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The Earth-Air Heat Exchanger System Performance Combined with a Solar Collector for Cooling an Indoor Space Room in Medan City

Tulus Burhanuddin Sitorus[1*], Syahrul Abda[1], Terang Ukur Hidayat Solihin Ginting Manik[1]

[1]Mechanical Engineering Department, Faculty of Engineering,
Universitas Sumatera Utara, Jl. Dr. Mansyur No. 9, Medan 20155, INDONESIA

*Corresponding Author

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Abstract: Cooling systems such as ventilation and air conditioning in rooms, offices, and homes have become one of today's most significant energy consumption aspects. Therefore, to reduce energy consumption, it is necessary to save energy. One way to save energy is by creating an alternative cooling system that does not consume electrical energy. One of them is the cooling system using the earth-air heat exchanger (EAHE). The research objective was to determine the EAHE system's performance combined with a solar collector for cooling an indoor space room in Medan city. This research is interesting because it utilizes cold temperatures from underground for a cooling system. The innovation obtained is a simple technology for the cooling process without depending on electrical and mechanical energy. The testing room has dimensions of 200 cm x 200 cm x 200 cm. Testing using a flat plate type solar collector to help air movement by taking advantage of air temperature differences. The testing process starts at 08.00 WIB to 17.00 WIB for several days. The measurement taken includes weather conditions include solar radiation intensity, ambient temperature, and air humidity. During the test, the solar radiation intensity ranged from 62.71-893.43 W/m^2, the variation in ambient temperature from 24.65-35.26°C, and the average air humidity 69.80%. The experimental data showed that indoor air temperature fluctuation ranged from 23.01°C to 31.84°C, and the average room temperature was 27.71°C. This study resulted in an average effectiveness value of the EAHE system of 51.56%.

Keywords: EAHE system, solar collector, performance, indoor room, Medan city

1. Introduction

The dependence of countries globally, especially developing countries, on the need for fossil energy has increased very rapidly. The International Energy Outlook organization predicts that energy consumption worldwide will increase by around 45% from 2017 to 2045. The building sector accounts for about 40% of total energy consumption, and 50% is used to maintain indoor thermal comfort, especially in several developed countries [1, 2, 3]. This condition is because world energy consumption increases significantly every year and is very dependent on fossil energy. Developing countries such as Indonesia also responded to this condition with the Ministry of Energy and Mineral Resources regulation number 39 in 2017 concerning implementing physical activities to use new renewable energy and energy conservation [4].

One of the cooling systems that utilize geothermal energy is the earth-air heat exchanger (EAHE). In general, the EAHE system has several advantages over conventional methods, namely using air as a working fluid, not consuming electrical energy, having a simple design, lower maintenance costs, and without pollution because it does not use

**Corresponding author: tulus.burhanuddin@usu.ac.id, tburhanudin@yahoo.com*

refrigerant. The EAHE system uses a network of pipes embedded below ground level at a depth of 2-3 m [5]. One end of the pipe serves as an inlet for ambient air and the other end as an outlet for the cooled object. Thus, the earth is used as a heat sink. Air enters from the inlet and continues to flow through the embedded heat exchanger pipe, and then the pipe goes through a stable underground temperature. The temperature will increase or decrease because it undergoes a conduction process with the underground and is then channeled to the outside to maintain the temperature difference with the ambient temperature. One application is the combination of an EAHE system with a solar collector. This system's uniqueness combines the potential of geothermal energy and solar energy for indoor air conditioning systems. For that information, in Indonesia, the annual sunshine duration ranges from 2500 hours, and solar radiation intensity averages 14500 kJ/m^2 [6]. This situation is an opportunity to exploit the potential of this solar energy source.

The heat transfer process in the EAHE system depends on three main mechanisms, namely convection heat transfers between the air flowing through the planted pipe and the inner surface of the pipe, conduction heat transfers between the inner and outer surface of the pipe, and conduction heat transfer between the outer surface of the implanted pipe and the ground around it [7]. Therefore, applying this natural passive cooling system can reduce home and office buildings' dependence on electrical energy consumption.

So far, to increase air movement in the EAHE pipe in the room cooling process, generally combining an EAHE system with a blower, solar air heater, solar chimney, and solar panels. For example, several researchers [8, 9, 10, 11, 12] combined the EAHE system with solar panels for room cooling. Meanwhile, researchers [13, 14, 15] combined the EAHE system with solar chimneys and solar collectors in their test applications. However, the testing combined the EAHE system with only a solar collector for cooling a room in this study.

In general, the EAHE system has three configurations, namely an open system, a closed system, and a hybrid system. This research uses a hybrid system to determine the EAHE system's performance combined with a solar collector for cooling an indoor room in Medan city. Furthermore, this research proves that a simple combination of an EAHE system with a flat plate type solar collector can produce a cooling process in a room.

2. Materials and Method

2.1 The EAHE Cooling System

Thermal comfort is a comfortable air condition so that humans can feel satisfied with the thermal environment. To achieve this condition, the ventilation and air conditioning systems in rooms, office buildings, and homes generally use one of these equipment to obtain thermal comfort. Table 1 shows the criteria for thermal comfort to humans for the tropics [16].

Table 1 - Recommended temperature range for thermal comfort

Category	Room temperature
Comfortable cool	20.50°C – 22.80°C
Optimal comfortable	22.80°C – 25.80°C
Warm comfortable	25.80°C – 27.10°C

Indonesia has a higher environmental temperature and air humidity than the recommended indoor air temperature and air humidity throughout the year. Indonesia has an environmental temperature ranging from 20-40°C and air humidity of 60-80% throughout the year is Medan city [17]. This condition is one of the considerations to investigate the possibility of implementing the EAHE cooling system's performance in Medan city. However, obtaining thermal comfort requires a relatively large consumption of electrical energy. Therefore, to reduce energy consumption massively, it is necessary to save energy. One alternative to saving energy is creating a cooling or air conditioning system that does not require electrical or mechanical energy to drive force, such as an earth-air heat exchanger. Generally, as a heating or cooling system, the EAHE system can improve controlled mechanical ventilation performance. The system's global energy performance has increased from 36-46% in summer and 29% in winter with EAHE [18, 19]. In addition, EAHE equipment can provide renewable energy from the ground in more environmentally friendly systems [20, 21]. The EAHE system is a room air conditioning method through a heat transfer process to balance the temperature to achieve thermal comfort. Determination of the experimental effectiveness value of an EAHE system uses the equation [22, 23, 24]:

$$\varepsilon = \frac{T_{a,in} - T_{a,out}}{T_{a,in} - T_{soil}} \quad (1)$$

Where $T_{a,\,in}$ is the air temperature entering the pipe, $T_{a,\,out}$ is the air temperature coming out of the heat exchanger's pipe, and T_{soil} is soil temperature. Determination of the temperature coming out of the pipe of the heat exchanger that uses the equation:

$$T_{a,out} = T_{a,in} - (T_{a,in} - T_{soil}) \times \varepsilon \tag{2}$$

The equation to determine the cooling or heating capacity of the EAHE system:

$$Q = \dot{m}a\ ca\ (T_{a,in} - T_{a,out}) \tag{3}$$

Where c_a is the specific heat of the air (kJ/kg. K) and $\dot{m}_a$ is the mass flow rate of air in the pipe. Another parameter to determine the performance of the EAHE is the coefficient of performance. The coefficient of performance (COP) is the ratio between the cooling capacity and the power required to drive the EAHE system (W), namely [25, 26, 27]:

$$COP = \frac{Q}{W} \tag{4}$$

Generally, EAHE systems for room cooling use a blower to increase the pipe's air velocity. However, this condition has weaknesses due to dependence on electrical energy. This experiment uses a flat plate-type solar collector to help the process of moving the airflow. The flat plate type solar collector's main advantage is that it utilizes solar radiation components through direct beam and scattering. Its simple design requires little maintenance and low manufacturing costs [28]. Generally, the flat plate type collector is for indoor heating, air conditioning, and industrial heating processes. The flat plate type solar collector's working principle absorbs solar radiation intensity energy and transfers solar radiation intensity to the collector's air. Part of the solar radiation intensity that falls on the cover glass will experience some reflection, some will experience absorption, and some will experience the process of being transferred to the surface of the collector plate. The equation to calculate the total heat loss in the flat plate type solar collector component is

$$Q_{total} = Q_{wall} + Q_{bottom} + Q_{top} + Q_{radiation} \tag{5}$$

Where Q_{wall} is the heat loss on the collector wall side (kJ), Q_{bottom} is the heat loss on the collector bottom side (kJ), Q_{top} is the heat loss on the collector top side (kJ), and $Q_{radiation}$ is the heat loss on the collector top side due to radiation (kJ).
The equation for determining the efficiency of the solar collector is [29]:

$$\eta = \frac{Q_u}{I\ .\ A} \tag{6}$$

I is the solar radiation intensity on the collector surface (W/m^2), and A is the collector surface area (m^2). The equation to determine the heat energy used is

$$Q_u = F' \times (Q_{in} - Q_{total}) \tag{7}$$

Meanwhile, the thermal energy reaching the collector's surface is

$$Q_{in} = I.\ A\ .\ \tau.\ A \tag{8}$$

Where τ is the transmissivity of the glass cover, α is the black collector plate's absorptivity (0.98), and the collector efficiency factor (F') for the flat plate type is 90% [30].

2.2 Experimental Scheme

The research method uses the technique of collecting data from several measurement points based on experimental testing. The cooling system consists of a heat exchanger, a testing room, and a solar collector. The EAHE has the main dimensions, as shown in table 2. Table 3 shows the sizes and types of materials for the testing room.

Table 2 - The main dimensions of the EAHE

Item	Dimension
Pipe diameter	4 inch
Pipe length	26.5 m
Pipe depth	2 m
Number of passes	8

Table 3 - The dimension of the testing room

No.	Component	Dimension		Material
1	Testing room	2 × 2 × 2	(m^3)	
2	Roof cross-sectional area	2 × 2	(m^2)	Asbestos cement (HW concrete)
3	Wall cross-sectional area	2 × 2	(m^2)	Red brick with cement plaster (common brick wall)
4	Redbrick volume	4.5 × 10 × 19	(cm^3)	Common brick fired clay
5	Thick cement plaster	1.5	(cm)	Cement plaster with sand aggregate
6	Airway cross-sectional area	0.0081	(m^2)	Polyvinyl chloride (PVC)

Briefly, the working principle of the EAHE system is as follows. Air with the same temperature as the ambient temperature enters the EAHE pipe through the inlet, placed at ground level. The air entering the EAHE pipe is cooled through the conduction process between soil and pipe wall and pipe wall with the air in the pipe. The cold air is then flowed into the room by convection. The difference in air temperature, leaving the room towards the collector, and the air temperature coming out of the collector results in differences in the collector's air density. The difference in density causes a difference in air pressure along the heat exchanger pipe. This pressure difference causes airflow along the pipe to the testing room until it exits the collector. An increase in solar radiation intensity that hits the collector's surface will further increase the collector's air temperature. Therefore, the greater the temperature difference, the more air flowing in the pipe increases, and vice versa. The testing of the combined EAHE system uses a flat plate type solar collector with a dimension of 1.5 m x 0.6 m x 0.2 m. A solar collector insulation process uses wood, Styrofoam, and Rockwool to reduce heat loss from the side walls. The solar collector is in a location exposed to sunlight so that the ventilation effect is maximized. The room door's position is facing south, the air inlet is located in the eastern part of the room, and the air outlet is located in the western part of the room, and the back of the room is towards the north. Figure 1 shows the heat exchanger pipes, testing room, and solar collector in these experiments.

(a) (b) (c)

Fig. 1 - (a) EAHE pipe; (b) testing room; (c) solar collector

Figure 2 shows the set-up experimental where a Cole Parmer acquisition data connect the cooling system components via a J-type thermocouple cable (accuracy ±0.75%). The measuring points are attached to the earth-air heat exchanger, the testing room, and the solar collector. Installation of a HOBO micro station data logger instrument measuring weather at the test site and recording weather conditions including solar radiation intensity with a pyranometer (accuracy of ±5%) and temperature and air humidity with T (accuracy ±0.2ºC) and RH (accuracy ±2.5%)

smart sensor. Measurement of airflow velocity in the pipe uses a flow meter measuring device with an accuracy of ±0.1%. The implementation of the data measurement process for every minute in Medan city in July 2020. Installation of PVC pipes from the testing room as a channel through which air flows at the solar collector's entrance. Painting the solar collector's surface with black color so that the heat absorption process becomes optimized without causing the atmosphere's radiation reflection effect.

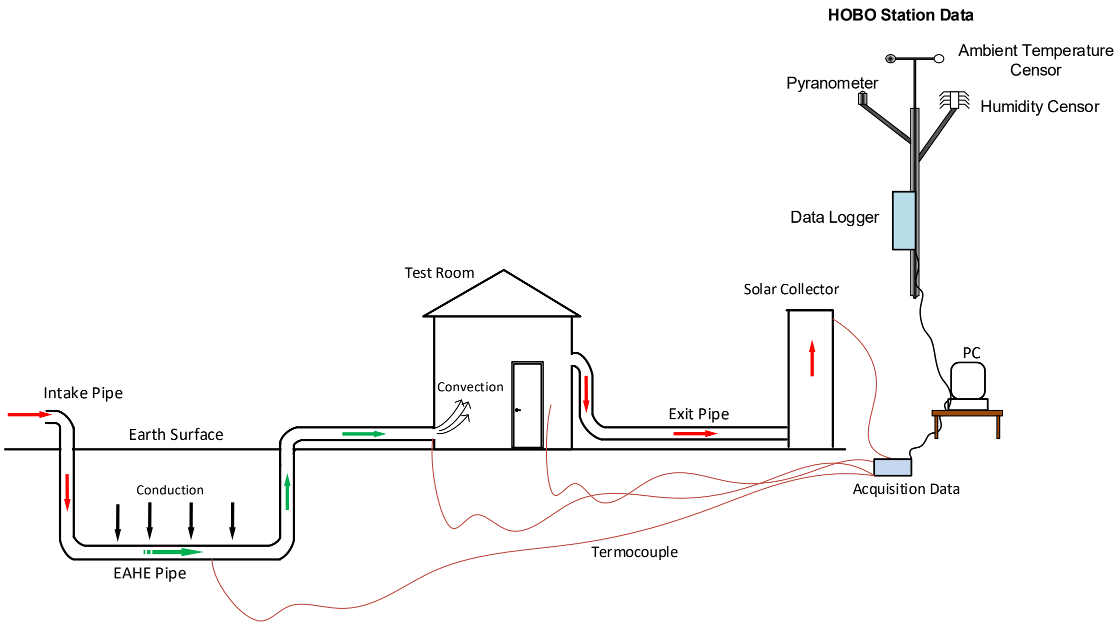

Fig. 2 - Experimental scheme

3. Results and Discussion

This section describes the data and the testing results that have been carried out. Parameters measured are weather conditions, including solar radiation intensity, humidity, ambient temperature, and temperature in the room and collector. The weather conditions and soil characteristics at a particular location will affect the temperature of the soil [31]. At the same time, the main parameters that are calculated that show the performance of the EAHE cooling system are effectiveness and COP (coefficient of performance).

3.1 Weather Condition During Experiments

The weather data from a location is an important parameter to determine the EAHE system's suitability with that location. Therefore, identify the technical feasibility before the actual development of the EAHE by observing the weather data from the area, namely air temperature, solar radiation intensity, air humidity, and soil temperature. The test will be carried out for 9 hours every day at locations exposed to solar radiation intensity from 08.00 WIB to 17.00 WIB. In Medan city, local time uses western Indonesian time or WIB (Waktu Indonesia Barat). The measurement data shows that the maximum solar radiation intensity conditions are at 11.51-13.31 WIB, and the maximum air temperature occurs at 12.05-13.47 WIB. Figure 3 shows the conditions of the solar radiation intensity during experiments.

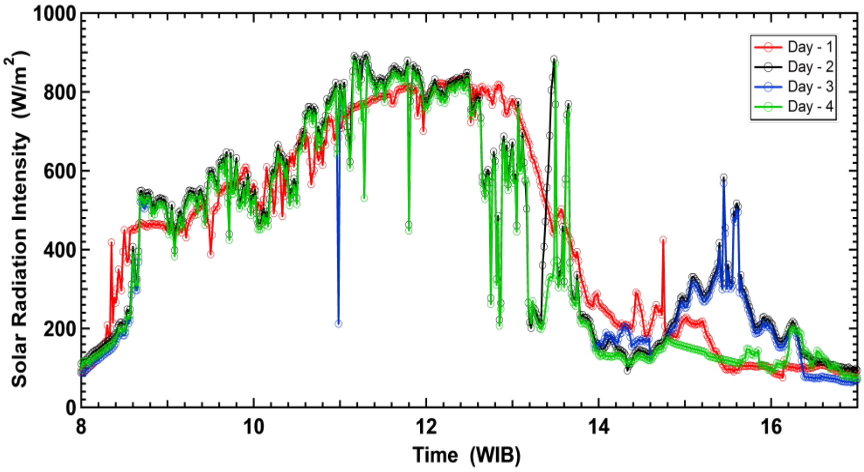

Fig. 3 - The solar radiation intensity measured during experiments

It shows that the measured solar radiation intensity has the same pattern even though it fluctuates over time. The maximum solar radiation intensity is 893.43 W/m^2, which occurs on the second day. Meanwhile, the average solar radiation intensity during the measurement is 431.25 W/m^2. Figure 4 shows the ambient temperature conditions during experiments. The environmental temperature ranges from 24.65°C to 35.29°C, with an average ambient temperature of 30.49°C. The average air humidity during the testing process is around 69.80%.

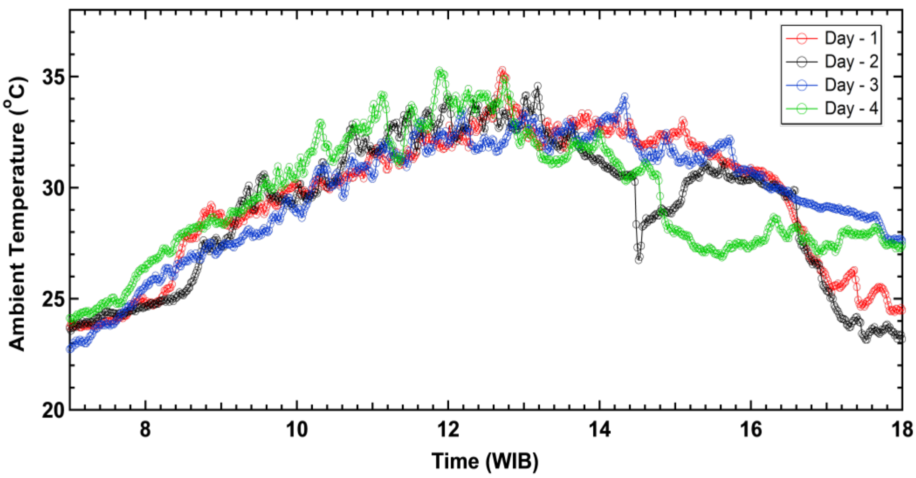

Fig. 4 - Ambient temperature measured during experiments

3.2 The Performance of The EAHE System

An explanation of the performance of the EAHE system with a solar collector is as follows. This test includes soil temperature measurements, room temperature, collector surface temperature, and air velocity in the pipe. Figure 5 shows the measurement results of the soil temperature distribution at the location.

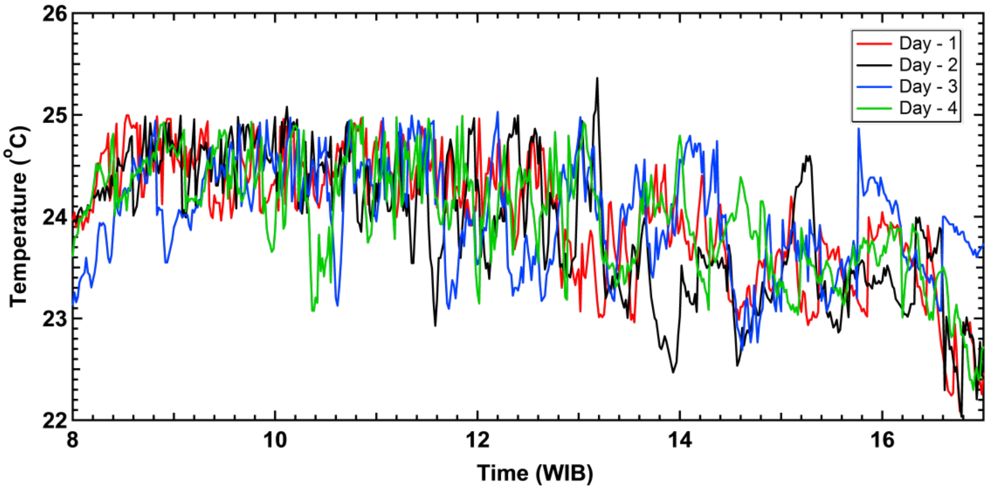

Fig. 5 - The conditions of soil temperature during experiments

As previously described, the EAHE cooling system utilizes a lower ground temperature than the ambient temperature. Therefore, the EAHE system is highly dependent on the ambient temperature at any location during summer and winter for cooling and heating. In summer conditions, the soil temperature is lower than the ambient and vice versa during winter [32]. Therefore, data on soil temperature conditions at the test site is needed. Measurement of soil temperature by inserting a thermocouple sensor into the ground as deep as two meters at the pipe location. The process of recording soil temperature data for every minute from 08.00-17.00 WIB. Soil temperature values during measurement ranged from 22.24-25.36°C with an average temperature of 23.87°C. It shows that the weather conditions effect is relatively small on soil temperature, with the measurement point's depth ranging two meters from the ground surface. Figure 6 shows the distribution of temperature changes in the testing room. The temperature measurement process starts at 08.00 WIB in the morning until 17.00 WIB in the afternoon. It shows that room temperature distribution has a pattern almost the same as changes in ambient temperature. This condition is because the air temperature entering the EAHE pipe is the same as the ambient temperature. The pipe entering the heat exchanger is at ground level. The room temperature fluctuation ranged from 23.01°C to 31.84°C, and the average room temperature was 27.71°C during the test.

Meanwhile, based on measurement data, the ambient temperature ranges from 24.65°C to 35.29°C, and the average temperature is 30.49°C. The cooling process occurs when the air flowing from the pipe enters the testing room; as long as the pipe's air flows, a conduction heat transfers from the ground to the pipe's air. Furthermore, the air that comes out of the heat exchanger pipe into the room experiences a natural convection process. This situation makes the process of changing room temperature slow. The average room temperature reduction process ranges from 1.86°C to 3.27°C by comparing it with the experiments' environmental temperature conditions.

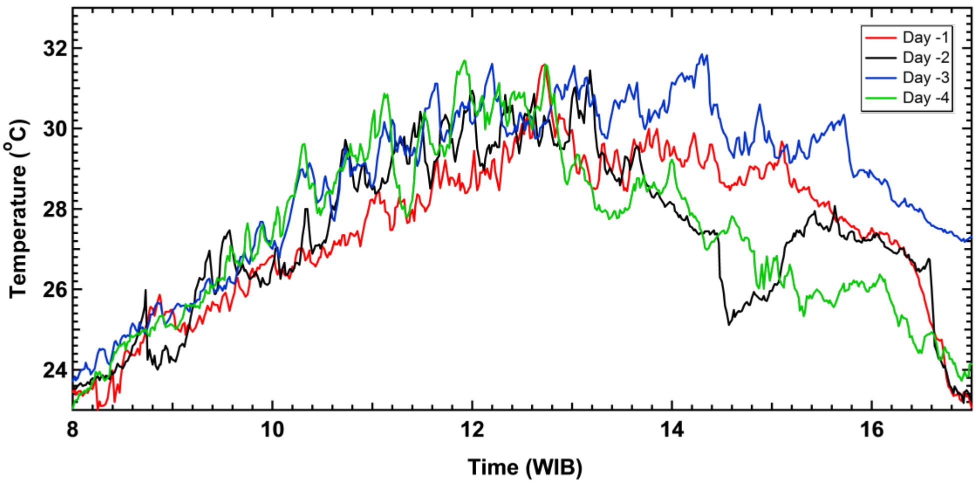

Fig. 6 - Distribution of room temperature during experiments

The EAHE system performance determined the parameters of effectiveness during the testing process. The EAHE system effectiveness is influenced by the depth of the installed pipe, the ambient temperature of a particular location, the soil thermal diffusivity, airflow velocity, and the length and diameter of the pipe and pipe's thermal conductivity [33]. Specifically, to obtain the effectiveness value of the earth-air heat exchanger experimentally, it requires variables such as the air temperature entering the heat exchanger pipe, the temperature of the air coming out of the heat exchanger to the testing room and the soil temperature. The value of the air temperature in the heat exchanger inlet pipe plays a role because the temperature difference affects the rate of conduction heat transfer between air and soil. It shows an increase in intake air temperature also affects the air temperature exiting the heat exchanger pipe to the testing room. The temperature of the pipe inlet air varies from 24.65°C to 35.29°C, the temperature of the air exiting the heat exchanger pipe to the room differs from 24.06°C to 29.29°C with a heat exchanger pipe length of 26.5 m. Figure 7 shows experimental data regarding the conditions of heat exchanger effectiveness during testing.

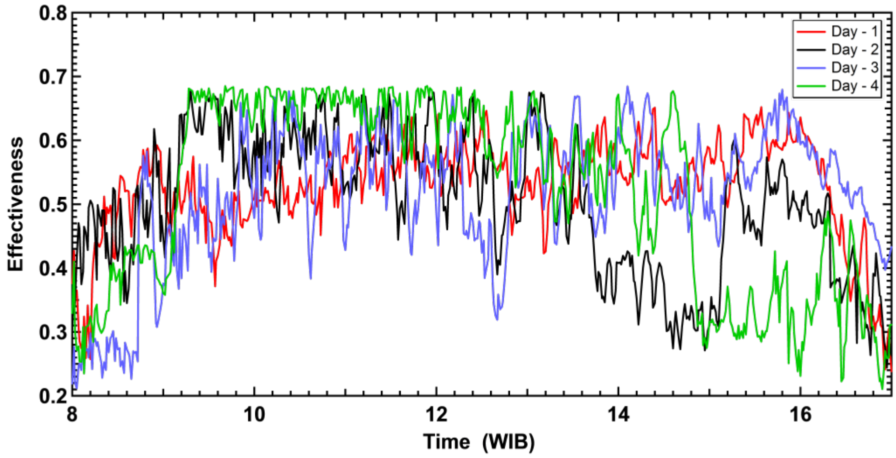

Fig. 7 - The EAHE system effectiveness during experiments

It shows that the effectiveness values varied during testing. The earth-air heat exchanger's effectiveness value ranges from 21.05% to 68.48%, and the average value of effectiveness was 51.56%. As previously explained, the solar collector's function in the system is a tool to drive the pipeline's airflow process. The solar collector is about five meters from the room with a 30° tilt position to the east. The experimental data shows that the surface temperature of the collector plate ranges from 81.95-93.87°C. Meanwhile, the average air temperature in the collector is 56.53°C. The value of the collector efficiency varies from 7.05-63.78%. The main parameters that affect the solar collector's performance in weather conditions include solar radiation intensity, air temperature, and air humidity. Changes in solar radiation intensity also cause fluctuations in air temperature inside the collector. Besides, the variable airflow rate in the collector also affects the collector's efficiency. The greater the collector's airflow rate, the higher the solar collector's performance and vice versa. Table 4 shows the collector efficiency during the testing process, where $_{Total}$ is the sum of the heat losses on the walls, top, bottom, and radiation at the collector.

Table 4 - The collector efficiency during experiments

Day	Solar radiation intensity (W/m^2)	$_{Total}$ (W)	Q_{in} (W)	Q_{used} (W)	Collector Efficiency (%)
1	838.10	44.30	150.51	95.70	60.44
2	893.43	44.22	151.26	96.85	60.86
3	879.40	44.08	153.41	99.06	61.38
4	880.60	42.50	161.57	108.40	63.78

Another parameter from the experimental data results and calculations is the value of the EAHE system's performance coefficient (COP). Figure 8 shows the performance coefficient condition of the earth-air heat exchanger system. It shows that the COP value has increased slowly, starting at 09.00 WIB and decreasing starting at 16.00 WIB with fluctuating conditions during the testing process. It shows that the COP values varying from 0.0012-0.1360, with an average value of 0.0312. Several variables that affect the COP of the EAHE are the air temperature entering the heat exchanger pipe, the air temperature exiting the pipe, solar radiation intensity, and cooling capacity. A research study [5] stated that the exit temperature of the EAHE pipe is a function of the length and diameter of the planted pipe. The length of the pipe is directly proportional to the temperature of the outlet pipe because increasing the length of the pipe can increase the temperature of the outlet pipe. This increase can increase the heating potential of the system. The optimal length of the pipe of an EAHE system is affected by weather conditions. The increase in the length of the pipe can cause the COP value to decrease, likewise with pipe diameter variables, increasing pipe diameter will increase the outlet pipe temperature and reduce the convection heat transfer coefficient, which can reduce the cooling capacity of the EAHE system. In other conditions, increasing the pipe diameter can reduce the pressure loss, which will increase the thermal potential but decrease the cooling potential, which results in a decrease in the COP value. The mass flow rate of air in the pipe affects the cooling capacity of the EAHE system. Meanwhile, the air velocity in the pipe affects the value of the air's mass flow rate during the test. During the test, the air velocity ranged from 0.126 m/s to 0.594 m/s, with an average value of 0.343 m/s. Air mass flow rate values ranged from 0.0011-0.0044 kg/s with an average value of 0.0026 kg/s and the maximum cooling capacity of 32.20 watts with an average value of 10.21 watts during experiments. The increase in air velocity in the underground pipe also affects the EAHE system's performance, resulting from the temperature difference between the air entering and leaving the pipe.

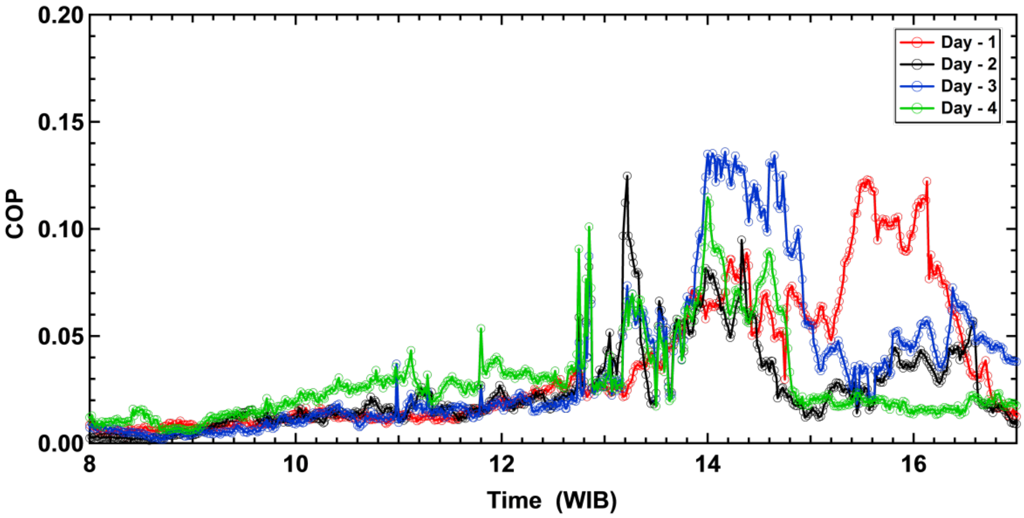

Fig. 8 - The EAHE COP during experiments

4. Conclusion

The experiment of EAHE system performance combined with a solar collector for cooling an indoor room in Medan city has been carried out. Combined system testing uses passive mode naturally. This is, of course, without the use of any mechanical or electrical equipment. The airflow is pushed into the room through passive solar energy. During the natural airflow mode, the increased outdoor temperature and radiation intensity increase the solar collector's natural airflow and the airflow into the room. Experimental data during testing showed that the average effectiveness of the EAHE was 51.56%. The maximum COP is 0.1360, and an average COP of 0.0312 during experiments. During the test, the combined system maintained a comfortable thermal environment in the room, with an average temperature of 27.71°C. The results showed that this alternative cooling system could produce a temperature drop ranging from 1.86 to 3.27°C. This research proves that the combined EAHE system with only a solar collector can perform a cooling process in an indoor space room in Medan city, although it needs improvement in the future. The results showed that EAHE is an energy-efficient system that can substitute for conventional methods for thermal comfort.

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