ANALYSIS OF VARIOUS DESIGNING PARAMETERS FOR EARTH AIR TUNNEL HEAT EXCHANGER SYSTEM

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ABSTRACT

Ground possesses high heat capacity as well as its insulation potential so, at a sufficient depth, the ground temperature is constant. It is found that throughout the year the temperature of earth remains almost constant at a depth of 4m. This temperature is found to be higher than that of the outside air in winter and vice versa in summer. This paper focuses on the various designing parameters of Earth air tunnel heat exchanger for room conditioning thereby utilizing the clean energy. This paper reviews the work done till date about the various design factors one should consider while designing the EATHE system, viz. velocity and mass flow rate of the air through tunnel, soil nature & material of the pipe, cross-section of the pipe.

Keywords: Clean Energy, Earth Air Tunnel Heat Exchanger (EATHE), Heat Transfer, Room Conditioning

1. INTRODUCTION

The EATHEs are considered as an effective substitute for heating/cooling of buildings. This is basically a series of metallic, plastic or concrete pipes buried underground at a particular depth. Through pipes the fresh atmospheric air flows. According to the temperature difference the heat transfer takes place between soil and air in pipes. The efficient design of the system is necessary as the system will ensure good performance. In that accordance the cross section area & type of cross section of pipe, velocity of air & nature of soil plays key role in efficiency of system. This uses green and clean energy in order to minimize pollution and to minimize conventional energy consumption. Also there are two major types of EATHE system exist: ‘open-loop’ (i.e., drawing outside air through the pipes to ventilate the house) or ‘closed-loop’ (i.e., re-circulating the air from the building through the earth tubes).
One of the important aspects in concern of EAHEs is categorization of the site in terms of geology availability. The knowledge of soil thermal and physical properties (thermal conductivity, density, diffusivity etc.), depth of bedrock, depth to water and the nature of soil is required. This information guides the designer in the selection of the type of EAHE system to be used and in the design of the system. Ghosal and Tiwari [6] reported the modeling of an earth to air heat exchanger with a greenhouse. Ghosal and Tiwari [6] developed a new thermal model for green-house heating and cooling with EAHE in New Delhi, India. It was found on average 7–8°C higher in the winter and 5–6°C lower in the summer than those of the same greenhouse without EAHE. They showed that greenhouse air temperature increased in the winter and decreased in the summer with increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe and increasing depth of ground up to 4m.

Using the following equation heat transferred can be calculated:

\[ P_{\text{sht}} = S_{\text{pipe}} \cdot h \cdot (T_{\text{air}} - T_{\text{pipe}}) \]

Where,

- \( P_{\text{sht}} \) = sensible heat transfer rate (W)
- \( h \) = heat exchange coefficient (W/m^2-K)
- \( T_{\text{air}} \) = air temperature (°C)
- \( T_{\text{pipe}} \) = pipe surface temperature (°C)
- \( S_{\text{pipe}} \) = pipe surface area (m^2)

The second kind seems to have fallen out of favor, probably because it is insufficient to provide heating to the building by itself, and because it does not help meet the building’s fresh air requirements.

1.1 Work in India

A large earth-air tunnel system meant to provide thermal comfort inside the whole building complex at one of the hospitals in India has been evaluated by Bansal [4]. A simple theoretical model is developed to validate the experimental measurements. An 80m length of the tunnel with a cross-sectional area 0.528 m^2 and with an air velocity of 4.89 m/s is found to have a cooling capacity of approx. 512 KWh and a heating capacity of 269 KWh. The heating capacity was found to be inadequate for providing the necessary comfort conditions.

2. DESIGN PARAMETERS

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2.1 Material of pipe & Velocity limit

Bansal [10] carried out the experiment on the pipe of 23.42m length and 0.15m diameter, temperature rise of 4.1–4.8°C has been observed for the flow velocity ranging from 2 to 5 m/s. The hourly heat gain through the system is found to be in the range of 423.36–846.72 kWh. Fig. 2 represents the comparison of the results of the simulation and experiments for air velocity of 2.0 m/s at the outlet of the steel and PVC pipes, respectively. Fig. 2 and Fig. 3 also depict that as the velocity of air is increased, the temperature of the air at the outlet of the pipe gets reduced. The reduction in temperature of the air at the exit of pipe due to increment in air velocity occurs because when the air velocity is increased from 2.0 to 5.0 m/s, the convective heat transfer coefficient is increased by 2.3 times, while the duration to which the air remains in contact with the ground is reduced by a factor of 2.5. Thus the later effect is dominant and therefore, lesser rise in temperature is obtained at higher air velocities. At higher velocities though the rise in temperature of air is less yet the total heating effect achieved per unit time is much more.

Bansal [7] concluded the experiment with the statement it’s the velocity of air through the pipe which affects the system performance greatly and not the material of buried pipe. Also stated that velocity 2 m/s is most suitable & economical to achieve desire effect.

Fig. 2: Temperature distribution along the length of the pipe for exit velocity 2.0 m/s for (a) steel pipe and (b) PVC pipe.
2.2 Soil Nature and operation period

Effect of soil thermal conductivity and time period of continuous operation of EATHE on thermal performance has been carried out for different pipe length of EATHE using experimentally validated CFD simulation by Bansal [9]. CFD System designed to validate EATHE model comprises of horizontal cylindrical PVC pipe of 0.10 m inner diameter with buried length of 60 m and buried at a depth of 3.7 m in a flat land with dry soil. Globe valves are fitted in pipe assembly for flow control of air. At the inlet, the open end of this single pipe was connected through a vertical pipe to a 0.75 kW, single phase variable speed blower having maximum speed 2800 RPM and maximum flow rate of 0.093 m$^3$/s. Ambient air is forced through the EATHE system with the help of blower. Velocity of air through the pipe can be varied by changing the RPM of the blower with the help of an auto transformer (0 – 270 V, 2 A. max., type: 2D-1Phase with a least count of 1 V). Energy consumption of the blower at 5 m/s is measured as 0.2 KW. Effect of thermal conductivity of soil on the thermal performance of EATHE system has also been studied by using three different types of soil namely S1, S2 and S3 in this study having thermal conductivity 0.52, 2.0 and 4.0 Wm$^{-1}$ K$^{-1}$.

Following color figures represents the temperature variations along pipe length after certain interval of time for different types of soil.
Table 1: Effect on soil temperature along the length of pipe at different period of time

<table>
<thead>
<tr>
<th>Length of Pipe (m)</th>
<th>Air Temperature at different section for soil S1, S2, S3 after different time interval (Kelvin)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After 1hr</td>
</tr>
<tr>
<td>10</td>
<td>S1</td>
</tr>
<tr>
<td></td>
<td>312.9</td>
</tr>
<tr>
<td>30</td>
<td>305.8</td>
</tr>
</tbody>
</table>

Fig. 5: Temperature contour of air and soil at 10 m section from for pipe inlet after 12 h for three soils (a) 0.52 Wm/ K, (b) 2.00 Wm/ K and (c) 4.00 Wm/ K.
Fig. 6- Temperature contour of air and soil at 30 m section from for pipe inlet after 12 h for three soils (a) 0.52Wm\(^{-1}\) K\(^{-1}\), (b) 2.00Wm\(^{-1}\) K\(^{-1}\) and (c) 4.00Wm\(^{-1}\) K\(^{-1}\).
Maximum deterioration in the performance in terms of temperature drop obtained during continuous operation of 24 hr is recorded as 2.9 K for soil with thermal conductivity of 0.52 Wm/ K. Thickness of soil annulus surrounding the pipe up to which the thermal influence is observed depends on the thermal conductivity of the soil and period of continuous running of EATHE system. The thickness of the soil annulus beyond which no significant rise in temperature of soil is observed is equal to the pipe diameter.

3. CONCLUSIONS

1. EATHE can be used as substitute for the conventional air conditioning systems
2. EATHE-evaporating cooling hybrid systems can be used in summer for better results.
3. More the thermal conductivity of soil better is the thermal performance of EATHE
4. With increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe and increasing depth of ground up to 4 m performance of EATHE becomes better.

4. REFERENCES