Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Snow-Melting on Sidewalks with Ground-Coupled Heat Pumps in a Heavy Snowfall City

Koji Morita[1] and Makoto Tago[2]

[1]National Institute of Advanced Industrial Science and Technology, 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan

k.morita@aist.go.jp

[2]Akita University, 1-1 Gakuen-cho, Tegata, Akita 010-8502, Japan

mtago@mech.akita-u.ac.jp

Keywords: snow-melting, heat pump, ground heat exchanger, GCHP, geothermal, solar heat, heat storage

ABSTRACT

The authors along with others have developed the Gaia Snow-Melting System. This system consists of vertical ground heat exchangers, a heat pump and heating pipes embedded in a pavement body. This system utilizes geothermal heat and summer time solar heat for melting snow.

In 2002, two Gaia Snow-melting systems were completed in Aomori City, Japan, for melting snow on sidewalks. This city is said to be the snowiest city in the world among cities with populations of about 300 thousand or more. Annual snowfall sometimes exceeds 10m. The formation at the snow-melting site is a complex of unconsolidated sedimentary formations along the total length of the heat exchangers (151.4m long). The measured in-situ thermal capacity and effective thermal conductivity of the formation as determined by a thermal response test were 2.2 MJ/m^3·K and 1.25 W/m·K, respectively, for the total section of the heat exchangers. The heat transfer mechanism in the formation indicated by the test was almost pure conduction.

Through two winters of operation, these snow-melting systems have demonstrated a snow-melting ability comparable to or more than that of electric heating cable systems. The annual electric power consumption was about 14% that of the electric heating cable systems adjacent to these Gaia Snow-Melting Systems.

1. INTRODUCTION

The Japan Sea side of Japan from central Honshu through Hokkaido is subject to heavy snowfall. In such snowy areas, many snow-melting apparatuses have been used over the past several decades for melting snow on roads, sidewalks, entranceways to private houses and parking lots, and they have been increasing in number. Also, recently the Japanese government has begun to promote barrier-free walking spaces in winter. Hence, the demand for melting snow on sidewalks might increase in Japan.

The sprinkling of groundwater over roads or circulating groundwater in heating pipes embedded in the pavement are popular methods in areas which are not much cold. Apparatuses using electric heating cables and boilers burning oil or gas are popular in northern Japan where the utilization of groundwater is not applicable because of low ambient temperatures. Heat pump systems that utilize groundwater, air or seawater as their heat source are also increasing in number.

As for the utilization of geothermal heat, the outflow hot water from spas has been used in the same manner as groundwater. A system which utilizes vertical ground heat exchangers has been used since the early 1980s in Aomori City. In this system, shallow (30m deep) vertical heat exchangers and heating pipes are connected directly, and antifreeze is circulated in this loop. A similar system, utilizing deeper vertical heat exchangers of about 100m in depth, has been installed since 1994.

The Gaia Snow-Melting System was developed by the authors along with others. The system consists of vertical ground heat exchangers, a heat pump and heating pipes embedded in a pavement body. This type of snow-melting system has greater snow melting ability than that of systems without heat pumps. The utilization of heat pumps can lead to the expansion of applicable areas.

Two Gaia Snow-melting systems were completed in Aomori City, Japan, in 2002 for melting snow on sidewalks. Aomori City is the snowiest city in Japan among the prefectural capitals. So far, these two systems have demonstrated sufficient snow-melting ability (e.g., Figure 1) and great potential in reducing power consumption and emission of carbon dioxide.

Figure 1: Condition on the snow-melting section on December 28, 2002.

2. THE GAIA SNOW-MELTING SYSTEM

Figure 2 shows the two operation modes of the system. This system utilizes the ground as a heat source and heat storage body. Another characteristic of the system is the utilization of Downhole Coaxial Heat Exchangers (DCHEs) proposed by the authors (Morita et al., 1985; Morita and Tago, 1995).

In summer, solar heat raises the temperature of the pavement, in which the heating pipes are embedded, up to between 30 to 50 ˚C. The solar heat is recovered from the hot pavement and charged into the ground by directly connecting the DCHEs and heating pipes, and by circulating antifreeze in this loop. Forward circulation is employed for efficient heat charging. Thus, geothermal heat and summertime solar heat are both used for melting snow.

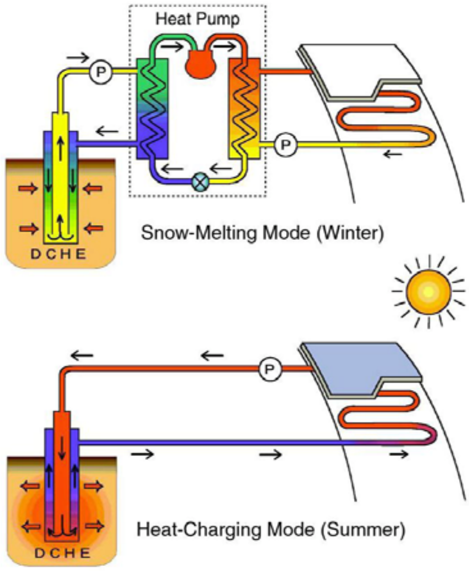

Figure 2: The operation modes of the Gaia Snow-Melting System.

The first Gaia Snow-Melting System was installed in 1995 in Ninohe, Iwate Prefecture (Morita and Tago, 2000). Currently a total of 10 units of this type of snow melting system, covering a total 4,750m^2, are in operation in northern Honshu.

3. WINTERS IN AOMORI CITY

Figure 3 shows the location of Aomori City. It is the northernmost prefectural capital on Honshu. The population of the city is about 296 thousand. It is said that the city is the snowiest city in the world among cities with populations of about 300 thousand or more.

Figure 3: Location of Aomori City.

Figure 4 shows the change in annual snowfall in the city since 1990. Normal annual snowfall (the average value for 1971 to 2000) in the city is 765cm. While, the average value for winters shown in Figure 4 is 690cm. The annual snowfall seems to be decreasing in recent years. However, in 1998 and 2000, the annual snowfall exceeded 10 m. Because the city is located by the sea, the ambient temperature in winter is not very low. The normal average daily low temperature for the month of January is -4.3˚C.

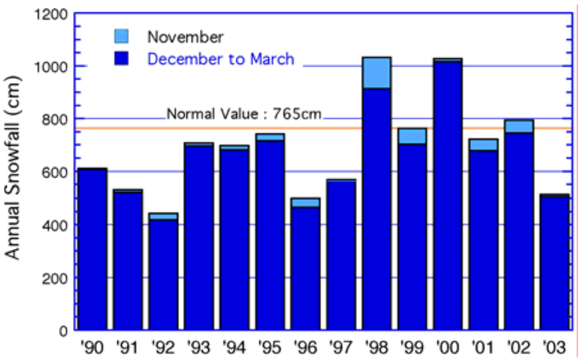

Figure 4: The change in annual snowfall in Aomori City.

Figure 5 shows the road and traffic conditions in the city in the winter of 2000. In this city, many kinds of snow-melting systems have been used. The unique snow-melting systems used in the city are the sprinkling of seawater and the utilization of seawater source heat pumps. The pumping up of groundwater for melting snow is prohibited here because of the induced ground subsidence. A snow-melting system using vertical ground heat exchangers has been used since the early 1980s, and currently more than 90 units are in operation.

Figure 5: Road and traffic conditions in winter 2000.

Recently, the city has been chosen as a model city for barrier-free walking spaces in winter, and the city, prefectural and Japanese governmental offices are cooperatively promoting snow-melting on sidewalks. Melting snow on roads is not considered important and the snow-melting facilities for this purpose are limited in number here. The major way of clearing road surfaces is the removal and disposal of snow.

4. GEOPHYSICAL CONDITIONS AT THE SITE

The formation at the snow-melting site is a complex of unconsolidated sedimentary formations along the total length of the heat exchangers (151.4m long). Volcanic products such as pumice and volcanic ash are included in the formation. The concentration of volcanic products is significant in the section shallower than 65m in depth.

Figure 6 shows the temperature profile in a DCHE measured at 50 days after the completion of the DCHE. The temperature inversion suggests the existence of a groundwater flow at around 60m in depth. The temperature at the bottom of the DCHE was 14.3˚C.

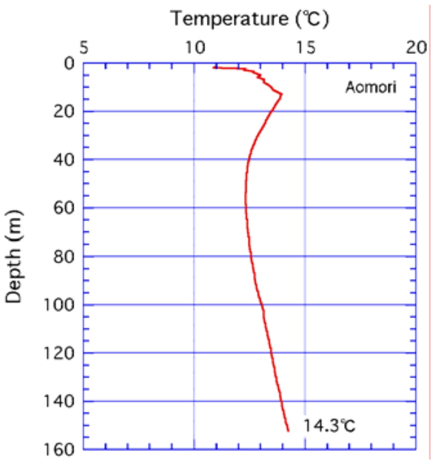

Figure 6: The initial temperature profile at the site.

Figure 7 shows the measured outlet temperature of a DCHE during a thermal response test at the site. A propylene glycol base antifreeze was circulated in the DCHE for four days. The inlet temperature was kept at 2˚C during the first two days, and at –3˚C for two successive days. The in-situ thermal capacity and the effective thermal conductivity of the formation were determined by numerical simulations. The computed outlet temperature is also shown in the figure. In this case, the thermal capacity and the thermal conductivity are assumed to be 2.2 MJ/m^3·K and 1.25 W/m·K, respectively.

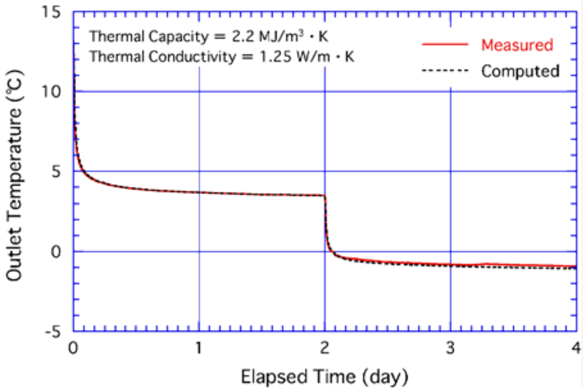

Figure 7: Comparison between the measured and the computed outlet temperatures of the DCHE.

In this case, the measured and computed outlet temperatures agreed quite well for the first two days. Thus, the thermal capacity and the effective thermal conductivity of the formation were determined to be 2.2 MJ/m^3·K and 1.25 W/m·K, respectively. The obtained thermal capacity is remarkably small in comparison with common unconsolidated formations. This would be caused by volcanic products, such as pumice and volcanic ash, in the formation. Also, in this numerical simulation, only conduction was considered as the heat transfer mechanism in the formation. Hence, such good agreement between the measured and computed temperatures indicates that the heat transfer mechanism in the formation is almost pure conduction.

In the following two days, the measured outlet temperature became higher than the computed one during the period when the outlet temperature was lower than 0˚C. This temperature difference must be caused by the frozen zone, presumably very thin frozen zone, formed around the DCHE. The effective thermal conductivity for this period was roughly estimated to be 1.4 W/m·K by the numerical simulation. The increase in the effective thermal conductivity is about 10%. This indicates that the frozen zone formed around the ground heat exchangers enhances heat transfer in the surrounding formation visibly, even if its thickness is small.

Figure 8 shows the measured and computed temperature profiles in the DCHE at 1 day and 3 days after stopping the circulation of antifreeze. As can be seen in this figure, the measured and computed temperature profiles changed at almost the same pace. This fact reinforces the accuracy of the obtained physical properties of the formation. In the section shallower than 65m in depth, where volcanic products are significantly included, the rate of temperature recovery is clearly slower than that in the deeper section. The zone around 30m in depth, where temperature recovery is remarkably slow, coincides with a layer of sediment formed by pyroclastic flows.

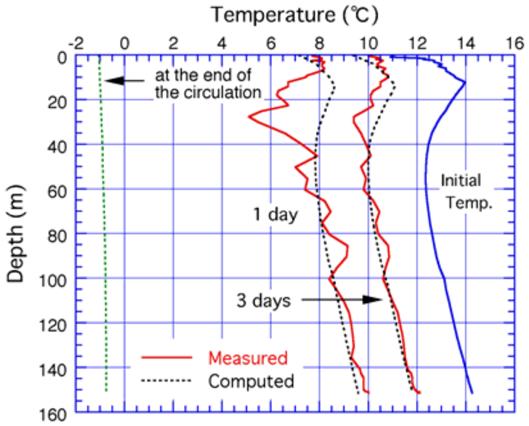

Figure 8: The temperature profiles measured at 1 day and 3 days after the stop of circulation.

Several flow zones of groundwater can be identified from this figure as zones where temperature recovery rates are slightly faster than in other zones. The inversion of the temperature profile at the site might be caused by these groundwater flows.

However, the difference in temperature recovery rates between these zones and other conduction zones are small. In addition, as described before, the heat transfer mechanism in the formation is inferred to be almost pure conduction. Besides, the measured effective thermal conductivity of the formation was only 1.25 W/m·K. All indicate that the effect of groundwater flows on heat extraction might be very small in this site. In other words, very slow groundwater flow has affected equilibrium temperature profiles here, however, the effect on the short-term heat transfer, such as heat transfer associated with heat extraction, might be very limited here.

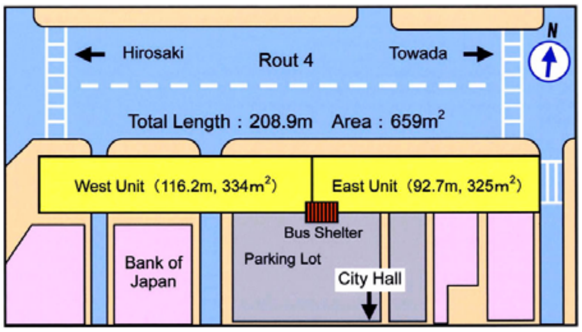

Figure 9: The schematic plain view of the site.

5. OUTLINES OF THE SNOW-MELTING SYSTEMS

Figure 9 shows a schematic plain view of the site. The total length and total area of the snow-melting section are 208.9m and 659m^2, respectively. Here, two units, the West Unit and the East Unit, each covering 334m^2 or 325m^2 were installed.

5.1 Design Conditions

Table 1 shows the assumed conditions for designing these two systems. The total snowfall shown in the table is the total snowfall over a snow-melting season, and does not coincide with the annual snowfall. The snow-melting season is from the first of December to the end of March.

Table 1: Design Conditions.

Terms	Values
Total Snowfall	801cm/season
Intensity of Snowfall	1.9cm/h
Ambient Temperature	-3.4˚C
Wind Velocity	4.0m/s
Density of Snow	0.08 g/cm^3
Heat Loss Ratio	15%
Design Heat Flux to be Supplied to Heating Pipes	170W/m^2

These systems were designed assuming a daily snowfall with a cumulative relative frequency of 80% in Aomori City. From the relationship between the daily snowfall and the cumulative relative frequency in the city shown in Figure 10, the design daily snowfall was determined to be 16cm/d. Also, from the relationship between the daily snowfall and the intensity of snowfall shown in Figure 11, the corresponding snowfall intensity to the design daily snowfall is obtained as 1.9cm/h.

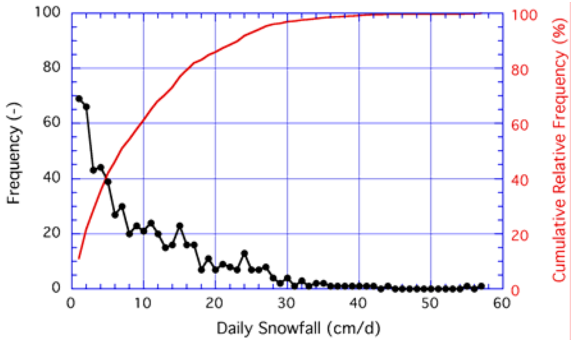

Figure 10: The relationships between daily snowfall and frequencies in Aomori City.

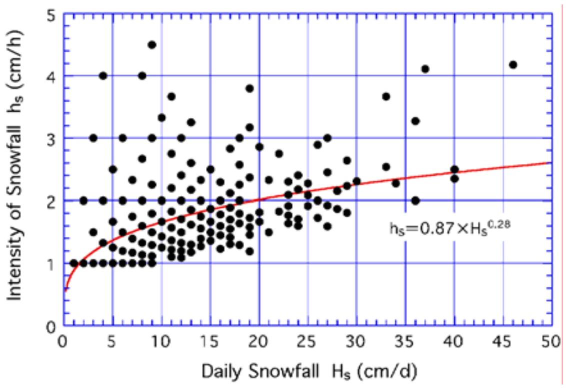

Figure 11: The relationship between daily snowfall and intensity of snowfall in Aomori City.

Based on the conditions shown in Table 1, the heat flux to be supplied to heating pipes was calculated to be 170 W/m^2. However, in the case of the Gaia Snow-Melting System, our experience indicates that greater heat flux, at least 185 W/m^2, is required in the city.

Table 2: Major Components for One Unit

Component	Specification
DCHE	151.4m × 4
Heat Pump	22.5kWe × 1
Circulation Pump	2.2kWe × 1 (for heat extraction) 1.5kWe × 1 (for heat radiation)

5.2 Major Facilities

Each unit consists of the same components. Table 2 shows the major components of one unit. Each unit employs four DCHEs each 151.4m long and one heat pump driven by a total 22.5 kW electric motors. The number of DCHEs and the required size of heat pumps were determined based on numerical simulations for each system. All the DCHEs, heat pumps and control boxes were placed in the parking lot of the city hall. The propylene glycol based antifreeze, with a freezing point of –20˚C, was used as the circulation fluid.

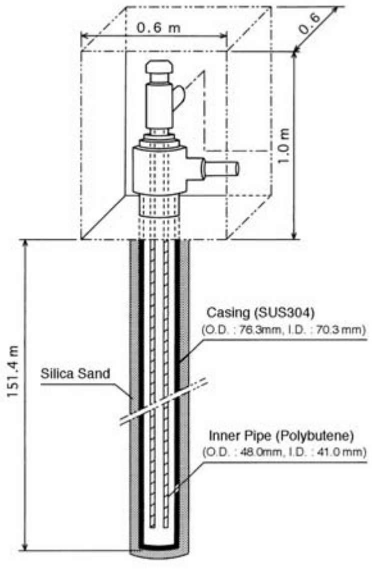

Figure 12: The structure of the DCHE.

Figure 12 shows the structure of the DCHE. The outer diameter is 76.3mm. Figure 13 shows the standard pavement structure of the sidewalks. Quartzite was used as the aggregate of the asphalt concrete to enhance the upward heat transfer from the heating pipes and to reduce downward heat loss. The use of quarzite makes a lower delivery temperature from the heat pumps possible, hence a higher COP, and faster onset of snow-melting. The material used for the heating pipe is bridged polyethylene. The inner diameter of the pipe is 17mm and the pipe spacing is 15cm.

The control box and the heat pump of the West Unit and the installation of the heating pipes for the East Unit are shown in Figures 14 and 15, respectively. The dimensions of the control box is 80cm (W) × 50cm (D) × 182cm (H), and the casing of the heat pump 167cm (W) × 115cm (D) × 178cm (H).

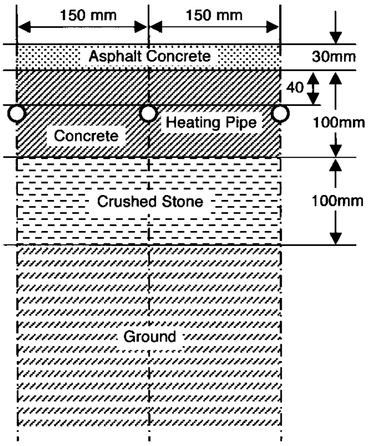

Figure 13: The standard pavement structure.

Figure 14: Control box (left) and heat pump (right) of the West Unit.

Figure 15: Installation of heating pipes (East Unit).

6. EXPERIENCES IN TWO YEARS OF OPERATION

The annual snowfall in the first winter (2002 winter) was 794 cm. This is roughly equal to the normal annual snowfall in the city (765cm). The annual snowfall in the second winter was only 514cm. Hence, the two Gaia Snow-Melting Systems have experienced operations during moderate and light annual snowfalls.

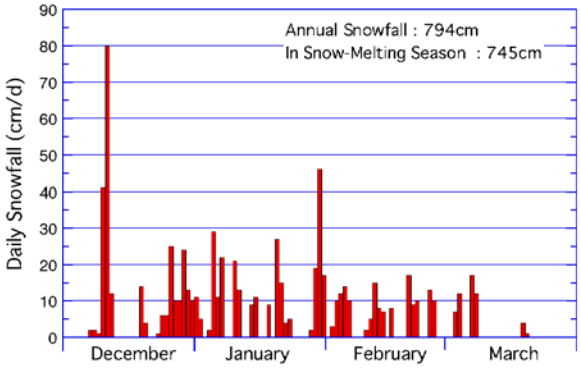

Figure 16: Daily snowfall during the 2002 snow-melting season.

6.1 Snow-Melting in Winter 2002

Figure 16 shows the change in daily snowfall during the 2002 snow-melting season (from the first of December to the end of March). The daily snowfall in this paper is the total snowfall in 24 hours between 9 a.m. of the specified day and 9 a.m. of the following day. The total snowfall during this season was 745cm. The largest daily snowfall during this period was 80cm on December 11, 2002. This was an unusually heavy daily snowfall even for such a snowy city.

Figure 17: Conditions on the snow-melting section at 12 a.m. on December 11, 2002.

Figure 18: Conditions on the snow-melting section at 4 p.m. on December 11, 2002.

Figures 17 and 18 show the conditions on the snow-melting section at noon and in the evening, respectively, on the day of the record snowfall. As can be seen from these figures, the Gaia Systems could maintain walking spaces. Figure 19 shows the conditions after the record snowfall. During this heavy snowfall, it was demonstrated that the Gaia Systems have sufficient snow-malting ability in the city, and that they also have comparable or greater snow-melting ability than that of the electric heating cable systems adjacent to them.

Figure 19: Conditions on the snow-melting section on December 14, 2002.

Figure 20 shows the change in daily operation time of the West Unit during the 2002 snow-melting season. The total operation time was 563h for 745cm of snowfall. This was significantly shorter than the standard operation time (1,000h) of the snow-melting facilities in the city.

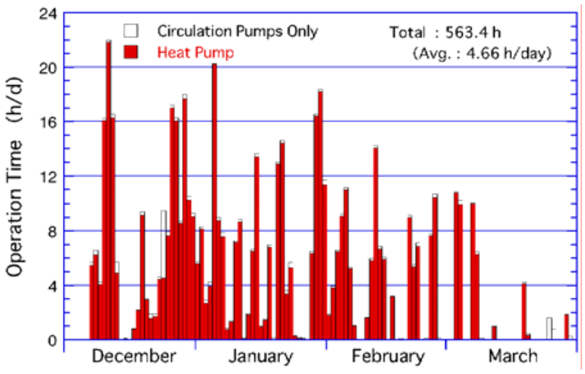

Figure 20: Daily operation time during the 2002 snow-melting season (West Unit).

6.2 Performance of the Gaia Snow-Melting System

6.2.1 Operational Performance

Table 3 summarizes the major characteristic values of the West Unit for two snow-melting seasons. The snow-melting efficiency shown in the table is the ratio between the amount of heat required to melt snow and the supplied heat to the heating pipes.

Table 3: Major Characteristic Values for Snow-Melting Seasons (West Unit).

Snow-Melting Season	2002	2003
Seasonal Snowfall (cm)	745	507
Avg. Low Temp. for January. (˚C)	-4.0	-3.2
Operation Time of System (h)	563.4	505.4
Operation Time of HP (h)	542.2	491.4
Avg. Inlet Temp. of DCHE (˚C)	-4.1	-3.7
Avg. Outlet Temp. of DCHE (˚C)	0.0	0.3
Avg. Delivery Temp. of HP (˚C)	15.5	15.7
Extracted Heat (MWh)	29.57	28.27
Supplied Heat (MWh)	36.79	34.77
Electric Power Consumption (MWh)	10.79	9.94
Power Consumption of HP (MWh)	7.66	7.08
Heat Supply Rate (W/m^2)	203	212
Specific Heat Extraction Rate (W/m)	90.1	95.0
COP of HP (-)	4.80	4.91
COP of System (-)	3.62	3.75
Snow-Melting Efficiency (%)	31.5	22.7

The average heat supply rates to the heating pipes per unit area of the snow-melting area over a snow-melting season were 203 and 212 W/m^2, and the average specific heat extraction rates of the DCHEs were 90 and 95 W/m. The COP of the heat pump were 4.8 and 4.9. All the performances improved in the second winter. These improvements owe greatly to the smaller seasonal snowfall, and thus shorter operation time.

However, the reduction in operation time was relatively small during the 2003 snow-melting season in comparison with the significantly smaller snowfall than that in the former season. Also, snow-melting efficiency dropped remarkably in the 2003 snow-melting season. These facts indicate that the setting of the control system has not yet been adapted adequately to the site conditions. Actually, the collected data indicated many unnecessary operations, especially in the second winter.

6.2.2 Power Consumption and Power Cost

Table 4 shows a comparison of the power consumption in both snow-melting seasons between the Gaia Snow-melting System and the electric heating cable system. The values for Gaia are the average of the two Gaia Snow-Melting Systems, and the values for the electric heating cable system are the average of the systems adjacent to these Gaia Snow-Melting Systems.

Table 4: Comparison of power consumption in the snow-melting season between the Gaia and electric heating cable system. (unit : kWh/m^2)

Snow-Melting Season	Electric Heating Cable	Gaia
2002	275.3 (100.0%)	33.9 (12.3%)
2003	237.3 (100.0%)	30.1 (12.7%)

The amounts of power consumption of the Gaia Snow-Melting System were 12.3 and 12.7% those of the electric heating cable systems. The annual power consumption for the FY2003 (from April to March) which includes power consumption for heat charging operation in the non-snow-melting season, was 33.4kWh/m^2, and was 13.6% that of the electric heating cable system. The annual power cost of the Gaia was 854 Yen/m^2 in this fiscal year.

6.3 Operational Character

6.3.1 Snow-Melting Efficiency

Figure 21 shows the relationship between daily snowfall and snow-melting efficiency in the winter of 2002 for the West Unit. As described before, the snow-melting efficiency is the ratio between the amount of heat required to melt snow and the supplied heat to the heating pipes. Only latent heat required for melting snow or ice was considered in this calculation, and the sensible heat to heat snow or ice up to the melting point and the removal of heat by convection and radiation were not taken into account.

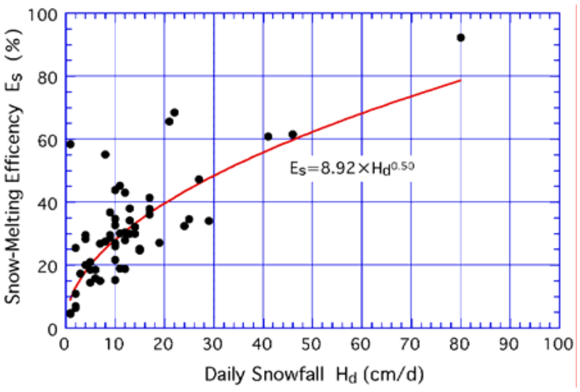

Figure 21: Relationship between daily snowfall and snow-melting efficiency.

However, it is useful to understand the system's efficiency or behavior in snow-melting. Also, it might be useful in estimating the system's daily operation time for a given snowfall model in designing new snow-melting facilities, though the relationship is site and system specific.

As shown in Figure 21, the smaller the daily snowfall, the smaller the snow-melting efficiency. One reason for this might be that the amount of heat removed from the surface of the snow or pavement by convection or radiation is relatively great with light daily snowfall. In the case of great snowfall, the layer of snow on the pavement functions as a blanket and reduces heat dissipation by convection or radiation. Also, in the case of light daily snowfall, and hence shorter daily operation time, a significant amount of heat supplied to the heating pipes is consumed for heating the pavement up to a sufficient temperature level for melting snow. In addition, at the early stage of the snow-melting operations, downward heat loss from the heating pipe is significantly great. That's why the snow-melting efficiency is smaller for smaller daily snowfalls and vice versa.

This relationship, therefore indicates that systems which melts snow by continuously circulating groundwater or hot geothermal water require less heat flux than systems such as the Gaia Snow-Melting System which operates only when snow-melting is necessary.

6.3.2 The Change in Heat Flux Supplied to Heating Pipes

Figure 22 shows the change in the supplied heat to the heating pipes per unit area of the snow-melting area during the 2002 snow-melting season for the West Unit. The average supplied heat flux over this season was 203 W/m^2 as shown in Table 3. This is greater than the design heat flux (170 W/m^2), by about 20%. It seems that this system has an excessive capacity for this site.

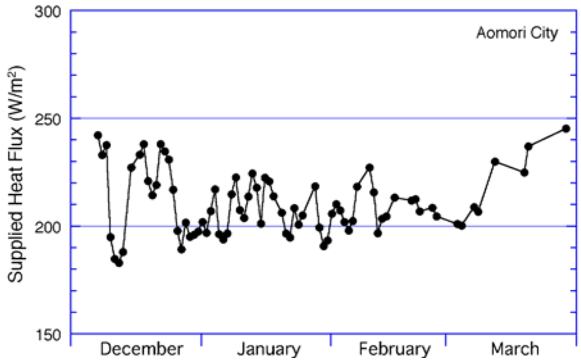

Figure 22: Change in supplied heat flux to heating pipes during the 2002 snow-melting season (West unit).

However, around the day of the record snowfall, i.e., December 11, the heat flux dropped rapidly as can be seen in Figure 22. One of the reasons for this could be the poor heat transfer capability of the formation, represented by the small thermal capacity and the small effective thermal conductivity. With such poor heat transfer performance of the ground, drop of the source temperature is rather fast. This result in a rapid decrease in the capacity of the heat pump. The heat flux decreased down to 185W/m^2 on the day of the record snowfall, and 183W/m^2 on the following day. Fortunately, the record snowfall was at a very early stage of the snow-melting season and the formation was not much chilled. If the record snowfall occurred in late January or in February, the supplied heat flux would have decreased around the design value because of the much chilled ground. Hence, it can be said that the heating capacity of this system meets the design capacity and is not excessive for this site.

The observed heat flux during the record snowfall and the pavement conditions shown in Figures 17 and 18 indicate that a heat flux of around 185W/m^2 is required to cope with such a heavy snowfall in the city. This is concordant with our empirical estimation.

6.3.3 Heat Balance and the Temperature Profile in the DCHE

Figure 23 shows the changes in the amount of charged heat into the ground and extracted heat from the ground for the West Unit. The extracted heat in the 2001 snow-melting season was that associated with the trial operation of the system during its construction. Figure 24 shows the temperature profiles measured at the end of the heat-charging seasons along with the initial temperature profile.

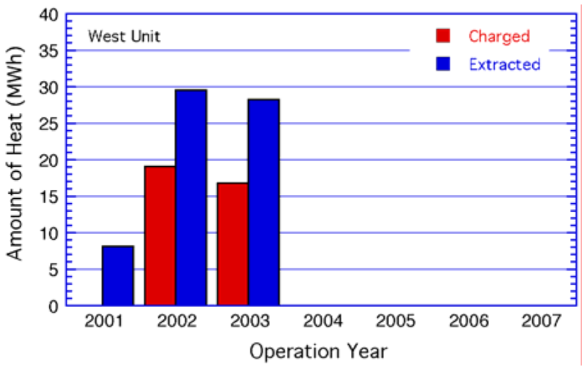

Figure 23: Changes in charged and extracted heat (West Unit).

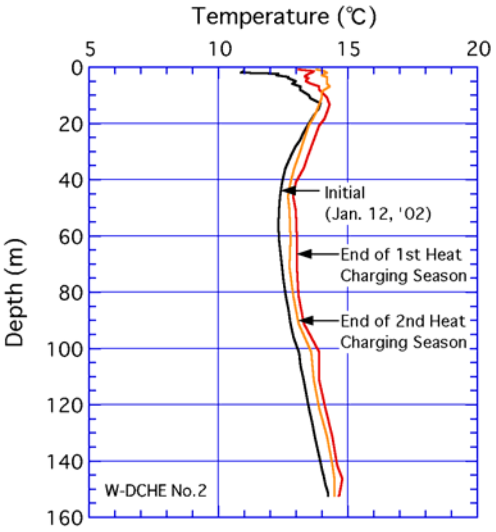

Figure 24: Measured temperature profiles at the end of heat-charging season along with the initial temperature profile.

At the end of the first heat-charging season, i.e., November 30, 2002, the charged heat was greater than the extracted heat by 11MWh, and the temperature profile measured at this time point was clearly higher than the initial temperature. At the end of the second heat-charging season, charged heat was less than the extracted heat by 2MWh in the cumulated amount. And, the measured temperature profile became lower than that of the previous year, though the temperature was still higher than the initial temperature. These observations indicate that the temperature of the formation is sensitive to the heat balance at this site.

6.4 Toward Better Performance

As described before, the obtained in-situ thermal capacity (2.2 MJ/m^3·K) and the effective thermal conductivity (1.25 W/m·K) at this site are small. With such poor heat transfer properties of the formation, the temperature of the ground is sensitive to the heat balance between extracted and charged heat, as indicated by Figures 23 and 24. In addition, the allowance of these systems in heating capacity seems to be very small. Hence, the heat balance should be important in maintaining sufficient snow-melting ability in long-term. Excess heat extraction or deficiency of heat charging could easily cause deterioration of the function of the formation as a heat source, and hence causes degradation of performance.

Fortunately, measured temperatures in the DCHE at the end of the second heat-charging season were still higher than the initial temperatures as shown in Figure 24. However, the amounts of extracted heat were significantly in excess of the charged heat in 2002 and 2003 on a fiscal year basis as can be seen in Figure 23. If this tendency continues regularly, the temperature of the formation should drop visibly and should cause degradation in performance here. Hence, further efforts are necessary to improve the heat balance.

The amount of charged heat is basically proportional to the total insolation duration from June to September. And, the artificial increment by adjusting the control system may be small. On the other hand, the total insolation duration in the above mentioned time period for 2003 was the shortest, and for 2002 was the second shortest in the years shown in Figure 25. Hence, increases in charged heat can be expected to some extent in normal years.

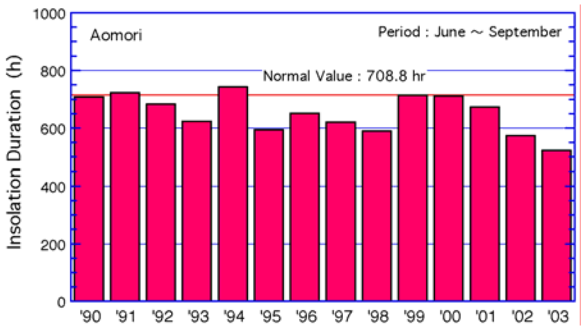

Figure 25: Change in total insolation duration in the period from June to September.

The most effective way of improving the heat balance may be reducing extracted heat by reduction of unnecessary snow-melting operations. As described before, the collected data indicated many unnecessary operations especially, in the second winter.

The reduction of unnecessary operations would also provide less cooled ground and more time for temperature recovery in snow-melting seasons. Therefore, a reduction of unnecessary operations leads to higher COP, a higher specific heat extraction rate and less power consumption.

7. CONCLUSIONS

Two Gaia Snow-melting systems were completed in Aomori City, Japan, in 2002 for melting snow on sidewalks. Measured in-situ thermal capacity and the effective thermal conductivity of the formation were 2.2 MJ/m^3·K and 1.25 W/m·K, respectively. The heat transfer mechanism in the formation was estimated to be almost pure conduction. Also, it was indicated that the frozen zone formed around the ground heat exchangers enhances heat transfer in the surrounding formation visibly, even if its thickness is small. The increase in the effective thermal conductivity of the formation by the frozen zone was about 10% in the thermal response test.

The inversion of the temperature at the site is thought to be induced by the cold groundwater flows. However, the effect of these flows on transient heat transfer phenomena such as heat extraction or heat charging might be very small.

The seasonal snowfall (snowfall from December to March) in the first snow-melting season was 745cm and the second season 507cm. The largest daily snowfall experienced was 80cm/d. Through two winters of operation, it was demonstrated that both Gaia Snow-Melting Systems have sufficient snow-melting capacity for the city. The annual power consumption was 13.6% that of the electric heating cable systems.

The change in the temperature profiles in the DCHE indicates that the temperature of the formation is sensitive to the heat balance between charged heat and extracted heat at this site. The amounts of extracted heat were significantly in excess of charged heat on a fiscal year basis. Further efforts to improve the heat balance are necessary to maintain performance. The most effective way may be a reduction of unnecessary snow-melting operations. This might also lead to better performance.

REFERENCES

Morita, K., Matsubayashi, O. and Kusunoki, K.: Down-hole Coaxial Heat Exchanger Using Insulated Inner Pipe for Maximum Heat Extraction, GRC Transactions, 1985.

Morita, K. and Tago, M.: Development of the Downhole Coaxial Heat Exchanger System : Potential for Fully Utilizing Geothermal Resources, GRC *Bulletin*, 1995.

Morita, K. and Tago, M.: Operational Characteristics of the Gaia Snow-Melting System in Ninohe, Iwate, Japan - Development of a Snow-Melting System which Utilizes Thermal Functions of the Ground, Proceedings WGC2000, 2000.