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# Solar driven cold rooms for industrial cooling applications

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## Abstract

KRAMER GmbH, a German supplier for cold room construction, insulation technology and shopfitting with more than 80 years of company experience, and INDUSTRIAL SOLAR GmbH (ISG), a supplier of high-quality solar process heat systems for industrial applications, and the FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS (ISE) are currently developing a standard solar driven cold room for industrial cooling applications.

Within the recent EU co-funded project SOLERA, ISE and ISG had gathered experience in the successful operation of the solar cooling technology. Main components of the SOLERA demonstration system are a linear Fresnel collector providing the driving heat at temperatures up to 200 °C for two cascading ammonia water absorption chillers, which produce cold temperatures down to -12 °C, as well as ice storages for peak shifting.

In the current project AgroKühl, which is co-funded by the German Federal Ministry of Education and Research, a consortium of five partners, among them the company KRAMER GmbH and ISE, constructed a cold room, that will now be driven by a similar solar cooling system.

Further technical details, operation experience and measurement data from the SOLERA demonstration system in 2011 as well as a description of the new system will be presented in the paper.

*Keywords:* Solar cooling; fresnel; process cold; dry heat rejection; ice storage

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## 1. Solar driven cold rooms

Solar cooling, so far, has mostly been discussed with a focus on air conditioning, and until now, Industrial Solar's biggest collector installation is powering a 700 kW absorption chiller for the air conditioning of a showcase football stadium [1] in Qatar.

It is now the goal of an industry consortium of five partners, among them Kramer and ISE, to develop a solar driven cold room as an integrated turnkey system for a better provision of mainly agricultural but also other products in rural areas within the currently running national research project AgroKühl, which is co-funded by the German Federal Ministry of Education and Research. As a first step a small pilot system will be constructed in Germany, which shall be monitored but also serve as demonstration site.

The target area of the technology will be areas of mainly arid, hot and sunny climate. Because of the climatic conditions in the target area and the need of dry heat rejection, ammonia water chillers will be used. This type of chiller is also able to provide cooling temperatures below 0 °C. Basically all cold rooms are being operated round the clock, therefore ice storages provide a solution for adapting the daily solar power supply curve to a constant load profile and in the same time provide a good ratio of storage capacity per size as well as per cost.

Linear Fresnel collectors like the LF-11 from the company Industrial Solar GmbH provide the necessary hot driving temperatures at 180 °C with reasonably low heat losses.

## 2. Demonstration of the cooling technology in recent EU project SOLERA

In early 2011, a pilot solar cooling system with two cascading water ammonia chillers has been installed on the rooftop of the PSE workshop near Freiburg / Germany within the research project SOLERA, which was co-funded by the EU.

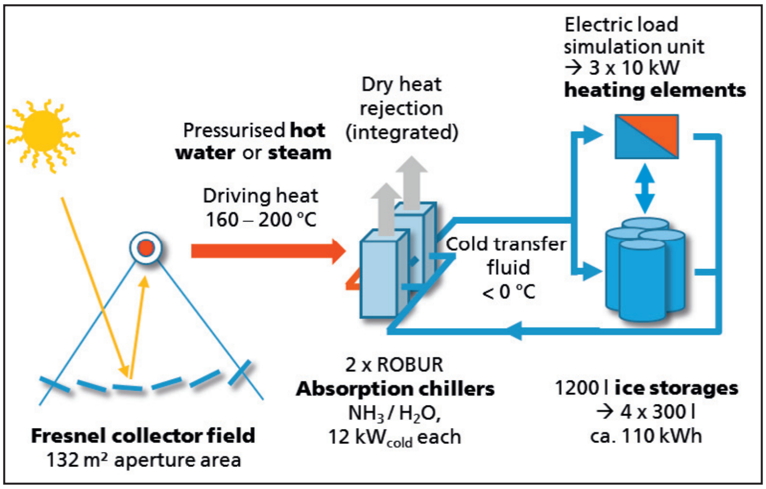

Fig. 1. The solar cooling demonstration system in Freiburg / Germany. The produced cold can be stored in ice storages or consumed by heating elements, which can be used to simulate user-defined load profiles. Source: © Fraunhofer ISE

A LF-11 linear Fresnel collector from the company Industrial Solar GmbH, consisting of six modules with a total aperture area of 132 m$^2$ was used in the system to heat pressurized water to an outlet temperature of 200 °C.

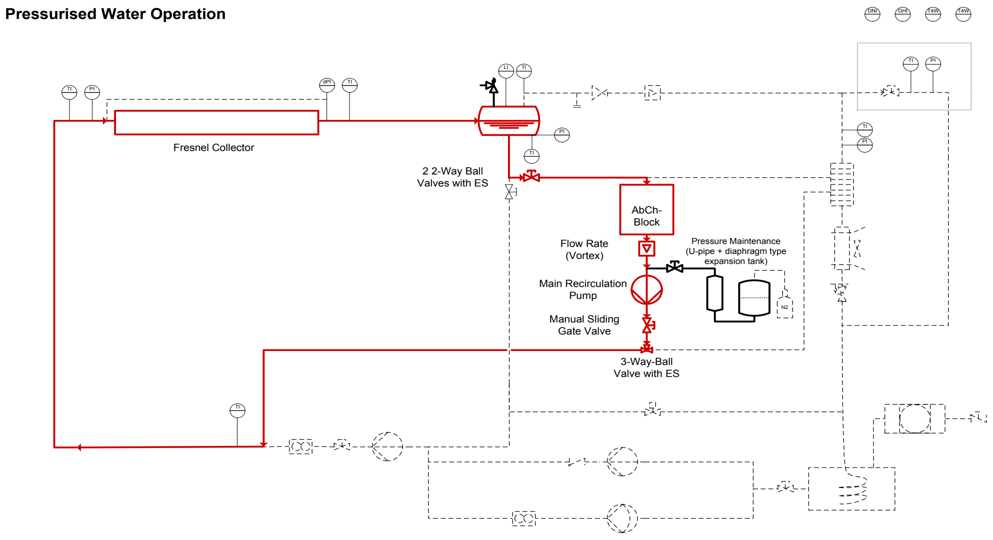

Fig. 2. P&ID of the hot water circuit in pressurized water mode

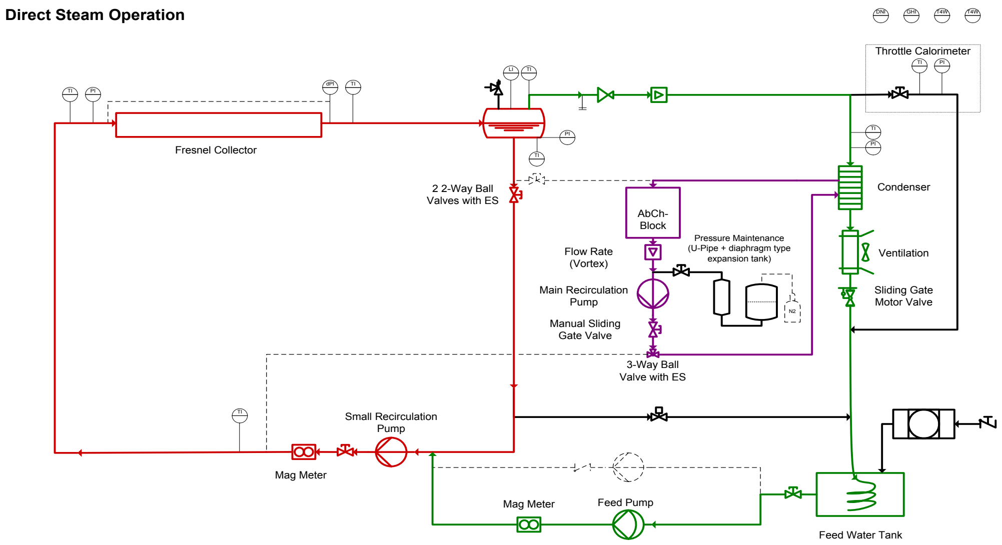

Fig. 3. P&ID of the hot water circuit in direct steam generation mode

Instead of one larger chiller, two smaller water ammonia absorption chillers with a rated thermal COP of 0.6 and total cooling power of 24 kW were chosen, to study part load behavior in cascaded operation. The system has been installed in a way to allow for pressurized water operation as well as for direct steam generation in the linear Fresnel collector. Since the water ammonia chiller cannot be operated with steam directly, a condenser is providing the condensation heat via a secondary hot water circuit, when the collector is running in direct steam generation. The hot water circuits are shown in a P&ID in Fig. 2 and Fig. 3. Three electric heaters were used on the cold side, to consume the produced cold with user-defined simulated load profiles. The four ice storages with a total water volume of 1200 l and a corresponding melting heat capacity of 110 kWh were used to enable peak shifting as well as to study the behavior of such latent heat storages in operation.

One of the goals was, to test the system under various conditions. Since commissioning in June 2011, the chillers have been operated on different temperature levels, and part load behavior has been tested with cascaded operation and without. Constant chiller driving temperatures have been tested at levels up to 200 °C. The COP of the chillers together with the chiller power rise with the temperature and reach rated values at an operating temperature of 200 °C. More interesting than constant driving temperatures, however, was finding out, that within a certain part load range, the combination of the chillers as heat sink and the collector as heat source adjusts itself to a stable equilibrium temperature. A rise in the collector power, like during the start-up in the morning, will cause a rise of system temperature and thereby cause a rise of the cooling power of the chillers along with the consumed driving power. When the chillers consume more power than the collector is able to provide, like in late afternoon, the system temperature will drop until the chiller power as heat sink has adjusted to the source.

This self-stabilization is limited by the maximum power of the chillers, of course. In case of the demonstration system in this project, the collector's peak power was higher than the maximum combined power of the two chillers. Therefore, when the collector operated in peak power, the temperature rose, until a pre-defined set-point was reached and the collector power had to be adjusted by controlling the active aperture area. Operated with pressurized water the collector has provided thermal power as expected (see Fig. 4). The temperature control worked within a range of ±0.5 K.

Fig. 4 shows as an example the results of September 21st. That day the collector had been operated with pressurized water and temperature control at 200 °C outlet temperature. At 12:30 the temperature set point is reached. At this time the collector provides 64 kW thermal power, as expected, with an efficiency of roughly 55 %, which is the expected value for autumn conditions at this time of the day. To keep the temperature constant, while the collector power had been higher than the power consumed by the chillers, several mirror rows were turned out of focus. The lime green curve in the figure is showing the active collector aperture area. The collector power (darker green line) was decreasing correspondingly, while the efficiency stayd at 55 %. The direct normal irradiation had been measured with a pyrheliometer and showed values of up to 900 W/m² until shortly after 2 p.m., when high clouds started to show and the DNI was becoming more fluctuating. In the afternoon, end losses caused by the small length of the demonstration collector decreased the collector power, so that the driving power of two chillers could not be provided. Therefore, one of two chillers has been shut down, the flow rate had been adjusted (grey curve) and the collector was used to drive one chiller.

Data evaluation of the cold circuit and the chiller performance has been carried out by ISE and was recently published [4]. Main results were, that the cooling output could be improved by cascaded operation and the rated COP of the chillers could be confirmed. The cold storage capacity was as expected, but the charging/discharging curve showed, that the heat transfer dropped very low during charging of the storages, as the ice layer built up around the heat exchanging surface. Conclusions may either be, to further decrease the charging temperature during the charging process, or what seems more reasonable, to use bigger ice storages and to use them only below a maximum charge level, that would have to be defined by economical optimization.

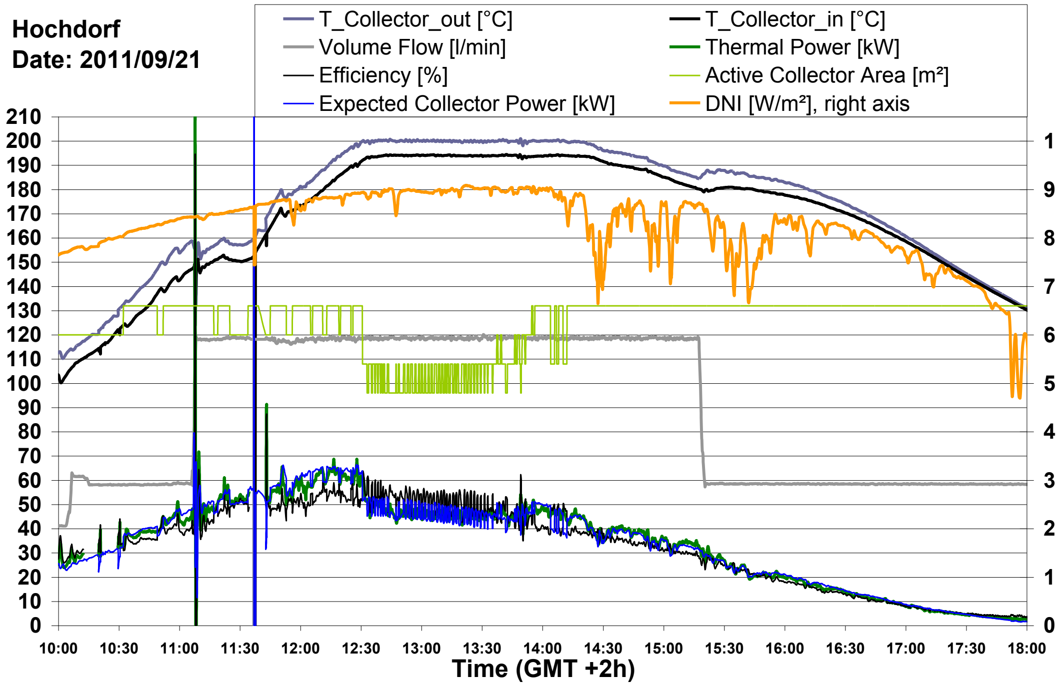

Fig. 4. Collector measurements with pressurized water on 2011/09/11.

Since the system has not yet been optimized for direct steam generation in this first step, the system losses were higher in this operation mode. Especially because of the non-pressurized, plastic feed water tank and the feed water pump, which was not designed for water temperatures above 60 °C, the condensate had to be cooled down below 100 °C and the feed water had a temperature below 60 °C. Therefore roughly 20 kW of the collector power were needed for preheating alone, so only one of the chillers could be operated stable with steam. However, it could be shown, that pressure control of the collector in direct steam generation mode is working. In the future, the feed water pump may be replaced by one, that is designed for higher temperatures and the tank may be replaced by a condensate tank, that does not require cooling of the condensate below 100 °C. Thereby the required preheating power for the feed water can be reduced and the steam production can be increased.

In 2012, after the end of the Solera project, ISE and Industrial Solar have decided to continue the measurements and thereby to gather more experience. The automated operation of the system will be optimized, control strategies in direct steam generation will be tested, and further measurement data will help to increase the understanding of such systems.

Fig. 5. The cold room in the atrium of the company area of Kramer GmbH in Freiburg-Umkirch (Germany). © Kramer GmbH

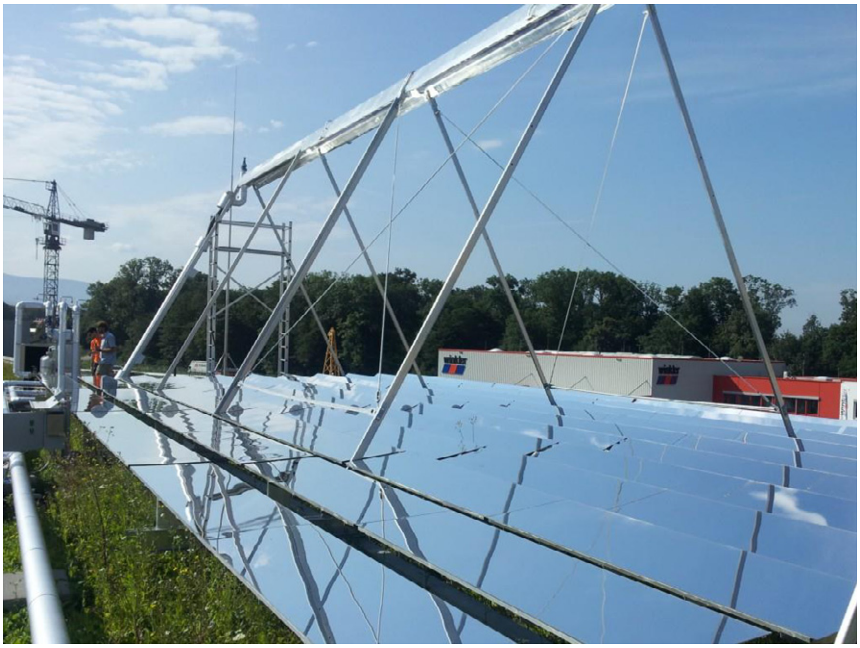

Fig. 6. July 5th, 2012: Commissioning of the new collector on the rooftop of the company Kramer GmbH in Freiburg-Umkirch (Germany). The collector is providing the driving heat for a ammonia water chiller, which cools down a cold room. Peak shifting is made possible by the use of ice storages.

## 3. Current project AgroKühl

Within a current KMUinnovative research project, in March 2012, a small linear Fresnel collector for a pilot system of a solar driven cold room has been installed at the office building of the company Kramer in Umkirch near Freiburg / Germany. For such cold rooms, process cold <0 °C must be provided.

The cold production technology is similar to the one of the Solera project. The cold room, as well as the balance of plant have been installed during June 2012, and commissioned could take place on July 5th, 2012 (see Fig. 5 and 6). The cold room with roughly 100 m³ of cooled volume has a dimension of roughly 8m x 4m x 3m (LxWxH), its walls consist of 120mm thick polyurethane sandwich elements, and the steel structure is completely outside. The cold room is being cooled by one 12 kW water ammonia chiller, driven by a Fresnel collector from Industrial Solar, consisting of four modules with a total aperture area of 88 m² at an operation temperature of 180 °C. The produced cold can be delivered to the cold room or the ice storage alternatively by use of a water glycol mix as heat carrier.

Within 2012 and 2013, the solar thermal driven cold room will be tested and monitored. The collector power is oversized for only one chiller for demonstration purposes, so that there will be more operation hours. The system, which is small for such cold rooms, will serve mainly for demonstration of the sustainable technology and help in leading to succeeding projects in the sunny target region. By developing an integrated as well as modular solution for solar thermal driven cold storages, the system shall serve as an example and help to decrease the effort of installation as well as engineering of such systems.

## 4. Outlook

The technology demonstrated leads the way towards an environmentally friendly and carbon neutral operation of cold rooms, which is an important step especially for agriculture and food industry in regions of sunny, hot climate. The complexity of solar cooling systems using absorption chillers has been seen as an obstacle at the market entry of industrial solar cooling. By providing turnkey solutions for solar cold rooms, that hurdle can be taken, thereby making industrial solar cooling more attractive.

If the collector circuit is being operated in steam generation or with pressurized water, is depending on the absorption chillers being used. For a Kawasaki triple effect chiller with a thermal COP of up to 1.9, steam generation is necessary. These chillers provide a high COP, but cannot provide cold below 0 °C and need wet heat rejection. The water ammonia chillers from Robur on the other hand require thermal oil or pressurized water operation.

## Acknowledgments

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