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Proportional Design of Earth Tube Heat Exchanger Materials For Cooling of Air : A Review

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***Abstract*— The use of ground coupled heat exchanger (GCHE) systems is increasing worldwide. They are mainly used for space conditioning, water heating, agricultural drying, bathing, swimming, etc. They reduce cooling load in summer and heating load in winter. GCHE systems make available excellent scope to conserve significant amount of primary energy and thus mitigating the impact on environment through emission reduction. This paper reviews the experimental and modeling studies carried out on GCHE systems. The reviewed literature focuses on performance of both types of GCHE systems viz. earth–air heat exchanger (EAHE) and ground source heat pump (GSHP) systems and brings out their merits and demerits.. Experimental investigations were done on the experimental set up in Oriental College of Technology, Bhopal. Effects of the operating parameters i.e. air velocity and temperature on the thermal performance of horizontal ground heat exchanger(GI Pipe & Copper Pipe) have been studied. For the pipe of 9m length and 0.05m diameter, temperature falling GI Pipe of 3.93^{0}C-12.6^{0}C in hot weather and temperature rising GI Pipe of 6^{0}C-10^{0}C in cold weather Same as temperature falling Copper Pipe of 3.93^{0}C-12.6^{0}C in hot weather and temperature rising Copper Pipe of 6^{0}C- 10^{0}C in cold weather have been observed for the outlet flow velocity 11 m/s. At higher outlet velocity and maximum temperature difference, the system is most efficient to be used.**

***Keywords*— GCHE,GSHP, EAHE,Temperature.**

I. Introduction

The way towards energy and environment sustainability is the incremental adoption and promotion of renewable energy technologies, practices and policies [1]. Green building control strategies use various concepts of natural heating, ventilation and air conditioning [2,3]. GCHE technique is one of them. It is an underground heat exchanger that can absorb from/release heat to the ground. The underground temperature remains relatively constant throughout the year or all year average of sol air temperature of its ground surface [4,5]. This constant temperature characteristic is due to high thermal inertia of the soil and as the depth increases, effect of temperature. Earth-air heat exchangers have been used in agricultural facilities (animal buildings) and horticultural facilities (greenhouses) in the United States over the past several decades and have been used in conjunction with solar chimneys in hot arid areas for thousands of years, probably beginning in the Persian Empire. Implementation of these systems in Austria, Denmark, Germany, and India has become fairly common since the mid-1990s, and is slowly being adopted in North America. fluctuations of the ground surface is reduced. Due to time lag between the temperature variations at the surface of the ground and below the ground, at a sufficient depth, temperature below the ground is always higher than that of the outside temperature of air in winter and is lower in summer. This temperature difference can be used for pre-heating in winter and pre-cooling in summer by installing appropriate GCHE system. Advantages of GCHE systems are high efficiency, stable capacity, good air quality, better thermal comfort, easy control, require simple equipments, low maintenance cost, environment friendly, long term cost effective, tax benefit, and noise free being the underground unit. Drawbacks are higher initial cost, limited availability of trained technicians and contractors. Performance of GCHE systems depends on air/liquid flow rate, depth and length of buried pipe/ tube (sufficient for air/liquid to lose the heat to certain extent), material and diameter of pipe/tube, temperature difference between earth and ambient, initial soil temperature, rating of blower fan, and various combinations of pipes.

1.1 Ground Coupled Heat Exchanger:

GCHE systems have multiple primary objectives. These are to achieve the best operational efficiencies, the lowest possible operational cost and run environmentally safe, to have lowest possible initial cost and surface area, to increase interior comfort levels and long-term system durability, to make possible ease of service and maintenance and to earn revenue under certified emission reduction (CER). Sequestration of one ton of carbon dioxide-equivalent (CO2-e) is represented by one CER unit. Developing country like India can earn additional revenue of 234 107 Euros under CER by using GCHE [6]. GCHE systems are preferred to those locations where fluctuation in ground surface temperature level is high and under the demands of reduction of CO2 released into the atmosphere. According to connection and orientation, it can be classified as series and parallel, horizontal and vertical.

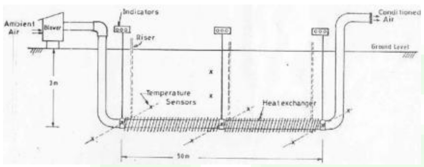

Fig.1 :Earth tube Heat Exchanger Line Diagram

II. LITERATURE REVIEW

Abbaspour-Fard et al. [30] tested the performance of an EAHE system on various parameters i.e. burial depth, length of pipe, air velocity, pipe material in Iran. After 72 experimental trials it was concluded that all parameters were directly related to performance except pipe material. Cooling coefficient of performance (COP) of 5.5 was higher than heating COP of 3.5

Mogharreb et al. [31] tested the performance of an EAHE system by taking two independent variables i.e. area of greenhouse and the percentage of vegetation coverage inside the greenhouse during both heating and cooling modes. It was concluded as variables had significant effect on the performance of EAHE system. Cooling COP was 4.32 higher than heating COP 1.01. The percentage of vegetation coverage had negative effect during cooling and positive effect during heating mode on the performance of EAHE system.

Mongkon et al. [32] presented the experimental results of horizontal earth tube system (HETS) for cooling in an agricultural greenhouse in the tropical climate of Thailand. Performance of HETS was monitored on typical days in the winter, summer and monsoon seasons. The experiments were conducted in 30 m2 of greenhouse volume with the 38.5 m of length and 0.08 m diameter HETS buried at a depth of 1 m. Readings of performance in various seasons were distinct. The values of COP were 3.56, 2.04, and 0.77 during summer, winter and monsoon days respectively. It was established that cooling COP was higher than heating. Soil conditions significantly affect the performance.

Ascion et al. [33] tested and concluded that best energy performance could be obtained for wet/humid soil by adopting pipe length of more than 50 m, buried at a depth of 3 m.

Balghouthi et al. [34] studied experimentally thermal and moisture behavior of dry and wet soil heated by buried capillary plaits, on a prototype similar to an agricultural tunnel greenhouse. It was concluded that the surface temperature amplitude was superior in wet soil as compared to dry soil.

Li et al. [35] constructed experimental setup at Herbin in China, for study of a ground sink direct cooling system in cold areas and concluded that there was substantial scope of energy conservation within a particular region. It was found that geographical and climatic conditions affect the performance level. Efficiency can be improved by reducing pipe diameter, mass flow rate of air, increasing pipe length, buried depth and buried pattern.

Goswami et al. [36] constructed an experimental setup at the energy research and education park at the university of Florida, which consisted of a 0.3 m diameter, 30.5 m long corrugated plastic pipe buried at a depth 2.75 m, a 0.2 kW blower, a 2½- ton heat pump, open loop. It was suggested that 0.3 m diameter for single pipe and 0.2–0.25 m diameter for multiple pipes in parallel could be suitable for achieving optimum performance but paper is silent on selection criteria for 0.3 m diameter pipe. It was observed that smaller diameter provided higher temperature drop, but consumed more fan power.

Bisoniya et al. [37] tested EAHE system for hot and dry summer conditions at Bhopal in India. The experimental set up had two cylindrical PVC pipes of 0.1016 m ID. The length of each cylindrical pipe was 9.114 m, connected in series. The total length of burial pipe assembly including elbows, connector pipe was 19.228 m, buried in black cotton soil at a depth of 2 m. For air flow velocities of 2 m/s, 3.5 m/s and 5 m/s, researchers concluded that decrease in air temperature was significant in initial length of pipe than in the remaining length of pipe. Maximum and minimum drops in air temperature were 12.9 1C, 11.3 1C observed at air flow velocities of 2 m/s and 5 m/s respectively. It was felt that lower air velocities would lead to higher temperature drop. A simulation model was developed on computational fluid dynamics (CFD) platform CFX 12.0 and simulation results validated satisfactorily with the experimental results.

Dubey et al. [38] tested EAHE system with pipes in parallel at Bhopal in India. Experimental setup had 3 GI pipes of 64 mm internal diameter (ID), 3 m each, connected in parallel to common intake and exhaust, buried at a depth of 1.5 m in a flat land with dry soil. Researchers found that temperature difference of air at the inlet section and exit section of the pipe at 1.5 m depth, varied from 8.6 to 4.18 1C in the air velocity range of 4.1–11.6 m/s and COP from 6.4 to 3.6. It was observed that lower air velocities resulted higher temperature drops and COPs. temperature at a depth of 1.5 m remained at about 30.4 1C. Paper does not provide selection criteria for serpentine pattern and comparison with others.

Woodson et al. [39] constructed experimental setup of EAHE system at the International Institute for Water and Environmental Engineering in Ouagadougou, Burkina Faso. It was a horizontal open-loop system used 25 m long, 125 mm diameter PVC pipe at a depth of 1.5 m. The EAHE system had two air inlets, located 15 m and 25 m away from the air outlet in the building. But this study was done only on 25 m long pipe which was laid down in serpentine pattern. It was found that 25 m long EAHE buried at a depth 1.5 m could reduce the temperature of air drawn from outside by more than 7.5 1C. While outdoor temperature varied from 25 1C to 43 1C and the soil.

Rodrigues et al. [40] experimented combination of EAHE with PCM as alternative of conventional air-conditioning. It was concluded that combined effect of EAHE with PCM conserved significant amount of energy as compared to conventional air conditioning system. It could enhance cooling up to 47%.

Misra et al. [41] made an experimental setup of EAHE system in hybrid with air conditioner (AC) at Ajmer in India. The experimental setup comprised of 60 m long, 0.10 m ID PVC pipe, buried at a depth of 3.7 m in a flat land with dry soil. There were four modes of test, in mode-I, alone AC supplied the conditioned air to the test room that was treated as base mode. In mode-II, AC and EAHE system both supplied their 100% conditioned air to the test room. In mode III, AC supplied conditioned air to room and but 100% conditioned air from EAHE system was supplied to AC's condenser coils to cool them only. In mode-IV, AC supplied conditioned air to room and 50% conditioned air from EAHE system was supplied to AC's condenser coils to cool them and remaining 50% air was supplied to test room.

Haghighi et al. [42] integrated EAHE system with solar chimney and concluded that 0.5 m diameter, 25 m length of EAHE system, 0.2 m air gap and outlet sizes of solar chimney could enhance the performance.

Tavakolinia [43] integrated EAHE system with wind catcher for cooling and natural ventilation for the single story spaces in Los Angeles area. It was concluded that integrated system could perform better than unity system.

Ralegaonkar et al.[44] tested EAHE system at Nagpur in India and concluded that geothermal cooling system i.e. EAHE could save up to 90% of electricity as compared to conventional air conditioning systems and 100% of water as consumed by evaporative cooling systems.

Chel et al. [45] made an experimental setup of EAHE system integrated with 2.32 kWp photovoltaic power system at solar energy park in New Delhi, India. This integration had estimated potential of up to 50% energy conservation.Appropriate modifications like cross ventilation, earth surface and soil–cement mixture treatment, wall configuration, etc. provide enhanced output.

III. DESIGN PARAMETERS

When designing earth tubes, choosing the type of pipe is the first decision. There are a variety of materials to choose from, from baked clay tiles, to steel duct work, to common PVC or the most modern HDPE plastics with anti-microbial coatings. Perhaps I will eventually come back and put this in a table, but for now, I will just list some of the pros and cons to each.

Note that the thermal conduction properties of the material do affect the rate that heat conducts thru them, but it doesn't seem to affect the overall performance of the earth tubes. Partially, this may be because the total resistance to thermal conduction includes both the R value and the thickness.

Although concrete conducts heat better than plastic, concrete pipe is typically much thicker and 2 inches of concrete ends up with a thermal resistance similar to 1/4 inch of HDPE. It is also somewhat because a somewhat stable temperature gradient is setup that eventually lets the heat thru. But the real reason the material conductivity doesn't matter very much is because it is the conductivity of the earth that is the bottleneck. Aluminum conducts heat very quickly, but can't draw it from the earth any faster than a plastic pipe can. More important aspects to consider include durability, cost, ease of installation, environmental concerns and the interior wall friction factor that has a direct effect on the frictional pressure losses of the system.

A. Clay or Cement

Clay or cement duct work has also been used. The idea is that if it is good enough for drainage tile or sewer systems, it is good enough for air. Their durability is not in question, however they are brittle and could be cracked with impact, most often during assembly when these heavy sections are lowered into the ground (typically with expensive equipment). The rough walls of these pipes provide a lot of resistance to airflow. The Friction factor for cement pipe is 200 times that of PVC. This friction has a direct effect on the frictional pressure losses. I suspect that the larger standard diameters can more than make up for the higher friction. The surface roughness can also make cleaning them impossible. The many joints are appreciated by bugs and mold.

Fig. 2: Installing Cement Earth Tubes

B. PVC (Polyvinyl Chloride)

PVC is a frequent choice. It is popular because you can go to any hardware store and buy as much or as little of it as you want. There are also a wide variety of fittings available. You can easily buy the tools and glue needed to assemble it or find someone to do that work for you. The downside is that PVC infamous for being one of the most hazardous consumer materials ever invented. Not only is it toxic in is fabrication, but many of those production chemicals are not actually bonded in the plastic and can leak out over time. No one wants dioxin or other carcinogens in their air supply. Structurally, PVC is brittle and gets more brittle over time (especially if it spends any time in the sunlight before it is installed). It is easily broken during installation (as testified to in the blogs of many who installed them). Flexible rubber joints have been used to repair breaks and some recommend them as a way to prevent breaks (flex instead of crack). Even after a successful installation, cycling temperatures cause thermal stress and micro-fractures. The joints can catch and hold water and make the pipes difficult to clean thoroughly.

Fig.3 PVC Earth-tubes

C. Copper Pipe

Copper is a chemical element with symbol Cu (from Latin: cuprum) and atomic number 29. It is a soft, malleable, and ductile metal with very high thermal and electrical conductivity. A freshly exposed surface of pure copper has a reddish-orange color. Copper is used as a conductor of heat and electricity, as a building material, and as a constituent of various metal alloys, such as sterling silver used in jewelry, cupronickel used to make marine hardware and coins, and constant an used in strain gauges and thermocouples for temperature measurement.

Fig.4:Copper Earth Tube Pipe

Copper is one of the few metals that can occur in nature in a directly usable metallic form (native metals). This led to very early human use in several regions, from c. 8000 BC. Thousands of years later, it was the first metal to be smelted from sulfide ores, c. 5000 BC, the first metal to be cast into a shape in a mold, c. 4000 BC and the first metal to be purposefully alloyed with another metal, tin, to create bronze, c. 3500 BC.

D. Aluminium Pipe:

Aluminum is a chemical element with symbol Al and atomic number 13. It is a silvery-white, soft, nonmagnetic and ductile metal in the boron group. By mass, aluminium makes up about 8% of the Earth's crust; it is the third most abundant element after oxygen and silicon and the most abundant metal in the crust, though it is less common in the mantle below. The chief ore of aluminium is bauxite. Aluminium metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals.

Fig.4: Aluminium Earth Tube Pipe

IV. CONCLUSION AND FUTURE WORK

After done the calculation in the previous chapter, we can see that the results are quite encouraging. The results are summarized under the following points:

- IN GI Pipe For the pipe of 9 m length and 0.05 m diameter, temperature rise of 3.230C-6.10C has been observed for the outlet flow velocity 11m/s
- IN COPPER Pipe For the pipe of 9 m length and 0.05 m diameter, temperature rise of 8.330C- 10.10C has been observed for the outlet flow velocity 11m/s
- IN GI Pipe The maximum COP obtained in summer season is 2.817 at time 14:00 and the maximum COP obtained in winter season is 2.25 at time 17:00
- IN COPPER Pipe The maximum COP obtained in summer Season is 3.68 at time 14:00 and the maximum COP obtained in winter Season is 2.39 at time 17:00 m/s. ow velocity 11m/s
- IN GI Pipe The COP of the system varies from 0.85 – 2.70 in summer season and 1.41-2.25 in winter season in outlet velocity 11m/s.
- IN COPPER The COP of the system varies from 1.53 – 3.68 in summer Season and 1.75-2.39 in winter Season in outlet velocity 11

The results also show that conduction plays very important role in the cooling of air, it is evident from the fact that temperature remains constant where the insulation is done.

If the blower speed is high and the length of pipe is less than the temperature difference inlet and outlet is very small.

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