HYDRONIC HEATING PAVEMENT SYSTEM FOR ROADS IN COLDEST REGIONS

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Abstract *Without winter maintenance of roads we can't move further because in winters the situation gets worse and worse day by day and the speed of vehicles gets reduced due to snowfall and ice in the coldest places of world. Normally we use mechanical snow clearane machines, salt and some chemicals but machines damage road structure, salting and other chemicals also damage the surrounding vegetation and salification of fresh water. Hence by observing and analysing the above disadvantages, I found an alternative solution by which we can stop using salt, chemicals and machines. A renewable alternative solution is to use a Hydronic Heating Pavement (HHP). The HHP system consists of embedded pipes in the road. A fluid as thermal energy carrier circulates through the pipes. Hence by HHP system we can move easily and without reduction of speed and can prevent accidents and damages.*

Key Words: Hydronic heating pavement system, De-icing in winters, Thermal energy carrier,

1.INTRODUCTION

Evey year again, ice and snow cause several times obstrucions to traffic all over Jammu and Kashmir and other coldest regions of the world. Ice and snow fall are responsile again and again every year for traffic jams and traffic accidents. The traffic jams in winter in coldest regions and the unavoidable use of de-icing salt of today form an environmental threat. Hence new technologies are needed in winter maintenance to increase road safety and mobility. It is very unsafe and so dangerous to drive on slippery road pavements due to snow fall and ice. A road pavement structure gets corroded by the use of salt and other chemicals for de-icing and sorrounding environment gets polluted by these two traditional methods. Normally when snow falls on the road pavement structure, the goverenment or private staff removes snow from road structures by Heavy Machines but using these heavy machines damage the road structure. Hence an alternative method is needed to mitigate the slippery coditions due to snow fall. By considering and analysing the undesired environmental effects and damage to pavement structure caused by salt, chemicals and heavy machines, it is very necessary to use a new technology by which we can stop using harmful chemicals, salt and heavy machines on road structure and hence can prevent road structure and surrounding environment from damage. In 2014, the cosumption of salt and sand used for winter maintenance of roads was around 0.6 and 1.7 million ton in scandinavia, respectively (Knudsen et al., 2014). Hyronic Heating Pavement is run by using renewable energy. According to (ASHRAE, 2003) the hydronic heating pavement sysem is a system with embedded pipes inside the road pavement structure in which a fluid like brine, oils or glycol-water circulates. Fluid gets warm during sunny days because the surface temperature of road gets increased. The energy of the warm fluid is saved in thermal energy storages for the de-icing purpose during winters.

Hydronic heating pavement (HHP) is not a new method for de-icing. This system was installed in Klamath Falls, Oregon, USA by Oregon Highway Department in 1948 which used geothermal energy (Pan et al., 2015). The idea to use renewable energies for Hydronic Heating Pavement for roads in coldest regions was introduced in this paper which was about how to maintain road pavement structure during winters in the coldest regions and make roads all weather roads for the movement of traffic, prevent accidents, and prevent damages caused by salt and chemicals to the surrounding environment (Peerzada Shuab Ahamd et al., 2020,; Peerzada Muhmmad Aadil et al, 2020).

In this paper, we have used three important parameters for the design of Hydronic Heating Pavement System, we have investigated the thermal properties of pavement materials, we have designed the Hydronic Heating Pavement system, We have investigated the seasonal thermal energy storage (STES).

1.1 Measuring Thermal Properties of Asphalt Pavement by Transient Plane Source Method

One of the impotant parameter that influence the efficiency of a Hydronic Heating Pavement System is thermal diffusivity. When thermal diffusivity is lower the suface of road takes longer time to achieve a certain temperature level. Furthermore, a high specific heat capaity will influence the desired amount of energy in a thermal energy storage. Thus, accurate determination of thermal properties of involved materials are essential in a Hydronic Heating Pavement System. There are several methods to measure thermal properties of materials at ambient conditions (Adl-Zarrabi et al., 2006; Mamlouk et al., 2005). Transient Plane source method is one of the most common type of method for measuring the thermal properties of matherials used in Hydronic Heating Pavement Systems. Gustafsson (1991) described the transient plane source method for thermal conductivity and thermal diffusivity measurements of solid materials. The measurement method was described in ISO22007-2 (International Organization for Standardization, 2015). Furthermore, Pan et al. (2014) used Transient plane source method to investigate influence of grapite on the thermal properties and anti-ageing properties of asphalt binder. In this paper, different sensor sizes were used to investigate the suitability of using the transient plane source method for measuring thermal properties of asphalt. Furthermore, the thermal properties of asphalt concrete samples were investigated at different depths and in different positions in order to investiate whether or not an asphalt concrete sample is an isotrophic material.

1.2 Sample preparation results

The selected sample of asphalt concrete was cylinderical and it's radius was 100 mm and it's thickness was 60 mm. In order to perform this test, two specimens are needed thus the sample of asphalt concrete was divided into two specimens with a thickness of 30 mm. Furthermore, the specimens of asphalt concrete were divided into two new specimens to measure the thermal properties in different depths.

The samples of asphalt concrete samples were conditioned in the laboratory. Temperature and relative humidity in the laboratory were 22^{0}C and around 55%. Figure 1 shows the surface of the sample and position of the sensor. Different sensor sizes were used in order to investigate the most proper size of the sensor related to aggregate size. Largest size of aggregate on the surface is measured to 11 mm.

1.3 Measurement results

1.3.1. Sensor size

In table 1 the results of measured thermal properties of the asphalt pavement sample using different sensor sizes are presented. As it is seen from the results, measuring thermal properties of the asphalt concrete samples using different sensor sizes offers different results. However, the variation of the results was expected. In the pavement surface, smaller sensor sizes (small diameter) do not cover proper amount of binder and aggregates; thus, will lead to inaccurate results e.g. the measured thermal conductivity of the sample using the sensor design of 5465 with the diameter of 6.36 mm is about 50% lower than the measured thermal conductivity by the sensor 5501 with a diameter of 12.8 mm. The reason for this large deviation is that the sensor design of 5464 covered mostly binder part of the sample.

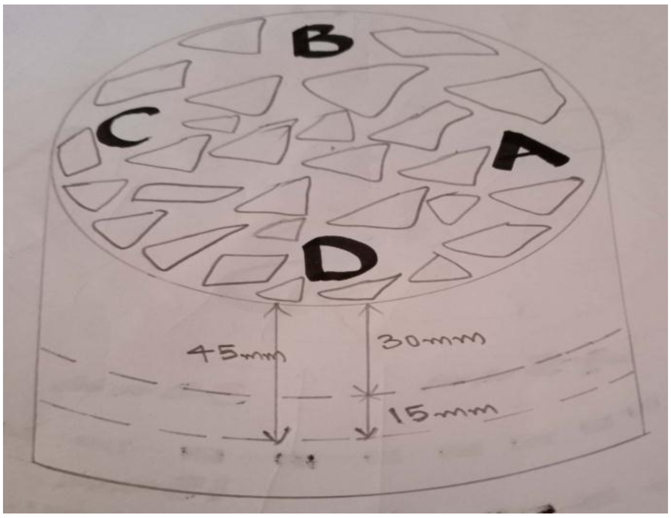


Fig -1: Measuring positions A-D on the surface and two different depths of the Asphalt specimen.

Table-1: Measuring thermal properties of the asphalt pavement sample with different sensor sizes.

Sensor Design	Sensor diameter (mm)	Conductivty (W/m.K)	Diffusivity (mm^2/s)	Volumetric heat capacity (MJ/m^{3}K)
5465	6.36	1.19	1.60	0.74
5501	12.8	2.33	1.34	1.73
8563	19.7	2.38	1.39	1.71
4922	29.2	2.62	1.28	2.04

Futhermore, the thermal properties of the aggregate will be measured if the sensor covers only an aggregate. The maximum size of aggregate is 11 mm. The diameter of the maximum aggregate size used in this study is smaller than the other sensors used in this study; therefore, there could be more acuracy in measuring the thermal properties of the sample. In order to achieve more accurate results then we have to keep the size of a sensor larger than the maximum size of aggregate (i.e; 11). We can easily findout the ratio between sensor size and maximum aggregate size.

1.3.2. Evalation of isotrophic assumption

The Asphalt concrete sample choosen for the test purpose in this study is assumed as an isotrophic material. Two different measurement setups were used to investigate this assumption. In the first setup, the sensor position was changed over the surface of the sample, see Fig 1. In the second setup, the sensor is placed in different depth from the surface i.e. 45 mm from the sample surface. The sensor design 8563 is used in this measurement. The thickness of samples under investigation should be at least equal to radius of the sensor, hence i selected this sensor according to recommendation for performing TPS measurements. In order to get accurate results and measurement, I selected the sensor design 8563 instead of sensor design 4922. The reasults are presented in Table 2 and Table 3.

The thermal properties of the sample in three positions A,B, and D are in the same range with a maximum deviation of 2% Furthermore, the diffusivity of the sample in positions A-D are in the same range with a deviation of 5%. However, in the position C the thermal conductivity and volumetric heat capacity of the asphalt concrete sample in comparison with other positions gets deviated by 10% to 20% respectively. A reason for the deviation might be the inconsistent distribution of the aggregates in the asphalt concrete sample. However, the concrete sample could be assumed as isotrophic at the surface of the sample if the size of the sensor was large enough, the deviation in the position C would be eliminated.

Table-2: Thermal properties of the asphalt pavement: different positions on the surface using sensor design of 8563.

Position	Conductivity (W/m.K)	Diffusivity (mm^2/s)	Volumetric heat capacity (MJ/m^3K)
A	2.38	1.39	1.71
B	2.39	1.38	1.73
C	2.67	1.28	2.07
D	2.43	1.32	1.84

The 6%, 14% and 14% are the variations of measured thermal properties in two different depths of 30 mm, 45 mm from the sample surface for conductivity, diffusivity, and volumetric heat capacity. Due to different compaction pressures and different aggregate distribution the deviation of the thermal properties in two different depths might happen. These variations can be used in a sensitivity analysis related to efficiency of a HP system. There is a need of further investigation in order to finalize the suitable set up for determination of thermal properties.

Table-3: Measuring thermal properties of the asphalt pavement in different depths using sensor design of 8563.

Position	Depth (mm)	Conductivity (W/m.K)	Diffusivity (mm^2/s)	Volumetric heat capacity (MJ/m^3K)
A	30 45	2.38 2.49	1.39 1.45	1.71 1.71
B	30 45	2.39 2.54	1.38 1.49	1.73 1.70
C	30 45	2.67 2.66	1.28 1.49	2.07 1.78
D	30 45	2.43 2.57	1.32 1.21	1.84 2.13

2. HYDRONIC PAVEMENT DESIGN

The efficiency of snow melting process is influenced by some parameters like the position of pipe, the depth of pipe from pavement surface (D), the distance of pipes from eachother or spacing from centre to centre (S). In order to investigate the influence of the pipe positions on snow melting performance, a numerical model was made in COMSOL Multiphysics. In Fig 2. The positions of pipes in a Hydronic Heating Pavement System is shown.

It was assumed that the snow layer is homogenous and porous in order to simulate the snow melting model. The heat supplied from the embedded pipes will melt the ice crystals in the snow and also increase the temperature of the snow. Furthermore, it was assumed that all melting process is done on the pavement surface and the pavement is ideally drained. According to Liu el at. (2007), two snow melting assumptions are considered which divide the snow melting process into two steps. First, the capillarity height in snow is lower than the accumulated snow on the pavement surface and second the capillarity height is greater than the snow height accumulated on the pavement surface. The heat insulator will be considered the only part of snow whose heght is greater than than the capillarity height; hence, in this step, the effect of ambient condition on the snow-melting will be low. While, in the second assumption, there is no insulating layer on the snow and so both convection and evaporation will affect the snow melting process.

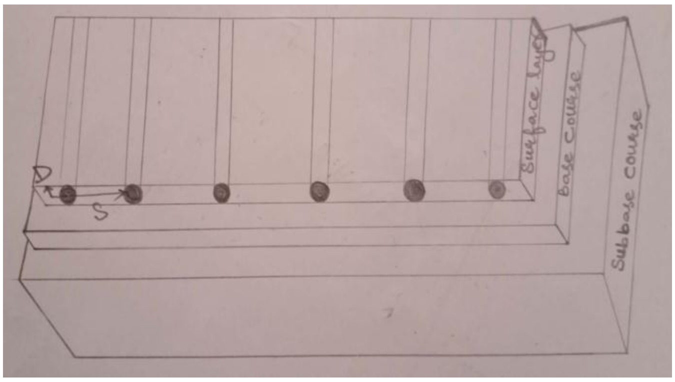


Fig -2: A scheme of the pipe in a Hydronic Heating Pavement System (S is the spacing between pipes from c/c and D is the difference from centre of pipes to the pavement surface).

Three courses of asphalt pavement was considered as shown in Figure 2. The asphalt pavement structre includes the following layers:

1.) Asphalt Layer.
2.) Base Course.
3.) Subbase Couse.

In Table 4. The thermal properties of the above given layers and also the thermal properties of the embedded pipe is mentioned.

Table-4: Thermal properties of materials associated with the simulated model (Theodore L. Bergman et al., 2011).

Course	Thickness (mm)	Thermal Conductivity (W/m.K)	Density (kg/m^3)	Heat Capacity of Constant pressure (J/kg.K)
Surface Layer (Asphalt Concrete)	150	2.5	2300	1000
Base	250	1.1	2000	1000
Subbase	250	0.7	1700	900
Pipe*(PEX^1)	1.5	0.42	1100	1465

*Pipe outside radius is 10mm.

2.1. Modelling, material properties and boundary conditions

The investigation of the effects of the pipe positions (D and S) on the snow-melting process were studied in this paper. The constant fluid temperature inside the pipe, the constant weather conditions are some boundary conditions that were assumed inorder to know know how the simulation works. In Table 5. The position of pipes and the boundary conditions are mentioned.

Table-5: The boundary conditions used to simulate the snow melting process.

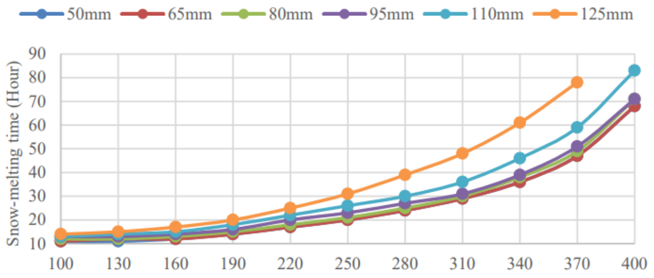
Condition	Value
Fluid temperature inside the pipes	15^{0}C
Ambient temperature inside the pipes	-2^{0}C
Humidity	80%
Wind Speed	5 m/s
Snowfall rate	20mm/hr.m^2
Snowfall duration	10 hours
Density of snow	117kg/m^2
Capillarity Height	25 mm
Distance beween two pipes	100-400mm
Buried depth of two pipes	50-125mm
Temperature in the bottom of subbase course	1^{0}C
Preheating	1 hour

For the initial S of 190 mm and increasing D by 15% and 30% the required time will increase around 13% and 25% respectively. However, for the initial D of 95 mm and increasing S by 15% and 30% the required time will increase around 25% and 44% respectively. The results shows that the altering pipe distance (S) in comparison with the burried depth (D) has more influence on the snow-melting process.

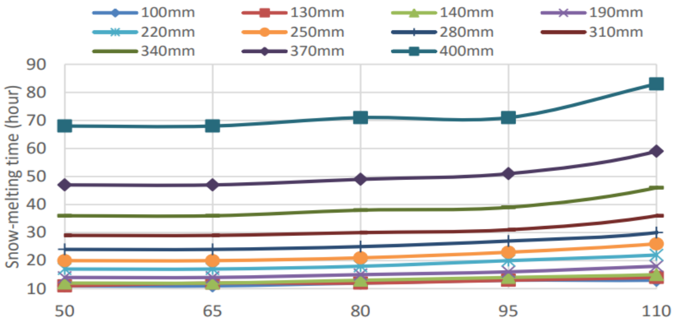
Table-6: Required time to remove all snow from the pavement surface with different positions.

D (mm)	S (mm)	190	220	250
95		16hr	20hr	23hr
110		18hr	22hr	26hr
125		20hr	25hr	31hr

The required time to melt snow will increase rapidly if the distance between pipes (S) is longer than 200 mm, as mentioned in Figure 2a. Therefore it is recommended to keep the distance between pipes less than 200 mm. If the depth of the pipes is shallower than 100 mm, then the effect of the buried depth on the snow-melting process will be negligible.



(a) different buried depth



(b) different pipe distance

Fig. 3. The required time to remove all snow from the pavement surface with different pipe positions.

3. SEASONAL THERMAL ENERGY STORAGE

Seasonal thermal energy storage (STES) is used to store solar energy in the end of heating seasons for anti-icing during winters. In the end of the heating season, there could be very cold nights which require a high temperature level. In the end of the heating season the temperature in the seasonal thermal energy storages (STES) will be at it's lowest level.

Following methods can be used to achieve the desired temperature level to melt the snow and ice from the road surface:

1.) Supplementary energy source such as using electricity for heating .
2.) Adding solar pannels.
3.) Increasing the depth and the number of bore holes in the STES.

The aim of this study is to investigate whether the hybrid system of a short-term thermal energy storage using solar pannel with a seasonal thermal energy storage would work or not. The aim of the study is to investigate if it would be possible to harvest the solar energy in early spring, store the energy and use it during night time. In order to reduce the initial constuction cost of the seasonal thermal energy storages (STES) the we should reduce the size of seasonal thermal energy storage.

3.1. Methodology

A number of numerical simulations were performed to investigate the combination of a short-term thermal energy storage using solar pannels with a seasonal thermal energy storage in the transient simulation tool (TRNSYS), which is well estabished software for investigating system combining solar energy and energy storage. On the basis of essential parameters the two systes were compared. System A is made of seasonal thermal energy storage and is connected to a cooling unit. The cooling unit simulated the energy demand to maintain a road ice free. System B consists of system A, but with the addiion of a thermal storage tank and solar collectors. In order to optimize the number of boreholes used in a seasonal thermal energy storage the simulation results can be used.

3.1.1. System Description

The fluid is heated in the system A in the seasonal thermal energy storage and this fluid is then pumped to the cooler and the constant amount of energy gets removed by the the cooler during the operation. The heated fluid leaves the seasonal thermal enery storage in system B and then enters the storage tank where the temperature gets increased when mixed with water in the storage tank. System A and System B is showen in figure 4 and figure 5. For simulation the data is presented in Table 7.

Table-7: Major parameters for the different systems

Parameter	System A	System B	Unit
STES size	80000	80000	m^3
Depth borehole	220	220	m
Fluid flow Pump1-E1	4,6-10	4,6-10	Kg/s
Storage tank size	-	10-20	m^3
Number of boreholes	25-105	25-65	-
Solar collector area	-	100	m^2

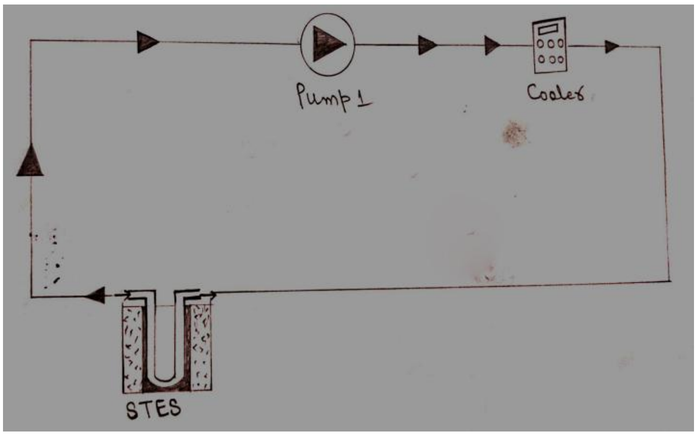


Fig-4: System A, STES with a cooler of 100kw.

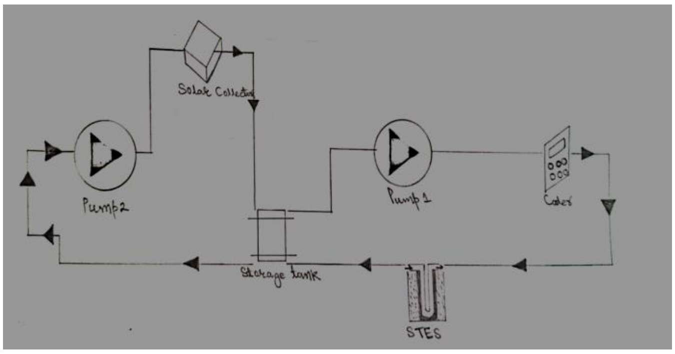
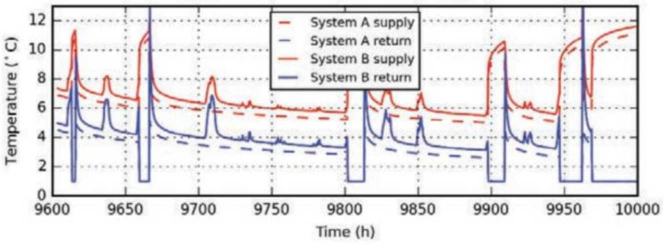


Fig-5: System B with short time thermal energy storage connected to seasonal thermal energy storages (STES).

3.2. Results and analysis

The temperature level of a seasonal thermal energy storage (STES) is closely connected to the maximum power that the seasonal thermal energy storage could supply as well as the amount of usable stored energy in the seasonal thermal energy storage. For the operation of Hydronic heating pavement system the temperature level of the seasonal theral energy storage is of great importance. The results from the simulations indicated that for a seasonal thermal energy storage which has a low mean temperature in the beginning of the heating season would benefit more from having a hybrid system like the system B than the seasonal thermal energy storage whih has a higher mean temperature. The system becomes more sensitive if the initial mean temperature is low. The heat extraction rate decreases when the temperature level in the seasonal thermal energy storage decreases. The system could still deliver the required heat when adding extra heat from the solar panels. It would be more beneficial to add solar panels to the seasonal thermal energy storage when the temperature level in the seasonal thermal energy storage.

(a) System A and B, same number of boreholes



(b) System A and B, 27 and 25 boreholes

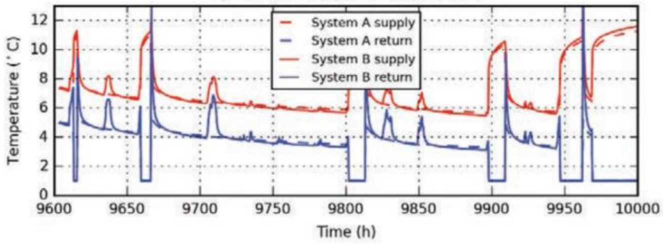


Fig 6. Simulation results from TRNSYS revealing the supply and return temperature to the pavement from seasonal thermal energy storage for system A and B with different configurations.

0.7°Cwas the difference, this difference seems low; however, it corresponds to an increased supply tempertature of 10% for system system B compared to system A. In this paper, it was also investigated how many more boreholes that system B would need to have same temperature performance as system A. There is almost no difference in fluid teperature when system A has 27 boreholes, it is equivalent to system B with 25 boreholes, as can be seen in Fig 6b. The two boreholes is the difference between two systems A and B. There is a temperature difference between two systems A and B when comparing the systems A and B. It can be seen from the Fig 6a. Supply and return flow comes from the hydronic pavement. Due to the extra maintenance costs of solar panels and pumps and the added system complexity it is unjustifiable.

4. CONCLUSIONS

In Jammu and Kashmir, the road administration spends a lot of money during winters for the snow and ice clearance and hence the economy gets reduced due to manual operations. In winters in the coldest regions, the ice and snow have always been a challenge for road administrators. Winter maintenance is always costly but life is priceless and we have to give priority to safety. Normally in winters in the snowy areas we remove snow and ice from the road surfaces by using heavy machinery and we spread salt for de-icing but salting damages the surrounding environment and the road structures. Salting decreases the durability of different types of pavement materials and hence decreases the life span of road pavement structure. An alternative method for de-icing is to use the Hydronic Heating Pavement System using renewable energy. Hydronic Heating Pavement System can reduce the traditional maintenance costs such as Labour costs, Salting Costs, Heavy machinery costs, Chemical costs etc. Hydronic Heating Pavement Structure can reduce the accident rates, traffic jams etc. In winters, it can be normally seen that when snow falls on the road surface even the snow maintenance vehicles also gets stucked and the traffic jam gets increased for long hours in coldest places of the world. In this paper, three different parameters that have major influence on efficiency of a Hydronic Heating Pavement System were investigated:

1.) Thermal properties of an asphalt sample.
2.) Embedded pipe positions in the road pavement.
3.) Seasonal thermal energy storage.

The Transient Plane Source was used to measure the thermal properties of asphalt concrete. In an asphalt pavement, at different depths there was a variation in thermal properties of about 6-14%. For embedded pipes, the numerical simulations were performed for the geometrical design. The system performance gets influenced by the space between the embedded pipes than the depth at which the pipe were buried. In order to decrease the energy loses and size of the seasonal thermal energy storage, solar panels were added and the system performance were eveluated. It is unjustifiable to add the solar panels to seasonal thermal energy storage because of the system complexity and the costs. The investigation on renewable energy by which we can produce the heat for de-icing during winters in coldest places is highly profitable and beneficial. This conclusion can be helpful and valid for other additional renewable energy as wind power. More investigations are required to make the roads all weather roads and to improve the performance of Hydronic Heating Pavement System.

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