Innovative Systems for Solar Air Conditioning of Buildings

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ABSTRACT

Solar air conditioning is an attractive technology to achieve comfortable room conditions, especially in hot and sunny climates. In particular air conditioning systems based on sorption technologies offer several advantages as they can be designed for a high efficient utilization of solar thermal energy. To show the today's and near future potential innovative solar cooling and air conditioning systems are discussed which are well adapted to the utilization of solar energy. The system performance of each air conditioning system is evaluated under Abu Dhabi design conditions.

INTRODUCTION

In air conditioning applications often a tight correlation between solar irradiation and cooling demand exits. Therefore the interest in solar air conditioning technology has increased in the last years.

Different technologies can be used to build up a solar air conditioning system. In any case a solar part of the total system converts solar irradiation to an intermediate form of energy, e.g. electricity, mechanical energy or thermal energy, and a second part of the system converts it to cold [1].

The total system investment costs are significantly influenced, if not dominated, by the costs of the solar part of the system. The size of the solar part scales with the coefficient of performance, COP, of the cooling part, defined as the ratio of cooling energy delivered to regeneration energy: $COP = Q_{cool}/Q_{Reg}$. Therefore, a cost optimization of the solar cooling system will have to enhance the COP of the cooling part to values significantly above the values usually accepted when firing fossil fuels.

In respect of solar costs three items are considered:

1. the **regeneration temperature** of the cooling system influences the efficiency of solar collectors;
2. cooling system **COP enhancement** will reduce the collector size;
3. **energy storage** is necessary to achieve a high solar fraction.

Thermal driven air conditioning systems based on sorption technologies offer several advantages. Of particular interest are single effect (open and closed) absorption cooling technologies, which can be driven by low temperature heat (60 ..90 °C) that can be supplied either by solar collectors or by waste heat from cogeneration. These absorption technologies (SE ACH) typically achieve COP´s of about 0.7. Double effect absorption chillers (DE ACH) achieve higher COP´s of about 1.2 but require higher regeneration temperatures of about 160 ..180 °C.

PRIMARY ENERGY SAVING

Solar energy can be used to reduce fossil energy consumption and CO_2 emission as well as electrical peak power demand. In Figure 1 the amount of primary energy necessary per unit cooling is shown as a function of the solar fraction of the solar cooling system and is compared to the same number for compression water chillers (COP CCH) in dependence of the efficiency of the power plant [2,3]. The different curves show the results for different COP´s.

In order to achieve any primary energy saving it shows that for single effect technology a solar fraction of at least 0.3 is necessary to compensate for the low COP. For a given solar fraction double effect technology achieves better (lower) primary energy ratios. This also means that the demand of solar energy is significantly reduced although the necessary regeneration temperature is considerably higher.

It is important to notice that compared to conventional compression chiller technology (CCH) the solar fraction has to be rather large to achieve any substantial primary or fossil energy saving.

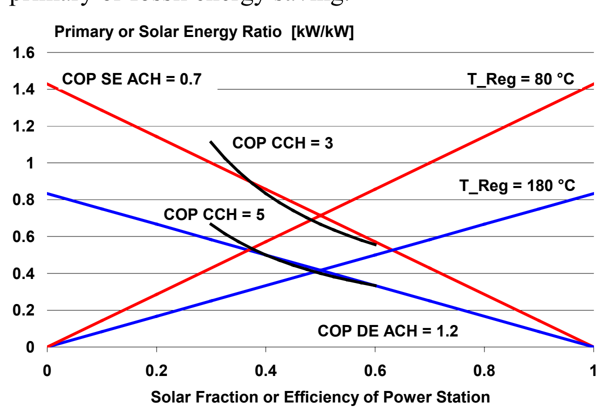

Figure 1: Comparison of primary energy ratio for different solar and conventional cooling technologies.

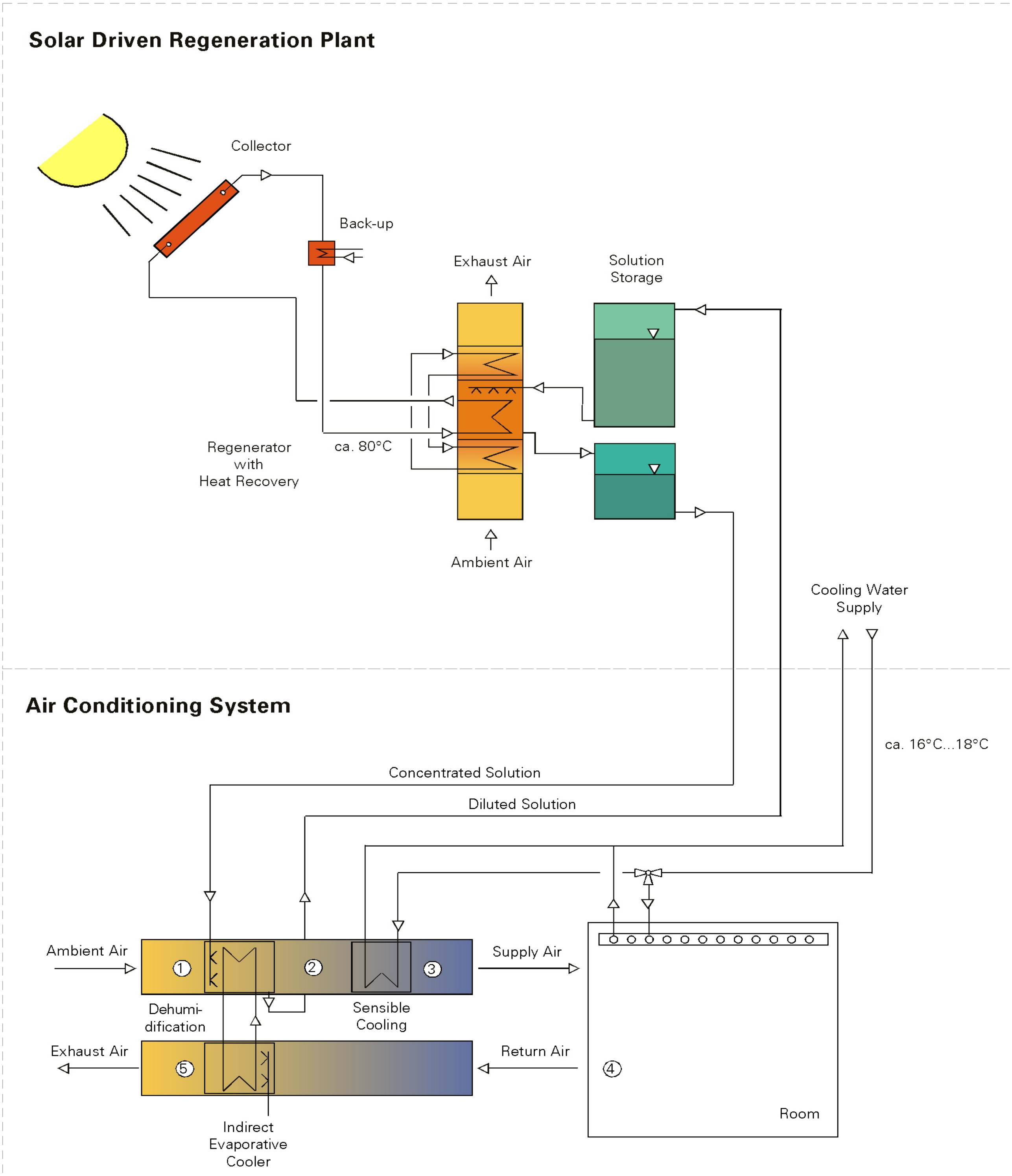

Figure 2: Solar Liquid Desiccant Cooling System LDCS

LIQUID DESICCANT COOLING SYSTEM LDCS

A novel sorption system with a cooled open cycle absorber, dehumidifying air by a very small flow of liquid desiccant (e.g. LiCl-H_2O solution) is shown in Figure 2 [4,5]. To give an example the components are arranged to the so called Ventilation Cycle. An air conditioning process for a typical office building is shown in Figure 3. The process is evaluated under Abu Dhabi design conditions.

Fresh ambient air (1) is dehumidified in a cooled absorption process (2) by a concentrated salt solution and subsequently cooled by cooling water to provide supply air of e.g. 16 °C and 8 g/kg (3). The room return air (4) is used in an indirect evaporative cooler to cool the absorption process (latent cold recovery, 5).

In hot and humid climates the proposed system can cover 100% of the total latent cooling load and up to 70% of the total sensible ventilation load.

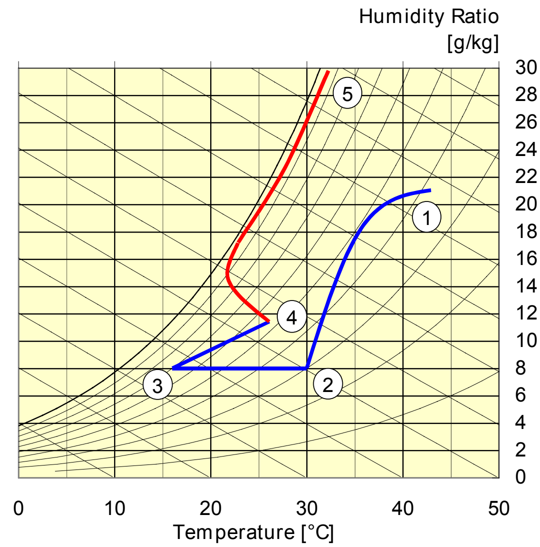

Figure 3: Abu Dhabi design conditions. Psychometric chart with an air conditioning process of a LDCS

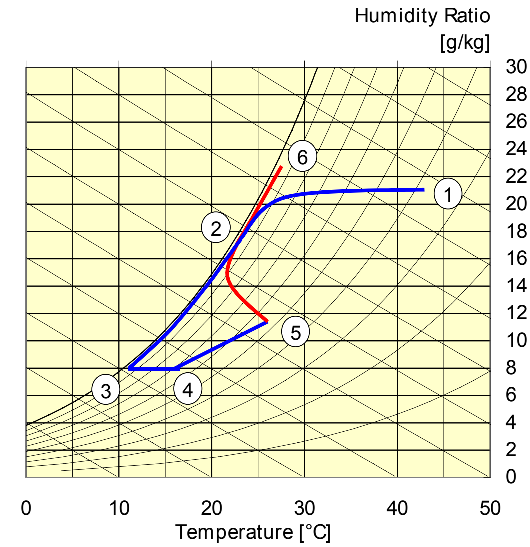

Figure 4: Psychometric chart with an air conditioning process with latent heat recovery

The coefficient of performance of the dehumidification process, defined as heat of dehumidification over the heat of regeneration is about 0.7. The total COP_{tot} (including the latent heat recovery) ranges from 0.7 up to 1.5 in well designed air conditioning systems thus considerably reducing the size and costs for the collector array.

Supply air and return air are coupled by a water circuit, dehumidifier and regenerator are coupled by a solution circuit. So the devices can be installed at separate locations within the building or outside.

High Efficient Solar Energy Storage

By the absorption process the desiccant solution is diluted. If solar heat e.g. form commercially available flat plate collectors at temperatures of about 60..80 °C is available the diluted solution can be regenerated. The liquid desiccant can efficiently be used as an energy storage. A very high energy storage capacity of about 250..330 kWh/m³ can be achieved. Thus a typical desiccant storage volume to cover a five hours mean dehumidification load of about 100 kW is only about 2 m³, which is a very small volume. Therefore the LDCS technology is especially suited to achieve high solar fractions.

To store the same energy in a hot water storage to drive a single effect absorption chiller a storage volume of about 23 m³ would be necessary (Taking a discharge temperature difference of 25 K in consideration and e.g. that the losses due to the COP of the chiller occur after the storage process!).

Because of the rather low regeneration temperatures the LDCS is also well suited for the combination with co-generation plants an other back-up heat sources.

COMBINED SOLAR AND GAS-FIRED ABSORPTION COOLING MACHINE

In respect to the technical and economical optimization of the total energy system a solar fraction of 1 is only rarely aimed at. In case of solar fractions smaller than 1, the cooling system has to be driven by fossil fuels e.g. by gas in order to cover the air conditioning or cooling demand. The COP should be as high as possible. To achieve a lower primary energy ratio than a conventional compression water chiller (COP CCH = 3) the solar fraction of a cooling system, based on a single effect absorption chiller with a COP of 0.7, has to be about 50% (see Figure 1).

One possibility to achieve a higher primary energy ratio is to utilize a new double effect closed cycle absorption chiller which can be driven by gas at high temperatures of about 180 °C. In the high efficient double effect gas mode the COP is about 1.2. Solar energy can be used in a special single effect driving mode at temperatures of about 90 °C with a COP of about 0.7 [6].

Figure 5 shows a solar driven chilled water plant with the proposed chilled water technology. The components solar collector, absorption chiller, cooling tower and gas fired back-up can be installed in a central plant to produce the chilled water.

Air Conditioning with High Efficient Latent Cold Recovery

In the air conditioning system, which can be installed decentralized, fresh hot and humid ambient air (1) is cooled and dehumidified (2) in a first condenser which is supplied with cold water from the exhaust air indirect evaporative cooler (latent cold recovery process).

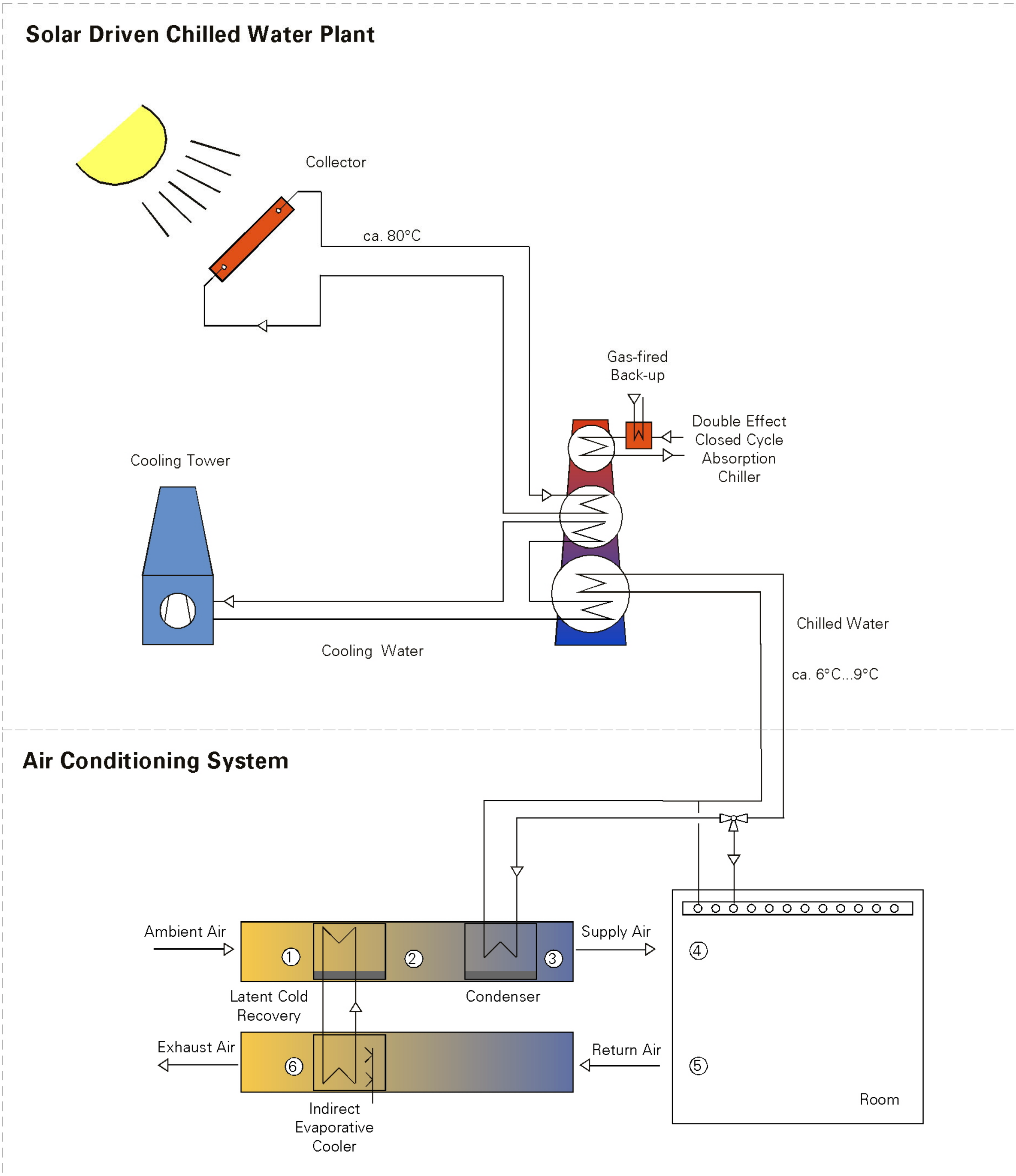

Figure 5: Combined solar and gas fired absorption system

The preconditioned air is then further cooled and dehumidified (3) in a second condenser which is supplied by chilled water from the absorption chiller. The cool air can be mixed in the room to comfortable supply air states (4). The room return air (5) is used in a latent heat recovery (6) (psychometric process see Figure 4).

To illuminate the excellent system performance a typical cooling load profile for a standard office building in the hot and humid climate of Abu Dhabi is shown in Figure 6. Up to 30% of the total cooling load is covered by the special latent cold recovery. Improving the mean total COP_{tot} to about 0.85 (solar only) and to about 1.15 in the combined mode (solar fraction about 50%). Thus the demand for solar and fossil energy is significantly reduced. The remaining load is covered by the chilled water from the combined solar and gas fired absorption cooling machine.

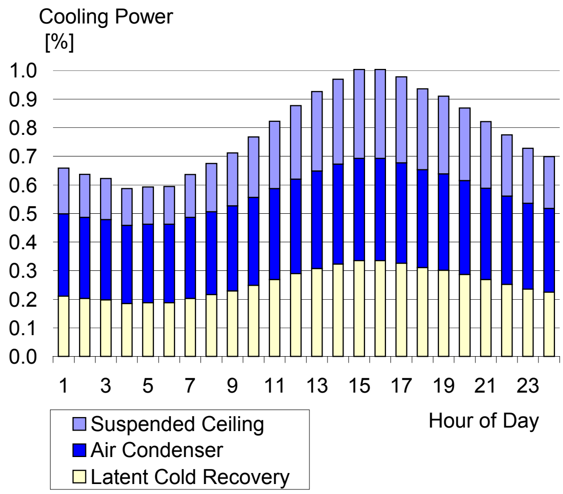

Figure 6: Typical load profile of air conditioning system with latent heat recovery evaluated for a standard office and Abu Dhabi Design conditions

SOLAR DRIVEN DOUBLE EFFECT ABSORPTION CHILLERS

A high efficient utilization of solar energy can be achieved with double effect closed cycle absorption chillers which are driven by hot water of about 160..180 °C. Such an absorption chiller technology is close to commercially available steam or gas-fired absorption chiller technology.

High Efficient CPC Collectors

To produce high driving temperatures with solar energy vacuum tube collectors can be used. Especially innovative CPC collector technology (Compound Parabolic Concentrator) shows a promising potential for cost effective collector arrays, see Figure 7.

The experimental results for the collector efficiency is given Figure 8. At ambient temperatures of about 45 °C and a solar irradiation of about 800 W/m² a solar efficiency of about 0.5 at a mean fluid temperature of about 180 °C can be achieved [7].

High Efficient Solar Chilled Water Production

An example for a high efficient solar chilled water plant is given Figure 9. Again the components solar collector, heat storage, absorption chiller, cooling tower and gas fired back-up can be installed in a central plant.

Hot water of about 160..180 °C is produced with the CPC collector array. The solar energy is utilized with a high COP of about 1.2 to produce chilled water.

Because of economic reason the solar energy production should be greater than 0,4 MW (solar chilled water capacity of about 0,5 MW).

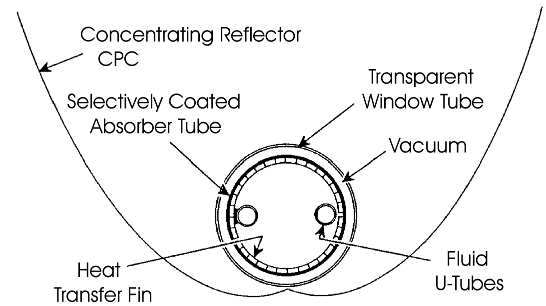

Figure 7: Compound parabolic concentrator CPC collector

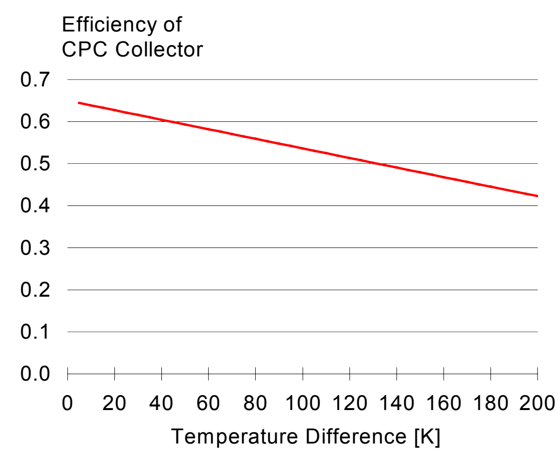

Figure 8: Efficiency of CPC collector

In case of additional chilled water load hot water of a pressurized boiler can be backed-up to drive the absorption chiller.

The air conditioning process is the same as described before, utilizing the latent cold recovery to reduce the total cooling loads (see example of psychometric process in Figure 4).

Under the given conditions the total COP_{tot} of the combined system is about 1.5 which is a remarkably high value.

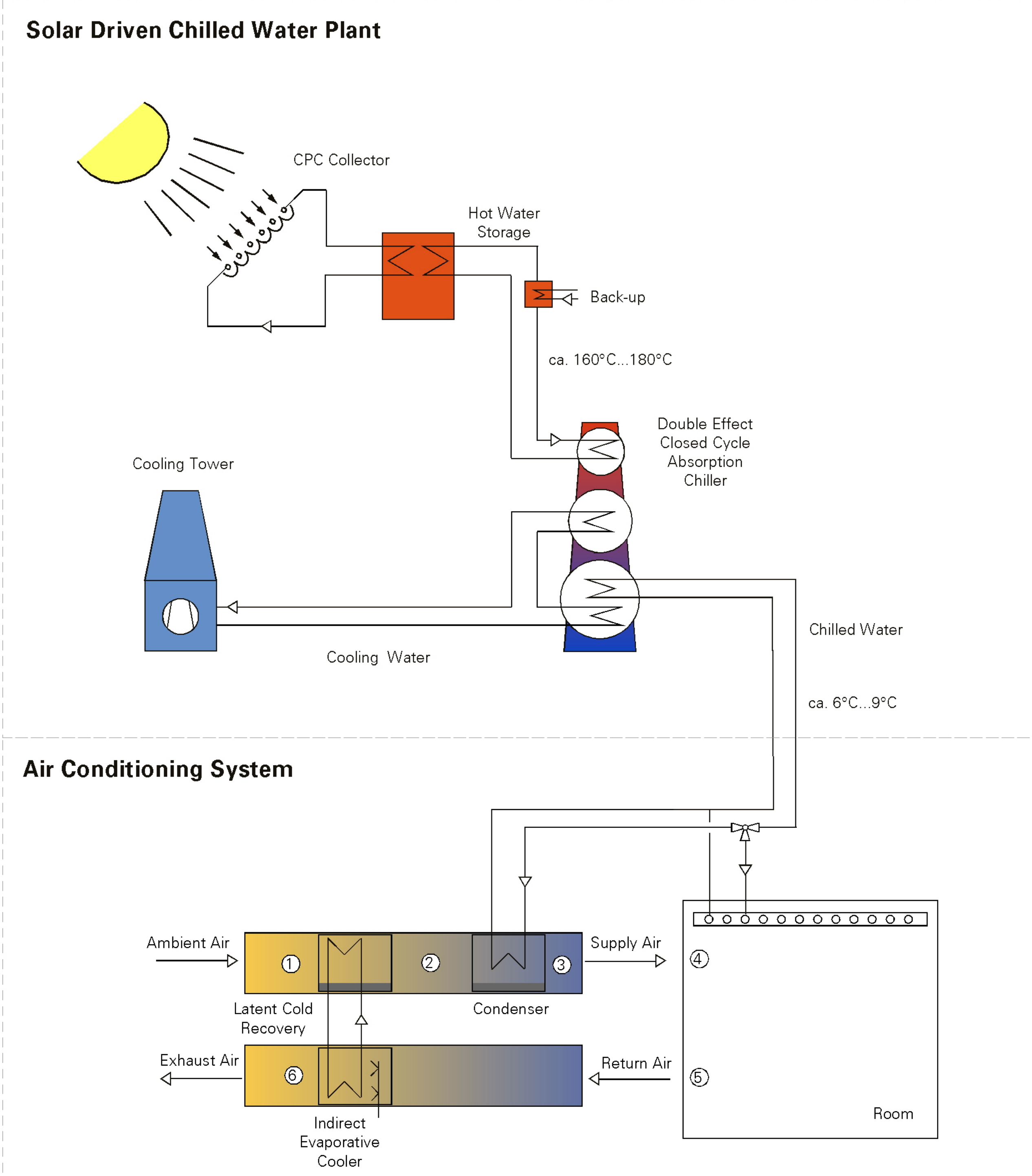

Figure 9: Solar driven double effect absorption chiller

CONCLUSION

Solar air conditioning is not yet a commercial standard product. Systems have to be well adapted for the conditions and the location of the application. At present state of development, solar air conditioning can not be expected to be cost competitive to conventional air conditioning. But it may contribute significantly to fossil energy saving and electrical peak load reduction. In situations where the electrical grid often fails because of high electrical peak loads e.g. due to compression chillers and conventional air conditioning systems, solar air conditioning technology may also contribute to a more reliable cold and electrical energy supply.

In particular air conditioning systems based on sorption technologies offer several advantages as they can be designed for a high efficient utilization of solar thermal energy.

The total system investment costs are usually dominated by the costs of the solar part of the system which scales directly with the coefficient of performance, COP. Therefore, a cost optimization of the total solar cooling system will have to enhance the COP of the cooling part to values significantly above the values usually accepted when firing fossil fuels. The discussed systems are especially designed to achieve very high total system COP´s.

Table 1: Comparison of basic system characteristics

	cooling medium	regeneration temperature		storage		COP	
system		80 °C	180 °C	medium	capacity	solar	back up
1 liquid desiccant cooling system	air	solar	-	liquid desiccant	> 250 kWh/m³	< 0.75	< 0.75
2 combined gas fired absorption chiller	water	solar	gas	hot water	< 30 kWh/m³	< 0.7	~ 1.2
3 double effect absorption chiller	water	-	solar	cold water	< 10 kWh/m³	~ 1.2	~ 1.2

In table 1 the basic system characteristics of the three discussed cooling and air conditioning systems such as: cooling medium, regeneration temperature, COP and energy storage features are summarized for comparison.

A novel liquid desiccant cooling technology is discussed which is well suited for air dehumidification and air conditioning in hot and humid climates. The COP ranges from 0.7 up to 1.5. The technology facilitates the utilization of solar energy as in general low grade thermal energy of about 80 °C is used as driving heat. In addition the technology offers a very high energy storage potential so high solar fractions can be easily achieved.

Two solar cooling systems are discussed based on novel double effect absorption chillers. These chillers are especially designed for the utilization of solar energy, as they produce chilled water with driving temperatures which can be produced either by commercially available flat-plate collectors (temperatures < 100 °C) or novel innovative CPC collectors (temperatures: 160 .. 180 °C). The air conditioning systems themselves utilize a high efficient latent cold recovery, which reduces the air conditioning loads of about 30%. Depending on the solar and the chiller technology the COP ranges from about 0.7 up to 1.5.

OUTLOOK

L-DCS Technology Pte. Ltd. and JTC Corporation are co-operating on a demonstration project in Woodlands, Singapore. A Stack-up factory in the Spectrum II development will be equipped with L-DCS's liquid desiccant dehumidification technology. The goal is to demonstrate the workability of the unique technology under extremely humid conditions in Singapore(design conditions: DB = 32°C, HR = 26.7 g/kg), and that this specific technology can be incorporated into the concept of district cooling.

Design outside air volume is about 16600 m³/h. The rated dehumidification capacity is about 190 kW with a thermal COP of about 1.1. The total cooling capacity of the hybrid system is about 480 kW.

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