SNOW-MELTING USING DIRECT GEOTHERMAL ENERGY

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In recent years, demand has arisen for energy-saving and environmentally-friendly snow-melting systems to make roads safe and easy to drive on in snowbound areas.

For the past 10 years, Misawa Environmental Technology has been working on a sprinkler-free snow-melting system called the Borehole Heat Exchange System (BHES). This system uses geothermal energy (from a depth of 50 to 150 meters), one of the most stable natural energy sources. We have conducted a study that verifies the system's snow-melting effectiveness and reliability, as well as a long-term follow-up study to confirm the system's energy-saving and environmentally-friendly characteristics based on its yearly thermal energy budget.

The study findings are based on measurements of weather observation, ground temperature, circulating fluid temperature, road surface temperature, and similar data. This report presents our findings on BHES, covering the following aspects of the system:

(1) Effectiveness at melting snow and preventing freezing
(2) Stability of geothermal energy supply
(3) Yearly energy budget and energy costs
(4) Ability to reduce fossil fuel consumption and CO_2 emissions
(5) Summer heat storage and yearly heat transfer characteristic

Our follow-up study has confirmed the system's effectiveness over a roughly 5-year period, and has demonstrated its highly energy-saving and environmentally-friendly characteristics.

1. System overview

Figure 1 illustrates the overall system concept. The system was constructed by installing heat exchange rods (made of polyethylene piping) in boreholes of about 50 to 150 meters deep. These rods were connected in sealed circuits with radiating pipes buried in the road surface. Antifreeze circulates through these sealed circuits. In winter, the circulating fluid cooled by the road surface extracts heat from the surrounding ground through the heat exchange rods. The heated circulating fluid heats the road surface through the radiating pipes, helping to melt snow and prevent freezing.

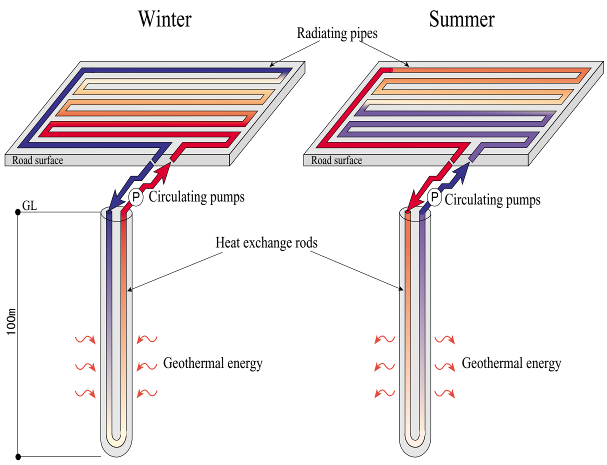

Figure 1 Overallsystem concept of BHES

In summer, the system can collect solar energy by circulating the fluid below the road surface. The heated circulating fluid heats the surrounding ground, creating stored heat that reduces the road surface's temperature rise.

2. Effectiveness at melting snow and preventing freezing

The follow-up study we conducted after installing BHES at each site demonstrated the system's effectiveness at melting snow and preventing freezing.

Figure 2 shows the relationship between the snow accumulation per day and the amount of snow that remained on the road surface when the system was operating. In all cases, good road surfaces were attained for snow accumulations of up to 20 to 25 cm/day. However, when the snowfall rate (accumulation per hour) was high at the time of measurement, some snow remained on the road even on days of low total accumulation.

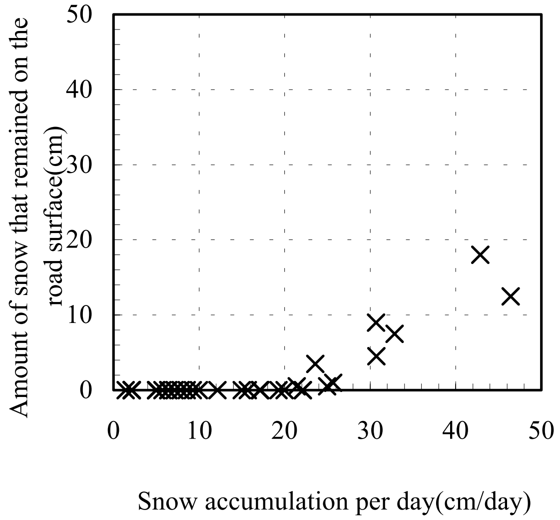

Figure 2 Relationship between the snow accumulation and the amount of snow that remained

Figure 3 shows how the snow accumulation on a road surface in which the system was operating changed over time in relationship to the snowfall rate. The system prevented almost all road-surface snow accumulation for snowfall rates of up to 2 cm/hour, demonstrating its effectiveness at melting snow. BHES was even more effective when operating at the onset of a snowfall, when it could prevent all road-surface snow accumulation even for snowfall rates of more than 2 cm/hour. We attribute this greater effectiveness to the effect of retained heat created by the continuous supply of thermal energy from before the onset of the snowfall. During continuous extended snowfalls of over 2 cm/hour, road-surface snow accumulated during the snowfall, and melting resumed when the snowfall ended.

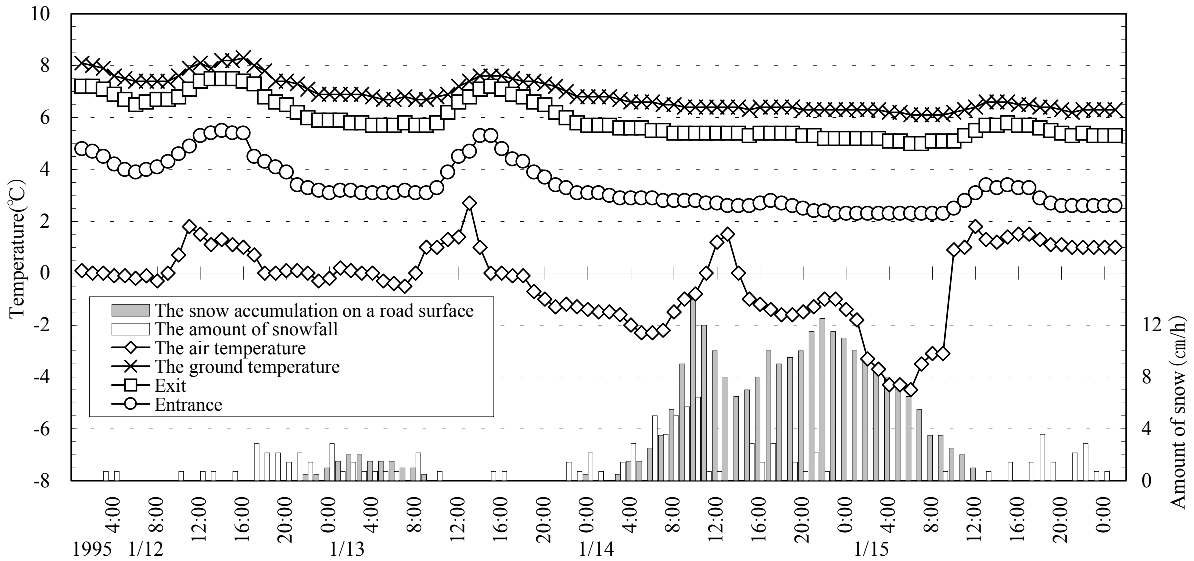

Figure 3 How the snow accumulation on a road surface changed over time in relationship to the snowfall rate

Figure 4 shows the relationship between the outside winter air temperature and the temperature of the road surface in which the system was operating. While effectiveness varied depending on the road and installation conditions, the system was generally able to keep the road surface above 0° C until the outside air temperature fell as low as -6° C, confirming its effectiveness at preventing freezing.

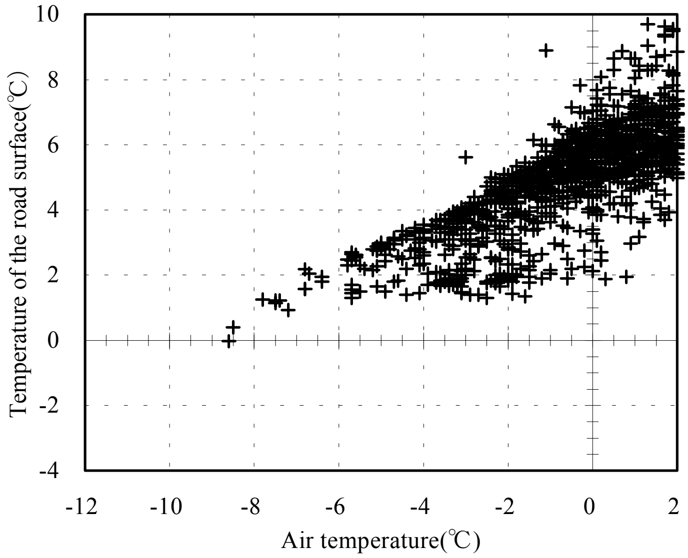

Figure 4 Relationship between the outside winter air temperature and the temperature of the road surface

3. Ground temperature/heat extraction rate stability

Figure 5 shows the frequency distribution of the heat extraction rate for all 25 experimental sites, based on our measurement of the geothermal energy level at each site. Before installing the system, we took these measurements to determine the amount of heat that could be extracted from the ground at each experimental site, so we could determine the number of heat exchange rods needed for the site's applicable surface area. The heat extraction rate and other characteristics of the heat exchange rods were measured by pumping chilled water of a constant temperature through the rods. The ground temperature and the temperature of the water in the piping inside and outside the rods were then measured at the steady state.

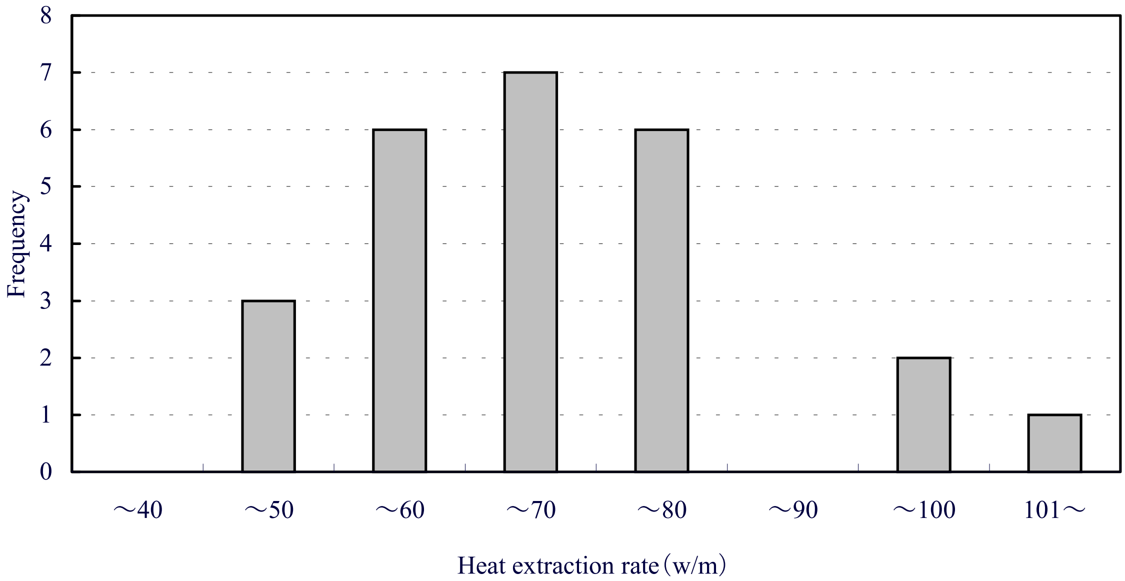

Figure 5 Frequency distribution of the heat extraction rate

The ground temperature and thermal conductivity created some variations in the data, but as shown in Figure 5, our measured heat extraction rate was generally between 40 and 80 W/m (per unit length of heat exchange rod).

Figure 3 also shows how the temperatures of the ground and circulating fluid changed over time while the system was operating. The system was operated continuously for about 100 hours in each case. During that time, the ground temperature was stable during times of peak load, and the supply temperature of the circulating fluid remained stable at around 5℃.

Figure 6 shows the change in the heat extraction efficiency of the heat exchange rods throughout winter. Heat extraction efficiency is defined as follows:

$$\psi = \frac{To - Ti}{Tg - Ti} \times 100$$

Where,

ϕ = Heat extraction efficiency (%)

To = Temperature at heat exchange rod exit (℃)

Ti = Temperature at heat exchange rod entrance (℃)

Tg = Ground temperature (℃)

While weather variations created some small fluctuations in the data, the heat extraction efficiency remained stable throughout the winter, confirming that the system can stably supply heat while continuously extracting heat from the surround.

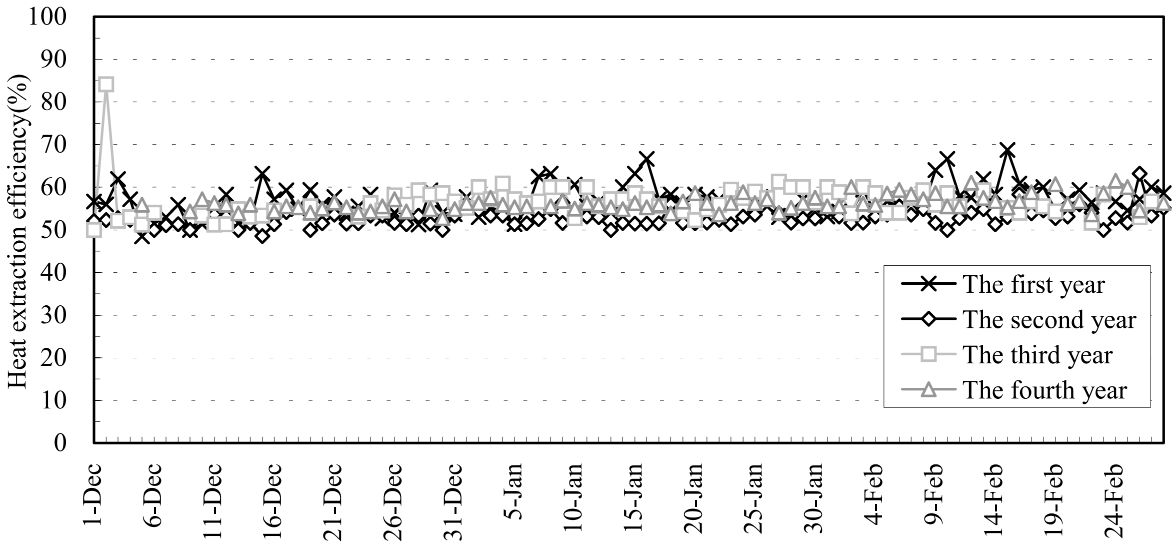

Figure 6 change in the heat extraction efficiency

4. Yearly energy budget and energy costs

Figure 7 shows the system's yearly thermal energy budget created by the heat transferred between the heat exchange rods and the ground. The heat transferred from the heat exchange rods to the ground is defined as a positive value, and the heat transferred from the ground to the heat exchange rods is defined as a negative value. From December to March, the amount of heat in the system was negative, indicating heat extraction from the ground. April to November was the system's heat storage period, with July the peak month for heat storage. While weather variations created some fluctuations, the general trend was consistent. The cumulative amount of heat storage was over 20% greater than the cumulative amount of heat extraction, a relatively large figure.

Table 1 shows the cost of the electricity needed to operate the system to melt snow in winter. Although the figures vary depending on the weather and system capacity, BHES can generally be operated for between 100 and 300 yen/m^2/year. We can say it requires much less energy than conventional electrical heating methods (costing about 5,600 yen/m^2/year) or oil boiler systems (costing about 2,500 yen/m^2/year).

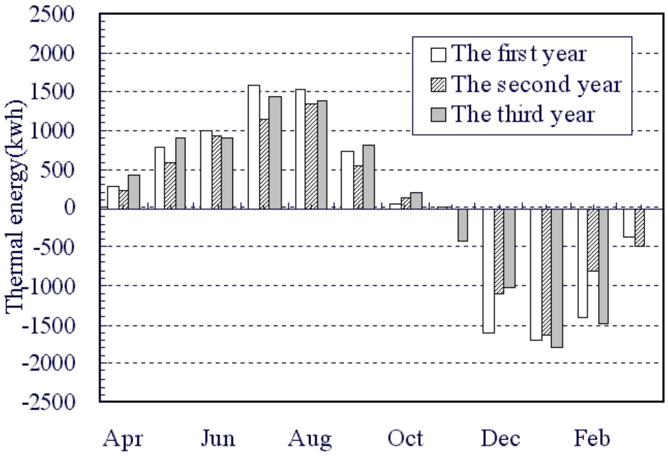

Figure 7 System's yearly thermal energy budget

Table 1 Operation cost

snow-melting surface area (m^2)	Operation cost (yen/m^2・year)
220	115
210	120
533	173
572	187
1,085	193
100	130
440	254
246	254
62	281

5. Ability to reduce fossil fuel consumption and CO_2 emissions

Table 2 shows the system's coefficient of performance (COP), amount of alternative energy supplied, and reduction in CO_2 emissions. The figures were calculated from the system's cumulative extracted heat and power consumption in winter. The system's COP was calculated by the following formula:

$$COP = \frac{Es}{Ep}$$

Where,

COP = System's coefficient of performance

Es = Total extracted heat

Ep = Total amount of energy needed to drive

Table 2 System's coefficient of performance

	cumulative extracted heat (kwh)	power consumption (kwh)	coefficient of performance (COP)	The amount of petroleum substitution (kℓ)	reduction in CO_2 emissions (t・C)
The first year	133,921	17,688	7.6	26.8	13.9
The second year	176,301	22,459	7.8	35.5	18.5
The third year	122,922	16,026	7.7	24.7	12.8
The fourth year	146,124	18,755	7.8	29.4	15.3

BHES has a COP of 7.8, indicating that the energy it supplies to the road surface is 7.8 times the amount of power it consumes. This COP value indicates that about 87% of the energy supplied to the road surface is extracted geothermal energy, underscoring the system's extremely efficient use of natural energy.

We estimated the system's rates of primary energy consumption and CO_2 emissions, and compared the values to those for conventional electric and hot water boiler snow-melting systems. Table 3 shows the estimated cumulative oil consumption and CO_2 emissions of 13 sites making joint use of BHES (with a total snow-melting surface area of 8,581 m^2).
The sites' estimated oil consumption was 86,000 liters, with CO_2 emissions equivalent to 45,000 kg of carbon. This level of CO_2 emissions was 301 tons lower than the figure for electrical heating systems, and 173 tons lower than the figure for hot water boiler systems.

By using natural energy for the majority of the energy consumed for snow melting, BHES has an extremely low rate of CO_2 emissions, and has demonstrated a quantitative lessening of environmental impact.

Table 3 Estimated cumulative oil consumption and CO_2 emissions

	primary energy consumption (ℓ)	CO_2 emissions (kg・C)
The electric heat method	665,000	346,000
Hot water boiler method	316,000	218,000
BHES	86,000	45,000

6. Summer heat storage and yearly heat transfer characteristic

We compared yearly changes in the ground temperature, with and without the use of the system's summer heat storage function. The result is shown in Figure 8, which shows the ground temperature every year before the start of winter operation of the system. When heat storage was performed, we confirmed a yearly increase in the ground temperature. When only winter heat extraction was performed each year without heat storage operation, there was almost no yearly drop in ground temperature. In this case, the ground temperature returned to close to its natural level.

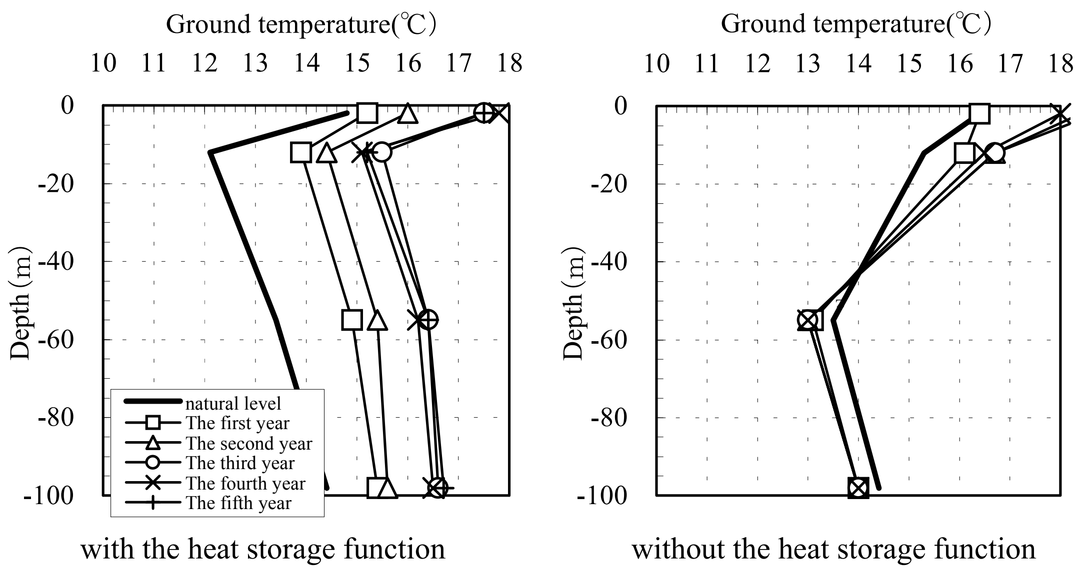

Figure 8 Yearly changes in the ground temperature

7. Conclusion

This study has demonstrated that the BHES sprinkler-free snow-melting system using geothermal energy is reliable, reduces environmental impact, and has a low yearly heat transfer characteristic. The study's conclusions are listed below.

(1) BHES can completely melt snow on road surfaces for snowfalls of up to 25 cm/day with snowfall rates of up to 2 cm/hour.

(2) BHES can prevent road surface freezing in outside air temperatures as low as –6℃.

(3) BHES can provide a stable heat supply throughout the winter, with no yearly drops in the amount of heat supplied.

(4) BHES provides efficient use of natural energy, and can greatly reduce the rates of primary energy usage and CO_2 emissions.

In future, geothermal, solar, and other natural energy sources will play a large role in road snow-clearing systems. The design of these systems must consider the need for passable roads in snowbound areas, environmental preservation, and the maintenance of access to amenities in the community. We believe that this study will serve as a foundation for the systems of the future.