PAVEMENT SNOW MELTING

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Abstract

The design of pavement snow melting systems is presented based on criteria established by ASHRAE. The heating requirements depends on rate of snow fall, air temperature, relative humidity and wind velocity. Piping materials are either metal or plastic, however, due to corrosion problems, cross-linked polyethylene pipe is now generally used instead of iron. Geothermal energy is supplied to systems through the use of heat pipes, directly from circulating pipes, through a heat exchanger or by allowing water to flow directly over the pavement, by using solar thermal storage. Examples of systems in New Jersey, Wyoming, Virginia, Japan, Argentina, Switzerland and Oregon are presented.

Key words: pavement snow melting, geothermal heating, heat pipes, solar storage, Wyoming, Virginia, Japan, Argentina, Klamath Falls.

Introduction

Pavement snow melting using geothermal hot water and steam has been demonstrated in several countries, including Argentina, Japan and the United States. These installations include sidewalks, roadways, bridges and runways. Most commonly it is done with a glycol solution, hot water or steam being circulated in pipes within or below the pavement, using either heat pipes or geothermal fluids, however, in one instances hot water has been sprinkled directly onto the pavement. This paper will attempt to present the general design requirement for a snow melting system and then give examples of those in operation using geothermal energy. The obvious benefits of these systems is that they eliminate the need for snow removal, provide greater safety for pedestrians and vehicles, and reduces the labor of slush removal.

General Design Criteria

The heating requirement for snow melting depends on four atmospheric factors: (1) rate of snow fall, (2) air temperature, (3) relative humidity, and (4) wind velocity (ASHRAE Handbook, 1995).

The snow melting system must first melt the snow and then evaporate the resulting water film. The rate of snowfall determines the heat required to warm the snow to 32°F and to melt it. The evaporation rate of the melted snow from the pavement is affected by the wind speed and by the difference in vapor pressure between the air and the melted snow. Since the vapor pressure is determined by the relative humidity and temperature of the air, and as the pavement surface temperature is usually fixed, the resulting evaporation rate varies with changes in air temperature, relative humidity, and wind speed. Convection and radiation loss from the melted snow depends on the film coefficient and the difference in temperature between the surface and air. The film coefficient is a function of wind speed alone, and since the pavement temperature is fixed, convection and radiation losses vary with changes in air temperature and wind speed (ASHRAE Handbook, 1995).

Chapman (1952) derives and explains equations for the heating requirement of a snow-melting system. Chapman and Katunich (1956) derive the general equation for the required pavement heat output (q_o) in Btu/h·ft^2:

$$q_o = q_s + q_m + A_r\,(q_e + q_h)$$

where

q_s = sensible heat transferred to the snow (Btu/h·ft^2),
q_m = heat of fusion (Btu/h·ft^2),
A_r = ratio of snow-free area to total area (dimensionless),
q_e = heat of evaporation (Btu/h·ft^2), and
q_h = heat transfer by convection and radiation (Btu/h·ft^2).

The sensible heat q_s to bring the snow to 32°F is:

$$q_s = s\,c_p\,D\,(32 - t_a)\,/\,c_1$$

where

s = rate of snowfall (inches of water equivalent per hour),
D = density of water equivalent of snow (62.4 lbs/ft^3),
c_p = specif heat of snow (0.5 Btu/lb·°F),
t_a = air temperature (°F). and
c_1 = conversion factor (12 in./ft).

For hot water (hydronic) systems, the above reduces to:

$$q_s = 2.6\,s\,(32 - t_a)$$

The heat of fusion q_m to melt the snow is:

$$q_m = s\,h_f\,D\,/\,c_1$$

where

h_f = enthalpy of fusion for water (143.5 Btu/lb).

For hot water (hydronic) systems, the above reduces to:

$$q_m = 746\,s$$

The heat of evaporation q_e (mass transfer) is (for hydronic):

$$q_e = h_{fg}\,(0.0201\,V + 0.055)\,(0.188 - p_{av})$$

where

h_{fg} = heat of evaporation at the film temperature (Btu/lb),
V = wind speed (mph), and
p_{av} = vapor pressure of moist air (inches of mercury).

the heat transfer q_h (convection and radiation) is (for hydronic):

$$q_h = 11.4\ (0.0201\ V + 0.055)\ (t_f - t_a)$$

where

t_f = water film temperature (°F), usually taken as 33°F.

The solution of the general equation for q_o for the required pavement heat output, requires the simultaneous consideration of all four climatic factors: wind speed, air temperature, relative humidity, and rate of snowfall. Annual averages or maximums for the climatic factors should not be used because they are most likely not to occur simultaneously. It is thus necessary to investigate the various combinations that might occur at a site, based on several year's worth of data, to determine the critical combination that is most likely to be experienced (ASHRAE Handbook, 1995). Some design weather data and required heat output for selected cities in the U.S. are given in chapter 46 of the 1995 ASHRAE Applications Handbook.

Chapman (1957) classifies snow melting installation according to type as Class I, II or III. These types are described as follows:

Class I (minimum): residential walks or driveways; interplant ways or paths.

Class II (moderate): commercial sidewalks and driveways; steps of hospitals.

Class III (maximum): toll plazas of highways and bridges; aprons and loading area of airports; hospital emergency entrances.

The 1995 ASHRAE Applications Handbook presents design output data for each of the three classes for selected cities in the U.S. As examples, the following four cities are given below:

	Design Output (Btu/h·ft^2)		
City	Class I System	Class II System	Class III System
New York City	121	298	342
Chicago	89	165	350
Reno, NV	98	154	155
Portland, OR	86	97	111

Piping Material and Pavement Installations

Piping materials are either metal or plastic. Steel, iron and copper pipes have been used extensively in the past, and are still used abroad, however, steel and iron corrode rapidly if they are not protected by coatings and/or cathodic protection. The use of salts for deicing and the elevated temperature accelerate corrosion of these materials. NACA (1978) experience indicates that the corrosion rate approximately doubles for each 18°F rise in temperature. Corrosion failures of iron pipe caused the shut-down of a Klamath Falls geothermal snow melting system after almost 50 years of operation. The corrosion was due to the failure of the outside protective wrapping of the pipes (Lund, 1999).

Present practice in the U.S. is to use plastic pipe with iron for the header pipe. Typical plastic pipes are of a cross-linked polyethylene (PEX), that according to ASTM standard F 876, can handle 180°F water at 100 psi or 200°F water at 80 psi. This type of pipe is lightweight and easier to handle, can be bent around obstructions or for reverse bends with radii of as little as 12 inches, comes in long sections, do not require expansion loops, and use mechanical compression connections. It obviously does not corrode, thus it has a life of over 50 years.

Generally, an antifreeze solution (ethylene or propylene glycol) is used in the pipes, circulated in a closed system and heated by a heat exchanger. Antifreeze solutions are necessary, as most systems will not be operated continuously in cold weather, and thus the system must be protected from freeze damage.

Chapman (1952) dervied the equations for the fluid temperature required to provide an output q_o (defined earlier). Using 3/4- to 1-inch diameter pipe placed approximately 2 inches below the pavement surface, the equation is:

$$t_m = 0.5\ q_o + t_f$$

where

t_m = the mean fluid (antifreeze solution) temperature in degrees F and t_f is generally taken as 33°F.

Portland cement concrete (PCC) or asphalt concrete (AC) may be used for snow-melting system. The thermal conductivity of AC is less than that of PCC, thus pipe spacing and temperatures are different. However, the main reason for not using AC pavements with pipes embedded in them, is that the hot asphalt may damage the pipes, as AC is usually placed at above 300°F in order to get adequate compaction. Also, the compaction process may deform and even break pipes and their connections.

With PCC pavements, the pipes can be attached to the reinforcing/expansion steel within the pavement (which may not always be used) , but should have at least 2 inches of concrete above and below the pipes. This then requires a pavement of at least 5 inches thick. In the case of sidewalks, the piping is usually place below the slab in a base or subbase, as these pavements are usually only 3 to 4 inches thick. In this latter case, the advantage of not placing the pipes in the concrete, is that future utility cuts or repairs can be made without damaging the pipes. In Klamath Falls, pipes under the sidewalks were covered with a weak fluid cement paste to hold them in place. Pipes should not cross expansion or contraction joints within highway pavement, as shrinkage during curing may be as much at 3/4-inch per 100 feet of slab, and long term expansions and contractions can be significant from hot to cold weather periods. All pavements must be protected from frost heave with proper drainage and adequate base or subbase thicknesses, as heaving may damage the pipes, especially where they are connected to a header along the edge of the pavement.

Geothermal Heat Supply and Example Installations

Geothermal energy can be supplied to the system by one of four methods: (1) through the use of heat pipes, (2) directly from a well to the circulating pipes, (3) through a heat exchanger at the well head, or (4) by allowing the water to flow directly over the pavement. All of these systems have been utilized to one degree or another throughout the world.

Heat pipes

This type of configuration was first used in Trenton, New Jersey in 1969 (Nydahl, et al., 1984). This system circulated an ethylene glycol-water mixture between pipes embedded 2 inches below the pavement surface and a horizontal grid buried 3 to 13 feet below the pavement on 2-foot levels. The total length of the ground pipes was twice as long as the pipes in the pavement. The measured undisturbed ground temperature at 7 feet depth varied between 48 and 57°F during the winter and the antifreeze temperature ranged between 40 and 52°F during most of the snow storms. Typical measured snow melting rates were 1/4 and 1/2 inches per hour when the corresponding air temperature ranged between 20 and 35°F. The performance of this ground system proved to be superior to that of a companion 68 Btu/h/ft^2 electric pavement heating system while requiring only about 2% of the electrical power to operate the circulation pump. One of the draw-backs with the system was the expensive excavation required for placement of the ground pipes.

A second project, using the results of the Trenton experience, was to conduct research on a vertical ground heat exchanger or gravity-operated heat pipe (Nydahl, et al., 1984). The gravity-operated heat pipe consisted of a sealed tube which contained a fluid in the liquid-vapor state. Ammonia and Freon were utilized as the working fluid partly because they were not susceptible to the freezing problem that plagued water based system, and they are chemically inert with respect to most steels. Today Freon could not be used due to restrictions on the use of CFCs. The lower end of the pipe was the evaporator while the upper portion served as the condenser. When the evaporator is warmer than the condenser, a portion of the liquid vaporizes and travels to the condenser where its latent heat of vaporization is released upon condensing. The evaporation and condensation processes create the driving pressure potential that is required to transport the vapor upward, while the condensate returns due to gravity in the slightly slanted condenser to the vertical evaporator. Since the thermal energy is transported in the form of latent heat of vaporization, the heat pipe can transport large amounts of energy over a long distance (about 180 feet at two experimental installations) with a relatively small temperature difference. There are no mechanical moving parts in this system, and the heat pipe self activates anytime the ground around the evaporator is warmer than the pavement in which the condenser is embedded.

The main problems anticipated with this system was to make sure all joints were sealed and that the pipes were protected against corrosion. Construction costs would increase for the pavement due the unusual characteristics of the system and for drilling and placing the vertical pipes. Full scale test projects were constructed on a highway ramp in Oak Hill, West Virginia and on two highway ramps near Cheyenne, Wyoming (Nydahl, et al., 1984). These 7% grade ramps utilized 177 field constructed heat pipes to warm 10,600 ft^2 of pavement. Each heat pipe had a 100-foot long evaporator attached to a manifolded condenser section with a total length of 120 feet. The ground temperature was 54°F, however the system performed to expectations. A more detailed section was constructed at Sybille Canyon (1976) and at Spring Creek Bridge (1980) in Laramie, Wyoming, which were extensively monitored. The latter installation included 60 large heat pipes, two header pipe vaults, four service vaults and 3 inches of polyurethane insulation on the underside of the heat portion of the deck. The evaporator pipes were made from 2 inch schedule 80 steel pipe with a spiral groove machined on the internal surface to enhance the wetting of the wall by the returning condensate. The evaporator pipes were placed in 8-inch diameter holes and consisted of 15 pipes located on 10-foot center at each corner of the bridge. The connecting pipes and the condensers were all made from 1-inch schedule 40 pipe, and set on a minimum grade of 2% to ensure condensate drainage back to the evaporators. The pipes were charged with ammonia so that the liquid level at the bottom of each evaporator was about one foot high. The installation was monitored for two years and performed well in preventing freezing of the heated deck. Even though the ground temperature was only 47°F, the heated bright surface was increased by as much as 27°F. The only serious design problem that became evident was that the pipe grades were insufficient to compensate for settling of the earth, thus producing liquid locks. It was recommended to increase the grades from 2 to 5% to overcome this problem.

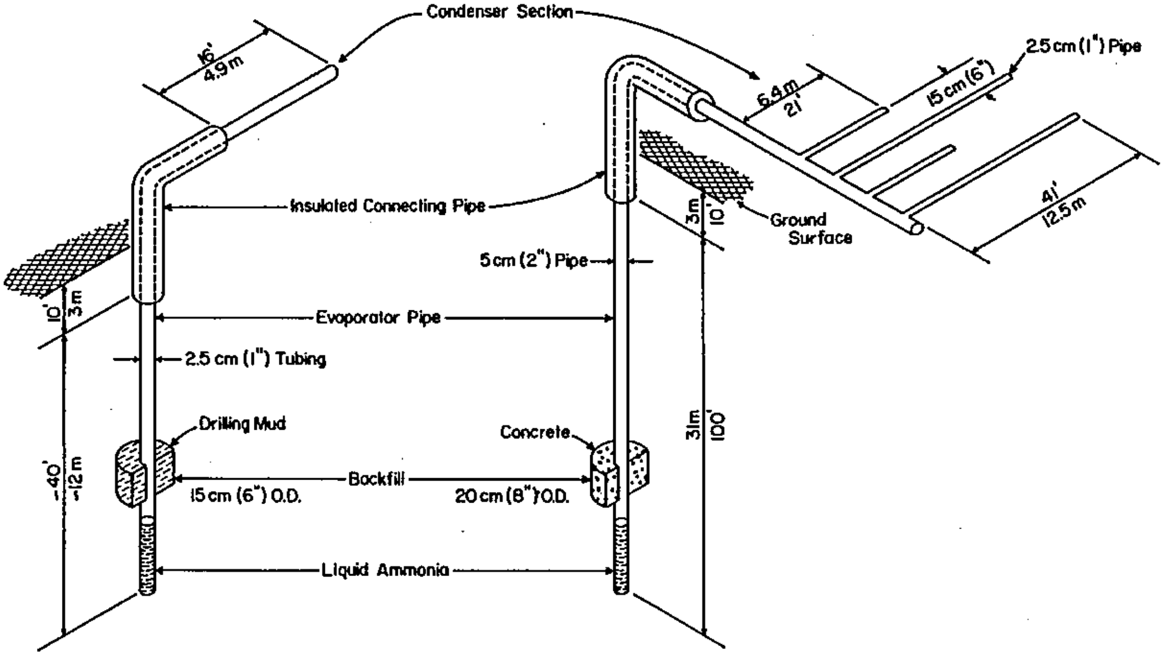

Figure 1. Schematic of Sybille and Spring Creek Heat Pipes (Nydahl, et al., 1984)

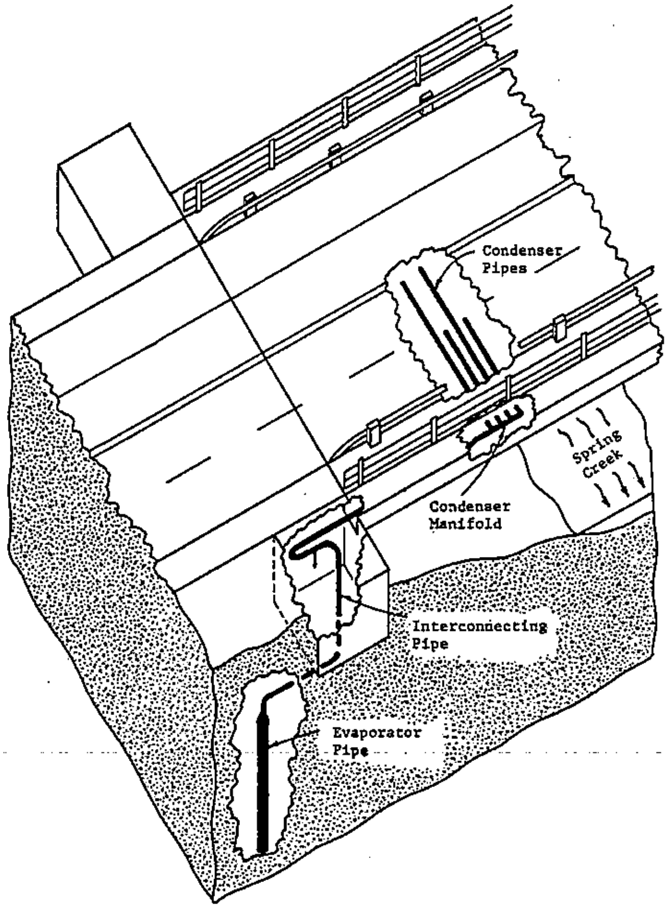

Figure 2. Schematic of the Spring Creek Heat Pipe System (Nydahl, et al., 1984)

Similar systems have been tested in Japan and by the Colorado Department of Highways near Glenwood Springs. In the later case, a water well was used to supply the heat rather than the ground.

Pavement Sprinkling

Sprinkling a roadway surface with warm water has been used in Fukui City of the Tohoku region of northern Japan (New Energy Plaza, 1997). This is a water cascaded snow melting system in which groundwater at 60°F flows through heat exchanger ducts buried in the sidewalk where the temperature is reduced to 45°F. After melting the snow on the sidewalk the water is sprinkled on the adjacent roadway. "Snowfall sensors" are used to automatically operate the snow-melting system. The sensors check whether snow has fallen and if snow is remaining on the surface, and whether the snow has melted thoroughly.

Geothermal Steam

In the Copahue-Caviahue Thermal Area of west-central Argentina on the slopes of the Andes, geothermal steam is used for heating streets and the access road to Villa Copahue, a ski resort (Pesce, 1998). The steam is produced from the 4,600-foot deep CO04 geothermal well, which produces 30 ton/h of steam. The steam is transported through an 8,500-foot long pipeline. Winter temperatures in the area are as low as 10°F; winds can reach 100 mph; and snow depths average 13 feet. Using the geothermal heat, the pavement temperature can kept between 54 and 61°F. The heating is done by radiant panels underneath the road surface, consisting of serpentine hot water distribution pipes, covering almost 24,000 ft^2 of road surface. The waste water is then discharged at the surface through a collector pipeline.

Geothermal Hot Water

Geothermal hot water has been used for pavement snow melting in Japan and the U.S. At Sapporo in Japan, water from the Jozankei Spa has been used for snow melting on roads since 1966 (Sato and Sekioka, 1979). The system covers 112,000 ft^2. Initial construction used steel pipes, but due to external corrosion, these were replaced with one-inch diameter polybutene pipes in 1973. Hot spring winter is circulated by three 10-hp pumps through three separate loops of pipe embedded three to five inches deep at one-foot spacings and then discharged to the Toyohira River at 77°F. The hot water flows in the three loops at between 40 to 50 gpm with inlet temperatures between 169 and 181°F, resulting in a total heat supply of 6.6 million Btu/hr or 1.92 MWt. Assuming lateral and downward heat loss of 20%, the effective heat supply to the road surface is 48 Btu/ft^2/hr, which was in good correlation with the calculated load of 49 Btu/ft^2/hr required for a continuous snowfall of 0.4 inches per hour according to ASHRAE.

The oldest geothermal pavement snow melting system was installed in Klamath Falls, Oregon in 1948 by the Oregon Highway Department (Lund, 1999). This is a 450-foot long section of Esplanade Street approaching a traffic signal on a 8% grade. The grid consisted of 3/4-inch diameter iron pipes placed three inches below the surface of the concrete pavement on 18-inch centers. The grid system was connected to a geothermal well with the heat transferred through a downhole heat exchanger to a 50-50 ethylene glycol-water solution that circulated at 50 gpm. The temperature drop in the grid was approximately 30 to 35°F with the supply temperature varying from 100 to 130°F, The system is estimated to supply a maximum of 3.5 x 10^5 Btu/hr at the original artesian flow of 20 gpm and 9.0 x 10^5 Btu/h at the pumped rate of 50 gpm. The latter energy rate could provide a relative snow free pavement at an outside temperature of -10°F and a snowfall up to three inches per hour, at a heat requirement of 41 Btu/ft^2/hr. Due to a temperature drop in the well from 143 to 98°F, the well was rehabilitated in 1992 (Thurston, et al., 1995).

By 1997, after almost 50 years of operation, the system had failed due leaks in the grid caused by external corrosion. In the fall of 1998, a contract was issued to reconstruct the bridge deck and highway pavement along with replacing the grid heating system. The top layer of concrete on the bridge deck was removed by hydroblasting and the roadway pavement was entirely removed, and new crushed rock base added. A 3/4-inch cross-linked polyethylene tubing (PEX) was then used for the grid section, placed in a double overlap pattern at from 14 to 16 inches on center.

The PEX pipe was attached to the reinforcing steel within the concrete pavement providing a cover of about 3 inches over the pipe within the 7-inch pavement section. The header pipe, placed along the edge of the roadway consisted of 1.25- to 2.5-inch insulated black iron pipe, which in turn was connected to the downhole heat exchanger. The header pipe has brass manifolds placed at about 40-foot intervals in concrete boxes, to allow for four supply and return PEX pipes to be attached.

The entire cost of the reconstruction project was approximately \$430,000 and the estimated annual maintenance cost will be \$500 and the operating cost (for the circulating pump) \$3,000. The heated bridge deck and pavement covers 22,000 ft^2 and is designed for a heat output of 50 $Btu/ft^2/hr$. The DHE supplies 100°F glycol mixture to the grid with a temperature drop of 24°F, estimated to increase to 30°F once the ground and concrete temperatures reach equilibrium. This is suppose to keep the deck clear during heavy snowfall down to -10°F. The renovated deicing system appears to be operating effectively, based on substantial snowfalls in January and February, 1999.

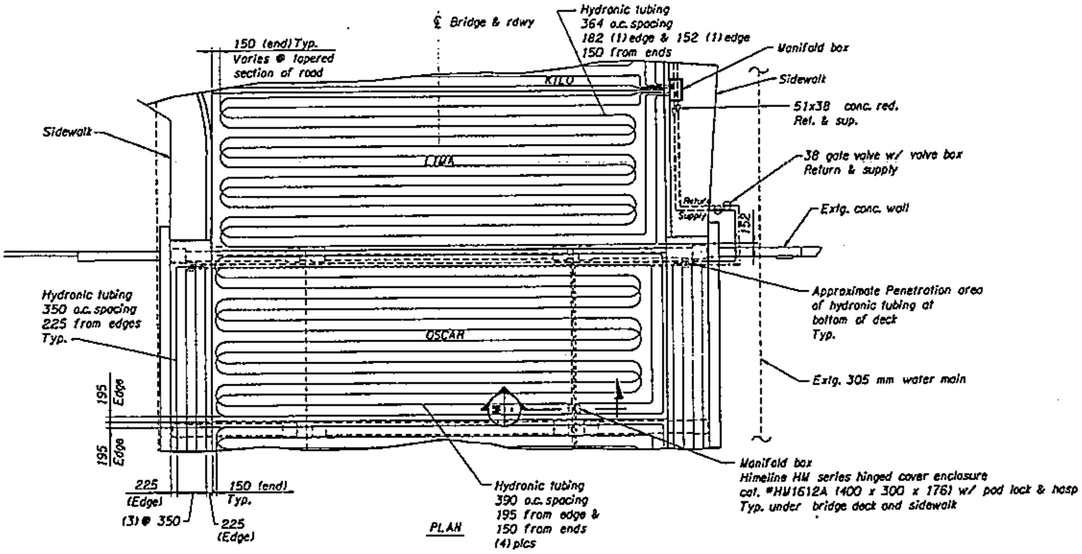

Figure 3. Detail of the loop system for the Klamath Falls Project (Lund, 1999).

Non-Geothermal Heating Systems

VDOT's Hot Bridge

The Virginia Department of Transportation has built a heat bridge on Route 60 over the Buffalo River in Amherst Country. The site is in the eastern foothills of the Blue Ridge Mountains, where road conditions during winter storms often can be treacherous. The bridge is 117 feet long and 44 feet wide and was built at a cost of \$663,937, including \$181,500 for the heating system. The anti-icing heating system was designed and fabricated by SETA Corporation of Laramie, Wyoming. The project contains approximately two miles of steel piping, including 241 heat pipes embedded in the concrete deck and approach slabs. The pipes are one half inch in diameter, spaced at seven to nine inches apart in the transverse direction. They were originally filled with Freon HCFC 123, but the resulting heat output was inadequate. In January of 1999 the system was converted to ammonia service and presently appears to be performing satisfactorily. A propane gas-fired furnace heats a mixture of propylene glycol and water. This antifreeze mixture circulates through a separate piping loop to evaporators, heating the ammonia in the pipes. The bridge is tilted slightly so one end of the pipes is higher than the other. As the fluid boils, vapor rises in the heat pipes from the lower end to the higher, and warms the bridge deck. As the vapor cools, it condenses and trickles back to the evaporators where it is re-heated.

A computerized control system continuously receives information from various sensors and automatically activates the heating cycle when certain conditions are met.

Any of three conditions can activate the system:

- Deck surface sensor indicates snow or ice
- Precipitation sensor indicates precipitation and deck surface temperature is below 35° F
- Deck surface sensor indicates wet deck and surface temperature is below 35°F

Either of two conditions will shut off the system:

- Deck surface sensor has indicated clear surface for more than 10 minutes
- Deck surface temperature is above 40°F

Additional details on this system can be found on the VDOT website: <www.vdot.state.va.us/info/hotbridge.html>.

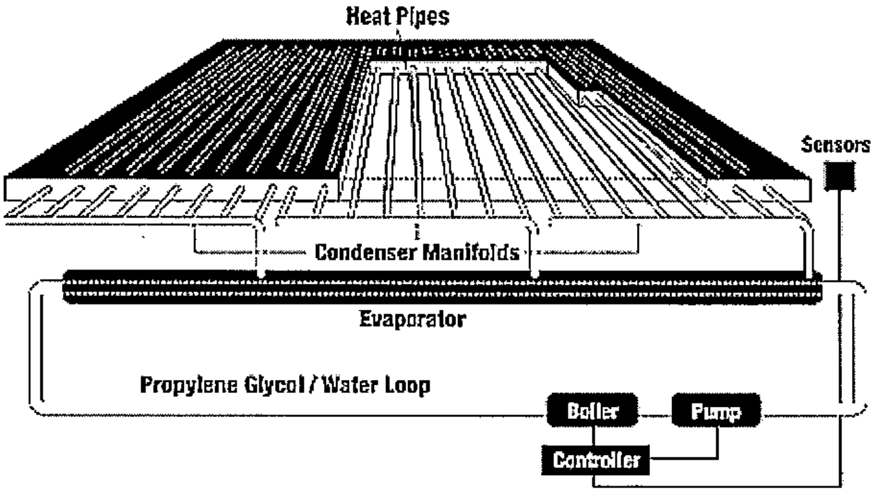

Figure 4. Schematic of the VDOT anti-icing system.

Swiss Solar Energy Pilot Project

A solar energy pilot project (SERSO) has be installed on a bridge in the Swiss highway network on Road 8 at Därligen in Berne canton (Schlup and Schatzmann, undated; Rauber, 1995). The project was initiated by the Energy Office of the canton of Berne and carried out by Polydynamics Ltd., Zurich. The aim of the project was:

- To collect the heat of an asphalt bridge surface during the summer period, when roadbed temperatures of 140°F and more are frequently reached
- To store the heat in an underground heat sink, and
- To utilize the heat during frost periods in winter to heat the bridge surface, thus preventing the formation of ice.

The essential components of the SERSO plant are:

- The heat exchange tube system embedded in the asphalt layer of the bridge, covering a surface of 14,000 square feet
- The underground heat sink, consists of 91 vertical bore hole heat exchangers, reaching a depth of 213 feet, thus forming a storage capacity of 1.94 million cubic feet of sandstone (area diameter of 98 feet)
- The hydraulic system, consists of the connecting pipework between bridge and heat sink, pumps, valves and mixing tanks.

During the summer period approximately 20% of the incident solar radiation on the activated road surface can be collected, corresponding to 150,000 kWh (512 million Btu). Losses amount to approximately 35% of this quantity, the remaining energy being available to keep the bridge surface free of ice during the winter period. The total cost of the SERSO pilot project amounted to 5 million Swiss francs (approx. $3 million), including preliminary studies, implementation, supervision and measurements. The system has been operational since the late spring of 1994. A follow-up system of similar dimensions would be expected to cost not more than about half this amount, since much of the preliminary research would not be necessary.

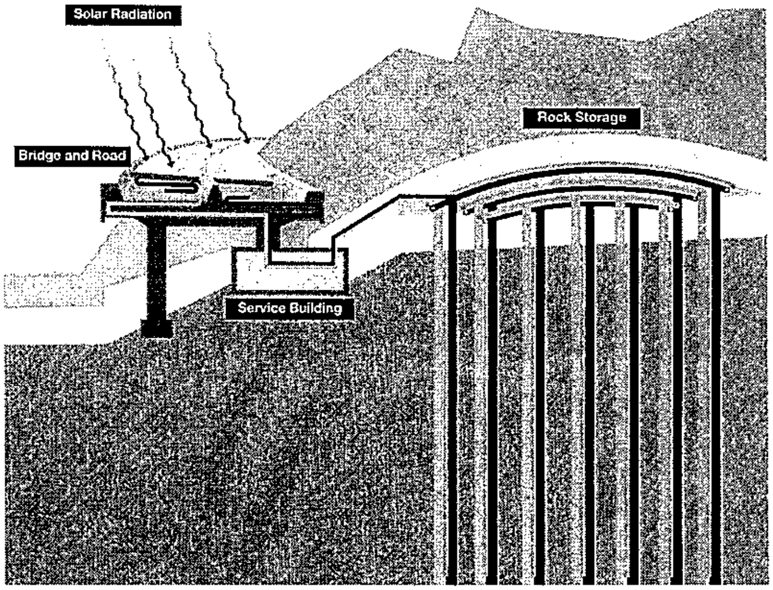

Figure 5. Swiss solar storage system (Rauber, 1995).

The heating coils are filled with a working fluid consisting of a glycol-water mixture. The 160 individual stainless steel coils, each 112 feet long, underlie a surface at a depth of 2.75 inches in the leveling course of the plastic/cement stabilized asphalt layer. The vertical heat exchangers in the rock are connected in groups to four closed loops, which are independently relayed to the service building.

Airport Runway Snow Melting System

To the author's knowledge, there are no airport runway geothermal snow-melting systems in place in the United States. However, a theoretic study was performed by Senser (1982), which indicated that such a system was practical using heat pipes. A computer simulation, based on the response factor technique, was developed for use in the design of the pavement heat pipe heating system. The resulting algorithm was shown to be both computationally efficient and accurate. A simple snow-melting model that should be appropriate for heated roadways and runways studies was also developed.

The computer simulation indicated that the potential for a runway pavement heating systems at Chicago using low-grade water sources is high. A practical heating system with a conductance of 50 W/m^2 °C (8.81 Btu/hr/ft^2 °F) and a water source temperature of 10°C (50°F) was predicted to melt the snow as rapidly as it falls approximately 40% of the time. Melting at the snow/pavement interface would occur 87% of the time that there was some snow cover. Therefore, only 13% of the time with runway snow cover would the runway clearing operation be faced with the complicated situation of a frozen interface.

• Conclusions

There are two main geothermal systems that can be used to heat a pavement for snow and ice melting: heat pipes and the direct use of geothermal hot water. The later case is less common due to the limited number of places in the U.S. where geothermal fluids above 100°F are available. On the other hand, heat pipes can be used with normal ground temperatures that are typical of the entire U.S. Heat pumps may not be as efficient as using geothermal waters directly, due to the lower temperature of the circulating fluid. Geothermal systems can be installed for around \$20/ft^2, plus the cost of the well and pumping system. Heat pipe systems will run \$35/ft^2 for typical highway bridge deck systems. Total cost for the deck and heating system will run \$100 to \$150/ft^2. It may not be practical to heat an extended section of a highway or an entire runway with this system. However, heating critical areas such as bridge deck (exposed to the elements from top and bottom) and airport hard stands, refueling area, baggage handling areas, and passenger walkways may be more beneficial from a safety and economic standpoint.

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