,0	4,3	6,3	10,7	15,2	17,4	19,4	19,6	18,3	16,0	11,1	6,9	**12,5**	1992	2000
11	Jordan University	2,7	3,2	5,3	8,8	12,4	15,7	17,6	17,5	15,9	12,7	8,0	4,3	**10,3**	1960	2000
12	Swaileh	3,6	3,6	5,2	10,1	14,0	16,2	18,1	18,3	17,0	14,2	9,6	5,6	**11,3**	1985	2000
13	Amman Airport	3,6	4,2	6,1	9,5	13,5	16,6	18,5	18,6	16,6	13,8	9,3	5,2	**11,3**	1923	2000
14	Roman Amph./ Amman	4,3	4,9	7,3	11,2	15,2	18,4	20,2	20,1	18,3	14,9	9,8	5,8	**12,5**	1974	2000
15	Q.A.I. Airport	1,4	2,1	3,9	6,9	9,7	11,7	13,7	13,5	12,2	9,5	5,7	2,4	**7,7**	1971	2000
16	Madaba	3,0	3,6	5,6	9,0	12,8	15,7	18,1	17,8	16,3	12,9	8,3	4,3	**10,6**	1970	2000
17	Er-Rabbah	3,4	3,8	5,7	8,7	12,0	14,9	16,9	17,0	15,4	13,0	8,9	5,2	**10,4**	1961	2000
18	Mu'tah University	2,8	2,7	4,8	9,4	13,2	15,7	17,6	17,5	16,1	13,2	8,6	4,9	**10,5**	1986	2000
19	Alhasan/Tafileh	2,1	2,7	4,5	8,4	12,2	14,8	17,1	17,0	15,1	12,1	7,6	3,8	**9,8**	1973	2000
20	Shoubak	1,2	0,8	1,4	4,7	7,6	10,8	13,3	12,9	10,1	6,8	3,0	0,0	**5,7**	1960	2000
21	Wadi Mousa	4,1	4,0	6,1	10,7	14,3	16,6	18,1	18,2	16,5	13,9	9,5	5,5	**11,5**	1984	2000
22	Ma'an	1,7	2,7	5,3	9,6	13,2	15,8	17,5	17,4	15,5	11,9	6,9	3,1	**10,1**	1960	2000
23	Mafraq	2,0	2,9	4,9	8,3	11,7	14,1	15,9	15,9	14,5	11,4	6,8	3,3	**9,3**	1953	2000
24	Al Al-Bayt University	2,7	2,6	4,6	9,0	12,8	14,6	16,9	17,1	15,1	11,5	6,9	3,8	**9,8**	1995	2000
25	Wadi Dhulail	2,0	3,0	5,4	8,8	12,6	15,0	17,1	17,1	15,4	11,7	6,6	3,0	**9,8**	1968	2000
26	Zarqa Refinery	3,4	4,5	6,8	10,6	14,3	16,9	18,7	18,2	16,8	13,2	8,3	4,8	**11,4**	1966	2000
27	Azraq South	3,0	4,0	6,8	11,4	15,5	18,1	19,8	20,0	18,4	14,4	8,4	4,2	**12,0**	1981	2000
28	Safawi (H-5)	2,5	3,9	6,8	11,3	15,8	18,8	20,6	20,3	18,7	14,5	8,7	4,2	**12,2**	1964	2000
29	Rwaished (H4)	2,1	3,4	6,3	10,8	15,0	18,0	19,9	19,8	17,4	13,3	7,6	3,5	**11,4**	1961	2000
30	Qatraneh	2,4	2,7	5,2	9,2	12,9	15,2	17,3	17,1	15,0	11,6	7,1	3,4	**9,9**	1984	2000
31	Al Jafer	0,7	2,0	5,2	9,5	13,5	16,1	17,6	17,9	16,0	12,1	6,6	2,0	**9,9**	1965	2000

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Table AIII 4: Absolute maximum air temperature

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	28,3	28,8	33,4	40,7	45,4	46,0	46,2	47,0	44,8	35,5	35,5	29,6	**47,0**	1967	2000
2	Wadi El-Rayyan	28,2	30,0	34,7	41,2	46,0	47,5	45,9	46,4	45,5	38,0	38,0	30,2	**47,5**	1961	2000
3	Deir Alla	28,8	30,6	36,0	41,5	46,0	48,5	47,0	46,4	45,0	39,2	39,2	33,0	**48,5**	1952	2000
4	University Farm	29,0	30,4	36,2	44,2	48,0	46,3	47,0	46,8	45,0	36,0	36,0	29,7	**48,0**	1986	2000
5	Ghor Safi	28,2	31,4	36,6	44,0	45,8	47,2	48,6	46,0	45,0	36,2	36,2	30,8	**48,6**	1975	2000
6	Aqaba Airport	31,5	32,7	36,9	44,7	45,2	47,6	46,0	47,6	45,0	37,6	37,6	32,0	**47,6**	1959	2000
7	Irbed	24,6	28,0	30,0	36,2	40,0	40,8	41,0	41,0	39,8	32,5	32,5	28,0	**41,0**	1955	2000
8	Ramtha	25,4	27,0	31,5	37,5	42,0	40,5	43,0	42,5	41,4	31,3	31,3	29,0	**43,0**	1976	2000
9	Ras Muneef	20,8	21,6	24,5	30,6	33,8	34,0	37,2	37,4	35,0	26,5	26,5	22,7	**37,4**	1977	2000
10	Salt	23,0	21,0	25,5	33,5	37,0	37,5	39,4	38,8	37,5	29,4	29,4	25,2	**39,4**	1992	2000
11	Jordan University	24,0	25,1	27,0	35,0	39,0	38,3	40,6	43,0	39,0	32,0	32,0	25,7	**43,0**	1960	2000
12	Swaileh	23,0	22,8	24,8	32,6	36,7	37,0	38,3	39,5	36,8	29,0	29,0	24,5	**39,5**	1985	2000
13	Amman Airport	26,3	29,4	32,5	39,2	40,6	42,8	43,5	42,8	40,6	32,8	32,8	27,2	**43,5**	1923	2000
14	Roman Amph./ Amman	26,1	29,1	31,2	37,1	41,5	41,5	43,8	44,0	41,1	32,0	32,0	28,5	**44,0**	1974	2000
15	Q.A.I. Airport	24,4	29,0	30,6	37,0	40,0	40,2	43,7	43,8	40,2	31,6	31,6	28,0	**43,8**	1971	2000
16	Madaba	27,7	27,9	31,8	38,0	41,3	40,4	40,5	42,2	40,8	35,6	35,6	29,8	**42,2**	1970	2000
17	Er-Rabbah	26,4	28,0	32,0	34,2	39,0	38,7	41,4	40,4	38,5	30,8	30,8	27,0	**41,4**	1961	2000
18	Mu'tah University	23,5	24,5	27,8	34,0	37,3	37,5	41,0	40,0	38,0	29,5	29,5	24,5	**41,0**	1986	2000
19	Alhasan/Tafileh	24,4	25,3	29,4	33,5	36,0	37,6	42,0	39,8	37,6	29,5	29,5	26,0	**42,0**	1973	2000
20	Shoubak	22,6	24,3	28,5	31,0	35,0	35,0	38,2	37,7	36,0	27,4	27,4	24,0	**38,2**	1960	2000
21	Wadi Mousa	24,0	25,0	27,1	34,0	37,1	37,1	38,0	39,0	36,5	27,5	27,5	25,0	**39,0**	1984	2000
22	Ma'an	27,7	29,0	33,4	35,6	39,2	40,0	42,2	41,5	38,7	29,6	29,6	28,0	**42,2**	1960	2000
23	Mafraq	24,4	27,3	32,6	37,5	40,0	40,5	43,5	43,6	40,0	31,0	31,0	26,0	**43,6**	1953	2000
24	Al Al-Bayt University	21,6	24,0	27,8	37,6	38,0	38,2	43,2	42,5	39,4	30,6	30,6	23,2	**43,2**	1995	2000
25	Wadi Dhulail	23,0	28,7	32,0	38,4	41,0	41,7	45,5	44,9	41,2	32,2	32,2	27,0	**45,5**	1968	2000
26	Zarqa Refinery	24,8	30,0	32,2	39,5	41,2	42,0	45,6	44,5	42,0	33,5	33,5	28,8	**45,6**	1966	2000
27	Azraq South	24,8	30,0	33,8	39,9	41,5	42,2	45,5	45,6	43,3	31,0	31,0	27,0	**45,6**	1981	2000
28	Safawi (H-5)	24,7	28,0	34,5	39,0	40,2	41,6	46,4	44,5	42,3	31,4	31,4	26,5	**46,4**	1964	2000
29	Rwaished (H4)	26,6	28,0	34,0	38,3	40,8	42,6	46,2	46,4	42,4	32,5	32,5	26,5	**46,4**	1961	2000
30	Qatraneh	25,0	28,0	30,8	36,5	38,4	41,0	43,0	43,2	40,0	32,0	32,0	28,1	**43,2**	1984	2000
31	Al Jafer	25,5	29,8	33,0	36,8	40,5	41,5	43,0	44,6	40,3	31,2	31,2	31,3	**44,6**	1965	2000

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Table AIII 5: Absolute minimum air temperature

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	-1,0	-1,6	0,0	-0,5	8,4	13,5	18,2	18,0	13,6	10,0	2,4	1,4	**-1,6**	1967	2000
2	Wadi El-Rayyan	-2,2	-2,6	-1,1	0,0	8,0	11,5	16,5	16,3	11,8	9,1	1,0	-1,5	**-2,6**	1961	2000
3	Deir Alla	0,5	1,8	3,9	6,2	10,6	16,0	18,1	19,8	16,3	13,9	3,8	4,6	**0,5**	1952	2000
4	University Farm	-0,8	0,0	4,0	3,0	11,0	16,0	20,0	20,2	15,8	11,0	3,8	3,0	**-0,8**	1986	2000
5	Ghor Safi	4,0	3,1	5,4	6,2	16,2	19,5	20,8	22,8	20,3	12,9	6,0	5,0	**3,1**	1975	2000
6	Aqaba Airport	1,4	2,8	4,2	6,2	13,6	17,8	19,5	21,0	18,0	13,4	6,0	2,5	**1,4**	1959	2000
7	Irbed	-4,5	-4,5	-3,2	0,0	5,2	10,4	14,1	14,0	11,6	5,2	-0,6	-5,0	**-5,0**	1955	2000
8	Ramtha	-7,0	-7,0	-4,5	1,0	2,5	7,5	11,2	10,5	9,8	6,5	-0,7	3,4	**-7,0**	1976	2000
9	Ras Muneef	-5,6	-8,0	-3,5	-3,5	3,8	6,8	10,8	12,0	9,5	5,4	-4,0	-5,0	**-8,0**	1977	2000
10	Salt	-3,2	-5,0	-0,6	-1,2	7,4	11,0	14,0	14,4	11,5	8,8	0,6	-1,2	**-5,0**	1992	2000
11	Jordan University	-8,3	-5,0	-4,5	-1,5	1,4	4,5	8,5	8,8	4,5	3,4	-2,0	-4,8	**-8,3**	1960	2000
12	Swaileh	-3,0	-6,6	-1,8	-2,2	4,5	6,4	11,3	13,5	11,6	7,0	-3,2	-3,2	**-6,6**	1985	2000
13	Amman Airport	-7,5	-6,5	-3,9	-2,0	3,0	7,8	11,0	11,5	8,9	4,9	-3,2	-5,3	**-7,5**	1923	2000
14	Roman Amph./ Amman	-2,7	-2,2	-2,5	-0,2	7,0	10,0	14,2	14,3	11,2	7,4	-0,5	-2,6	**-2,7**	1974	2000
15	Q.A.I. Airport	-7,4	-5,4	-6,2	-6,0	-1,5	3,4	6,0	5,2	4,0	0,3	-5,0	-6,2	**-7,4**	1971	2000
16	Madaba	-6,8	-5,0	-2,0	-4,5	2,6	6,2	10,5	10,8	8,8	4,5	-2,8	-7,0	**-7,0**	1970	2000
17	Er-Rabbah	-5,2	-3,4	-3,5	-3,6	1,2	6,5	8,5	10,0	8,0	4,2	-2,5	-4,8	**-5,2**	1961	2000
18	Mu'tah University	-6,0	-5,2	-2,0	-3,5	2,0	8,0	11,0	11,5	10,5	4,5	-3,0	-2,5	**-6,0**	1986	2000
19	Alhasan/Tafileh	-6,8	-5,5	-6,5	-4,5	0,8	6,3	10,3	11,0	8,2	4,7	-3,6	-3,5	**-6,8**	1973	2000
20	Shoubak	-14,0	-12,5	-11,6	-6,6	-3,2	-2,0	4,2	4,0	1,0	-2,4	-11,2	-10,0	**-14,0**	1960	2000
21	Wadi Mousa	-4,6	-3,0	-1,8	-3,0	3,5	9,0	12,1	11,8	9,1	4,2	0,5	-2,2	**-4,6**	1984	2000
22	Ma'an	-7,7	-7,2	-6,8	-2,0	4,4	8,5	9,2	10,2	7,4	3,3	-3,2	-7,6	**-7,7**	1960	2000
23	Mafraq	-8,2	-6,8	-5,3	-5,5	2,8	4,9	9,6	10,0	7,0	3,2	-6,5	-7,6	**-8,2**	1953	2000
24	Al Al-Bayt University	-4,6	-6,6	-1,0	-5,0	4,0	9,0	10,4	11,8	9,8	3,8	-4,0	-4,2	**-6,6**	1995	2000
25	Wadi Dhulail	-8,6	-6,4	-4,8	-3,7	4,3	8,0	11,6	11,5	7,0	3,7	-4,6	-8,1	**-8,6**	1968	2000
26	Zarqa Refinery	-6,6	-5,5	-3,5	2,4	6,3	9,0	10,6	9,0	9,0	3,8	-1,6	-7,4	**-7,4**	1966	2000
27	Azraq South	-7,5	-4,4	-1,8	-2,2	7,0	11,8	15,4	14,4	11,2	5,0	-3,2	-5,4	**-7,5**	1981	2000
28	Safawi (H-5)	-6,8	-5,0	-3,6	-4,4	5,6	10,2	14,0	12,6	10,2	4,5	-3,6	-6,4	**-6,8**	1964	2000
29	Rwaished (H4)	-12,0	-8,4	-4,0	-5,0	5,0	11,3	14,0	14,0	9,5	0,4	-5,4	-8,7	**-12,0**	1961	2000
30	Qatraneh	-4,0	-6,0	-2,8	-2,0	3,4	8,0	11,0	12,0	8,4	4,0	-4,0	-5,0	**-6,0**	1984	2000
31	Al Jafer	-9,6	-7,0	-6,6	-1,5	4,6	7,8	11,1	10,5	9,2	3,7	-3,0	-10,5	**-10,5**	1965	2000

Annexes

Table AIII 6: Mean sunshine hours

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	5,1	5,9	6,7	8,4	10,4	11,9	11,8	11,1	9,8	8,2	6,8	5,3	**8,5**	1967	2000
2	Wadi El-Rayyan	5,1	5,9	6,6	8,2	9,9	11,3	11,4	10,9	9,6	8,2	6,7	5,3	**8,3**	1974	2000
3	Deir Alla	5,7	6,5	7,0	8,7	10,9	12,4	12,5	11,9	10,2	8,9	7,4	5,9	**9,0**	1953	2000
4	University Farm	3,4	13,4	7,4	9,2	10,3	10,7	12,1	11,7	10,2	8,9	7,4	5,6	**9,2**	1986	2000
5	Ghor Safi	5,6	6,1	7,3	8,4	10,1	11,8	11,7	10,9	9,8	8,3	6,9	5,5	**8,5**	1974	2000
6	Aqaba Airport	7,0	7,9	8,3	8,9	10,1	12,0	12,1	11,6	10,5	9,4	8,0	6,4	**9,4**	1964	2000
7	Irbed	5,4	6,1	7,1	8,3	10,2	11,9	11,9	11,3	10,2	8,5	7,1	5,4	**8,6**	1965	2000
9	Ras Muneef	4,8	5,4	6,4	8,2	10,3	12,3	12,1	11,7	10,3	8,5	6,8	5,0	**8,5**	1977	2000
10	Salt	5,1	6,2	7,5	9,4	10,7	12,2	12,3	11,9	10,5	8,9	6,9	5,5	**8,9**	1992	2000
11	Jordan University	5,1	5,9	7,0	8,3	10,4	11,9	12,1	11,4	10,0	8,4	6,7	5,0	**8,5**	1967	2000
12	Swaileh	4,0	5,0	6,5	8,7	10,3	12,1	12,4	11,6	9,2	7,7	5,7	3,7	**8,1**	1985	2000
13	Amman Airport	6,1	6,8	7,8	9,3	10,8	12,6	12,7	12,1	10,8	9,3	7,6	6,0	**9,3**	1922	2000
15	Q.A.I. Airport	5,8	6,4	7,5	8,6	10,2	12,1	12,1	11,6	10,4	8,9	7,5	5,8	**8,9**	1970	2000
17	Er-Rabbah	5,6	6,2	7,3	8,7	10,2	11,9	11,8	11,3	10,1	8,7	7,1	5,6	**8,7**	1974	2000
19	Alhasan/Tafileh	6,6	7,4	8,2	9,3	10,6	12,1	12,3	11,8	10,6	9,3	7,8	6,6	**9,4**	1973	2000
20	Shoubak	5,7	6,5	7,7	9,1	10,5	12,2	12,3	11,8	10,7	9,2	7,3	5,9	**9,1**	1966	2000
21	Wadi Mousa	3,4	5,6	6,4	9,2	9,2	11,8	10,7	11,6	9,9	8,4	6,8	5,5	**8,2**	1984	2000
22	Ma'an	7,2	8,1	8,5	9,1	10,4	12,2	12,3	11,8	10,7	9,2	7,3	5,9	**9,4**	1964	2000
23	Mafraq	5,4	6,4	7,3	8,3	10,3	11,9	12,0	11,4	10,0	8,6	7,2	5,5	**8,7**	1960	2000
25	Wadi Dhulail	5,6	6,4	7,5	8,6	10,1	11,9	12,0	11,3	10,3	8,8	7,3	5,5	**8,8**	1971	2000
27	Azraq South	6,0	6,8	7,7	8,7	9,7	11,3	11,2	10,9	9,8	8,4	7,2	5,9	**8,6**	1981	2000
28	Safawi (H-5)	6,2	7,1	7,9	8,8	10,3	12,1	12,1	11,6	10,3	8,9	7,5	6,0	**9,1**	1964	2000
29	Rwaished (H4)	7,1	8,4	9,2	8,5	10,0	12,2	12,4	11,8	10,6	8,8	7,4	5,8	**9,4**	1964	2000
30	Qatraneh	6,2	7,1	7,9	9,1	10,2	12,1	12,0	11,5	10,4	8,9	7,6	6,2	**9,1**	1984	2000
31	Al Jafer	6,9	7,7	8,2	9,0	10,1	11,9	12,0	11,5	10,1	9,0	7,9	6,7	**9,3**	1967	2000

Annexes

Table AIII 7: Mean daily global solar radiation

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
3	Deir Alla	949,5	1266,8	1716,5	2167,2	2533,0	2732,8	2648,5	2412,2	2028,4	1579,3	1160,3	940,0	**1844,5**	1989	1999
5	Ghor Safi	1026,1	1310,2	1718,8	2268,0	2579,1	2878,9	2703,8	2467,6	2144,8	1531,8	1152,9	990,3	**1897,7**	1989	1999
6	Aqaba Airport	1285,3	1618,1	2089,5	2479,1	2672,1	2963,2	2816,9	2628,3	2294,6	1827,1	1436,5	1218,2	**2110,7**	1989	1999
7	Irbed	987,9	1305,8	1700,6	2243,2	2602,6	2842,3	2755,6	2544,8	2188,3	1646,4	1189,2	982,4	**1915,8**	1989	1999
13	Amman Airport	1058,2	1337,1	1766,4	2342,5	2705,5	2975,9	2896,4	2671,4	2252,2	1706,0	1274,5	996,6	**1998,6**	1986	1999
20	Shoubak	1191,6	1543,7	1988,5	2569,3	2841,0	3144,5	3053,3	2860,7	2494,9	1917,4	1428,9	1130,8	**2180,4**	1987	1999
25	Wadi Dhulail	1063,5	1447,6	1888,0	2401,6	2720,1	2976,5	2924,0	2709,8	2330,1	1811,1	1318,6	1018,9	**2050,8**	1989	1999
27	Azraq South	1127,9	1485,3	1944,9	2414,4	2545,3	2993,2	2861,2	2656,9	2298,1	1794,9	1309,0	1058,4	**2040,8**	1991	1999

Annexes

Table AIII 8: Mean daily diffuse solar radiation

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
3	Deir Alla	420,1	539,3	704,8	857,6	828,9	734,4	749,7	688,0	646,0	524,7	470,0	417,5	**631,8**	1989	1999
5	Ghor Safi	413,6	531,5	686,2	844,0	827,3	736,3	703,3	652,8	574,6	506,3	415,0	506,7	**616,5**	1989	1999
6	Aqaba Airport	434,1	583,4	725,5	1039,0	984,7	760,6	753,6	868,5	726,0	561,7	530,3	399,3	**697,2**	1989	1999
7	Irbed	411,7	499,9	650,9	784,7	805,9	655,9	654,9	580,6	562,9	505,8	431,5	410,3	**579,6**	1989	1999
13	Amman Airport	456,7	612,6	808,0	967,3	868,6	621,2	656,6	556,7	558,1	599,8	463,4	411,3	**631,7**	1986	1999
20	Shoubak	401,1	498,1	612,5	725,6	752,8	496,8	430,5	421,3	402,5	434,5	385,1	358,0	**493,2**	1987	1999
25	Wadi Dhulail	433,1	532,8	743,0	860,6	810,0	607,2	604,5	566,2	495,4	485,8	439,4	415,1	**582,8**	1989	1999
27	Azraq South	458,0	599,1	717,3	793,4	853,6	627,2	713,4	586,7	525,9	504,8	440,0	411,3	**602,6**	1991	1999

Table AIII 12: Mean number of days with relative humidity ≥ 80%

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	10,9	9,2	7,8	2,0	0,4	0,2	0,3	0,0	0,2	1,3	3,7	9,2	**45,2**	1967	2000
2	Wadi El-Rayyan	12,6	8,2	7,0	1,6	0,3	0,0	0,2	0,1	0,2	1,3	3,9	9,7	**45,1**	1961	2000
3	Deir Alla	4,0	3,0	2,3	0,6	0,0	0,1	0,0	0,0	0,0	0,3	1,5	3,5	**15,3**	1961	2000
4	University Farm	6,5	4,5	2,8	0,4	0,1	0,9	0,6	0,2	0,2	0,6	1,5	6,5	**24,8**	1986	2000
5	Ghor Safi	0,5	0,6	0,1	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,8	**2,5**	1974	2000
6	Aqaba Airport	0,5	0,3	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,2	0,5	0,6	**2,3**	1961	2000
7	Irbed	11,5	9,0	7,8	2,9	0,7	0,3	0,2	0,3	0,2	2,1	4,3	9,5	**48,8**	1961	2000
8	Ramtha	14,1	10,7	8,0	2,1	0,6	0,1	0,6	0,1	0,7	1,8	4,3	9,8	**52,9**	1985	2000
9	Ras Muneef	17,5	14,5	14,2	8,0	4,5	3,9	5,3	7,2	6,8	7,5	9,6	15,6	**114,6**	1976	2000
10	Salt	16,2	13,1	13,0	4,9	1,8	1,8	2,9	3,2	4,6	5,8	9,8	13,7	**90,8**	1992	2000
11	Jordan University	12,1	8,7	7,4	2,4	0,4	0,1	0,1	0,1	0,1	1,3	4,4	10,4	**47,5**	1967	2000
12	Swaileh	17,6	14,9	11,8	4,8	1,8	0,5	0,5	1,0	2,3	5,4	9,0	16,6	**86,2**	1985	2000
13	Amman Airport	12,6	9,4	7,2	2,0	0,4	0,1	0,2	0,6	0,8	2,0	4,6	10,4	**50,3**	1957	2000
14	Roman Amph./ Amman	6,9	4,5	2,8	1,0	0,2	0,0	0,0	0,0	0,0	0,9	1,2	5,2	**22,7**	1974	2000
15	Q.A.I. Airport	15,2	10,9	9,7	2,5	0,5	0,2	0,1	0,1	0,5	2,2	5,9	13,1	**60,9**	1970	2000
16	Madaba	28,8	11,2	7,3	2,8	1,2	1,5	2,1	0,9	2,8	4,1	6,0	11,6	**80,3**	1985	2000
17	Er-Rabbah	13,1	10,0	8,3	2,3	0,9	0,2	0,1	0,3	0,4	1,4	4,9	11,0	**52,9**	1961	2000
18	Mu'tah University	9,5	8,3	5,2	1,0	1,7	0,3	0,0	0,3	0,5	1,2	3,4	8,9	**40,3**	1986	2000
19	Alhasan/Tafileh	9,3	7,5	5,4	1,7	0,3	0,0	0,1	0,0	0,2	0,6	3,4	7,6	**36,1**	1973	2000
20	Shoubak	13,9	10,8	7,5	2,4	0,5	0,1	0,1	0,3	0,3	2,0	6,3	11,8	**56,0**	1965	2000
22	Ma'an	6,1	3,5	1,6	0,3	0,1	0,0	0,0	0,0	0,1	0,4	2,0	5,0	**19,1**	1960	2000
23	Mafraq	14,4	10,1	6,4	1,4	0,3	0,0	0,1	0,2	0,4	2,6	4,8	12,3	**53,0**	1960	2000
25	Wadi Dhulail	15,1	10,5	7,4	2,2	0,5	0,0	0,2	0,2	0,8	2,1	5,5	14,0	**58,5**	1968	2000
26	Zarqa Refinery	8,0	4,9	2,7	0,5	0,3	0,0	0,0	0,0	0,1	0,4	1,7	5,5	**24,1**	1966	2000
27	Azraq South	9,6	4,3	2,0	0,3	0,2	0,0	0,0	0,2	0,0	1,4	2,7	9,1	**29,8**	1981	2000
28	Safawi (H-5)	5,6	3,0	1,4	0,3	0,0	0,0	0,0	0,0	0,0	0,3	1,6	4,2	**16,4**	1963	2000
29	Rwaished (H4)	4,0	1,8	0,7	0,3	0,0	0,0	0,0	0,0	0,0	0,6	2,3	3,9	**13,6**	1961	2000
30	Qatraneh	9,9	6,0	3,9	0,8	0,1	0,1	0,0	0,0	0,1	1,8	3,6	8,1	**34,4**	1983	2000
31	Al Jafer	3,9	2,5	1,7	0,2	0,0	0,0	0,0	0,0	0,1	1,1	2,2	3,5	**15,2**	1965	2000

Table AIII 13: Mean number of days with relative humidity ≤ 30%

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	1,1	0,3	0,8	1,2	0,8	0,3	0,1	0,0	0,5	1,5	2,1	0,4	9,1	1967	2000
2	Wadi El-Rayyan	0,1	0,0	0,2	0,4	1,2	0,9	0,1	0,0	0,1	0,7	0,5	0,0	4,2	1961	2000
3	Deir Alla	1,1	1,2	1,7	2,6	3,0	1,3	0,5	0,2	0,8	2,9	4,2	1,4	20,9	1961	2000
4	University Farm	0,5	0,1	0,2	1,5	2,0	0,2	0,1	0,1	0,5	0,7	0,8	0,0	6,7	1986	2000
5	Ghor Safi	0,3	0,1	0,6	1,2	1,8	1,8	2,1	0,5	0,1	0,6	0,2	0,1	9,4	1974	2000
6	Aqaba Airport	0,7	0,9	2,4	6,9	12,7	12,5	11,5	7,0	2,0	2,3	2,0	0,4	61,3	1961	2000
7	Irbed	0,5	0,4	1,7	3,9	6,4	4,2	1,6	0,6	2,3	3,5	2,3	0,6	28,0	1961	2000
8	Ramtha	0,6	0,4	1,1	6,3	9,4	3,1	1,7	1,7	2,2	1,8	1,6	0,9	30,8	1985	2000
9	Ras Muneef	0,5	1,3	2,1	6,8	7,3	2,9	2,2	3,0	4,7	5,8	3,0	2,4	42,0	1976	2000
10	Salt	0,4	0,4	0,4	6,4	7,2	2,7	2,1	1,4	2,7	3,0	2,8	0,8	30,3	1992	2000
11	Jordan University	0,1	0,2	1,0	2,1	5,0	3,0	2,2	1,3	1,5	2,3	1,7	0,4	20,8	1967	2000
12	Swaileh	0,9	1,1	2,4	8,1	8,9	5,4	4,7	2,6	4,1	3,8	1,7	1,4	45,1	1985	2000
13	Amman Airport	0,2	0,3	1,7	4,1	7,6	6,6	4,6	2,8	2,4	3,3	1,5	0,2	35,3	1957	2000
14	Roman Amph./ Amman	0,1	0,3	1,1	6,5	10,7	9,0	5,4	4,7	3,9	3,8	2,2	0,2	47,9	1974	2000
15	Q.A.I. Airport	0,1	0,1	1,0	2,0	3,5	1,2	1,2	0,2	1,1	2,4	0,9	0,5	14,2	1970	2000
16	Madaba	0,0	0,0	1,1	2,7	2,9	3,1	1,9	1,4	1,9	1,4	0,6	0,1	17,1	1985	2000
17	Er-Rabbah	0,8	1,0	2,0	4,7	6,6	4,4	3,7	2,2	2,1	3,9	2,4	0,7	34,5	1961	2000
18	Mu'tah University	1,3	1,9	2,1	6,5	5,3	5,2	4,3	4,9	4,7	3,9	1,9	1,2	43,2	1986	2000
19	Alhasan/Tafileh	1,0	1,2	2,2	6,2	7,3	5,4	4,1	2,5	3,1	4,2	2,2	1,3	40,7	1973	2000
20	Shoubak	0,4	0,5	1,3	3,0	4,4	3,6	3,4	1,6	1,8	2,2	0,7	0,6	23,5	1965	2000
22	Ma'an	0,9	1,7	4,1	7,9	9,6	9,3	8,9	8,0	6,7	4,8	1,3	0,7	63,9	1960	2000
23	Mafraq	0,0	0,2	1,5	4,3	7,4	4,9	2,4	1,0	1,7	3,5	1,6	0,1	28,6	1960	2000
25	Wadi Dhulail	0,0	0,0	0,8	2,0	4,2	3,0	1,2	0,7	1,2	1,3	0,4	0,0	14,8	1968	2000
26	Zarqa Refinery	0,0	0,2	1,4	3,4	7,5	5,1	3,9	2,1	2,3	2,4	1,0	0,0	29,3	1966	2000
27	Azraq South	0,1	0,5	2,4	4,7	6,7	3,9	1,9	1,0	2,7	2,7	0,7	0,6	27,9	1981	2000
28	Safawi (H-5)	0,4	1,4	4,5	9,6	13,3	13,9	13,1	10,1	8,8	7,6	2,5	0,6	85,8	1963	2000
29	Rwaished (H4)	0,6	1,2	4,6	8,8	14,4	16,4	15,9	12,6	10,3	6,9	1,9	0,3	93,9	1961	2000
30	Qatraneh	0,5	1,2	3,4	7,4	10,1	4,9	4,1	1,8	2,2	3,7	2,7	0,8	42,8	1983	2000
31	Al Jafer	0,4	0,8	3,1	6,0	10,0	7,8	6,6	5,6	3,3	2,9	0,3	0,2	47,0	1965	2000

Table AIII 19: Mean number of days with fog

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	0,1	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	**0,4**	1976	2000
2	Wadi El-Rayyan	1,1	0,8	0,7	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,8	**3,7**	1974	2000
3	Deir Alla	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	**0,1**	1965	2000
4	University Farm	0,0	0,0	0,3	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	**0,4**	1986	2000
5	Ghor Safi	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0,0**	1974	2000
6	Aqaba Airport	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0,0**	1959	2000
7	Irbed	0,9	0,3	0,6	0,4	0,1	0,1	0,2	0,6	0,1	0,1	0,1	0,6	**4,1**	1965	2000
8	Ramtha	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	**0,3**	1981	2000
9	Ras Muneef	15,4	14,2	16,2	11,2	7,7	7,9	11,1	14,2	12,7	9,4	8,4	12,4	**140,8**	1976	2000
10	Salt	6,1	3,9	3,7	0,8	0,2	0,0	0,0	0,0	0,0	0,0	1,4	3,5	**19,6**	1991	2000
11	Jordan University	1,2	0,8	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,3	1,3	**4,2**	1964	2000
12	Swaileh	6,4	4,5	3,5	1,3	0,3	0,0	0,2	0,3	0,1	0,7	2,3	4,2	**23,8**	1985	2000
13	Amman Airport	1,4	0,8	0,5	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,3	1,0	**4,2**	1923	2000
15	Q.A.I. Airport	3,0	1,7	1,6	0,3	0,1	0,0	0,0	0,0	0,1	0,4	1,5	2,7	**11,4**	1970	2000
16	Madaba	1,8	0,4	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,7	**3,4**	1970	2000
17	Er-Rabbah	2,4	1,6	1,2	0,3	0,1	0,0	0,0	0,0	0,0	0,0	0,4	1,5	**7,5**	1974	2000
18	Mu'tah University	1,7	1,0	0,7	0,4	0,3	0,0	0,0	0,1	0,1	0,0	0,1	0,5	**4,9**	1986	2000
19	Alhasan/Tafileh	0,6	0,4	0,2	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,3	**1,8**	1973	2000
20	Shoubak	6,2	6,1	5,3	1,8	0,8	0,2	0,1	0,1	0,3	0,8	2,8	5,0	**29,5**	1965	2000
21	Wadi Mousa	0,8	1,1	0,7	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,3	**3,1**	1985	2000
22	Ma'an	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,2	**0,5**	1960	2000
23	Mafraq	3,2	2,0	1,6	0,8	0,4	0,2	0,6	1,0	1,5	0,8	1,3	3,3	**16,7**	1953	2000
25	Wadi Dhulail	2,0	1,2	1,3	0,4	0,0	0,0	0,0	0,3	0,2	0,1	0,5	2,1	**8,1**	1974	2000
26	Zarqa Refinery	0,4	0,2	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	**1,0**	1977	2000
27	Azraq South	1,6	0,6	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,3	1,5	**4,3**	1981	2000
28	Safawi (H-5)	1,6	0,3	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	1,0	**3,4**	1963	2000
29	Rwaished (H4)	1,3	0,4	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,2	0,5	1,1	**3,7**	1961	2000
30	Qatraneh	1,3	0,4	0,4	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,3	0,7	**3,3**	1983	2000
31	Al Jafer	0,8	0,3	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,3	0,7	**2,4**	1965	2000

Table AIII 21: Mean number of days with mist (visibility < 5km)

	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly	Period	
1	Baqura	0,7	0,1	0,5	0,7	0,2	0,2	0,7	0,7	0,4	0,1	0,2	0,6	**5,1**	1976	2000
2	Wadi El-Rayyan	0,7	0,5	0,8	0,6	0,6	0,5	0,5	0,4	0,0	0,1	0,3	0,7	**5,7**	1975	2000
3	Deir Alla	0,1	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	**0,4**	1965	2000
4	University Farm	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	**0,1**	1986	2000
5	Ghor Safi	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,2	**0,4**	1975	2000
6	Aqaba Airport	0,4	0,6	0,2	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,4	**1,9**	1959	2000
7	Irbed	1,9	1,0	1,8	1,7	2,4	3,7	6,6	8,3	3,5	0,9	0,9	1,8	**34,5**	1965	2000
8	Ramtha	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	**0,2**	1981	2000
9	Ras Muneef	3,6	3,3	3,4	3,5	2,8	2,5	3,9	4,8	4,8	3,7	2,4	4,0	**42,7**	1976	2000
10	Salt	3,0	2,4	3,1	1,2	0,6	0,3	0,8	0,4	0,0	0,7	1,9	4,2	**18,6**	1992	2000
12	Swaileh	2,9	2,0	2,1	1,1	0,4	0,3	0,3	0,7	0,8	0,9	1,6	3,1	**16,2**	1985	2000
13	Amman Airport	3,7	2,6	1,9	0,9	0,3	0,2	0,3	0,3	0,4	0,5	1,6	3,6	**16,3**	1946	2000
14	Roman Amph./ Amman	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0,0**		
15	Q.A.I. Airport	4,2	2,5	2,2	0,8	0,4	0,2	0,3	0,3	0,5	0,9	1,0	3,9	**17,2**	1971	2000
17	Er-Rabbah	0,8	0,7	0,8	0,5	0,3	0,2	0,9	0,6	0,2	0,2	0,2	1,0	**6,4**	1976	2000
18	Mu'tah University	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	**0,2**	1986	2000
19	Alhasan/Tafileh	0,4	0,6	0,2	0,0	0,0	0,1	0,1	0,0	0,0	0,1	0,0	0,0	**1,5**	1973	2000
20	Shoubak	0,3	0,1	0,1	0,2	0,1	0,1	0,0	0,2	0,3	0,2	0,1	0,3	**2,0**	1975	2000
21	Wadi Mousa	0,3	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,9	**1,6**	1985	2000
22	Ma'an	0,2	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,1	**0,6**	1960	2000
23	Mafraq	6,0	3,8	4,6	2,9	2,8	3,2	5,7	8,5	5,7	3,0	3,1	4,8	**54,1**	1953	2000
25	Wadi Dhulail	1,3	0,9	0,7	0,7	0,6	0,4	0,7	1,8	1,0	0,2	0,5	2,3	**11,1**	1975	2000
26	Zarqa Refinery	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	**0,1**	1965	2000
27	Azraq South	3,1	2,2	2,3	1,3	1,1	0,5	2,1	2,6	1,0	0,5	1,4	4,1	**22,2**	1981	2000
28	Safawi (H-5)	3,1	1,6	0,9	0,4	0,1	0,0	0,1	0,0	0,1	0,3	1,2	2,6	**10,4**	1964	2000
29	Rwaished (H4)	0,3	0,2	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,2	**1,0**	1961	2000
30	Qatraneh	0,5	0,6	0,2	0,1	0,1	0,0	0,1	0,1	0,1	0,5	0,2	0,7	**3,2**	1983	2000
31	Al Jafer	1,5	0,8	0,6	0,3	0,1	0,0	0,2	0,0	0,3	0,7	1,1	1,2	**6,8**	1965	2000

Annex IV: Overview of companies

Overview of companies selling flat plate and / or evacuated tube systems

Table AIV 1: Companies selling flat plate and / or evacuated tube systems

Company	System Type	Homepage	Comments
Bosch Buderus (D)	Flat plate collectors Evacuated tube collectors	http://www.buderus.de/sixcms/detail.php/Buderus_Startseite2229897-.html	Mainly focus on heating systems
GreenOneTec (AT)	Flat plate collectors Evacuated tube collectors	http://www.greenonetec.com/en/home/home/	Large, established manufacturer, large market share
KBB (D)	Flat plate collectors	http://www.kbb-solar.de/en/products/collectors.html	Have additional installation accessories (e.g. mounting systems)
ökoTech (AT)	Flat plate collectors	http://www.oekotech.biz/	
Paradigma Ritter (D)	Evacuated tube collectors	http://www.paradigma.de/home/	Mainly focus on heating systems
Schüco (D)	Flat plate collectors	http://www.schueco.com/web/uk	
Solarfocus (AT)	Evacuated tube collectors	http://www.solarfocus.at/	The collectors are compound parabolic concentrators
Solvis (D)	Flat plate collectors Evacuated tube collectors	http://www.solvis.de/	
Sunda (D)	Evacuated tube collectors	http://www.sunda.de/	
Viessmann (D)	Flat plate collectors Evacuated tube collectors	http://www.viessmann.de/de.html	Active also in industrial sector, mainly focus on heating systems
Wagner Solar (D)	Flat plate collectors	http://www.wagner-solar.com/en/	Sell also storage tanks

Overview of companies selling CSP systems

Table AIV 2: An overview of companies selling CSP systems

Company	System Type	References	Homepage	Comments
Industrial Solar (D)	Fresnel collectors	In Germany, Spain, Italy, MENA	http://www.industrial-solar.de/cms/en/	Experience in MENA region
Novatec Biosol (D)	Fresnel collector (steam output)	In Spain and Australia	http://novatecsolar.com/	Single units can be combined to larger system
PSE AG (D)	Fresnel collector	In Germany, Italy and Spain	http://www.pse.de/typo3/t3site/de/home.html	
Solarlite (D)	Parabolic trough collector	Several projects in Germany, Spain and Thailand	www.solarlite.de/en/	Not many references
Solitem (D)	Parabolic trough collectors	Several projects in Turkey, MENA (also the system on the Dead Sea Spa Hotel in Jordan)	http://www.solitem.com.tr/en/	Experience in Jordan

Overview of companies selling absorption and adsorption systems

Table AIV 3: An overview of companies selling absorption and / or adsorption systems

Company	System Type	References	Homepage	Comments
AGO (D)	Absorption chiller with NH_3/H_2O	Many in industry and service sector, mainly in Germany	http://www.ago.ag/en/home/	Large company, a lot of expertise, large capacity range No experience in MENA region
BROAD (CHN)	Absorption chiller, single and double step, with H_2O/LiBr		http://www.broad.com:8089/english/index.asp	Big capacity range
EAW (D)	Absorption with H_2O/LiBr	In Germany, Austria	http://www.eaw-energieanlagenbau.de/solares-kuehlen-rubrik_5.php	

ECO-MAX (USA)	Adsorption systems with H_2O/ silica gel		http://www.eco-maxchillers.com/	
Invensor (D)	Adsorption systems H_2O/zeolite		http://www.invensor.com/en/products/cooling-systems.htm	
Kawasaki (J)	Absorption chiller, double and triple effect		http://www.kawasakitrading.co.jp/eg/index.html	
PINK (AT)	Absorption chiller with NH_3 /H_2O (also sell other systems)	In Austria	http://www.pink.co.at/thermische-kaeltemaschinen.htm	Also work on solar side and with storage systems; can also be used for process cooling in small companies#, no references in MENA region
Robur (D)	Gas fired absorption heat pumps and chillers	Many reference, mainly in Europe	http://www.robur.com/products/	A lot of expertise, many different products to choose from, but only gas fired systems – can be adopted to work with solar energy, but not in serial production
Solarice (D)	Absorption refrigerator with NH_3/H_2O		http://www.sortech.de/sortech/downloads/	
SorTech (D)	Adsorption systems with H_2O/ silica gel and H_2O/zeolite	In Europe	http://www.thermax-europe.com/products.aspx	
Thermax (IND)	Absorption chiller (steam and hot water driven), single and double step, with H_2O/LiBr and NH_3/H_2O	In Europe, Brazil, USA, India	www.thermaxindia.com	Large product range
Yazaki (J)	Absorption Chiller, single and double step with H_2O/LiBr	In USA	http://www.yazakienergy.com/	Double step is only gas-fired

Overview of system integrators

Table AIV 4: An overview of system integrators

Company	Main market	Strength	Weakness
Climatewell (SE)	Residential	• Patented technology on absorption machine • Largest company specialized on solar cooling • Focus on small segment of the market (small commercial / residential) • Worldwide operations • Production standardized with costs reductions • Commercial competitiveness of products	• Less focused on commercial market
Industrial Solar (D)	Commercial	• Specialization on commercial solar cooling • Good technology competence • Several reference in MENA region with highly efficient CSP solar cooling technology • Cooperation with efficient absorption cooling providers • Focus on high quality components	•Technology not patented •Small company
SolarNext (D)	Residential	• Offer adsorption and absorption kits • Offer system controlling units	
Solid (AT)	Commercial	• Large references – > 500 kW Beijing Olympics and Singapore • Technical competence as system integrator	• Focus on less efficient flat plate /vacuum type solar systems • No patented technology • Less specialized on specific technology know how, more working as system integrator • Few or no references in MENA (systems possibly more suitable for diffuse sunlight)
Sopogy (USA)	Residential	• Small commercial, residential sector	• Mainly focusing on smaller absorption machines
Sortech (D)	Residential	• Small commercial, residential sector	• Mainly focusing on smaller absorption machines in the range of 10 - 50 kW

Commercial refers to systems > 500 kW, residential to systems < 500 kW

Annexes

Annex V: Examples of existing solar cooling projects

Office cooling, Esslingen (Germany)

The company Festo AG & Co. KG cool offices and atria by three H_2O/silica gel adsorption chiller (Typ Mycom ADR-100) with 353 kW cooling capacity each, which is one the largest H_2O/silica gel adsorption chiller worldwide. The systems can be run by waste heat from compressors, heat from gas-/oil- boilers and also by a solar system (CPC-evacuated tubes, from Paradigma / Ritter XL Solar). The solar collector area is 1330 m², and has a solar storage of 17 m³.
The provided solar heat can also be used throughout the year by other heat consumers and for heating in winter.

The emission savings from the solar system alone are 134 t CO2, and above 80% of the needed cold needed on the premises can be supplied by the solar heat and waste heat combined (Hochschule Offenburg, see also http://www.scope-online.de/news/Festo-erhaelt-ersten-Esslinger-Klimapreis.htm, 2011).

Figure AV 1: Premises of the Festo AG & Co. KG in Esslingen from above, also showing the solar collector field, initial operation in 2007 (Source: http://www.ritter-xl-solar.com/referenzen/industrie-und-gewerbe/esslingen/).

Cooling of a computer center, Dessau, Germany

A 50 kW chiller from the TU Berlin cools a computer centre in the building of the German Federal Environment Agency. Heating is provided by a solar thermal system consisting of 216 m² heat pipe collectors. Additionally, district heating as backup is available. Together with a hybrid recooling system, 25-35 kW of cooling energy is supplied by the systems. This correlates to a reduction in primary energy consumption of approximately 50% compared to previous systems (BINE TUB Projektinfo, 2012).

Cooling of a football stadium, Doha, Qatar

A football stadium as showcase for the upcoming world cup in 2022 is cooled by an absorption cooling system that delivers approximately 700 kW of cooling, using a double-step chiller from Thermax. Up to 200° C super-heated water to run the system is provided by solar Fresnel collectors with an area of 1400 m². The chilled water is used to cool offices, hospitality facilities as well as the pitch and grandstand (see http://www.mottmac.com/worldcupstadium/).