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Study on Heat Transfer Calculation Method of Ground Heat Exchangers Based on Heat Pump Unit Operation Characteristics

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Abstract

For ground source heat pump (GSHP) system, the dynamic heat rejected to or extracted from the ground is an important parameter to analyze the heat transfer performance of ground heat exchanger (GHE). Coupled with dynamic indoor load and actual operation characteristics of heat pump unit, a method to calculate actual dynamic heat load input of GHEs was introduced and a calculation program was developed. In an actual GSHP system project, the dynamic heat load input of GHEs was calculated and used as a boundary condition, a three-dimensional heat transfer model of this GHE field was established, and then the water temperature variation of GHEs was obtained. The actual water temperature variation of GHEs was tested and it was similar to the theoretical calculation results, thus the method was validated and could be applied in the actual engineering projects.

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Keywords: Ground source heat pump; Operation characteristics; Ground heat exchanger field; Numerical simulation; Dynamic load;

1. Introduction

Ground source heat pump (GSHP) system is a sustainable environmental quality control system of transferring waste heat to the ground, the efficiency of which is affected by heat transfer performance of ground heat exchangers (GHEs). As a key factor in analyzing heat transfer performance of GHEs, the ground heat rejection and absorption are different from the heating and cooling load of building due to the operation characteristics of heat pump unit.

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As common performances in GSHP system, on/off cycling and part-load operation have been studied by many authors. The part load factor (PLF) is adopted as a correction coefficient applied to steady-state performance parameters including heat load, energy consumption and energy efficiency ratio (EER) of the machine [1,2]. Affected by factors like climate, building function and control strategies, the given parameters by PLF approach are not applicable to all the units, thus the direct application of these parameters will lead to calculation error [3]. On the other hand, many researchers present accurate distributed models that allow tracking fluid flowing in the evaporator, condenser and compressor etc. [4,5], such detailed models need a large number of parameters and calculations that are not appropriate and necessary in simulating the GSHP system during life cycle. However, most researches on dynamic simulation of GSHP system neglect operation characteristics, and the heat load transferred by GHEs is obtained by inputting dynamic building load into equations (GB50366 2009) instead [6,7]. Kummert and Bernier have compared 'dynamic' (including dynamics in the fluid loop, borehole and heat pump) and 'steady-state' (neglect those dynamics) models by simulating in TRNSYS, and found that the steady-state models could overestimate up to 75% of the energy use for undersized exchangers [8]. He et al. present transient simulation of a GSHP system with a single GHE using a dynamic three-dimensional numerical GHE model in EnergyPlus [9]. Integrated building performance simulation tools such as TRNSYS and EnergyPlus typically neglect the dynamics in the borehole and fluid, considering the grout is part of the ground volume; an available dynamic model implemented in TRNSYS can only take one borehole with double-U tube into account [8]. Therefore, convenient and accurate calculation methods of dynamic simulation for GHE field during life cycle are required.

Based on previous researches, a calculation method of dynamic heat load input of GHE was obtained coupled with dynamic building load and operation characteristics of GSHP system, which was achieved by programming in MATLAB. In an engineering project, actual dynamic heat extracted from and rejected to the ground were calculated and used as boundary conditions, and a three-dimensional heat transfer model of this GHE field was established, then the water temperature variation of GHEs was obtained after simulation, which was ultimately validated by testing data.

Nomenclature

Q_1	building side heat load
Q_2	output load of heat pump unit
Q_3	heat extraction of condenser with dynamic EER
Q_4	ground heat extraction/rejection
T	temperature
T_0	initial temperature
C_P	specific heat
m	mass flow
Q_R	rated cooling load of heat pump unit
P	power
PLR	part load ratio
d	diameter

Greek letters

λ	thermal conductivity
ρ	density of soil

Subscript

in	inlet
out	outlet
ch	chilled water
co	condenser water
w	water
r	refrigerant