CONCEPT OF THE UTILISATION OF THERMAL ENERGY OF ROAD FOR SUPPLYING HOT WATER

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ABSTRACT

Solar Energy is one of the most abundant form of renewable source of energy available on the earth. But utilisation of solar energy is one of the biggest issues due to intermittency in nature. Nowadays most of the researchers are doing research to store solar energy due to its intermittency in nature. This paper describes a method to use the solar energy available on the roads surface to heat the available water through a pipe network, which are laid at certain depth from the roads surface. The paper uses the average data of solar radiations that are available on earth's surface at the given latitudes. The analysis is made on determining pipe material to get effective heat transfer. The result shows an effective way to reduce the heat island effect and the utilisation of the heated water for various purposes ranging from household to industry.

Keywords: Asphalt Pavement, Heat Transfer, Solar Energy,Water

I.INTRODUCTION

Solar energy is one of the most abundant forms of renewable source of energy. In hilly areas solar energy is available in abundant form so its efficient utilization is a great issue. In this research work more focus is given on the utilization of solar energy for heating water inside a road pavement in hilly areas of Uttarakhand. In hilly areas supply of electricity is main issue due to its geographical condition. In winter season we can use heat energy of road to heat water by inserting a pipe inside a road pavement.Water-energy nexus is the interdependency between the water and the energy, and is exponentially growing in importance as demand for both water and energy increases, and this is producing an impact on the environment [1].Heat island effect refers to the increase in temperatures of an urban area as compared to the temperatures of surrounding suburban and the rural areas. Heat island effect is one of the most documented phenomenon of the climate change and is documented for the various geographic regions [2]. In Japan, there have been development of several kinds of cool pavement or the roadsand their cooling effects were investigated; by introducing the paint coating technology a new type of pavement is developed to satisfy both high albedo and low brightness [3]. Pavementscover a good percentage of a city's surface and also their thermal characteristics play a dominant role in the formation of the heat island effect. The conventional pavements are usually made of concrete and asphaltic mixes, having the variable solar reflectance values, these can reach to peak during the summertime, that contributes to the surface temperatures of about 48-67 °C[4]. The reduction in temperature caused by the process which will further increases the life of the pavement or the road and the reduction in the temperature of the air nearer to the surface of the road will lead to saving in energy consumption of the environment and also improve the air quality i.e. by reducing the ozone concentration [5].

Solar energy from the sun in the form of the radiations falls on the earth's surface and some part of it being scattered in the atmosphere. The amount of radiations reaching a specific location on the earth's surface depends on a number of factors-

- The month of the year
- Solar altitude angle (angle between a line collinear with the sun's rays and the horizontal plane)
- Extra-terrestrial solar radiation
- Clearness number (difference between local and average sea level condition)

Asphalt surfaces gets heated up by the sun, the reason is while light coloured surfaces reflects the sunlight, asphalt mixes do not reflect that much of the heat energy received by the sun in the form of the radiations, rather absorbs the solar radiations more. This leads to an increased temperature of the air around the asphalt pavement surfaces contributing to urban heat island effect. Rise in air temperature leads to an increase in energy and water consumption, and indirectly contributes to the formation of smog and ozone production, which leads to significant health concern. It is estimated that the extent of the problem is significant since more and more pavements or the roads are being constructed with time. In the Houston metropolitan area, the parking facilities account for approximately 60% of the transportation land use. The predominant surface type in pavements is asphalt[5].

This paper presents the concept of using a piping network below the surface of road i.e. the asphalt pavements to flow the water, to reduce the temperature of the pavement or roads surface, to reduce the urban heat island effect and to use the preheated water for different end applications such as power generation, heating or refrigeration.

II.MATERIALS AND METHODS

2.1. Asphalt surfaces

The presence of the asphalt binder, makes asphalt pavement material behaves as a viscoelastic material. It exhibits higher stiffness at lower temperatures andrelatively lower stiffness at higher temperatures. Consequently, the potential of shear stress related deformation (rutting) increases at higher temperatures.

Rutting is one among the important distresses occur in asphalt pavements[5].

2.2. Factors involved in the heating of the asphalt pavement.

There are three factors which are involved in the heating of the asphalt surfaces:

- Solar radiation absorbed and emitted by the pavement
- Conductive transfer of heat through the pavement
- Convective heat transfers above the pavement surface

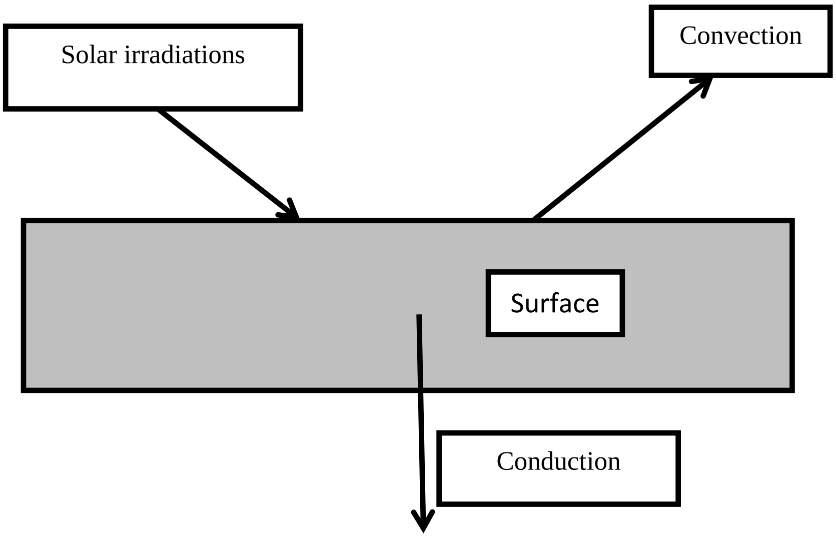

Figure 1: Heating of the asphalt surface

2.3. Energy harvested by the pavement

2.3.1 Direct solar radiations.

The energy from the direct solar radiations is given by

$$q = \alpha \times R_i \tag{1}$$

Where α is the absorptivity of the surface to the solar radiations and R_i is the incident solar radiations.

The part of the solar radiations reflected back to the atmosphere which is not absorbed by the surface is given by

$$q_r = (1 - \alpha) \times R_i \tag{2}$$

For some of the materials α varies with in a very wide range depending upon the wavelength. For the asphaltic materials it seems that α_{solar} does not vary substantially over a wide range. Typically $\alpha_{solar}$for the asphalt mixtures varies from 0.85 to 0.93[6].

2.3.2 The atmospheric radiations

The radiations from the atmosphere absorbed by the pavement surface is to be calculated using the following equation which is developed by Geiger [6]

$$q = \varepsilon_a \, \sigma \, T_{air}^4 \tag{3}$$

Where $\varepsilon_a = G - J\,(10^{-P\rho})$,

σ= Stefan-Boltzmann constant = 5.67×10^{-8} W/(m^2.K^4)

T_{air} = the air temperature (kelvin)

ρ = the vapour pressure varying between 1 and 10 mm of mercury.

G, J and P can be represented by constant values of 0.77, 0.28, 0.074, respectively, according to Geiger[6].

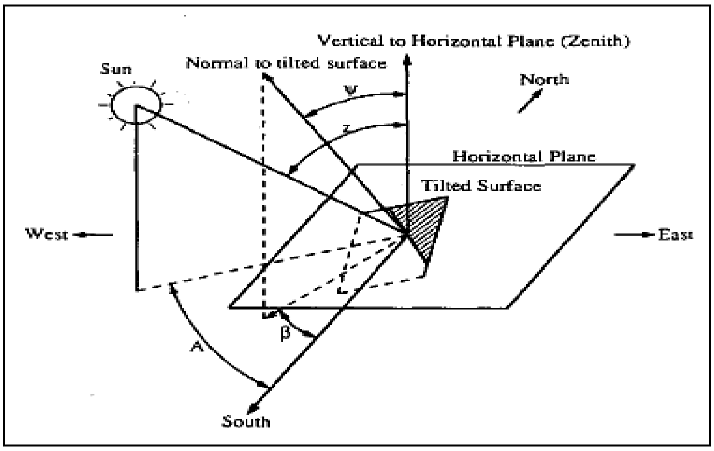

Figure 2: Definition of solar and surface angles.[7]

The various calculations have been done by the data of direct normal irradiance and horizontal irradiance available at theLatitude: 30.35 Longitude: 78.05(Dehradun, Uttarakhand, India)[8].

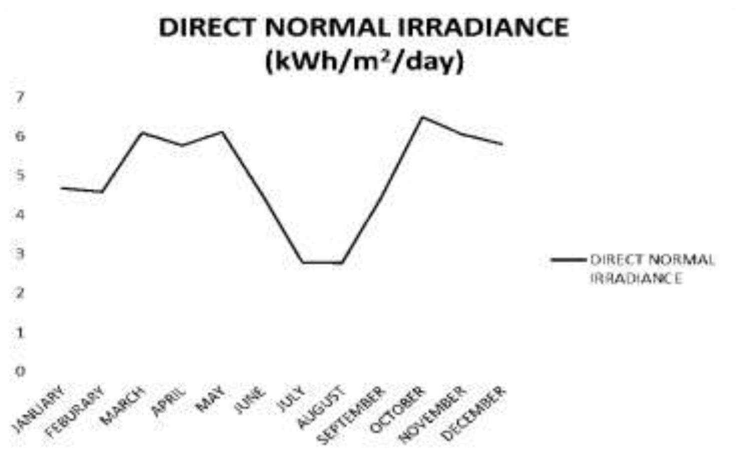

Figure 3: Direct Normal Irradiance

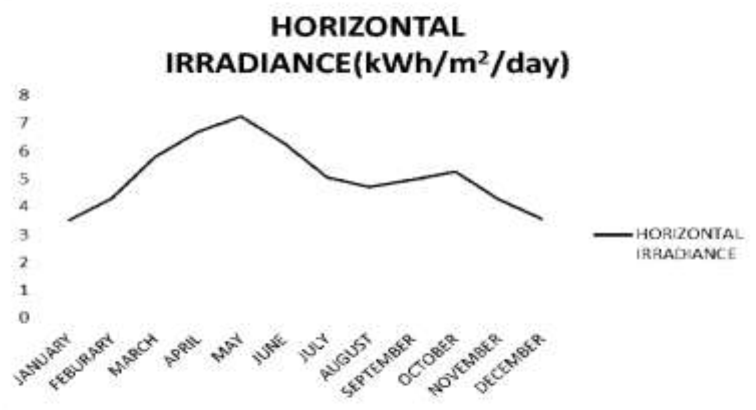

Figure 4: Available Solar Irradiations

2.3.3Heat radiated from the surface to the atmosphere

The heat that is radiated from the surface of the pavement is given by thedifference of the temperature between the pavement surface and the air(atmosphere), according to the following equation:

$$q_r = \varepsilon\sigma\left(T_s^4 - T_{air}^4\right) \tag{4}$$

Where q_r = emitted radiation,
ε is the emissivity of the material,
σ = Stefan-Boltzmann constant= 5.68×10^{-8} W/(m^2·K^4),
Ts is surface temperature in Kelvin

T_{air} is air temperature Kelvin.

Emissivity and absorptivity is involved in any heat transfer by radiation. For a body at the same temperature, they have the same numerical values. For asphaltic materials, the emissivity and absorptivity to shortwave radiations (such as the solar absorptivity) have been reported to be identical (about 0.93)[6].

2.4. Temperature variation with the depth.

The temperature at any depth of the pavement depends on the pavement materials and the surface temperature, which depends on a number of factors including the location, surface, the wind speed and the cloud cover.Based on available models, pavements temperatures at different depths can be predictedthroughout the year.Examples of regression equations developed to predict the temperatures at any depth of the pavement are as follows:

Temperature at the surface [5],

$$T_{surface} = T_{air} - 0.00618 latitude^2 + 0.2289\ latitude + 24.4 \qquad (5)$$

Where, T is expressed in ^{0}C and the latitude is in degree.

Temperature at different depth [6],

$$T(d) = T(s)(1 - 0.063d + 0.007d^2 - 0.0004d^3) \qquad (6)$$

Where, T(d) and T(s) are in ^{0}F and the depth d is in inches

According to these regression equations, pavement temperature at different depthsthroughout one year were calculated for the cities of Houston, TX, Jacksonville, FL, Reno, NV,Atlanta, GA, Boston, MA. Albuquerque, NM, Nashville, TN and Los Angeles, CA. As examples,temperatures at a depth of 2 inches for the different cities [5]

2.5. Designing of the pipe mechanism.

2.5.1 Pipe materials.

A special type of pipe is devised which consists of the CAST IRON and ALUMINIUM.The outer layer consists of CAST IRON and the inner layer consists of ALUMINIUM.The system is such developed to strengthen the piping system with the use of the cast iron and the use of the aluminium in addition provide good thermal conductivity.In aluminium, it is found that, its thermal conductivity increases with the increase in temperature, which is the exception of such case; and it is also a reliable cheaper resource to maintain the good thermal conductivity. The thermal conductivity of cast iron and aluminium are 55-65 and 225 W/(m-K)

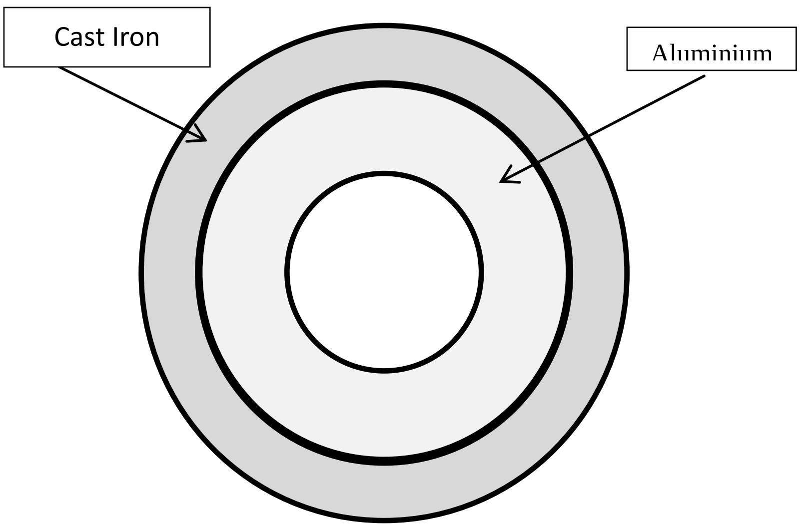

Figure 5: Cross section of the pipe network

2.5.2 Laying of the pipe

The road network consists of various layers which is one of the advantageous factors for the laying of the pipe network.The plan is to lay the pipe in such a way that the network does not experience a lot of wear and tear, so pipe line network is laid below the surface of various mixtures and within the stone bed layer, third layer, in this way the wear and tear of pipes would be less. The depth of the pipe network is kept nearly 6 inches from the surface.

2.6. Calculation of the water temperature in the pipe.

2.6.1 Calculation of the surface temperature

The average solar radiations falling on the latitude throughout the months of year [8], is converted into the emissive power, which further provides the surface temperature of the road or pavement, the following graph shows the variation of normal irradiance and horizontal irradiance with respect to the months of the year.

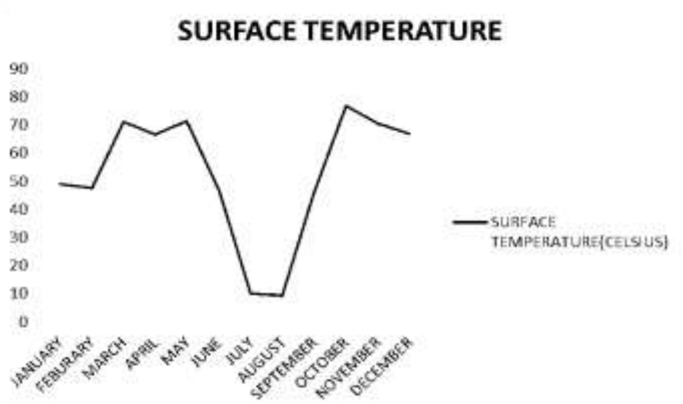

Figure 6: Using Direct Normal Irradiance.

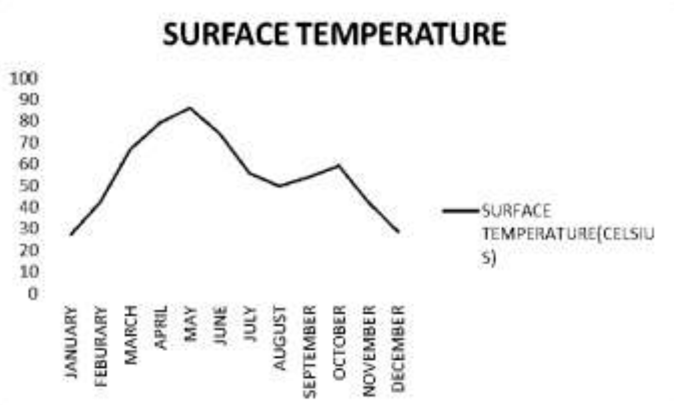

Figure 7: Using Horizontal Irradiance

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2.6.2 The temperature at the required depth

The work has been calculated to determine the temperature at depth of six inches. The calculation of this temperature is governed by the Eq. 6

The road mixtures consist of the asphalt mixtures, concrete, cement, charcoal, stones, etc.

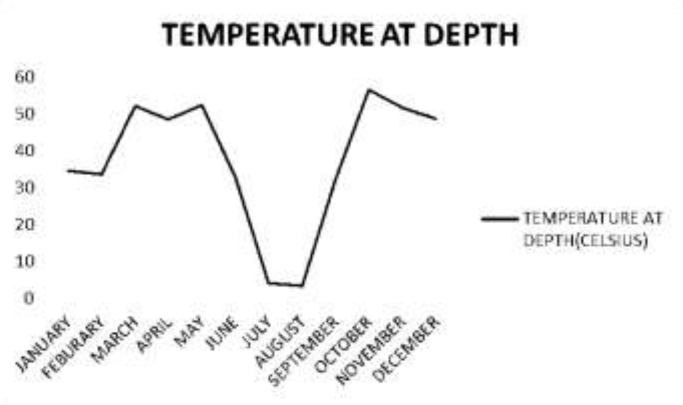

Figure 8: Using Normal Irradiance

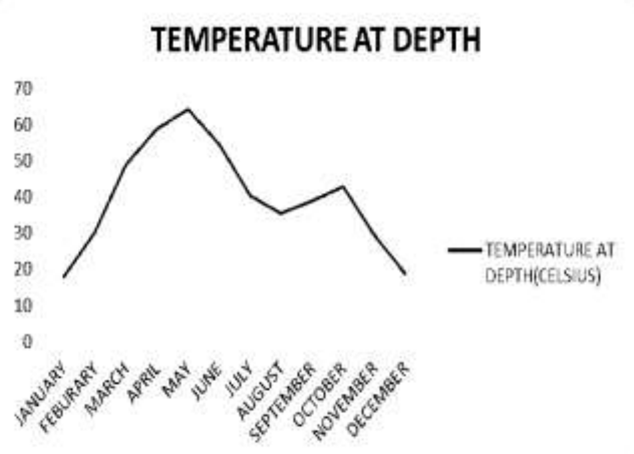

Figure 9: Using Horizontal Irradiance

2.6.3 Layer-wise temperature variation in pipe network.

On determining the temperature at the required depth, the estimation of the temperature of upper surface of the pipe is determined, with that the temperature at the coincidence of the two pipe surfaces is determined and further the temperature at the innermost surface of the pipe is determined; the water stays in the pipe network upto the point until it gains the maximum required temperature and then pumped out or further processed for the required applications.

The equation governing the temperature through the various layers is;

$$q = \frac{T_1 - T_2}{R_{th1}} = \frac{T_2 - T_3}{R_{th2}} \tag{7}$$

Where T_1= temperature at the upper surface; T_2= temperature at the interface; T_3= temperature at the innermost layer.

2.7 Calculation of R_{th}

When two physical systems are described by similar equations and have similar boundary conditions, these are said to be ANALOGOUS. The heat transfer processes may be compared by analogy with the flow of electricity in an electrical resistance[9].

$$R_{th} = \frac{dy}{kA} \tag{8}$$

For the pipe network the calculation of the R_{th} is given by the following equations

$$R_{th1} = \frac{\ln\left(\frac{r_1}{r_2}\right)}{2\pi k_1 L} \tag{9}$$

$$R_{th2} = \frac{\ln\left(\frac{r_2}{r_3}\right)}{2\pi k_2 L} \tag{10}$$

Where R_{th1} = thermal resistance due to cast iron, R_{th2} = thermal resistance due to aluminium., r_1, r_2, r_3 = the radii of pipe system, k_1, k_2 = thermal conductivities of cart iron and aluminium, respectively, L = length of the pipe system. The variation in the temperature of the water present in the pipe network is shown by the following graphs.

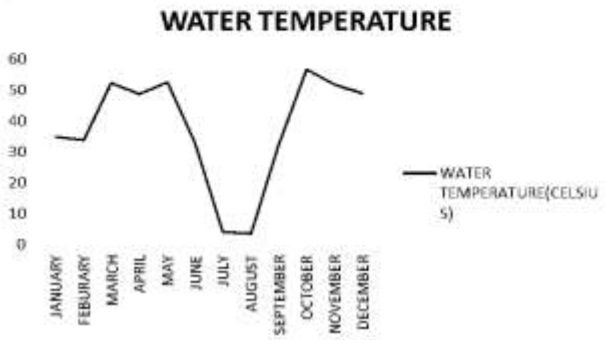

Figure 10: Using Normal Irradiance

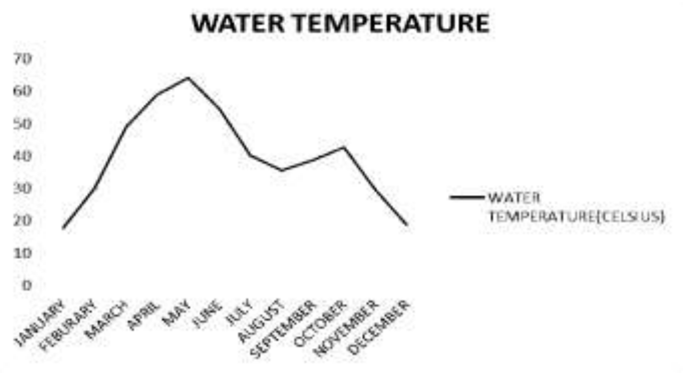

Figure 11: Using Horizontal Irradiance

III.CONCLUSION

1. The discussed concept is useful and capable of determining the maximum road or pavements temperature with appreciable amount of accuracy.
2. At higher latitudes, it is expected that the difference between maximum road or pavement temperature and that of air is lower.
3. The system is also providing a mechanism that protects human from the harmful effects of the environment.
4. Higher surface temperature is due the lower thermal conductivity of surface material.
5. The installed system of pipe network requires regular checks.
6. The water heated to certain temperature which is further utilised for the different purposes and is serving as a source to save the non- renewable energy resources.
7. The system serves as source of water harvesting.

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