# SNOW MELTING SYSTEM USING SHALLOW GROUND HEAT AT “MICHI-NO-EKI”, HACHI-KITA

H. Watanabe
Department of Architecture and Civil Engineering, University of Fukui
hw@snow.xrea.jp

T. TANAKA
Ministry of Land, Infra. And Trans., Japan
tanaka-t86iy@kkr.mlit.go.jp

K. KAWASAKI
Ministry of Land, Infra. And Trans., Japan
kawasaki-k86ij@kkr.mlit.go.jp

T. FUKUHARA
Department of Architecture and Civil Engineering, University of Fukui
fukuhara@u-fukui.ac.jp

## ABSTRACT

"MICHI-NO-EKI" (a kind of rest area or travel plaza), “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 to create areas where drivers can put on or take off tire chains safely and where people can walk safely. One is a Reservoir Heat Collection System (RHCS) that includes two underground water tanks developed for melting snow on a parking lot with an area of 1120m$^2$. The other is a Borehole Heat Exchange System (BHES) used for melting snow on a sidewalk with an area of 310m$^2$. Temperature data from 160 locations, meteorological data, and heat carrier fluid flow rates are monitored continuously and automatically. The RHCS and the BHES can provide a snow-free parking lot and sidewalk areas and can be used as a road cooling system during the summer to lower the surface temperature of the pavement connected with the RHCS by 10-15 °C compared with normal pavement temperatures. The road cooling operation is also effective at enhancing the road heating performance in the early winter through the use of seasonal thermal energy storage (STES). Use of RHCS reduced carbon dioxide emissions by 292ton for one winter, compared to a conventional electric road heating system.

## KEYWORDS

ROAD HEATING / ROAD COOLING / GROUND HEAT / RHCS / BHES / STES

## 1. INTRODUCTION

Approximately 63% of the land area in Japan is subject to heavy snowfalls, and 37% of the population lives in snowy regions. Recent years have seen wide use of groundwater sprinkling systems that are economically efficient but can 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 about 5m below the surface stays within a seasonal range 10°C to 18°C (SASATANI et al., 1991, WATANABE et al., 1995 and FUKUHARA et al., 2000). 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 the use of heat pumps.

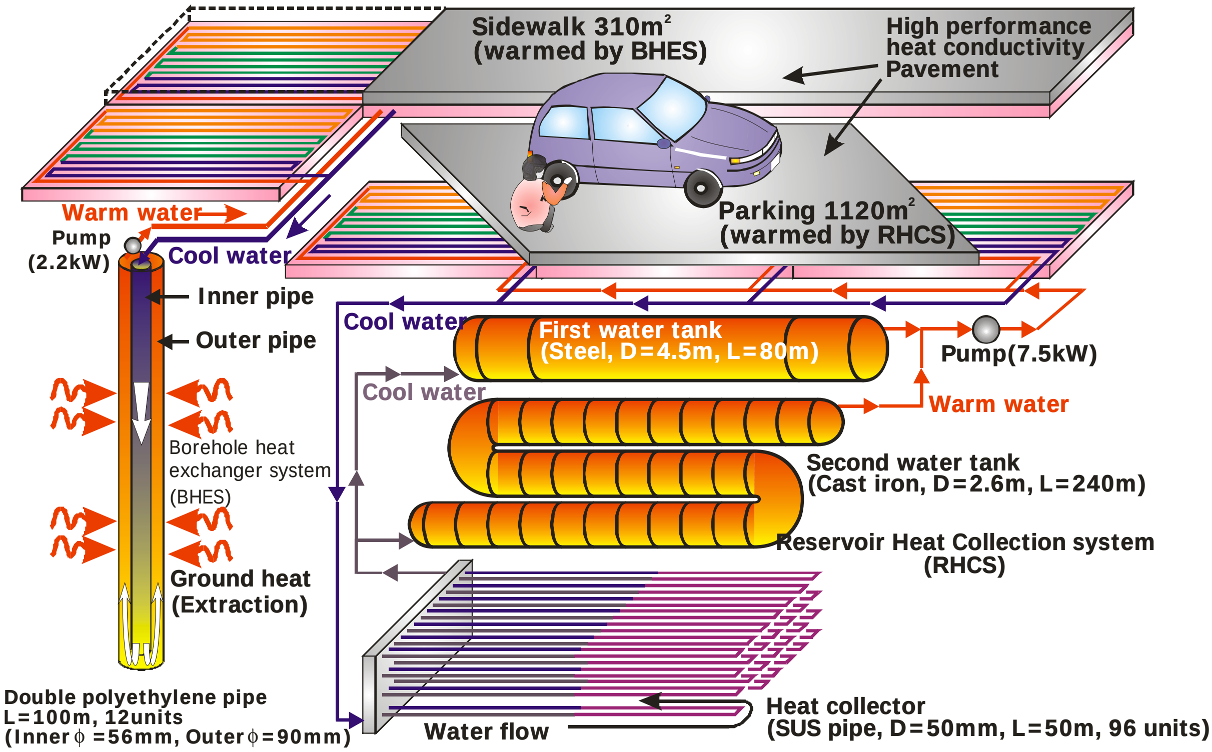


Figure 1 – Schematic view of snow-melting systems using ground heat at " HACHI-KITA"

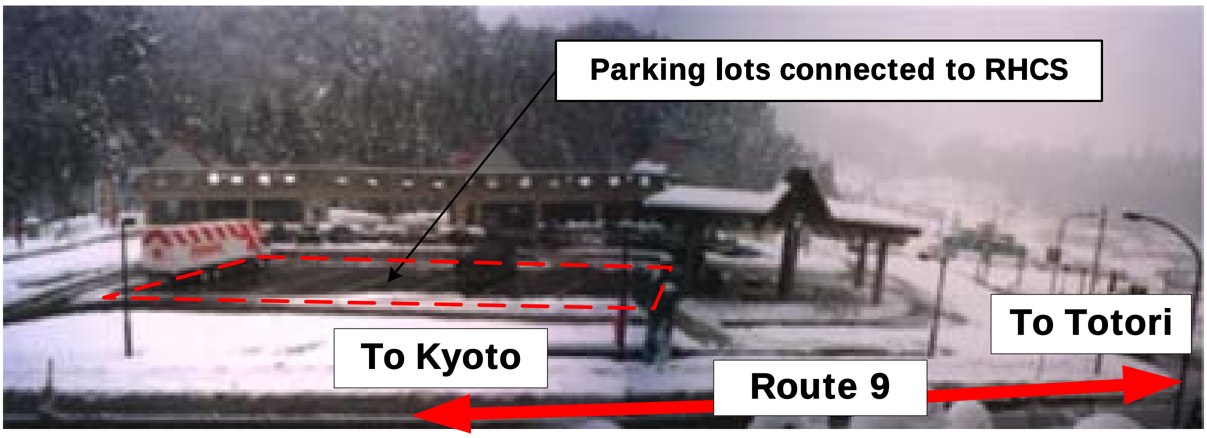


Photo. 1 – Snow melting conditions at "HACHI-KITA"

The snowy area "HACHI-KITA" is located at the foot of "Hyono," the highest mountain in Hyogo prefecture, at an altitude of 340m. It is often crowded with many skiers from Osaka, Kobe and Kyoto because of its convenient access to transportation systems. Moreover, there is a steep road with a maximum 8% incline on both sides of the "Tajima" tunnel. For these reasons, a parking area to put on or take off tire chains was desired for many years to enhance traffic safety during the winter. Therefore, the snow-melting (road heating) systems, schematically shown in Figure 1 and Photo 1, were designed by the authors and constructed at the "MICHI-NO-EKI", a kind of rest area or travel plaza, 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 the ground surface adopted for the road heating/cooling of a parking lot with an area of 1120m$^2$. The other is the BHES (Borehole Heat Exchange system) for melting snow on a sidewalk with an area of 310m$^2$. In the remaining areas (3160m2), where users do not normally walk, a sprinkling snow-melting system (a popular snow-melting system in this area) using river water from near "HACHI-KITA" was adopted (WATANABE et al., 2002 and FUKUHARA et al., 2002).

This paper primarily describes the road heating/cooling performance, energy balance, and the carbon dioxide emission reduction of the RHCS, using data collected continuously from 1998 to 2005.

## 2. GROUND HEAT USAGE IN HACHI-KITA

### 2.1. 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 be noted that the tank water can also be used as an emergency water supply in the case of fire or other 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 any fall in the pavement temperature in winter. 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. Conversely, when the ground temperature is lower than the pavement temperature, relatively cool fluid is supplied from the lower part of the water tank to the snow-melting pavement. Therefore, the ground heat as a cooling source can suppress the rise in pavement temperature in summer. 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. This heat flow can prevent the pavement from rutting due to heavy vehicles and can reduce the upward long-wave radiation from the pavement surface. From the perspective of the balanced use of underground heat, summer operation (road cooling operation) of the RHCS contributes effectively to the long-term usage of the heat.

### 2.2. BHES

The BHES consists of a long borehole heat exchanger and a snow-melting pavement with a heat exchanger pipe embedded 3cm below the sidewalk surface. The borehole is 100m in length and is comprised of inner and outer pipes made of polyethylene. The inner pipe has an outside diameter of 56mm with a 3mm wall thickness. The outer pipe has an outside diameter of 90mm with 4mm wall thickness. Based on preliminary testing in 1996, twelve boreholes were vertically installed in small open spaces between buildings behind the parking lot, including a gift shop 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 for road heating. In summer, the heat of the pavement (a black body that absorbs solar radiation) is injected to the ground during the circulation in the borehole, such that the BHES can suppress the rise in sidewalk temperature.

## 3. SEASONAL PAVEMENT TEMPERATURE CONTROL

### 3.1. Snow melting and de-icing performance in winter

Photo. 2 shows the snow-melting conditions on the sidewalk connected to the BHES and on the parking lot connected to the RHCS. Both the BHES and the RHCS have significant

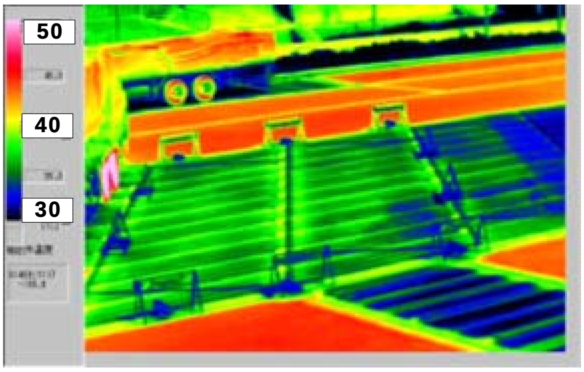

Figure 3 – Thermograph of road cooling in summer

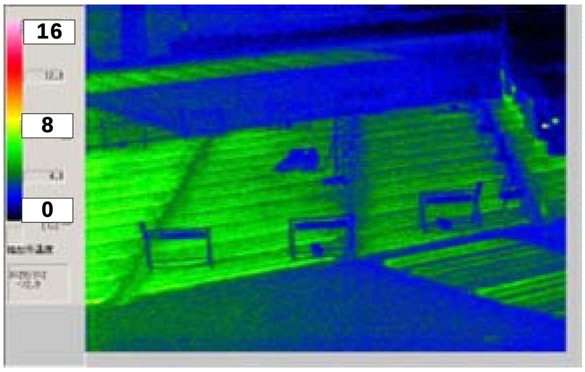

Figure 4 – Thermograph of road heating in winter

snow-melting / de-icing performance. Users are now able to walk around the parking lot buildings without slipping and to put on or take off tire chains safely

3.2. Pavement temperature control in summer and winter

Figures 3 and 4 show the isothermal contours of the surface temperature on the parking lot in summer and in winter, respectively. The former is a typical thermal image during road cooling operation. The surface temperature of the pavement connected with the RHCS, Ts, was about 15-20°C lower than that of the normal pavement, Tn. The distribution of the pipes associated with the circulation of cool water supplied from the water tanks is clearly recognizable. Figure 4 is a typical thermal image during road heating operation. Ts was approximately 5°C higher than Tn. It can be seen that the RHCS has sufficient snow-melting/de-icing performance and road cooling potential.

## 4. THERMAL BEHAVIOR OF RHCS

4.1. Monthly change of the fluid temperatures in the first water tank

It is important to know how the fluid temperature in the two water tanks and the surrounding ground temperature change in relation to long-term use. Figure 5 shows the time variations of the ground temperature, Tg, (thick solid line), the fluid temperatures in the first water tank, Tw1 (three symbols) and the monthly operation time, Op1 (thin solid line). The three symbols for Tw1 (circle, triangle and square) represent the top, middle and bottom of the first water tank, respectively. Tg is an ambient ground temperature at a depth of 9m below the pavement surface, which is equal to the depth of the centre of the first water tank, and ranged from 11 to 19°C in a year. The maximum of Tg appeared in November and then Tg gradually fell to the minimum in April. The minimum of Tw1, Tw1min, remarkably rose from 10 to 15°C in winter of 2002-2003 because the road heating operation was conducted intensively to evaluate the road heating performance of the heat collector for three years beginning 2002. Tw1min, therefore, became same as Tg around March in 2003-2005. On the other hand, the maximum of Tw1, Tw1max, which appeared in August or September, gradually

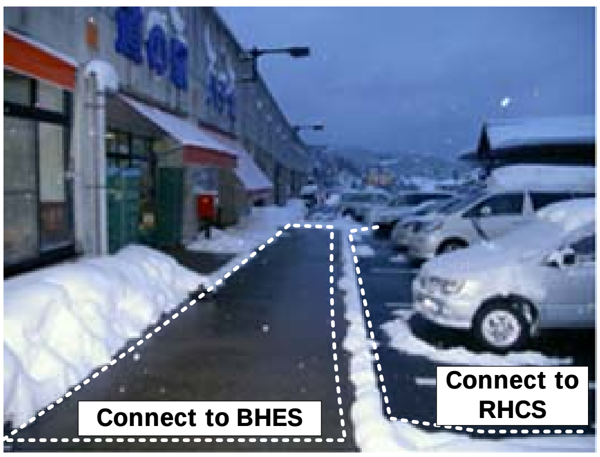

Photo. 2 – Snow melting conditions on the sidewalk and the parking lot

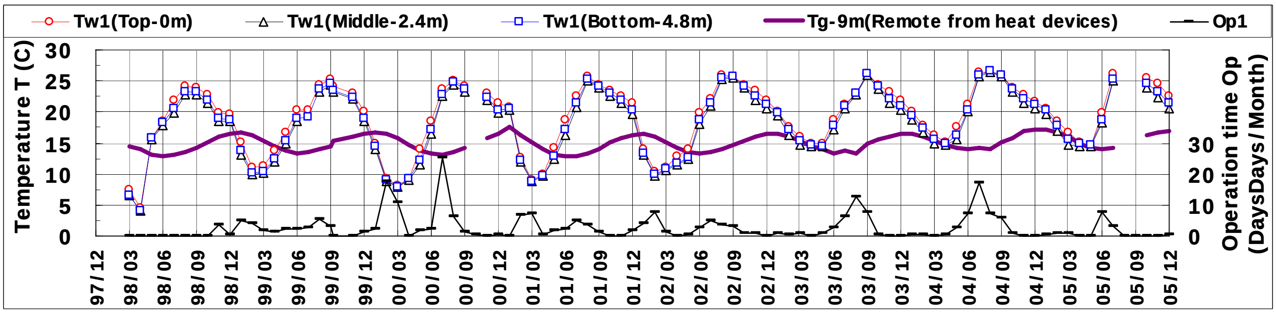


Figure. 5 – Time variations of the ground temperature and the water temperatures of the first water tank

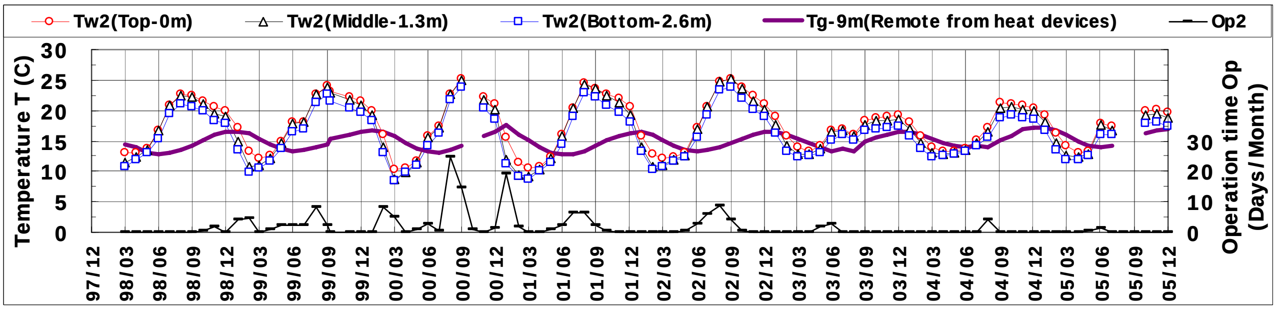


Figure. 6 – Time series of the ground temperature and the fluid temperatures in the second water tank

rose from 24°C in 1998 to 26°C in 2005. This trend may be attributed to the road cooling operation in summer.

4.2. Monthly change of t the fluid temperatures in the second water tank

Figure 6 shows the time variations of the ground temperature, Tg, (thick solid line), the fluid temperatures in the second water tank, Tw2 (three symbols) and the monthly operation time, Op2 (thin solid line). The three symbols (circle, triangle and square) used for Tw2 represent the top, middle and bottom of the second water tank, respectively. The variation of Op2 indicates that the operation of RHCS for road cooling in summer and road heating in winter was repeated in turn during three years (from March 1998 to March 2001). However, it is observed from the profile of Op2 that use of the second water tank was controlled after 2002. This was done to reduce operating costs. The maximum of Tw2, Tw2max, gradually rose from 23 to 25°C, which is related to the storage of solar heat extracted from the snow-melting pavement lot as a result of road cooling operation (1998-2002). After that, Tw2max, however, remarkably fell to 18-20°C, which is related to the restriction of the road cooling operation (2003-2005). Conversely, the minimum of Tw2, Tw2min, rose from 10 to 13°C, which is related to the restriction of the road heating operation (2003-2005). As a result, the difference between Tw2min and Tg in winter became smaller after 2003. It is observed that the road heating operation enhances the road heating performance of the RHCS in winter.

4.3. Monthly change of the ground temperatures around the heat collector

Figure 7 shows the time variations of the ambient ground temperature, Tg, (thick solid line), the ground temperatures around the heat collector, Tgc (two symbols), and the monthly operation time, Opc (thin solid line). The symbols, a circle (Tgc7) and a triangle (Tgc5), represent the bottom and centre of the heat collector, respectively. Tgc7 and Tgc5 were measured at depths of 7m and 5m below the pavement surface, respectively. The time variation of Tgc5 was quite similar to that of Tw1 and Tw2, although the maximum and

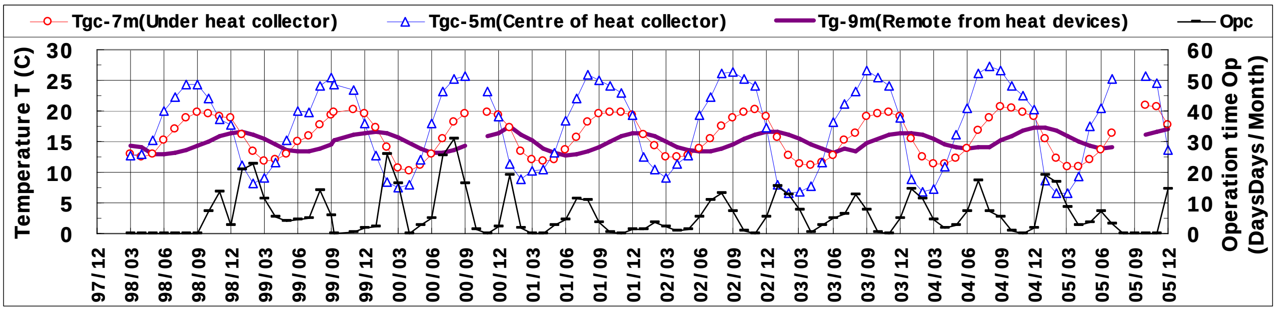


Figure. 7 – Time series of the ground temperatures around the heat collector

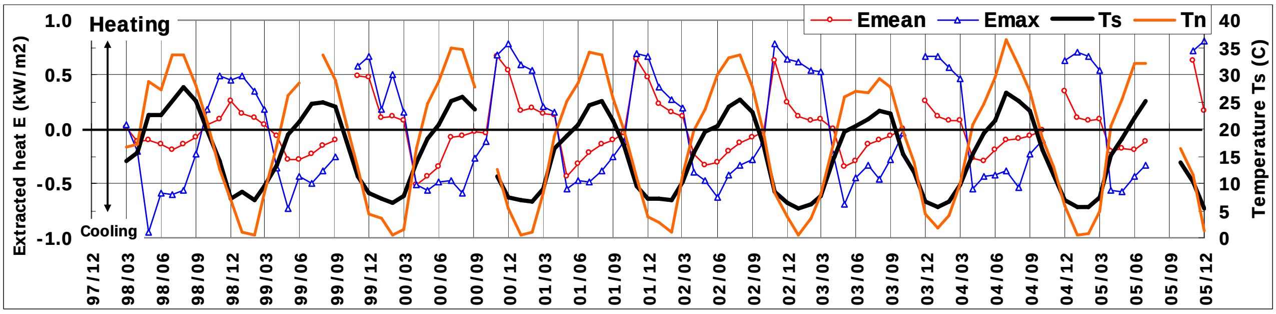


Figure. 8 – Time series of the heat fluxes and pavement temperatures

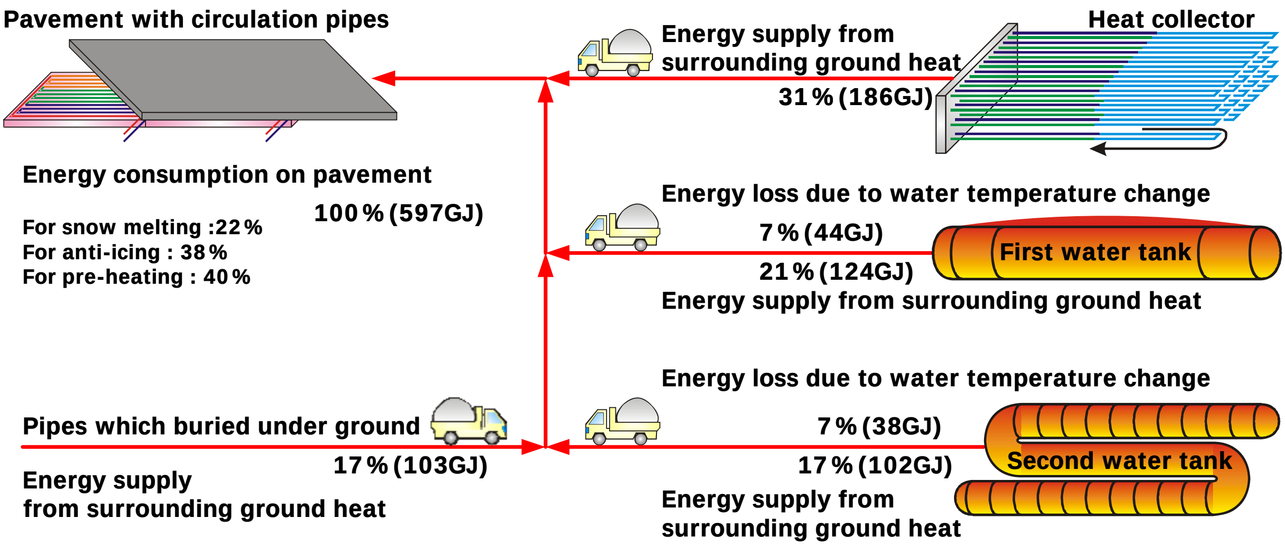


Figure 9 – Energy budget of RHCS from Dec. 1998 to Mar. 1999

minimum of Tgc5 were a little bit higher or lower than those of Tw1 and Tw2, respectively. Of course the amplitude of Tg was smallest and appearance time of the maximum ground temperature were delayed in order of Tgc5, Tgc7 and Tg.

## 4.4. Monthly change of the heat fluxes at the pavement surface

Figure 8 shows the mean pavement flux, Emean, the maximum pavement flux, Emax, the normal pavement temperature, Tn, and the snow-melting pavement temperature, Ts. The pavement flux, E, was calculated by dividing the heat extracted or injected while the heat carrier fluid passed through the heat exchanger pavement by its pavement area. Emean is the monthly average pavement flux and Emax is the maximum value of E every month. The left axis of Figure 8 indicates Emean and Emax and the negative and positive values represent road cooling and road heating, respectively. The value of Emean was kept positive in winter and negative in summer. The absolute value of the Emean depends on the climate conditions and the road heating and cooling operations. The absolute maximum values of Emean were observed immediately before winter and summer, respectively, because the difference between Tw and Ts, ΔT, became greatest during these times of the year. There may be two reasons of the decrease in Emean as time elapsed. One is the rise in Tw over time in summer and the fall in Tw over time in winter. The other reason is the reduction of ΔT associated with the fall in Ts due to the road cooling operation and with the rise in Ts due to the road heating operation. Especially, the second reason stated above indicates that the RHCS has the self control function of saving the extraction of ground heat. Therefore, Emax maintained a high energy level at even the end of summer and winter. Ts was lower by a maximum of 10°C than Tn in summer, while Ts was higher by a maximum of 5°C in winter. It is seen that the ability of the pavement temperature control is guaranteed by the supply of energy from the heat collector and the RHCS.

### 4.5. Energy budget of RHCS during the winter period

Figure 9 shows the schematic view of the heat balance between the first water tank, the second water tank, and the heat collector from December 1998 to March 1999. The total energy consumption on the snow-melting pavement surface was 597GJ. A breakdown of this energy consumption shows that 131GJ was spent for snow-melting, 240GJ for pre-heating, and 226GJ for anti-icing, respectively. On the other hand, the total energy consumption of 597GJ was due to the following factors. First, the internal energy consumption of the fluid in the two water tanks was 82GJ (44GJ for the first water tank and 38GJ for second water tank). The other factor was the extracted ground heat, which reached 515GJ. A breakdown of this extracted energy shows that 124GJ (21%) was from the first water tank, 102GJ (38%) from the second water tank, 186GJ (31%) from the heat collector, and 103GJ (17%) from the heat transportation pipes buried in the ground under the parking lot, respectively.

Finally, it was seen that the total energy consumption of "HACHI-KITA" during one winter was equivalent to the consumption of 130,000 litters of kerosene. This amount is not only equivalent to the electric power consumed by 228 households (family of four) in a year but also represents a reduction of the $CO_2$ emission by 292 tons, compared to a conventional electric road heating system.

## 5. CONCLUSIONS

Long-term monitoring of “HACHI-KITA” was conducted to evaluate the thermal performance of road heating/cooling by the RHCS and the BHES, respectively and the energy efficiency since March 1998. Continuous measurement of the tank water temperatures and the surrounding ground temperatures allows the following conclusions to be drawn;

1) The snow-melting performance of the RHCS was satisfactory, except during occasional heavy snow fall of more than 0.2-0.3m overnight. The RHCS made it possible for drivers and users to walk on a snow-free parking lot and sidewalk, and to put on or take off tire chains safely.
2) Road cooling operations in the summer contribute to the rise in the tank water temperature and the surrounding ground temperature by injecting solar heat into the water tanks and enhance the road heating performance of the RHCS, especially at the beginning of the next coming winter.
3) The RHCS has the self control function of saving the extraction of ground heat when both road heating/cooling operations are conducted.

4) The breakdown of the energy consumption at “HACHI-KITA” in winter (597GJ) was 22% due to snow-melting, 38% to anti-freezing and 40% to the pre-heating of the pavement, respectively.
5) The contribution rate to the total thermal energy extracted from the shallow ground was 31% from the heat collector by, 52% from the two water tanks, and 17% from the heat transportation pipes buried in the ground under the parking lot.
6) Use of RHCS reduced carbon dioxide emissions by 292ton for one winter (equivalent to consumption of 130,000 litters of kerosene), compared to a conventional electric road heating system

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