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A dynamic building and aquifer co-simulation method for thermal imbalance investigation

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HIGHLIGHTS

- A co-simulation tool including COMSOL-MATLAB-TRNSYS was developed and applied.
- Thermal imbalance problem of ATES was investigated for cooling dominated loads.
- The cold well temperature was decreased by 2.5 °C by maintaining a thermal balance.
- Thermally balanced building performed up to 13.7% higher performance.

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ABSTRACT

Due to their favorable supply temperature, aquifer thermal energy storage (ATES) systems perform as an efficient heating/cooling energy storage facility for buildings. ATES systems consist of a warm and cold well. They are designed to operate with a temperature difference of at least 8 °C between wells, whereas the existing installations operate in practice with an average temperature difference of 4 °C. The ATES supply temperature is influenced by heat losses to the surroundings and the yearly balance of total heat exchange of heating and cooling between a building and the groundwater. Previous studies mainly focused on the investigation of heat losses to the environment. This paper explored the influence of thermal imbalance of a building load on the temperature of the aquifer and the heating/cooling system performance for the building. Due to the lack of tools capable of simulating the system that connects ATES with the buildings, we develop a co-simulation method that combines COMSOL, MATLAB and TRNSYS. In this method, COMSOL was used to model ATES, TRNSYS to simulate buildings and heating, ventilation and air conditioning (HVAC) systems and MATLAB as a mediator to exchange information between the simulation tools. The developed method was applied to a case study with three different insulation parameters to present different thermal load profiles. The results indicated that a thermally balanced building load achieved a 2.5 °C higher temperature difference between the sources for cooling than a case with a thermal imbalance ratio of 79%, which resulted in a 13.7% and 6% higher system coefficient of performance (COP) higher than the case with 79% thermal imbalance ratio and 51% thermal imbalance ratio, respectively.

1. Introduction

Energy consumption in buildings has been inevitably increasing for the last several decades. Heating and cooling systems are responsible for the majority of the energy use within a building. As a result, numerous underground thermal storage systems have been introduced as energy-efficient sources for heating and cooling applications in combination with a heat pump, due to the suitable and stable supply temperature.

Commonly, there are two underground thermal storage systems that have inter-seasonal operation. One is borehole thermal energy storage (BTES), and the other is aquifer thermal energy storage (ATES). In the BTES system, heat is exchanged with the ground through closed-loop pipes by means of conduction. ATES utilizes readily available groundwater to transport heat to a building using an open-loop pipe system. The exchanged heat is stored in the same storage field throughout the season in a BTES system, while it is stored separately using doublet wells in an ATES system: in a cold well in the winter and a warm well in

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Nomenclature

K	hydraulic conductivity (m/s)
h	hydraulic head (m)
	flow flux (m^2/s)
ρ	density (kg/m^3)
S_s	storage term
Q_s	source term (m^3/s)
K	hydraulic conductivity (m/s)
$(pc)_f$	specific heat capacity of fluid $(kJ/kg°C)$
$(pc)_{aq}$	specific heat capacity of aquifer $(kJ/kg°C)$
λ_{aq}	thermal conductivity of aquifer (mC/kJ)
Q_{inj}	injected heat to the ground (kJ)_
Q_{ext}	extracted heat from the ground(kJ)
T_{ww}	extraction temperature from the warm well $(°C)$
V_{max}	maximum flow rate of water (kg/hr)
Q_b	heat transfer to the building (kJ)
COP_{HPC}	COP cooling supply in heat pump mode
COP_{direct}	COP of direct cooling supply
$COP_{cooling}$	cooling COP
$COP_{heating}$	heating COP
COP_{sys}	system COP
Q_{hpc}	cooling supply to the building (HP mode) (kJ)
Q_{dc}	cooling supply to the building (DC mode) (kJ)
Q_{cool}	total cooling supply to the building (kJ)
$W_{pump,cw}$	electricity consumption of cold well pump (kJ)
$W_{pump,ww}$	electricity consumption of warm well pump (kJ)
T_{cw}	extraction temperature from the cold well $(°C)$
$W_{pump,cw}$	electricity consumption of cold well (kJ)
W_{max}	maximum pump electricity consumption (kJ)

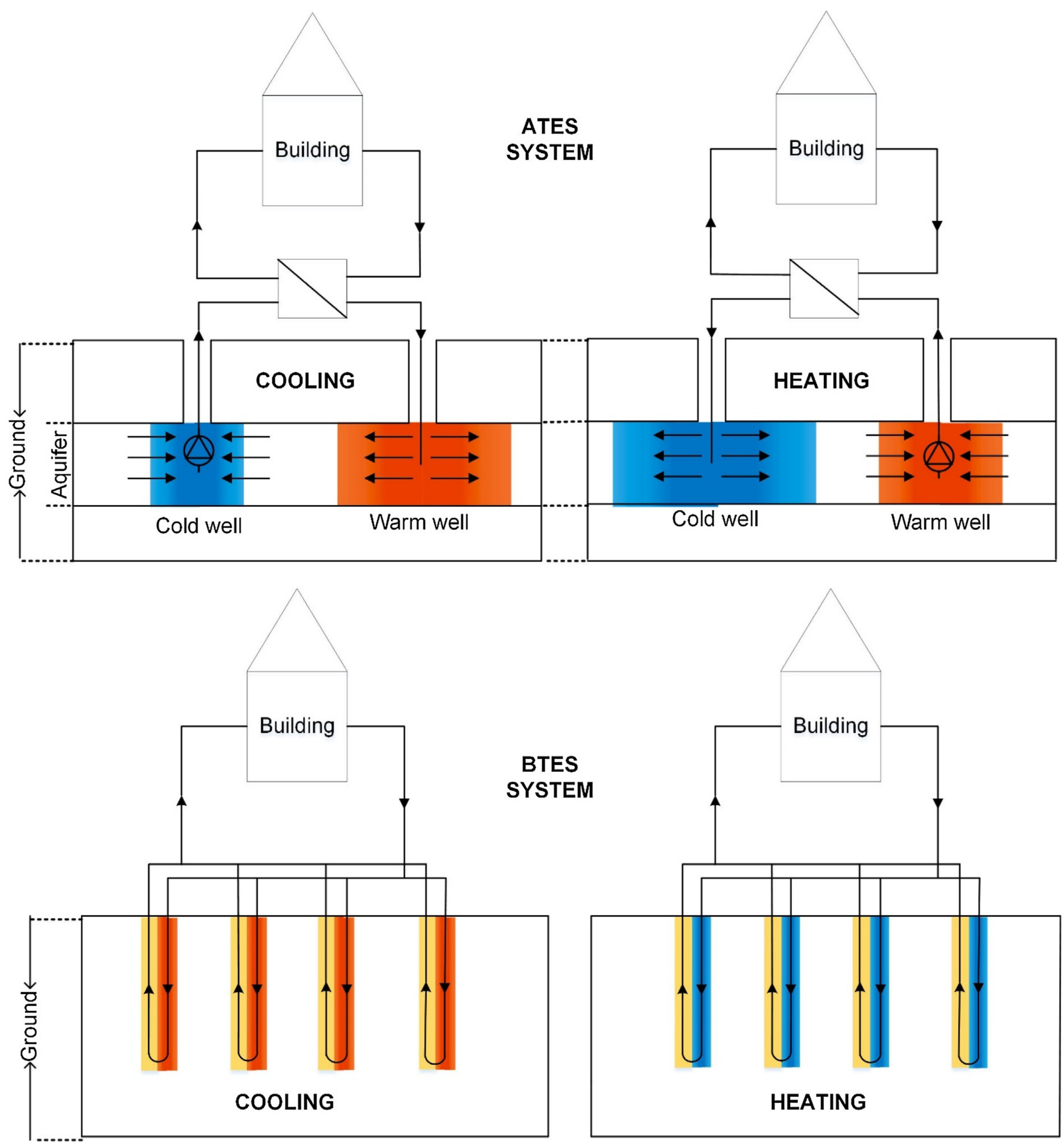

Fig. 1. The principles of ATES and BTES systems (modified from [1]).