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A CRITICAL ANALYSIS OF DESIGN OF EARTH AIR TUNNEL HEAT EXCHANGER

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ABSTRACT

The earth air tunnel heat exchanger is an interesting subject of passive heating or passive cooling techniques. With the help of earth to air heat exchanger preheating or precooling can be done of ventilating air or outlet air depending upon weather session. Many researchers have been worked for the designing of earth air heat exchanger and developed a standard procedure for designing EATHE. Most of them are based on discretization of one dimensional, 2-dimensional and 3-dimensional calculation models. The methods available for designing of EATHE are highly complex and cannot directly used in real work problem. This paper represents simplified set of equations which can be directly used for preliminary design of EATHE which are recently being used. Using these equations the designer can enable to calculate heat transfer, convective heat transfer coefficient, pressure drop and length of tube of EAHE with desired effectiveness. A longer pipe with small size diameter having average air flow velocity gives better performance. The design analysis also manipulated by experimental investigations.

Keywords: Earth air Tunnel heat exchanger, Number of transfer units (NTU), Nusselt number (Nu), Friction factor (f) etc.

NOMENCLATURE

AFP = Air fan power	$C_{p,a}$ = Specific heat of air (J/Kg-K)
d = Depth of tube (m)	f = fluid flow friction factor
h_c= Convective heat transfer coefficient form air to tube wall (W/M^2-K)	
K_t = Thermal conductivity of tube (W/M-K)	K = Thermal conductivity of air (W/M-K)
L = Length of tune (m)	$\dot{m}$ = Mass flow rate of air (Kg/s)
NTU = Number of heat transfer unit	n = Number of parallel tube
Nu = Nusselt number	ΔP = Pressure loss (bar)
R_e = Reynolds number	r_i, r_o = inlet and outlet diameter of tube (m)

U_t = Overall heat transfer coefficient (W/M^2-K)v = velocity of air (m/s)

V = Total volume flow of air (m^3)ϵ= Effectiveness of EATHE system

ρ = density of air (Kg/m^3)

μ = Dynamic viscosity (N-s/m^2)

I. INTRODUCTION

Thermal comfort is required to provide good quality of air at desired place but environment is a great concern. So everyone is looking towards green energy. Passive heating or passive cooling systems are known for their advantages of consuming no or very less active energy. Earth to air heat exchanger is one of the most important passive system it provides both heating effect in winter and cooling effect in summer. Here earth acts as both source and sink. At sufficient depth up to 3-4 m the ground temperature is nearly constant; this is around mean annual average air temperature of that region at particular location (longitude and latitude). When ambient air is drawn through buried tube at certain depth in the ground the outlet air temperature is reduced in summer and enhanced in winter by heat transfer between air and grounded soil.

There are two types of EATHE system (1) open loop system in which ambient air is drawn and sent it to Specified location after heat exchanging process (2) close loop system in which room air is recirculating for heat exchanging process. There are different parameters which affect the design and performance of the EATHE system (1) design parameter (tube depth, length of tube, diameter of tube, flow velocity of air, tube material etc.) (2) Climate condition (relative humidity, ambient air temperature, undisturbed soil temperature, etc.) (3) Soil properties (thermal diffusivity, thermal capacity etc.). (4) Convective heat transfer coefficient. Heat transfer between soil and air also depends on surface area of tube and affected by thermal resistance of tube diameter.

In recent years, a lot of researches have been conducted to develop an analytical and numerical analysis of EATHE system; Mihalakakou et al. (1994), Bojic et al. (1997), Gauthier et al. (1997), Hollmuller et al. (2001), Lee et al. (2000) Su et al. (2012), Sehli et al. (2012), Ozgener et al. (2013) etc. mostly them are limited to space constraints and economic boundary conditions. They lead to complex calculation part which is not regard able for common use. For general use the simplified design equations are needed. However for modeling of EATHE EnergyPlus and TRNSYS computer techniques are available but these techniques are time consuming and far greater from common use. Presently, computational Fluid Dynamics (CFD) is most popular technique for analyzing of performance and modeling of EATHE system. In this paper we extended our work using Tzaferis et al. (1992), Paepe et al. (2003), Badescu et al. (2011), Bisoniya et al. (2013) analysis. We include most recently developed correlation to find effective length of tube, tube diameter, pressure drop and effectiveness of EATHE system. The simple EATHE diagram is shown in Fig.1.

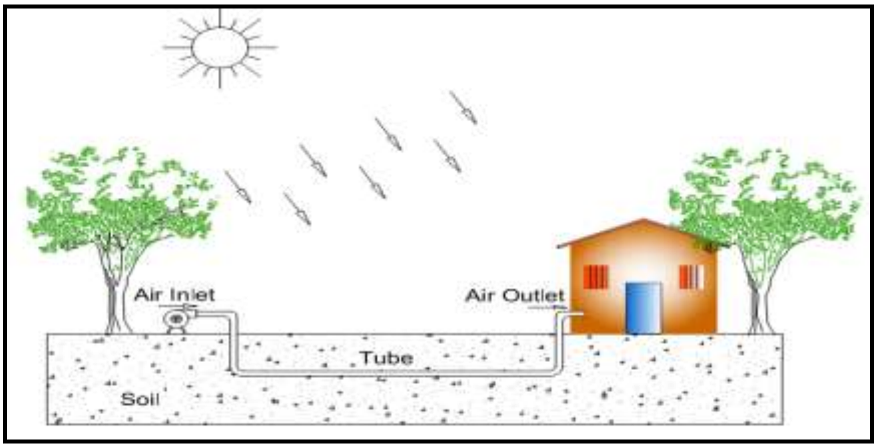

Fig: 1. Modal ofearth air tunnel heat exchanger system

II. MODELING OF DESIGN PARAMETER

Preliminary design of EATHE use basic heat transfer and fluid flow equations. The design parameters of EATHE are selected according to space conditioning. The mass flow rate and outlet temperature of ventilating air, which are the sizing parameters are the fixed for a specified requirement. Now input parameter and variables are required to identify which affect the effectiveness of EATHE system.

The inlet air temperature and ground temperature vary with climate condition. The soil temperature at a depth of 3-4 meter is estimated as mean annual average temperature at particular location. Once the design output is fixed then we directly relate our governing equations to estimate length of tube, pressure drop across one particular tube and effectiveness.

III. DIMENSIONS OF EATHE

The geometric parameters of an EATHE include the tube diameter (D), Tube length (L) and number of tubes in parallel (n) in the heat exchanger. First we select arbitrary size (D) of tube and then with the help of known mass flow rate the number of parallel tube are calculated. We have to select optimum combination of size and number of tubes to meet EATHE performance. For a tube diameter (D), air density (ρ) air flow velocity (v) and number of parallel tubes (n); the mass flow rate of air through a tube, $\dot{m}$ is given by:

$$\dot{m} = \frac{\frac{\pi}{4}D^2\rho v}{n} \qquad (1)$$

These parameters are selected in such a way that the boundary conditions and the EATHE performance are met.

IV. EARTH GROUND TEMPERATURE

Earth surface temperature varies with climate condition at particular location and also varies from morning to evening. After selecting the location, fluctuation in ground temperature can be reduced by increasing depth. At 3-4 m depth of ground temperature is nearly constant which is called earth un-disturbed temperature. The temperature at depth z and time t can be calculated for homogeneous soil of constant thermal diffusivity.

$$T_{z,t} = T_m - Ae^{\left[-z\left(\frac{\pi}{365\alpha}\right)^{\frac{1}{2}}\right]}\cos\left[\frac{2\pi}{365}\left\{t - t_0 - \frac{z}{2}\left(\frac{365}{\pi\alpha}\right)^{\frac{1}{2}}\right\}\right] \quad (2)$$

Where $T_{z,t}$is the ground temperature at time t (s) and depth z (m), T_m is the average soil surface temperature (°C), A is the amplitude, α is the soil thermal diffusivity (m^2/s), t is the time elapsed from beginning of the calendar year (day) and t_o is the phase constant of soil surface (s). Generally earth ground temperature (EUT) is taken as mean annual average air temperature at specified location.

V. ASSUMPTIONS

To simplify the design equations following assumptions are made.

- Temperature of surrounding soil of tube is constant (uniform temperature in axial direction)
- Earth ground temperature (EUT) is constant along the length of tube.
- Turbulent flow of air throughout the tube so that entrance length is small in the small size tube.
- The surface temperature of the ground is taken as ambient air temperature, which is equal to inlet air temperature.
- Thermal resistance of pipe is negligible.
- The temperature on the surface of tube taken as uniform in axial direction and which is equal to earth's undisturbed temperature.
- Uniform cross-section of tube with smooth surface at inner side.
- Thermo-physical properties (density, viscosity, thermal conductivity and specific heat capacity etc.) of air and soil are constant.

VI. HEAT TRANSFER

If the output of EATHE system is fixed, inlet conditions are known then heat transfer can be calculated using log mean temperature difference (LMTD) or number of transfer units (NTU) or by calculating over all heat transfer coefficient. In this paper we used NTU method because of its simplicity.

In the earth air tunnel heat exchanger, air is the transportation medium. The heat is being released or absorbed by the air by heat transfer process between air and underground soil. Heat transfer between air and the tube wall by convection and from tube wall to the surrounding soil by conduction. If the contact of the tube wall with the earth is assumed to be perfect and the conductivity of the soil is taken to be very high compared to the surface resistance, then the wall temperature at the inside of the tube can be assumed to be constant.

The total heat transfer to the air flowing through a buried tube is given by:

$$Q_t = \dot{m}C_{p,a}\,(T_{out} - T_{in}) \quad (3)$$

Where ṁ is the mass flow rate of air (kg/s), $C_{p,a}$is the specific heat of air (J/kg-K), T_{out} is the temperature of air at outlet of EATHE tube (°C), and T_{in} is the temperature of air at inlet of EATHE tube(°C).

Due to convection between tube wall and the air, the heat transfer can also be given by:

$$Q_t = h_c A \Delta Tlm \quad (4)$$

Where h_c; the convective heat transfer coefficient from inner side to outer side of tube and A is the internal surface area of the tube.

Over all heat transfer coefficient per unit length from air to soil is given as:

$$U_t = \left(\frac{1}{h_c} + \frac{1}{2\pi k_t}\log\frac{r_0}{r_i}\right)^{-1} \quad (5)$$

$$Q_t = U_t A \Delta Tlm \quad (6)$$

Where k_t ; the thermal conductivity of tube, r_0 is the outer radius of tube, r_i is the inner radius of tube. In this equation we assume that thermal resistance of tube is negligible. $h_c$can be calculated with the help of Nusselt number.

$$h_c = \frac{NuK}{D}$$

Where K; the thermal conductivity of air, N_u is Nusselt number and D is the hydraulic diameter of cross section. The value of Nusselt number is given by:

$$N_u = \frac{f/8(R_e - 1000)P_r}{1 + 12.7\sqrt{f/8}\left(P_r^{2/3} - 1\right)} \text{ for turbulent flow} R_e > 2300 \quad (7)$$

$$N_u = 3.66 \qquad \text{for laminar flow} R_e < 2300 \quad (8)$$

Where R_e; the Reynolds number, P_r is Prandtl number, and f is the friction factor for smooth surface.

$$f = (1.82 \log R_e - 1.64)^{-2} \qquad 2300 \le R_e < 5 \times 10^6 \text{ and } 0.5 < P_r < 10^6$$

The Reynolds number is calculated using the average air flow velocity (v) and diameter of tube (D):

$$R_e = \frac{\rho v D}{\mu}$$

The Prandtl number is defined as: $P_r = \frac{\mu C_p}{K}$ where c_p is the specific heat of air.

Once h_c or $U_t$is calculated the outlet air temperature of EATHE system can be estimated as a function of tube wall temperature and inlet air temperature using equation (3) and (4)

$$T_{out} = T_{wall} + (T_{in} - T_{wall})e^{-(hA/\dot{m}c_{p,a})} \quad (9)$$

And using equation (1) and (3)

$$T_{out} = T_{wall} + (T_{in} - T_{wall})e^{-(U_tA/\dot{m}c_{p,a})} \quad (10)$$

Non dimensional heat transfer unit (NTU) is defined as:

$$NTU = \frac{h_c A}{\dot{m}c_{p,a}} = U_t A/\dot{m}C_{p,a} \quad (11)$$

Here area is defined A $=2\pi r_i l$.

The effectiveness of EATHE system is defined as:

$$\epsilon = \frac{(T_{out} - T_{in})}{(T_{wall} - T_{in})} = 1 - e^{-NTU} \quad (12)$$

VII. DESIGN EQUATIONS

Development of design equations are derived from above relations. For estimating the length of tube and pressure drop across the tube we are known to the value of total volume flow rate, size of tube, depth at which tubes are placed and number of parallel tubes.

Pressure drop across the can be estimated without considering tube bend effect.

$\Delta P = \rho f \frac{v^2}{4r_i} L$ (13)

Where $f = \frac{64}{R_e}$ if $R_e < 2300;$

And $f = (1.82 \, log R_e - 1.64)^{-2}$ if $R_e > 2300$

Now air fan power (AFP) is given as follow for total pressure drop (ΔP) and total volume flow rate of air (V).

AFP = $V\Delta P$ (14)

The value of NTU as follow:

$NTU = -\ln(1-\epsilon)$ (15)

Now the required length of tube for derived value of NTU using relation.

L = $\frac{\dot{m} C_{p,a} NTU}{h_c}$ (16)

Both *NTU* and *ΔP* are proportional to the length of the tube and we can use NTU/L and ΔP/L as the main performance characteristics to determine the desired length of tube for specified effectiveness.

VIII. HX Design Sheet (Mathematical Analysis)

In the HX design sheet the effectiveness of EATHE is fixed according to set of input parameter and fixed output parameter. With the help of input of tube size (D), inlet temperature, volume flow rate (V), number of parallel tube (n), mean annual average air temperature and fixed output temperature the value of NTU is estimated. For the determining of length of tube for a desired NTU parameter we used design calculations. The mean temperature input in Celsius and selected PVC material of tube having thermal conductivity (k_t) equal to 0.19 *W/MK*. We select surface roughness ϵ for different tube material using ASHRAE STANDARD 2009. The main output of design sheet is length of tube (m), pressure drop across the tube, NTU, U_t, h_c and effectiveness.

$\frac{m}{\rho} = Q0.0945 \ m^3$/sec, Diameter of Tube (D) = 0.10 m, Dynamic Viscosity of air (μ) = 1.804E-05 (kg/m-s);

TABLE: 1. Different design parameters with varying flow velocities

PARAMETERS	V_a= 3 m/sec	V_a= 4m/sec	V_a= 5m/sec
Re	20371.39	27,161.85	33,952.316
Pr	0.715	0.715	0.715
F	0.0255	0.0241	0.02291
Nu	52.63	65.49	76.51
h_c	13.3	16.571	19.359

NTU	2.16	2.699	3.153
ϵ	0.884	0.932	0.957
L (m)	18.89	18.83	18.82
ΔP (pa)	2.65	4.44	6.6

TABLE: 2.Thermo-physical properties of materials used in calculations

Parameter	Material		
	Air	Soil	PVC
Density (kg m^{-3})	1.225	2050	1380
Specific heat capacity (J kg^{-1} K^{-1})	1006	1840	900
Thermal conductivity (W m^{-1} K^{-1})	0.0242	0.52	0.19

IX. CONCLUSION

The earth air tunnel heat exchanger system (EATHEs) can be significantly used in passive heating/cooling depend upon weather season. The result observed from design calculations show that increase in flow velocity can be directly relate increase in effectiveness, But from literature review it can be said that this happen up to a limit. Bisoniya et al. (2013) reveal that effectiveness is constant when NTU exceed the value 4. From experimental investigations it is observed that velocity affect the effectiveness of EATHEs a little. Ideal design calculations show higher values of effectiveness than the experimental calculations, variation in effectiveness due to real problem analysis because in design analysis we had taken assumptions.

By using design equations we calculated different design parameters. With the optimized value of diameter of pipe and volume flow rate selected after studying different research paper, the value of Reynold's number, Nusselt number, friction factor, length of pipe and pressure drop is calculated. The effectiveness is calculated which 88.4 %, 93.2 % and 95.7 % is for flow velocities 3 m/s, 4 m/s and 5 m/s respectively. Increasing the flow velocity increases turbulence means Reynold's number so heat transfer increases. It is also observed that as NTU is increases the effectiveness is also increases. The same results were observed by Paepe et al. (2003) and Bisoniya et al. (2013).

REFERENCES

[1] V. Badescu, D. Isvoranu"Pneumatic and thermal design procedure and analysis of earth-to-air heat exchangers of registry type". Applied Energy (2011) 88:1266–1280.

[2] M. De Paepe, A Janssens,"Thermo-hydraulic design of earth-air heat exchangers". Energy Build (2003) 35:389–397

[3] O. Ozgener, L. Ozgener, “A practical approach to predict soil temperature variations for geothermal (ground) heat exchangers applications”. Int J Heat Mass Transfer (2013) 62: 473–480.

[4] C. Gauthier, M. Lacroix, H. Bernier, “Numerical simulation of soil heat exchanger storage system for greenhouse”. Sol Energy (1997) 60(6):333–346

[5] T.S. Bisoniya, A Kumar, P Baredar, “Experimental and analytical studies of earth–air heat exchanger (EAHE) systems in India: a review”. Renew Sustain Energy Rev (2011)19:238–246.

[6] T.S. Bisoniya, A Kumar, P Baredar, “Energy metrics of earth–air heat exchanger system for hot and dry climatic conditions of India”. Energy Build (2015) 86:214–221.

[7] R. T. Muehleisen, “simple design tools for earth-air heat exchangers”.Conference paper (2012).

[8] V. Bansal, R. Misra, G.D. Agrawal, “Performance evaluation and economic analysis of integrated earth–air–tunnel heat exchanger–evaporative cooling system”. Energy and Buildings (2012) 55: 102-108.

[9] V. Bansal, R. Misra, G.D. Agrawal,”Performance analysis of earth–pipe–air heat exchanger for winter heating” Energy and Buildings (2009) 41:1151-1154.

[10] K. H. Lee, R.K. Strand, “The cooling and heating potential of an earth tube system in buildings” Energy and Buildings (2008) 40: 486-494.

[11] H. Bulut, y. Demirtaş, R. Karadağ and l. Hilali,“ID 57 - Experimental Analysis of an Earth Tube Ventilation System under Hot and Dry Climatic Conditions” (2015).

[12] T. S. Bisoniya, “Design of earth–air heat exchanger system”Geothermal Energy (2015).