Development and Planned Operation of a Ground Source Heat Pump Test Facility

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A new heating, ventilation and air-conditioning laboratory has been established at Chalmers University of Technology, Sweden. The new laboratory provides test facilities for experimental studies of various HVAC systems including borehole thermal energy storage and heat pump systems. The test facility can be used to test operation and control strategies, to develop and validate models for ground source heat pump systems and to conduct thermal response tests. This paper reports on the design and development of the laboratory's ground storage and heat pump system and its planned operation.

Introduction

The division of Building Services Engineering at Chalmers University of Technology, Sweden, has recently built a new heating, ventilation and air-conditioning (HVAC) laboratory [1]. The test facility was developed with an aim to conduct experimental studies on system solutions for space conditioning, integrated control-on-demand and optimized control of HVAC systems. An integral part of the laboratory's HVAC system is its ground source heat pump (GSHP) system, which was primarily developed to study the performance of a wide range of GSHP system configurations. The GSHP test facility consists of a borehole thermal energy storage system (BTES), heat pumps, thermal storage tanks and multiple heat exchangers. The test facility can be used, among other things, to develop, test and optimize control strategies for different GSHP system configurations, to develop and validate component and system models and to perform thermal response tests (TRTs) under different experimental conditions. The following sections describe the design and development and the planned operation of the test facility.

Design and development

The GSHP system consists of a BTES, made up of nine boreholes, connected to three water-to-water heat

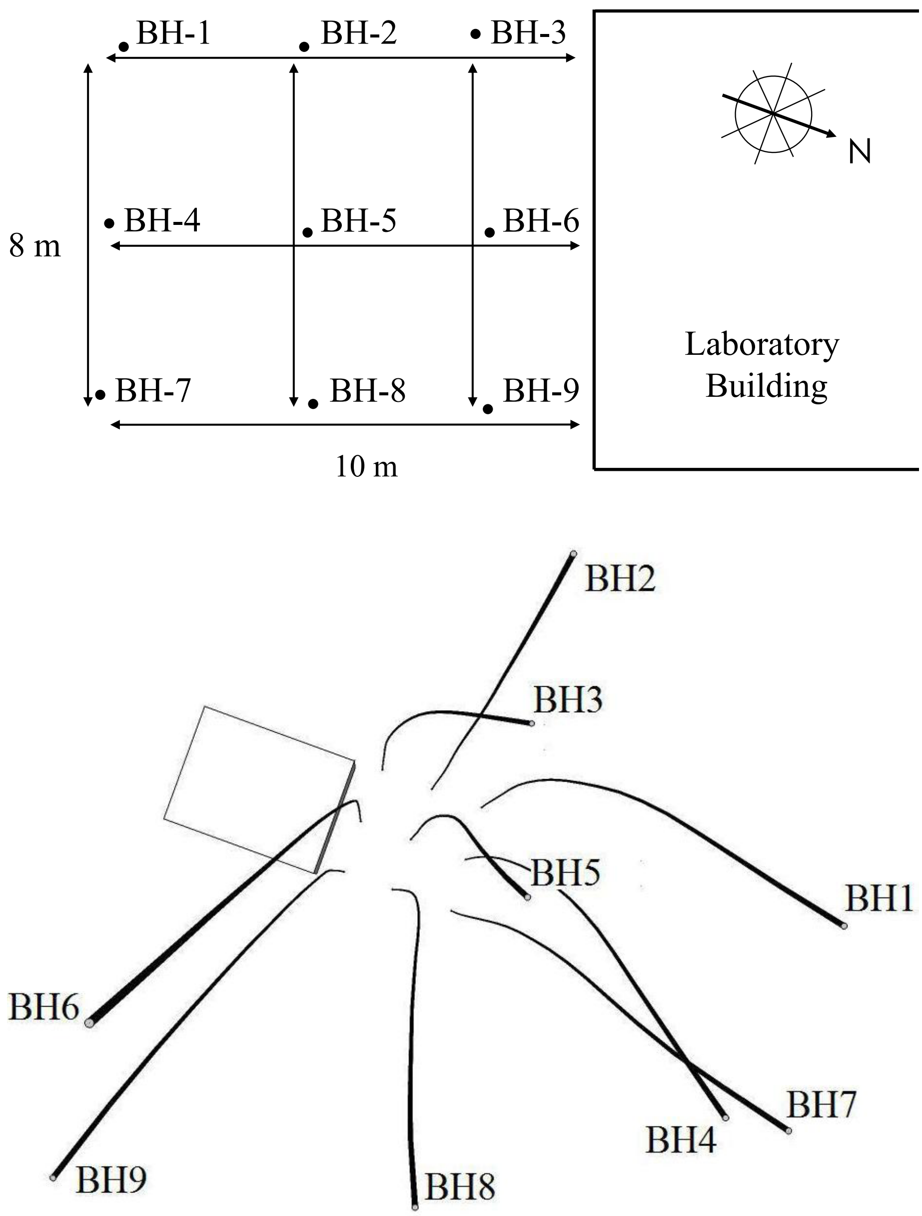

Figure 1 Layout and geometry of the borehole system.

pumps. The boreholes are drilled in a 3x3 rectangular configuration. All the boreholes are groundwater filled and have single U-tubes as ground loop heat exchangers. The distance between adjacent boreholes is around 4 m and each borehole has an active depth of around 80 meters. The inclination of all nine boreholes in the ground has been measured and the horizontal deviation between the two ends of the boreholes varies between 1.7 to 7.2 meters. Figure 1 further illustrates the borehole system layout and the geometry of the nine boreholes.

All nine boreholes have dedicated variable speed pumps and flow control valves to monitor and control brine flow in individual boreholes. Brine exiting the borehole system is stored and distributed through the accumulator tank AT1. From AT1, brine can either be supplied to the evaporator of heat pump HP1 or directly pumped to the heat exchanger HX1 to provide free cooling. The effects of long-term heat injections or heat extractions on the boreholes can be minimized by balancing borehole loads or by recharging the boreholes using direct heat transfer between the brine and the ambient air by means of dry cooler DC1.

The accumulator tank AT2 stores low temperature water (5-15 °C). This water may be cooled directly by heat pumps HP2 and HP3 or indirectly by the ground storage or by outdoor air (DC1) via heat exchanger HX1. AT2 is also used to cool the condenser of heat pump HP1. The low temperature water is used for various laboratory operations. It is supplied to the air handling unit to produce cooling in summer, it is pumped to heat pump HP2 and HP3 evaporators as a low temperature heat source to produce heating and it is used in other laboratory operations requiring process cooling. The HW1 hot water (20-55 °C) produced by HP2 and HP3 can either be directly supplied for heating and process heating applications or can be stored in accumulator tanks AT3 and AT4 and used when required. In case of additional heating requirements or high-temperature water demand, HW2 hot water (20-80 °C) produced by the EP1 electric storage water heater and stored in accumulator tank AT5 can be utilized. Any excess heat in the hot water storage system can be rejected to ambient air using heat exchanger HX2 and dry cooler DC2.

A state-of-the-art building management system has been installed to monitor and control the test facility and for data acquisition and storage. Temperature measurements in the system are made at the inlet and outlet of all the installed components using electronic immersion temperature transmitters. Flow measurements in the system are taken for all the flow circuits using vortex flow meters. Electric power measurements in the system are made for all major components by means of meters that also provide the possibility of waveform analysis. Ambient air temperature and indoor air temperature in each room are measured using electronic temperature transmitters.

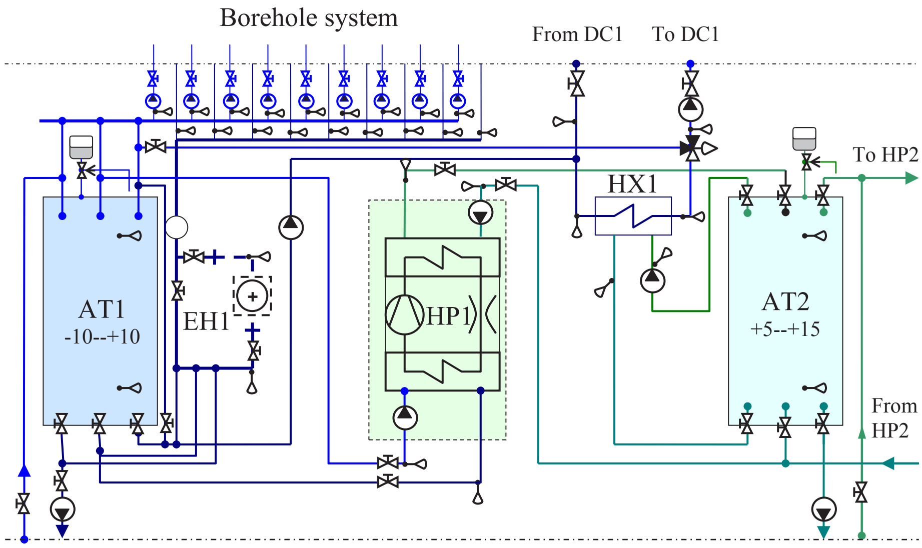

Figure 2 Brine and process cooling water system.

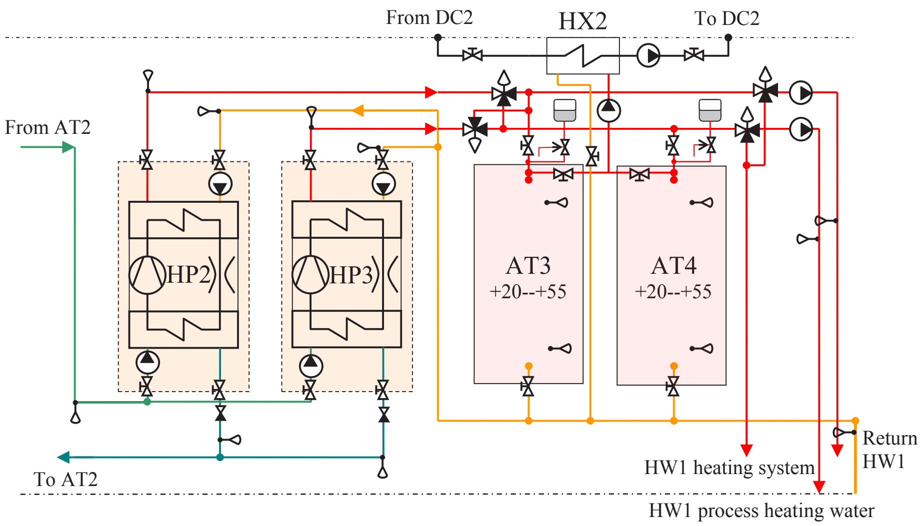

Figure 3 The HW1 heating and process heating system.

Planned operation

The test facility can be used to investigate the effects of various control strategies on the operation and performance of GSHP systems. Traditionally, controlling the heat pump entering fluid temperature has been the most common control strategy as a higher entering fluid temperature in winter and a lower entering fluid temperature in summer increase the heat transfer and positively influence the performance of the heat pump. However, requirements for heating and cooling in buildings have changed considerably in recent years. Today, many commercial and office buildings have a cooling demand during the day, even in a climate as cold as Sweden's, and a heating requirement during the night. Other commercial buildings, like shopping centres and supermarkets, have simultaneous heating and cooling demands. These changing heating and cooling demands require new control strategies that need to be investigated and adapted to optimize the performance and operation of GSHP systems [2]. Such strategies may be based on actual and predicted system loads, forecasted and historical energy use etc.

The new test facility will be used to study existing and new control strategies for different configurations of GSHP systems. The flexible design of the test facility permits components to be included or excluded from the system as per test requirements. The GSHP system to be investigated can be designed using various configurations of the borehole system, heat pumps, accumulator tanks and supplementary heat exchangers. Depending on the application, the borehole system can be used in heat storage or heat dissipation modes. When used in the rectangular configuration, the borehole system acts as a heat storage system to store thermal energy in the ground at a time of energy surplus for extraction later. When used in a line, a U or an open rectangular configuration, the borehole system acts as a heat dissipation system. Any number or configurations of boreholes can be chosen for a particular test. Dry cooler DC1 can be used to moderate borehole system temperature but it can also be used as a standalone alternative for free cooling during periods of low outdoor temperature.

The size and augmented thermal mass of the system can be altered as it is possible to use either of heat pumps HP2 and HP3 with either of the accumulator tanks AT3 and AT4. Alternatively, it is also possible to operate HP2 and HP3 together with either or both of AT3 and AT4. Dry cooler DC2 can be used to reject any excess heat present in the hot water storage systems. Electric resistance heaters installed in all the accumulator tanks and electric storage water heater EP1 can be utilized to provide additional heating or to meet high-temperature water requirements. All of these possibilities allow a wide range of GSHP system configurations with flexible levels of temperature, thermal loads and thermal mass in the system. The test facility will be used to investigate control strategies for different GSHP system designs and to study the effects of system design on the operation and the performance of the GSHP system.

The test facility will also be used to develop new component and system models, to experimentally validate existing and new models and to conduct experimental studies. At a component level, models for the borehole system, heat pumps, storage tanks and auxiliary equipment can be developed, tested and validated. At the system level, investigations regarding operation, control and optimization of simple and hybrid GSHP systems can be carried out. The test facility can be used to test borehole system models both for heat storage and heat dissipation modes. Investigations regarding short-term borehole response, long-term borehole performance deterioration and thermal interaction between boreholes are of particular interest.

Other examples of possible experimental investigations which can be conducted using the test facility include studying the differences between the thermal response of peripheral and central boreholes, attainable free cooling in relation to ground heat injection and the trade-off between heat pump and the circulation pump energy consumption in free cooling modes. The laboratory system makes possible the testing of both brine-to-water and the

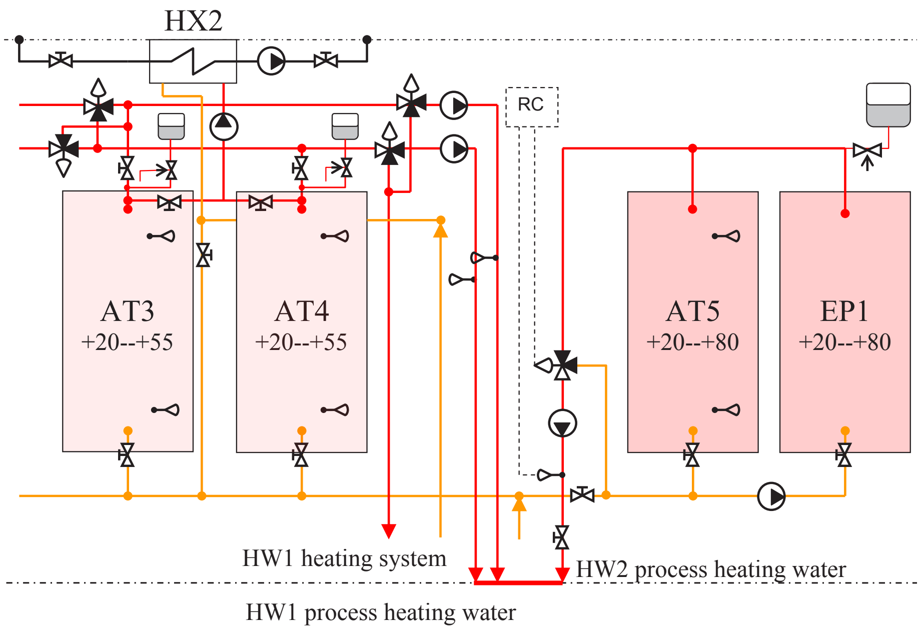

Figure 4 The HW1 and HW2 process heating system.

water-to-water heat pump systems. Simultaneous testing of heat pumps at similar or different temperature levels is also possible using the test facility.

Another feature of the test facility is its flexibility in conducting TRTs. The laboratory borehole system provides a unique opportunity to study ground thermal properties such as undisturbed ground temperature, thermal conductivity and the borehole resistance of nine boreholes in close proximity. Such an investigation has rarely been conducted on an academic level in controlled laboratory conditions. Issues like repeatability and reproducibility of TRTs can be comprehensively studied using various alternative approaches. The installed electric resistance heater EH1 can be used to conduct the thermal response testing in the heat injection mode. It is also possible to conduct TRTs in heat extraction mode using heat pump HP1. Another possibility is to conduct TRTs using brine at constant input temperature to the boreholes.

When conducting a TRT, the brine accumulator tank, AT1, can either be included or excluded from the flow circuit. The storage tank is bypassed if the conventional constant heating flux approach is used for the thermal response testing. Alternatively, the storage tank is included in the flow circuit and is used to provide brine at a constant input temperature to the borehole for constant heating temperature approach. The installation of nine variable speed pumps, one for each borehole, and an adjustable electric heater for heat input allow investigations regarding effects of different flow and heat injection rates when conducting TRTs. The results from TRTs of the laboratory borehole field can be used to simulate the long-term response of the individual boreholes. The differences between the long-term responses of the different boreholes can then be used to underline the uncertainties related to the borehole system design process.

Additional testing facilities

In addition to the GSHP system, the laboratory building houses a conference room and two test rooms for specific test applications. The first test room is designed as a 'clean room' with stainless steel interior and a dedicated air conditioning system. This test room is used to perform experiments which require precisely controlled temperature and air quality. It can also be used to test components like sensors and air cleaners and to study emissions from different materials.

The second test room is made of clear glass and has a dedicated ventilation system. Special filming equipment has been installed to study the room-air and ventilation-air movement under specific conditions, e.g. that of an operating theatre etc.

The conference room was purpose built to investigate issues related to thermal climate and indoor air quality, lighting and noise, the control and positioning of room sensors and the operation and control of decentralized pumps and fans etc. The temperature in the room can be maintained using supply air from the centralized air handling unit or by using radiators, fan coil units, or under-floor heating and cooling as alternate systems. Supply and exhaust air flow rates, indoor air quality and noise levels in the conference room can all be precisely monitored and controlled. The use of four sets of supply and return ducts to the conference room also permits the division of the room into four cell-type offices to study the effects of indoor climate on the performance and behaviour of people.

Conclusion

This paper reports on the design and the development of a GSHP laboratory. The laboratory setup includes a BTES, three heat pumps, five accumulator and storage tanks, two dry coolers and several additional auxiliary components. The laboratory offers facilities to test different GSHP system configurations in controlled laboratory conditions. The planned operation of the laboratory was also reported. The laboratory will be used to test operation and control strategies for GSHP systems, to develop and validate system and component models and to conduct thermal response tests.

References

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