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# A Desiccant Assisted Air Conditioning System with Use of Geothermal Energy

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## ABSTRACT

During summer, the use of conventional electrically driven air conditioning systems often results in high electricity consumption. On the other hand, heat demand is very low, so heat from solar collectors or from Combined Heat and Power plants (CHP) cannot be used. Thermal driven desiccant assisted air conditioning systems offer the possibility to shift energy requirements from electricity to heat. Furthermore, as sorptive pre-drying air does not require cooling under the dew point for dehumidifying or any subsequent heating, cold sources at higher temperatures (e.g. 18°C) can be used for cooling (e.g. shallow geothermal energy).

A research project from the Hamburg University of Technology combines a desiccant assisted air conditioning system with shallow geothermal energy. The geothermal system comprises 3 boreholes and 5 energy piles and supplies the cooling energy for the air conditioning system. The authors regard the two systems as a whole and focus on the combination as well as the interaction between them. The study and the numerically simulation of the heat injection rate of ground source heat exchanger and the air-cooling in rooms are part of the research. It is found that the combination of desiccant wheels and earth energy systems yields considerable energy savings compared to conventional electric systems. Furthermore, a combination with solar thermal energy allows a sustainable air conditioning system.

## 1. INTRODUCTION

Due to the Energy Savings Ordinance for Buildings in Germany, the heat demand of new buildings has been drastically reduced in the past years. As a result of better housing insulation to meet the low energy standards, high inner and outer sensible loads in summer lead to room temperature peaks. This causes in an increasing demand for air conditioning systems even in milder climate zones with a maximum allowable conditions in the building of 26°C and 50% relative humidity.

In conventional air conditioning systems, outside air is usually cooled below the dew point of about 12°C for dehumidifying and is subsequently heated to a desired supply temperature. Condensing out water from the air requires a large cooling capacity, which is often provided by electric compression chillers. Hence, conventional air conditioning leads to high electricity consumption. In a desiccant assisted system, moist air is first dehumidified by means of a desiccant wheel, as shown in **Figure 1**.

The wheel consists of a honeycomb structure which is coated with desiccant materials like silica gel or lithium chloride. Water vapor is absorbed by desiccant material as humid air passes through the wheel. If the desiccant is regenerated by heating, the moisture is released. As the heat of condensation and sorption is discharged, the air temperature rises and is subsequently pre-cooled in a heat recovery unit (Figure 2 and 3).

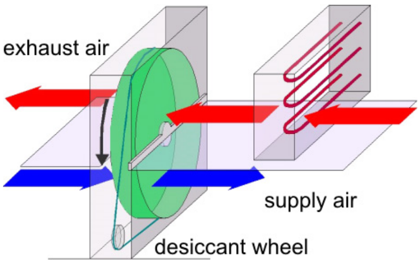


**Figure 1: Desiccant wheel for dehumidification.**

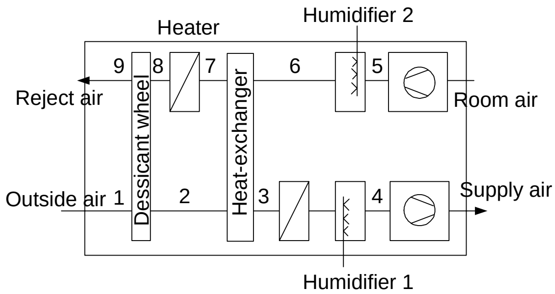


**Figure 2: Scheme of a DEC-system.**

In the air conditioning cycles of a DEC - system (Desiccant Evaporative Cooling), final temperature reduction is usually accomplished by injecting water into the air stream using evaporative coolers (see **Figure 2**). Despite the fact that a compression chiller is not necessary for such systems and their electricity requirements are very low, they are not widely accepted in the European market. Some disadvantages are high investment costs, difficult control and poor dynamic properties, since cooling capacity is limited by air humidity. Furthermore, the use of potable water is a drawback in the view of environment protection. However, for the proposed system in this paper, no water evaporation takes place. Air is cooled by passing it through a conventional cooling coil instead. This “hybrid system” has been investigated in several studies. Unlike conventional systems, air passing through the coil does not need to be cooled below the dew point for dehumidifying or be subsequently reheated. Therefore, instead of conventional chillers, other cold sources such as borehole heat exchangers at higher temperatures (e.g. 18°C) may be utilized. Heat input at relatively low temperatures (e.g. 60-70°C) is needed to regenerate the desiccant wheel, depending on the desiccant material. Due to desiccant technique, cooling demand can be reduced to 30% of the demand of a conventional system. Energy demand for air conditioning is shifted from electricity to thermal energy, while primary energy consumption is also reduced (Casas, 2005).

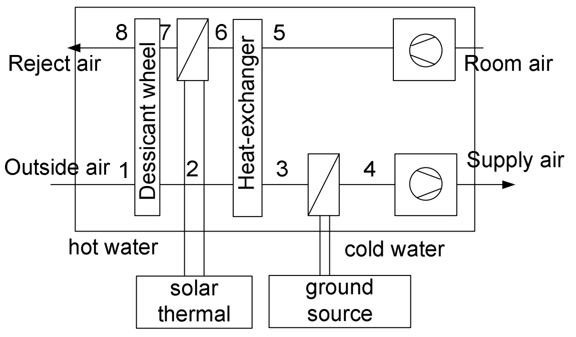


**Figure 3: Scheme of the hybrid system.**

## 2. SYSTEM DESCRIPTION

A research project from the Hamburg University of Technology combines a hybrid system with shallow geothermal energy. The geothermal system comprises of 3 boreholes and 5 energy piles and works as a heat sink for the air conditioning system in the summer case and as heat source in the winter case. Each borehole has a depth of around 75 m, and the energy piles have depths of around 14 m. The combination scheme of the air conditioning system and the geothermal system is shown in **Figure 4**.

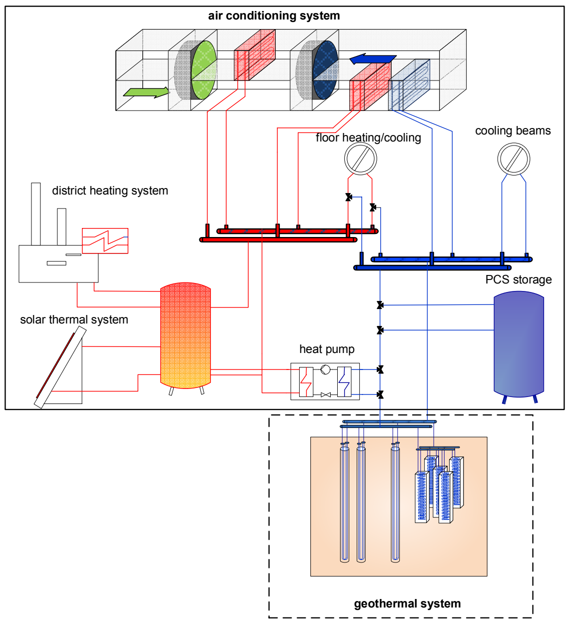


**Figure 4: Scheme of the air conditioning system combined with the geothermal system.**

The air conditioning and geothermal systems are connected by hydraulic switches (**Figure 9**). There is no extra heat exchanger between the systems, and they lead heat transfer medium into and then extract it from the switch. This means the whole system uses the same heat transfer medium, which is a mixture of water and ethylene glycol (20 Vol.-%). The hydraulic switches make it possible, that the two systems can run hydraulic independently.

### 2.1 Air Conditioning System

2.1.1 Thermodynamic Basics of the Hybrid System

The scheme of the air conditioning system is shown in **Figure 3**. The thermodynamic process is illustrated on the psychometric chart in **Figure 5**. Outside air (1) is first dried in the desiccant wheel. The pre-dried air (2) is cooled by passing it through the rotating heat exchanger followed by a supplemental cooling in a water/air heat exchanger (3). As the air does not require cooling under the dew point for dehumidification, cold sources at higher temperatures (e.g. 18°C) can be used for cooling (e.g. shallow geothermal energy).

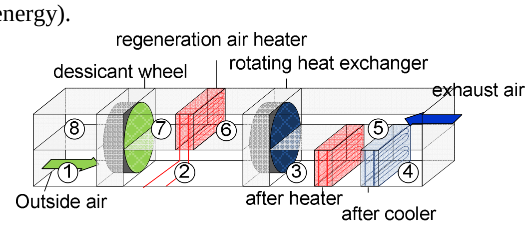


**Figure 5: Scheme of the air conditioning system**

The process uses the warm, dry air after the drying process (2) to preheat the exhaust air (5) in a rotating heat exchanger, because the regeneration of the desiccant wheel requires a temperature level of around 60°C. Additionally, the preheated exhaust air (6) must be heated by a different heat source (e.g. solar thermal energy). The warm regeneration air (7) carries moisture from the desiccant wheel to the surroundings. This process regenerates the desiccant wheel.

For comparison, **Figure 6** also shows a conventional air conditioning process with dehumidification by cooling below the dew point (2*) and the subsequent heating to the supply air temperature (4). The enthalpy difference between 1-2* and 3-4 represents the reduction in cooling demand when using a desiccant system.

2.1.2 Development of the Air Conditioning System

It has been shown in several studies that the combination of a hybrid system and a geothermal system can lead to significant primary energy reduction in comparison to conventional air conditioning systems. Anyway, the combination of an air conditioning system and a geothermal energy system needs further studies. On the one hand, a geothermal heat sink has to be well planed and controlled to provide a constant temperature level to control the supply air temperature. On the other hand, the air conditioning system has to prepare the air for using it with a geothermal heat sink (e.g. pre-drying).

Therefore, the research project is divided into two parts: the design and development of the air conditioning system and that of the geothermal energy system.

The equipment for air conditioning system including technical installations is placed in two 20’ construction containers. Other four 20’ office containers simulate an office, which will be supplied with the air conditioning system. The office containers were constructed to meet the standard of the German regulation for energy saving in buildings and building systems. At the south side of the office containers, 6 windows were placed to increase the heat load during summer time (see **Figure 7**). The U-Values of the windows are $U$=1,1 W/(m2•K). The container is insulated by $s$=100 mm mineral rock wool at the surrounding areas.

The air conditioning system with the usage of shallow geothermal energy is planned for the summer as well as for the winter case.

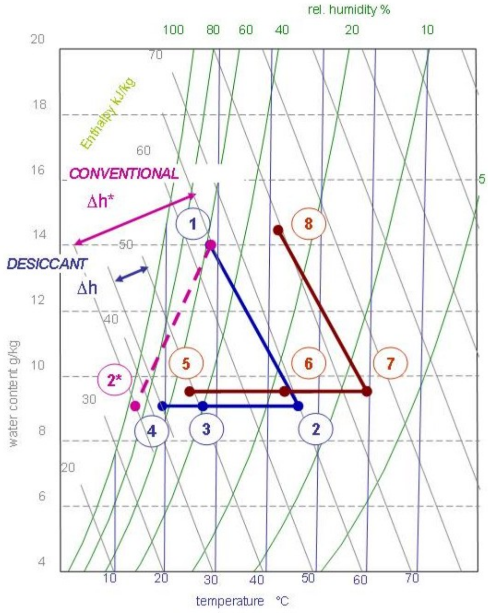


**Figure 6: Thermodynamic processes of the air conditioning system.**

Due to the dry supply air, other cooling systems such as ground floor cooling or cooling beams can be used. Within the described office building, both systems were integrated. The ceiling contains four cooling beams, each with a size of 4 m*0.84 m. Additionally a floor heating/cooling system was placed at ground level. The cooling beams and the ground floor cooling system are directly connected to the geothermal energy system by hydraulic switches.

The heating system is supplied by several heat sources as a solar thermal system, a district heating system and a heat pump. The combination of a natural geothermal heat sink and e.g. a solar thermal system allows an air conditioning system based on renewable energy systems.

2.1.3 Description of the Air Conditioning System

The office area has a base area of 57.5 m² and a total height of 2.5 m. The total volume of the office area is 144 m³. The air conditioning system has a designed supply air flow rate of 1100 m³/h, which can be increased to a maximum of 1600 m³/h.

The solar energy system has a total area of 20 m² and is oriented directly to the south. The solar collectors are tilted at the angle of 45° and series connected in a group of 4 panels (see **Figure 7)**

Beside, the air conditioning system includes a district heating connection as high temperature source (~75 °C) and a conventional heat pump for low temperature sources (~35°C). The district heating system is used as backup system for the summer case and the heat pump is used for the radiant heating in the winter case as well as backup for the summer case.

The heat sources are connected to 1000 liter stratified heat storage. The cold sources are only used in the summer case and connected to a 1 m³ PCS (Phase Change Slurry) storage tank. Using a PCM-storage the geothermal energy system can be downsized.

Additionally, the heat pump can be used in the summer case. Connected to the supply flow of the hybrid system, the heat pump can after-cool the heat transfer medium coming from the earth. The combination of heat pump and natural cooling for the summer and the winter case, combined with a hybrid system opens a new market for geotechnics and building service engineering.

### 2.2 Geothermal Energy

2.2.1 Basics of Soil Heat Exchangers

Measurements at the test site show that the underground and groundwater temperatures from a depth of 10m under the ground surface are constantly between 11°C and 13°C (**Figure 8**). As this temperature is relatively stable throughout the year, it gives rise to the opportunity of heat discharge and extraction for environmental and economical heating and cooling.

**Figure 7: Desiccant assisted air conditioning system with use of shallow geothermal energy.**

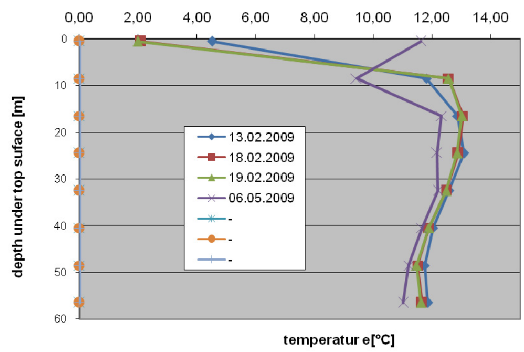


**Figure 8: Undisturbed soil temperature measured at different times at the test site.**

The test site for the pilot plant, which has a base area of 460 m², was installed with 8 soil heat exchangers consisting of 5 energy piles (EP) and 3 borehole heat exchangers (BHE). Energy piles are one of the most used thermo-active ground structures. Statically required piles were assembled with plastic U-tubes (seldom with metallic tubes) and then filled with a heat transfer medium. During circulation of the heat transfer medium in the U-tubes, heat can be extracted from or discharged into the ground. The double function of the piles enables a cost reduction during manufacturing. BHE are not statically required and are therefore flexible in their performance.

2.2.2 Arrangement of Heat Exchangers

Four of the five energy piles are arranged under the corner point of the office containers (**Figure 9**). The other is located in the center. None of the piles are determined statically, since the last of the containers is very low. They are only used as energy sources.

**Figure 9** shows the position of the three BHE. BHE 1 and 2 supply the air conditioning system. In order to cover the peak load in summer and to improve the temperature of heat transfer medium in winter, a heat pump is installed. In normal situation, the heat pump is connected to the BHE 3 for summer operation. In winter, the BHE and energy pile are used as heat source and are connected to heat pump.

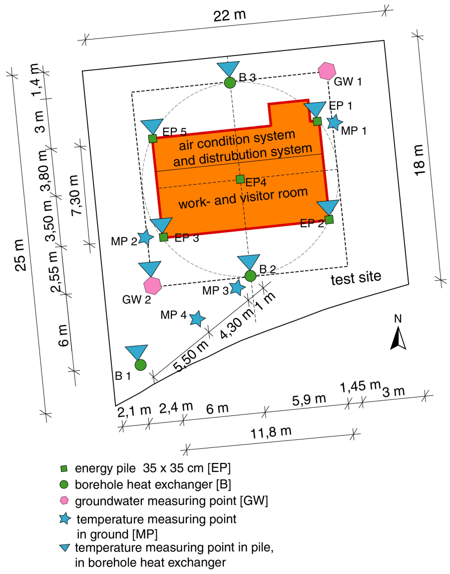


**Figure 9: Site plan of the geothermal system.**

The hydraulic plan of the geothermal system is shown in **Figure 10**. Each soil heat exchanger is fed by one pump. In this way, their mass flow can be controlled separately. The air conditioning, heat pump and geothermal systems are connected by hydraulic switches.

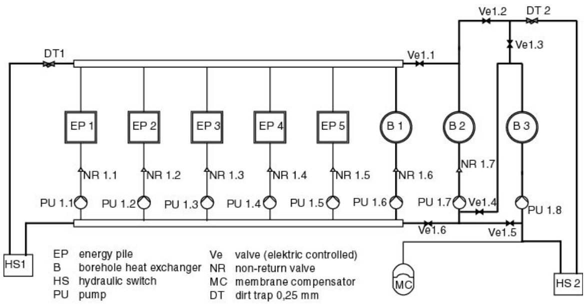


**Figure 10: Scheme of hydraulic plan of the geothermal system.**

2.2.3 Installation of Heat Exchangers

The energy piles are pre-cast concrete piles. U-tubes and temperature strings are fixed directly on the reinforcement cage. Outside of them is a 4 cm concrete covering, which protects both the reinforcement cage and the U-tubes. After concreting, they are transported to the test site and driven into the underground.

In a standard energy pile, 2 U-tube loops are assembled. As a variation, 3 U-tube loops are embedded in two of the five test energy piles (**Table 1**).

Both, the begin of feeding tube and the end of the return tube, between which the maximal temperature difference exists, stand at the top of piles. In order to reduce the undesirable heat transfer between them, thermal insulation is installed on return tubes of the last meter.

**Table 1: Configuration of the 5 energy piles**

| Pile | Number of U-tube loops | Thermal insulation at the last meter of U-tubes | Temperature measurement |
|---|---|---|---|
| EP1 | 2 | Yes | -0.5, -4.5, -12.5m |
| EP2 | 3 | No | -0.5, -8.5 m |
| EP3 | 3 | Yes | -0.5, -4.5, -8.5, -12.5 m |
| EP4 | 2 | No | No |
| EP5 | 2 | No | -0.5, -4.5, -8.5, -12.5 m |

The quality of pre-cast can be well guaranteed, especially by the installation of U-tubes and temperature strings. The drawback of cast-in-place concrete piles is the potential noise and swinging emissions during pile-driving. In urban regions, these piles can only be applied under certain conditions.

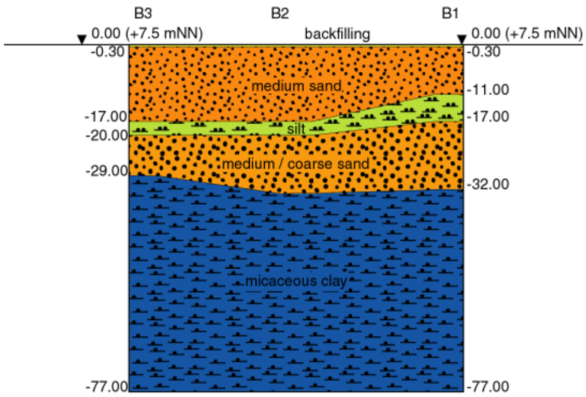


**Figure 11: Soil buildup of the test site (cross section B1-B2-B3).**

Around the test site, there are several swinging-sensitive buildings, such as the SAP-building, Vattenfall heat plant and the tunnel for the subway line No. 4. In order to insure the driving work and to monitor the driving causing swinging, evidences were preserved and driving accompanying swinging-measurements were carried out.

Cone penetration tests showed that the soil up to 8 m under the top surface is hard compact. In order to minimize swinging and noise, the soil was pre-drilled and loosened up to 8 m before the piles were driven with hydraulic hammer.

The holes for the BHE were produced using the hydraulic-circulation drilling method. U-tubes were plugged after the final depth of the borehole was reached. The boreholes are the filled with a cement-clay mixture with a thermal conductivity of 2 W/(m·K).

2.2.4 Measurements Program

The geothermal system is accompanied by a complex measuring program, which includes the measurement of temperature in boreholes, piles, and soil; pore water pressure in soil; the return temperature of the heat transfer medium; and the mass flow and pressure drop in the soil heat exchangers.

Penetration test with lost cone was utilized to install temperature string in the soil. One temperature sensor was installed in the penetration cone, and the other sensors were located in the wire (**Figure 12**). The cone and the wire build a temperature string, which was penetrated into the underground.

All the measurement sensors are connected to a central data acquisition system, which uses LabVIEW as data collecting software.

**Figure 12: Penetration cone with installed temperature sensor.**

## 3. SYSTEM PERFORMANCE

To make a reliable statement about annual energy requirements, different outside air conditions and sensible loads of the building have to be considered.

### 3.1 Air Conditioning System

The hybrid air conditioning system combined with a geothermal energy system can be used in the summer case as well as in the winter case. In the summer case the hot and humid air is dehumidified and cooled by the desiccant assisted air conditioning system. In the winter case the system can be used for remoistening the supply air by the humid outgoing air.

While using a natural geothermal heat sink within building service engineering it is important to pre-dry the air in the summer case. Moist air could cause dew formation in the building. Figure 12 shows the performance of the desiccant wheel for late summer 2009. Please note that these values are only for scientific reasons due to the very low moisture content in the supply air. The results can approve the operability of the desiccant assisted air conditioning system.

To evaluate the energy efficiency of a hybrid system coupled with a geothermal heat sink it is necessary to take the auxiliary power of the additional equipment into account (e.g. circulating pump). To compare the energy requirement of the geothermal coupled air conditioning system with a conventional system a characteristic number is introduced (see **Chapter 3.2**).

### 3.2 Geothermal System

The injected heat into the underground (*E*) is calculated using the difference between inlet and outlet temperatures *($\vartheta_i$, $\vartheta_o$)* of the heat transfer medium

$$E = \int \rho_{htm} A v_{htm} c_{htm} \left(\vartheta_i - \vartheta_o\right) dt \,, \qquad (1)$$

where A is the inner cross section of the U-tubes, $\rho_{htm}$, $v_{htm}$, and $c_{htm}$ are the density, flow velocity and specific heat capacity of heat transfer medium. The specific cooling capacity (*Pc*) of each soil heat exchanger can then be calculated by

$$P_c = \frac{E(T)}{L \cdot T} \,, \qquad (1)$$

where *E(T)* is the injected heat during the time T and L the length of the heat exchanger. The analyzed specific cooling capacity (SCC) is a daily average, since it is considered to be a better indicator of the long-term evolution than instantaneous values (Wood et al., 2009).

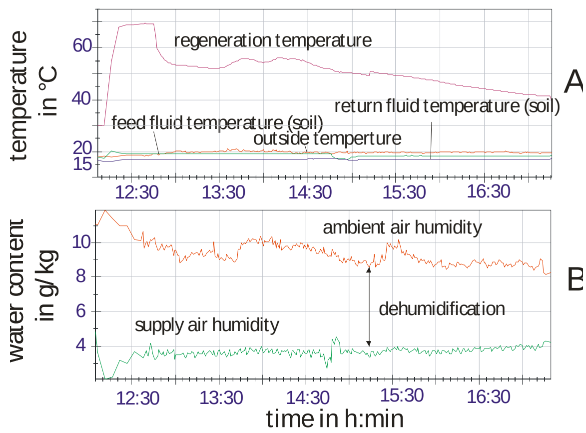


**Figure 13: Measurement results for the desiccant assisted air conditioning system (08.09.2009)**

Because of irregular maintenance and optimization work, the pilot plant has been in use only for several days. The total operation time amounts between 70 to 95 hours (**Table 3**). The injected energy is not so much that an overheating of the subsoil can't occur. As a result, a reduction of SCC with time is not to detect.

The average SCC of EP over the whole operation time is about 40 W/m, which compares to the numerically calculated value of 42 W/m very well (**Table 3**). The BHE have relative lower SCC values of about 30 W/m. It is even lower than the recommended specific heat capacity (SHC) in clay (35-50 W/m, VDI, 2001). The reason for the low SCC value may be attributed to the low average flow velocity of the heat transfer medium in the U-tubes (0.22 m/s, **Table 3**).

It can be seen, that EP 2 and 3 have a larger SCC than that of EP 1 and 5. The reason being that in EP 2 and 3 three U-tube loops were installed, which increase the heat transfer area between heat transfer medium and the subsoil and therefore the heat transfer velocity. EP 4 also has a high SCC value, which ascribes to its beneficial location. It lies in the shade of the office container and its top most meters have least effect from the temperature change of the atmosphere, which is higher than the temperature of the subsoil in summer.

In EP 1 and 3 the last meter of the tube is heat insulated. Compared with EP 5 and EP 2, their SCC is larger.

Although the increasing factor amounts only 1.7% for EP 1 and 5.4% for EP 3 and can thus be neglected.

The geothermal energy is available all over the world, but it is not free for use. In our system, circulation pumps are needed to transfer heat from air conditioning system to the subsoil. To evaluate the efficiency of the geothermal system, the cooling performance factor (CPF), analog to the seasonal performance factor (SPF) of heat pump is introduced in this paper. It is defined as

$$CPF = \frac{E}{E_{GS}}, \tag{3}$$

where $E_{GS}$ is the energy consume of the pump to discharge the heat energy $E$ into the soil.

**Table 3: Summarization of the energy piles and borehole heat exchangers**

| heat exchanger | EP 1 | EP 2 | EP 3 | EP 4 | EP 5 | BHE 1 | BHE 2 |
|---|---|---|---|---|---|---|---|
| flow velocity of HTM (m/s) | 0.31 | 0.31 | 0.31 | 0.32 | 0.31 | 0.22 | 0.22 |
| injected energy [kWh] | 46 | 53.7 | 56.3 | 55.5 | 44.7 | 167.8 | 155.7 |
| energy consume of pumps [kWh] | 2.5 | 2.8 | 2.8 | 2.8 | 2.1 | 1.6 | 1.4 |
| total operation time [h] | 94 | 93.5 | 93 | 92 | 92.8 | 74.7 | 70.7 |
| length of heat exchanger [m] | 14 | 14 | 14 | 14 | 14 | 75 | 75 |
| injection capacity [kW] | 0.49 | 0.57 | 0.61 | 0.60 | 0.48 | 2.25 | 2.20 |
| specific injection capacity [W/m] | 35.0 | 41.0 | 43.2 | 43.1 | 34.4 | 30.0 | 29.4 |
| cooling performance factor (CPF) [-] | 18 | 19.4 | 20.4 | 19.8 | 21.7 | 107.8 | 110.2 |

The CPF of EP amount about 20. BHE obviously have higher CPF values of about 110. This means that the BHE need only about 1/5 energy for the same energy output of EP. The reason being, that the U-tubes in BHE have a larger diameter (40 mm) than those in EP (20 mm), and therefore the hydraulic resistance in BHE is correspondingly smaller, which leads to higher SCC values.

## 4. CONCLUSIONS AND OUTLOOK

The realization of the desiccant assistant air condition system combined with shallow geothermal energy was only possible with careful planning and coordination with the participatory authorities and companies.

The specific cooling capacity of soil heat exchangers depends on a lot of parameters and is not easy to be estimated exactly. The measurements in HafenCity Hamburg show that The BHE point lower SCC but better CPF values compared to EP.

The measurement will be continued in this winter and next summer. More variation performances will be carried out to get detailed information about the relationship between SCC and its dependent parameters. The long term temperature development of subsoil around the soil heat exchangers will also be investigated. Further, numerical simulations with in-situ soil characters and varied boundary conditions are planned to investigate the thermodynamic reaction of EP and BHE systems under other conditions.

Another important research point is the interaction of the air conditioning system and geothermal system, which requires close team work between thermodynamic and geotechnical engineers.

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