OPERATIONAL RESULTS OF A 10 kW ABSORPTION CHILLER IN HEAT PUMP MODE

A. Kühn, T. Meyer, F. Ziegler
Technische Universität Berlin, Institute of Energy Engineering, KT 2,
Marchstraße 18, 10587 Berlin, Germany

Abstract: A 10 kW H_2O/LiBr absorption chiller designed for operating on low-grade driving heat (solar, tri-generation or district heat) was developed and built jointly with the company SK SonnenKlima GmbH and the Bavarian Centre for Applied Energy Research (ZAE Bayern). At nominal conditions the chiller supplies chilled water at 15/18°C using a hot water driving temperature of 75/65°C and cooling water of 27/35°C with a coefficient of performance (COP) of up to 0.8. In 2003, a pilot plant was integrated in a solar cooling system in Berlin where it operates successfully. In the last years several demonstration plants have been installed in Europe.

To save primary energy also in heating periods as well as to extend the operation time of the chiller and thus shorten the payback period, the system should also be able to run in heat pump mode. Traditionally, operation limits of the H_2O/LiBr-working pair are the freezing of the refrigerant at 0°C on the one hand and the crystallisation risk of the LiBr-solution on the other. Laboratory test results which demonstrate that it is possible to manage both problems, especially operating below the freezing point of water, will be presented and discussed.

Key Words: ***absorption chiller, heat pump, solar cooling, operation below 0°C***

1 INTRODUCTION

Absorption cooling systems in most cases are not yet economical compared to compression chillers [Eicker, 2006]. Therefore, it is important to extend the operation time and thus shorten the payback period by additionally operating an absorption chiller as a heat pump in winter time. As long as the coefficient of perfomance (COP) of the system is better than that of a modern condensing boiler, primary energy can also be saved in heating periods.

However, in heating mode often heat source temperatures are around or below 0°C. There is the general opinion that absorption cooling systems using water as refrigerant are limited to operate at chilled water temperatures above 3-4°C because of the freezing risk of the refrigerant water. In the following, results of laboratory tests operating below the freezing point of water are presented.

2 SPECIFICATION OF THE SUN*INVERSE*-CHILLER

The sun*inverse* absorption chiller was developed with focus on a small cooling capacity and low driving temperatures as they can be supplied by economic flat plate collectors or mini-cogeneration units [Schweigler et al., 2001]. Special qualities of the chiller are a good controllability with a high coefficient of performance in part and overload operation as well as a compact design. Demonstration plants are running since 2003 in several European countries [Clauß et al., 2007]. Figure 1 shows the prototype and summarizes the technical data for nominal load.

Working pair	H_2O/LiBr
COP	0.76
Cooling capacity	10 kW
chilled water in/out	18/15°C
flow rate	2.9 m³/h
Driving heat capacity	13.2 kW
hot water in/out	75/65°C
flow rate	1.2 m³/h
Rejected heat capacity	23.2 kW
cooling water in/out	27/35°C
flow rate	2.6 m³/h
Dimensions:	1.80 x 0.45 x 0.85

Figure 1. Prototype of the 10 kW absorption chiller and technical data

3 CARACTERISTIC DATA OF THE SUN*INVERSE*-CHILLER IN COOLING MODE

The development of sun*inverse* was focused on cooling operation. The following measuring results demonstrate that the chiller can be run with very different driving, cooling and chilled water systems as it works in a wide range of driving, cooling and chilled water temperatures.

Experimental values for cooling capacity and COP (ratio of cooling capacity and driving heat) using driving temperatures from 50°C to 105°C are represented in Figure 2.

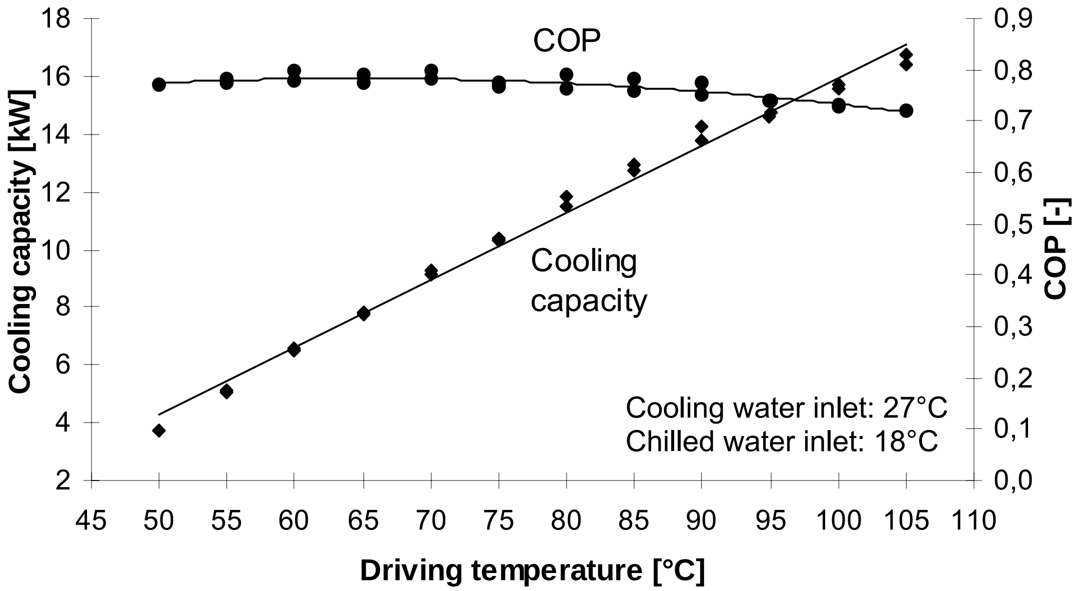

Figure 2: Chiller performance at varying driving temperatures

With a driving temperature of only 55°C a cooling capacity of 5 kW, i.e. 50% of nominal load can be achieved. In the whole part and overload range of 40 to 170% the COP exceeds the value 0.72 and reaches 0.8 at nominal load. That indicates an efficient use of the heat source, particularly at low driving temperatures allowing an efficient chiller operation combined e.g. with simple flat plate collectors.

The level of cooling water temperature has the strongest influence on the cooling capacity (see Figure 3). The cooling capacity is improved by low cooling water temperatures as they can be achieved with a wet cooling tower if the climate is not too humid. The chiller can also be operated at higher cooling water temperatures so that dry cooling towers can also be used.

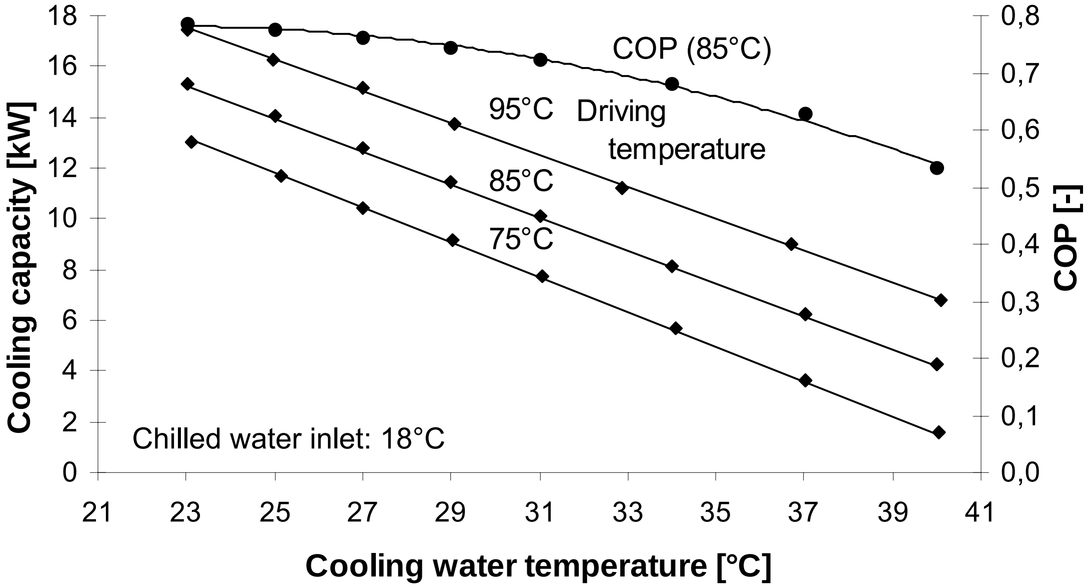

Figure 3: Chiller performance at varying cooling water temperatures

Figure 4 shows cooling capacity and COP values for different chilled water temperatures.

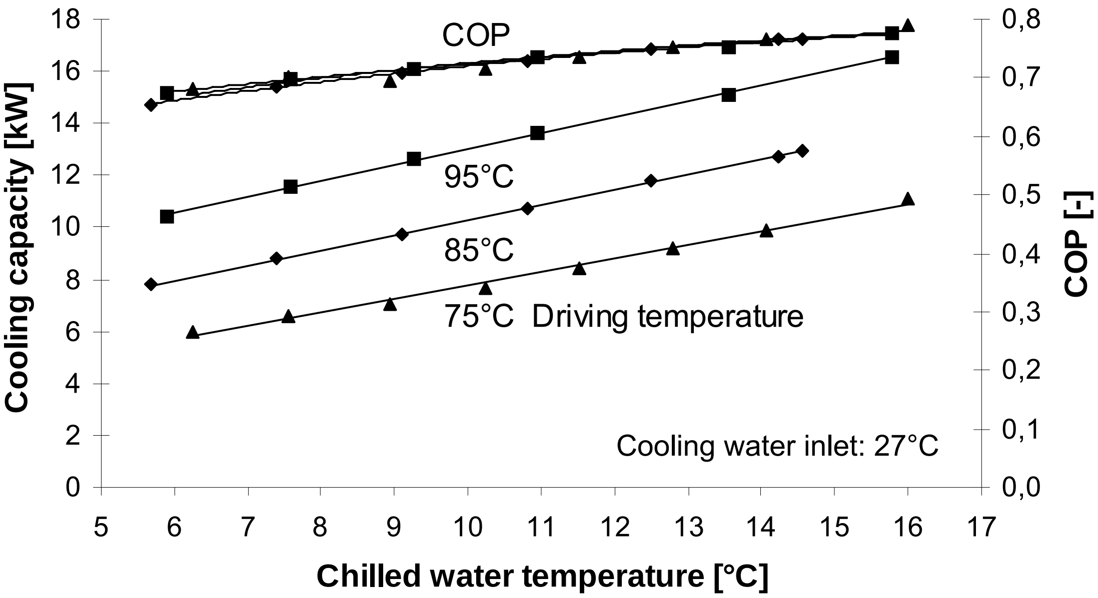

Figure 4: Chiller performance at varying chilled water temperatures

The chiller is designed to supply water for chilled ceilings. For this application a chilled water temperature of about 15°C is sufficient. Nevertheless, chilled water with temperatures down to 6°C can also be produced. This temperature level is needed for the use of fan coils, where the air can additionally be dehumidified.

4 CARACTERISTIC DATA OF THE SUN*INVERSE*-CHILLER IN HEATING MODE

In the following, operation results for the heat pump application are presented. In heating mode driving heat is provided by the boiler. The use of cooling and chilled water circuits is reverse: the cooling water circuit now provides the useful heat for the building and via the chilled water circuit heat from the environment is taken. The connection to the environment is the heat sink from the cooling mode and this can be a cooling tower or a ground coupling system (boreholes, ground collectors, groundwater). Solar air collectors or waste heat from e.g. computer centers or stables can also be used as heat source for the evaporator. The higher this temperature is the better. The opposite applies to the building's heating system; low temperature heating systems are advantageous. Air heating systems need the lowest temperatures of around 25°C. Floor and wall heating systems work with 35°C. Also radiators can be applied if they are designed for supply temperatures not higher than 45°C.

Operation results with 40°C heating temperature (supply temperature to the heating system) are presented in Figure 5. Here, the driving temperature has been varied. The upper curves of cooling capacity and COP (ratio of useful heat and driving heat) are measurements with 95°C driving temperature; the respective lower curves are measurements with 85°C driving temperature. In addition, the evaporator inlet temperature, i.e. the temperature of the environmental heat source has been varied from 5 to 25°C.

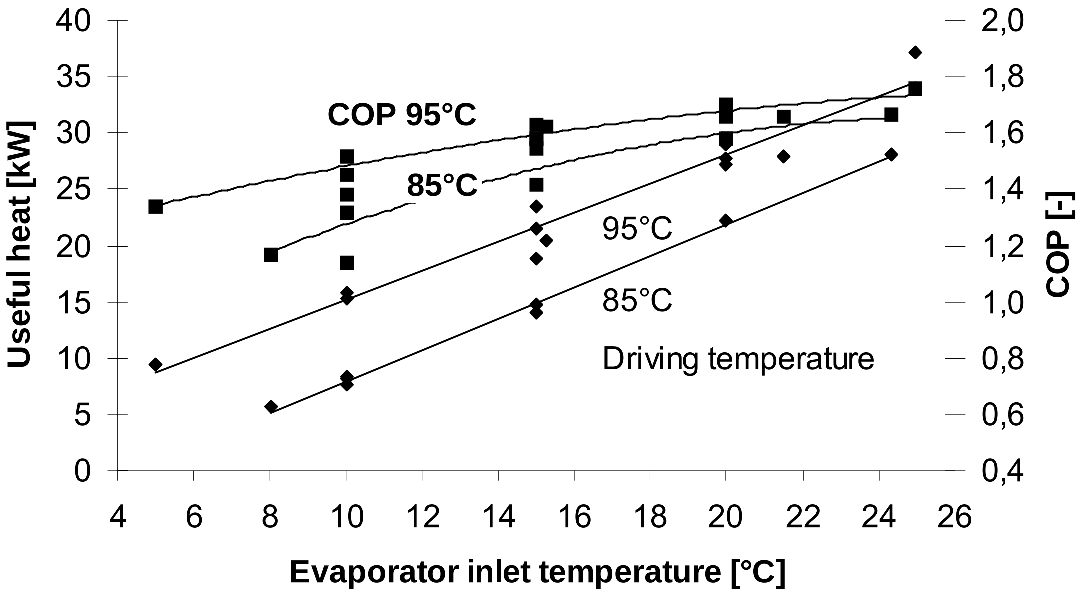

Figure 5: Results at 40°C heating temperature

Using a driving temperature of 95°C, 10 kW of useful heat can be produced at an evaporator inlet temperature of 5°C and 37 kW at 25°C. The COP ranges between 1.3 at the low and 1.8 at the higher evaporator temperature level. As a water/water heat pump using groundwater at 10°C a useful heat of 15 kW can be achieved. With a value of 1.5 the COP is considerably higher than that of a state-of-the-art condensing boiler.

In order to increase the efficiency of the burner which is used to drive the heat pump, the driving temperature should be as low as possible, e.g. 85°C. In this case, on the heating circuit side radiators at 45°C can not be used since at 8°C evaporator inlet temperature only 5 kW useful heat are produced and the COP is only 1.2. Low temperature heating systems have to be applied or the temperature level of the environmental heat source must be higher (use of waste heat). The effect of the environmental heat source temperature is tremendous: at 24°C evaporator inlet temperature 28 kW useful heat can be achieved with a very attractive COP of 1.7.

Figure 6 shows operation results with different heating temperatures. At varying evaporator inlet temperatures test series with 40°C (upper curves of useful heat and COP) and 45°C (lower curves) have been carried out. One point with 35°C heating temperature has been plotted for comparison. This comparison shows clearly the benefit of floor, wall or air heating systems; useful heating capacity and COP increase considerably. While at an evaporator inlet temperature of 6°C and a heating temperature of 40°C 10 kW useful heat (COP 1.4) are produced, 26 kW (COP 1.7) can be obtained when the heating temperature is only 35°C. Radiators with 45°C supply temperature should only be used if an environmental heat source of more than 15°C is available.

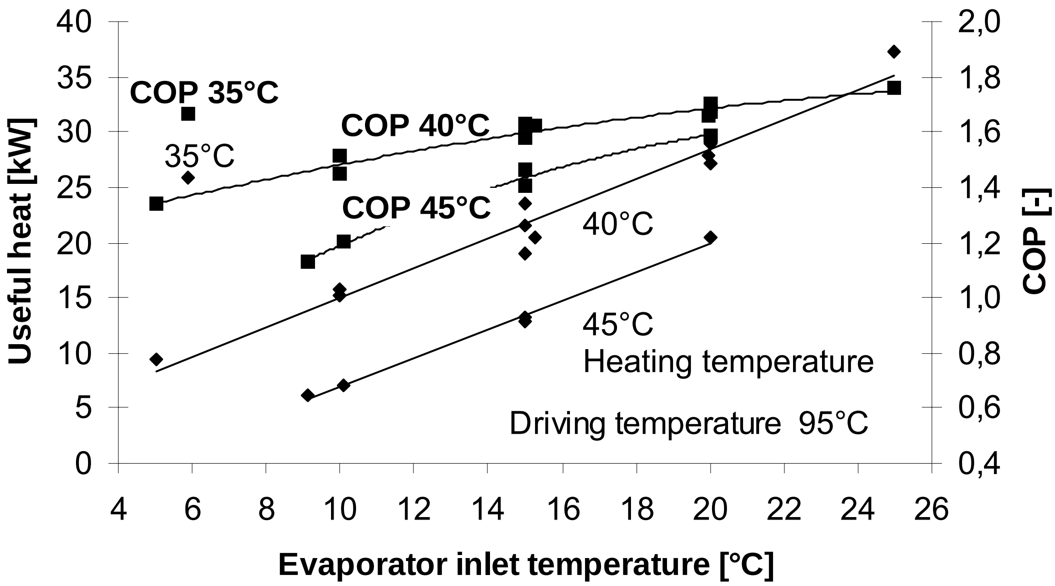

Figure 6: Results at 35°C (single point at the top), 40°C (upper curve), 45°C (bottom curve) heating temperature

Measurements presented in Figures 1 and 2 have been carried out at a minimum evaporator inlet temperature of 5°C. As water is the refrigerant in LiBr-absorption chillers there is the risk of freezing at lower temperatures. Therefore, absorption chillers with this working pair are traditionally not used for chilling below approximately 5°C.

If groundwater can be used as environmental heat source, evaporator inlet will not sink below 10°C. For ground coupled heat pumps an inlet temperature of 0°C has to be considered (see DIN 33830). In the normal case of using the heat pump in summer time as a chiller, reject heat of around 35°C is brought into the ground during this period so that the temperature will probably be always higher than 5°C, too. But if the cooling tower is used to take heat from the environment, evaporator inlet temperatures below 0°C must be considered. So, this operation condition had to be tested, also.

It is well known that in LiBr-water chillers there is always a minute spill over of salt into the evaporator. If this salt is not bleeded to the absorber but if the amount is artificially increased there will be enough freezing point depression to prevent the evaporator from freezing. The control is easily done and there is no problem to switch back into the normal mode. Operation below zero causes no problems if the chiller is designed in the right way.

Figure 7 shows measuring values of useful heat and COP for evaporator inlet temperatures in the range of 2°C to –2°C. The supply temperature for the heating system is 31-32°C.

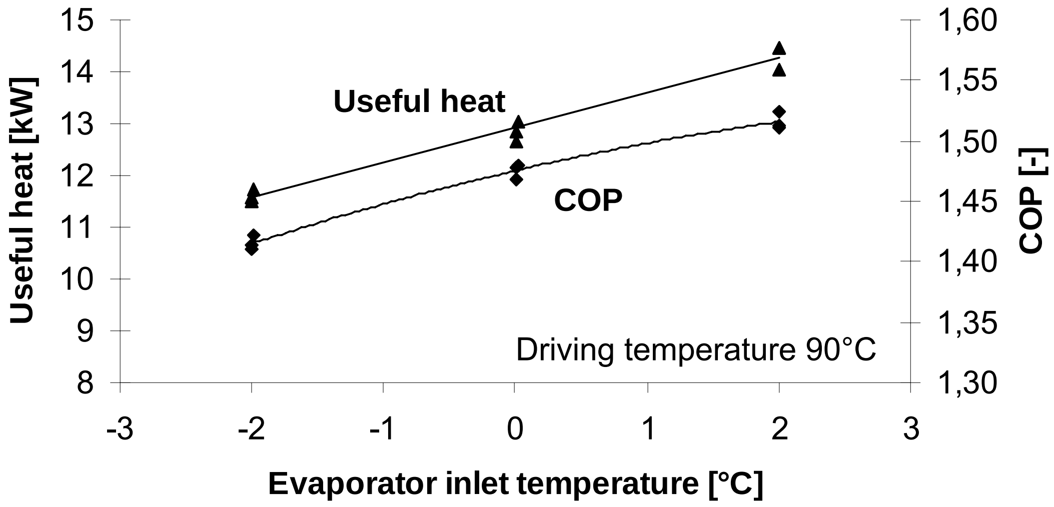

Figure 7: Results at 31-32°C heating temperature

Finally, it will be shown that the operational conditions of chilling and heat pumping fit together well. The cooling capacity of an absorption chiller in dependence of the so-called characteristic temperature function is described by the characteristic equation [Ziegler, 1997]. Data points of all steady-state measurements in chilling operation (Figures 2-4) are plotted in Figure 8.

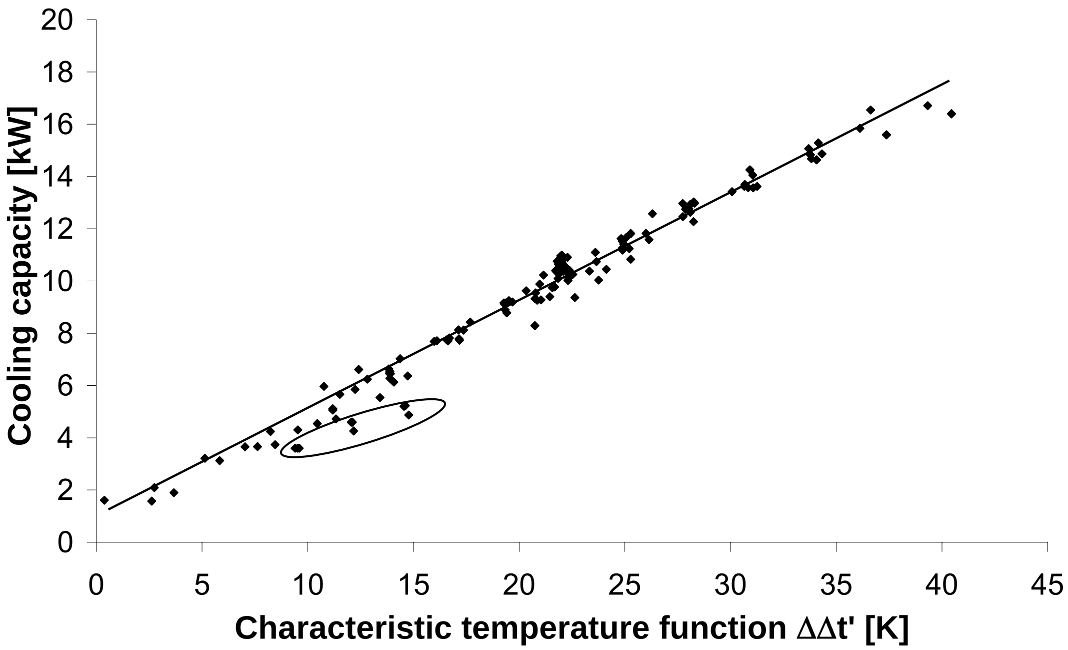

Figure 8: Heat pump in comparison to chiller operation

The characteristic behaviour is approximated by the equation $\dot{Q}_E = 0{,}42 \cdot \Delta\Delta t' + 0{,}9$ [Kühn, Ziegler, 2005]. Data points of the heat pump measurements presented in Figure 7 are marked by an ellipse. Although the operation with salt in the evaporator deviates considerably from the normal operation the characteristic curve for the cooling capacity still holds quite well. The small deviation can be explained by a shift in salt concentration of the working fluid. The deviation of COP isn't very significant either (Figure 9).

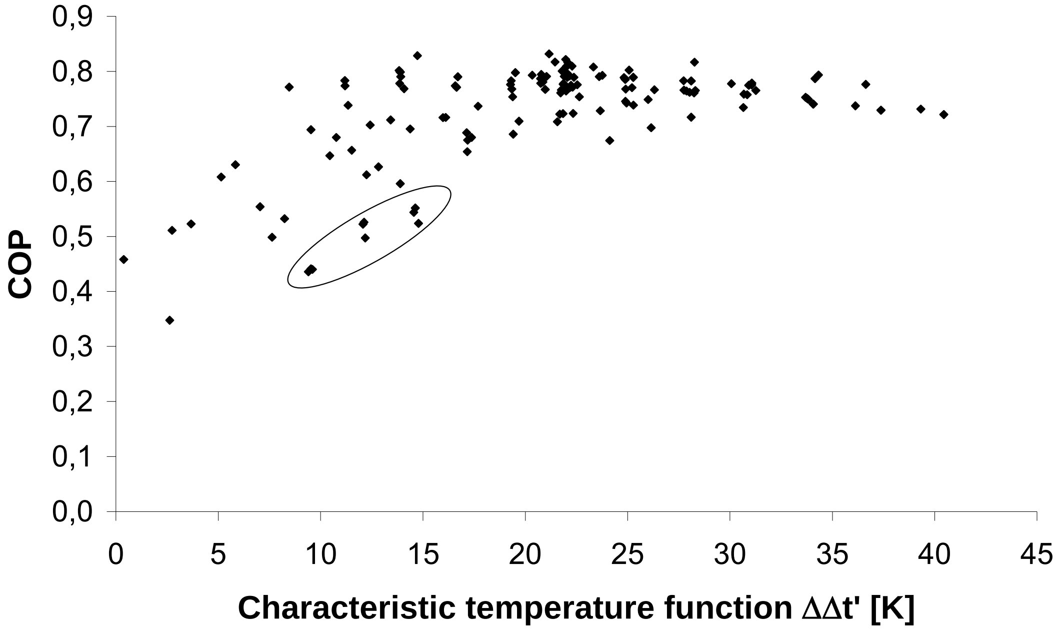

Figure 9: COP comparison of heat pump and chiller operation

5 CONCLUSION

It is desirable to use absorption chillers as heat pumps in winter time to increase their economic efficiency. The sun*inverse* chiller is applicable for year-round operation as chiller and heat pump with reasonable COP-values. By specific addition of salt to the refrigerant it is even possible to use evaporator inlet temperatures below 0°C. The use of ground coupling brings forth higher heat source temperatures in winter mode and lower heat sink temperatures in summer mode. We can conclude that – in contrast to the typical notion of today's state of the art – LiBr-absorption chillers can be used as heat pumps very effectively.

6 REFERENCES

Clauß V., A. Kühn, C. Schweigler 2007. "Field testing of a compact 10 kW water/LiBr absorption chiller", *Proceedings of the 2nd International Conference Solar Air Conditioning*, 18/19th October 2007, Tarragona, Spain.

Eicker U. 2006. "Entwicklungstendenzen und Wirtschaftlichkeit solarthermischer Kühlung", *Tagungsband des 4. Symposiums Solares Kühlen in der Praxis*, Hochschule für Technik, Stuttgart, Germany.

Kühn A., F. Ziegler 2005. "Operational results of a 10 kW absorption chiller and adaptation of the characteristic equation", *Proceedings of the 1st International Conference Solar Air Conditioning*, 6/7th October 2005, Bad Staffelstein, Germany.

Schweigler C., A. Costa, M. Högenauer-Lego, M. Harm, F. Ziegler 2001. "Absorptions-kaltwassersatz zur solaren Klimatisierung mit 10 kW Kälteleistung", *Tagungsbericht der Deutschen Kälte-Klima-Tagung 2001 Ulm,* Deutscher Kälte- und Klimatechnischer Verein, Stuttgart, Germany.

Ziegler F. 1997. "Sorptionswärmepumpen", *Forschungsberichte des DKV Nr. 57, Habilitationsschrift*, Erding, Germany