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Field measurements and analyses for a hybrid system for snow storage/melting and air conditioning by using renewable energy

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Abstract

This paper aims to propose a hybrid system for snow storage/melting and air conditioning by using renewable energy-resources, and clarify the effects of an actual realized application. First, the outline of the system installed at an office building, which was completed in Sapporo, Japan in 2001, is shown. The hybrid system is composed of an underground thermal utility for snow melting by using vertical earth heat-exchangers and space cooling through seasonal cold storage of snow-and-ice cryogenic energy. Second, at the comparatively severe climatic conditions (the lowest outside air-temperature −9.2 °C and the amount of daily snowfall 8.1 cm), it was found that the underground thermal utilization system contributes to preventing freezing of a road surface, and that the road-surface exposure rate was approximately 90%. The effectiveness of this system on energy conservation, environmental protection and cost was verified through numerical analyses. Also, as a result of measuring snow-storage characteristics and space-cooling performance, the effective amount of snow stored on the first day of the space-cooling period was approximately 74%, which gave comparatively good agreement with the predicted value.

Keywords: Underground thermal utilization; Snow-and-ice cryogenic energy; Snow melting; Space cooling

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Nomenclature

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))
$D_{\theta \mathrm{l}}$	liquid moisture-diffusivity (kg/(m s m^3/m^3))
$D_{\theta \mathrm{v}}$	vapor-moisture-diffusivity (kg/(m s m^3/m^3))
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 (–)
T	temperature (°C)
T_{f}	freezing temperature (°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-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 matrix potential (Pa)

1. Introduction

Japan consists of many islands (Fig. 1). It extends north to south from sub-frigid zones to the subtropics, so it has a wide range of climates. The average annual temperature ranges from 6 °C to 23 °C. Japan's snowy-regions account for almost half of the nation's total land-area. Sapporo (latitude 43°N, longitude 141°E), Japan is located in the snowy region. The first snowfall usually occurs in late October. From early December onward, is, the ground is continuously covered with snow. The maximum snow-depth between December and February can reach up to approximately 1 m, and the annual cumulative