POSSIBILITY OF ECONOMICAL AND ECOLOGICAL SNOW MELTING SYSTEM WITH A SMALL SIZE GROUND SOURCE HEAT PUMP SYSTEM

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Abstract: A half of the Japanese land has been legislated as the heavy snowfall area by the government and more than twenty million people live there. In order to enhance urban appeal as well as the safety and comfort daily life, the snow melting system of the pavement has been getting more recognition in the central are of the city. From energy conversation and CO_2 reduction as well as saving running expense point of view, snow melting system using ground heat source heat pump as heating unit has been recognized as the most promising potential.
In this paper, the outline of the developed novel designing and performance prediction tool is explained first. Next, a new type heat pump with an inverter-control compressor and measurement of its performance are explained. Last, possibility region for direct circulating for snow melting system is discussed by using developed designing tool and the effect of grid spacing of GSHP-SM with heat recharge applied collected solar energy through embedded piping in the pavement during summer is also discussed.

Key Words: snow melting, ground source heat pump, heat pump, simulation

1 INTRODUCTION

A half of the Japanese land has been legislated as the heavy snowfall area by the government and more than twenty million people live there. Snow precipitation in a day sometimes reaches over 600 mm high and people expend a considerable amount of work and time remove accumulated snow and to maintain the daily activities. The top of citizen's demands to solve municipal issues is always related snow in this area. In order to enhance urban appeal as well as the safety and comfort daily life, the snow melting system of the pavement has been getting more recognition in the central are of the city.
Popular snow melting systems use electrically heating wires buried in the pavement. On the other hand, hot water circulating snow melting system in the embedded tubes heated by kerosene or gas boilers are also commonly used for not only residential front yards but also for big parking spaces and precipitous roads. However, snow melting systems consume much bigger amount of thermal energy than most people think due to a large amount of heat loss to the ambient in addition to needed heat for melting snow. For example, 400 litters of oil are burned in winter season for 20 m^2 wide residential snow melting system in average in Hokkaido area. This amount of oil consumption is almost equivalent to the annual oil consumption for domestic hot water supply of a single family house. From energy conversation and CO_2 reduction as well as saving running expense point of view, heat pump technologies have been applied into the snow melting system in the northern districts of Japan. Some kinds of natural heat resources such as air, ground water and ground heat source become the candidates of the heat source of the heat pump. In particular, ground heat source has been recognized as one of the most promising renewable energy on account of its universal existence and long term indubitability. In facts, total installed number of the ground source heat pump units has been reached up to 500 by the end of 2010. From

our original research, it is estimated that approximately 10 % - 15 % numbers of the installed ground source heat pump units have been applied for snow melting system.
A simple method according to the steady state or numerical calculations using FDM by scientists has been carried out in the case of planning and designing. However, there has been no reasonable designing and performance prediction tool which bases on the theoretical calculation and provides user friendly interfaces and graphical data output screens for the GSHP snow melting system (GSHP-SM).
The authors have developed a novel designing and performance prediction tool for the GSHP snow melting system. This tool has following very strong advantages.

1. High speed heat transfer calculating algorithm for multiple boreholes using convolution technique of the cylindrical heat source theory based on the hourly heat demand data
2. Providing user friendly data input interfaces and graphical output screens
3. Plural combinations of on-off control for snow melting system
4. Direct circulation mode between ground and pavement is also available
5. Physical properties of general soils and materials are included
6. Inverter-control heat pump unit can be applied

In this paper, the outline of the developed novel designing and performance prediction tool is explained first. Next, a new type heat pump with an inverter-control compressor and measurement of its performance are explained. Last, possibility region for direct circulating for snow melting system is discussed by using developed designing tool and the effect of grid spacing of GSHP-SM with heat recharge applied collected solar energy through embedded piping in the pavement during summer is also discussed.

2 A DEVELOPED DESIGNING AND PERFORMANCE PREDICTION TOOL FOR GSHP-SM

The configuration of GSHP-SM and calculation modules of the software are shown in Figure 1. It can be divided into mainly three parts. First part is snow melting pavement. Second is a heat pump unit as heating unit. Third is ground heat exchangers and surrounding ground. According to these three parts, the authors have develop numerical calculation modules.

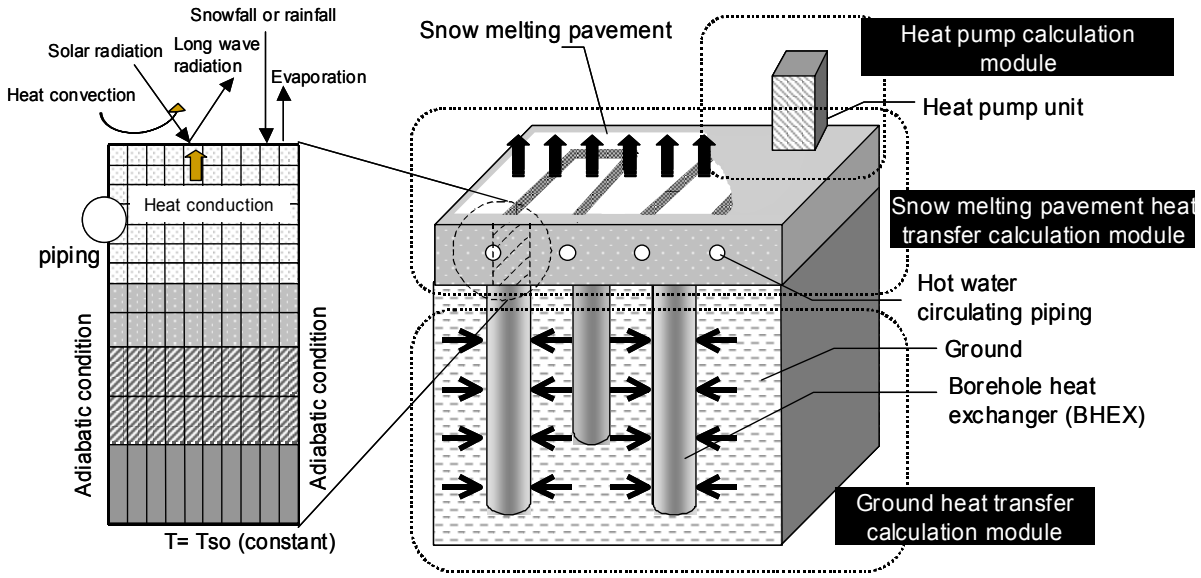


Figure 1: Configuration of ground heat sour heat pump snow melting system - calculation modules and heat transfers on the surface of the pavement

2.1 Heat transfer of snow melting pavement

In order to calculate transient heat conductive phenomena in the pavement, the FDM is used as illustrated in Figure 1. According to the vertical adiabatic condition based on the average fluid temperature in the embedded tube, the calculating region provides a half of inner piping spacing. Appropriate physical properties are given for the plural horizontal layers. On the other side, the heat balance equation on the surface reflects the actual heat transfer phenomenon, which includes convective and radiative heat transfers between the ambient, heat for phase change of the snow and water, heat conduction through the accumulate snow layer, evaporation of liquid water and heat flux from the inner pavement side. Here, we assume that melted snow is once absorbed in the accumulated snow up to 15 % of volumetric water contents and then drains. Finally, the authors summarized these boundary conditions into eight cases according to the surface condition of the pavement as indicated in Figure 2.

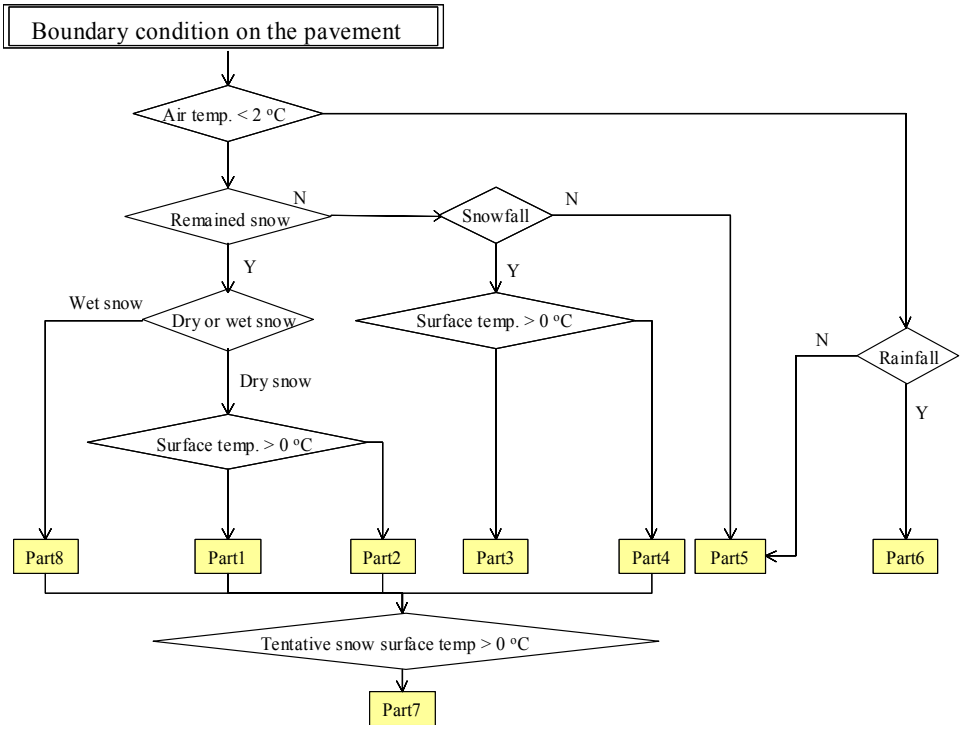


Figure 2: Flow diagram of boundary conditions on the surface of the pavement

2.2 Calculation of heat output from a heat pump unit

This tool has provided approximate performance functions of actual heat pump units according to the fluid temperatures of primary- and secondary-side made from presented performance curves. On the other side recent emerged inverter-control heat pump units have possibility to modify seasonal performance factor (*SPF*) as well as to stabilize the output temperature of secondary-side. This will give great advantages to GSHP-MS. Here, the authors actually measure a newly developed high performance heat pump unit which has a 10 HP scroll type compressor driven by an inverter unit with a liquid-gas heat exchanger. A photograph in Figure 3 shows a used testing apparatus for a middle class of a heat pump unit up to 30 HP. The feature of this testing apparatus is that it works almost autonomously by applying a plate type heat exchanger between primary-side and secondary-side. In other word, extracted heat is supplied from thermal output and surplus heat is released by a convector or cooled by water. Measured results are shown in Figure 4. It is very important that *COP*s become incredible high at the part-load operation under 35 °C of secondary-side outlet temperature T_{2out}. This characteristic is very effective for GSHP-SM which has a wide

fluctuation range of the heat demand and a seasonal long term operation. From these experimental results the *COP* of this heat pump unit can be numerically expressed by using following three parameters, which are heat output Q_2, primary-side inlet temperature T_{1in} and secondary-side outlet temperature T_{2out}.

$$COP = -0.0557\,Q_2 + 0.0985\,T_{1in} - 0.095\,T_{2out} + 8.63 \qquad (1)$$

In the real calculation in the tool, required T_{2out} is determined, then T_{2in} is resulted after the heat transfer from piping to surrounding pavement and Q_2 is calculated from the temperature difference between T_{2out} and T_{2in}. Finally, *COP* of the heat pump unit and needed rotation frequency of the compressor under this condition is determined.



Figure 3: Photograph of a tested heat pump unit (left) and a performance testing apparatus (right)

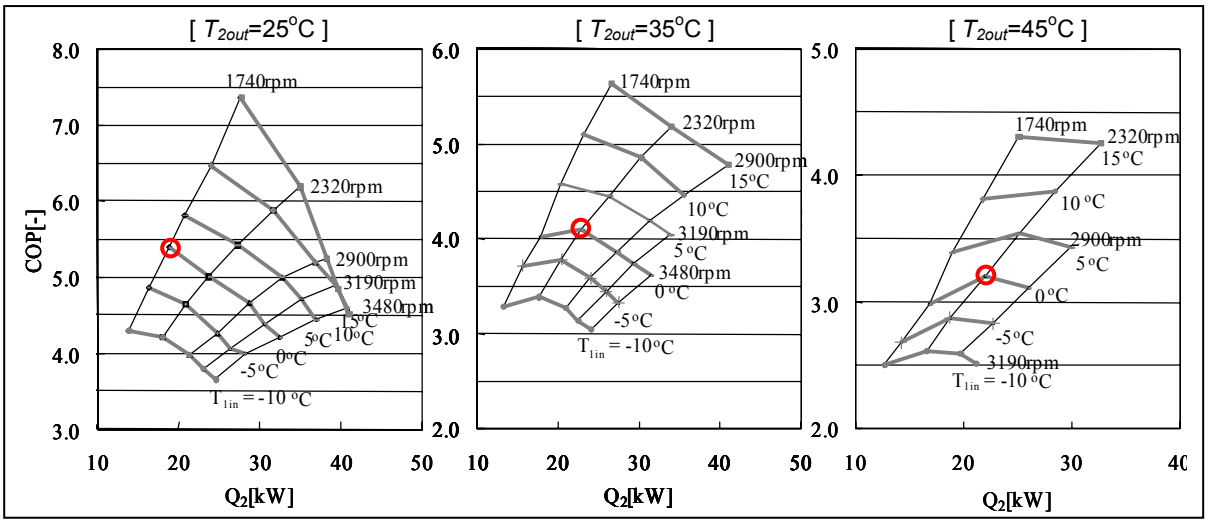


Figure 4: Performance diagram of Heat pump measured by using a testing apparatus according to Q_2, compressor revolution, T_{1in} and T_{2out}

2.3 Modeling of ground heat exchanger and calculation of heat transfer in surrounding ground

Heat capacity of the fluid in the ground heat exchanger is taken into account as the one mass system and heat balance according to the temperature deference between fluid and borehole surface is calculated. On the other hand, superposition of temperature responses of the cylindrical heat source theory is adapted to the calculations of heat transfer in the ground surrounding ground heat exchangers. Also, the authors have invented a unique computational technique for very high speed calculation of heat interaction among multiple ground heat exchangers. More detail information is referred to the published papers.

3. DISCUSSION OF RESULTS

3.1 Performance predictions of snow melting system by using ground thermal energy

Performance of snow melting system by using ground thermal energy is predicted in six cities in the snowy region of Japan shown in Figure 5. Table 1 indicates representative ground temperatures and the maximum snowfall rates for six selected cities, which are Sapporo, Aomori, Akita, Yamagata, Toukamachi and Toyama. Here, the authors examined two systems. One is examination of available region of the direct circulating system, which means direct use of ground thermal energy for snow melting by circulating fluid between ground heat exchangers and piping in pavement without a heat pump unit. The other one is examination of variation of performance due to grid spacing of ground heat exchangers of GSHP-SM.

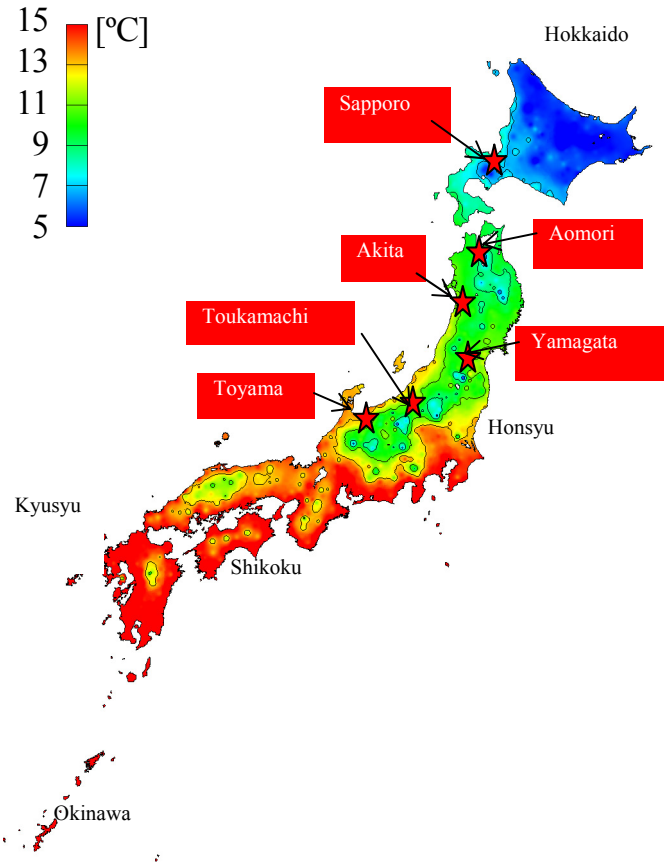


Figure 5: Locations of selected six cities in Japan and the annual average air temperature

Table 1: Uses ground temperature and maximum snowfall rate of selected six cities

Name of city	Sapporo	Aomori	Akita	Yamagata	Toukamachi	Toyama
Ground temperature [ºC]	10.4	11.8	12.9	12.8	12.9	15.1
Maximum snowfall rate [cm/h]	2.08	2.43	1.77	1.11	7.41	4.34
Needed heat output [W/m^2]	198	227	165	104	690	412

3.2 Examination of available region for the direct circulating system

First, the direct circulating system with grid geometry consisted from twenty five borehole type heat exchangers (BHEX) of 60-meters long is examined for snow melting area of 300 m^2 in these six cities as shown in Figure 6. Total length of BHEX is 1500 m. As the seasonal thermal energy storage effect can be expected in the grid geometry, collected heat through the pavement is recharged into the ground during summer when the fluid temperature in the embedded tube in the pavement is 5 ^{o}C higher than that in the BHEX. Calculating conditions are listed in Table 2. In addition, a sectional plan of the pavement and embedded tubes used for the calculation are illustrated in Figure 7.
Figure 8 shows the frequency of appearance of remained snow depth on the pavement as the summary of the calculated results for six cities. In Sapporo, surface of the pavement is completely covered by snow for half the period of time of winter season. In addition it's found that the surface temperature of the pavement often dropped under 0 ^{o}C. This means refrozen melted snow could derive the dangerous of slips on the pavement.
On the other hand, remained snow depth keeps less than 5 cm for more than 90 % of winter in Akita, Yamagata and Toyama city. It can be concluded that direct circulating snow melting system is sufficiently available in not only these cities but also in the Hokuriku region faced on the Japan sea when the active heat collection from the pavement and thermal energy storing is operated in the summer season. In Aomori it keeps less than 10 cm for more than 90 % of this period. From this result it is expected that the direct system can be applied to the limited purposes such as parking space of the supermarket. Also it will be very effective snow melting system when this passive system has the small back up heating system.

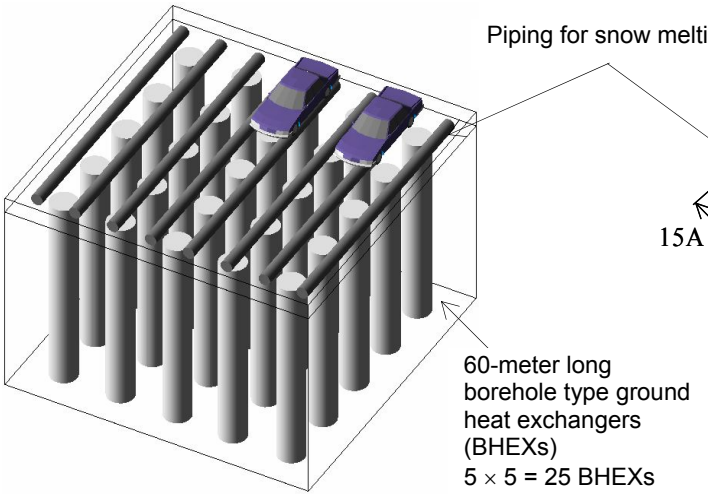


Figure 6: Grid GHEX geometry.

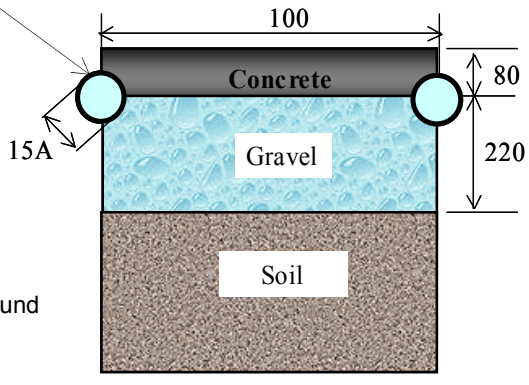


Figure 7: Section of pavement

Table 2: Calculating conditions for direct circulating system

Snow melting area		300 m^2
Control		Winter: circulating fluid when snow falls Summer: recharging
Dry snow density		80 kg/m^3
Effective thermal conductivity of soil		1.5 W/m/K
Ground heat exchanger (GHEX)	Type	Double U tube
	Grid spacing	3 m
	Depth	60 m
	Number of GHEX	25 (5×5)
	Total length of GHEX	1500m
Circulation pump	Electric power consumption	4.0 kW
	Flow rate	400 L/min

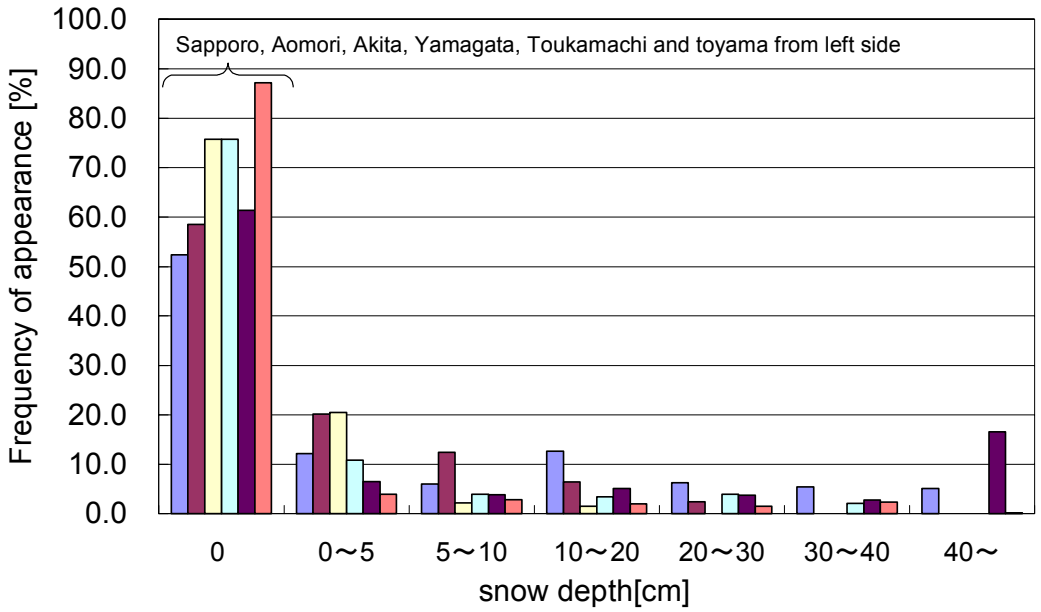


Figure 8: Direct circulating system with grid geometry of BHEXs

3.3 Consequences of grid spacing of ground heat exchangers to GSHP-SM performance

Here, consequences of grid spacing of ground heat exchangers to GSHP-SM performance is evaluated under the calculating conditions shown in Table 3 in Sapporo and Aomori city. In this calculation, two types of BHEX geometries are examined. One is inline straight geometry with ten 150-meters long BHEXs illustrated in Figure 9. The other one is gird geometry with twenty five 60-meters long BHEXs. Total length of BHEXs is 1500 m in both cases. A heat pump with heat output capacity of 75 kW is assumed to be used for 300 m^2 of snow melting pavement. *COP* of this heat pump under the condition of 0 °C for T1in and 35 °C for T_{2out} is assumed to be 4.5 in these calculations. The operation of a heat pump is controlled by basically four sensors, which mean air temperature, pavement surface temperature, snowfall sensor and moisture on the surface. A control diagram and each threshold value are referred to Figure 10. SPF of a heat pump unit is compared according to geometries and their BHEX spacing.

Calculated results are shown in Figure 11. Here, star marks in figure indicate results for a single borehole. In the case of inline straight geometry, changes of *SPF* is little according to the BHEX spacing. However, it is very interesting that there is a point which takes the maximum *SPF* at the appropriate the BHEX spacing in the case of grid geometry due to the thermal storage effect of heat recharge. From this figure, it is realized that the optimum BHEX spacing is 5.0 m for Sapporo and 3.5 m for Aomori, respectively. However, the highest *COP* for the grid geometry in Sapporo is just equal to that for inline straight geometry and it is still lower than the value for a single borehole. In distinction from Sapporo's case, the maximum *COP* for the grid geometry is bigger than that for a single borehole in Aomori. This result represents the performance for the grid geometry influenced a great deal by the balance of amount of extracted heat during winter and amount of recharged heat during summer. In Aomori, needed extracted heat for the snow melting is rather smaller and collected heat by solar radiation and from the ambient air for recharging is larger compared to those in Sapporo.

Table 3: Calculating conditions for GSHP-SM system.

Snow melting area		300 m^2	
Control		air temperature sensor + snowfall sensor + pavement temperature sensor + moisture sensor	
Dry snow density		80 kg/m^3	
Effective thermal conductivity of soil		1.5 W/m/K	
Ground heat exchanger (GHEX)		inline straight geometry (1×10)	grid geometry (5×5)
	Type	Double U tube	
	Grid spacing	From 2 m to 7 m	From 2 m to 6 m
	Depth	150 m	60 m
Circulation pump of primary side	Electric power consumption	4.0 kW	4.0 kW
	Flow rate	400 L/min	1000 L/min
Circulation pump of secondary side	Electric power consumption	2.0 kW	
	Flow rate	200 L/min	
Heat pump	Heat output capacity	250W/m^2	250W/m^2
	COP	4.5 (at T_{1in} 0 °C – T_{2out}35 °C)	

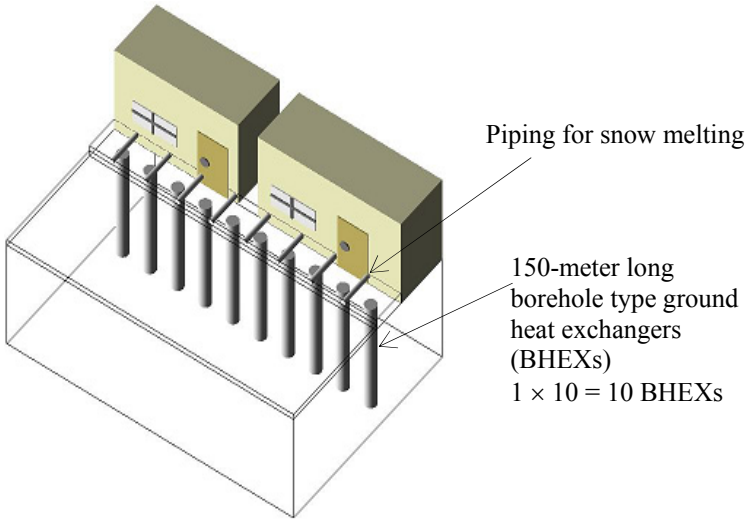


Figure 9: Inline straight geometry.

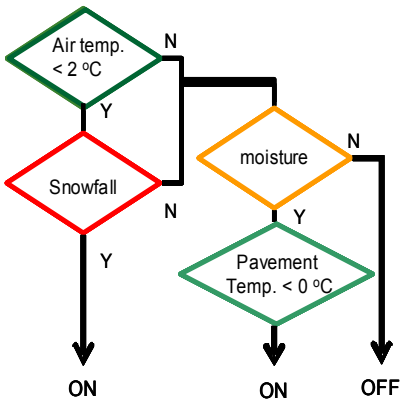


Figure 10: Heat pump on-off control diagram.

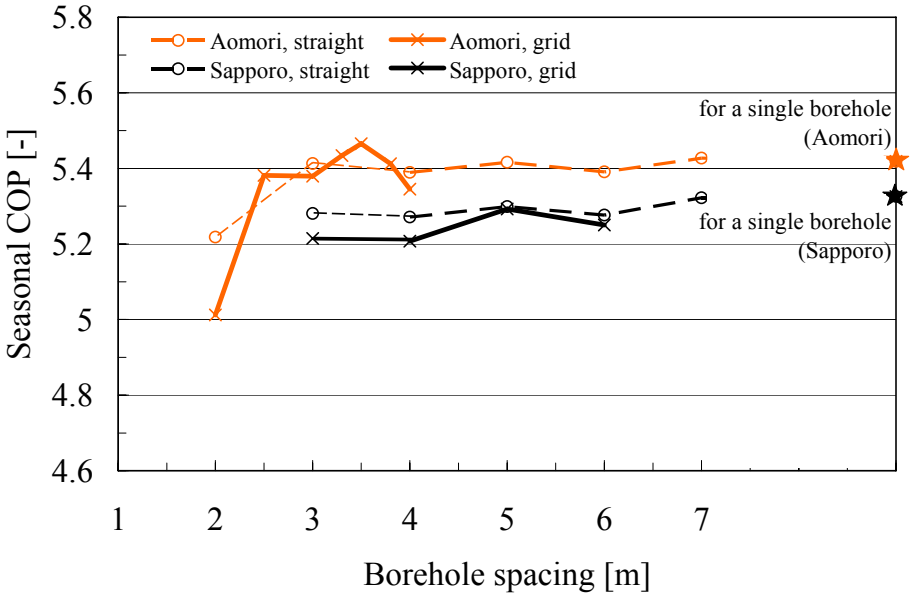


Figure 11: SPF of heat pump unit according to grid spacing.

4 CONCLUSION

1. The authors have developed a novel designing and performance prediction tool for the GSHP snow melting system. This tool has a number of strong advantages.
2. Measurements related to *COP* and heat output according to the inlet temperature of primary-side, the outlet temperature of secondary-side and the frequency are carried out. Then a simple numerically approximate expression which can determine *COP* is made in order to contain a mathematical expression of a heat pump performance with an inverter-control compressor in the designing tool.
3. Performance for the direct circulating system is evaluated by using a developed designing tool. From the calculations, it is found that the direct circulation snow melting with BHEXs in grid geometry can apply into Akita, Yamagata and Toyama city. Also, results shows that a little snow removal work gives a possibility of using this system in Aomori. However, installation of this system is very restricted in Sapporo and Toukamachi city.
4. Consequences of grid spacing are examined for GSHP snow melting system. In the case of inline straight BHEX geometry, the effect of increasing spacing does not appear specifically. In Contrast to straight geometry, there is a point which shows the maximum *SPF* at the appropriate BHEX spacing in the case of grid geometry due to the thermal storage effect of heat recharge during summer. The maximum *SPF* is bigger than that for a single borehole in Aomori. However, the highest *SPF* for grid geometry in Sapporo is just equal to that for inline straight geometry and it is still lower than the value for a single borehole.

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