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NUMERICAL ANALYSIS OF AIR-WATER HEAT EXCHANGER AS PASSIVE COOLING SYSTEM IN AIR VENTILATION

Firman Omni Saputra[1], Remon Lapisa[2], Refdinal[3], Budi Syahri[4]
Universitas Negeri Padang, Indonesia
firmanomni@student.unp.ac.id; remonlapisa@ft.unp.ac.id

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Abstract

Indonesia has a humid tropical climate and many major cities are located along the coast, causing a large energy demand for thermal comfort. It takes a lot of energy to get thermal comfort. So one of the effective strategies for energy efficiency of HVAC (Heating, Ventilation, and Air Conditioning) systems is passive cooling techniques. Therefore, savings are made by using heat transfer devices as passive cooling in air vents. This research was conducted to see the comparison between experimental data and Computational Fluid Dynamic (CFD) simulations. The implementation method in this research was carried out on Solidoworks 2020 software. Based on experimental data, the inlet temperature is 32.35˚C, the outlet temperature is 28.4˚C and the water temperature is 27.58˚C and the mass flow rate is 0.0936 kg/s, the effectiveness is 0.228, then a variation with a mass flow rate of 0.1872 kg/s is obtained with an effectiveness of 0.122 and a mass flow rate variation of 0.2808 kg/s is obtained with an effectiveness of 0.083.

Keywords: HVAC; CFD; Solidworks 2020; Temperature; Effectiveness

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INTRODUCTION

Indonesia has a humid tropical climate and requires high power consumption for building operations, namely in the building cooling system, if the building is not planned properly. Large energy consumption is used to cool buildings for humid tropical climates. Thermal comfort is strongly influenced by the air conditioning system and ventilation system. To meet the thermal comfort of occupants in tropical climates, buildings are usually equipped with air conditioning and ventilation equipment often called HVAC (Heating, Ventilation, and Air Conditioning) systems. However, HVAC systems in buildings require considerable energy and have the potential to damage the environment (Lapisa et al., 2023).

Indonesia is known as a strong country in shipping, both nationally and internationally, which is shown by the many coastal cities in Indonesia. The increase in population in coastal cities is in line with the history of the civilization of the ethnic groups that live along the coast in Indonesia. The increase in population causes an increase in the size of coastal cities in Indonesia, so this increase will have an impact on increasing energy use (Wibowo & Supriatna, 2011).

Conventional (non-renewable) energy is only available in limited quantities on earth and cannot be regenerated or replaced in a short time (Çolak et al., 2023). The sources of these energy reserves are increasingly depleted, the cost of mining is increasing, and this has an impact on increasing the selling price to the public. At the same time, conventional energy is a major contributor to global warming by releasing carbon emissions into the atmosphere. This is why conventional energy is said to be environmentally unfriendly, because by causing pollution to the environment (air, water and soil) it also has an impact on reducing the level of health and living standards for living beings who live in the increased need for energy can increase the budget that must be spent on cooling (Yolcan, 2023). One of the effective strategies for energy efficiency of HVAC systems is passive cooling technique. This technique is a method of reducing the temperature of a building by using two principles, namely minimizing heat gain from the environment and maximizing heat dissipation to the environment. Some alternative passive cooling techniques that can be applied to buildings include natural ventilation, sun protection, evaporative cooling, cooling by soil, materials, thermal stratification (Lapisa & Romani, 2020). Therefore, savings are made by using a heat transfer device as a passive cooler on air vents. The way

this tool works is by means of a heat transfer device from the air flowing in the heat exchanger pipe, which is immersed in a tube filled with water. The heat carried by the air is then transferred into the water as it passes through the heat exchanger pipes submerged in the reservoir. The effectiveness of passive cooling is analyzed by reducing the air temperature between the inlet and outlet of the ventilator after passing through the heat exchanger.

Computational Fluid Dynamics (CFD) is still a useful tool to thoroughly study the flow dynamics and heat transfer in a heat exchanger before improving its design (Khabbaz et al., 2016). It allows to capture the heat transfer that occurs as well as possible 3D coherent structures embedded in the mean flow, which can greatly affect the heat transfer. It also gives access to the heat transfer coefficients internally, which are not usually captured experimentally (Kayaci et al., 2019). However, the authors put more emphasis on the numerical analysis of the effect of mass flow rate on heat transfer.

METHODS

SolidWorks is a CAD (Computer Aided Design) computer-aided design software, which is used to create 2D or 3D Models. This computer program allows designers to machine parts and highly detailed part assembly and production drawings. SolidWorks is a good program for creating product development stages. This software provides the necessary tools to produce complex surfaces, structural weld assemblies, and more, it also allows you to test your design before it is produced using various tools in solidworks: fluid dynamics, static and dynamic response and heat transfer.

Flow Simulation is an additional feature regarding fluid flow analysis available in Solidworks software to obtain solutions to the Navier-Stokes equations that govern fluid movement (Hapsoro & Srigutomo, 2013). The following stages are carried out to run the simulation on the flow simulation is as follows:

1. Create 3D Model

The 3D model was created using the Solidworks application.

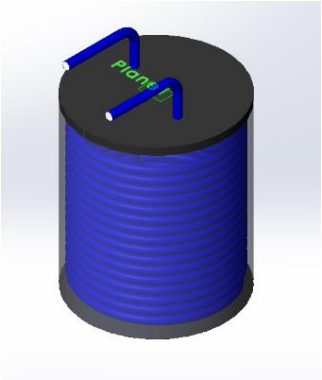


Figure 1. 3D Model of Heat Exchanger

2. *Lids & Check Geometry*

The finished 3D model is made lids on the inlet and outlet holes. Then a geometry check is carried out which serves to determine whether there is a leak in the design.

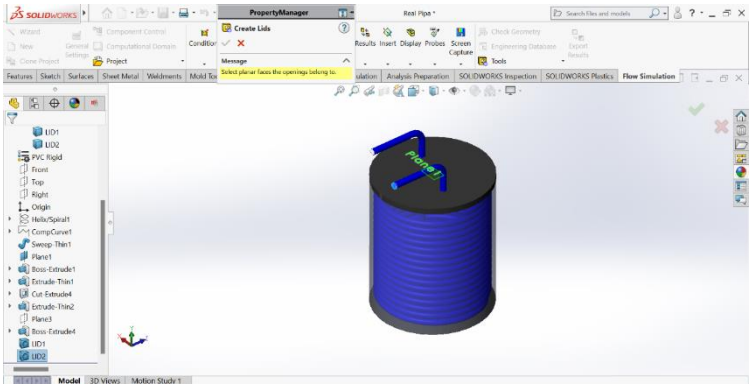


Figure 2. Create Lids

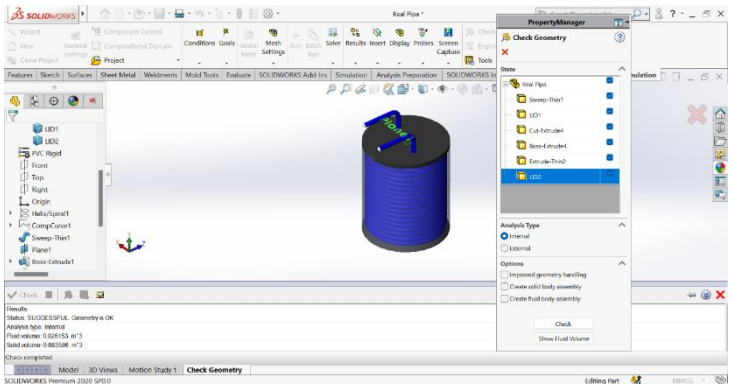


Figure 3. Check Geometry

3. *Input Fluid Subdomain*

Because this research uses two kinds of fluids so that the input fluid subdomain is needed as a barrier between the two fluids, namely air and water.

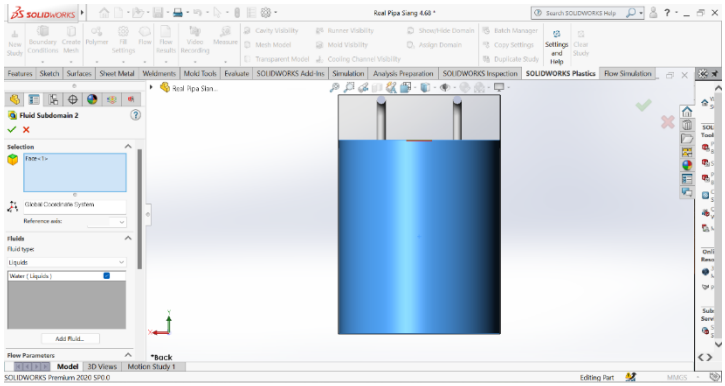


Figure 4. Input Fluid Subdomain of Water

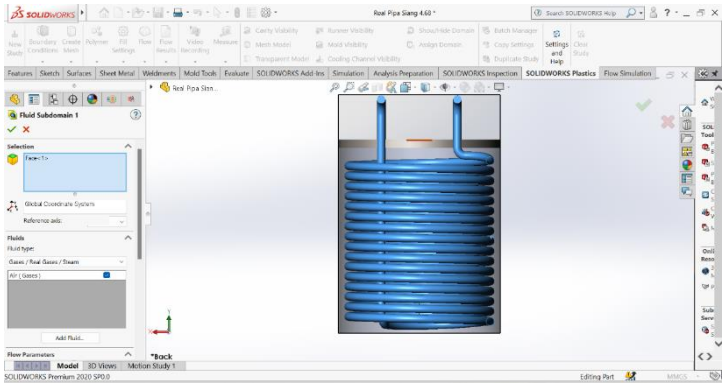


Figure 5. Input Fluid Subdomain of Air

4. *Input* Material

The material data entered is the material that matches the field conditions. In this research, rigid PVC material is used for spiral pipes and AISI 1023 Carbon Steel Sheet for heat exchanger tubes.

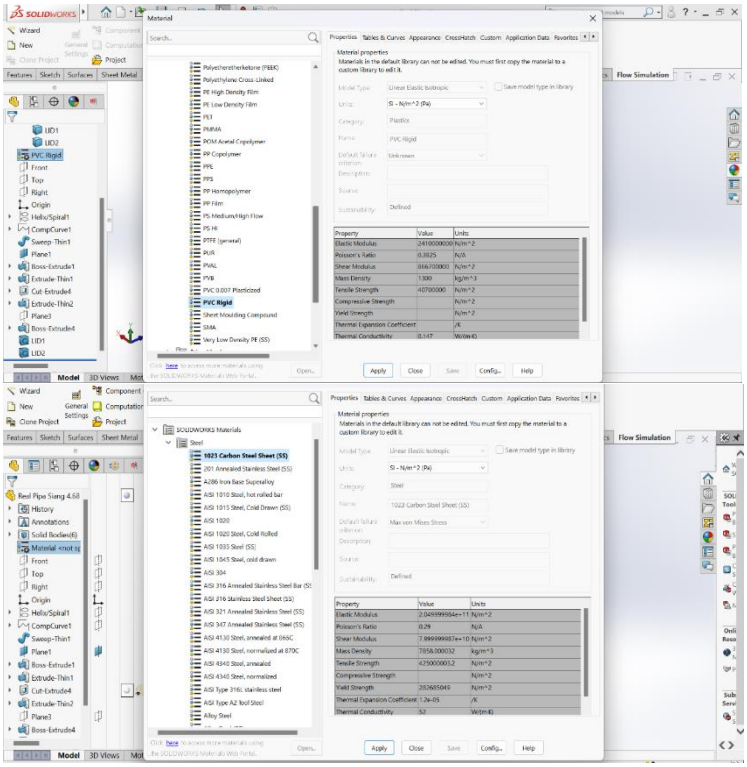


Figure 6. Input Material

5. Boundary Condition

At this stage, we will define operating data such as velocity, temperature or flow rate at the boundary conditions at the inlet and outlet.

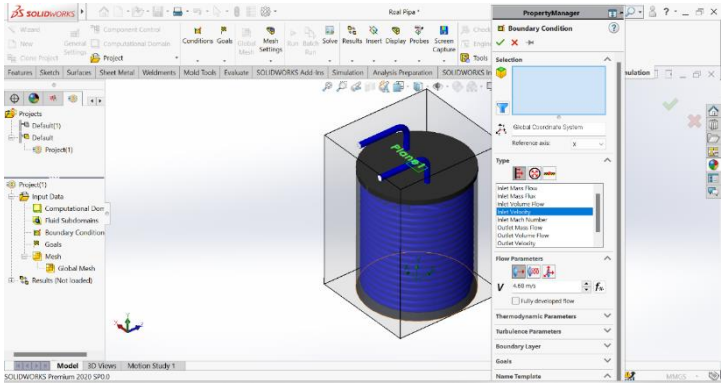


Figure 7. Input Boundary Condition

6. Goals

In this section, we define the parameters to be achieved to see the output of the running results.

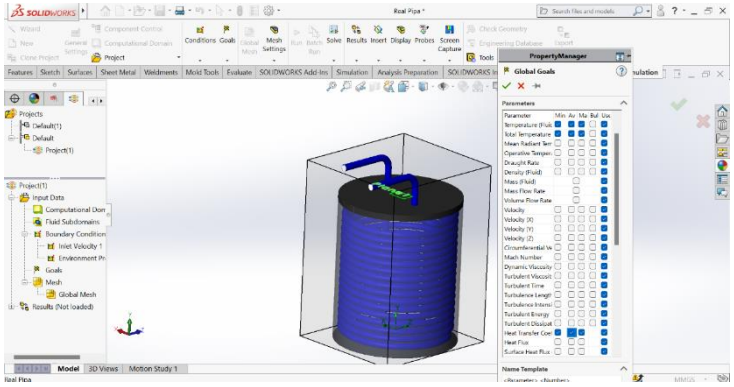


Figure 8. Input Goals

7. Meshing

   In the meshing stage, 7 levels of cell fineness are provided where the higher the level, the number of cells will also increase. This will also increase the validity of the simulation. Next, the running process is carried out to perform the simulation (Ben Slimene et al., 2022).

8. Goal Plot

   At this stage we can already see the calculation results such as fluid velocity at the inlet and outlet, flow rate, temperature and pressure.

RESULTS AND DISCUSSION

This research was conducted using the Computational Fluid Dynamic (CFD) simulation method by setting the inlet fluid flow discharge that matches the experiment, namely 4.68 cmm with variations of 9.36 cmm and 14.04 cmm in numerical simulations and different data collection times. However, the solidworks application uses a mass flow rate so a conversion from fluid flow discharge to fluid flow mass is required.

$\dot{m} = \varrho \times Q$	$\dot{m} = \varrho \times Q$	$\dot{m} = \varrho \times Q$
$= 1{,}2\ kg/m^3 \times (4{,}68\ m^3/60)$	$= 1{,}2\ kg/m^3 \times (9{,}36\ m^3/60)$	$= 1{,}2\ kg/m^3 \times (14{,}04\ m^3/60)$
$= 0{,}0936\ kg/s$	$= 0{,}1872\ kg/s$	$= 0{,}2808\ kg/s$

In the experimental results in the field, the outlet temperature value of the heat transfer device with a mass flow rate of 0.0936 kg / s is 28.4 °C. While numerical analysis at a mass flow rate of 0.0936 kg / s obtained the outlet temperature value of

the heat transfer device is 28.69 ˚C. Then at a mass flow rate variation of 0.1872 kg / s, a value of 26.7 ˚C is obtained and at a mass flow rate variation of 0.2808 kg / s, a value of 23.11 ˚C is obtained.

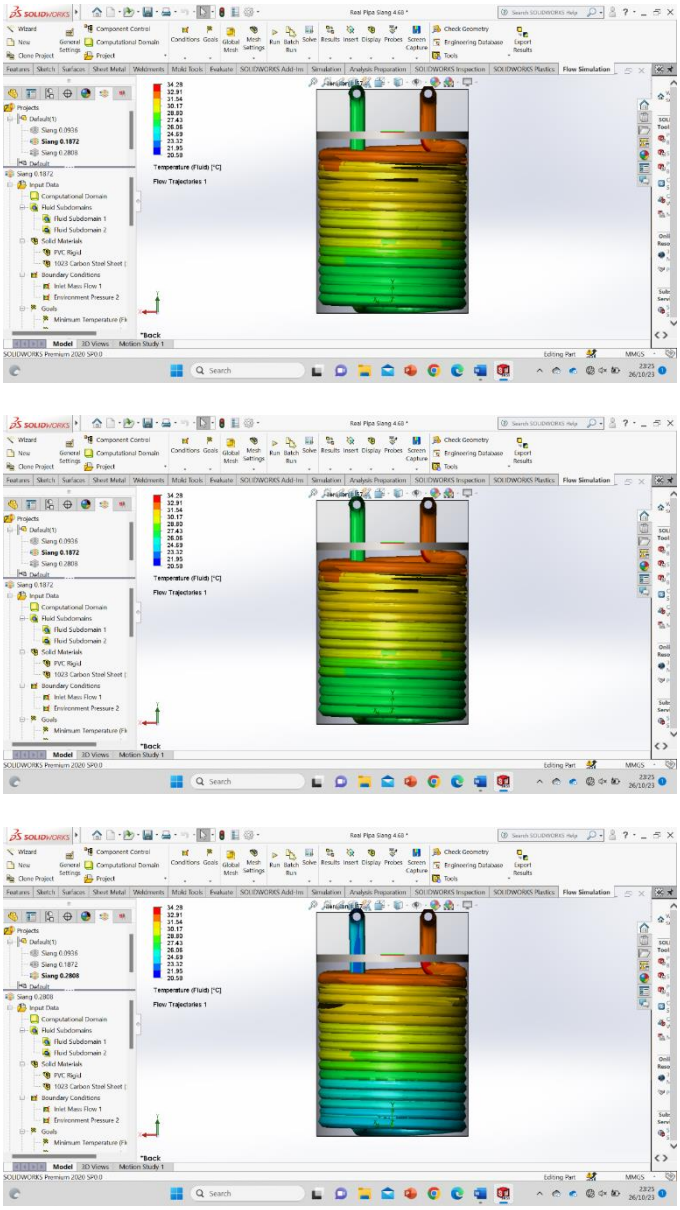


Figure 9. Numerical Analysis Results

After simulating the air-water heat transfer device, it is shown that the highest and lowest temperatures of this device are not at the inlet or oulet but on the bent side of the hose. This can happen because it is caused by turbulence in the fluid flow.

Tabel 1. Numerical Analysis Results

No.	Inlet Temperature (˚C)	Outlet Temperature (˚C)	Outside Temperature (˚C)	Water Temperature (˚C)	Mass Flow Rate(Kg/s)
1	32,35	28,69	29,2	27,58	0,0936
2		26,7			0,1872
3		23,11			0,2808

Analysis Of Effectiveness

For Mass Flow Rate 0,1872 Kg/s

a. Calculation of Heat Transfer

Due to the type of flow used is single stream. Then the magnitude of the heat transfer value of the heat exchanger can be calculated in a way:

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

$= 0{,}1872\ x\ 1.005\ kJ/kg^{\circ}C\ x\ (32{,}35\ ^{\circ}C - 26{,}7^{\circ}C)$

$= 188{,}136\ x\ 5{,}65$

$= 1.062{,}968\ W/m^2\ ^{\circ}C$

Dimana : C_p = Specific heat of air

p = Density of air

b. Calculation of pipe thermal resistance can be use equation:

$$R_{pipe} = \frac{1}{k_{pipe}\ 2\pi L} \ln\left(\frac{re}{ri}\right)$$

$$= \frac{1}{0{,}52\frac{W}{m}^{\circ}C\ x\ 2\ x\ 3{,}14\ x\ 48}\, ln(0{,}0264/0{,}0254)$$

$$= \frac{1}{156{,}748}\, 0.038$$

$= 0{,}0002\ m^2/w$

c. The thermal resistance between the inner wall of the pipe and the air is determined by the equation:

$$R_{con} = \frac{1}{hA}$$

$$= \frac{1}{371{,}5686\ x\ 2\ x\ 3{,}14\ x\ 0.0254\ x\ 48}$$

$= 0{,}02\ m^2/w$

d. The thermal resistance for water is determined by the equation:

$$R_{air} = \frac{1}{K_{air} 2\pi L} \ln\left(R(z,x)|re\right)$$

$$= \frac{1}{0{,}61\ x\ 2\ x\ 3{,}14\ x\ 48} \ln\left(1{,}2|0{,}0264\right))$$

$$= \frac{1}{183{,}878} 3{,}81$$

$= 0{,}021\ m^2/w$

So to calculate the thermal conductivity of the heat exchanger is:

$R_{tot} = R_{con} + R_{pipe} + R_{air}$

$= 0{,}0002\ m^2/w + 0{,}02\ m^2/w + 0{,}021\ m^2/w$

$= 0{,}0412\ m^2/w$

$U = 1/\ R_{tot}$

$= 24{,}271$

e. Then the value of the Number Transfer of Units of the air-water heat exchanger can be determined by the equation:

$$NTU = \frac{UA}{\dot{m}\ C_p}$$

$$= \frac{24{,}271}{188{,}136}$$

$= 0{,}129$

To determine the effectiveness of the air-water heat exchanger, the equation is obtained:

$\varepsilon = 1 - e^{-NTU}$

$= 1 - 0{,}878$

$= 0{,}122$

For Mass Flow Rate 0,2808

a. Calculation of Heat Transfer

Due to the type of flow used is single stream. Then the magnitude of the heat transfer value of the heat exchanger can be calculated in a way:

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

$= 0{,}2808\ x\ 1.005\ kJ/kg^{\circ}C\ x\ (32{,}35\ ^{\circ}C - 23{,}11^{\circ}C)$

$= 282{,}204\ x\ 9{,}24$

$= 2.607{,}564\ W/m^2\ ^{\circ}C$

Dimana : C_p = Specific heat of air

p = Density of air

b. Then the value of the Number Transfer of Units of the air-water heat exchanger can be determined by the equation:

$$NTU = \frac{UA}{\dot{m}\, C_p}$$

$$= \frac{24{,}271}{282{,}204}$$

$= 0{,}086$

To determine the effectiveness of the air-water heat exchanger, the equation is obtained:

$\varepsilon = 1 - e^{-NTU}$

$= 1 - 0{,}917$

$= 0{,}083$

CONCLUSION

From the results of the solidworks simulation of the air-water heat exchanger with a mass flow rate of 0,0936 kg/s as experimental data with variations in mass flow rates of 0,1872 kg/s and 0,2808 kg/s compared to theoretical results, it can be concluded that The effectiveness of the air heat exchanger at a mass flow rate of 0,0936 kg/s is 0,228, a mass flow rate variation of 0,1872 kg/s is 0,122 and a mass flow rate variation of 0,2808 kg/s is

0,083 and The greater the mass flow rate, the greater the inlet-outlet temperature difference but inversely proportional to its effectiveness.

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