

SUSTAINABLE HEATING AND COOLING WITH SOLAR-POWERED DIFFUSION - ABSORPTION TECHNIQUE WITH EARTH HEAT EXCHANGERS

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Abstract: Earth heat exchangers in combination with reversible electrical heat pumps are regularly used for air-conditioning of recent low-energy buildings. At the University of Applied Sciences in Stuttgart, the exchange of the electrical heat pump by a thermal powered diffusion-absorption machine with a nominal cooling power of 3.5 kW and heating power of 7.5 kW is investigated. The driving energy is supplied by solar power, in the wintertime assisted by an auxiliary heater. Two earth heat exchangers with a length of 80 m each can be used for direct cooling of the building during summertime as well as for removal of heat from the condenser / absorber of the machine. During wintertime this energy can be retracted from the ground for heating purposes. The projected saving of primary energy is 56%.

Key Words: *Geothermal heating and cooling, earth heat exchanger, diffusion-absorption heating and cooling*

1 INTRODUCTION

To establish a comfortable room climate is one of the main targets of the modern building construction. On the one hand in the middle European climate the heating of the building is the main interest, on the other hand the demand of air-conditioning is continuously increasing. Since the earth heat is free of charge, direct use for cooling or coupled operation with a heat pump/cooling machine is interesting. Absorption cooling machines with a small power level are not yet on the market. The target of the present project is the development of a thermal heating and cooling system for buildings with the utilization of solar and geothermal energy. The combination of these technologies promises low emission- and low noise air-conditioning of buildings with low cost. Furthermore in comparison to conventional compression heat pumps the above mentioned technology is expected to promote substantial saving of primary energy as well as reduction in CO₂-Emission. For a residential building, which has a maximal heating load of 7.5 kW and a cooling load of 2.5 kW giving an annual heating and cooling consumption of 13,500 kWh and 1,750 kWh respectively, the reduction of primary energy is estimated in comparison with electrical heat pumps / cooling machines. Assuming a 100 % solar energy supply for cooling and 20 % supply for the heating system the saving of primary energy is 56 % annually.

As an energetically advantageous solution the thermal Diffusion-Absorption heat pumps / -cooling machine (DACM) can be applied instead of the typical electrical heat pumps. During summer and partially during winter the heat can be almost completely generated by the thermal solar collectors. In summer the earth heat exchangers can favourably supply energy either directly for the air-conditioning of the building or for removing the heat from condenser / absorber at a low temperature level. The efficiency of the thermal cooling machine is then higher than that of the conventional wet cooling tower. In winter period the energy will be

withdrawn from the ground and utilized for heating of the buildings. If the Diffusion-Absorption Cooling Machine (DACM) is used as a heat pump in winter, an optimal system combination can be achieved. The projected range of performance of the test plant is approximately 3.5 kW refrigerating capacity with coefficient of performance (COP) of 0.5 and 7.5 kW heating capacity with a COP of 1.5.

The following figures show the system sketch of the planned plant in heating and cooling operation.

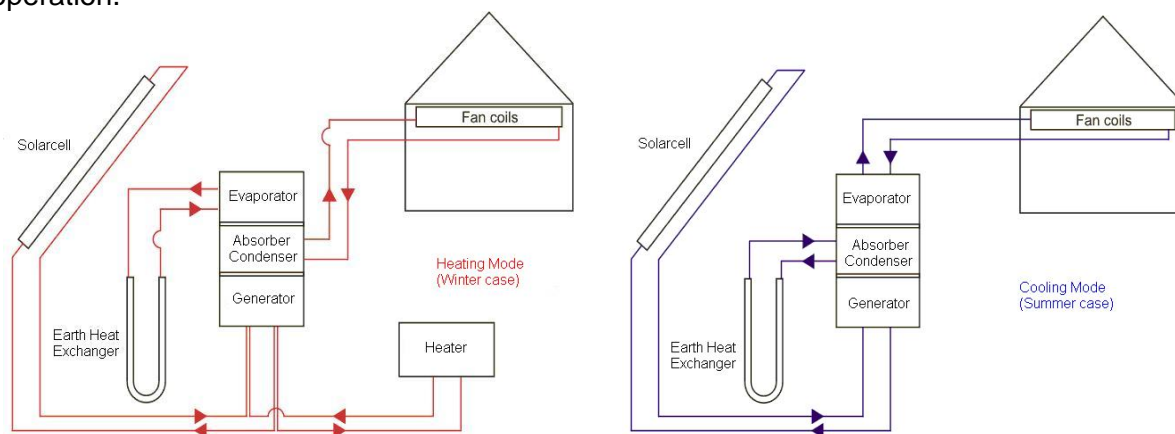


Figure 1: Sketch of the planned plant in heating and cooling operation

2 DIFFUSION-ABSORPTION HEAT PUMP / -COOLING MACHINE

The thermal diffusion-absorption cooling machine based on ammonia–water is presently commercially deployed only with small range of performance (up to approx. 100 W) in which the preferential criteria are absolute low noise level (refrigerators for hotel) and independence from the energy supply (camping gas refrigerators). The cooling machines with simple mechanical construction demonstrate low performance and high energy demand. For heat pump applications for a house or apartment building, thermal cooling aggregates with a low to middle range of performance are at the present limitedly available.

For the present project a Diffusion-Absorption Cooling Machine developed at the HFT Stuttgart has been modified. The focal points are developing the hydraulic system as well as simulation of groundwater influences. Until now the prototypes were exclusively designated and developed for the solar thermal cooling production. In contrast to the pure cooling mode where the systems are fixed to the periphery, the combined operation mode demands switchable interfaces. In cooling case the evaporator of DACM is directly connected to a fan coil or other heat and cold distribution equipment; the condensation heat and the absorption heat from DACM will be conducted into the ground. On the other way round in heating mode the evaporator gains the energy from the earth heat exchanger; the condensation and absorption heat will be used for space heating via the fan coil.

In the first stage the influence of the earth heat exchangers on the operating performance of the combined solar heating and cooling / geothermal plant will be investigated with a focus on performance and annual efficiency parameters.

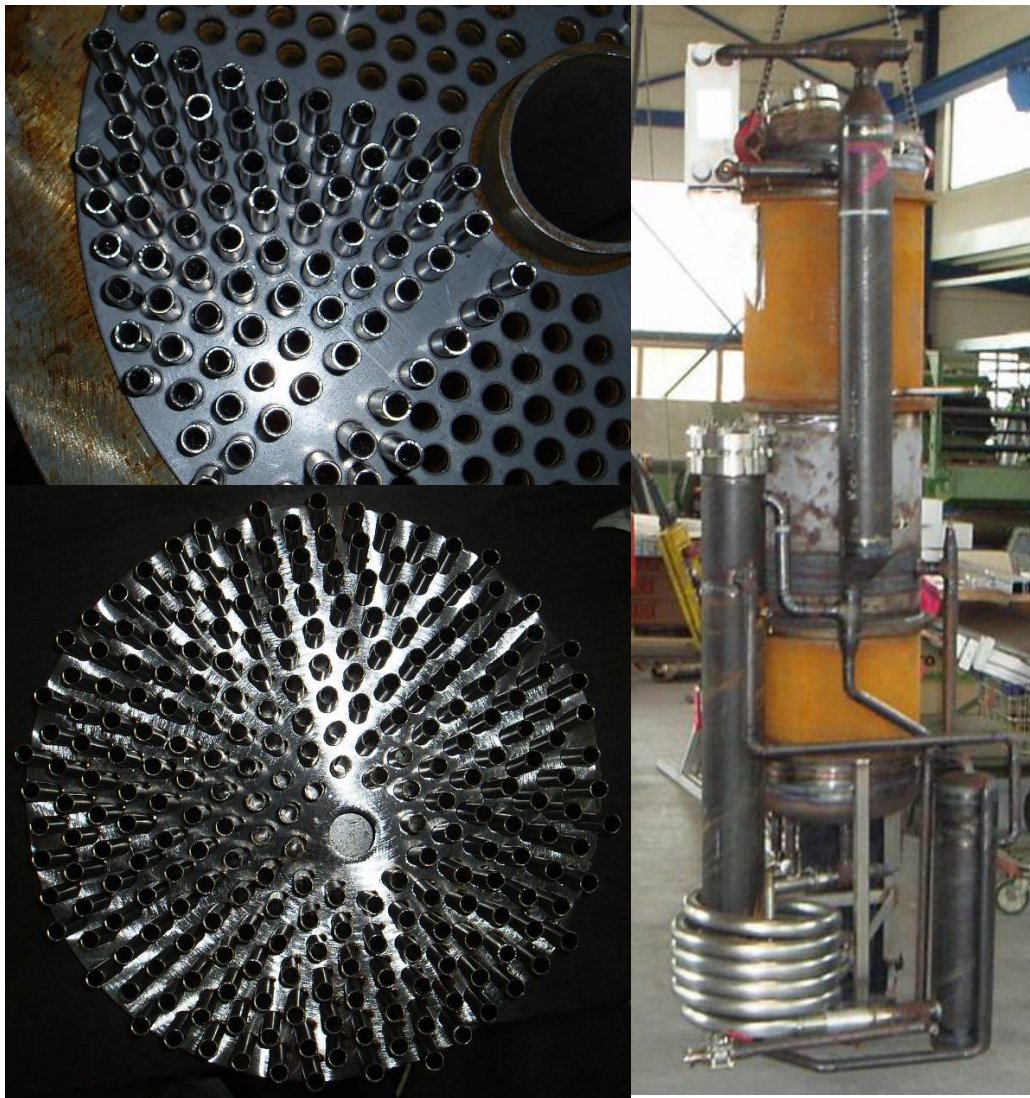


Figure 2: Component parts of DACM and completed prototype

Figure 3 illustrates the results of temperature measurement from DACM and the power at each part of DACM as well as the heating capacity. The temperature was measured at the input and output of generator, condenser, absorber and evaporator. The power at absorber, condenser and evaporator and the heating capacity were calculated later on.

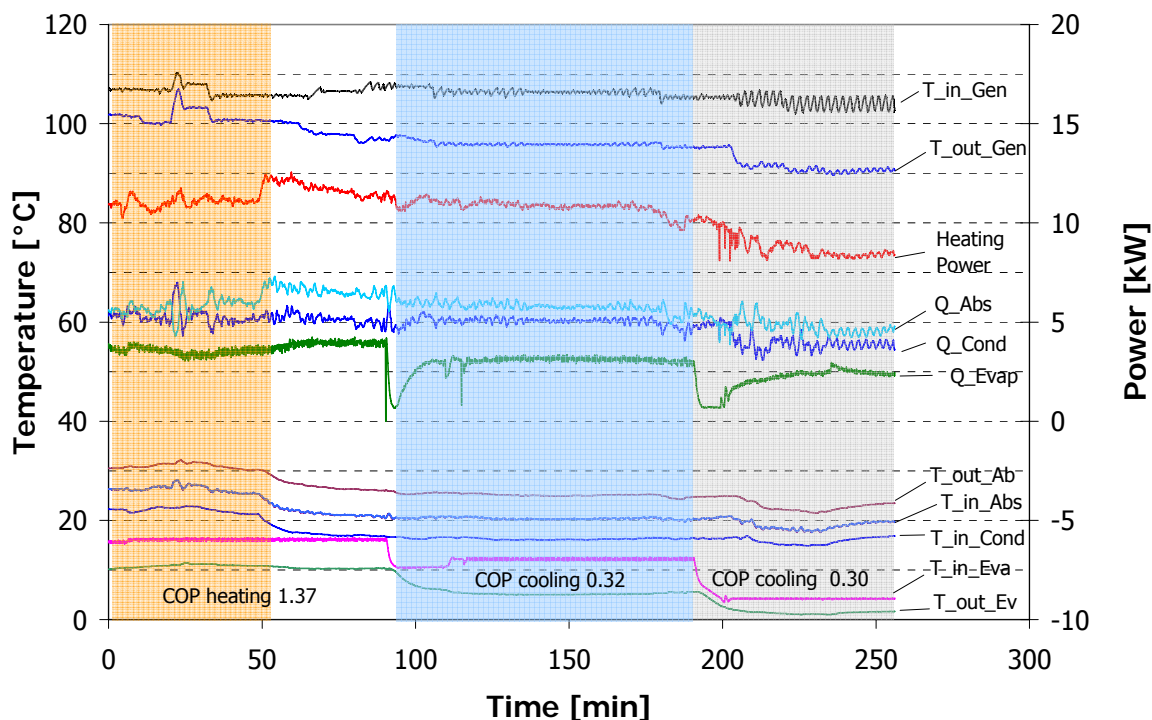


Figure 3: Results of temperature measurement from DACM and heating capacity

The figure is divided into three sections. The first 50 min. represent the heating mode with a COP of 1.37. A heating power of 11 kW was achieved at a temperature level, which can be used for floor heating.

The second and third section represents the cooling mode with a COP of 0.32 and 0.3 respectively. From minute 90 to 190 the DACM was operated at standard cooling temperatures of 6 to 12°C, which are suitable for heat exchangers in air-conditioning devices. From minute 190 on the DACM was operated at even lower temperatures of 1 to 4°C.

3 GEOTHERMAL ENERGY

After obtaining the drilling approval for the boreholes for the earth heat exchangers from the office for the environment, city Stuttgart and the building authorities of University of Stuttgart in July 2007, two heat exchangers with a length of 80 m each were constructed.

To be able to investigate the influence of the refill material of the borehole (backfill) on the performance of the earth heat exchange the two heat exchangers were filled with different material. One was filled with standard backfill with a heat conductivity of $1.6 \text{ W m}^{-1} \text{ K}^{-1}$ and the other with Stuewatherm backfill with a heat conductivity of $2.0 \text{ W m}^{-1} \text{ K}^{-1}$. The borehole heat exchangers are tested with a thermal power of 3 kW. The heat conductivities of the complete system (tube, backfill and surrounding soil), as derived from the thermal response tests, are $1.94 \text{ W m}^{-1} \text{ K}^{-1}$ and $2.17 \text{ W m}^{-1} \text{ K}^{-1}$ respectively. The use of high performance backfill leads to a 12% higher total heat conductivity. The thermal response tests are also simulated by means of the before mentioned numerical model. The results are shown in figure 5.

The numerical simulation model of the earth heat exchangers in the ground has been developed at the HFT Stuttgart. The aims of this development are to simulate the conductive heat transport between the heat exchangers and rock matrix and also the convective heat transfer between the fluid in heat exchanger and the heat exchanger conduit. The model

serves for two purposes; the first is the possibility to dimension the earth heat exchangers and the second is to connect this model to the existing solar cooling model with the controlling and regulating concept for the whole plant.

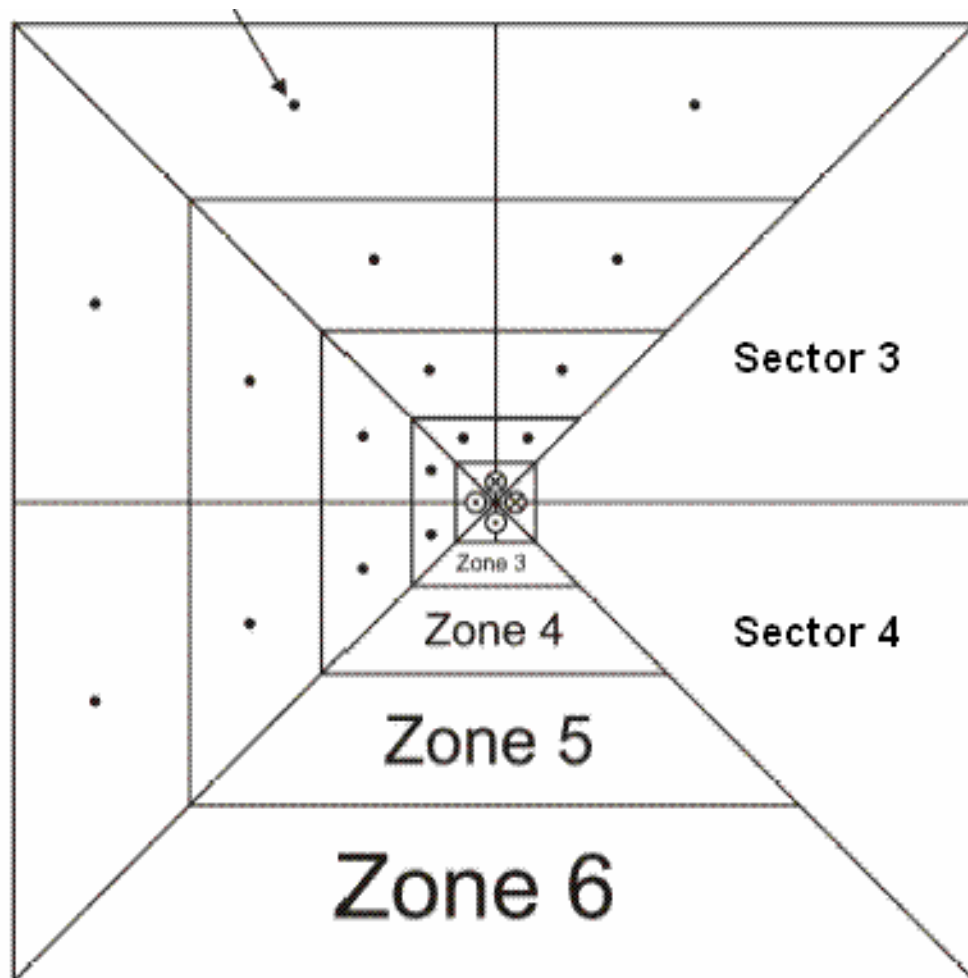


Figure 4: Geometry of the earth heat exchanger model in horizontal cross section

Within the model each of the double-U-shaped heat exchangers and the ground are discretised into polygonal 3D elements (see figure 4). There are eight clockwise ordered sectors and six radially partitioned zones. The conduits of the heat exchanger are in zone 1; the refill material of the bore hole is in zone 2, close- and far range ambient ground are in zone 3 to 6. According to the temperature gradient the width of the zone is increased with increasing distance to the centre.

It was designed to discrete the ground vertically into 80 elements. For a better and more accurate simulation it is possible to refine the grid, but the aforementioned geometry offers the ideal compromise taking accuracy and calculation time into account.

The heat exchange of all elements i.e. of heat exchanger conduits, of refill material of borehole and of ground are considered with the neighbouring elements both horizontal- and vertical direction. Since it is possible to set up the heat exchanger model next to each other and to adjust the dimension, it is possible to model a combination the preferential series of the earth heat exchanger is feasible. The edge of the model is assumed to be isotherm and has undisturbed ground temperature. It can be simplified since the temperature gradient in the far range of the earth heat exchanger is extremely small. The input parameters for the

calculation are the thermal ground parameters, the flow temperature of brine as well as the volume rate. Furthermore the flow rate and the groundwater temperature are required. As the results the temperature of the re-circulate brine and the thermal efficiency in dependent of the time are measured.

In order to examine the simulation model, the thermal response tests were numerical simulated. The results were satisfying. Figure 5 illustrates the measured values and the simulation results of the earth heat exchanger 1 and 2 (HX1 and HX2).

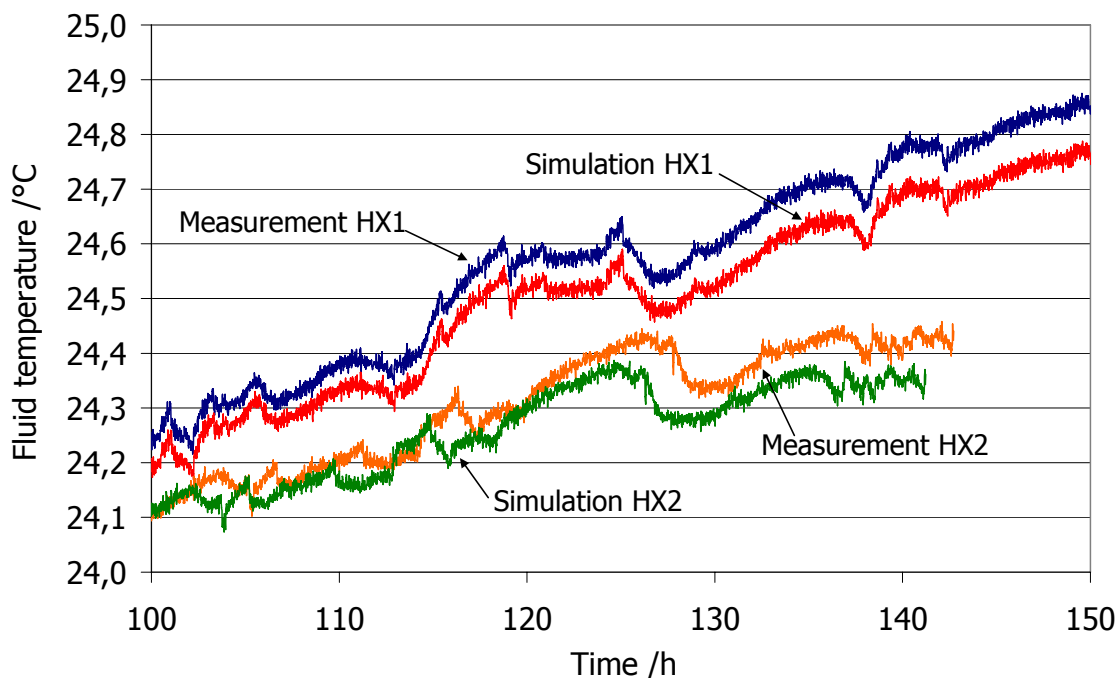


Figure 5: Results of the Thermal Response Tests

4 CONCLUSIONS

In the work, a heating and cooling system with solar thermal and low depth geothermal energy supply for residential buildings has been developed and implemented in a first prototype system. Heating and cooling is provided using a diffusion absorption system with a heating power of 7.5 kW and a cooling power of 3.5 kW maximum. The machine is connected to two ground heat exchangers with 80 m depth each. Thermal response tests have been carried out for two different borehole materials with 25% difference in heat conductivity. The effective ground heat conductivity increases by 12%. First measurements were done on the diffusion absorption machine. The design heating and cooling power could be obtained and very low cooling water temperatures were achieved at reasonable COP's around 0.3-0.4. In heat pump mode the COP's measured were about 1.4. The system has a high potential for substantial CO₂ reductions especially for combined heating and cooling operation.

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