PAVEMENT SNOW MELTING SYSTEMS USING GROUND HEAT AT "MICHI-NO-EKI", HACHI-KITA

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1. Abstract

"MICHI-NO-EKI", “HACHI-KITA” has been in operation on Route 9 in MURAOKA, Hyogo prefecture, since March 1998. "HACHI-KITA" has two types of snow melting systems using ground heat that is typical of untapped energy. One is a Reservoir Heat Collection System (RHCS) that includes two water tanks under the ground developed for melting snow on the parking lot of 1120m^2 to put on or take off tire chains safely. The other is a Borehole Heat Exchange System (BHES) used for melting snow on a sidewalk of 310m^2. Temperatures at one hundred sixty points, meteorological data and heat carrier fluid flow rates have been monitored continuously and automatically.

This paper presents the snow melting and pavement cooling performance of the RHCS and of the BHES and the monthly changes of the tank water temperatures and of the surrounding ground temperatures, besides the seasonal thermal energy storage of the RHCS.

2. Introduction

Approximately 63% of the land area in Japan is subject to heavy snowfalls, and 37% of all the population lives in the snowy regions. The currently widely used groundwater sprinkling systems are

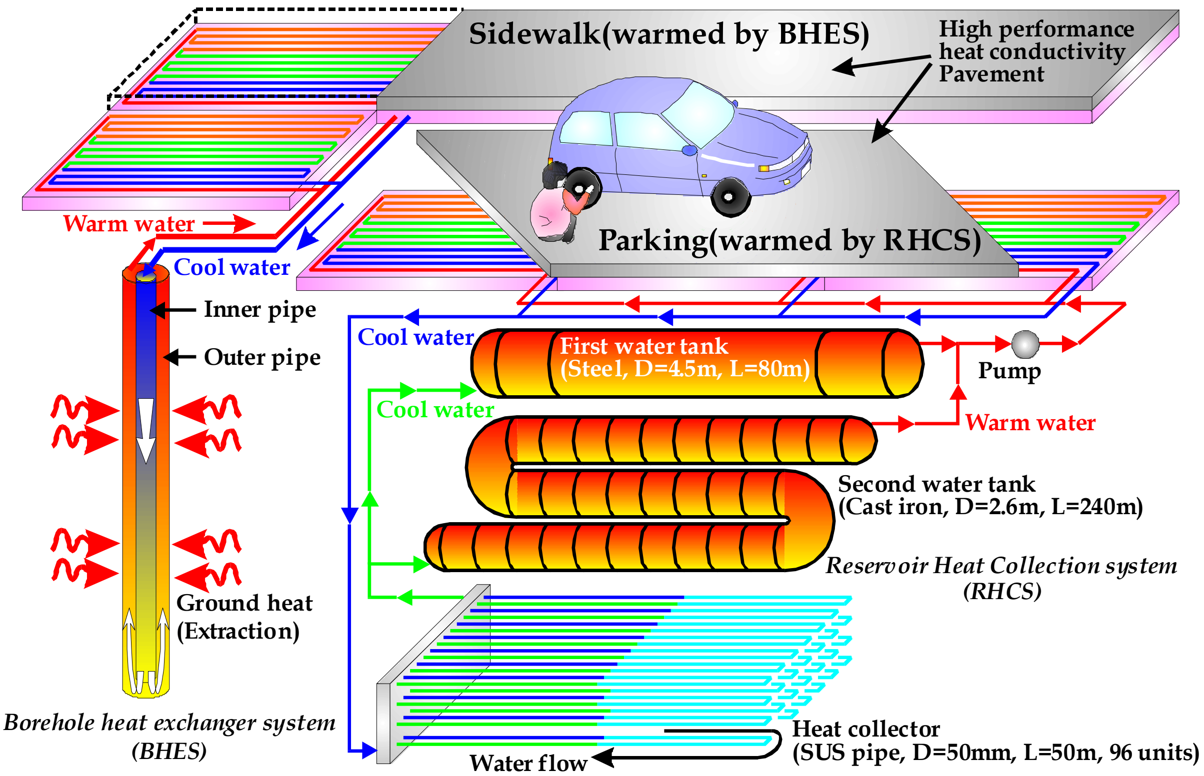


Figure 1 Schematic view of snow melting systems using ground heat at “ HACHI-KITA”

energy efficient but sometimes cause serious ground subsidence, lowering of the groundwater table, water pollution and other environmental problems. In a major snowy region near the Japan Sea coast, the temperature of the ground below about 5m from the surface stays within a seasonal range 10℃ to 18℃ (SASATANI et al., 1991, WATANABE et al., 1995, KAMIMURA et al., 2000 and YOKOYAMA et al, 2001). This, along with the weather and soil characteristics found in this region, suggests the suitability of using ground heat directly to melt snow on roadways without using heat pumps.

The snowy area “HACHI-KITA” is located in the foot on the highest "Hyono" mountain in Hyogo prefecture and is at a high altitude of 340m. It is often crowded with many skiers from Osaka, Kobe and Kyoto because of traffic convenience. Moreover, there is a steep road with a maximum of 8% of inclination on both sides of "Tajima" tunnel. For these reasons a parking area to put on or take off tire chains has been required for many years for winter traffic safety. Therefore, the snow melting (road heating) systems, schematically shown in Figure 1, were designed by the authors and constructed at the "MICHI-NO-EKI", which is a kind of public parking and road service station, at "HACHI-KITA", MURAOKA town in 1998. "HACHI-KITA" has two types of snow melting systems using ground heat. One is the RHCS (Reservoir Heat Collection System) that includes two water tanks buried 5m below and applied to a parking area of 1120m^2. The other is the BHES (Borehole Heat Exchange System) for melting snow on a sidewalk of 310m^2. In the remaining area (3160m^2), where users do not normally walk, a sprinkling snow melting system using river water from near " HACHI-KITA" parking lot was adopted.

This paper describes thermal interaction between the tank water and the surrounding ground, monthly heat energy balance of the water tank from 1998 to 2000 and the seasonal thermal energy storage of the RHCS.

3. Ground heat usage in “HACHIKITA”

3.1. RHCS

The RHCS consists of two water tanks and a heat collector. The first water tank was fabricated from steel (diameter 4.5m, length 80m), the second water tank was fabricated from cast iron (diameter 2.6m, length 240m) and the heat collector was a group of 96 stainless pipes (diameter 50mm, length 50m). It should also be noted that the tank water could be used multi-purposely as an urgent water supply in the case of fire and disaster.

As the arrows in Figure 1 illustrate, relatively warm fluid is supplied from the upper part of the water tank to the heat exchanger pavement slab (snow-melting pavement), suppressing the decrease in the pavement temperature that would otherwise occur. The heat carrier fluid is then cooled as it passes through the pavement heat exchanger pipe, until it returns to the lower part of the water tank via the heat collector. If the tank water temperature is lower than the surrounding ground, heat flows from the ground toward the water tank, preventing the tank water temperature from dropping rapidly.

On the other hand, when the ground temperature is lower than the pavement slab temperature, relatively cool fluid is supplied from the lower part of the water tank to the heat exchanger pavement slab. Therefore the ground heat as a cool source can suppress the rise in pavement temperature that would otherwise occur. The heat carrier fluid is then warmed as it passes through the pavement heat exchanger body, until it returns to the upper part of the water tank. If the tank water temperature is higher than the surrounding ground temperature, heat flows from the water tank toward the ground, preventing the pavement from rutting due to heavy vehicles. This summer operation of the RHCS can contribute more effectively to the long-term heat usage.

3.2. BHES

The BHES consists of a long borehole heat exchanger and the snow-melting pavement with a heat exchanger pipe embedded 3cm below the sidewalk surface. The borehole is 100m in length and comprises an inner and an outer pipe made of polyethylene. The inner pipe is 56mm outside diameter with a 3mm wall thickness. The outer one is 90mm outside diameter with 4mm wall thickness. Based on the preliminary test in 1996, twelve boreholes were vertically installed in a small vacant lot behind the parking buildings such as a shopping store and a restaurant.

In winter, the fluid, returning from the heat exchanger pipe in the sidewalk, is circulated downward along the inner pipe and upward along the outer pipe. The ground heat extracted through the borehole is used as a heat source to melt the snow. In summer, the heat of the pavement, received from the atmosphere, is injected to the ground during the circulation in the borehole, so that the BHES can

Photo. 1 Overview of pavement connected to RHCS and BHES (Aug. 3, 1999)

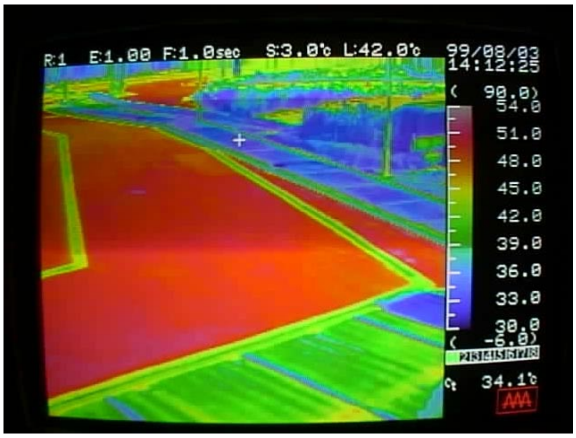


Photo. 2 Isothermal contour of pavement connected to RHCS and BHES (14:12, Aug. 3, 1999)

Photo. 3 Snow melting condition of pavement connected to RHCS and BHES (Jan. 21, 2000)

Photo. 4 Snow melting condition of pavement connected to RHCS (Jan. 12, 1999)

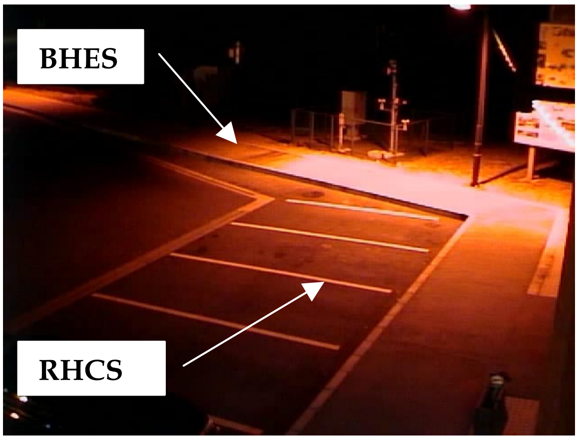


Photo. 5 Overview of pavement connected to RHCS and BHES (Jan. 12, 2000)

Photo. 6 Isothermal contour of pavement connected to RHCS and BHES (Jan. 12, 2000)

suppress the rise in the sidewalk temperature.

3.3. Pavement temperature control and operation of the system

To optimize the operation of the RHCS and of the BHES, running times should be limited to the minimum required to completely melt snow or to maintain sufficiently low pavement temperatures in summer. Although the operation can potentially be refined further, the RHCS and the BHES are presently operated according to the following criteria. In winter, flow commences when the temperature at a point 0.01 m below the snow-melting pavement surface falls below 7℃ and stops when it subsequently rises above 10℃. In summer, flow commences when the pavement temperature rises above 25℃ and stops when it subsequently falls below 20℃. These setting temperatures were sometimes changed for purposes of the experiment.

4. Seasonal pavement temperature control

4.1. Pavement cooling performance in summer

Photo.1 shows the overview of the pavements coupled with the RHCS and the BHES, i.e., the snow-melting pavements, and of adjoining normal pavements. Photo 2 is the isothermal contour of the surface temperatures of the pavements appearing in Photo.1 and was measured at 14:12, August 3, 1999. This figure indicates that the pavement cooling performance of the RHCS and the BHES is very definite. It was observed that the surface temperatures of the snow-melting pavements were approximately 20℃ lower than those of the normal pavements.

4.2. Snow melting and deicing performance in winter

Photos. 3 and 4 indicate that the BHES and the RHCS have a significant snow melting and deicing performance. Without minding a slippery pavement and sprinkling water, the users became able to walk around the parking area and to put on or take off tire chains safely.

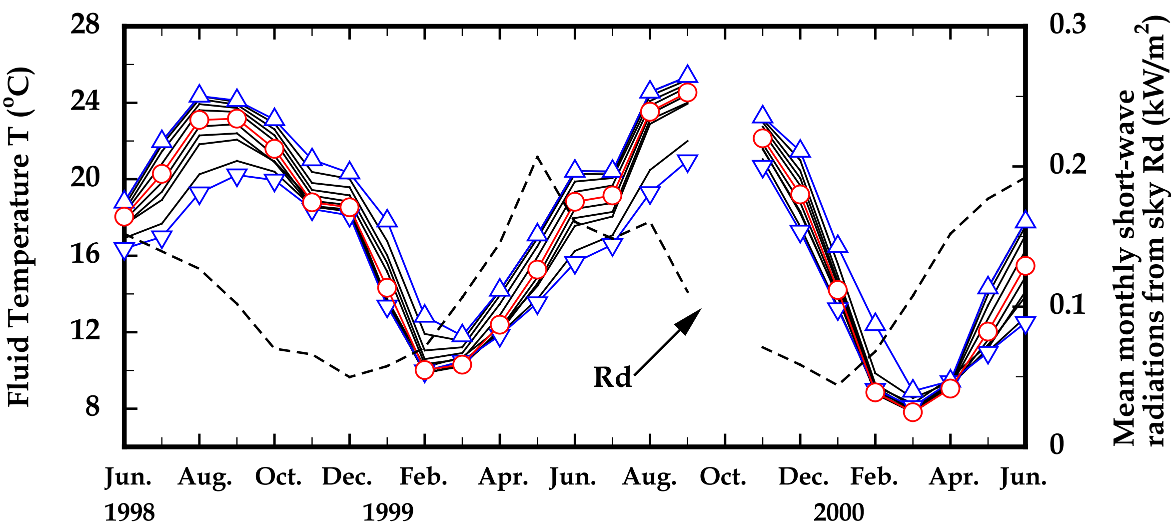
Photo. 5 shows the overview of the snow-melting and normal pavements subjected to radiative cooling (2:00, Jan. 12, 2000).

Photo. 6 is the isothermal contour of the surface temperatures of the pavements in Photo. 5. The surface temperatures of the snow-melting pavements were approximately 5℃ higher than those of the normal pavements. It was also seen that the RHCS and the BHES have a sufficient snow melting and deicing performance.

5. Thermal behavior of RHCS

5.1. Monthly change of the tank water temperature

It is important to discuss whether or not the RHCS has the function of the seasonal thermal energy storage (STES) and if the STES contributes to the pavement cooling and snow melting performance. Figure 2 shows the time variations of fluid temperatures in the first water tank. The symbols of the triangle, the circle and the reversed triangle represent the top, middle and bottom of the water tank, respectively. The measuring system broke down in October 1999 causing a lack of data. The upper fluid temperature (△) reached 24℃ in August of the first year, and fell to 10℃ at the end of the following winter. However, it had kept a temperature higher than 20℃ in December, just before the heavy snow season. The difference between the top and the bottom fluid temperature was approximately 5℃ in August 1998 and was approximately 1℃ in March 2000. It was smaller in winter than in summer. The tank water, however, was always stratified and stable. The minimum fluid temperature, 8～10℃ is still capable of melting snow on the pavement. As mentioned above, the seasonal variation



Figures 2 Time variations of fluid temperatures

of the tank water temperatures depends on the climate, the snow melting operation and the pavement cooling operation.

5.2. Monthly change of tank water and ground temperature profiles

Figure 3 shows the monthly change of two-dimensional profiles of the tank water temperatures and the ground temperatures around the first water tank from June 1998 to May 1999. In this figure, the horizontal axis x/r and the vertical axis h/r are the dimensionless distance, normalized by the tank diameter (r=2.25m). The temperature profiles in the range of 5 m around the water tank are drawn horizontally and vertically.

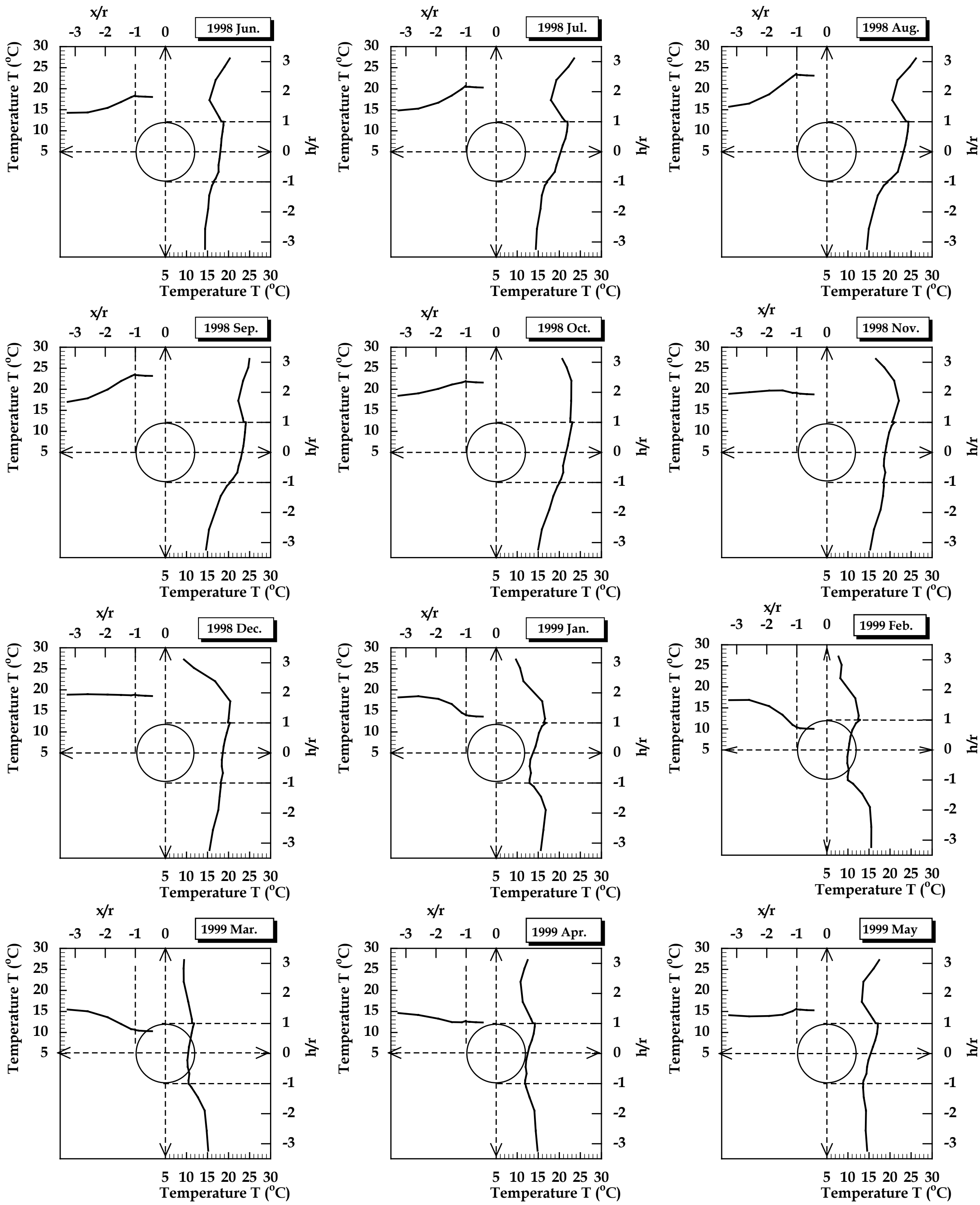


Figure 3 Temperature profiles of tank water and the surrounding ground from June, 1998 to May, 1999

The period from June to August 1998: Since relatively warm fluid returns to the upper part of the water tank during the summer, the tank water and the surrounding ground temperatures were gradually raised. The horizontal temperature profiles show that the rise of the ground temperature becomes more obvious as one approaches the water tank. In the vertical profiles, the ground temperature clearly rose nearer the water tank and nearer the ground surface.

The period from September to November 1998: The ground temperature gradient in the horizontal direction gradually decreased with time. The negative gradient of the vertical ground temperature profile becomes clear near the ground surface with time. The top fluid temperature was higher than the bottom one and the tank water was stratified as mentioned above.

The period from December 1998 to February 1999: The ground temperature near the water tank was uniform in the horizontal direction in December at approximately 20℃, 5℃ higher than the ambient ground temperature. From January through February, the fluid temperature rapidly decreased about 10℃, associated with the warm energy extraction for snow melting. However, the ground temperature 5m below the tank bottom was mostly steady and remains about 15℃ for a long time in spite of the depression of the tank water temperature. From this result, it was found that the heat storage in summer is effective against snowfalls in the beginning of the winter season at least.

The period from March, 1999 to May: The minimum tank water temperature recovered slowly to about 10°C, due to the extraction of ground heat and with the inflow of warm fluid into the water tank through the pavement cooling operation.

5.3. Seasonal heat energy balance of RHCS

The heat energy balance of the water tank is governed by the following equation (FUKUHARA et al., 2000).

$$dU = E_G + E_F \qquad (1)$$

where, dU is the time rate of the internal energy of the tank water, E_G is the energy flux across the tank wall (E_G>0 corresponds to the incoming ground heat) and E_F is the net energy gain from the circulating heat carrier flow. E_F is calculated from the product of the volumetric heat capacity (ρc), the circulation flow rate Q and the difference between the inlet temperature T_{in} and the outlet temperature T_{out}.

Figure 4 shows the time variation of heat energy budget of the first water tank from May 1998 to June, 2000. The value of E_F was negative from November to March, associated with the

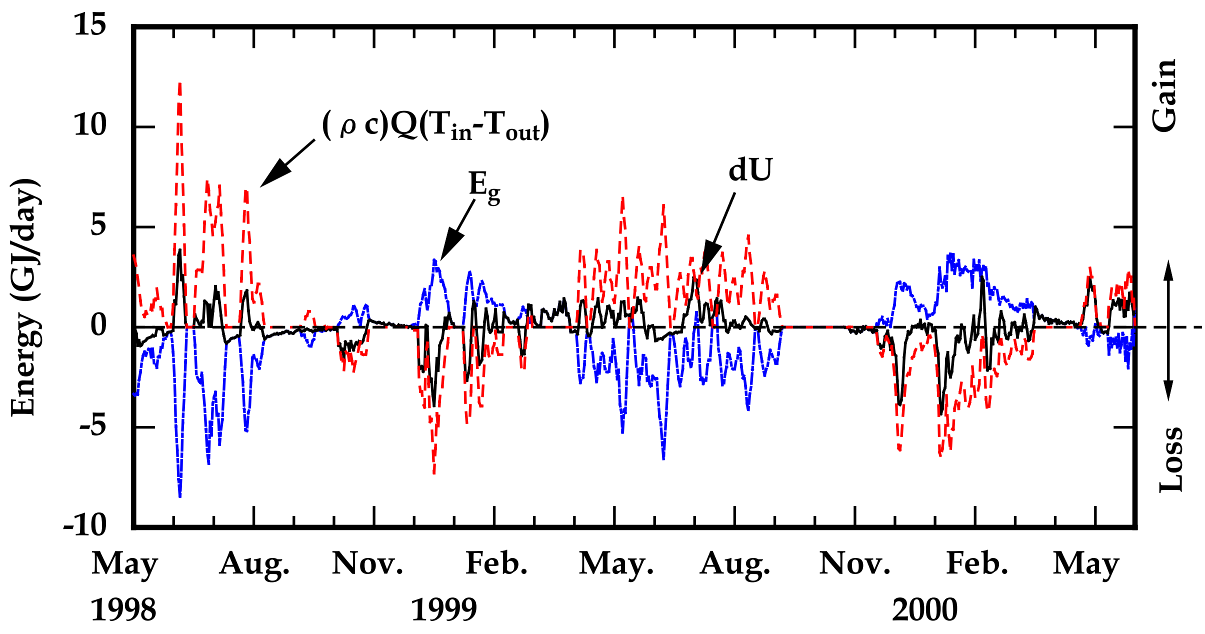


Figure 4 Time series of heat energy balance of the first water tank from May 1998 to Jun., 2000

snow-melting operation. On the other hand, E_F was positive from April to September, due to the pavement cooling operation. There exists a strong negative correlation between E_F and E_G. This means that the heat energy supplied from the water tank to the snow-melting pavement is smoothly transported from the ground during winter and that the heat energy gained from the snow-melting pavement was smoothly injected to the ground through the tank wall during summer. Consequently, this seasonal heat transfer enables the suppression of a severe increase or decrease of dU.

6. Conclusion

For the purpose of monitoring the thermal behavior of the RHCS and of finding out its optimal operation, continuous measurements of the tank water temperatures and the surrounding ground temperatures have been carried out at “HACHI-KITA” since March 1998.

The following conclusions were drawn:

1) As the heat energy released from the heat exchanger pipe placed in the pavement can keep the pavement temperature over 6℃, the snow melting performance of the RHCS and the BHES was completely satisfactory. This fact made it possible and easy for the drivers and users to walk on a snow-free pavement from the parking lot to the "MICHI-NO-EKI" buildings and to safely put on or take off tire chains.
2) The fluid temperature was as high as 19.8℃ on December 31 and there existed a ground zone with a high temperature (17-20℃), which was 2-5℃ higher than the ambient ground temperature around the water tanks, even in winter. From these results, it was confirmed that the thermal energy storage during summer remained until the beginning of the following winter.
3) The pavement cooling operation could suppress the pavement temperature to lower than 40℃ in summer. This can prevent the pavement from rutting due to heavy vehicles and can reduce upward radiation from the pavement and sidewalk surfaces.
4) A part of the snow melting performance and the pavement cooling performance is supported by the seasonal thermal energy storage of the water tank and the surrounding ground as far as the RHCS is concerned.

7. References

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