DEVELOPMENT OF A ROAD HEATING SYSTEM USING URBAN WASTE HEAT

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1. Abstract

Road heating systems are used to keep the roads open in winter in the cold and snowy regions of Japan by heating the road surfaces and melting the snow on the road.

Road heating systems do not impede traffic and are especially demanded at road sections that are prone to accidents in winter, such as crossings, and in cities where the traffic volume is large. However, such systems are expensive to construct and operate and are costlier than mechanical snow removal.

To reduce the total cost of road heating systems, we propose the use of urban waste heat and urban-type heat accumulators. The running cost of road heating systems can be reduced by utilizing the heat that is now wasted. Heat accumulators stabilize the supply of urban waste heat, the production of which is unstable, and make road heating systems smaller and more useful.

We then compared a conventional system and a system that heats the road using sewage heat and stores heat in an accumulator. Since underground heat accumulators are now expensive, our estimation showed that the new system was approximately 10% more expensive than the conventional system in total cost.

We will develop methods for manufacturing inexpensive heat accumulators and efficiently utilizing non-utilized urban heat sources to reduce the cost of the new system to the level of the conventional systems.

2. Introduction

In the snowy areas of Japan, people depend mostly on roads to travel and transport goods. Roads are protected from snow and freezing to enable traffic to flow by removing snow with machines, spreading antifreeze agents, and melting on-road snow with road heating systems.

Road heating systems, which are permanently installed infrastructures, secure the flow of traffic in winter more easily than mechanical snow removal since the systems do not hinder the flow of general traffic nor depend on the speed of snow removers. On the other hand, road heating systems are expensive to build and operate, and are not installed along the full length of roads but only at limited road sections.

3. Conventional snow-melting systems

Conventional systems melt snow either by spraying underground water or sea water on the road surfaces or heating the surfaces with heating wires or radiating pipes. The spraying method is used in limited areas since it needs a water source, the use of which is not restricted by regulations, near the site. The rest of this paper discusses non-spraying snow-melting methods.

3.1 Demands of non-spraying snow-melting systems

A questionnaire survey on road administrators [1] showed that approximately 60% of the problems of road heating systems were financial, hence the slow installation of snow-melting systems especially due to their high construction costs.

Approximately 90% of non-spraying snow-melting systems have been constructed in highly populated areas [1], showing that the demand is especially high in urban districts where traffic volumes are large.

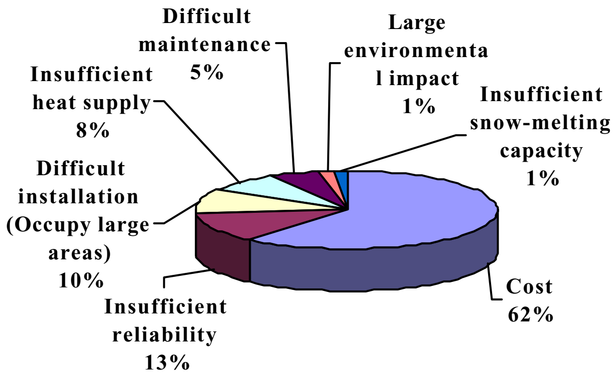


Figure 1. Issues of existing snow-melting systems

3.2 Advantages and disadvantages of non-spraying snow-melting facilities

A comparison of conventional and new road heating systems, all of which were assumed to melt the same amount of snow on the same road surface area, is shown in Table 1.

Table 1. Advantages and disadvantages of non-spraying snow-melting systems

Conditions: Heat supply:170W/m^2, snow-melting area:2000m^2

Method		Hot water boiler (circulates antifreeze solution)	Heating wires	Underground water method (returns the water underground)	Soil heat exchanger	Solar heat accumulator	Heat pump (recovers heat from the air)	Wind power generation method(*1)	Heat pump (recovers heat from sewage)
Advantages and disadvantages in terms of cost	Initial cost				Expensive Heat exchanging wells are expensive.	Expensive The construction of a heat accumulator is expensive.	Expensive The high-capacity heat pump is expensive.	Expensive The construction of a windmill is expensive.	Expensive The heat pump is expensive.
	Running cost	Expensive The boiler consumes much fuel.	Very expensive It consumes much electricity.	Inexpensive It utilizes the heat of underground water.	Inexpensive It utilizes the heat of the ground.	Inexpensive It utilizes solar energy.		Inexpensive It can sell surplus power.	Inexpensive It utilizes the heat of sewage.
Ratio of total cost(*2)		130	160	100 (set as a standard)	220	240	140	245	135

Notes: *1. Conditions of wind power generation method: Heat supply:200W/m^2, snow-melting area:1281m^2

*2. Total cost = Initial cost + Running cost

The methods that use natural energy sources, such as the heat of underground water, the heat of the soil, solar energy, and wind power, are expensive to construct but are inexpensive to operate since the energies are free. Especially, the systems that use the heat of underground water and return the water into the ground and heat pumps that recover heat from sewage are as cheap as or cheaper than the conventional boiler method in total cost.

The total cost of road heating systems may be reduced by using free natural energy sources to reduce the operation cost and developing cheaper construction methods.

4. Utilization of non-utilized energy sources

Non-utilized energy sources listed in Table 2 are candidate energy sources to reduce the running costs of road heating systems. Of these sources, waste heat in cities, which is easy to use, is produced in large quantities in highly populated areas (cities), where demand for road heating systems is high.

Table 2. Classes and configurations of heat sources

Heat source class			Configuration	Application to non-spraying snow-melting systems
Natural energy	Non-utilized energy		Heat of underground water	Widely used in underground-water systems (which return the water underground)
			Heat of the ground	Used in heat pipe systems and soil heat exchanging systems
			Solar heat	Used in shallow underground heat accumulator systems and in-fill accumulator systems
			Wind power	Used in wind power generation systems
			Heat of the air	Widely used and recovered by heat pumps
			Heat of sea water	Used and recovered by heat pumps
			Heat of river water	Not used so far
Local energy		Waste heat in cities	Heat of sewage	Used and recovered by heat pipes
			Waste heat from subways	Used and recovered by heat pumps
			Waste heat from transforming stations	Used
			Waste heat from buildings	Not used so far
			Waste heat from factories	Used
			Waste heat from incinerators	Used in vapor heat exchange systems and RDF waste heat systems
			Heat of hot springs	Used directly, in heat exchange systems, and heat pipe systems
Fossil energy			Hot water boiler	Very widely used
			Electric heating	Very widely used

4.1 Balance between the heat needed to melt snow and the amount of non-utilized heat

We should first examine whether there is sufficient urban waste heat to melt on-road snow.

We estimated the amount of non-utilized energy in 31 cities of at least 100 thousand in population in the cold and snowy areas in Japan, calculated the amount of heat needed to melt snow, and analyzed the heat balance and heat availability in each city for the non-utilized heat types listed in Table 2.

Our analyses showed that the heat was not sufficient to melt the on-road snow during peak snowfalls in all 31 cities. In 11 cities, the acquirable heat was over one third of the necessary energy, suggesting that the snow can be melted by storing heat for two days. Therefore, in many areas, non-utilized heat would be sufficient to melt the deepest on-road snow if the heat is

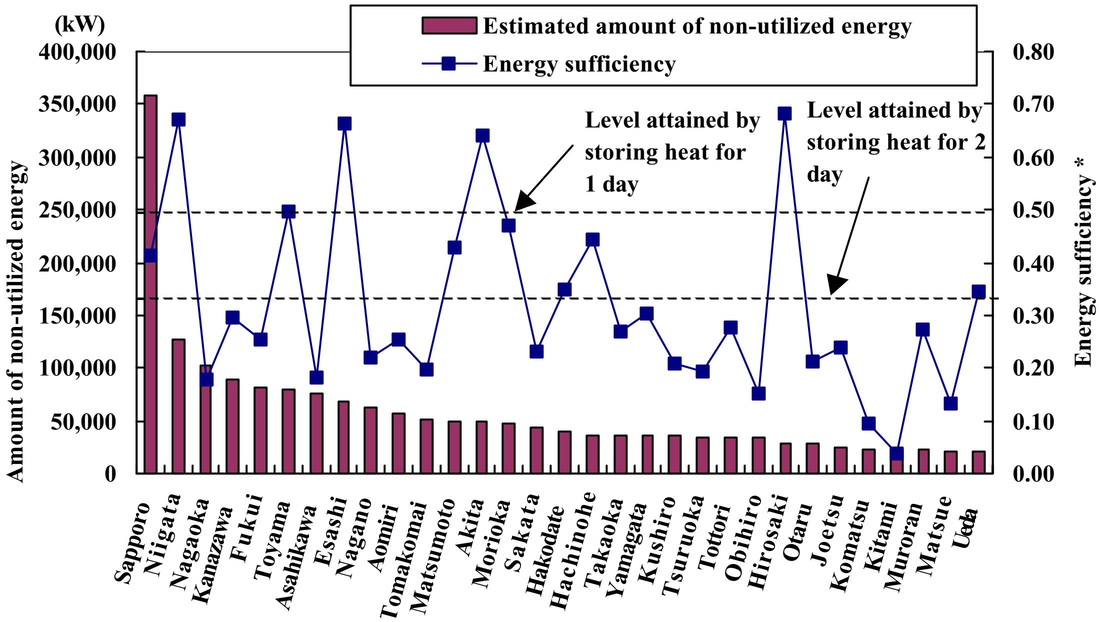


Figure 2. Non-utilized energy and sufficiency of energy [(2)]

stored while there is no snow.

We then divided each city into meshes of 1 km, estimated the acquirable and necessary amounts of heat for each mesh, and calculated the heat balance along principal roads.

The mesh analysis showed that there is sufficient non-utilized energy to melt snow in districts that have incinerators, sewage treatment plants, and other big energy sources, and in midtown districts, which produce much sewage from which much heat can be collected.

From our heat balance analyses, we can conclude that:

1) Non-utilized energy can be used to melt snow in more areas by storing heat, and
2) In highly populated midtown areas, there is abundant heat in the sewage, which is likely sufficient to melt on-road snow.

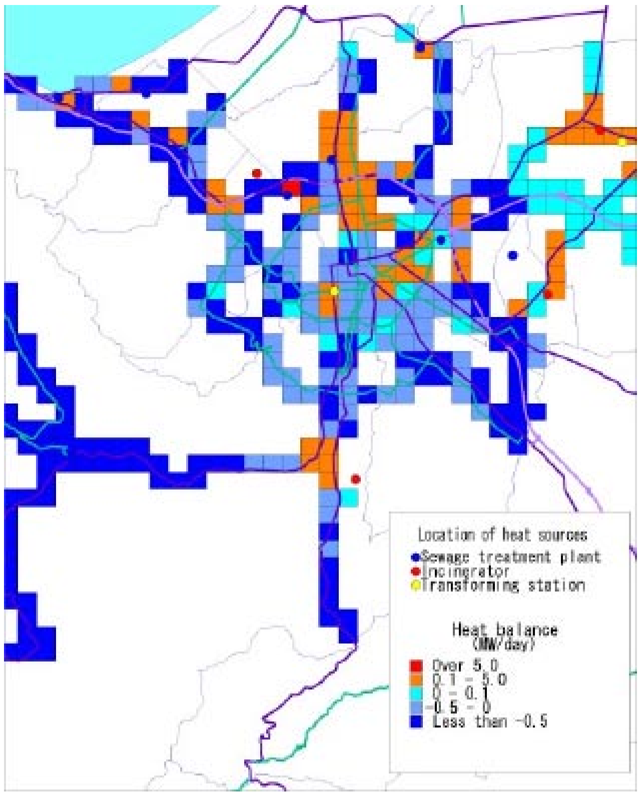


Figure 3. Examples of mesh analyses [(2)]

(Sapporo , maximum snowfall)

4.2 Characteristics of sewage heat

This section describes the characteristics of heat in sewage, which our analyses suggested is a promising heat source.

The temperature of sewage before treatment is 12 to 15℃ in winter. Since snow-melt water flows into sewers during the daytime, the amount of sewage increases and the temperature drops. The amount of sewage is a minimum in the early morning when people are least active. The heat of sewage fluctuates with time as shown in Figure 5, and is small in the early morning (2:00-6:00) and early afternoon (12:00-16:00) and large in the mid morning (8:00-12:00) and evening (18:00-1:00) when people use much water.

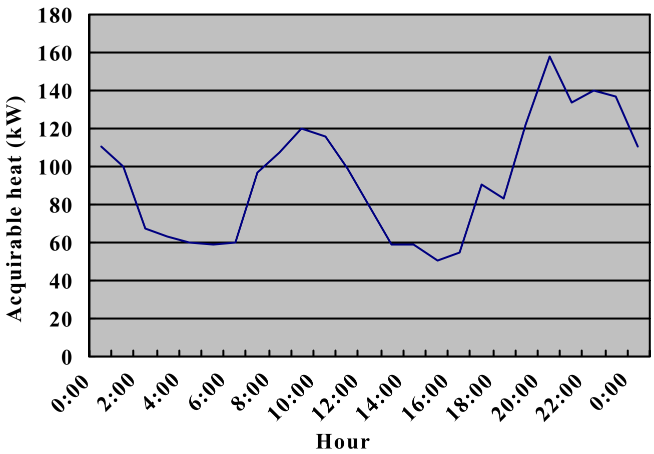
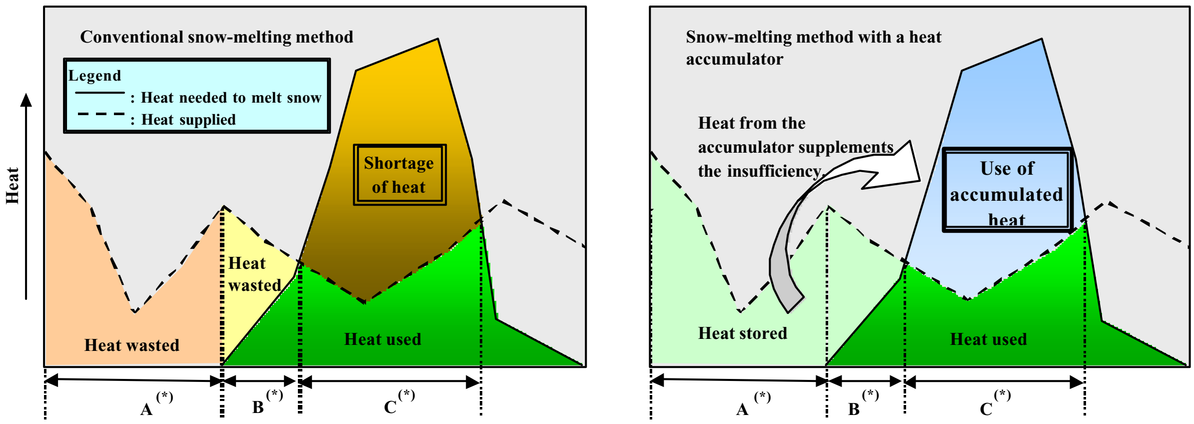


Figure 4. Energy acquirable from sewer pipes (ϕ 600 mm, calculated from measurements)

5. Effects of heat accumulators

5.1 Stable supply of heat needed to melt snow

As mentioned above, the amount of heat that can be collected from non-utilized energy sources is not stable, and there may be periods during which the heat is insufficient to melt snow. Since snowfall is neither constant or continuous, even the deepest on-road snow can be melted by storing such unstable heat while it is not snowing (see Figure 5).



Notes: * A: Time period with no snowfall
B: Time period during which the heat supply exceeds the heat needed to melt the snow
C: Time period during which the heat supply is insufficient for melting the snow

Figure 5. Measures against heavy snowfall

In-fill accumulator systems have been developed to store solar energy in summer and use the heat in winter. Due to prolonged accumulation, the systems lose large proportions of the heat, need a large volume of banking soil and large-scale construction works, and are very expensive to construct.

We propose the following urban-type heat accumulator and construction method to store waste heat in cities:

1) Small accumulators that store the heat of several hours to several days not to supply the entire heat needed to melt snow but to supplement the heat shortfall, and
2) Cheap and easy methods for building small and highly efficient accumulators in cities, where space is limited.

5.2 Reducing the capacity of road heating systems

It is possible to reduce the capacity of a road heating system (heat exchangers and heat pumps) by installing a heat accumulator to supplement the heat shortfall. The capacities of heat exchangers and heat pumps are determined by peak snow depths. Heat accumulators will melt parts of snow and reduce the design snow depth and the necessary capacities of these and other heat collecting systems.

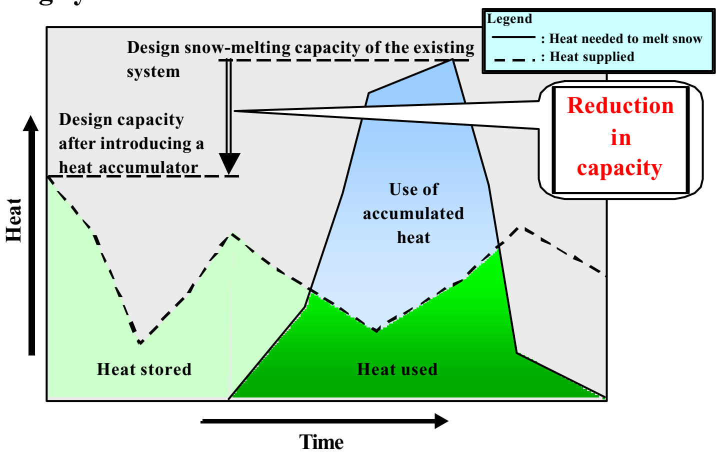


Figure 6. Reducing the capacity of an existing snow-melting system

Urban-type heat accumulators will stabilize the supply of waste heat, demand less capacity of snow-melting systems, and reduce the total cost of the systems.

6. Systems installed with heat accumulators

We propose a snow-melting system that recovers heat from sewer pipes and has a heat accumulator. The design conditions were an area of 2,000 m2 and a heat supply of 170 W/m2.

Table 3. Comparison between a conventional system and a heat accumulator system, both of which recover heat from sewage with heat pumps

Design conditions: snow-melting area: 2000 m^2, heat supply: 170 W/m^2

Item		Heat pump to recover heat from sewage	Underground heat accumulator + a heat pump to recover heat from sewage(*)
Capacity	Heat pump	Output: 340 kW	Output; 220 kW
	Heat exchanger	100 (set as a standard)	Approximately 65
Economy	Initial cost	181.6 million yen	202.7 million yen
	Running cost (20 years)	26.7 million yen	24.3 million yen
	Total cost (20 years) (Initial and running costs)	208.3 million yen	227 million yen
Stability of snow-melting performance (heat output)	Adaptability to changes in snowfall and heat supply	Adaptable within the range of heat supply from the heat sources	Can supply more heat than the heat from the heat source by using the heat stored in the accumulator. After the heat in the accumulator has been consumed, this system can provide only a half of the heat of the conventional system.
Efficiency	Utilization efficiency of the heat from the heat sources	Can only use the heat when there is snow to melt. The utilization efficiency is low.	Stores the heat when there is no snow and uses it for melting snow afterwards. The utilization efficiency is high.

Notes: * This system was assumed to obtain 50% of heat from the heat pump and 50% from the underground heat accumulator, and to have an operation efficiency of 100%.

Heat accumulators are very effective for systems that operate at the maximum power for short periods of time. Since the performance of such a system is reduced by half after the heat in the accumulator has been consumed, the heat accumulator should have a surplus capacity. At present, the new system is approximately 10% more expensive than the conventional system in total cost (see Table 3), which is attributable to the high cost of manufacturing the heat accumulator.

Future topics are to reduce the cost of heat accumulators, establish methods for designing the capacities of heat-collecting systems so as to minimize the total cost, and reduce the total cost to the same or lower level than the conventional systems.

7. Methods for actualizing the snow-melting systems

To reduce the total cost to a level that allows actual installation of our system, we should develop inexpensive methods for manufacturing heat accumulators and efficient methods for using heat.

7.1 Inexpensive methods for manufacturing heat accumulators

Since areas available for heat accumulators are limited in cities, most heat accumulators have small cross sections and are vertically long to ensure sufficient volume. Deep excavation is needed, which is expensive and time consuming.

The cost may be reduced by designing a thin and long accumulator that also exchanges underground heat and using the ground around the accumulator as the heat accumulating agent. With this method, we can reduce the size and construction cost of the heat accumulator.

Another method is to build a heat accumulator that is made of concrete culverts filled with water, as in a regional air conditioning system, beneath the roads. Widely used precast concrete box culverts may be used to reduce the cost and shorten the working period.

7.2 Efficient methods for using heat

Highly efficient heat-use systems should be developed to 1) determine the best balance between the necessary heat (design conditions) and the capacities of a heat collector and accumulator, 2) control in real time the supply of heat, such as supplying X% of heat from the heat source and Y% from the accumulator, and 3) minimize the systems.

The capacities of a heat collector and a heat accumulator are derived by inputting the necessary heat to melt snow (time-sequential data) and acquirable heat (time-sequential data) and calculating the heat balance. Systems that have minimum capacities but most efficiently use heat will be chosen and standardized by investigating heat collectors and heat accumulators of various capacities.

8. Conclusion

Installation of heat accumulators will stabilize the supply of heat to melt snow and minimize road heating systems. The element technologies shown in Figure 7 should be developed to reduce the total cost. Cheap and useful road heating systems will also be developed which recover waste heat from sources other than sewage.

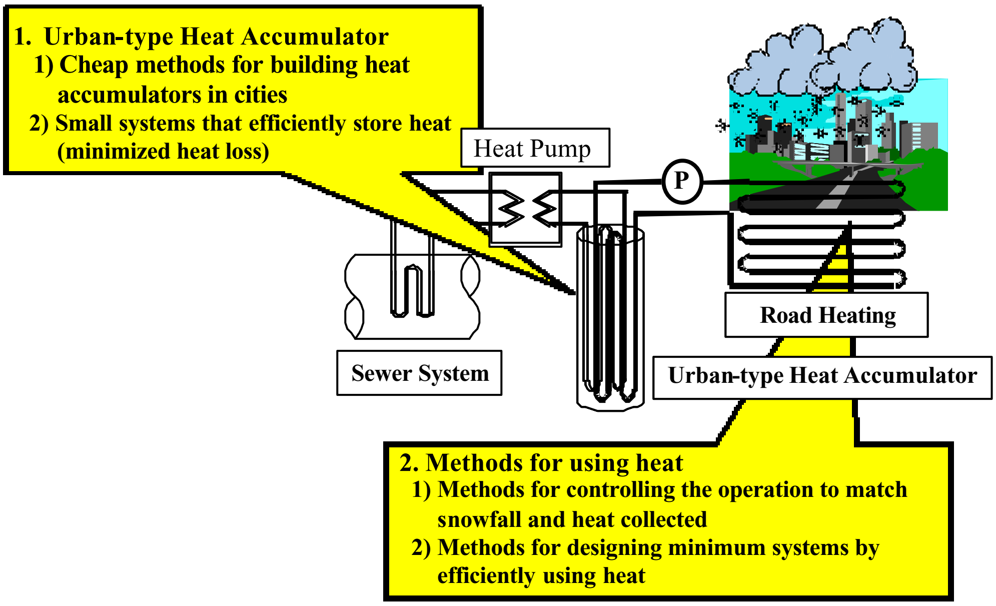


Figure 7. Development of element technologies to actualize heat accumulator systems

9. Reference

(1) Tohoku Regional Development Bureau (1994) "Entrusted surveys of non-spraying snow-melting systems in fiscal 1993 "

(2) Public Works Research Institute (2000) "The facility for melting on- road snow by using new heat" Technical Memorandum of PWRI No.3749