The experimental and simulation study of an earth-air heat exchanger in Medan city

T U H S G Manik¹, T B Sitorus¹, M L Panjaitan¹ and Y O Saragih¹

¹Mechanical Engineering, Universitas Sumatera Utara, Medan - Indonesia

Email: dayatginting10@gmail.com

Abstract. The earth-air heat exchanger (EAHE) is an air-conditioning device utilizing a heat exchange between the air in the room and the soil. This paper purpose to determine the EAHE performance with experimentally and simulation. The simulation used are transient CFD, turbulent and 3-dimensional. The ambient air was distributed to the pipes with the different velocity of 2 m/s and 3 m/s. It was found that the earth-air heating exchanger effectiveness at air velocity 2 m/s for testing was 0.84 while for theoretical of 0.97. The coefficient of performance (COP) of EAHE increase from 1.341 to 1.761 when the increasing air velocity from 2 m/s to 3 m/s. The COP value also increases from 1.473 to 2.278 at the increasing of air velocity from 2 m/s to 3 m/s. The average of the COP value of the simulation result of the incoming air velocity was 1.99422 for velocity 3 m/s and 1.41426 for the velocity 2 m/s. For the average effectiveness of the simulation result obtained 1.00074 for the velocity of 3 m/s and 0.86100 for velocity 2 m/s.

1. Introduction
The development of the calculation model of Earth-Air Heat Exchanger (EAHE) use the fundamental equations of heat transfer [1]. This research use the one-dimensional model for the EAHE simulation. The ambient air temperature is determined using the effective formula of EAHE which is the function of Number Thermal Unit (NTU). The equation model used was developed by Bisoniya [2]. In an EAHE, the transport medium for heat is air. If the contact between the pipe wall and the earth is assumed to be perfect and the soil conductivity is very high compared to the surface resistance, so the inner wall pipe temperature can be considered constant [3, 4]. In this study, the type of flow used is a single stream type and used the relationship of evaporator heat exchanger or condenser in which one of the sides has a constant temperature in this case of the inner pipe wall. The effect of design parameters for NTU values can be investigated through heat transfer and pressure drop [5, 6]. The parameters of NTU value are convection heat transfer coefficient, cross-sectional area in pipe, mass flow rate. The air temperature at the outlet side pipe of the EAHE system can be determined in the form of an exponential function of the pipe wall temperature (Twall) and the inlet side temperature [7, 8].

\[
T_{out} = T_{wall} + (T_{in} - T_{wall})e^{-\frac{hA}{mCp}}
\]
The equation to determine the effectiveness of an EAHE [9, 10] is
\[
\varepsilon = \frac{T_{\text{in}} - T_{\text{out}}}{T_{\text{in}} - T_{\text{wall}}} = 1 - e^{-\frac{(hA/\dot{T})}{mC_p}}
\] (2)

The COP value of the EAHE device is determined from the equation [11, 12, 13]
\[
\text{COP} = \frac{Q_c}{P_f}
\] (3)

The amount of cooling capacity \(Q_c\) that occurs is [14]:
\[
Q_c = \dot{m} \cdot C_p (T_{\text{in}} - T_{\text{out}})
\] (4)

Where \(P_f\) is the power required to drive the blower on an earth-air heat exchanger.

2. Materials and Method

2.1. Materials

The EAHE is assembled using PVC diameter of 0.1016 m and a thickness of 3 mm. To circulate the air, a rotary blower is used for rotation using an inverter. The thermocouple is placed on both the inlet and the outlet side and at 4 points along the EAHE. As well as a thermocouple sensor is placed on the ground at a depth of 2 m. The object of the study is the ambient air that is circulated into the EAHE to be cooled.

2.2. Experimental Scheme

The testing process is carried out starting at 10.00 WIB in which the blower begins to circulate the air into an earth-air heat exchanger. The Cole-Parmer acquisition data will record the temperature at both the inlet and the outlet side as well as along the pipe of the EAHE. Soil temperatures were also recorded using Cole-Parmer acquisition data. Cole-Parmer acquisition data is associated with K-type thermocouples. Data acquisition works to record the temperature every minute, and it is saved in the data of the worksheet. To produce suitable inlet air velocity is used 3 phase electric motor inverter. Testing ends at 18:00 every day. Furthermore, the test will be done the next day at the same hour. The tests were conducted for two days consecutively in September 2017 in Medan city.

| Table 1. The specifications of an EAHE system used |
|---|---|---|
| No | Data | Information |
| 1 | Pipe diameter | \(d = 0.1016 \text{ m}\) |
| 2 | Pipe length | \(L = 26.5 \text{ m}\) |
| 3 | Depth of earth | \(Z = 2 \text{ m}\) |
| 4 | Media cooled | air |
| 5 | The number of blowers | 1 unit @ 2850 rpm |

Figure 1 shows the, and figure 2 shows the experimental scheme performed.
All of the dimensions of the earth-air heat exchanger has been measured 3D geometry images, PVC pipes can be made using SolidWorks 2014. The geometry that has been drawn can be seen in Figure 3.
The thermocouple is placed at four measurement points of temperature along the pipe and connected to the computer using data acquisition of Cole-Palmer 18200-40 consisted of 8 channels. Zones 1, 2, 3 and four are placed along horizontal pipes with a distance of 5 m between thermocouple. The zone 3 is set on the inlet side of the tube, and zone 4 on the outside of the tube, and two thermocouple points are placed at a ground depth of 2 m and at an altitude of 0.5 m above the soil surface to measure the ambient temperature. The results of the acquisition are displayed in the form of data and graphs using the Tracer-Daq software. Figure 4 shows process path of simulation.

![Figure 4. Process path of simulation](image)

3. Results and Discussions

3.1. Earth temperature and inlet air temperature

The experimental process is carried out in open locations which experience directly solar radiation. The method of measuring weather conditions is carried out over two days of testing. The measurement time range is done every minute. Table 2 shows the average state of the inlet air temperature during experiments.

| $V_{\text{air}}$ (m/s) | Statistics | $T_{\text{in}}$ (°C) |
|-------------------------|------------|---------------------|
| 3                       | Maximum    | 39.0                |
|                         | Minimum    | 29.3                |
|                         | Mean       | 34.9                |
| 2                       | Maximum    | 36.6                |
|                         | Minimum    | 29.7                |
|                         | Mean       | 32.7                |

The reason for sampling analysis on the clock is due to warming of the surrounding air because of solar radiation. The temperature on the pipe wall is assumed to be equal to the average temperature of the soil.
### Table 3. The soil temperature during experiments

| $V_{air}$ (m/s) | Statistics | $T_{soil}$ ($^{\circ}$C) |
|-----------------|------------|--------------------------|
| 3               | Maximum    | 27.6                     |
|                 | Minimum    | 25.2                     |
|                 | Mean       | 26.6                     |
| 2               | Maximum    | 27.7                     |
|                 | Minimum    | 25.9                     |
|                 | Mean       | 26.6                     |

#### 3.2. Inlet experimental temperature

To validate the equation model developed, experimental and theoretical data are compared in the table below to obtain an error value. The testing process is carried out on conditions in the open air precisely in the field of the Department of Mechanical Engineering, Universitas Sumatera Utara. In the test is used variation in air velocity of 2 m/s and 3 m/s. Below is shown theoretical and experimental $T_{out}$ comparison chart. Also, a graph of inlet air temperature in the earth-air heat exchanger is also shown. This is intended to show clearly the performance of the earth-air heat exchanger. Temperature is acquired every single one minute from 10.00 Am to 6.00 pm daily. Figure 5 shows the theoretical and experimental $T_{out}$ comparison for $V_{air} = 2$ m/s.

![Figure 5](image_url)

**Figure 5.** The output temperature for inlet air velocity of 2 m/s

Figure 6 shows the theoretical and experimental $T_{out}$ comparison for $V_{air} = 3$ m/s.
Figure 6. The output temperature for 3 m/s inlet air velocity

Table 4. The outlet experimental and theoretical temperature comparison

| $V_{\text{air}}$ | Statistics | $T_{\text{in}}$ (°C) | $T_{\text{out}}$ (°C) | % error |
|----------------|------------|----------------------|----------------------|---------|
|                |            | Experimental | Theoretical |                       |         |
| 2              | Mean       | 32.1          | 27.1          | 26.5              | 1.86%   |
| 3              | Mean       | 33.8          | 27.3          | 26.9              | 2.73%   |

Table 4 shows that the output average error temperature ($T_{\text{out}}$) given for the experimental model of the varied theoretical model between 1.86% to 2.73%. In which the average outlet air temperature of the heat exchanger increases with the increase of inlet air velocity of the earth-air heater exchanger. The average outlet temperature is experimentally higher than the outlet ideal average temperature.

3.3. Temperature contour analysis

The simulation results of the temperature contour can be seen the decrease in temperature of the first fluid coming along a pipe of the earth-air heat exchanger. The temperature contour distribution of the fluid flowing along the tube at a velocity of 3 m/s and 2 m/s can be seen in Figure 7 and 8.

3.3.1. Spreading temperature at 3 m/s

If viewed from pascal law, the pressure that fills a room should be evenly distributed and equal, however in some cases, and pressure may be uneven. For example, in the case of flow in the PVC pipe, the effect of the length and shape fluid flow presenting in the heat exchanger chamber may be reduced by the pressure and the temperature imposed on it can cause a decrease of pressure and temperature at some different point with the other points even in the same room. The temperature distribution of the fluid flowing along the pipe at a velocity of 3 m/s can be seen in figure 7.
Figure 7. The fluid contour analysis in a transmitter of EAHE rapidity 3 m/s

Figure 7 shows the reduced velocity of the fluid entering in the EAHE so that the longer air circulates with the cold pipe wall and a fluid which comes out more relaxed than the incoming fluid. Figure 8 shows a comparison between simulated $T_{\text{out}}$ and experimental $V_{\text{air}} = 3 \text{ m/s}$.

Figure 8. Experimental and simulation $T_{\text{out}}$ comparison ($V_{\text{air}} = 3 \text{ m/s}$)

3.3.2. Temperature spread at velocity 2 m/s
Temperature distribution at 2 m/s as shown in figure 9.
Figure 9. The fluid contour temperature analysis within a pipe of the earth-air heat exchanger of 2 m/s

Figure 10 shows a simulated and experimental $T_{\text{out}}$ comparison for $V_{\text{air}} = 2$ m/s

![Temperature Comparison Graph](image)

Figure 10. Experimental and simulation $T_{\text{out}}$ Comparison ($V_{\text{air}} = 2$ m/s)

From figure 8 and 10, we can take the average outlet temperature for both experimental and experimental simulation results as shown in table 5 and 6.

Table 5. The temperature comparison of experimental and simulation

| $V_{\text{air}}$ (m/s) | Statistics | $T_{\text{in}}$ ($^\circ$C) | $T_{\text{out}}$ ($^\circ$C) | $T_{\text{out}}$ ($^\circ$C) |
|------------------------|------------|---------------------|---------------------|---------------------|
|                        |            | $T_{\text{in}}$     | $T_{\text{out}}$     | $T_{\text{out}}$     |
|                        |            | Theoretical         | Experimental        | Simulation          |
| 3                      | Maximum    | 39.0                | 27.7                | 30.2                | 27.6                |
|                        | Minimum    | 29.3                | 26.6                | 26.6                | 25.2                |
|                        | Mean       | 34.9                | 26.9                | 27.5                | 26.6                |
| 2                      | Maximum    | 36.6                | 26.5                | 29.3                | 27.2                |
|                        | Minimum    | 29.7                | 27.7                | 26.4                | 26.0                |
|                        | Mean       | 32.7                | 26.5                | 27.4                | 26.5                |
3.4. The Effectiveness of EAHE

Table 6 shows that the EAHE effectiveness at velocity of inlet air of 3 m/s is higher among the inlet air velocity of 2 m/s.

| $V_{air}$ (m/s) | Statistics | Theoretical Effectiveness ($\varepsilon$) | Experimental Effectiveness ($\varepsilon$) | Range (%) |
|-----------------|------------|------------------------------------------|------------------------------------------|-----------|
| 2               | Maximum    | 0.97922                                  | 0.97917                                  | 0.0054%   |
|                 | Mean       | 0.97877                                  | 0.84424                                  | 13.7448%  |
| 3               | Maximum    | 0.97322                                  | 0.98245                                  | -0.9483%  |
|                 | Mean       | 0.97248                                  | 0.90967                                  | 6.4590%   |

The highest number of the effectiveness of EAHE was achieved at inlet air velocity of 3 m/s which is 0.98245. The velocity of inlet air influences the effectiveness of EAHE. This is evidenced based on the experiment that when the EAHE are given inlet air velocity ($V_{air}$) of 2 m/s, the effectiveness of heat exchanger is 0.84424. As the inlet air velocity increases to 3 m/s, the effectiveness rises to 0.909673. However, at inlet air velocity of 2 m/s gives the difference between experimental data with the calculation of 13, 7448%.

| $V_{air}$ (m/s) | Statistics | $T_{air}$ (°C) | Effectiveness ($\varepsilon$) | Range (%) |
|-----------------|------------|----------------|-----------------------------|-----------|
|                 |            | Experimental   | Simulation                  |           |
| 3               | Maximum    | 39.0           | 1.00000                     | 16.66700  |
|                 | Minimum    | 29.3           | 0.63380                     | 23.94400  |
|                 | Mean       | 34.9           | 0.90128                     | 9.94500   |
| 2               | Maximum    | 36.6           | 1.02571                     | 16.66700  |
|                 | Minimum    | 29.7           | 0.36364                     | 23.99400  |
|                 | Mean       | 32.7           | 0.87340                     | 9.99290   |

The effectiveness of the simulation results shows that the average number of the effectiveness of the EAHE increases because of increased inlet air velocity. The error rate between experimental and simulated effectiveness at inlet air velocity of 3 m/s is given at 9.945%, and a 2 m/s inlet air velocity is given 9.99%.

3.5. COP of The EAHE

Table 8 shows the COP of EAHE based on theoretical calculations, experimental tests and simulation results are:

| $V_{air}$ (m/s) | Statistics | Theoretical COP | Experimental COP | Simulation COP |
|-----------------|------------|-----------------|-----------------|---------------|
|                 |            | Theoretical COP | Experimental COP | Simulation COP |
| 2               | Maximum    | 2,641           | 2,454           | 2.45945       |
|                 | Mean       | 1,473           | 1,341           | 1.41426       |
| 3               | Maximum    | 4,024           | 2,748           | 2.72678       |
|                 | Mean       | 2,278           | 1,761           | 1.99422       |

The COP given from the theoretical results also show the same result as the experimental results. In which COP increases with increasing inlet airflow velocity from 2 m/s to 3 m/s. The inlet air velocity of 3m/s yields the highest average COP.
4. Conclusions
The performance of air-conditioner systems using EAHE in Medan city has been tested its performance comparing between experimental models and equations models which is previously developed by researchers. The benefits of this air-conditioner system completed this heat exchanger type is minimum and straightforward maintenance, energy and environmentally friendly. In the two-day test using inlet air velocity of an EAHE of 2 and 3 m/s obtained an average outlet temperature of 26.5°C and 26.9 °C. Maximum effectiveness were 0.97917 and 0.98245, and the average effectiveness were 0.84424 and 0.90967. The maximum COP is obtained respectively of 2.454 and 2.748. The simulation results are obtained outlet average temperature 26.6°C for air velocity of 3 m/s and 26.0°C for 2 m/s. The average COP of simulation at the inlet air velocities is 1.99422 for 3 m/s and 1.41426 for 2 m/s. The average effectiveness of simulation results is 1.0074 for the velocity of 3 m/s and 0.861 for the velocity of 2 m/s. The results show great potential for EAHE development as a solution to the building's passive cooling system in Medan city.

References
[1] Bulut, H., Demirtas, Y. 2014. Experimental analysis of an earth tube ventilation system under hot and dry climatic conditions. *Proceedings of the 12nd National Sanitary Engineering Congress*. Vol 2. 1789-1804.
[2] Bisoniya, T.S. 2015. Design of earth-air heat exchanger system. *Geothermal Energy*. Vol 3. 18-28
[3] Ariani F et al. 2017 IOP Conf. Ser.: Mater. Sci. Eng. 277 012045
[4] Sitorus T B et al. 2018 IOP Conf. Ser.: Mater. Sci. Eng. 309 012089
[5] Sitorus T B et al. 2016 TAE - Proceedings of 6th International Conference on Trends in Agricultural Engineering.
[6] Sitorus T B et al. 2016 International Journal of Technology 5: 910-922, ISSN 2086-9614.
[7] Sitorus T B et al. 2017 Journal of Engineering and Technological Sciences, Vol. 49, No. 5, 657-670.
[8] T.U.H.S. Ginting Manik et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 420 012026
[9] Pintoro A et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 308 012026
[10] Incropera, F.P., Dewitt, D.P. 2011. *Introduction to Heat Transfer*. Edisi ke 7,John Wiley & Sons, New York
[11] De Paepe,M., Janssens, A. 2003. Thermo-hydraulic design of earth air heat exchanger. *Energy Build*. Vol. 35. 389-397.
[12] T.B. Sitorus et al 2018 IOP Conf. Ser.: Mater. Sci. Eng. 420 012025
[13] Irvan et al. 2017 IOP Conf. Ser.: Mater. Sci. Eng. 206 012028.
[14] Arjuna J et al. 2018 IOP Conf. Ser.: Mater. Sci. Eng. 309 012088.