DEVELOPMENT OF A HOT WATER PANEL HEATER TYPE SYSTEM FOR MELTING SNOW ON SIDEWALKS

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1. Abstract

Conventionally, in cold regions covered with snow in winter, it was difficult to secure safe sidewalk spaces for pedestrians due to the piles of snow removed from roadways and the roofs of private houses and heaped by the side of the road. The sidewalk snow melting systems currently in use consist of the same sprinkling method, electric heater method and hot water pipe method used to melt snow from roadways. These conventional systems pose problems such as low service level due to puddles formed on sidewalks, high running costs, and the difficulty of securing installation space in urban areas.

Ministry of Land, Infrastructure and Transport and local governments are moving to provide snow melting systems in order to secure sidewalk spaces in city centers, around public institutions and so on, in accordance with "Transportation Barrier-Free Law" (enacted in May 2000). Furthermore, while moving to reduce the total cost of the snow melting systems, these entities are actively working to develop snow melting systems that effectively utilize non-conventional energy and natural energy. To respond to these needs, the authors, utilizing the sheet steel hot water panels that were successfully used on railways in 1992, began developing a hot water panel snow melting system for sidewalks that employed non-conventional energy in the form of low-temperature heat sources such as sewage heat and the exhaust heat from cities.

In applying hot water panels to sidewalks, there were two requirements that needed to be satisfied: (1) the panels had to be able to withstand the weight on the sidewalk, and (2) for safety purposes, the surface of the panels had to be slip-proof. For this reason, a structural study was conducted and four prototype panels were produced: (1) a polyurethane panel (2) a concrete jacketed panel (3) an interlocking panel and (4) a tiled panel. These prototype panels were used in site snow melting tests conducted in a cold region covered with snow in winter. The following results were obtained:

1) All of the panels radiated less heat than conventional sheet steel hot water panels, but the radiated heat was at a level that allowed application to sidewalks.
2) Each of the panels melted snow with higher efficiency than conventional hot water pipe method.
3) The sidewalk hot water panels could melt snow at the feed water temperature of around 10°C, enabling the use of sewage heat and exhaust heat from cities, heretofore non-conventional energy.

2. Introduction

Ministry of Land, Infrastructure and Transport and local governments are moving to provide snow melting systems in order to secure sidewalk spaces in city cnters, around public institutions and so on, in accordance with "Transportation Barrier-Free Law" (enacted in May 2000). Furthermore, while moving to reduce the total cost of the snow melting systems, these entities are actively working to develop snow melting systems that effectively utilize heretofore non-conventional energy and natural energy.

To respond to these needs, the authors, utilizing the sheet steel hot water panels [1)](hereafter "hot water panels") that were successfully used on railways in 1992, began developing a hot water panel snow melting system for sidewalks that employed non-conventional energy in the form of low-temperature heat sources such as sewage heat and exhaust heat from cities. This paper will report on the structural study of hot water panels for use in melting snow on sidewalks, the manufacture of several different prototypes, and the results of the snow melting tests conducted in a cold region covered with snow in winter in order to evaluate the performance of these prototypes.

3. Specifications

3.1 Configuration

This section will cover the features of the hot water panel. Figure 3-1 shows the structure of the panel.

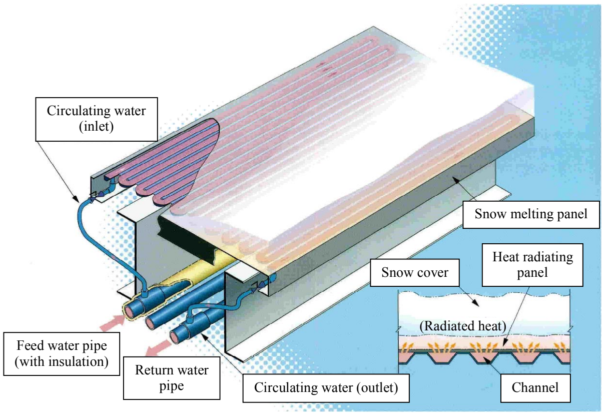


Figure 3-1 Steel Hot Water Panel

(1) The panel was made of sheet steel and had a series of trapezoidal channels in the cross-section.

(2) The hot water panels were placed continuously along the track. Snow removed by a Russell snow plow and piled up on top of the hot water panels was melted, becoming hot water that flowed out through the channels.

(3) Since the panels had a unit configuration with the pipes built in, it was easy to install them at the site.

(4) The coefficient of thermal conductivity was high, and even with a low temperature heat source (3 - 5°C), the panels were capable of removing fallen snow adequately.

The following requirements had to be resolved to apply the hot water panels to sidewalks:

(1) The hot water panels have a load-carrying capacity of 3 kN/m^2 to enable them to withstand the weight of snow removed from other areas and piled up on the panels, and since the route where the panels were placed would be used as an inspection route. However, in order for them to withstand the weight of crowds of people traveling along sidewalks, they must have a load-carrying capacity of 5 kN/m^2 [2)].

(2) To ensure pedestrian safety, the surface of the panels must have a variety of slip-proofing measures, and this will impair the high thermal conduction that is their main feature.

3.2 Structural Study

(1) Load Capacity

Theoretical strength calculations were performed to determine whether the conventional hot water panels are able to withstand the weight of crowds of people (5 kN/m^2).

In the study model (a four-sided fixed plate) shown in Figure 3-2, the values for deflection, moment and stress of the hot water panel when subjected to uniform load P are calculated as follows. [3)]

Maximum deflection : $W_{max} = 0.00254PA^4/D'$
Moment at point C1 : $(M_y)_{C1} = -0.0829PA^2$
Moment at point C2 : $(M_x)_{C2} = -0.0571PA^2$
Moment in center of plate : $(M_y)_O = 0.0412PA^2$
$(M_x)_O = 0.0158PA^2$
Maximum bending stress : $\sigma_{max} = (6/h^2)M_{max}$

D' : Flexural rigidity 1,140,750 (N・mm)
h : Thickness of hot water panel 3.9 (mm)

The results obtained from calculations using these formulas are shown in Table 3-1. The results in Table 3-1 confirmed that the hot water panels had the capacity to withstand the weight of crowds of people (5 kN/m^2).

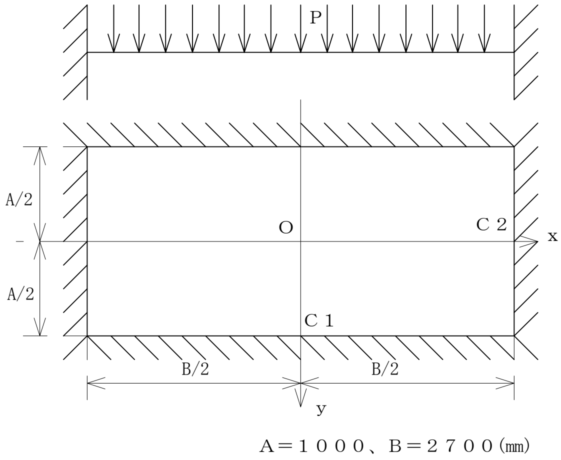


Figure 3-2 Study Model

Table 3-1 Results of Theoretical Strength Calculations

Uniform load P (kN/m^2)		1	2	3	4	5
Maximum deflection	Wmax(mm)	2.2	4.4	6.6	8.8	11.0
Maximum bending moment	Mmax(N・m/m)	83	166	249	332	415
Maximum bending stress	σ max(N/mm^2)	33	66	99	132	165
Tensile strength of panel σ s		280 N/mm^2				

(2) Slip-proofing

Two materials were studied for use in making the panels slip-proof: 1) coating and 2) sidewalk construction materials.

1) Coatings

The polyurethane coating for outdoor playing fields, factory floors and the like were selected as a coating material. Bending tests, weatherability tests, walking comfort tests and other basic tests were performed for the material.

From the results of these tests, the polyurethane coating was confirmed to be usable for the sidewalk hot water panels.

Using the polyurethane coating, two types of hot water panel were manufactured, a thin panel (0.3 mm thick) and a thick panel (3 mm thick), and the changes in these panels over a period of one year were observed. Since the thin (0.3 mm) panel peeled dramatically (see Figure 3-3), the thick panel was selected.

2) Sidewalk Construction Materials

As sidewalk construction materials, the concrete, interlocking bricks and tile that are in common use were selected.

Accordingly, four different prototypes were manufactured: (1) a polyurethane panel (2) a concrete jacketed panel (3) an interlocking panel and (4) a tiled panel. Each panel measured 920 mm (width) x 2,750 mm (length). Figure 3-4 shows the cross-sections of these panels. A braille plate for the visually impaired (made of soft artificial rubber/t = 2 mm) was attached to the surface of the polyurethane panel.

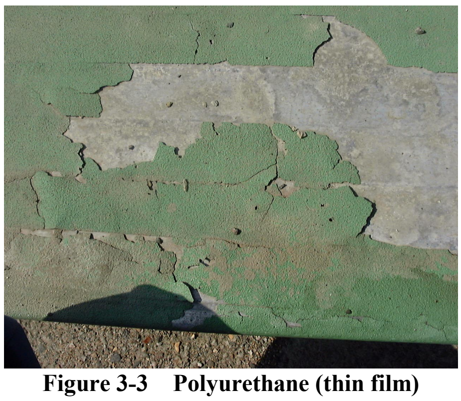


Figure 3-3 Polyurethane (thin film) Peeling

4. Snow Melting Test

4.1 Outline

Snow melting tests were conducted in Amarume-cho in Yamagata Prefecture, a cold region that is covered in snow in the winter, during the winter of 1999 (January through March 2000) and the winter of 2000 (February through March 2001). The test equipment flow chart is shown in Figure 4-1.

4.2 Procedure

(1) Tests

The following three tests were conducted:

1) Snowfall test: A test of how the hot water panel melted snow that fell naturally onto the surface of the panel
2) Natural snow cover test: Snow was allowed to pile up naturally on the surface of the hot water panel and then a test of how the panel melted the snow was conducted.
3) Artificial snow cover test: Snow was piled up onto the surface of the hot water panel manually and then a test of how the panel melted the snow was conducted.

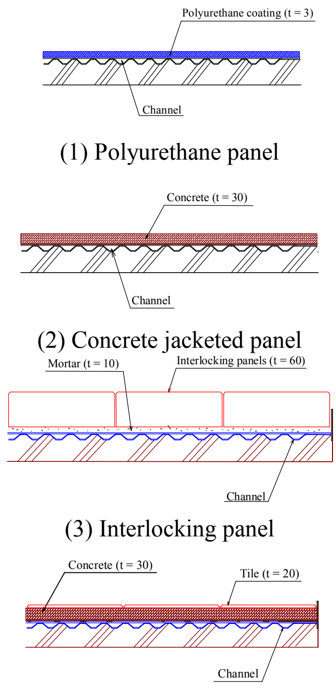
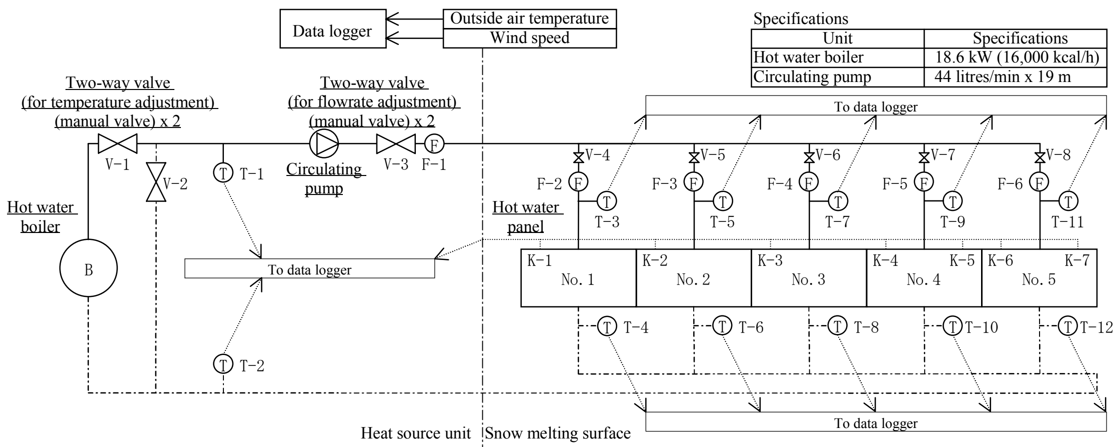


Figure 3-4 Cross-Sections of Sidewalk Hot Water Panels

(2) Test Conditions

The test conditions for each of the three tests (snowfall test, natural snow cover test and artificial snow cover test) are shown in Tables 4-1 through 4-3, respectively.



F :Flowmeter (site indicator flap type)
T :Thermometer (resistance temperature detector)
K :Thermometer (thermocouple)

No.1 Interlocking panel No.2 Concrete jacketed panel No.3 Steel hot water panel
No.4 Polyurethane (thin film) panel / Braille
No.5 Polyurethane (thick film) panel / Braille

Figure 4-1 Test Equipment Flow Chart

4.3 Test Results

(1) Snowfall Test

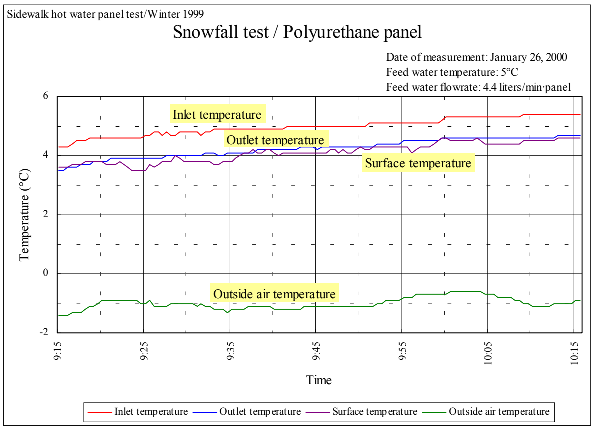
Figure 4-2 shows the results for the snowfall test.

Table 4-1 Test Conditions for Snowfall Test

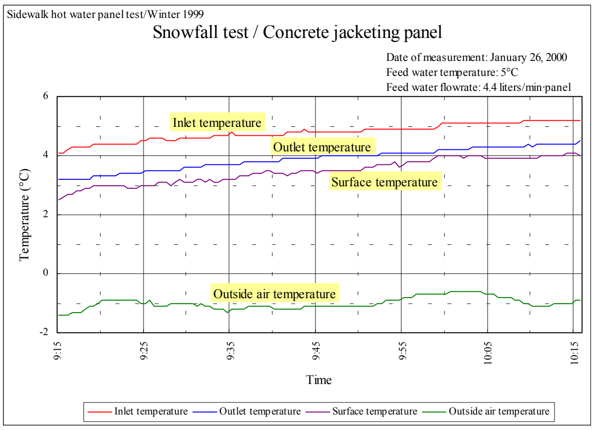
No.	1	2	3	4	5	6
Feed water temperature (°C)	5	10	15	5	10	15
Hot water panel flowrate (liters/min·panel)	2.2			4.4		

1) With inlet temperatures of 10°C and over, the sidewalk hot water panels demonstrated good snow melting performance regardless of the flowrate.
2) With an inlet temperature of 5°C, flowrate of 2.2 liters per minute per panel, and outside air temperature of -5°C, snow cover was detected on the surface of the concrete jacketed panel and the interlocking panel, and on the braille plate on the polyurethane panel.
3) With an inlet temperature of 5°C and flowrate of 4.4 liters per minute per panel, the difference between the inlet temperature and outlet temperature was only about 1°C for each of the panels.

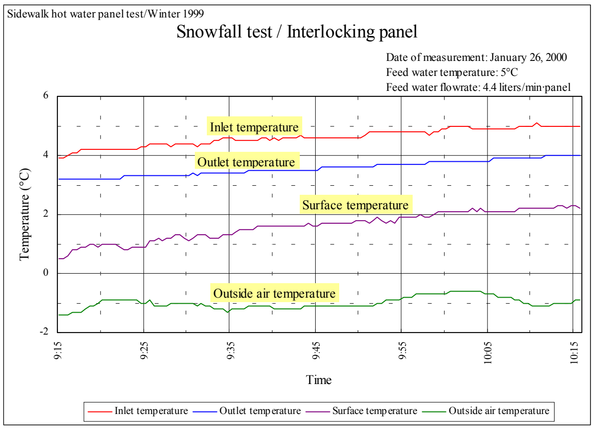
Snowfall test



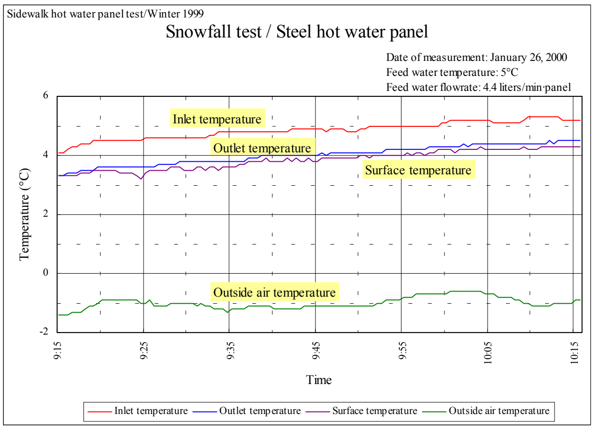
(1) Polyurethane panel



(2) Concrete jacketing panel



(3) Interlocking panel



(4) Hot water panel

Figure 4-2 Results of Snowfall Test (under test condition No. 4)

(2) Natural Snow Cover Test

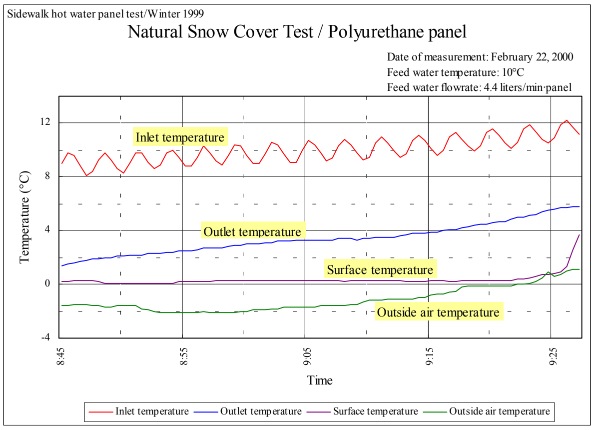
Table 4-2 Test Conditions for Natural Snow Cover Test

No.	1	2	3	4	5
Feed water temperature (°C)	10	20	10	20	20
Hot water panel flowrate (liters/min·panel)	2.2		4.4		7.3

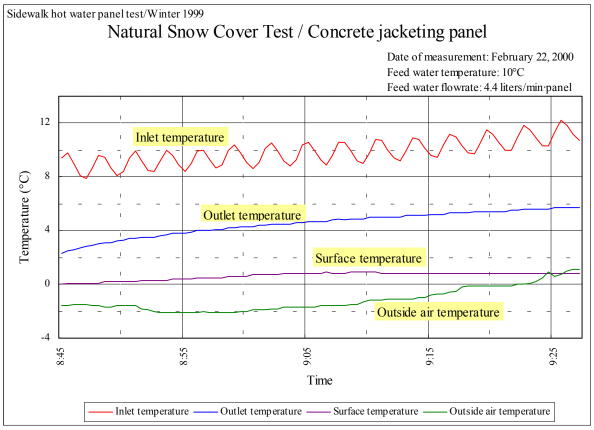
Figure 4-3 shows the results for the natural snow cover test.

1) The best snow melting performance was obtained with, in order, the hot water panel, polyurethane panel, concrete jacketed panel, tiled panel, and interlocking panel.
2) On the polyurethane panel, snow melting was completed first on all areas except the braille plate. Subsequently all snow was melted from the surface of the braille plate.
3) With inlet temperature of 10°C and flowrate of 2.2 liters per minute per panel, snow cover was detected only on the surface of the interlocking panel. All of the other panels demonstrated good snow melting performance.
4) Ranked in order of greatest difference between inlet and outlet temperatures, the panels are as follows: hot water panel, polyurethane panel, concrete jacketed panel, tiled panel and interlocking panel.

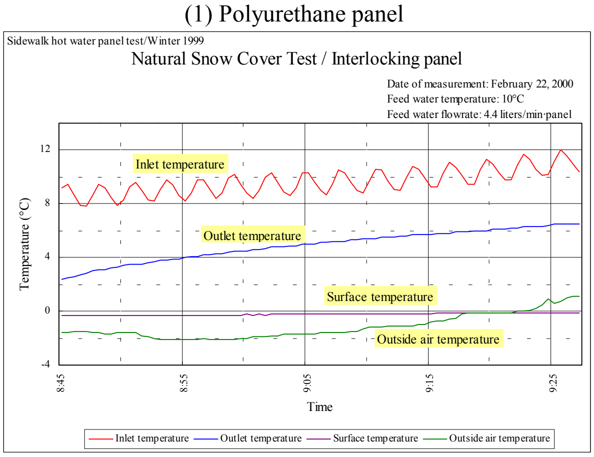
Natural Snow Cover Test



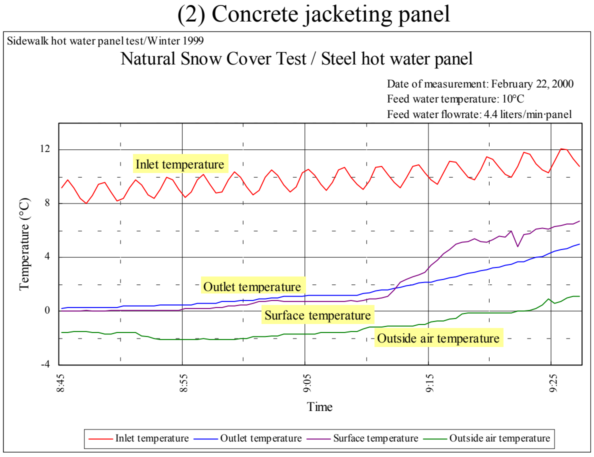
(1) Polyurethane panel



(2) Concrete jacketing panel



(3) Interlocking panel



(4) Hot water panel

Figure 4-3 Natural Snow Cover Test Results (under test condition No. 3)

(3) Artificial Snow Cover Test

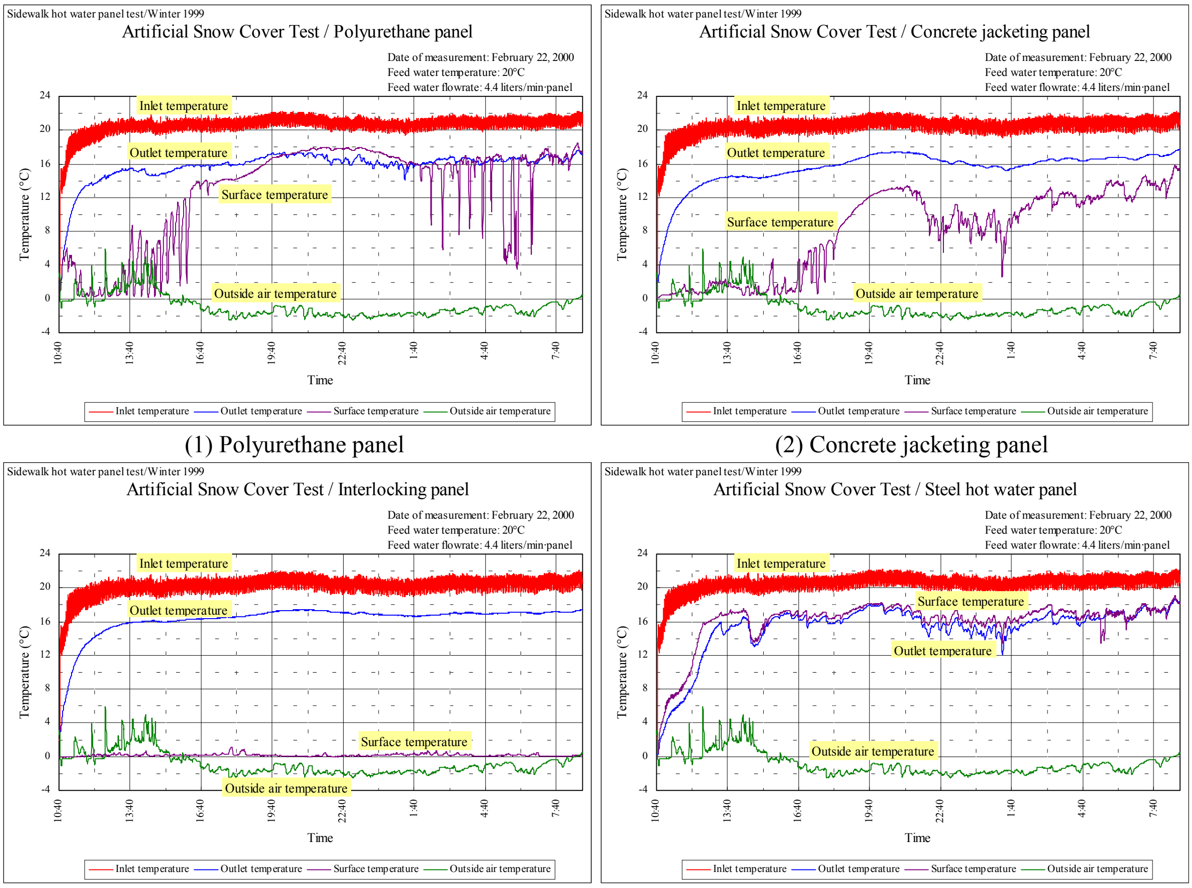
Table 4-3 Test Conditions For Artificial Snow Cover Test

No.	1	2	3	4	5	6
Feed water temperature (°C)	10	20	30	10	20	30
Hot water panel flowrate (liters/min·panel)	2.2			4.4		

Figure 4-4 shows the results for the artificial snow cover test.

1) The panels ranked in order of best snow melting performance are as follows: hot water panel, concrete jacketed panel, polyurethane panel, and interlocking panel.
2) The formation of snow bridges on the polyurethane panel and interlocking panel was determined by a visual check, and in some cases these impeded snow melting.
3) With an inlet temperature of 20°C and a flowrate of 4.4 liters per minute per panel, the difference between the inlet temperature and outlet temperature was approximately 3°C for all panels.
4) The difference between the inlet and outlet temperatures was almost constant for all of the panels up until snow melting was complete.

Artificial Snow Cover Test



(1) Polyurethane panel

(2) Concrete jacketing panel

(3) Interlocking panel

(4) Hot water panel

Figure 4-4 Artificial Snow Cover Test Results (under test condition No. 5)

5. Discussion

Evaluation of the performance of the sidewalk hot water panels is done in the same manner as was done for the hot water panels: by applying a regression formula to the values for amount of heat radiated and inlet temperature obtained in the test.

5.1 Snowfall Test

(1) Hot Water Pipe Method

In evaluating the performance of the sidewalk hot water panels, for purposes of comparison the hot water pipe method was used as a typical conventional snow melting method for trial design [4) 5)], The data for the test conditions was that for Sakata City, Yamagata Prefecture, which is the area adjoining the test location (Amarume-cho, Yamagata Prefecture).

1) Trial design weather conditions
   - a) Temperature: -1.6°C b) Depth of snowfall at time: 2.3 cm/h c) Wind speed: 2.0 m/sec
   - d) Snow temperature: -1°C e) Snow density: 0.07 g/cm^3
2) Results of trial design
   - a) Amount of heat needed: 170 W/m^2 b) Feed water temperature: 17°C

(2) Snowfall Test

Figure 5-1 shows the regression lines for amount of radiated heat, depicting the heat radiation performance of each of the hot water panels in the snowfall test, and the amount of heat needed in the hot water pipe method. From this figure, the following can be learned.

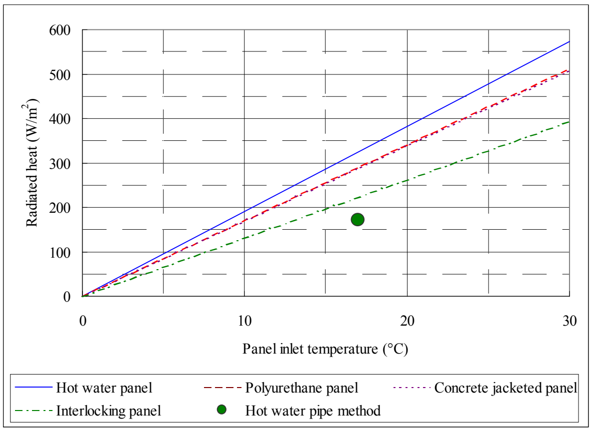


Figure 5-1 Amount of Radiated Heat in Snowfall Test

1) Ranked by the degree to which the heat radiation performance is greater than the regression line, the panels are: hot water panel, polyurethane panel, concrete jacketed panel, and interlocking panel.
2) There was only a slight difference between the polyurethane panel and the concrete jacketed panel. This can be assumed to be because, while the snow melting status confirms the high heat radiation performance of the polyurethane alone, the speed of snow melting on the braille plate section was low, reducing the heat radiation performance of the panel as a whole.
3) Under the same conditions as the hot water pipe method, all of the hot water panels emitted superior levels of radiated heat.
4) Whereas the hot water pipe method requires a feed water temperature of 17°C, the hot water panels demonstrated good snow melting with a feed water temperature of 10°C.

5.2 Natural Snow Cover Test

Figure 5-2 shows the amount of heat radiated by each of the hot water panels in the natural snow cover test after regression analysis. From Figure 5-2, the following can be learned.

1) Ranked in order of the degree to which the heat radiation performance is greater than the regression line, the panels are: hot water panel, polyurethane panel, concrete jacketed panel, tiled panel and interlocking panel.
2) There was only a slight difference between the polyurethane panel and the concrete jacketed panel. However, as noted in 5.1, the essential heat radiation performance of the polyurethane panel can be assumed to be greater than the test results.
3) With a feed water temperature of 10°C, at which all of the hot water panels demonstrated good snow melting performance, the interlocking panel demonstrated the lowest heat radiation performance (290 w/m^2). A feed water temperature of 28°C would be needed to produce the same amount of radiated heat as with the hot water pipe method.

5.3 Artificial Snow Cover Test

Figure 5-3 shows the amount of heat radiated by each of the hot water panels in the artificial snow cover test after regression analysis. From Figure 5-3, the following can be learned.

1) The panels ranked in the order of greatest heat radiation performance are as follows: hot water panel, polyurethane panel, concrete jacketed panel, and interlocking panel.
2) There was only a slight difference between the polyurethane panel, the concrete jacketed panel and the interlocking panel. However, as noted in 5.1, the essential heat radiation performance of the polyurethane panel can be assumed to be greater than the test results.
3) With a feed water temperature of 10°C, at which all of the hot water panels demonstrated good snow melting performance, the interlocking panel demonstrated the lowest heat radiation performance (210 w/m^2). A feed water temperature of 20°C would be needed to produce the same amount of radiated heat as with the hot water pipe method.

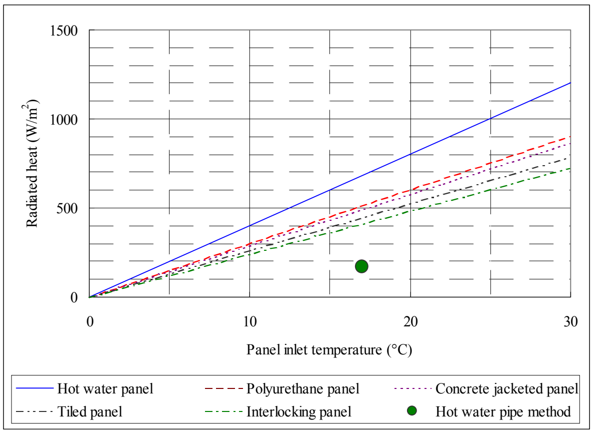


Figure 5-2 Amount of Radiated Heat in Natural Snow Cover Test

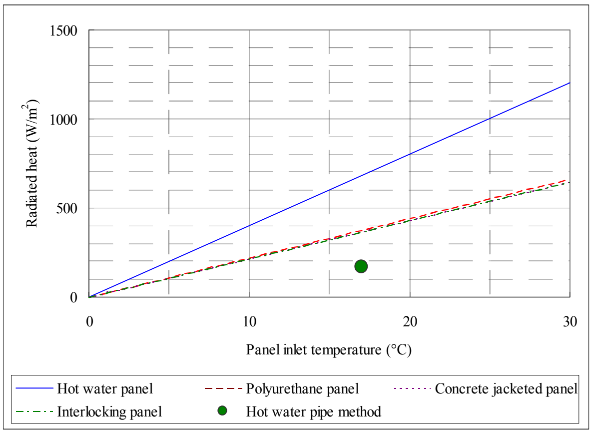


Figure 5-3 Amount of Radiated Heat in Artificial Snow Cover Test

From the above, it was confirmed that all four types of sidewalk hot water panels for which the site snow melting test was implemented demonstrated greater heat radiation performance than the hot water pipe method, and that they could demonstrate sufficient snow melting performance even at a feed water temperature of 10°C.

6. Conclusion

The results obtained through snow melting tests conducted for the sidewalk hot water panels in Amarume-cho, Yamagata Prefecture during the winter of fiscal 1999 and fiscal 2000 can be summed up as follows:

(1) All four prototype sidewalk hot water panels (interlocking panel, concrete jacketed panel, polyurethane panel and tiled panel) have the necessary strength to be used as sidewalk panels.

(2) In the snowfall test, natural snow cover test and artificial snow cover test, each of the sidewalk hot water panels demonstrated good snow melting performance.

(3) From the regression formula for the amount of heat radiated by the four prototype sidewalk hot water panels (interlocking panel, concrete jacketed panel, polyurethane panel and tiled panel), the amount of heat radiated by the panels was confirmed to be superior to that for the hot water pipe method.

(4) Since snow can be melted at a feed water temperature of around 10°C, it was confirmed that non-conventional energy (exhaust heat from subways, sewage heat, ground water, etc.), which has a temperature level of greater than 10°C, can be used as a heat source.

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