Design of Earth Tube Heat Exchanger

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Abstract - *Now a day we all are aware of the increasing price of electricity. So, everyone is moving towards sustainable living. In this case, Earth Tube Heat Exchanger is the best choice for the HVAC facility. In residential buildings more than 40% of the electricity required for heating and cooling purpose. To reduce the burden on the active system we have moved towards a renewable source of energy. Earth Tube Heat Exchanger works the basic principles of a heat transfer and uses geothermal energy as a source of energy. This project presents the results of theoretical calculation and computer simulations (analysis) of Earth Tube Heat Exchanger. By this system, we can achieve full and partial HVAC facilities in the living area. Analysis of the system is done by using solid works. NTU method is used to calculate the length of ETHE and the effect of the velocity on the effectiveness of the ETHE. The experimental setup consisted of a 21 m long aluminium tube buried at a depth 3.5 m and having a diameter of 0.15 m. A 250 W blower is used for transporting the air in an open-loop system.*

Key Words: **Geothermal energy, NTU, Effectiveness of ETHE.**

1. INTRODUCTION

Worldwide, it is estimated that the residential buildings, offices, and stores consume around 40% of our energy and 70% of our electricity. Heating and cooling for residential, commercial, and industrial purposes account for a large share of total final energy demand. To lessen the burden on the active systems transforming renewable energy into the thermal or electrical energy, a necessary first step is to apply the optimal combination of passive design strategies, foremost among them passive solar design strategies. Geothermal energy is considered a renewable source of energy (never-ending source of energy).

Traditional heating and cooling system required compressor, condenser, and evaporator setup. While Earth tube heat exchanger is an underground heat exchanger that can capture heat from the ground for heating purposes and dissipate heat to the ground for cooling purposes. Earth tube heat exchanger is a creative way to use the geothermal energy to our advantage, both for heating and cooling inside the living area. Earth tube heat exchanger required blower to move the air throughout the setup of the ground loop heat exchanger. Heat is extracted from or rejected to the ground through a buried pipe, through fluid flow. This simple setup helps in reducing cost, electricity consumption for the system. This system eliminates the compressor, condenser, and evaporator cost by simply using geothermal energy.

2. DESIGN PARAMETERS

The following parameters are very important in designing of ETHE.

1. Tube Material: While selecting the tube material for ETHE we have to consider given properties like strength, corrosion resistance, durability, and cost of the material.
2. Tube Length:
Heat transfer depends on the surface area.
The surface area of a pipe depends on: a) Diameter.
b) Length
So, the increased length would mean increased heat transfer rate and hence higher efficiency. After, a certain length no significant heat transfer occurs. Hence optimize length. Increasing length also results in a pressure drop. Hence increase fan energy.
3. Tube Diameter:
Smaller diameter gives better thermal performance but results in larger pressure drops increased diameter results in a reduction in air speed and heat transfer.
4. Tube Depth: Ground temperature affected by the:
a) External climate.
b) Soil Composition.
c) Water Content.
d) Thermal Properties.

The ground temperature fluctuates in time, but the amplitude of fluctuation diminished with depth. Burying pipe/tubes as deep as possible would be ideal. Generally, 4-5m below the earth's surface dampens the oscillation significantly.

3. OBJECTIVE

Earth tube heat exchanger is a creative way to use the geothermal energy to our advantage, both for heating and cooling inside the living area. The main objective of this project is mention below:

1. To find an alternative solution for active heating and cooling system like air conditioning, heater.
2. Taking advantage of the encircling environment and ground temperature.
3. Moving towards a renewable source of energy.
4. Addressing technology that is more environments friendly.
5. Reducing energy consumption by heating and cooling system.

This project will help you to design geothermal energy-based heating and cooling system. In this project, we explained about important parameters while designing ETHE.

4. TUBE MATERIAL SELECTION

The tube is the main element of ETHE. There are certain properties we have to take into consideration while finalizing the tube material. Tube material must have good thermal conductivity, strength, corrosion resistance, durability, and the cost of the tube material.

1. Copper has a thermal conductivity of 385 W/mk.
2. Aluminium has a thermal conductivity of **205 W/mk.**
3. Brass has a thermal conductivity of 109W/mk.
4. Iron has a thermal conductivity of 79.5 W/mk.
5. Steel has a thermal conductivity of 50.2 W/mk.
6. PVC has a thermal conductivity of 0.19 W/mk.

We take **aluminium as a tube material**. It has good thermal conductivity, better corrosion resistance, and cheaper in cost.

5. DESIGN CALCULATION

Here is a list of formulas we consider while calculating the length of earth tube heat exchanger, and efficiency of the earth tube heat exchanger at a different velocity.

1. Mass flow rate

$$m = (v \times \rho \times \pi \times D_i^2)/4$$

2. Reynolds number

$$Re = \frac{\rho v D_i}{\mu}$$

3. Prandtl number

$$Pr = \frac{\mu C_p}{K_a}$$

4. Nusselt number

$$Nu_D = \frac{(f/8)(Re_D - 1000)Pr}{1 + 12.7(f/8)^{1/2}\left(Pr^{2/3} - 1\right)}$$

$$f = (0.79 \ln(Re_D) - 1.64)^{-2}$$

5. Convective heat transfers Co-efficient per unit length

$$h = \frac{Nu\, k_{air}}{D_o}$$

6. Overall heat transfer coefficient

$$U_t = \left(\frac{1}{h_c} + \frac{1}{2\pi k_t}\ln\frac{r_o}{r_i}\right)^{-1}$$

7. Effectiveness

$$\epsilon = \frac{T_{air,out} - T_{air,in}}{T_{wall} - T_{air,in}} \qquad \epsilon = 1 - e^{-NTU}.$$

8. NTU

$$NTU = \frac{U_t A}{m_a C_p} = \frac{U_t \pi D_i L}{m_a C_p} \qquad NTU = -\ln(1-\epsilon).$$

9. Amount of heat transfer

$$Q = m\, C_p\, (T_{out} - T_{in})$$

10. Coefficient of performance

$$COP = m\, C_p\, (T_{out} - T_{in}) / \text{Power input}$$

By using above these formulas, we found out the length of ETHE. Calculation results are given below.

Table – 1. INPUT PARAMETERS

No.	Input Parameters	Symbols	Value	Unit
1.	Inlet Temp.	T_{in}	40	°C
2.	Length of Tube	L	35	°C
3.	Pipe wall Temp. (below 5ft)	T_{wall}	25	°C
4.	Thermal conductivity of the Air	k_{air}	0.0266	W/mK
5.	Thermal conductivity of the Pipe	k_{pipe}	205	W/mK
6.	Thermal Capacity	C_p	1006	J/KgK
7.	Viscosity	μ	1.84×10^{-5}	N/ms
8.	Density of the Air	P	1.1465	Kg/m^3
9.	Velocity of the Air	v_{air}	1.5, 2, 3, 4	m/s
10.	Outer dia. of the Pipe	D_o	0.18	m
11.	Inner dia. Of the Pipe	D_i	0.15	m
12.	Outer radi. of the Pipe	R_o	0.09	m
13.	Inner radi. Of the Pipe	R_i	0.075	m

6. DIMENSTION AND COOLING CAPACITY OF AN EXPERIMENTAL SETUP

Length of an experimental setup = 3.048m Height of an experimental setup = 1.585m Breadth of an experimental setup = 1.128m

There are two methods to calculate cooling capacity (By reference of living area).

(1) Area Method
(2) Volume Method We used volume method.

Cooling capacity = (10feet) X (5.2feet) X (3.7feet)/1000
= 0.1924 ton

7. LENGTH OF EARTH TUBE HEAT EXCHANGER

We are calculating the length of the earth tube heat exchanger for that we are considering a minimum temperature drop is equal to 10°C. All the input parameters are mentioned in the above table.

1. Mass flow rate (m) = 0.0608 Kg/sec
2. Reynolds number (Re) =28039.4022
3. Prandtl number (Pr) =0.6959
4. Nusselt number (Nu) = 66.3627
5. Convective heat transfer coefficient per unit length (h) = 9.8069 W/m^2K
6. Overall heat transfer (U_t) = 9.7933

7. Effectiveness = 0.7 8. NTU = 1.2

9. Length of tube = 20.89 (Approx. 21m)

10°C temperature drop is achieved when the length of ETHE is equal to 21m. Now we have calculated the change in outlet temperature when the velocity of a fluid change from 1.5, 2, 3, 4m/sec, and COP of the system. The results are shown in the below table.

Table – 2. OUTLET TEMPERATURE, HEAT FLOW, COP AT DIFFERENT VELOCITY.

Velocity	1.5	2	3	4
m	0.030	0.0405	0.0608	0.081
Re	14019.7	18692.9	28039.4	37385.9
Pr	0.6959	0.6959	0.6959	0.6959
f	0.0287	0.0266	0.024	0.0224
Nu	38.3481	48.6212	66.3627	82.8448
h	5.7409	7.1851	9.8069	14.6911
U_t	5.7362	7.1778	9.7933	14.6605
NTU	1.9	1.721	1.5	1.032
€	0.85	0.8	0.7	0.6
T_{out}	27.25°	28°	29.5°	31°
Q (w)	384.795	488.916	642.230	733.374
Q (ton)	0.109	0.139	0.183	0.209
COP	1.5	1.9	2.5	2.9

8. SIMULATION

The 3D model has been developed in SOLIDWORKS flow simulation software, version-2018. After a creating 3D model. Analysis of the earth tube heat exchanger is done with SOLIDWORKS 2018 flow simulation software. It shows the flow of fluid and rate of heat transfer (heat transfer between soil and fluid) in ETHE. The fluid goes through basic set up of the wizard, adding lids on the inlet & outlet, assigning goals for the temperature drop, and viewing a few results. Heat transfer between soil to earth tubes to fluid is observed as shown in the above analytical model. A temperature drops of 20°C was observed by this simulation.

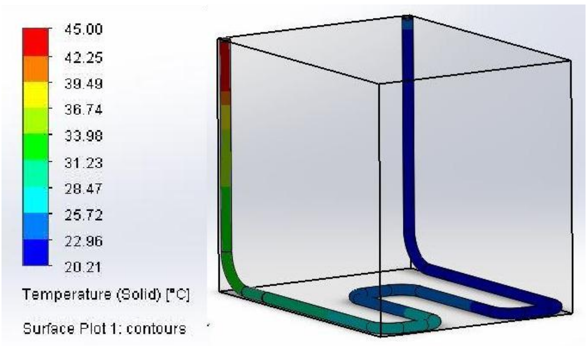

Figure 1. Shows the temperature of a fluid in ETHE.
(Convective heat transfers take place)

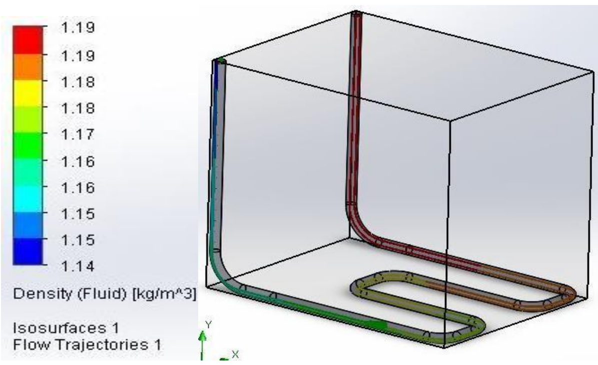

Figure 4. Shows a density of the fluid in each section of the pipe.

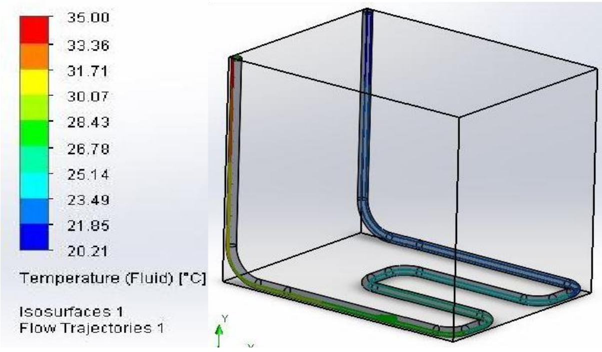

Figure 2. Shows the heat transfer between soil and aluminum tube
(Conductive heat transfers take place)

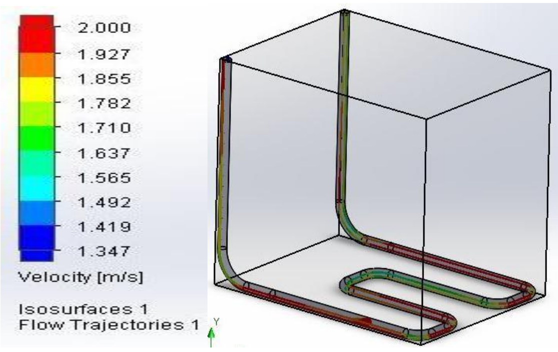

Figure 3. Shows a velocity of the fluid in each section in the pipe.

9. RESULT AND DISCUSSION

The results are summarized under the following points:

- The experimental setup consisted of a 21 m long Aluminium tube buried at a depth 3.5 m and having a diameter of 0.15 m. A 250 W blower is used for transporting the air in an open-loop system.
- 10°C temperature drop is considered to calculate the optimum length for ETHE.
- Theoretical calculations were carried out for different fluid velocity, which are 0.15m/sec, 2m/sec, 3m/sec, 4m/sec respectively.
- It has been observed that if the fluid velocity increases the heat transfer rate through the heat exchanger is decreases. With the minimum heat transfer rate, the temperature drop is also decreased compared to a low fluid velocity.
- But as an air velocity decreases pressure inside the heat exchanger also decreases. Therefore 2m/sec to 4m/sec is an appropriate range from air velocity.
- The tube material is one of the most important parameters while designing ETHE. We know that increased length would mean increased heat transfer rate. But after, a certain length no significant heat transfer occurs. So, the tube material will help to increase the heat transfer rate.
- Aluminium has high thermal conductivity and good corrosion resistance, because of this property better amount of heat transfer takes place through the heat exchanger. Therefore, we used aluminium as a tube material.
- COP of the system is also increased from 1.5 to 2.9. With increasing fluid velocity in the system from 1.5m/sec to 4m/sec.

10. CONCLUSIONS

In this paper design of Earth Tube Heat Exchanger (ETHE) and an analytical model is generated. The experimental setup consisted of a 21m long Aluminum tube with a diameter of 0.15m. NTU method is used for theoretical calculation.

The present work shows that air velocity is inversely proportional to the heat transfer rate. As velocity increases temperature drop decreases. 21m is calculated as an optimum length for ETHE. Lower air velocity gives better cooling and heating but optimum air velocity is required which is in a range of 2m/sec to 4m/sec.

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