The simulation performance analysis of the EAHE open system with finned iron pipes

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Abstract. This study focuses on the Eart-Air Heat Exchanger (EAHE) which serves to reduce the energy consumption of air conditioning units, and analyze the thermal performance of air-ground heat exchangers using computational fluid dynamics modeling and validated against experimental observations. The simulation used is for flow-resisting, incompressible, turbulent, and 3-dimensional. Simulations were carried out using finned iron and PVC 3.0 "with a thickness of 2 mm and a length of 6.7 m. The simulation conditions were limited to the fluid flow with variations of the velocity of 1 m/s, 2 m/s, and 3 m/s. The average air temperature outlet from 3D simulation using Ansys 17.0 software was obtained 25.45 ^{o}C for the velocity of inlet air of 1 m/s, 25.73 ^{o}C for a velocity of 2 m/s, and 25.84^{o}C for the velocity of inlet air of 3 m/s. The experimental results obtained of 25.99 ^{o}C for a velocity of 1 m/s, 26.33 ^{o}C for a velocity of 2 m/s, and 26.0 ^{o}C for the velocity of inlet air of 3 m/s. The highest deviations between the simulation and experimental results were obtained at -3.04% for the velocity of 3 m/s, and the lowest deviation is -10.28% for the velocity of 1 m/s. The average of COP value of the simulation results is 0.703 for the velocity of 1 m/s, 0.624 for the velocity of 2 m/s, and 0.774 for the velocity of 3 m/s, while the experimental results are *obtained* 0.6307 for the velocity of 1 m/s, 0.5417 for the velocity of 2 m/s, and 0.7504 for the velocity of 3 m/s. For the average effectiveness value of the simulation results were obtained of 0.956 for the velocity of 1 m/s, 0.940 for the velocity of 2 m/s and 0.960 for the velocity of 3 m/s, while the experimental results were obtained of 0.8590 for the velocity of 1 m/s, 0.8164 for the velocity of 2 m/s, and 0.8970 for the velocity of 3 m/s.

1. Introduction

Alternative and renewable energy sources in the modern era have become topics that are often discussed or researched by the public and especially academics experts around the world. This is due to the depletion of fossil energy reserves contained in the bowels of the earth. It is also due to the side effects of fossil energy use, namely global warming [1, 2, 3].

As we know, global warming is an increase in the average temperature of the earth's surface, which causes the temperature warmer. Indonesia, as a tropical country, has two seasons, namely the rainy and the dry season. Temperatures in tropical countries are rather hot. Therefore, the Indonesians, especially those who work in the office, use air conditioning. Air conditioning (AC) requires a lot of electricity to operate and also one of the keys to global warming. Therefore, to replace the AC, the use of energy from the soil using the Earth Air Exchanger (EAHE) method. EAHE is the method of heat transfer from the soil layer [4, 5].

The pipeline will be planted in the soil, and then the air flows through the pipes with a blower. The transfer process takes effect, that is, the soil absorbs air to flow in the pipeline, so that the heat from the soil absorbs the airflow, and then the air temperature out of the pipes becomes lower.

2. Literature Study

The heat exchanger is a device that allows heat transfer between two fluids that have different temperatures without mixing the two fluids. Heat exchangers are usually used practically in the wide applications, such as in the case of heating and air conditioning systems, chemical and power generation processes. The heat exchanger is different from the mixing chamber i.e., and heat exchanger does not allow two fluids mixed [6, 7, 8]. For example, on a car radiator, heat is removed from the hot water flowing through a pipe found on a radiator which is added to a plate at a small distance by passing air between them.

The heat transfer is a science to predict the transfer of energy that occurs due to the temperature difference between materials [9, 10, 11]. The science of the heat transfer not only tried to explain how heat energy moves from one object to another, but also be able to predict the level of displacement that occurs under certain conditions . Solar energy radiation is a considerable force and has the potential to a large application so that it needs to support and exchange it to other forms of energy. The soil receives radiation from the sun on its surface and serves as a reservoir of solar energy. Because of the soil high thermal inertia, the amplitude of soil temperature fluctuations will decrease with increasing depth of soil [12, 13]. The total capacity of thermal energy from the soil has encouraged various studies to utilize the sold as heat recipients through the planted pipe system. In the planted pipe system, constant heat energy stored in the soil at a certain depth can be utilized by using a heat exchanger between the soil and air. By flowing air through a pipe planted, there will be heat exchange between the air flowing with the soil layer.

In the summer, warm air releases the heat contents into the wall of the pipe through convection then will be dissipated to the soil through conduction. The air comes out will be cooler than the air environment, can be used directly for cooling the chamber when the temperature is low. Alternatively, the outlet air can be cooled again using a refrigeration machine. Second, EAHE can reduce the cooling load and energy consumption [14 – 17].

The size of the Continuity Equation of the EAHE can be determined as follows:

$$\frac{\delta\rho}{\delta t} + \nabla \cdot \rho U = 0 = 0 \tag{1}$$

The value of NTU of EAHE can be determined [2]:.

$$\mathrm{NTU} = \frac{\mathrm{hA}}{\dot{\mathrm{m}}\mathrm{Cp}} \tag{2}$$

The value of the effectiveness of EAHE r can be determined from equation:

$$\varepsilon = \frac{\mathrm{T_{in}} - \mathrm{T_{out}}}{\mathrm{T_{in}} - \mathrm{T_{soil}}} \tag{3}$$

The value of the COP EAHE can be determined from equation:

$$\mathrm{COP} = \frac{Q_c}{P_f} \tag{4}$$

3. Methodology

3.1. 3D Geometry Depiction

From all the dimensions of EAHE that has been measured in 3D geometry, a pipe iron can also be made using Solid Works 2014 software. The geometry shapes that have been drawn can be seen in figure 1.

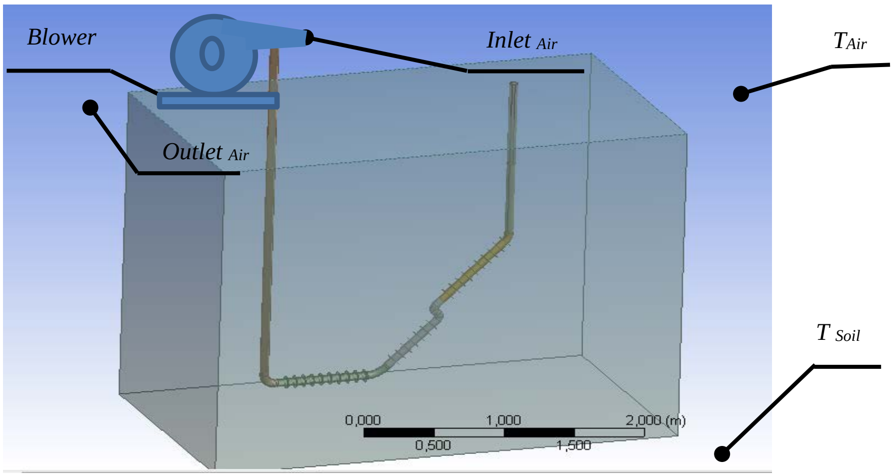

Figure 1. 3D Geometry with Display of Hidden Line Visible

The geometry must be exported to the Parasolid format (.x_t) to be read by Ansys. The Thermocouples are placed at the four temperature measurement points along the pipe and is connected to a computer using data acquisition of Cole-Palmer 18200-40 8 channels. Zone 1 is placed on the soil to measure the ambient temperature, and zone 2 is placed on the inlet side of the pipe, zone 3 is placed at the outlet of the pipe, zone 4 is set at a depth of two meters to measure soil temperature. The acquisition results are presented in the form of data and graphics using the Tracer-Daq software. The data received is stored in the form of a .txt file.

3.2. Scheme of Simulation

Figure 2 shows the flow of the simulation preparation process.

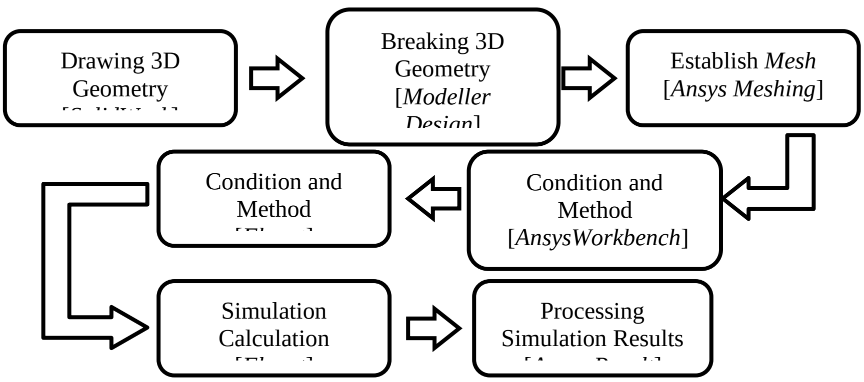

Figure. 2. The flow of the Simulation Preparation Process

3.3. Set-Up The Experimental

The air is flowed into the pipe using a blower with the air velocity of the inlet air flow of 3 m/s and 2 m/s. The blower is connected to an inverter so that the blower rotation frequency can be adjusted to produce the desired air flow velocity. To ensure the air velocity produced is suitable for use anemometer. Figure 3 shows the experimental scheme of EAHE simulation.

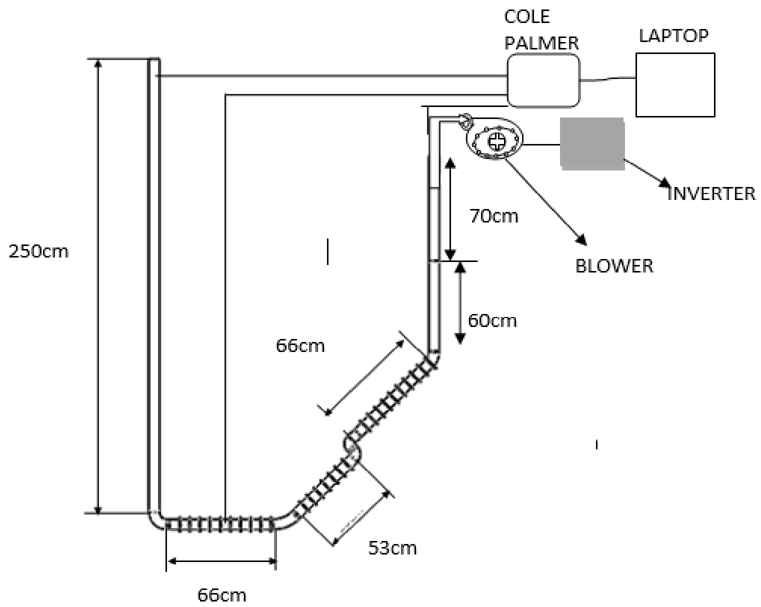

Figure 3. Set-up of Experimental of EAHE

4. Results and Discussions

4.1. Analysis Results on Fluent Software Ansys 14.5

After the data inputted into a fluent, an analysis of the EAHE pipe is titrated to temperatures in PVC pipes in the soil for 6 hours of testing started at 10:00 WIB until 16:00 WIB. Following is the input temperature during the simulation, complete experimental data in table form can be seen in table 1.

Table 1. Temperature In and Out During The Experimental

V_{air} (m/s)	Statistics	T_{in}(˚C)	Tout (˚C)
1	Maximum	32,19	26,99
	Minimum	29,55	25,5
	Average	30,64	25,99
2	Maximum	31,32	26,69
	Minimum	28,97	25,79
	Average	30,23	26,33
3	Maximum	33,37	26,22
	Minimum	29,92	25,78
	Average	31,38	26,01

The reason for sampling analysis at these hours due to the heating surrounding air because of the existence of solar radiation. The temperature on the pipe wall is assumed to equal to the ratio of the soil temperature at a depth of 2 m is shown table 2.

Table 2. The Average of Soil Temperature

V_{air} (m/s)	Statistics	T_{soil}(˚C)
1	Maximum	25,41
	Minimum	25,10
	Average	25,22
2	Maximum	25,65
	Minimum	25,26
	Average	25,45
3	Maximum	25,88
	Minimum	25,45
	Average	25,61

4.2. Analysis of The Temperature Contour

From the simulation results of the temperature contours, it can be seen that there is a temperature decrease from the first inlet fluid along the EAHE pipe. The temperature contour distribution on the fluid flows along the pipe at a velocity of 3 m/s and 2 m/s can be seen in figure 4.

a) Temperature dispersion at velocity of 1 m/s

If reviewed from the Law of Pascal, the pressure of filling one chamber should be equal, but in some instances, the pressure may be uneven. For example, in the case of flow in iron and PVC pipes, due to the length and shape of fluid flow in the APK chamber can be reduced due to the pressure, and heat inflicted on it can cause a decrease in pressure and the temperature at several points different from other locations even in the same chamber. The temperature distribution of the fluid flowing along the pipe at a velocity of 1 m/s can be seen as follows:

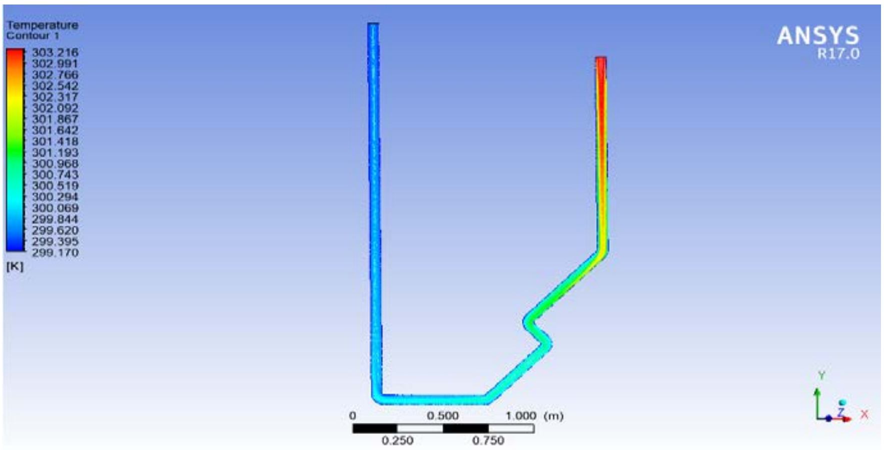

Figure 4. The Results of Fluid Temperature Contour Analysis in an EAHE at Velocity of 1 m/s

Figure 4 shows that with the reduction of the velocity of the inlet fluid on EAHE, so that the air circulates longer with the cold pipe wall, and the fluid out is cooler than the inlet one. The graph below shows a comparison of T_out simulation and experimental for V_air = 1 m/s.

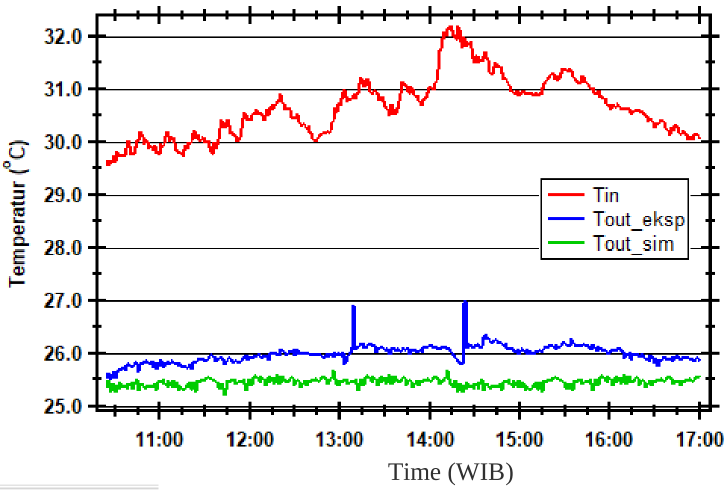

Figure 5. The Comparison of Experimental and Simulation T_out (V_air = 1 m / s)

b) Temperature Dispersion at Velocity of 2 m/s

The distribution of temperature at a velocity of 2 m/s can be seen as follows:

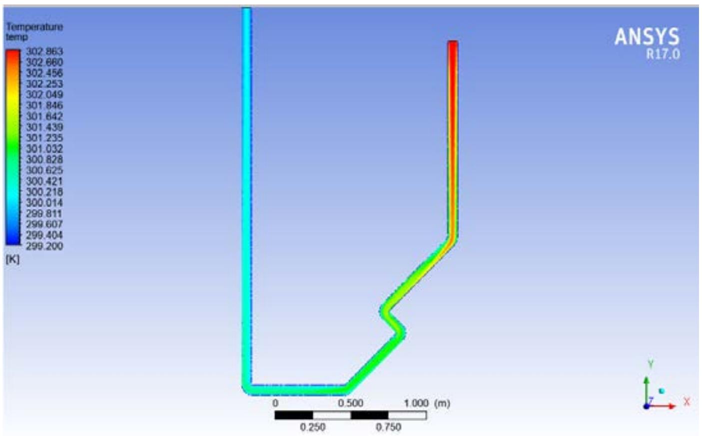

Figure 6. The Results of fluid temperature contour analysis in an EAHE pipe at a velocity of 2m/s

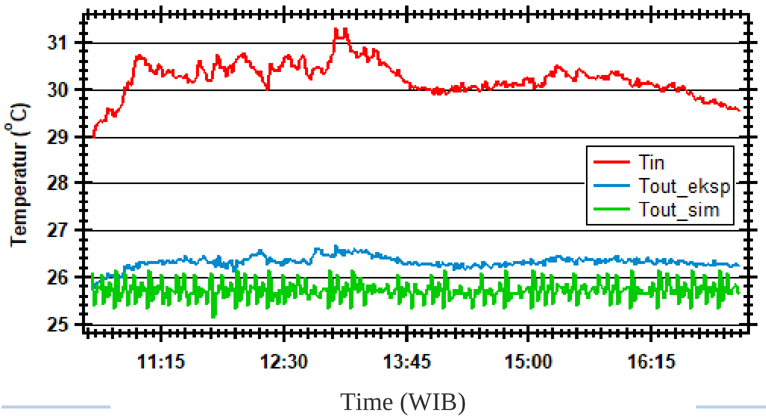

Figure 7. The Comparison of T_out Experimental and Simulation (V_air = 2 m / s)

c) The Temperature Dispersion at Velocity of 3 m/s

Fifure 8 shows the distribution of temperature at a velocity of 3 m/s.

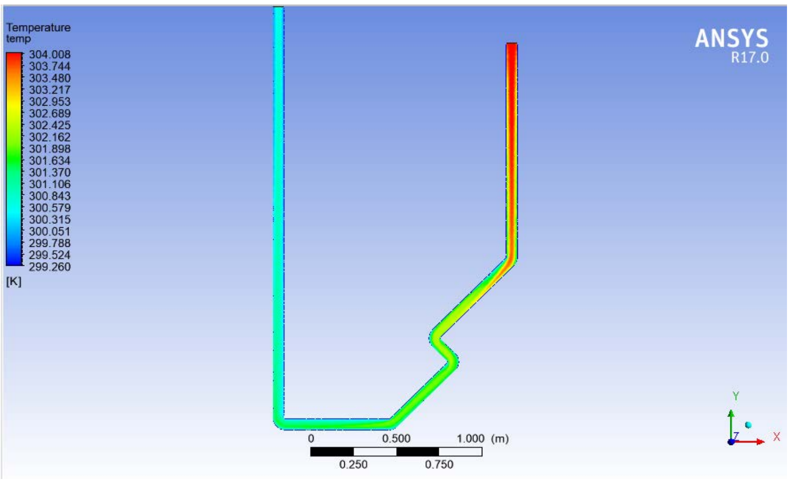

Figure 8. The Results of Fluid Temperature Contour Analysis in the EAHE pipe at a Velocity of 3 m/s

Table 3. The comparison of experimental outlet temperature and simulation

Vair (m/s)	Statistics	Tin (˚C)	Tout (˚C) Experimental	Tout (˚C) Simulation	Error (%)
1	Average	30,64	25,99	25,45	2,12
2	Average	30,23	26,33	25,73	2,33
3	Average	31,38	26,01	25,84	0,65

4.3. The Effectiveness of Simulation of EAHE.

Table 4 shows the effectiveness value of the simulated of the EAHE.

Table 4. The comparison of experimental effectiveness with simulation effectiveness

Vair (m/s)	Statistics	Tin (˚C)	Tout (˚C) Experimental	Tout (˚C) Simulation	Effectivity (ε) Experimental	Effectivity (ε) Simulation	Error (%)
1	Average	30,64	25,99	25,45	0,8590	0,956	11,29
2	Average	30,23	26,33	25,73	0,8164	0,940	15,13
3	Average	31,38	26,01	25,84	0,8970	0,960	7,02

5. Conclusions

In simulation and experimental, by decreasing the velocity of inlet air (V_{air}), then the outlet temperature (T_{out}), performance coefficient value (COP) and effectiveness value (ε) for EAHE will decrease and inversely proportional to the value of the NTU will increase. The average of an outlet air temperature of the results of 3D simulation using Ansys 17.0 Software obtained of 25.45 ^{o}C for the inlet air velocity of 1 m/s, 25.73 ^{o}C and air velocity of 2 m/s, and

25.84 ^{o}C. The experimental results obtained of 25.99^{o}C for air velocity of 1 m/s, 26.33 ^{o}C for air velocity of 2 m/s and 26.01 ^{o}C for air velocity of 3 m/s.

Acknowledgment
The authors say thank to the Directorate General of Higher Education-DRPM for the research fund (PTUPT) in 2019.

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