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SOIL TEMPERATURE DISTRIBUTION IN BULDANA

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Abstract

The objective of this work is to study the monthly and daily variation of soil temperatures at various depths at Buldana. This knowledge will facilitate the suitable placement of Earth-Air Heat Exchanger. A 3-m deep temperature probe was installed in the campus of Rajarshi Shahu Polytechnic, Buldana . Readings were taken over a period of one year. The probe has six temperature sensors, mounted at 60 cm intervals. The probe was buried in a vertical position. The first sensor is at ground level, the second at 0.6 m depth, third at1.2 m, the fourth at1.8cm, the fifth at 2.4 m and the sixth at a depth of 3 m. Temperatures from all the sensors were noted everyday for a year. Readings were noted in the morning at 8 am, noon at 1 pm and evening at 5 pm. In this paper, the results are presented. Temperatures were noted at intervals of 1 hour on some days in every month.

Introduction

Vidrabha region has widely varying temperatures ranging from 10-12°C in winter to 42-45°C in summer. People use desert coolers in the summer. These are both water intensive and power intensive. Both, power and water are scares commodities in this region.

A cheaper alternative and one which does not require the use of water is the Earth Tube Heat Exchanger. These are in the form of pipes buried deep in the soil. Through the pipes, air is blown which is cooled by the heat exchanger. The installation of such exchangers requires the knowledge of soil temperatures at various depths. Temperature data of deep layers of soil is not available for any site in Vidarbha. Such data for some other places in the country [1,2.3] have been reported.

To obtain the data in Buldana, a probe which has 6 temperature sensors was installed in the soil in a vertical position.. The first is at ground level and the others at intervals of 0.6 m with the last one at 3 m. The temperatures at various depths were recorded daily over a period of 2 years. Readings were taken at 5 am, 1 pm and at 6 pm. To obtain the diurnal data, readings were taken on some days on an hourly basis over a 24 hour period.

The temperature data and a simplified expression for soil temperature distribution is presented.

The average temperatures (in degrees Centigrade) at various depths over a 12 month period are as shown in Table 1.

	Ground	0.6 m	1.2 m	1.8 m	2.4 m	3.0 m
January	26.27	26	25.2	25.2	25.2	25.2
February	28.46	28.23	27.73	27.6	27.5	27.4
March	32.76	28	27.47	27.3	27	27
April	38.1	29	27.4	27.3	27	27
May	39	29.5	27.43	27.15	27.1	27
June	34.9	28	27.4	27.2	27	27
July	33.3	28	27.5	27.35	27	27
August	29.8	27.5	27.4	27.1	27.1	27
September	30	28.9	27.5	27.1	27	27
October	33.2	27.9	27.5	27.15	27	27
November	30.9	28	27.5	27.15	27.1	27
December	31.5	27.9	27.46	27.1	27	27

Table -1 Average Monthly Temperatures At Various Depths

The same data is shown in the form of a graph in Fig. 1

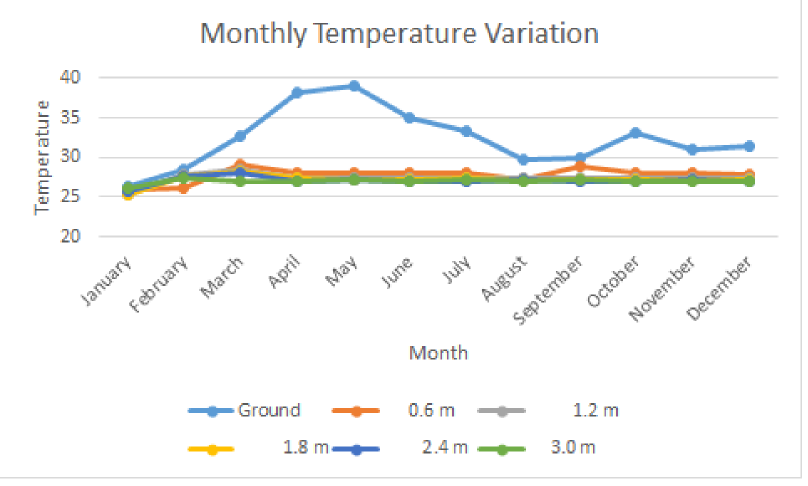

Fig. -1 Average Monthly Temperatures At Various Depths

The annual ground level temperature varied from a minimum of 26.27°C to maximum of 39.0 °C. The mean was 32.67 °C and the amplitude (difference between the highest and lowest temperatures divided by 2) was 6.3 °C. At 0.6 m depth the temperature varied from 29.5°C to

26°C. The amplitude was reduced to 1.75°C. At 1.2 m depth the temperature varied from 25.2 to 27.73°C with the amplitude being 1.15 °C. At 1.8 m depth there is hardly any change from the temperatures at 1.2 m depth. At 2.4 m depth the temperature varied from 25.2 to 27.5°C with the amplitude being 1.15°C. And at the depth of 3.0 m depth the temperature varied from 25.2 to 27.4 °C with an amplitude of 1.1°C.

The attenuation of the temperature wave is clearly evident, as it penetrates into the soil. It is also seen that the damping of amplitude with depth is slower as compared to the diurnal wave.

June to September is the rainy season in Buldana. But the effect of moisture in the soil is felt only on the surface. At depths of more than 0.6 meters, the temperature varies over a very narrow range but the phase-lag associated with depth is visible.

The temperature versus time (ONE means 1 am, TWELVE hours means midday, FIFTEEN hours is 3 pm and so on) is shown in Table 2.

Time	Ground	0.6 m	1.2 m	1.8 m	2.4 m	3.0 m
ONE	32	28.2	27.4	27.4	27.2	27.4
TWO	30	27.3	27.2	27.2	27.1	27
THREE	29.1	28	27	27.2	27	27
FOUR	28	28.1	27.4	27.4	27.2	27.2
FIVE	27	27.1	27	27	26.8	26.8
SIX	28	27.3	27.2	27.2	27.1	27
SEVEN	29	28	27	27.2	27	27
EIGHT	30	28.1	27.4	27.4	27.2	27.2
NINE	30.2	28.1	28	27.4	27.1	27.1
TEN	31.7	28.2	27.4	27.4	27.2	27.4
ELEVEN	34	28.1	28	27.4	27.2	27.3
TWELVE	35.5	28.2	27.4	27.4	27.2	27.4
THIRTEEN	36.5	28.3	28.3	27.4	27.2	27.4
FOURTEEN	36.7	28.2	27.4	27.3	27.2	27.4
FIFTEEN	36.7	28.1	28	27.5	27.2	27.3
SIXTEEN	37.5	28.2	27.4	27.4	27.4	27.4
SEVENTEEN	37.4	28.3	28.3	27.2	27.2	27.3
EIGHTEEN	37.2	29	27.4	27.4	27.2	27.2
NINETEEN	36.6	28.5	28.2	27.4	27.2	27.3
TWENTY	36	28.3	27.4	27.4	27.2	27.2
TWENTY ONE	35.2	28.3	28.3	27.4	27.2	27.2
TWENTY TWO	34.4	28.1	28	27.4	27.2	27.3
TWENTY THREE	33	28.2	27.4	27.4	27.2	27.4
TWENTY FOUR	32.5	28.1	28	27.4	27.1	27.1

Table - 2 Temperature fluctuation on a given day

Fig. 2shows the above data in the form of a graph It can be seen that the same pattern - reduction in diurnal fluctuation with depth - was uniformly present through twelve months.

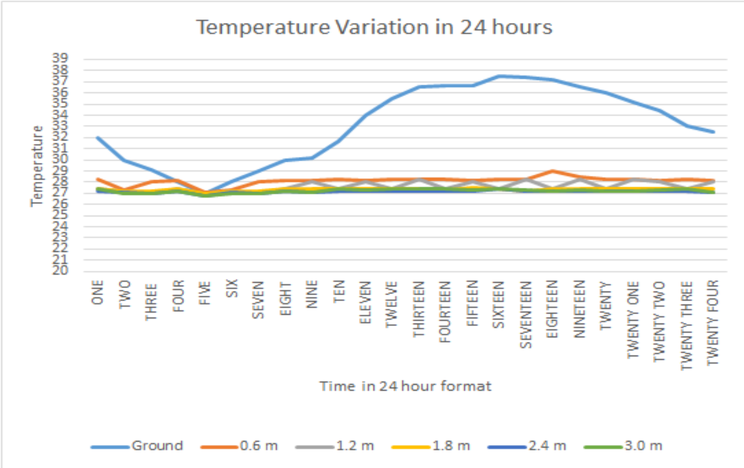

Fig. 2 Temperature variation in 24 hours

Analytical Expression for Daily Mean Soil Temperature :

Consider a semi-infinite medium as shown below. It is assumed that the entire medium is initially at a constant temperature. Surface of the medium is maintained at a temperature that varies cyclically.

Let

Z space coordinate (here depth below surface, positive downward) in meters

t time in days

$T_{(z,t)}$ temperature of points at depth z, time t (^{o}C)

T_a temperature of the medium initially (^{o}C), constant

A_0 amplitude of the temperature wave at the surface (^{o}C)

ω angular frequency of the temperature wave at the surface (radians/day)

k thermal diffusivity of the material of which the medium is made (m^2/day)

Equation (1) describes one dimensional heat flow through a semi-infinite medium

$$\frac{\partial T}{\partial t} - k \frac{\partial^2 T}{\partial z^2} = 0 \qquad (1)$$

Temperature at time t=0 and at depth zis $T_{(z,0)}$. Let this be designated as T_a

$T_{(z,0)} = T_a$ (2)

Temperature at surface (z = 0) and at time *t* (*t*> 0) is say$T_{(0,\,t)}$

Then the variation in temperature at the surface (input) can be expressed as

$$T_{(0,t)} = T_a + A_o \cos(\omega t - \varphi) \quad (3)$$

where $\varphi$is the phase lag.

To simplify the expressions, let

$= T - Ta$

Equations 1,2, and 3 can now be written as

$$\frac{\partial}{\partial t} - k \frac{\partial^2}{\partial z^2} = 0 \quad (4)$$

$(z, 0) = 0$ (5)

$(0, t) = A_o \cos(\omega t - \varphi)$ (6)

where φ is the phase lag

The amplitude of the temperature wave at a depth *z* is given by the product of amplitude of the input wave *Ao* and $e^{-\alpha z}$ where the temperature wave number α given by $\alpha = \sqrt{\frac{\omega}{2k}}$

The solution to equation 4 is given in several books on heat transfer [4]

$(z, t) = A_o e^{-\alpha z} \cos(\omega t - \alpha z - \varphi)$ (7)

In terms of original variable T (z, t),

$T(z, t) = T_a + A_o e^{-\alpha z} \cos(\omega t - \varphi - \alpha z)$ (8)

The waves are very strongly attenuated. Lower the thermal diffusivity, higher the attenuation. This is however, a rather simplified view of a complex phenomenon. Soil temperature depends on many factors which influence the conductive, convective and radioactive heat exchange between soil and atmosphere. The above equation takes into account only the unsteady sate conduction through the soil. It is assumed that the soil is homogeneous, which is generally not the case. Moisture content of the soil varies with depth. This may change the properties assumed constant here.

To apply equation 8 to the conditions in Buldana, we need to determine T_a , A_0, andφ.

Buldana's climate is considered to be '***Aw'*** according to the Köppen-Geiger climate classification and the average annual temperature is 30 °C [6]. We will use this as an approximation of the average soil temperature, Ta.

Amplitude A_0 of the annual temperature wave at the soil surface is different for different seasons. The year may be broadly divided into two parts. February to July is the summer season and August to January is the winter season. The amplitudes of the annual temperature wave is different for the two seasons. From the temperature data (Table 1), it is 5.027^o for the summer and 3.26^o for the winter. There are two expressions for the two seasons. The value of φcan be estimated. The peak of the temperature wave at the ground level in a year of 365 days (counted from January) occurs at about day 120 i.e. 1st May. The soil temperature may be expressed by equation 8 which takes the form

$$T(t,z) = 30 + A_0 e^{-\alpha z} \cos(\frac{2\,\pi(t-120)}{365} - \alpha z) \qquad (9)$$

The parameter α represents the thermo physical properties of soil. The soil in Buldana is red loamy sand soil with a thermal diffusivity of 0.84-2.36 x 10^{-6} m^2/s [7]

Average thermal diffusivity for red loamy sand soil may be taken as 1.6 x 10^{-6} m^2/s or 0.1382 m2/day. Hence the wave number α works out to 0.2495 m^{-1}. Equation 9 for the summer and winter seasons can be written as

$$T(t,z) = 30 + 5.027\, e^{-0.2495\, z} \cos(0.0172\,(t-120) - 0.2495\, z) \qquad (10)$$

$$T(t,z) = 30 + 3.260\, e^{-0.2495\, z} \cos(0.0172\,(t-120) - 0.2495\, z) \qquad (11)$$

The actual temperature and the temperature computed using equations 10 and 11 are shown in figures 3 and 4. Figure 3 is for the temperatures at the ground level while figure 4 is for temperatures at the depth of 0.6 m.

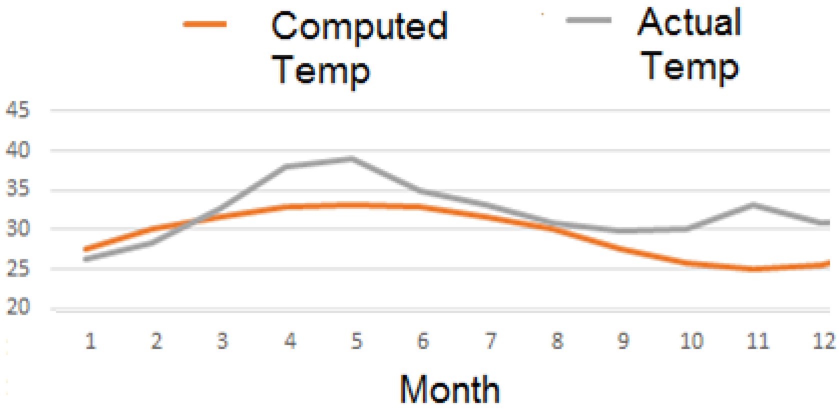

Fig. 3 Temperatures At Ground Level

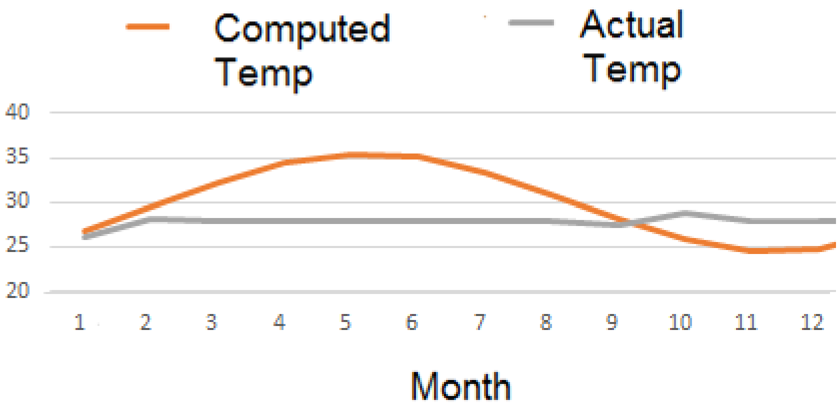

Fig. 4 Temperatures At the Depth Of 0.6 m

Conclusion

1. Measurement of temperature up to the depth of 3-m at Buldanashow that diurnal fluctuations diminish rapidly with depth and the temperatures at 1.2 m and beyond become constant. Amplitudes of annual wave too diminish with depth, but less rapidly than the diurnal.

2. Amplitude of the annual temperature wave at the soil surface is different for the summer and the winter seasons. The temperature computed using the equations 10 and 11 and the actual temperatures are in broad agreement.

The strata between 1.2 m to 1.8 m is suitable for installation of earth-air tube heat exchanger. The soil temperatures do not decrease appreciably at greater depths. Also the cost of making a trench for the pipes increases with depth without any material change in amplitude.

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