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Enhancing Mini Greenhouse Design: A CFD Analysis of Temperature, Humidity, and Wind Flow Distribution

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ABSTRACT

Research has been carried out on simulating the distribution of temperature, humidity and wind direction in a mini greenhouse using CFD ansys with several fan speed variations. This study aims to simulate the microclimate in a mini greenhouse, namely in the form of temperature, humidity and wind direction with variations in fan speed, namely with speeds of 1.7 m/s, 2.0 m/s and 2.2 m/s. Field measurement data regarding temperature, humidity (RH) in the tunnel-type mini greenhouse that has been carried out is used as input or input to the boundary conditions in the CFD mini greenhouse simulation. The results of the mini greenhouse CFD simulation using Ansys FLUENT are shown in the form of contour images of each condition. Temperature distribution contour, the humidity distribution contour (RH) and the airflow velocity distribution contour indicated by the vector will be used as the focus of this research. The numerical simulation shows quite good results when compared with the results of measurements in the field with the maximum error value obtained, which is 4.04%.

1. INTRODUCTION

Global warming has a negative impact on the life sector, one of which is agriculture. Climate change such as rising temperatures, erratic rain patterns can affect the process of growing and developing plants. This causes crop production to decrease (Surmaini *et al*., 2015). The decline in agricultural productivity will also directly affect farmers' income. To overcome this problem, we need a technology that can maintain the productivity of farmers' crops. One technology that can be used as an alternative is the greenhouse.

Greenhouse is a building with a framework covered with translucent material so that it can transmit light properly to maintain crop production (Mulyono *et al*., 2018). Greenhouse as a closed greenhouse has many advantages when compared to outside crop systems, namely: safe from pest attacks, protected from wind and rain, controllable quality of plants and adjustable harvesting schedules (Siwi *et al*., 2018). In a greenhouse, the process of controlling the microclimate and the treatment process are more controlled and maintained so that crop failures caused by climate change can be minimized (Telaumbanua *et al*., 2016).

Greenhouse as a house plant that has a closed structure causes a difference between the climate inside and the climate outside the greenhouse. Inside the greenhouse, the air tends to be hotter than outside, making it less suitable for plant growth (Az-zaky *et al*., 2020). The structure of the walls and roof of the greenhouse is in the form of a bubble and is translucent, this aims to manipulate the environment so that the plants in it can develop optimally and well (Farid *et* *al*., 2021). Greenhouse before being used as a plant production house should be known in advance the conditions of distribution of temperature, humidity and wind direction, so that parts of the greenhouse can be identified which are not suitable as a place for plant production. Inappropriate flow conditions will affect the process of plant growth and development, because temperature directly affects plant physiological processes such as transpiration, respiration, reproduction, ion uptake, pigment formation and others. While humidity affects the process of photosynthesis, leaf growth, pollination and affects the translocation of food and nutrients (Fahmi *et al*., 2014). Meanwhile, dry winds and strong wind speeds will affect production

The flow distribution can be simulated using the computational fluid dynamics (CFD) method using Ansys software. The CFD method is a computer technology capable of studying the dynamics of flowing substances or objects (Az-zaky *et al*., 2020). The output of this simulation is in the form of colors and vectors that can display the flow direction of temperature, humidity and wind direction in the mini greenhouse, so that it can be observed and used as a reference in improving the mini greenhouse design before use. The flow distribution of temperature, humidity and wind direction cannot be seen directly, so it is necessary to do research on "Simulation of Temperature and Humidity Distribution and Wind Direction in a Mini Greenhouse with the Computational Fluid Dynamics Method".

1.1. Research purposes

This study aims to simulate the flow of temperature, humidity and wind direction using the Computational Fluid Dynamics (CFD) method on several variations of fan speed in the mini greenhouse and describe the distribution of temperature, humidity and wind direction in the mini greenhouse in the form of colors and vectors in 2D geometry using the CFD method on ansys.

2. MATERIALS AND METHODS

The research flowchart that explains the research process from start to finish can be seen in Figure 1.

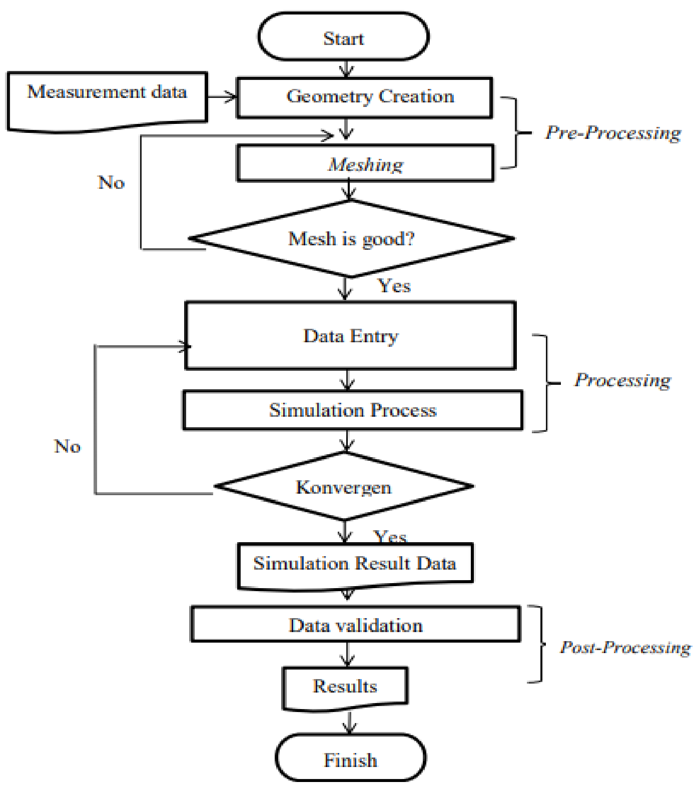


Figure 1. Research flow chart

2.1. Tools and materials

The material used in this research is a tunnel-type mini greenhouse with dimensions of 3 x 2.5 x 3 meters. The main frame is made of wood, the pipes and the roof and walls are made of UV plastic. The greenhouse walls use Mesh 40 of insectnet. There is ventilation in mini greenhouse, namely at the top of the door. While the tools used in the mini greenhouse include: (1) Software: CFD Ansys (2) Hardware: personal computer or laptop, thermohygrometer. In this study, the mesh size used was 0.1 mm.

2.2. Method

In the research that will be conducted there are 4 stages, namely; 1) measuring data in the field, 2) creating a 3D greenhouse design geometry, 3) the CFD simulation stage using ansys student, 4) validating the results. There are several limitations used in the simulation: a). Simulation is carried out in a mini greenhouse without plants (empty state); b). Air flow in a steady state; c) The air outside the greenhouse is considered constant, so the viscosity and specific heat of the air remain constant during the simulation; d) The main frame of the mini greenhouse is considered to have no effect on the heat transfer process, so it does not need to be used as input during the simulation The research was carried out in several stages according to the flowchart. For more details, the scheme of measurement points to be carried out can be seen in Figure 2.

Measurement of internal parameters is carried out when the greenhouse is empty or without plants. Measurements were taken every 08:00 WIB, 13:00 WIB and 16:00 WIB for 9 consecutive days with 3 variations of district 1 (1.7 m/s), district (2.0 m/s) and district 3 (2.2 m/s). Internal climate measurements were carried out at three points in the greenhouse, namely in the front, middle and rear with a height of 1 m, 2 m and 3 m.

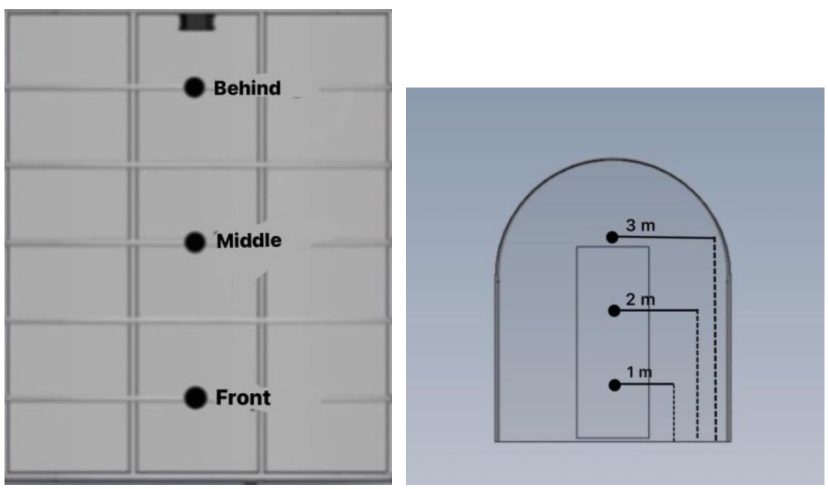


Figure 1. Measurement scheme: top view (left), and front view (right)

2.3. Stages of Research

2.3.1. Micro climate measurement in a mini greenhouse

2.3.1.1. Temperature measurement

Temperature is the state of hot and cold that is transferred from one object to another by the processes of convection, radiation and conduction (Friadi & Junadhi, 2019). Plants that require a low temperature limit can grow well at temperatures of 45 – 60°F while plants that require high temperatures can grow well at temperatures of 60 - 75°F (Tando, 2019). If the temperature is too hot, the intake of air into the leaves is reduced, photosynthesis is low and plant production decreases (Margiwiyatno & Sumarni, 2011). Temperature measurement can be done with a measuring instrument Thermohygrometer.

2.3.1.2. Moisture measurement

Humidity is defined as the ratio between the water vapor content at a certain time and the maximum limit of water vapor that can be accommodated by air at a balanced pressure and temperature (Alahuddin, 2013). In general, the moisture needed by plants is 80% (Hariadi, 2007). Humidity can be measured using the same tool as measuring temperature, namely a thermohygrometer.

2.3.1.3. Wind direction

The stronger the wind, the greater the evaporation, causing damage to plants (Setiawan, 2009). The optimum wind speed for plant growth is 0.5 m/s (Alahuddin, 2013). Wind speed was measured using an anemometer.

2.3.2. CFD Simulation

FLUENT is a form of CFD program using the finite volume method. Mesh generation in FLUENT can use large or fine mesh sizes from pre-prepared meshes based on flow solutions (Wicaksono *et al*., 2022). The application of the computational fluid dynamic (CFD) method is used because this method is able to obtain test parameters without having to carry out actual tests. In general, the CFD simulation process can be divided into 3 stages, namely:

2.3.2.1. Pre-processing

Pre-processing is the stage of making a CFD model in the form of a CAD (Computer Aided Design) package. At this stage the room will be divided into several parts such as grids or mesh and determining boundary conditions.

2.3.2.2. Processing

The processing stage calculate the input data which is applied to the pre-processing stage which is useful as a solution seeker. The simulation process until it reaches convergence is also contained in this processing process.

2.3.2.3 Post-processing

The final stage is post-processing, where at this stage all CFD simulation data are interpreted in the form of graphs, contours, images and can even be animated according to a predetermined pattern (Tuakia, 2008).

2.3.3. Validation of results

Validation is an activity of equating simulation results with measurement results obtained in the field. If the percentage error is less than 10%, then the simulation results are said to describe the actual conditions (Anwar & Panggabean, 2019). The percentage error can be expressed by the following equation:

$$Error = \left|\frac{(X_{simulation} - X_{measure})}{X_{measure}}\right| \times 100\% \qquad (1)$$

where $X_{simulation}$ is simulated parameter (temperature or humidity), and $X_{measure}$ is measured parameters.

3. RESULTS AND DISCUSSION

3.1. Results of Meshing

In the meshing stage the geometry is divided into smaller parts. The mesh size used will affect the accuracy of the simulation analysis performed. The better the results of the mesh used, the results obtained will be more accurate. In this study, the mesh size used was 0.1 mm because this size has achieved good skewness and orthogonal values, so the resulting mesh quality is also good. The greenhouse geometry and mesh results can be seen in Figure 4.

The mesh quality criteria that must be met in carrying out the simulation are the Skewnes value < 0.98 and the Orthogonal quality value > 0.2. The quality of the simulated mesh must reach a safe range to increase the accuracy of the simulation results (Saini & Saini, 2018). This meshing process is a pre-processing stage, where in this section the process of creating a mini greenhouse 3D geometry will be divided into smaller parts or parts so that the simulation results are the same as the actual values. From the meshing process that has been carried out, the mesh values are 17113 nodes and 87099 elements with an average Skewnes value of 0.235667 and an average Orthogonal quality value of 0.76268. The quality of the meshing results can be seen in the mesh quality range table (Guhardiputra, 2022) in Figure 5.

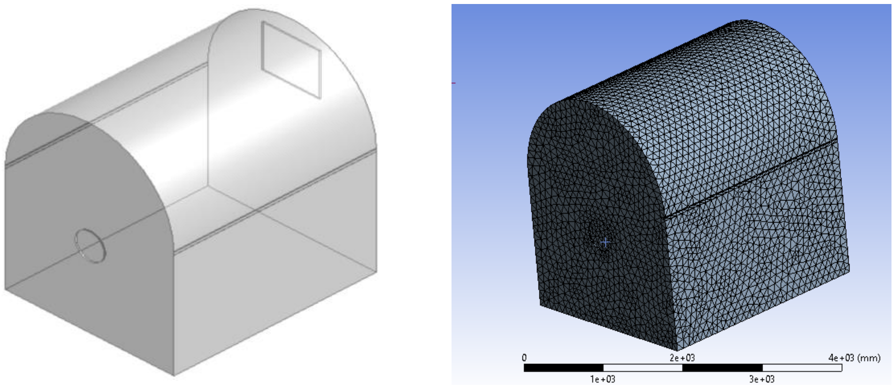


Figure 4. Greenhouse geometry and meshing results

Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.900000)
Smoothing	Medium
Mesh Metric	Orthogonal Quality
Min	3.5928e-002
Max	0.99365
Average	0.76268
Standard Deviation	0.13058

Mesh Metric	Skewness
Min	3.1995e-007
Max	0.96407
Average	0.23567
Standard Deviation	0.13227

Skewness mesh metrics spectrum:

Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

Orthogonal Quality mesh metrics spectrum:

Unacceptable	Bad	Acceptable	Good	Very good	Excellent
0-0.001	0.001-0.14	0.15-0.20	0.20-0.69	0.70-0.95	0.95-1.00

Figure 5. Meshing quality

3.2. Distribution of Temperature and RH in the Greenhouse

The results of temperature and humidity measurements can be seen in Table 1. The measured values contained in the table are the average values of three repeated measurements on day 1 to day 3. The speed variations for fan 1, fan 2 and fan 3 are 1.7 m/s, 2.0 m/s and 2.2 m/s respectively. The fan speed variation affects the temperature and RH values in the mini greenhouse. The lowest greenhouse room temperature is in the fan 1 variation at 08:00 at 25.06°C. While the highest temperature was on fan 3 at 13:00 at 35.42°C.

From the results of field measurements, the ambient temperature and the temperature in the greenhouse can be observed. Fans with a flow rate of 1.7 m/s cannot reduce the temperature in the greenhouse. Meanwhile, the fan with a flow rate of 2.0 m/s in the greenhouse tends to fall at each measurement time. Meanwhile for the fan with a flow speed of 2.2 m/s, the temperature drop only occurred at 08:00 and 16:00. Based on the measurement results, the temperature difference inside and outside the greenhouse is less than 1°C. Ventilation is still considered quite effective if the temperature rises below 6°C (Romdhonah *et al*., 2015). In other words, the greenhouse design in this study has a pretty good performance in tropical climates.

Table 1. Results of measuring temperature and relative humidity (RH)

Fan Variation	Time		Measurement of Temperature (°C) & Humidity (%)	
			Inside the Greenhouse	Outside the greenhouse
District 1	08:00	Temperature (°C)	25.06	25.03
		RH (%)	82	82
	13:00	Temperature (°C)	31.58	31.37
		RH (%)	69	68
	16:00	Temperature (°C)	27.52	27.17
		RH (%)	80	80
District 2	08:00	Temperature (°C)	25.78	25.90
		RH (%)	88	87
	13:00	Temperature (°C)	29.42	30.00
		RH (%)	79	78
	16:00	Temperature (°C)	27.59	27.63
		RH (%)	84	82
District 3	08:00	Temperature (°C)	25.96	26.23
		RH (%)	83	82
	13:00	Temperature (°C)	35.42	34.60
		RH (%)	53	54
	16:00	Temperature (°C)	32.07	32.90
		RH (%)	62	54

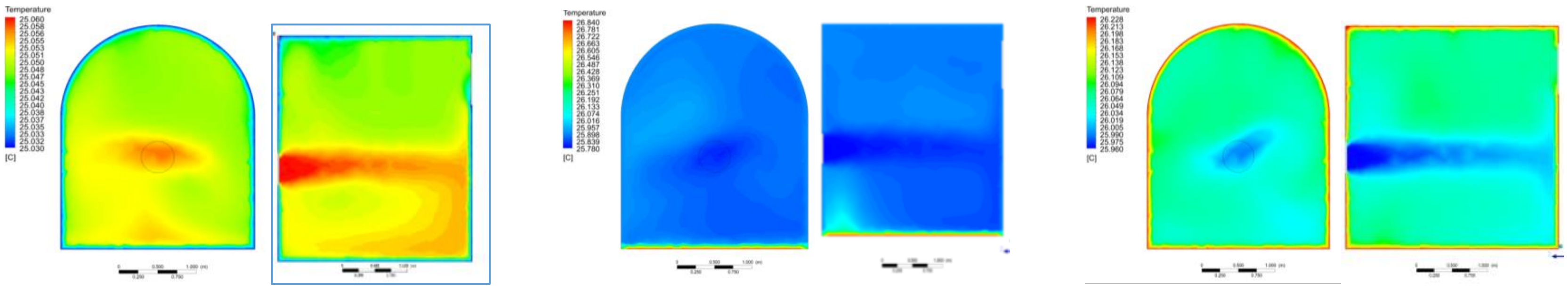
3.3. Temperature distribution in the mini greenhouse

After carrying out the pre-processing stage, the next stage is the processing stage. Processing is the process of inputting the values obtained based on measurements in the field along with the methods needed in CFD ansys to get the desired simulation results based on the previously entered values. The temperature distribution of the mini greenhouse is shown by the color gradations on the left side of the plot. The blue color represents low temperature. While the red color indicates a high temperature area.

Figure 6 explains that the speed variation 1 has a temperature distribution range that is not too high. The lowest temperature value was obtained at 25.03°C around the greenhouse wall. Meanwhile, the highest temperature of 25.06°C came from the inlet flow which then spread to the greenhouse room. In the variation of speed 2, the lowest temperature value comes from the inlet flow which then spreads to the greenhouse room, the lowest temperature is 25.7°C. However, the temperature value increases as the air flows towards the bottom of the greenhouse, reaching 26.84°C at the bottom of the greenhouse near the inlet. For the variation of speed 3, the lowest temperature was found on the inlet side towards the front of the greenhouse at 25.96°C. Meanwhile, the highest temperature is around the greenhouse wall with a temperature value of 26.23°C. Simulation of temperature distribution at 08:00 WIB.

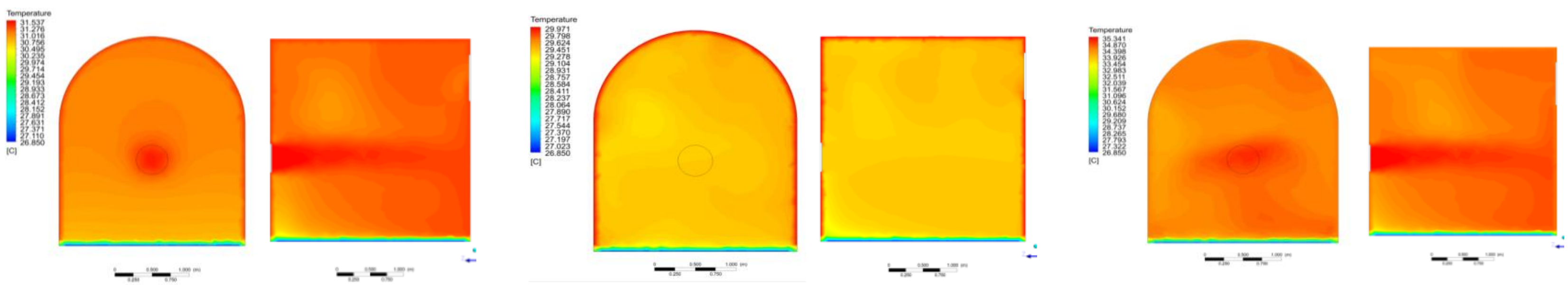
The temperature distribution at 13:00 for each fan speed variation is shown in Figure 7. At speed 1, the highest temperature was 31.53°C on the inlet side. After that the flow from the inlet spreads throughout the greenhouse room. The highest temperature at speed 2 is 29.97°C around the greenhouse wall. Meanwhile, the temperature in the greenhouse ranged from 29.27°C – 29.62°C. At speed 2, the temperature gradient near the inlet is not so obvious, but the area near the wall seems to have a higher temperature due to the higher ambient temperature. The highest temperature value at speed 3 is 35.34°C on the inlet side, which then flows into the greenhouse room. Of the three speed variations 1, 2 and 3 have the same lowest temperature, which is 26.85°C (Wibowo *et al*., 2017).

The greenhouse temperature distribution at each fan speed variation at 16:00 is presented in Figure 8. For the speed variation 1, the highest temperature 27.51 °C was obtained on the inlet side, leading to the front of the greenhouse then flowing to the bottom towards the floor. In the variation of speed 2, the highest temperature around the greenhouse wall is 27.62 °C. While the lowest temperature is 26.85 °C at the bottom of the inlet towards the greenhouse floor. At speed 2 it can be seen in the figure that the temperature distribution in the greenhouse room is uniform, which ranges from 27.51–27.57 °C. Whereas the variation of speed 3 is almost the same as speed 2, where the highest temperature is on the greenhouse wall and the lowest temperature is below the inlet. The highest temperature is 32 °C.



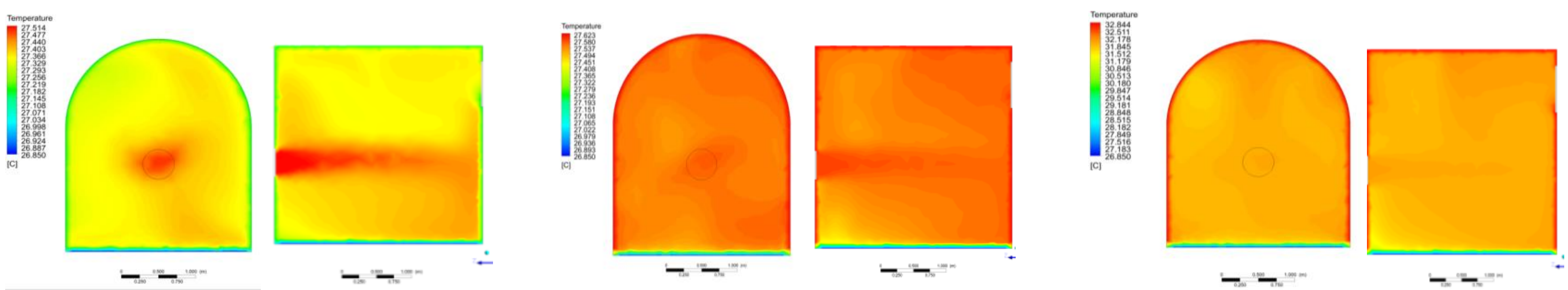
Temperature distribution simulation district 1 Temperature distribution simulation district 2 Temperature distribution simulation district 3

Figure 6. Temperature distribution simulation at 08:00 West Indonesian Time



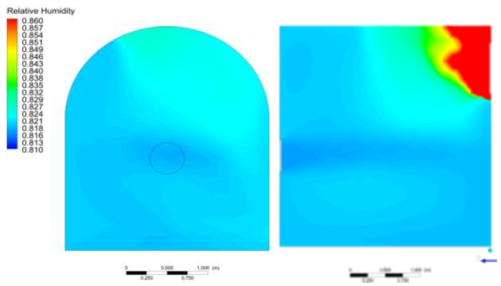
Temperature distribution simulation district 1 Temperature distribution simulation district 2 Temperature distribution simulation district 3

Figure 7. Temperature distribution simulation at 13:00 West Indonesian Time

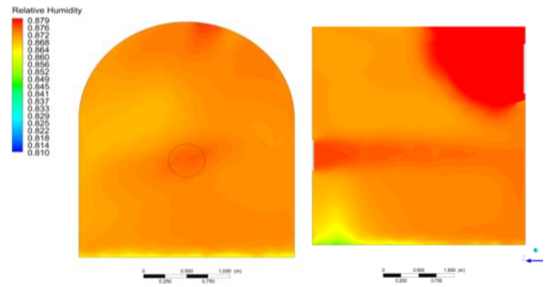


Temperature distribution simulation district 1 Temperature distribution simulation district 2 Temperature distribution simulation district 3

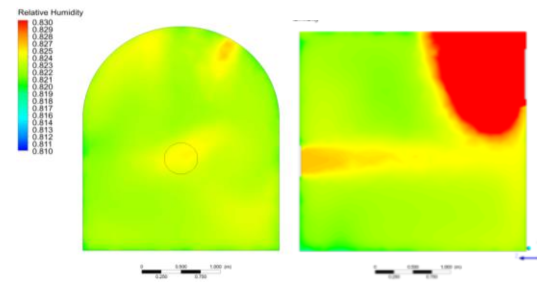
Figure 8. Temperature distribution simulation at 16:00 West Indonesian Time



RH distribution simulation district 1

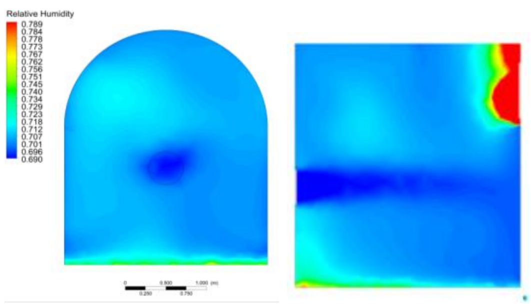


RH distribution simulation district 2

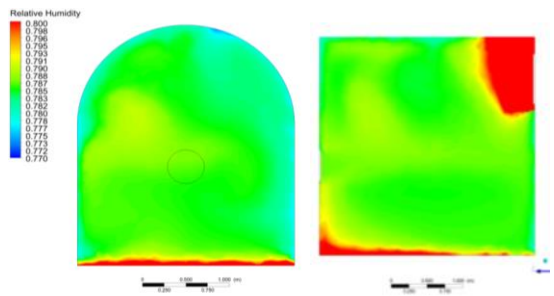


RH distribution simulation district 3

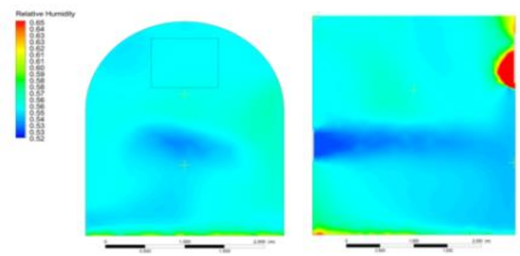
Figure 9. RH distribution simulation at 08:00 West Indonesian Time



RH distribution simulation district 1

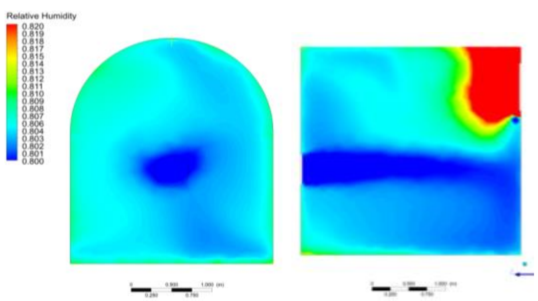


RH distribution simulation district 2

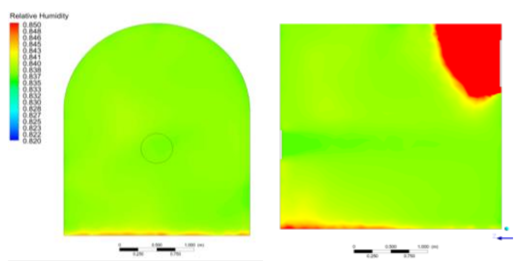


RH distribution simulation district 3

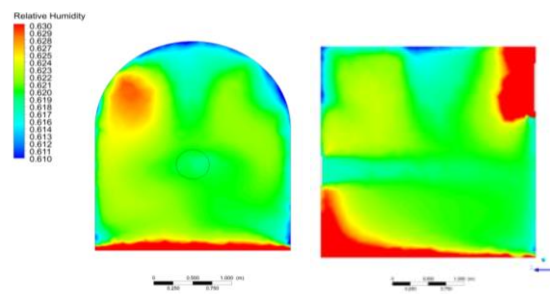
Figure 10. RH distribution simulation at 13:00 West Indonesian Time



RH distribution simulation district 1



RH distribution simulation district 2



RH distribution simulation district 3

Figure 11. RH distribution simulation at 16:00 West Indonesian Time

3.4. Distribution of relative humidity (RH) in mini greenhouses

The distribution of RH in the greenhouse at 08:00 can be seen in Figure 9. At speed 1, the bottom of the inlet flow has a higher RH than the RH at the inlet. Meanwhile, speed 2 and speed 3 have a lower room RH value than the inlet area, but the three fan variations have the same highest RH in the outlet section because the outlet area is an area in the ventilation section so it is connected to the surrounding air environment. The RH distribution of the greenhouse at 13:00 can be seen in Figure 10. At speed 1 and speed 3, the RH inlet has a lower value than that in the room. The RH value of the inlet speed variation 2 has a value that is close to the RH of the room, so that the RH contour of the flow looks more uniform with the RH of the room. Of the three fan variations, the base and outlet with the greenhouse have a higher RH value than other locations. The RH distribution of the greenhouse at 16:00 can be seen in Figure 11. For variations of speed 1 and speed 2, the distribution of RH in the greenhouse has almost the same pattern as the distribution of RH at 13:00. In the 3 speed variation, the upper side of the inlet (front view) seems to have a higher RH. Whereas in the variation of speed 3 at 08:00 and 13:00, the RH contour in the upper inlet area (top view) looks more uniform. At the 3 speed variation, the lower inlet also has higher RH values. Overall from 08:00–13:00 the highest RH is on the side around the outlet.

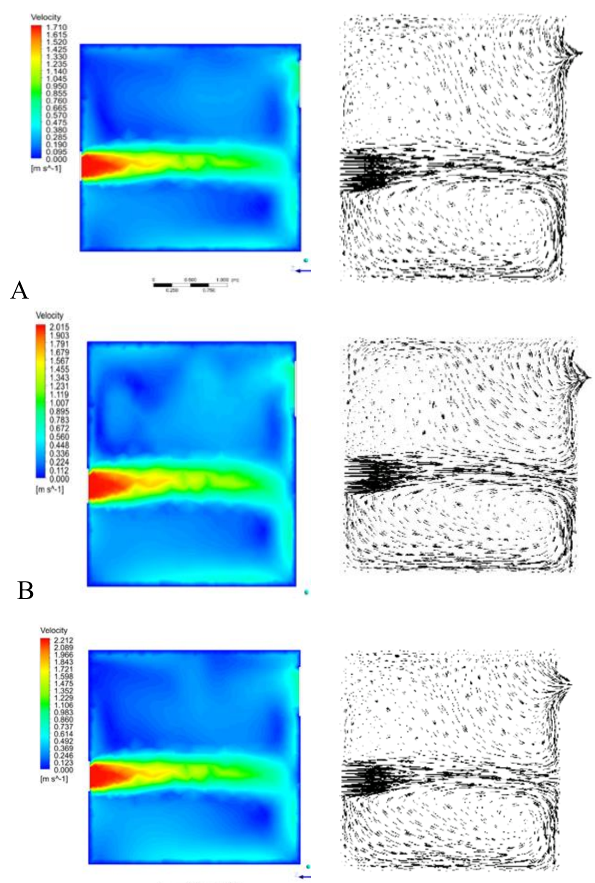


Figure 12. Simulation of wind direction distribution at fan speed 1 (A), 2 (B), and 3 (C)

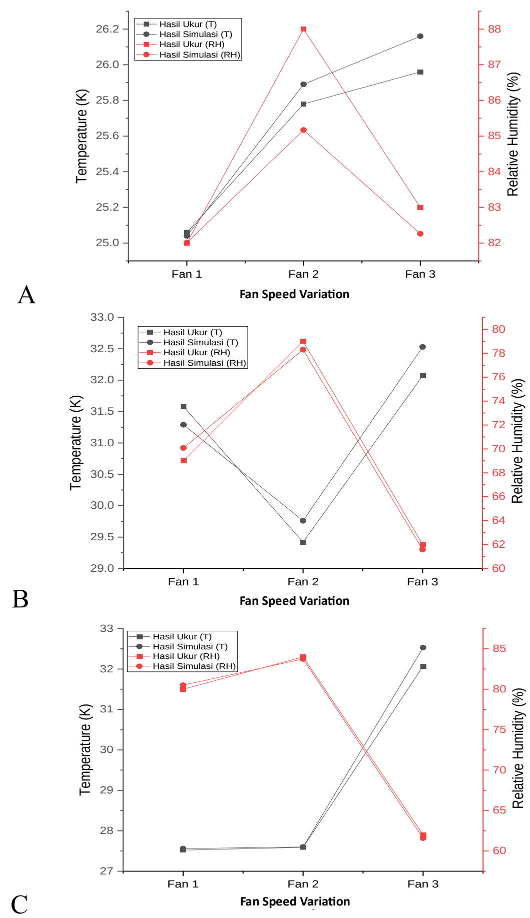


Figure 13. Graph of temperature and RH at 08:00 (A); 13:00 (B); and 16:00 West Indonesian Time (C)

3.5. Distribution of wind direction in a mini greenhouse with CFD simulation

Fan with a speed of 1, which is 1.7 m/s, the air from the inlet fan flows into the room, after which it hits the wall in front of the greenhouse. The air velocity after the collision tends to decrease and is deflected in all directions. In addition, the vector pattern that is formed also indicates that there is a vortex flow at the bottom of the between flow fan and base wall. Simulation of wind direction distribution at fan speed 1 can be seen in Figure 12 (A). At wind direction at speed 2 with air flow of 2.0 m/s, it can be observed that the airflow pattern is still similar to the case of speed 1 in Figure 45. However, the air velocity at speed 2 is higher. This is characterized by higher values on the contour and velocity vector density. The eddy flow formed in the velocity vector looks denser and elongated. Simulation of the distribution of wind direction with fan speed 2 can be seen in Figure 12 (B). Contours and velocity vectors for speed 3 can be seen in Figure 12 (C). The fan speed variation in this case is the highest. The velocity vector in this case is the densest and the longest indicates the highest speed. The vortex flow that is formed is the most dense and longest.

3.6. Validation of simulation results with field measurement results

The post-processing stage is the last stage in the ansys simulation, where the value of the simulation results will be compared with the value of the measurement results in the field to find out how similar the values obtained from the simulation results are to the actual values. Based on Table 2 of the validation results below, the parameters in the form of temperature and relative humidity from the measurement results can be predicted quite well by numerical simulations. The highest error value from the simulation results to the measurement results is 4.04%. With the results of these error values, the greenhouse simulation results with CFD in this study can be said to be valid and correct, where the error value is less than 10% (Anwar & Panggabean, 2019).

Based on the validation results in the field with the simulation results, it can be explained using a graph between the results in the field and the simulation results using CFD. The following is a graph of the similarities between field measurement values and simulated values using CFD ansys. At 08:00 WIB, the temperature tends to rise when the fan speed increases from the variation of speed 1 to the variation of speed 3, while the RH value increases from the variation of speed 1 to speed 2, but at speed 3 the RH tends to decrease to the RH value at speed 1. In the graph it can be seen that the value of the simulation results at speed 2 is equal to 85.17% while the results of field measurements are 88%, so there is little difference in the value between the value of the measurement results in the field and the value of the simulation results. The validation graph between temperature and RH at 08:00 WIB can be seen in Figure 13 (A). At 13:00 the temperature dropped from the variation of speed 1 to the variation of speed 2, this was caused by the lower ambient temperature. However, it rose again at the 3-speed variation because the ambient temperature was too high. While the trend of changes in RH increased from variation of speed 1 to variation of speed 2, then decreased to variation of speed 3. It can be seen from the line graph that the values obtained from the simulation results are not nearly the same as the values measured in the field. The validation graph between temperature and RH at 13:00 WIB can be seen in Figure 13 (B). At 16:00 the temperature tends to rise when the fan speed increases from the variation of speed 1 to speed 3. Meanwhile the RH value increases from speed 1 to speed 2 and then tends to decrease at speed 3. From the graph it can be said that the value of the simulation results obtained is the same as the measurement results in the field, because on the graph it can be seen that the line between the value of the simulation results and the line of values of the measurement results in the field is one. The validation graph between temperature and RH at 16:00 can be seen in Figure 13 (C).

Table2. Validation results of simulation results with field measurement results

Time	**Fan Variation**	**Temperature (°C)**			**RH (%)**		
		Measuring	Simulation	Error(%)	Measuring	Simulation	Error (%)
08:00	District 1	25.06	25.04	0.08	82	82.01	0.012
	District 2	25.78	25.89	0.43	88	85.17	3.22
	District 3	25.96	26.16	0.77	83	82.26	0.89
13:00	District 1	31.58	31.29	0.92	69	70.08	1.57
	District 2	29.42	29.76	1.16	79	78.30	0.89
	District 3	35,42	34.58	2.37	53	55.14	4.04
16:00	District 1	27.52	27.26	0.95	80	80.50	0.625
	District 2	27.59	27.60	0.04	84	83.73	0.32
	District 3	32.07	32.53	1.43	62	61.58	0.68

3.7. Simulation of Temperature and Humidity Distribution with Fan Speed Variations

3.7.1 Simulation of temperature distribution

Simulation of temperature distribution by applying 3 fans in one mini greenhouse with the same fan flow rate of 1.7 m/s at 13:00 obtained the simulation results in Figure 14 (left). The distribution of temperature flow can be said to be spread evenly when compared to the use of one fan, where the highest temperature of 31.53°C came from the inlet flow then headed to the front of the greenhouse and spread to the greenhouse room, while the lowest temperature of 26.85°C was at the bottom of the greenhouse. If you look at the simulation results in the 3D greenhouse room and the side view, it is found that the temperature distribution is even from the front to the middle of the greenhouse, while the temperature at the back which is close to the fan tends to decrease, ranging from 30-31°C.

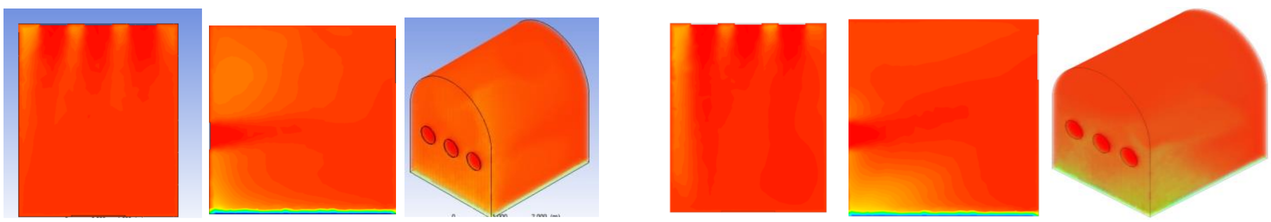


Figure 14. Temperature distribution by using 3 fans with the same speed (left) and different speeds (right)

While the temperature distribution simulation by adding 3 fans with different speeds for each fan, namely 1.7 m/s, 2,0 m/s and 2.2 m/s can be seen in Figure 14 (right). The distribution of temperature flow in the greenhouse is even, the area at the bottom of the inlet with the highest speed of 2.2 m/s tends to lower the temperature inside the greenhouse when compared to fans with speeds of 1.7 m/s and 2.0 m/s. That's because the fan with a speed of 2.2 m/s is the fan with the highest speed, so the air exhaled by the fan is able to reduce the temperature in the area under the fan's flow.

3.7.2 Simulation of humidity distribution

Figure 15 (left) shows the RH distribution using 3 fans with the same flow speed of 1.7 m/s. In the figure it can be seen that the distribution of RH also tends to be even. Where the area at the inlet has a lower RH than the RH of the room. When compared to the use of 1 fan, where the highest RH is at the outlet (ventilation) so the use of fans in greenhouses is less optimal when compared to the use of 3 fans which can increase and distribute RH optimally.

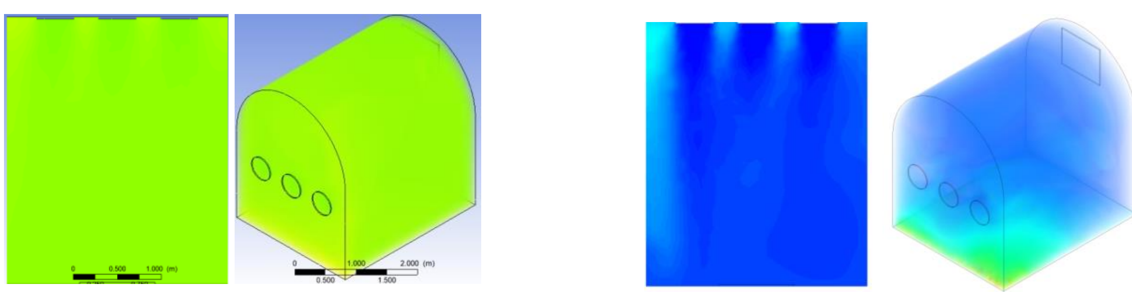


Figure 15.Distribution of RH by using 3 fans with the same speed (left) and different speeds (right)

The RH distribution of the greenhouse using 3 fans with different speeds at 13:00 is shown in Figure 15 (right). The RH at the bottom of the inlet at the highest speed of 2.2 m/s has a higher value compared to the other bottom areas of the inlet. Meanwhile, the RH values of the inlet velocity variations of 2.0 m/s, 1.7 m/s and 2.2 m/s have values that are close to the RH of the room, so that the RH contour of the flow looks more uniform with the RH of the room.

3.7.3. Simulation of wind direction distribution

The simulation of the distribution of wind directions can be seen in Figure 16 (left). The use of 3 fans with the same speed of 1.7 m/s in a mini greenhouse can reach all parts of the greenhouse. Air comes from the inlet, towards the front of the greenhouse and there is a collision, so that the air is deflected all over the inside of the mini greenhouse. In the figure it can be seen that the use of 3 fans in a mini greenhouse is able to distribute air well when compared to the use of 1 fan, where the air tends after the impact on the front to be deflected to the lower area or the ground floor of the greenhouse only.

While the wind direction uses 3 fans with different speeds in each fan, it can be seen that the air distribution produced by the 3 fans is able to spread evenly in the greenhouse, but the fan with a speed of 2.2 m/s can produce higher airflow and a wider spread. more relatively regular when compared to fans 1.7 m/s and 2.0 m/s. Where the fan with a speed of 2.2 m/s is more able to deliver air from the fan to the front area of the greenhouse. While fans of 1.7 m/s and 2.0 m/s can also deliver air in all directions of the greenhouse, however, the air flow is immediately scattered before it reaches the front of the greenhouse. The image of the simulation results of the distribution of wind directions using 3 fans with different flow speeds can be seen in Figure 16 (right).

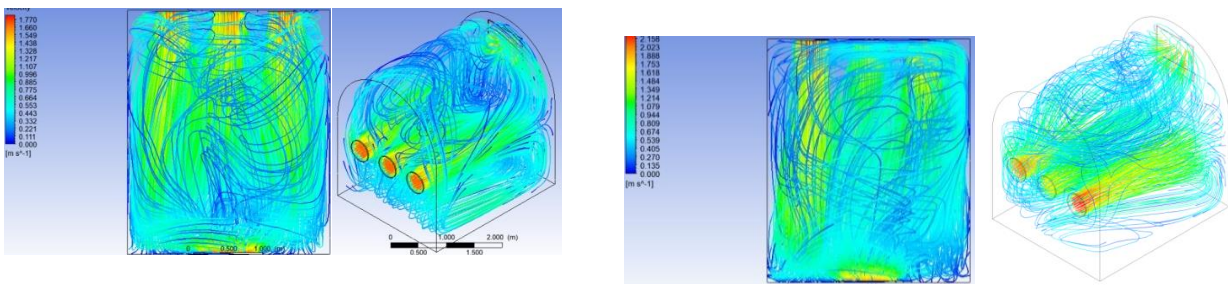


Figure 16. Distribution of wind direction by using 3 fans with the same speed (left) and different speeds (right)

4. CONCLUSIONS AND SUGGESTION

4.1. Conclusion

Based on the research that has been done, it can be concluded that, fan speed and data collection time affect the temperature and RH in the greenhouse. Fan variations with speed 1.7 m/s cannot reduce the temperature in the greenhouse. While fan variations with speed 2.0 m/s can lower the temperature at each measurement time. Meanwhile for fan speed 2.2 m/s, the temperature drop only occurred at 08:00 and 16:00 RH has the same trend of changing values from 08:00 to 16:00, that is, the value increases from variation of speed 1.7 m/s to speed 2.0 m/s, then decreases to speed 2.2 m/s. Meanwhile, temperature has a pattern that tends to be random. High fan speed can increase vortex flow in the room. CFD numerical simulation can predict the temperature and RH of the mini greenhouse room quite well when compared to the measurement results, where the highest error value is 4.04 %.

4.2. Suggestion

It is necessary to collect data from measurement results or numerical simulations at the same boundary conditions. For example, data collection was carried out at 13:00 on the same day with various fan speed variations. Due to limitations, this cannot be done.

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