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Improved underground heat exchanger by using no-dig method for space heating and cooling

Yasuhiro Hamada*, Makoto Nakamura, Hisashi Saitoh, Hideki Kubota, Kiyoshi Ochifuji

Graduate School of Engineering, Hokkaido University, N13-W8 Kita-ku, Sapporo, Japan

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Abstract

This paper describes experiments and analyses on an improved underground heat exchanger by using a no-dig method for the purpose of the cost reduction of a space heating and cooling system using underground thermal energy. First, the improved underground heat exchanger was installed on the campus of Hokkaido University, and it was shown that a ground source heat pump system utilizing the heat exchanger was sufficient for space heating and cooling. Second, evaluation program of the heat exchanger was developed, and the program was verified to give good predictions by comparing with experimental results. As a result of system simulations, an energy reduction for a system installation relative to a conventional vertical earth heat exchanger reached 78%. The primary energy reduction rate including the system installation and operation relative to a typical air source heat pump was 29%.

Keywords: No-dig method; Underground thermal energy; Ground source heat pump; Space heating and cooling

1. Introduction

In the Third Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) held in 1997, it was decided that CO_2 emissions of Japan would be reduced by 6% to the 1990s level. The Japanese government set a target of 83.6 million tons for CO_2 reduction in 2010. 27.4 million tons or 33% come from the residential/commercial sector. Efforts to reduce CO_2 emissions are required in houses and

*Corresponding author. Tel.: +81 11 706 6284; fax: +81 11 707 6585.
E-mail address: hamada@eng.hokudai.ac.jp (Y. Hamada).

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Nomenclature

COP	coefficient of performance (—)
c	specific heat of soil (J/kg K)
D_{Tl}	liquid thermal moisture diffusivity (kg/m s K)
D_{Tv}	vapor thermal moisture diffusivity (kg/m s K)
$D_{\theta l}$	liquid moisture diffusivity (kg/m s m^3/m^3)
$D_{\theta v}$	vapor moisture diffusivity (kg/m s m^3/m^3)
EER	energy efficiency ratio (—)
g	gravitational acceleration (m/s^2)
h_l	enthalpy of liquid water (J/kg)
h_v	enthalpy of water vapor (J/kg)
K	hydraulic conductivity (kg/m s Pa)
L_b	latent heat of vaporization of water (J/kg)
L_f	latent heat of freezing of water (J/kg)
M	molecular mass of water (kg/mol)
R	universal gas constant (Pa m^3/mol K)
RH	relative humidity (—)
$SCOP$	system coefficient of performance (—)
T	temperature (°C)
T_f	freezing temperature (°C)
T_{gcome}	fluid return temperature from underground (°C)
T_{hcome}	fluid return temperature for space heating (°C)
T_{ua}	experimental constant (—)
T_{ub}	experimental constant (—)
t	time (s)
z	vertical space coordinate (m)
θ_a	volumetric air content (m^3/m^3)
θ_i	volumetric ice content (m^3/m^3)
θ_l	volumetric liquid water content (m^3/m^3)
λ	thermal conductivity (W/m K)
Π	absolute temperature (K)
ρ	density (kg/m^3)
ρ_i	density of ice (kg/m^3)
ρ_l	density of liquid water (kg/m^3)
ρ_v	density of water vapor (kg/m^3)
ψ	total hydraulic potential (Pa)
ψ_m	soil water matric potential (Pa)

buildings. Therefore, renewable energy should be utilized more actively, in addition to energy conservation measures such as the improvement of thermal insulation, air tightness, equipment efficiency, and the utilization of urban waste heat.

The technologies of underground thermal systems have evolved considerably in many countries over the past 30 years [1,2]. In Japan, however, they have yet to be generalized, although there have been experimental and analytical studies on heat transfer