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Combined simulation of a deep ground source heat exchanger and an office building

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ABSTRACT

It is analyzed, if and to which share the deep borehole heat exchanger (BHE) at RWTH Aachen University in its current state is capable of heating an office building located at its top, called SuperC. Furthermore, possible modifications to the BHE and to the hydraulic connection to the building's heating system are discussed.

Models of the BHE and of the building are each validated with measurement data and than connected to each other to carry out system simulations for one heating period. It is found that the BHE in its current state can support the heating system by a notable share of the annual heating demand by supplying the low temperature heating systems of the building. An alternative system configuration and a different inner BHE pipe provide the opportunity of higher supply temperatures leading to a higher fraction of geothermal heating.

1. Introduction

We present a study analyzing the possible contribution of geothermal energy for heating of the SuperC building at RWTH Aachen University. An exceptional deep geothermal heat exchanger is located under the building. In the heating period of 2010–2011 measurements were done and data of the building control system were collected (Section 2). The modeling and simulation of the borehole heat exchanger (BHE) and the building is described in Section 3. Numerical studies of the BHE and the building complete the study (Section 3.9).

Borehole heat exchangers used for building heating are within the scope of research since many years, especially since the 1980s when heat pumps were widely used for the first time. The research of Eskilson contributed a lot to this research [1]. The work is still used or enhanced [2–5].

Most of the research in the field of geothermal heating systems for buildings deals with shallow soil heat exchangers that are used as heat sources for heat pumps [6,7]. Being implemented in office buildings, multiple BHE are often also used for a direct cooling [8–10]. This generally provides the annual energy in- and outputs of the ground to be balanced. Usually geothermal systems are operating with low temperature distribution systems such as floor heating or concrete core activation [11].

Deep BHE are rarely used for building energy systems and they are rare in general. Florides gives an overview on different types of ground source heat exchangers [12], but closed loop deep boreholes are not mentioned explicitly. Kohl presents two deep BHE that exist in Switzerland and are comparable to the one discussed within this paper both in their dimensions as well as in their use [13,14].

1.1. The SuperC building

At RWTH Aachen University the construction of the student services center SuperC was finished in 2008. It is a building with an area of 4600 m^2 hosting mainly office and conference areas. It is located in the city centre of Aachen. It consists of six stories above ground whereof the highest has an overhang of 16 m making the building architecturally recognizable (see Fig. 1). A basement floor owns a big hall that is used for multiple purposes. The 6th floor has two conference rooms.

1.2. The SuperC borehole heat exchanger

As heat source for heating of the building a BHE of 2500 m depth has been built. The drilling of the borehole was done in the year of 2004. It has been planned to insert an inner pipe to the borehole to complete a coaxial pipe in 2004. A delay concerning the building construction led to a suspension of the borehole completion. When finally in 2008 the building was finished and the admission for inserting the inner pipe was given, conditions changed: In a similar

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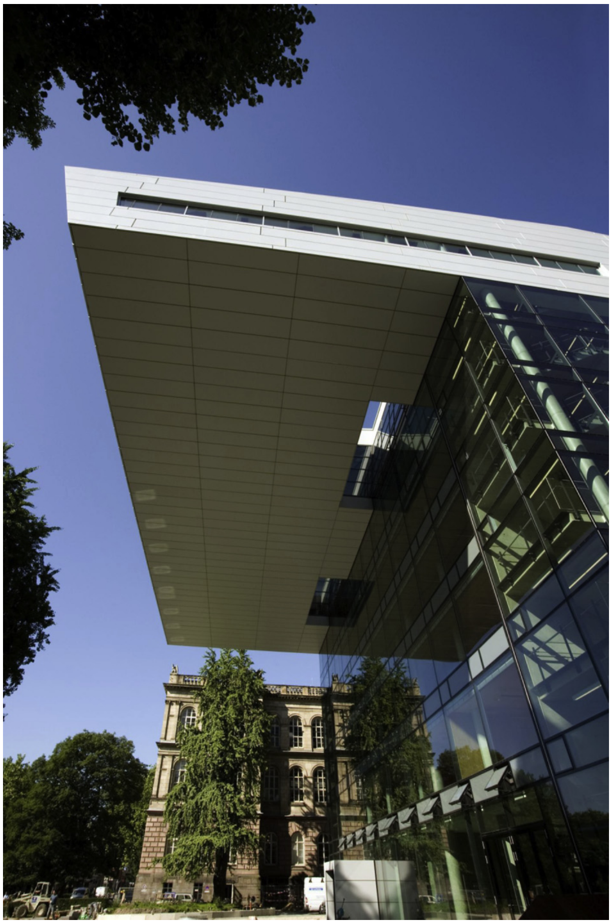

Fig. 1. Side elevation of the SuperC building. Source: RWTH Aachen university, Peter Winandy.

borehole in the city of Arnsberg (North Rhine-Westphalia, Germany) the inner pipe was damaged while being inserted into the borehole. That led to the decision of not using this kind of glass fibre reinforced plastic pipe in Aachen. A new type of inner pipe was designed which is made of plastic. Then, with the new pipe, too, difficulties occurred while inserting the pipe into the borehole in Aachen. It could only be inserted to a depth of 1970 m. The difficulties on one hand had to do with misplaced weights at the inner pipe intended to balance its buoyancy in the borehole water. On the other hand the inner pipe is equipped with spacers assuring a central location in the borehole which got stuck. The borehole heat exchanger was finalized in 2009, more than a year after the opening of the building which made it necessary to arrange for an alternative heating source in the meantime. The BHE since then has been used only for research and not has not been included into the building's heating concept yet.

1.3. The SuperC HVAC systems

The district heating of Aachen University was chosen as heating source when geothermal heat was not available. The supply temperature of district heating is between 100 and 110 °C, the return temperature between 50 and 65 °C. Thus, the heating system was adapted for the use of district heat and not according to geothermal heat.

The SuperC holds an extensive hardware for heating, ventilation and air conditioning (HVAC). In this paper only the heating mode is considered. Nevertheless, Section 1.3.2 gives a brief overview on cooling applications. A building control system delivers time series of the sensors installed in the HVAC systems.

1.3.1. Heating appliances

All heat consumers of the building are listed in Table 1 with the according nominal heat flows. The offices and smaller conference rooms of the building are naturally ventilated. The four ventilation systems are supplying the larger conference rooms and the corridors as well as the ground floor. They are supplied with a water temperature of 70 °C.

The base load of heat is distributed by concrete core activation (CCA). It is installed in the concrete ceilings of the ground floor and 1st to 4th storey. The 5th and 6th floors are equipped with heating panels (HP). The CCA and the HP are each connected to heat exchangers which on the primary side are connected to a heating distributor and a cooling distributor allowing them to be used both for heating and for cooling purposes. The supply temperature of the CCA and HP is controlled by the mass flow on primary side of the heat exchangers. The nominal supply temperature on the primary side is 55 °C for heating operation.

Radiators are installed in the whole building. In most parts of the building they serve as additional heat delivery system to the CCA and HP covering peak loads at the windows. In the basement floors they are installed, too, covering the loads that are not delivered by the ventilation units. The ground floor with its entrance area has underfloor convectors which are supplied by air that is conditioned by the ventilation system 3. Their supply temperature is 55 °C at nominal conditions (−12 °C ambient temperature) and controlled by an ambient air temperature dependend heating curve.

1.3.2. Cooling systems

The SuperC building holds systems for cooling and air conditioning. Two compression refrigeration machines (108 kW nominal cooling capacity each) are installed for delivering the cooling capacity. Two re-cooling plants can adiabatically disperse 500 kW of heat to the ambient air. Below ambient air temperatures of 9 °C it is possible to drop heat from the building by free cooling. Otherwise heat rejected by the refrigeration machines can be dissipated.

The consumers of cooling capacity are the ventilation units, the CCA and the HP. The nominal supply temperature on the primary side of heat exchangers for CCA and HP and for the ventilation units is 13 °C for cooling operation.

2. Measurements

2.1. Heat flow of district heating

A number of measurement data has been collected to comprehend the distribution of thermal energy delivered by district heating within the building. The data of the heat flow from the

Table 1
Heat consumers in the SuperC building.

	Nominal power in kW
Ventilation System 1	151
Ventilation System 2; Ventilation System 3	78
Ventilation System 4, Radiators 6th floor south	149
Radiators basement, ground floor	39.7
Radiators 1st to 5th floor; 6th floor north	160
CCA and HP	126