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# Space Cooling With Underground Heat Exchangers

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Abstract **Day to day advanced cooling techniques and refrigerants makes the world to attain most desired cooling effects. But these advances will induce the green house gasses in the environment which in turn causes Global warming. In order to reduce this, passive cooling techniques using renewable energy resources can be a possible alternative. One such technique is using underground heat exchangers.**

**In this paper, an attempt was done to carry theoretical analysis for the feasibility of using underground Heat Exchanger to cool the room for the conditions of Anantapur, in Andhra Pradesh of India. A total of 20 different depths from the surface, ranges from 0.5m to 10m are used for the analysis. Heat exchangers are placed at these depths. Air and water are used as heat exchanging fluids. It is observed that the constant temperature of 27$^{o}$C was obtained at 8m depth. Theoretical results indicates the power consumption for water is less and heat removal rate is more than that of air and the total cost of water system is around 10.37% more than the air system. Obtained theoretical values are compared with the conventional air conditioning system.**

***Keywords* — *Geothermal, Number of air changes, Passive cooling, Renewable energy, Underground Heat Exchanger, Undisturbed temperature***

## I. INTRODUCTION

Due to swift growth in buildings, industries and infrastructure resulting increased energy consumption, especially electricity usage. In order to reduce high grade energy consumption some of the passive cooling techniques are being developed. One such proposition is the Space Cooling with Underground Heat Exchangers.

Previous studies shows that at depths below the surface of the earth the temperature differences may occur but at a certain depth nearly 5-10 m, the temperature remains constant throughout the year which will approximately equal to the annual average temperature of that place. As the depth of the ground increases the temperature fluctuations of the ground are diminished because of the high thermal inertia of the soil and also there is a time lag between the surface of the earth and in the ground. The ground temperature is always lower than that of atmospheric air temperature in summer and higher in winter. By using Underground Heat Exchangers (UHE) Both of the above uses can reduce energy consumption.

Studies on the effect of the working parameters such as pipe material, pipe diameter, pipe length, depth of burial of the pipe, flow rate of air and different types of soils on the thermal performance of earth-air heat exchanger (EAHE) systems is very crucial to ensure that thermal comfort can be achieved [1]. Earth air-pipe heat exchanger (EAPHE) system is proposed to check the technical feasibility for thermal applications in hot and arid conditions. The induced air temperature drop up to 24 $^{0}$C was achieved and also EAPHE system suggests that it can be effectively used for heat rejection in air-cooled condenser units [2]. Tiantian Zhao et al. Calculated the ground temperature distribution, borehole wall temperature and also concluded that enthalpy of ground will change after 20 years of operation. The analysis was carried out by the most effective Ground Heat Exchanger (GHE) for different loading conditions are evaluated [3]. Ravindra Singh Jhala and Ravi RanjanManjul et al. [4,6] investigated the performance analysis of Earth Air Tunnel Heat Exchanger (EATHE). It can be a possible replacement for the Conventional air conditioning system for better results in summer. The design of EATHE mainly depends on the Heating or Cooling load, requirement of a building to be conditioned and also found that the COP of EATHE system is higher than the conventional AC.

A Review of Hybrid Ground Coupled Heat Exchanger (GCHE) Systems by Suresh Kumar Soni et.al [7] Concluded that Hybrid system with evaporative cooler could increase cooling effect by 69% and reduce length of buried pipe up to 93.5%, GSHP (Ground Source Heat Pump) with conventional Air Conditioning System could reduce power consumption by 15.5 %. Earth tunnel heat exchangers (ETHE) are used to utilize the heat capacity of the soil effectively and to increase their efficiency coupled with heat pump. Simulation and mathematical models are developed for sizing of system and to predict the performance of ETHE.

Effect of pipe materials on performance of earth air heat exchanger is negligible and which will mainly depends upon the air flow rate and ambient air temperature [9,12]. Yasuhiro Hamada et.al [10] carried out experimental analysis of underground heat exchanger for cost effective coolig. Trilok S Bisonia et.al [11] presented an Earth to Air Heat Exchanger (EAHE) system which can be used effectively to reduce cooling load of buildings in hot and dry summer weather conditions, also stated that a

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considerable amount of electrical energy can be saved if EAHE is used in place of conventional AC for summer cooling. The metallic earth-air tunnel system considers cooling load, heating load, optimum underground temperature and weight of the soil acting on the underground duct. Results showed that $13^0$C reduction in temperature and above system is best when summer is on its peak [13]. Air Conditioner System with Ground Source Heat Exchanger (ACSWGSHE) was tested in an open hole, initially tested with air after that tested with water, the COP of the system increased from 2.11 to 3.72 when it is tested with water. The power consumption of the air conditioning system will be reduced by 29% when the air cooled condenser of conventional air conditioning system was replaced by ACSWGSHE but the initial cost is high [15].

Earth Air Heat Exchanger (EAHE) has been designed for a given dimension of room with optimized values of number of air changes, length of pipe and depth at which heat exchanger to be installed [17]. Wenke Zhang et al. [18] analyzed the heat transfer analysis of borehole and ground heat exchangers (GHEs) of ground coupled heat pump. Earth air heat exchanger (EAHE) system reduce the heating or cooling load of buildings, power consumption, CFC and HCFC and green house gas emissions. The thermal performance of EAHE system increases with increase in length and depth of burial pipe, while decreases with increase in pipe diameter and air velocity [19,28]. Silvia Cocchi et al. [21] in his work present a simulation of an air conditioning system with geothermal heat pump by usig TRNSYS 17 software. It has been observed that there is decrease in 5-$6^0$C in the outlet air temperature. Gaffar G.Momin et al. [22] investigates the closed looped geothermal cooling system, and also devised the experimental analysis of the system and heat transfer calculations. V. Bansal et al. [23] developed a transient and implicit mathmatical model to estimate the cooling capacity and thermal performance of EPAHE by FLUENT simulation program.

Cooling tubes are long pipes placed at under the ground which are usually used to cool and dehumidify hot outside air. These are affected by the average ground temperature, Temperature extremes of the summer, diameter and length of tubes and handling of condensation [26]. Hamada Y et al. [27] developed a improved underground heat exchanger using no-dig method and concluded that the primary energy consumption for a system installation was reduced by 78% comparing with a vertical underground heat exchanger system. The analytical and computational modeling for a space cooling system with an underground water storage tank is presented by Recep Yumrutas et al. [29]. Open loop air tunnel systems or closed loop air tunnel systems can operate with a COP of nearly 3 times higher than the conventional air-conditioning system and these earlier systems are recommended to use in agricultural buildings where a drop in air temperatures of $7^0$F to $10^0$F [31]. The study of heat transfer characteristics for making long term thermal energy storage has been carried out by Ochifuji K et al [32].

### THERMAL BEHAVIOUR OF SOIL

The use of UHE for buildings requires knowledge on the temperature profile of the soil. The climatic conditions and seasonal variations affect the temperature profile of soil. soil temperatures as a function of solar radiation, rainfall, local vegetation cover, soil type and depth in ground. Up to 3-5 m depth, ground temperatures are varied due to sun and rain.

The methodology and instrumentation system for the indirect measurement of the thermal diffusivity of a soil of very low enthalpy geothermal energy (VLEGE) systems has been carried out and The amplitude of the ground temperature variation decreases exponentially with depth and it tends to equalize the average temperature of the place [5]. Experimental study of air conditioner using earth air tunnel heat exchanger (EATHE) has been noted that more the thermal conductivity of soil, better is the thermal performance of EATHE and then EATHE is the substitute for conventional air conditioning system [8]. The ground heat exchanger (GHE) is produce sustainable energy for cooling which can be used for reducing energy consumption in buildings and agricultural greenhouses. GHE for cooling purpose has been identified that it can give a better performance. Thermal performance of GHE depends upon several factors ground temperature variation, design of system and specification of GHE pipe [14].

The nature of the soil has a high impact on the performance of the heat exchanger since the soil will transmit the heat to exchanger and depth of the buried pipe depends on the diffusivity of the ground. The pipe material has no effect on the performance of the heat exchanger [16]. Onder Ozgener et al. [20] reported a practical approach to estimate soil temperature from daily air temperature data for EAHE, assuming one dimensional heat flow and constant thermal diffusivity of soil. F. Droulia et al. [24,25] calculated the ground temperature profiles by using analytical model and semi-empirical model. Methodology to predict underground thermal properties are taken by using GIS (Geographical information system) and hydro geological information was developed [30]. Georgios Florides et al. [33] studied the short-period temperature variations in winter and also the measurement of underground temperatures compared to the calculated values. The temperature between 15 and 50 m remains relatively constant at about 22.5℃ since the water present in these ground layers smoothens any variations.

## II. SPACE COOLING TECHNIQUES

### Geothermal Air Cooling System (GACS):

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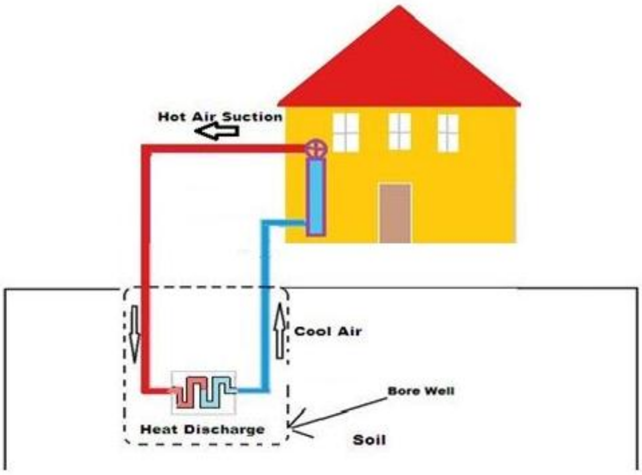

**Fig.1 Block diagram of a UHE for space cooling with air**

The open loop UHE system cools the atmospheric air by passing through it. This air is then introduced directly into the conditioned space of a room.

In a closed loop system air from the conditioned space with some ventilation air is recirculated through the UHE. The above mentioned Fig.1 comes under the closed loop system. At a 8m depth of earth, temperature remains constant This constant temperature is called undisturbed temperature of earth. This temperature is utilized by air passes through blower in 5 m buried pipe, for cooling. It takes electrical energy to rotate the blower for sucking atmospheric fresh air and circulate them in buried pipe to exchange the heat with ground and then cool air is supplied to the room. This technique is preferred to those locations where ground temperature fluctuations level is high.

### Geothermal Water Cooling System (GWCS):

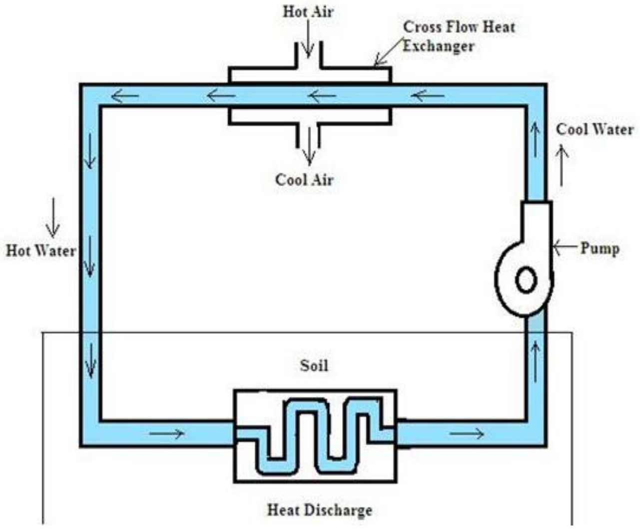

**Fig.2 Block diagram of a geothermal heat exchange system with water**

In a geothermal water cooling system cross flow heat exchanger is used to exchange the heat. Two types of cross flow arrangements are possible. The air flow across the finned-tube bundles and is thus unmixed as it is confined in separate channels between the fins. Similarly the other fluid passing through the tubes is also unmixed. This exchanger is widely used in air-conditioning applications.

The another type of arrangement is tubes without fins, the air flowing across the tubes is said to be mixed because it can move about freely in the exchanger as it exchanges heat. For mixed flow conditions the temperature varies only in the flow direction because there will be a tendency for the fluid temperature to equalise in the direction normal to the flow due to mixing. When a fluid is unmixed, the temperature variation will be in both the flow and normal directions. The overall heat transfer rate for the heat exchanger will thus depend on the nature of the mixing condition.

The underground pipes called as “underground heat exchangers”, circulates water which discharge heat to ground and returns it to the indoor cross flow heat exchanger by using pump. The hot air from the conditioned space flow over a cooling water, water will absorb heat from the hot air. The cooled air was distributed throughout the room. The warm water is recirculated to ground. Load can be removed in a room by making use of the low temperatures prevailing under the earth surface.

## III. THERMAL ANALYSIS

Thermal analysis for Space cooling technique is divided into three parts:

i) Estimation of temperature distribution below the surface of the earth

ii) Determining the outlet temperature of air at the UHE

iii) Calculating the outlet temperature of water at the UHE and also find out the outlet temperature of cool air at (Cross Flow Heat Exchanger) CFHE.

### Temperature Variations in Semi-infinite solid:

The vertical temperature distribution of the ground is a function of the time of year and the depth below the surface and could be described by the following correlation [33].

$$\mathbf{T_{soil}(z,t) = T_m - T_a\, e^{-z\sqrt{\frac{\pi}{365\times\alpha}}}} \cdot \cos\left(\frac{2\pi}{365}\left[t_{year} - t_{shift} - \frac{z}{2}\sqrt{\frac{365}{\pi\times\alpha}}\right]\right)$$

To apply the above equation the weather variables for Anantapur are needed. For this purpose the weather reports of Anantapur are taken [34]. These have been generated from monthly measurements for a one year period from January 2017 to December 2017. According to this data the annual average temperature of Anantapur (14.68° N, *77.60° E)* is taken as $27^0$C. soil varies depending on the depth and anything that disturbs the type, compactness and uniformity of the ground and of course moisture or groundwater (anything that changes the ground thermal diffusivity).

This means that in general the ground thermal diffusivity will not be constant. The average thermal diffusivity values are considered by the type of soil ($0.19\times 10^{-6}$ to $0.923\times 10^{-6}\ m^2/s$).

- As the depth increases the second term of above equation tends to zero, which means that the soil temperature tends to the annual average in the place.
- The amplitude of the temperature variation decreases exponentially with depth.

As the depth increases, the amplitude of thermal fluctuations decreases, and their maximum and minimum are going phased out (due to the thermal inertia of the soil itself).

**Outlet air temperature of underground heat exchanger:**

A room of length 18ft, breadth 18ft and height 12ft, for desired number of air changes and power requirement the optimum design has been chosen. For a living room number of air changes per hour (NACPH) is taken as 5-8.

**Volume flow rate (Q)** $=\frac{\mathbf{NACPH\times Vol.of\ room}}{\mathbf{3600}}$

The thermal energy gain by the air from the UHE is given by [17]

$$\mathbf{Q_{ua} = \dot{m}_a C_a (T_{ao} - T_{ai})}$$

$$\mathbf{Q_{ua} = \dot{m}_a C_a (T_g - T_{ai})\left[1 - e^{-\frac{2\pi r h_c L}{\dot{m}_a C_a}}\right]}$$

The pressure difference and power is required to supply the air to UHE

$$\mathbf{\Delta P = \frac{\rho f L v^2}{2D}}$$

$$\mathbf{Power =\ \dot{m}_a \frac{\Delta P}{\rho}}$$

$$\mathbf{Heat\ Removal\ Rate\ (HRR) = \dot{m}_a C_a (T_{ai} - T_{ao})}$$

**Table 1. Values of different parameters used in analysis.**

| | |
|---|---|
| $\rho \quad = 1.145\ kg/m^3$ | $Q \quad = AV\ m^3/s$ |
| $C_p \quad = 1007\ J/kg\ K$ | $h_c \quad = \frac{k_a Nu}{d} W/m^2\ K$ |
| $k \quad = 0.02625\ W/m\ K$ | $Re \quad = \rho v d/\mu$ |
| $\mu \quad = 1.895\times 10^{-5}\ \frac{kg}{m} s$ | $Nu \quad = 0.023 Re^{0.8} Pr^{0.3}$ |
| $Pr \quad = 0.7268$ | $f \quad = (1.82\times \log Re - 1.64)^{-2}$ |

**Outlet water temperature of UHE and outlet air temperature of CFHE:**

The thermal energy gain by the water from the UHE is given by

$$\mathbf{Q_{uw} = \dot{m}_w C_w (T_{wo} - T_{wi})}$$

$$\mathbf{Q_{uw} = \dot{m}_w C_w (T_g - T_{wi})\left[1 - e^{-\frac{2\pi r h_c L}{\dot{m}_w C_w}}\right]}$$

The outlet temperature of water at the UHE

$$\mathbf{T_{wo} = \frac{Q_{uw}}{\dot{m}_w C_w} + T_{wi}}$$

Let us assume the outlet temperature of water at UHE is equal to the inlet temperature of CFHE

**Table 2. Values of different parameters used in analysis.**

| | |
|---|---|
| $\rho \quad = 996\ kg/m^3$ | $h_f \quad = Nu\ k/d\ W/m^2 K$ |
| $C_p \quad = 4178\ J/kg\ K$ | $A \quad = n_p \pi d L$ |
| $k \quad = 0.615\ W/m\ K$ | $Nu \quad = 0.023 Re^{0.8} Pr^{0.3}$ |
| $\mu \quad = 0.798\times 10^{-3}\ \frac{kg}{m} s$ | $U \quad = \frac{1}{\frac{1}{h_a}+\frac{1}{h_f}}\ W/m^2 K$ |
| $Pr \quad = 5.42$ | $C_{min} \quad = (\dot{m}C)_{air}$ |
| $h_a \quad = 100 W/m^2 K$ | $C_{max} \quad = (\dot{m}C)_{water}$ |

In the thermal analysis of heat exchangers by the LMTD method is quite simple, when all the thermal temperatures are known are easily determined. The difficulty arises if the temperature of the fluids leaving the exchanger are not known. This type of situation is encountered in the selection of a heat exchanger or when the exchanger is to be run at off design conditions. Although the outlet temperature and heat flow rates can still be found with the help of the charts yet it would be possible only through a tedious trial and error procedure. In such cases, it is preferable to utilize an altogether different method known as the Effectiveness-NTU method.

$$\mathbf{NTU = \frac{UA}{C_{min}}}$$

$$\mathbf{Effectiveness\ (\varepsilon) = 1\text{-}exp\left[\frac{exp(-N\times C\times n)-1}{C\times n}\right]}$$

$$\mathbf{\left[N = NTU, C = \frac{C_{min}}{C_{max}}, n = N^{-0.22}\right]}$$

$$\mathbf{Heat\ transfer\ rate\ (\dot{Q}) = \varepsilon C_{min} (T_{h,i} - T_{c,i})}$$

$$\mathbf{T_{h,o} = T_{h,i} - \frac{\dot{Q}}{C_{min}}}$$

$$\mathbf{T_{c,o} = \frac{\dot{Q}}{C_{max}} + T_{c,i}}$$

$$\mathbf{Power{=}(\Delta P + \frac{\rho v_1^2}{2} + \rho g \Delta h) Q_L}$$

## IV. COST ANALYSIS

Cost analysis was done by the comparison of conventional Air Conditioning system with the geothermal air cooling system and geothermal water cooling system. Split 1.5 Ton, 5star, cooling capacity 5000 W of Air conditioner system was considered to compare with the obtained results. The coefficient of performance (COP) of given air-conditioning system is taken as 3. Power consumption of given Air Conditioning system is calculated from the Energy Efficiency Ratio (EER). Each air conditioner has an energy efficiency rating that lists how many BTU's per hour are used for each watt of power it draws.

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For room air conditioners , this rating is the Energy Efficiency Ratio or EER. For central air conditioners, this rating is the Seasonal Energy Efficiency Ratio or SEER.

These ratings are posted on an Energy Guide Label, which must be attached in a visible place on all new air conditioners. Many AC manufacturers are voluntary participants in the Energy Star labeling program. Energy Star labeled appliances indicate that high EER and SEER ratings.

$$\textbf{Power Consumption} = \frac{\textbf{Cooling Capacity of AC}}{\textbf{EER}}$$

$$\textbf{HRR} = \textbf{COP} \times \textbf{Power Consumption}$$

**Table 3. Cost and HRR of three different systems**

| Type of System | Cost of System (Rs.) | Operating cost per month (Rs.) | HRR (kW) |
|---|---|---|---|
| **Air Conditioner ( 1.5 Ton)** | 45,000-50,000 | 1,768 | 4.26 |
| **GACS** | 40,000 | 1,435 | 1.02 |
| **GWCS** | 45,000 | 732 | 1.46 |

In a thermodynamically closed system, any power dissipated into the system that is being maintained at a set temperature (which is a standard mode of operation for modern air conditioners) requires that the rate of energy removal by the air conditioner increase. This increase has the effect that, for each unit of energy input into the system. The air conditioner removes that energy. To do so, the air conditioner must increase its power consumption by the inverse of its efficiency (COP) times the amount of power dissipated into the system. As an example, assume that inside the closed system a 100 W heating element is activated, and the air conditioner has a coefficient of performance of 200 %. The air-conditioner's power consumption will increase by 50 W to compensate for this, thus making the 100 W heating element cost a total of 150 W of power.

It is typical for air conditioners to operate at efficiencies of significantly greater than 100%. However, it may be noted that the input electrical energy is of higher thermodynamic quality (lower entropy) than the output thermal energy (heat energy).

## V. RESULTS AND DISCUSSION

The monthly average ground temperature has been shown in Fig.3 from the figure it is clear that, at a optimized depth of 8m the ground temperature is equal to 27$^0$C which is the annual average temperature of the place. It can be observed from the Fig.4 that, as the depth increases the temperature fluctuations decreases and nearly approaches to a constant value. Fig.5 depicts the variation of outlet air temperature of the UHE along the length of the UHE for four different number of air changes namely N=5, N=6, N=7and N=8 at 0.08 m pipe diameter. It can be inferred from the figure that, for larger pipes the outlet air temperature approaches to constant ground temperature. For the average ambient temperature of 35$^0$C in summer, The outlet temperatures of UHE is 31.1$^0$C and 29.5$^0$C respectively, the length of the UHE corresponding to these outlet air temperatures were 5 m and 10 m for 5 number of air changes.

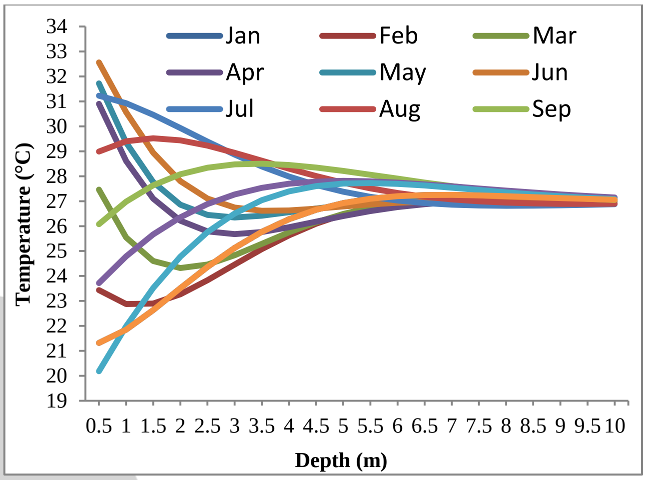

**Fig.3 Ground temperatures at different depth**

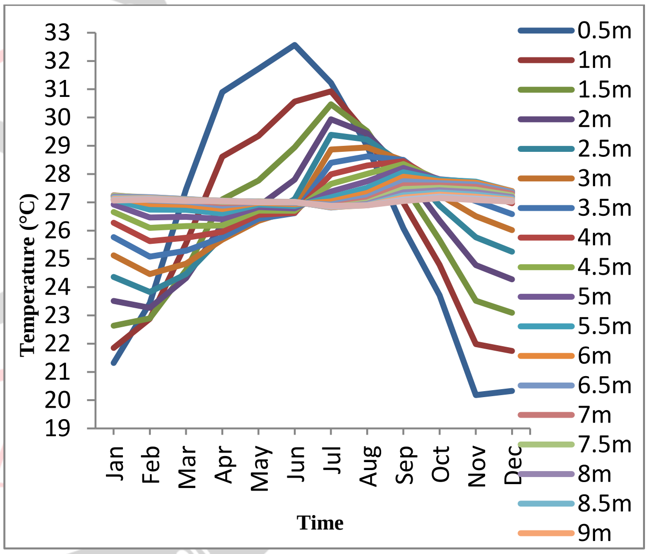

**Fig.4 Monthly ground temperature variation different depths**

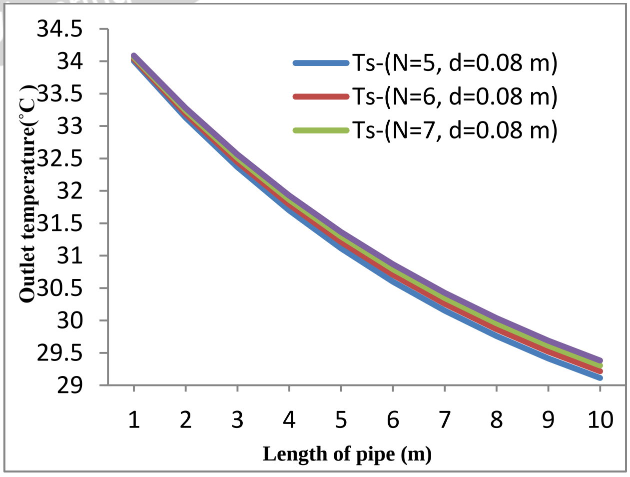

**Fig.5 Variation of outlet air temperature with length for different pipe diameters**

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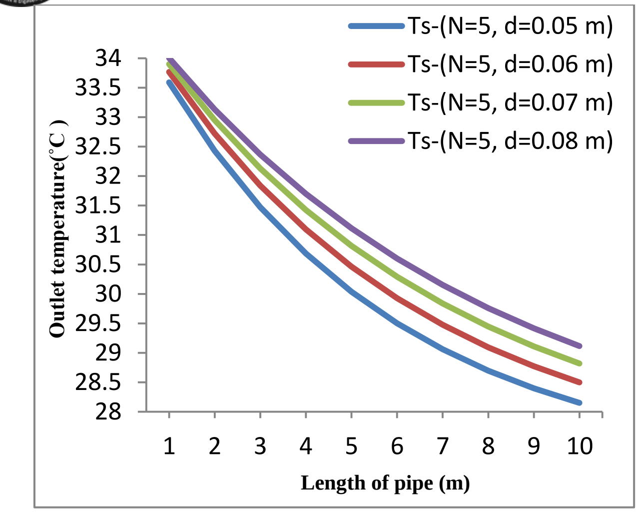

**Fig.6 Variation of outlet air temperature with length for pipe diameter 0.08m at different number of air changes.**

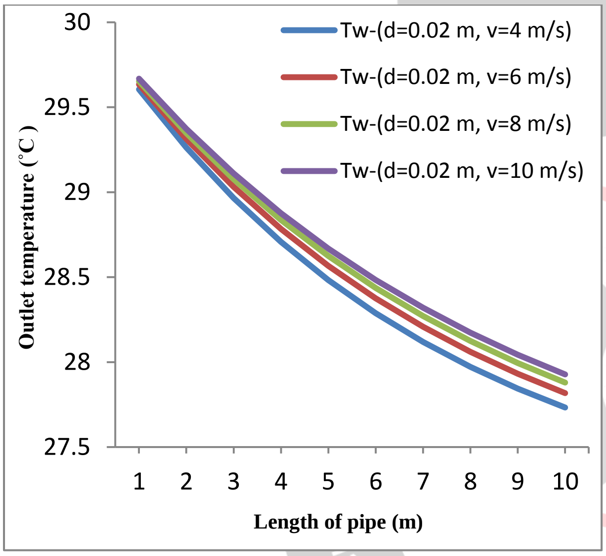

**Fig.7 Variation of outlet water temperature with length for pipe diameter 0.02m for different velocities.**

The variation of outlet air temperature of UHE for 5 number of air changes and four different diameters (0.05 m, 0.06 m, 0.07 m and 0.08 m) of pipe in summer has been shown in Fig.6 from the figure one can see that as the diameter of the pipe increases, the optimized length for the desired outlet air temperature from the UHE increases. Because the diameter of the pipe increases the volume of air to be cooled increases and hence optimized length increases. The outlet temperatures of water at UHE for four different velocities (4, 6, 8,10 m/s) and 0.02 m diameter as shown in Fig.7 If the velocity of water increases the outlet temperature of water increases so at low velocities of water optimum temperatures are obtained.

## VI. CONCLUSION

The ground temperatures at different depths are calculated for monthly average temperature cycle. The depth between 8-10 m temperature remains constant throughout the year which is approximately equal to the 27°C. The heat transfer and cost analysis has been done.

The outlet temperatures of air and water cooling systems are obtained as 30.5°C and 29.7°C. From the observation of graphs the GWCS will give better cooling temperatures when compared to GACS.

In a geothermal air and water cooling systems blower and pump are a power consumption devices. For operating of blower and pump, 1.25 kW and 0.83 kW of power was consumed. Operating cost per month for GACS is Rs.1,435 and GWCS is Rs. 732. Total cost of water cooling system is around 10.37% more than the air cooling system. The heat removal rates are 1.02 and 1.46 kW for air and water cooling systems. These results are compared with the conventional split 1.5 ton air conditioning system. The power required to run the geothermal systems are much lesser than conventional AC systems. Heat removal rates for UHE systems are less compared to conventional AC system. Better heat transfer mechanisms are needed to increase HRR of UHE system.

## NOMENCLATURE

$T_{soil}$ = Temperature of soil at depth z
$T_m$ = Mean surface temperature (practically the average temperature of air in the place)°C
$T_a$ = Amplitude of surface temperature (Annual amplitude of the monthly average Temperature cycle in the place) °C
z = Depth below the surface (m)
$\alpha$ = Thermal diffusivity of the soil ($m^2/s$)
$t_{year}$ = Current time (day)
$t_{shift}$ = Day of the year of the minimum surface Temperature
Q = Volume flow rate of air ($m^3/s$)
$\dot{m}_a$ = Mass flow rate of air (kg/s)
$C_a$ = Specific Heat of air (J/kg K)
$T_g$ = Ground temperature outside of the pipe (°C)
$T_{ai}$ = Inlet temperature of air at UHE (°C)
$T_{ao}$ = Outlet temperature of air at UHE(°C)
$h_c$ = Convective heat transfer coefficient from inner surface pipe to the air ($W/m^2K$)
r = Radius of pipe (m)
L = Length of pipe (m)
f = Friction coefficient
v = Velocity of air (m/s)
NTU = Number of transfer units
$T_{h,i}$ = Inlet temperature of air(°C)
$T_{c,i}$ = Inlet temperature of water(°C)
$T_{h,o}$ = Outlet temperature of air(°C)
U = Overall heat transfer coefficient ($W/m^2K$)
$v_1$ = Velocity of water (m/s)

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$\Delta h$ =Vertical height difference between water intake level and discharge pipe exit (m)

$Q_L$ = Liquid flow rate ($m^3/s$)

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