Solar Assisted Cooling and Heating with Multi-Stage Absorption Chiller

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Abstract

Resorting to commercially available components solar cooling installations are commonly based on hot water-driven single-effect absorption chillers. This configuration yields a considerable solar cooling performance, when solar heat is applied as driving heat source only. Yet in commercial installations requiring reliable supply of cooling with no regard to the current availability of solar driving heat, fossil fired boilers are applied as back-up heat source. In this case a rather poor utilisation of the driving heat is accomplished as measured by the exergetic content of the fossil driving heat.

For improved utilization of the fossil fuel serving as backup driving energy input for the absorption chiller an integrated double/single-effect chiller is applied. Solar driving heat is supplied to the conventional single-effect sub-cycle, whereas fossil back-up firing drives the double-effect stage of the chiller when indicated, allowing for a more efficient utilisation of the fossil energy.

During the transitional period the plant can serve for simultaneous cooling and heating. In the cold season the system operates as heat pump enhancing low temperature heat provided by the solar collectors or any other ambient heat source to useful heat. This concept offers higher efficiency of the chiller and results in lower primary energy consumption compared to a single effect chiller backed-up by conventionally produced heat using fossil fuels in a hot water boiler. By integration of the backup heating device into the absorption chiller no additional backup device is required and thus a reduction of the complexity of the overall system is achieved. Additionally, this energy system can also be operated self-sufficiently in heating mode. Ideally the machine functions as a heat pump using an ambient heat source like low temperature solar heat or ground water. If this ambient source is not available or not sufficient, the machine can be run in heat-pipe mode where the high temperature stage is used as a boiler vessel while the lower stage is not operating.

Currently a first pilot installation is under construction with commissioning in August 2010.

Keywords: absorption chiller, solar-assisted cooling, double-effect solar cooling, solar heat pump

1. Basic Concept

As mentioned introductorily, a pilot installation of a solar assisted cooling and heating energy system is under preparation. Figure 1 shows the schematic design of the system. The system consists of a standard hot water driven single-stage absorption chiller (with the working pair LiBr/H_2O) which is driven by solar heat at about 90 °C. In times of insufficient solar radiation and simultaneous chilled water demand the fossil backup-firing of the machine is operated. For the purpose of reliable backup-operation the absorption chiller comprises a topping stage containing a direct gas fired high temperature generator and a high temperature condenser. As in conventional double-effect cylces, the high temperature condenser provides driving heat for the low temperature generator (double effect) yielding increased efficiency in cold production (COP[1]) as compared to simple single-stage devices. At the same temperature level solar heat can be used simultaneously as driving heat input for the low temperature generator. In total a so-called Double-Effect/Single-Effect cycle (DE/SE) is formed.

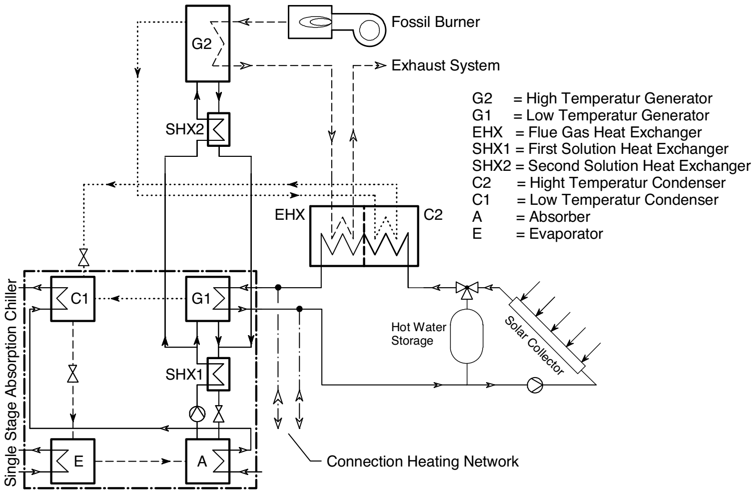

Figure 1: Schematic design of the solar assisted absorption cooling / heating energy system

This concept offers higher efficiency of the chiller and results in lower primary energy consumption compared to a single effect chiller backed-up by conventionally produced heat using fossil fuels in a hot water boiler. By integration of the backup heating device into the absorption chiller no additional backup device is required and thus a reduction of the complexity of the overall system is achieved. Additionally, this energy system can also be operated self-sufficiently in heating mode. Ideally the machine functions as a heat pump using an ambient heat source like low temperature solar heat or ground water. If this ambient source is not available or not sufficient, the machine can be run in heat-pipe mode where the high temperature stage is used as a boiler vessel while the lower stage is not operating.

[1] COP = Coefficient of Performance = Ratio of chilled water capacity to driving heat capacity.

2. System concept – different operational modes

The system is installed in an office building for the provision of both cooling and heating. It is adapted to local conditions which allow maximum flexibility in using this energy system. The primary objective in this installation is solar cooling. The system is designed to cover about 65% of the yearly demand or maximum load in cooling, exclusively using solar heat as a renewable energy source. The solar collector area and the size of the single-stage absorption chiller are dimensioned to comply with these boundary conditions. On basis of a commercially available single-stage chiller a DE/SE plant has been designed which covers the maximum cooling load (chilled water) in "mixed mode" operation with driving heat input from the solar system and the fossil co-firing. For that purpose the cycle has been equipped by an additional solution pump and controls forming a para-flow double-effect sub-system.

The high temperature stage is equipped with a low-radiation surface natural gas burner which delivers a hot flue gas whose heat is transferred into the high temperature generator (G2). The generated refrigerant vapour condenses in the high temperature condenser (C2) which is cooled by the heat carrier collecting solar heat from the solar panels. This hot water is then supplied to the low temperature generator (G1) contributing to the chiller's generation of refrigerant vapour. A water heat storage tank is installed in this hot water loop to buffer excess solar heat in times of low or no cooling demand.

For the transfer of reject heat of the absorption chiller (absorber A0 and condenser C1) to the ambient at a temperature level of about 40 °C a dry air cooler installed on the roof of the building. The relatively high coolant temperatures are tolerable due to the moderate temperature level of the chilled water of about 15 °C. The temperature of the hot water driving the single-effect sub-cycle is about 90°C. These conditions allow for efficient cooling of the building by means of radiative cooling via activated ceilings without dehumidification of the indoor air.

An existing ground water well which delivers all-year constant temperatures of about 10-12 °C can be either used for backup cooling in unlikely cases of dysfunction of the absorption chiller or as an ambient heat source in heat pump mode.

The following schemes show the four dominant operational modes: exclusively solar cooling, mixed (solar/–fossil) cooling, solar heating in the transition periods (spring and autumn), and finally fossil heat pump mode.

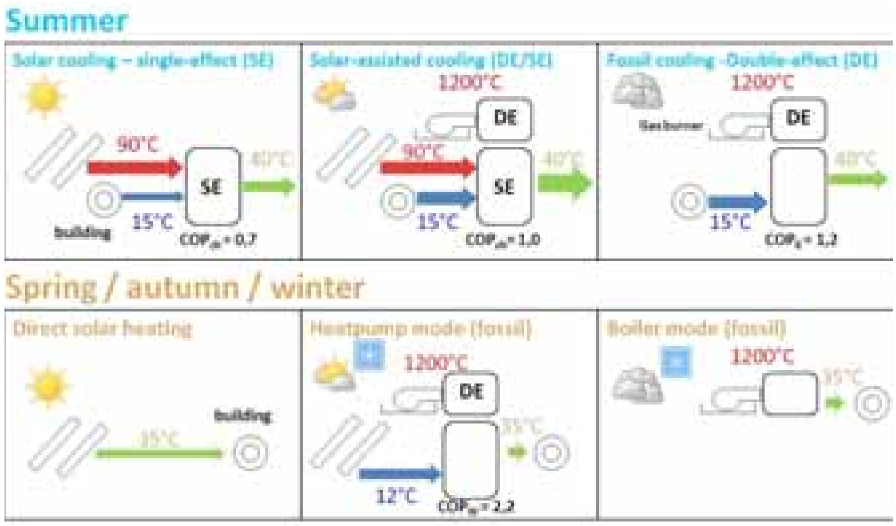

Figure 2: Different operational modes of the energy system

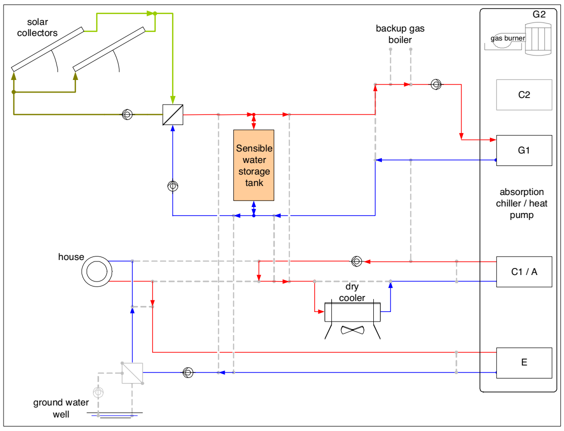

Figure 3 Exclusively solar cooling

In this operational mode the whole chilled water capacity is delivered by using solar heat only. Only the single-stage absorption chiller is in operation.

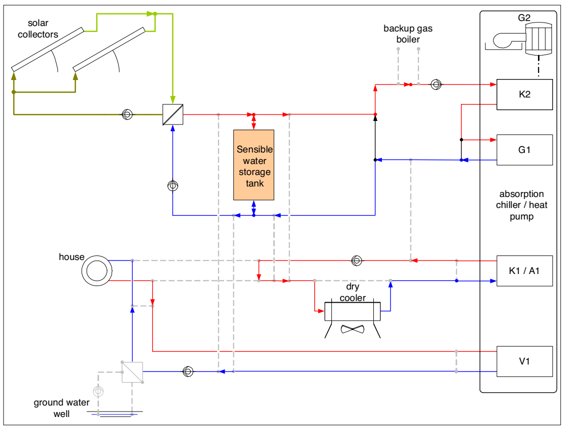

Figure 4 Mixed (solar/fossil) cooling: Solar cooling with fossil backup heat

In case of low or insufficient solar radiation the machine can either be operated in pure fossil mode where the absorption chiller works in double-effect mode or in mixed double/single-effect mode with simultaneous usage of solar and fossil heat.

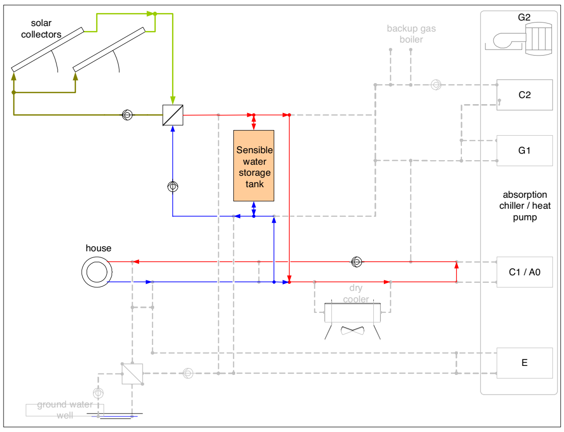

Figure 5 Solar heating

In transition times the solar panels can be used to deliver energy to heat the building. The ceilings being used for cooling are also used as heaters. As they are dimensioned for radiative heat transfer a rather large activated area is installed, facilitating operation at comparatively low supply temperatures (~ 35°C). These temperatures are easily reached in solar heating mode. Thus, a rather high solar fraction (close to 100%) is expected.

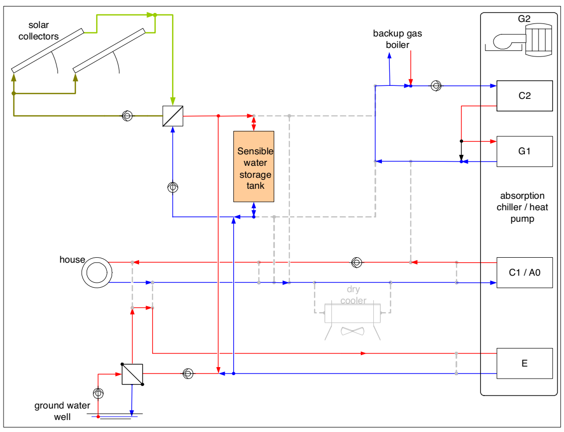

Figure 6 Fossil heat pump mode

In seasons where solar radiation is too low to gain sufficient heating energy from the solar panels it is necessary to apply fossil fuels. In this case the two-stage absorption chiller can be used as a heat pump lifting ambient heat from about 10 °C to heating temperatures of about 35 °C. The solar heat can be used as ambient heat source as well as the ground water from the well. Substantial primary energy saving is reached in comparison to fossil hot water boiler usage.

3. System Design Data

Location of installation:

Lindner AG, Arnstorf, Germany 48° 34′ N, 12°49′ °E

Coolig and heating of an office building

Solar loop:

- 120 solar thermal flat panels, total area 300 m², orientation south, 10° east, collector slope 35°
- Nominal capacity 90 kW. peak performance 150 kW @ 90°C

Heat storages:

- Sensible water storage tank (17 m³), specific storage volume: 57 l/m² collector area
- Latent heat storage (PCM, calcium chloride hexahydrate, melting point @ ~29°C), storage capacity 180 kWh with maximum storage load 40 kW.

Absorption chiller/heatpump:

- Integrated gas/solar-driven double/single effect absorption chiller (Water / LiBr)
- Nominal chilled water / heating capacities
  - Cooling: 90 kW chilled water max, 60 kW chilled water single-effect cooling (COP 0,7..1,2)
  - Heating: 160 kW useful heat (COP 1,2)
- Nominal temperature levels (cooling / heating):
  - Chilled water loop (18/15 °C / 12/6 °C)
  - (Reject) heat loop (36/42 °C / 30 / 38 °C)
  - Hot water loop (70..90 / 60..80°C / -)
  - Gas firing (1300 °C / 200 °C, natural gas, combustion air ratio 1,5), Burner capacity 75 kW

Flue gas heat exchanger:

The flue gas heat exchanger uses the remaining useful heat of the fluegas leaving the high temperature generator (G2, approx. 200°C) and transfers it either to the solar hot water loop (90 °C) in cooling operation or to the return of the heating loop in heating mode (30 °C) where it additionally transfers the latent heat of evaporation of the water vapour in the fluegas by condensing (usage of upper heating value of the natural gas). This heat exchanger improves the efficiency of the system significantly as up to 15 kW which are approx. 20 % of gas input capacity, can be used additionally in heating mode.

Cooling tower:

- Dry cooling tower
- Capacity 200 kW at ambient temperature of 32 °C.

Monitoring system

There will be meticulous measurement of all relevant temperatures, flow rates, capacities and electrical consumers; o the 3rd level of monitoring procedure for solar-cooling systems of IEA SHC Task 38 is reached and a comprehensive energetic analysis of the energy system is possible.

Conclusion and outlook

An integrated Double-Effect/Single-Effect chiller for solar cooling with fossil backup-firing is being developed and implemented in a pilot installation in Bavaria. Based on a conventional single-stage cycle, complemented by a direct gas-fired high-temperature regenerator, a pilot plant has been designed. Utilization of the driving heat supplied by a fossil burner in the topping-stage of the cycle assures improved energy efficiency compared to conventional solar cooling installations.
A detailed modelling of the system performance is under preparation. Validation of the theoretic predictions by operational results of the pilot installation is expected for summer 2010.