Journal of Information System and Technology Management JISTM
EISSN: 0128-1666

Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

JOURNAL OF INFORMATION SYSTEM AND TECHNOLOGY MANAGEMENT (JISTM)
www.jistm.com

GLOBAL ACADEMIC EXCELLENCE

COMPUTER ASSISTED VENTILATION OPTIMIZATION IN NARROW AND LONG SINGLE-SPAN GREENHOUSES IN YANGTZE RIVER DELTA VIA CFD SIMULATION

Zhang WeiJian [1], Nurnida Elmira Othman [2*], Azli Abd Razak [3]

[1] School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia
Email: m15751010257@163.com
[2] Wind Engineering & Building Physics (WEBP); School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia
Email: nurnida@uitm.edu.my
[3] Wind Engineering & Building Physics (WEBP); School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Malaysia
Email: azlirazak@uitm.edu.my
[*] Corresponding Author

Article Info:

Article history:
Received date: 30.04.2025
Revised date: 21.05.2025
Accepted date: 03.06.2025
Published date: 30.06.2025

To cite this document:

Zhang, W., Othman, N. E., & Razak, A. A. (2025). Computer Assisted Ventilation Optimization in Narrow and Long Single-Span Greenhouses in Yangtze River Delta via CFD Simulation. *Journal of Information System and Technology Management, 10* (39), 265-284.

DOI: 10.35631/JISTM.1039018

Abstract:

In the Yangtze River Delta, weak summer wind conditions often lead to inadequate air circulation in greenhouses, particularly in narrow and elongated single-span structures, negatively affecting crop growth. This study combines computational fluid dynamics (CFD) simulations with experimental validation to optimize the ventilation performance of such greenhouses. The validated CFD model (RMSE = 1.55, MAE = 1.09) analyzed three cases: baseline (no side windows), and two designs with 45° and 90° side window openings. The original greenhouse design without side windows was called Case A. In Case A, the average indoor wind speed in the modeling condition was 0.38m/s; there were 9 points with less than 0.3m/s. Redesign simulation experiments were carried out by adding side windows to the greenhouse; the openings were set to 45° and 90°, respectively. The case with 45° side windows was called Case B, and the case with 90° side windows was called Case C. Results show significant improvements in airflow, with average wind speeds increasing from 0.38 m/s (baseline) to 1.71 m/s (90° window). Ventilation efficiency also varied with external wind speed and direction. When the vector of the direction in the east-west direction increases, the average wind speed in the greenhouse increases. In Case A, the east-west direction vector component increased from 34% to 99%, resulting in a slight rise of 0.15 m/s in greenhouse wind speed. In Case B, the same vector increase led to a substantial 1.21 m/s rise in indoor wind speed. Case C also saw the vector increase from 34% to 99%, contributing to a 1.03 m/s increase in average indoor wind speed. These

Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

findings offer practical design guidance to enhance natural ventilation in narrow single-span greenhouses in low-wind regions.

Keywords:

Single-span Greenhouse; Gas Flow Improvement; Side Windows; CFD; Yangtze River Delta Region

Introduction

In summer, due to the weak wind speed in the Yangtze River Delta region, many greenhouses face the problem of insufficient air flow. The narrow, long single-span greenhouse is particularly prominent because of its special structure. Air flow is a significant indicator in greenhouse cultivation. If the air flow is insufficient in the greenhouse, it is easy to affect the efficiency of plant photosynthesis and cause plant diseases, which are both unconducive to greenhouse cultivation. The Yangtze River Delta region has a large population and complex terrain. Due to regional restrictions, greenhouses are often built narrow and long, in such greenhouses, that makes the problem worse and needs to be paid special attention.

Scope

The CFD and experiments were combined to study the gas flow improvement problems of narrow and long single-span greenhouses in the Yangtze River Delta region. Figure 1 illustrates the specific research pathway. This study aims to developed strategies to benefit the improvement of air flow in a single-span greenhouse in the Yangtze River Delta region in summer to relieve the problem of single-span greenhouse was prone to poor air circulation in the weak wind characteristics environment in summer in the Yangtze River Delta region. Experiment and CFD simulation was used to optimize the ventilation design to improve the air flow. Alao the air flow in greenhouse under different wind speeds and directions was analyzed.

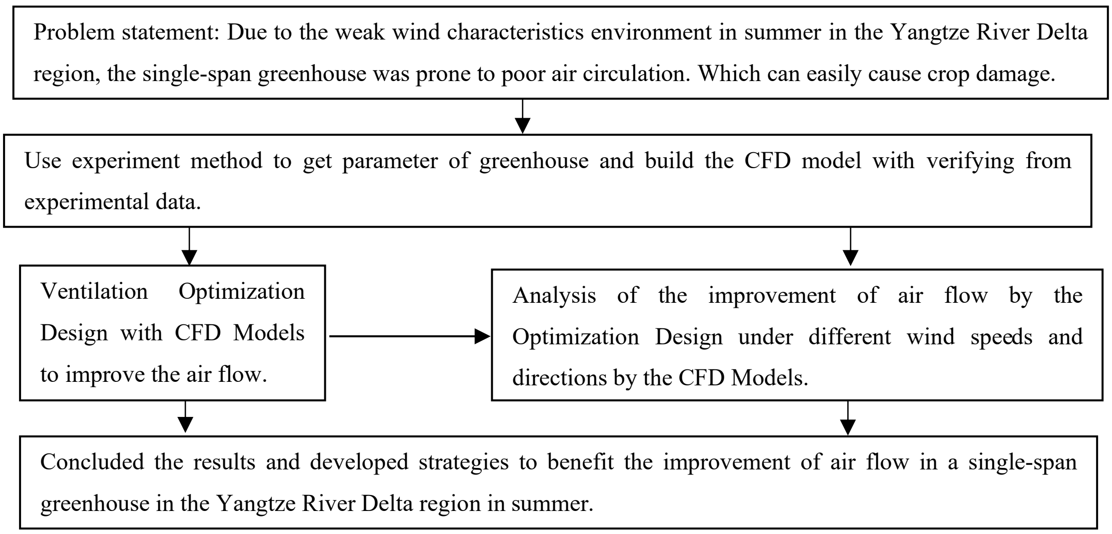


Figure 1: Overall Research Framework

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

Objectives

The objectives of this paper can be summarized as follows: (1) To examine the airflow within the narrow greenhouse during summer natural ventilation, (2) To utilize CFD models to enhance the greenhouse ventilation design and promote increased air circulation, (3) To assess the effects of varying outdoor wind speeds and directions on the optimized greenhouse ventilation design.

Literature Review

In the study of single-span greenhouses, Ogunlowo (2021) conducted a comparative analysis between single-span and multi-span greenhouses and found that there were apparent differences in the performance of many greenhouse parameters when they were given the same condition, proving single-span greenhouses need to follow different regulation rules from multi-span greenhouses. Kim (2024) found that the ventilation rate of a single-span greenhouse increases linearly with ventilation area and outdoor wind speed. Kim (2022) studied the height of side vents of single-span greenhouses in South Korea and found that higher side vents lead to a negligible difference in greenhouse indoor and outdoor temperatures. Li (2024) built a numerical model for a single-span greenhouse in a high-altitude area and verified the model using experimental data. The results showed that measured values agreed with simulated values. Many experts and scholars have already done a lot of research on promoting the gas flow of the greenhouse by adjusting the ventilation [10]. Xin Lyu (2022) found that the size of the side window and the crop height had a significant effect on the micro-environment in the greenhouse. Furthermore, wind speed had a weaker impact on the microclimate than the effects of side window size. Mohammad Akrami (2020) found that the location of the side vents affects convection loops and air flow rate at the plant level in the greenhouse. Changes in roof vents had a distinct effect on the temperature and airflow rate of the roof area but had little impact on the plant layer area. You (2023) studied the use of greenhouses for tomato cultivation and found that proper ventilation can create a suitable thermal environment for the growth of tomatoes.

In the study of the impact of the wind environment on greenhouses, Chu (2019) studied the effectiveness of ridge vents for greenhouse ventilation. It was found that wind direction greatly influences the indoor ventilation of greenhouses. Teitel (2008) found that wind direction significantly impacts flow patterns at roof openings. In addition, wind direction also significantly affects greenhouse ventilation rate and air temperature distribution. Fatnassi (2009) studied the effect of wind direction on greenhouses and found that wind direction strongly correlates with crop height and leaf area index.

Edwin Villagran (2020) conducted a study on a single-span greenhouse built in the Colombian Caribbean environment, and the main results obtained showed that under the experimental conditions, based on the thermal effect driving natural ventilation, the average velocity of airflow inside the greenhouse was less than 0.5 m/s. It was also found that temperature values between the interior and exterior of the greenhouses were below 2.0 °C, and the relative humidity values were below -6.3% under the Colombian Caribbean region meteorological feature. These values were low compared to other parts of the world. Barlin D (2021), in his study of single-span greenhouse, defined windward-only roof vent ventilation as A, leeward-only roof vent ventilation as B, windward sidewall vent with leeward roof vent ventilation as C, and leeward sidewall vent with windward roof vent ventilation as D. The study found that A and B were relatively less affected by outdoor wind speed. Type C provides adequate airflow

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018
at outdoor wind speeds of 2 to 3 m/s, while type D provides a favorable greenhouse microclimate at 4 to 6 m/s. The key findings was shown in Table 1.

Based on the above literature analysis, it can be seen that although many scholars have studied the internal gas flow environment of greenhouses since the greenhouse is greatly affected by the regional climate, the research in different regions can only be used as a reference and cannot be used as direct theoretical guidance. In addition, previous greenhouse research has focused chiefly on plastic or glass multi-span greenhouses, with fewer studies on narrow and long glass single-span greenhouses. However, few studies about the internal gas flow of single-span greenhouses in the Yangtze River Delta region must be supplemented.

Table 1: Key Findings

Author	Theoretical Framework	Design factors	Key Result
Qazeem Opeyemi Ogunlowo (2021)	CFD	Number of spans	Temperature difference between the center and sides was about 0.88-1.0 °C in single-span greenhouses, and about 1.03 °C in multi-span greenhouses.
Xin Lyu (2022）	CFD	Size of side windows	Wind speed had a weaker effect on the microclimate compared to the effect of side window size.
Chia-Ren Chu(2019)	CFD	Ridge vents opening or closing	Ridge vents of greenhouses should be oriented directly towards the prevailing wind direction.
Edwin Villagran (2020)	CFD	Colombian Caribbean environment	Study on single-span greenhouse built in the Colombian Caribbean environment.

Methodology

The main research methods used in this study were experiments and CFD simulation. The specific process was shown in Figure 2, which mainly included experimental analysis and simulation model built and verification as well as simulation experiments and summary results and strategy development.

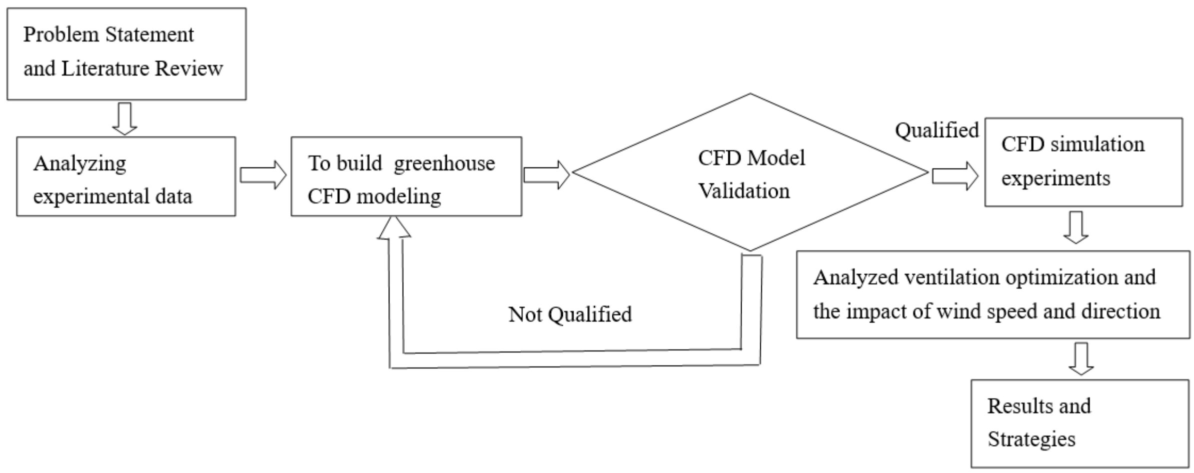


Figure 2: Flow Chart of the Processes

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

Experiment

The experimental greenhouse was located in Shanghai, the Yangtze River Delta. The greenhouse was 60 meters long, 8 meters wide, and 4.3 meters high. It was a typical narrow and long single-span greenhouse. The greenhouse had a fully open roof and no side windows. There were doors in the south and north greenhouse walls. The south door was 2 meters wide, and the north was 0.1 meters wide; both were 2 meters high.

The experiment was conducted on July 30. The ZDR-3WIS temperature and humidity sensor was used to measure the internal temperature and humidity of the greenhouse. The data was automatically read every 5 minutes. The sensor's layout in the greenhouse was shown in Figure 3. The inverted triangle shape in the figure represented the sensor. The sensors were distributed on three levels, namely C-C, D-D, and E-E. The specific dimensions were marked in the figure. The TYD-ZS2 weather station measured environmental parameters outside the greenhouse; the distance from the greenhouse was 5 meters. The weather station parameters included outdoor temperature, humidity, radiation, wind speed, wind direction, etc. The data was automatically read every minute. A Fluke infrared thermometer measured the inside and outside ground and the temperatures of the east, west, south, north, and roof glass walls.

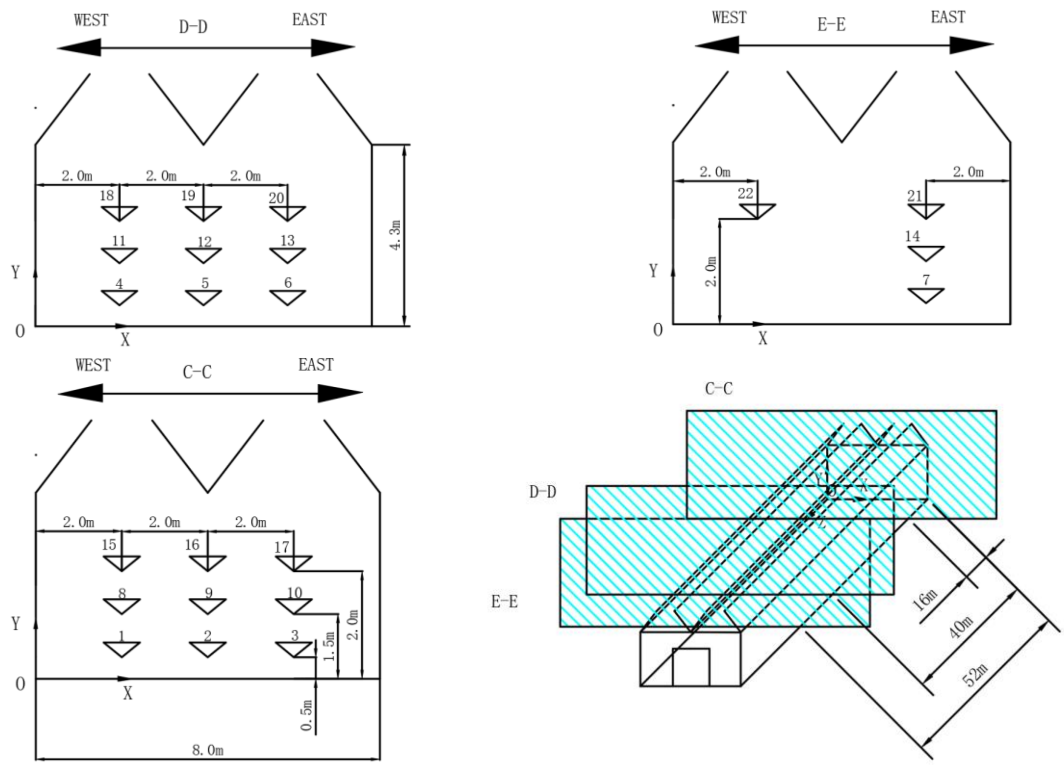


Figure 3: Sensors layout in the greenhouse

Source: Experiment

CFD Modeling

Upon completion of the experiment, data from 12:33 on the experimental day were selected as the modeling boundary condition. The calculation domain was established to be ten times the size of the greenhouse, as illustrated in Figure 4. To minimize calculation error, the doors and roof openings meshes were refined, resulting in a total of 4.04 million meshes. Additional

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018
calculations yielded 0.6 million and 1.92 million meshes, respectively. Following these calculations, mesh independence was confirmed in the model.

The model utilized the Energy Equation alongside the Discrete Ordinates Radiation Model. By calculating the Rayleigh number, it was determined that the airflow in the experimental greenhouse was turbulent. Additionally, experimental analysis was conducted using the Standard Turbulence Model and the Standard Wall Function model for simulation purposes.

In the experiment, a single layer of shade net was utilized within the greenhouse. This approach, along with insights from existing research literature and the physical parameters of the shade net implemented in the experimental greenhouse, enabled the simulation of greenhouse shading through a radiation reduction method. Consequently, the outdoor solar radiation value decreased from 797 W/m² to 449 W/m² for the greenhouse under a single layer of shade net.

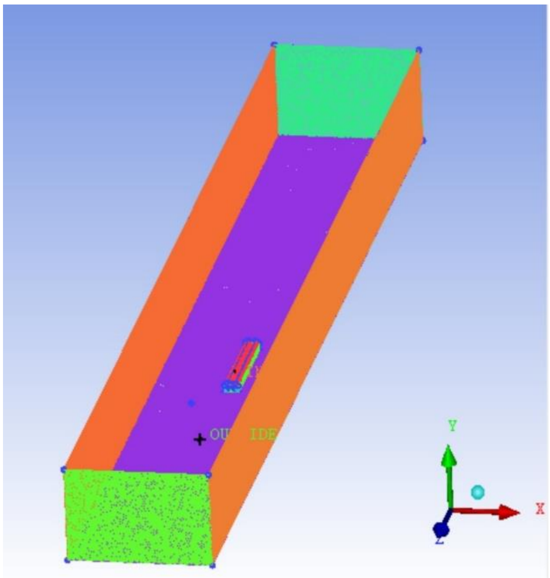


Figure 4: Mesh

Source: CFD Simulation

The air inlet temperature in the calculation domain was set at 36.5℃ based on the experimental measurement. Table 2 and Table 3 show material properties and boundary conditions in the simulation. As shown in Table 1, the simulation mainly used three materials, air was a fluid, concrete and glass were solids. Table 2 shown the simulation setting temperatures of different glass walls and floors, and the temperatures were from experimental collected. The SIMPLE algorithm was used to do the calculation.

Table 2: Material Properties

Material type	Density /kg.m^{-3}	Specific heat capacity /Jkg^{-1}.K^{-1}	Thermal conductivity /Wm.K^{-1}	Absorption coefficient /m^{-1}	Refraction Rate
Concrete	2100	880	1.4	0.6	1.6
Glass	2500	700	0.7	0.1	1.7
Air	1.17	1 025.5	0.03	0	1.0

Source: Simulation Setting

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

Table 3: Temperatures of the wall and floor

Area	Outside floor	Inside floor	South wall	North wall	East wall	West wall	Roof glass
Temperature/℃	54.1	39.9	38.8	36.0	35.5	37.2	39.4

Source: Experimental measured

CFD Model Verification Analysis

The simulated data are compared with experimentally measured data at sensor locations P1–P22 to validate the CFD model. It was found that the maximum relative error was 9.5%, averaging 4.4%, the maximum absolute error was 3.83℃, and the RMSE and MAE values were 1.55 and 1.09. The comparison between the simulation and experiment values is shown in Figure 5, which indicates strong agreement. The CFD model can accurately reflect the greenhouse environmental situation.

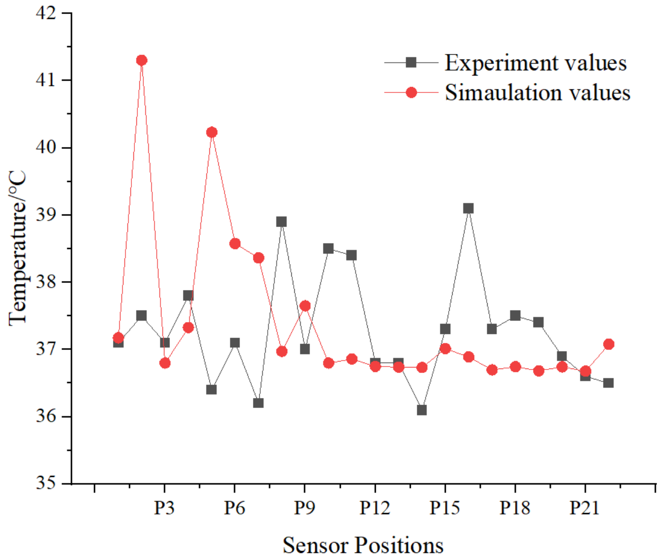


Figure 5: Simulated and Measured Values Comparison

Source: Experiment and Simulation

Results and Discussion

Case A Greenhouse Airflow Analysis

For discussion and analysis, the current greenhouse operating conditions have been designated as Case A. Figure 6 illustrates the gas flow conditions at X=2, X=4, and X=6 within the Vertical Sections of Case A. Despite the greenhouse featuring a fully open roof, the prevailing weak wind conditions during the summer in the Yangtze River Delta region result in several areas experiencing slow gas flow (less than 0.5 m/s), which can lead to potential crop damage.

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

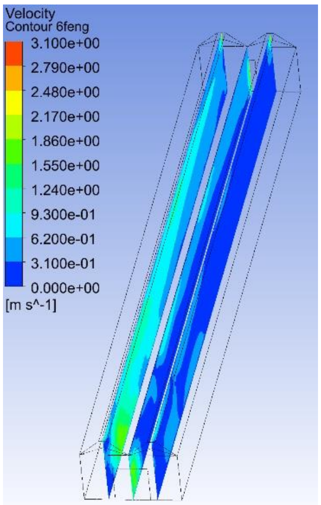


Figure 6: Airflow of Case A

Source: Simulation

The greenhouse's narrow and elongated design restricts airflow, with the south door only impacting a small adjacent area. As a result, the central section experiences inadequate circulation, particularly along the south-north axis. Enhancing airflow throughout the greenhouse is crucial for improving overall environmental conditions.

As shown in Table 4, for Case A, the average wind speed at each measuring point was 0.38m/s, which was relatively low. In the greenhouse, there were 9 points with wind speeds less than 0.3m/s among the 22 measuring points, and the minimum speed was 0.05m/s. The air flow in the greenhouse area needs to be enhanced. If plants were in such slow air flow areas for a long time, it would efficiently inhibit plant photosynthesis and easily cause plant diseases and insect pests, affecting crop yields.

Table 4: Case A ventilation quality analysis

The average wind speed at each measuring point	**Number of measuring points less than 0.3m/s**	**Minimum wind speed at the measuring point**
0.38m/s	9	0.049 m/s

Source: Simulation

Effect Of Window Opening Angle

To solve the problems, the greenhouse ventilation structure was redesigned to improve the air flow with the CFD simulation. Considering the characteristics of the greenhouse itself, side windows on the east and west walls were to be added. The height of the side windows was 2 m, and the installation height on the greenhouse wall was 0.3 m to 2.3 m to adapt to the height of the plant planting. To observe the influence of side window opening on the airflow, the opening of the east and west side windows was set to 45° for Case B and 90° for Case C, as shown in Figure 7.

Journal of Information System and Technology Management JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

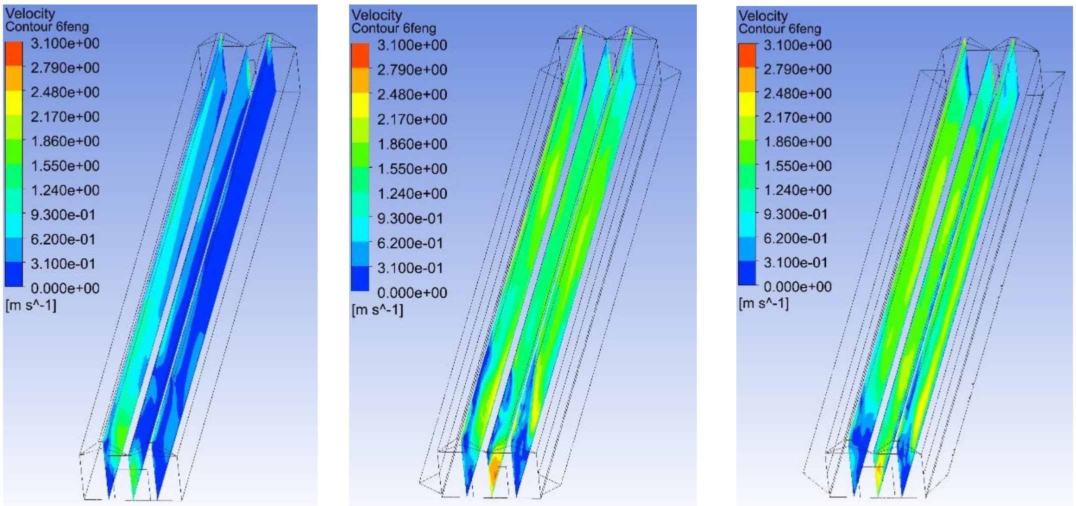


Figure 7: Comparison of Case A, B, and C Under Operating Conditions

Source: Simulations

In Case B, the gas flow was significantly better than the current operating condition of Case A. After adding the side windows, the gas flow has been improved considerably. The lack of airflow in the south-north direction was supplemented by the east-west airflow, ensuring the gas flow activity. At the same time, after the airflow enters the greenhouse from the east-west direction, part of the airflow has the characteristics of upward movement affected by the oblique angle of the side windows, which causes the airflow activity to be partially lost at the plant height. In Case C, right-angle side windows were used. In the east-west direction of the greenhouse, the airflow has no momentum loss, so after the airflow enters the side windows, it presents a more significant flow force, which provides better flow characteristics for the plant area compared to Case B.

Figure 8 was a comparison of the wind speeds at each measurement point of Case A, Case B, and Case C. Through the comparison, it was found that the ventilation was significantly improved after adding side windows. By the Formula (1), the average wind speeds at each measuring point of Case A, Case B, and Case C were 0.38 m/s, 1.55 m/s, and 1.71 m/s, respectively, as shown in Table 5. The ventilation improvement effect of adding 90° side windows was more evident than that of 45°. In Case B and Case C, the values of all measurement points were greater than 0.3m/s.

$$\mu = \frac{\sum v_i}{n} \tag{1}$$

In the formula,
μ represented the average wind speed of each measuring point;
v_i represented the wind speed value of each measuring point;
n represented the number of measuring points.

Table 5: Average Wind Speed

	Case A	**Case B**	**Case C**
The average wind speed at each measuring point/ m/s	0.38	1.55	1.71

Source: Simulations

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018
By the Formula (2), the standard deviations of wind speeds at each measuring point of Case A, Case B, and Case C were 0.31m/s, 0.26m/s, and 0.44m/s, respectively, as shown in Table 6. From a numerical point of view, Case B also has a better uniform distribution.

$$\sigma = \sqrt{\frac{\sum (v_i - \mu)^2}{n}} \quad (2)$$

In the formula,
μ represented the average wind speed of each measuring point;
v_i represented the wind speed value of each measuring point;
n represented the number of measuring points;
σ represented the standard deviation.

Table 6: Standard Deviations

	Case A	Case B	Case C
Standard deviations of wind speeds at each measuring point/ m/s	0.31	0.26	0.44

Source: Simulations

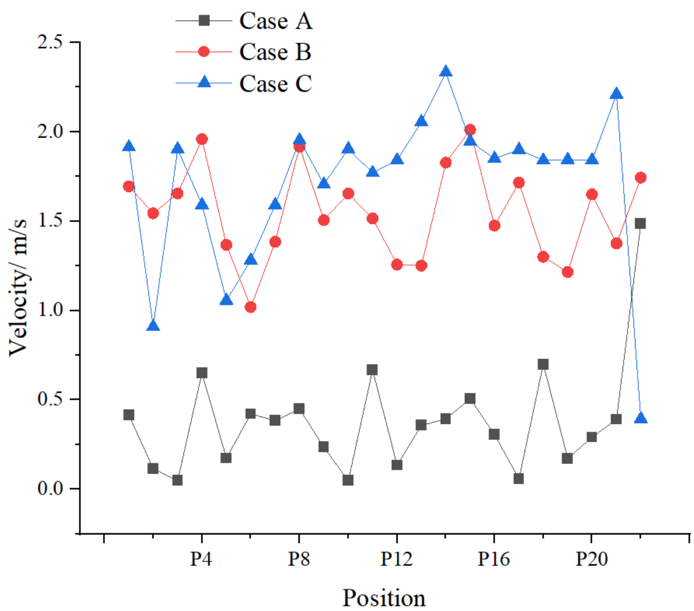


Figure 8: Wind Speed At Each Measuring Point Comparison
Source: Simulations

Effect Of Wind Speeds
To enhance the practicality of the design. To investigate the effectiveness of ventilation redesign, simulations of Case A, Case B, and Case C with different wind speeds were conducted. In the Yangtze River Delta region, daytime wind speeds are generally between 0.5 and 1.7 m/s in summer. The wind speed rose diagram on the day of the experiment is shown in Figure 9. Three wind speed conditions of 0.7 m/s, 1.1 m/s, and 1.5 m/s were selected for comparative simulation experiments to investigate the effect of wind speed on greenhouses with different work conditions.

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

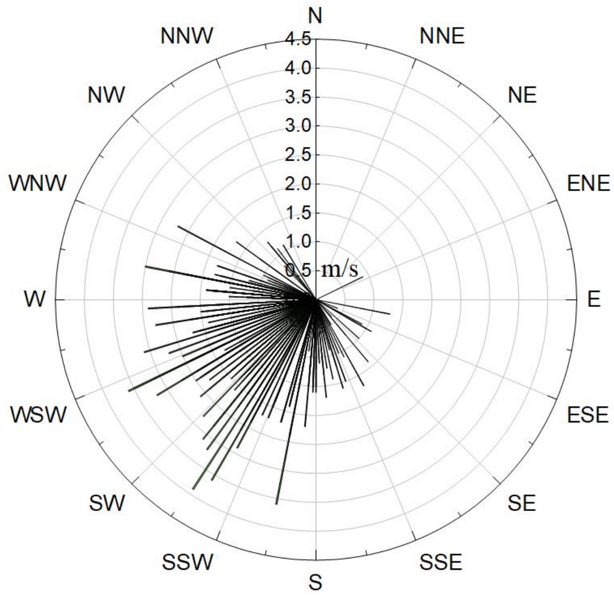


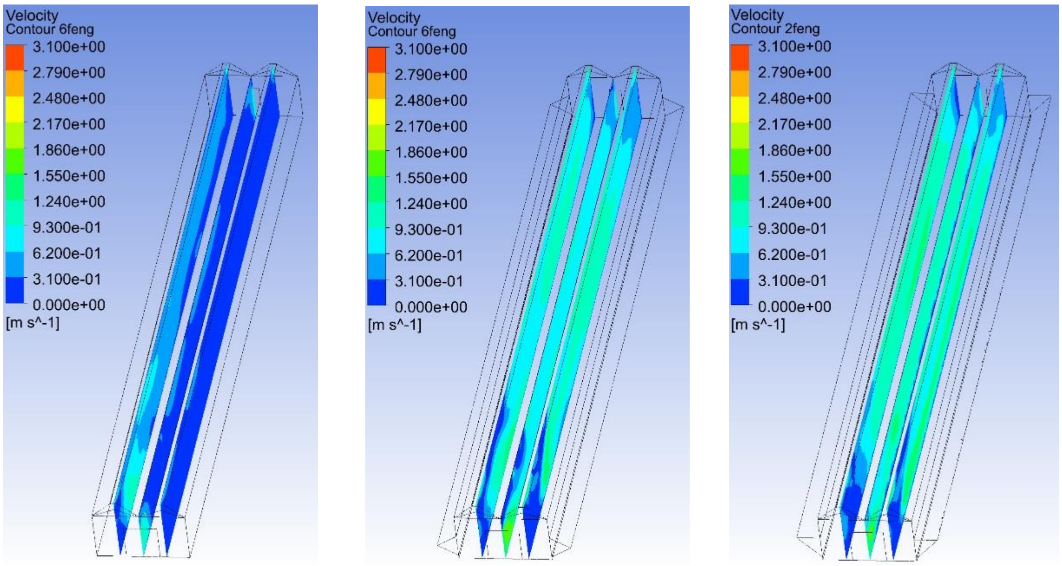
Figure 9: Wind Speed Rose Diagram On The Day Of The Experiment
Source: Experiment measured

Figure 10 compares three wind speeds of 0.7m/s, 1.1m/s, and 1.5m/s for Case A, Case B, and Case C. All three cases show stronger external wind speed results in a more substantial internal gas flow.

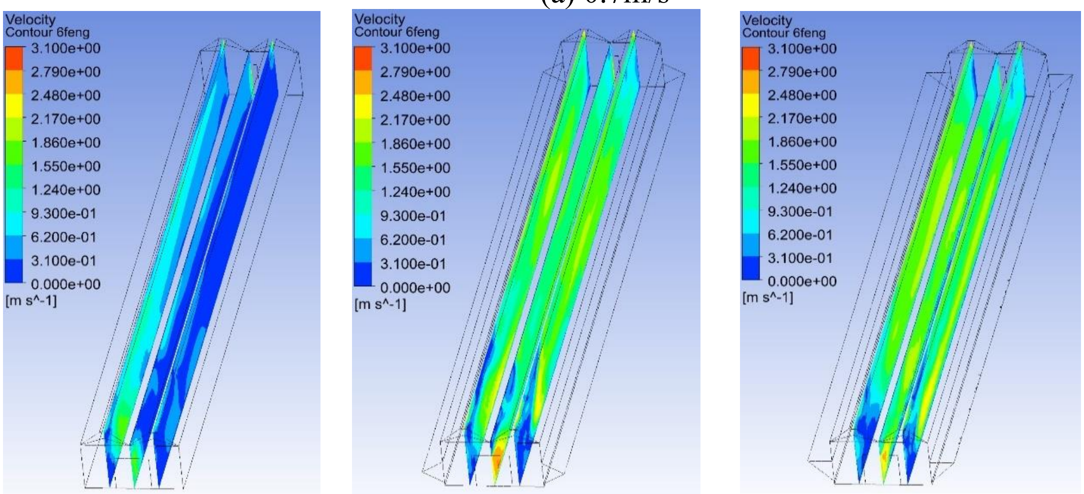
Case A was the least affected by external wind speed compared with Case B and Case C. Case A was the least affected by external ventilation compared with Case B and Case C. In this case, the lack of side windows made the internal gas flow insensitive to external airflow. Despite an intense wind speed of 1.5 m/s, some areas still had slow airflow.

In Case B, the strong external airflow can smoothly enter the greenhouse from the east-west direction due to the side windows. Also, due to the angle, part of the momentum of the airflow was guided upward, slowing down the movement speed in the horizontal direction. Case C responds best to external airflow; the east-west direction of external airflow entered the greenhouse without momentum loss with the right-angle side window design.

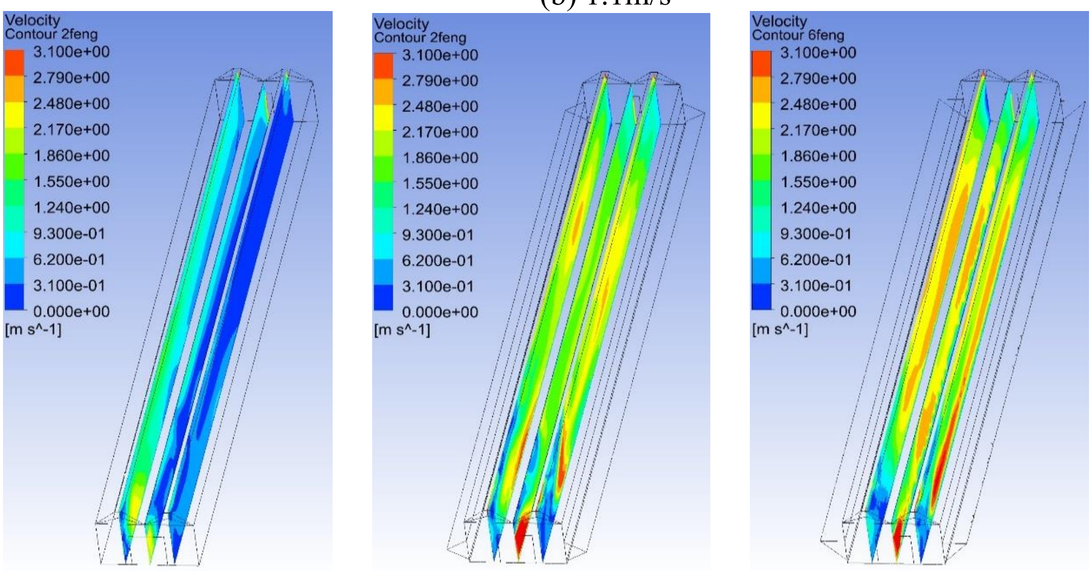
Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018



(a) 0.7m/s



(b) 1.1m/s



(c) 1.5m/s

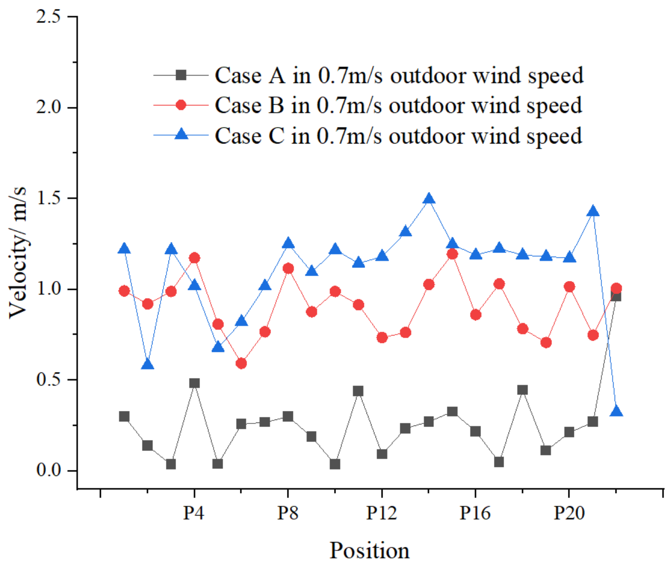
Figure 10: Comparison of Case A, B, and C Under Different Wind Speeds

Source: Simulations

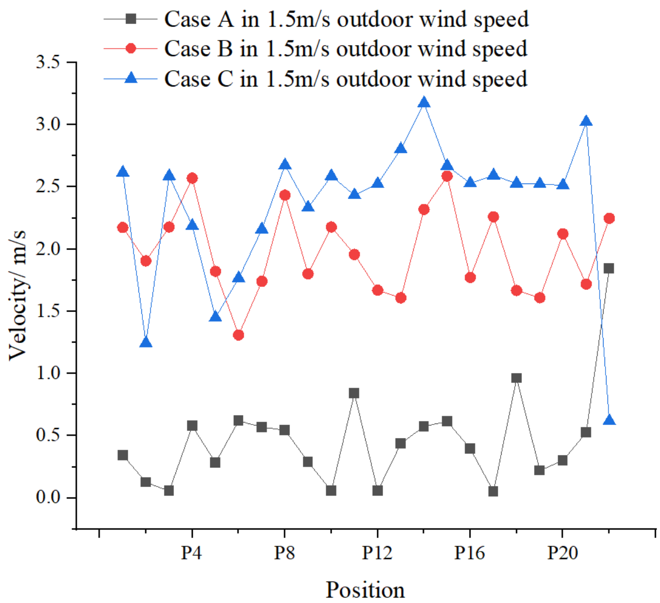
Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

When facing weak airflow, Cases A, B, and C showed insufficient gas flow inside the greenhouse. However, in comparison, Case A was the worst, and Case C was the best among the three work conditions. When the external gas flow power was weak, the right-angled side windows of Case C were conducive to the external airflow entering the greenhouse without power loss, improving the gas flow inside the greenhouse.

The angled side windows of Case B can only use part of the external air momentum to propel horizontally in the greenhouse, and the air flow in the greenhouse was relatively sufficient, but it was not as good as that of Case C. For Case A, since there were no side windows, it cannot fully utilize the east-west wind speed, weakening the internal gas flow in the greenhouse when facing weak external airflow.



a. Outdoor speed of 0.7m/s



b. Outdoor speed of 1.5m/s

Figure 11: Comparison of Wind Speed At Each Measuring Point

Source: Simulations

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018
When the outdoor wind speed was 0.7m/s, in Case A, the average wind speed at each measuring point was 0.26m/s, and there were 17 points with a wind speed less than 0.3m/s indoors. The indoor wind speed was very low, and the air flow in a large greenhouse area was insufficient, which could not meet the ventilation conditions for plant growth.

Table 7 compares average wind speeds with wind speeds in Case A, Case B, and Case C. Compared with Case A, the comparison showed that Case B and Case C can still maintain good ventilation at the outdoor wind speed of 0.7m/s. The average wind speed of each measuring point of Case B increased by 0.65m/s, and Case C increased by 0.84m/s. At an outdoor wind speed of 1.5m/s, compared with Case A, Case B increased by 1.52m/s, and Case C increased by 1.87m/s. Figure 11 compares the wind speeds at indoor measurement points of Case A, Case B, and Case C. Case C has better air flow performance under various working conditions.

Table 7: Average Wind Speed

	Case A	Case B	Case C
Average wind speed of each measuring point with outdoor 0.7m/s wind speed / m/s	0.26	0.91	1.10
Average wind speed of each measuring point with outdoor 1.1m/s wind speed / m/s	0.38	1.55	1.71
Average wind speed of each measuring point with outdoor 1.5m/s wind speed / m/s	0.47	1.99	2.34

Source: Simulations

Table 8 shows the standard deviation of wind speeds at each point under various working conditions. Case B has the most uniform indoor air flow distribution under different working conditions.

Table 8: Standard Deviations

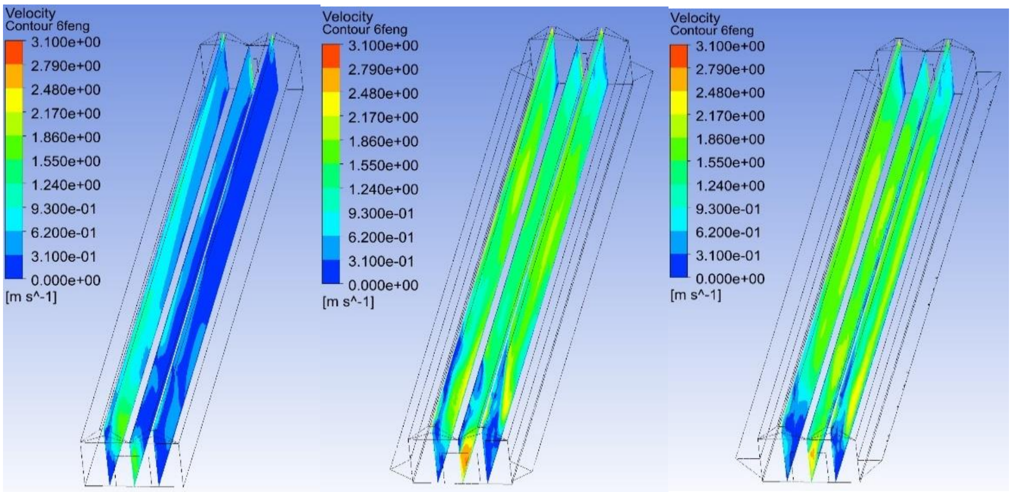
	Case A	Case B	Case C
Standard deviation of measuring points with 0.7m/s outdoor wind speed / m/s	0.21	0.16	0.27
Standard deviation of measuring points with 1.1m/s outdoor wind speed / m/s	0.31	0.26	0.44
Standard deviation of measuring points with 1.5m/s outdoor wind speed / m/s	0.39	0.34	0.59

Source: Simulations

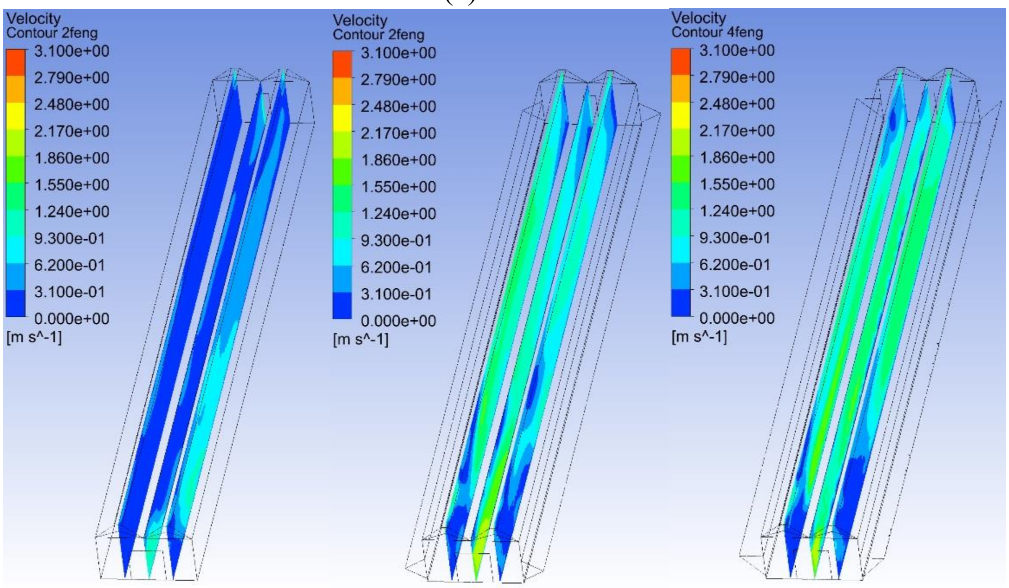
Effect Of Wind Directions

Based on the analysis of the prevailing wind direction in the Yangtze River Delta region in summer, three angles of 147°, 200°, and 270° were selected for comparative simulation experiments to investigate the impact of wind direction on greenhouses with different work conditions. Figure 11 compares three wind directions of 147°, 200°, and 270° for Cases A, B, and C.

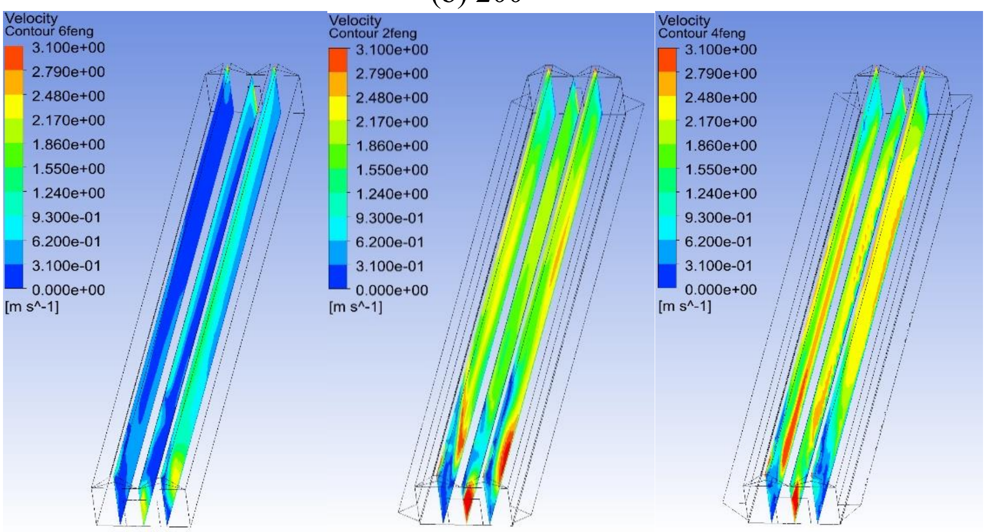
Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018



(a) 147°



(b) 200°



(c) 265°

Figure 12: Comparison of Case A, B, and C Under Different Wind Directions

Source: Simulations

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

As it was shown in Figure 12. Case A was least affected by the external wind direction, Case B was more affected, and Case C was the most affected. For Case B and Case C, the trend of being affected by wind direction was the same, and Case C was slightly stronger than Case B in terms of degree. In addition, it can be seen that for the south-north layout greenhouse, when the east-west component of the wind direction was more significant, the ventilation conditions of Case B and Case C were significantly better. When the south-north element in the wind direction was more important, it was still good only near the south door; in other areas, the air activity was limited.

Experimental analysis found that the size of the component of wind direction perpendicular to greenhouse side windows greatly influences greenhouse ventilation. Using side windows in the greenhouse can increase the greenhouse's utilization of outdoor wind. The experimental greenhouse was oriented north-south. When the wind direction is 90° or 270°, the direction is perpendicular to the side windows.

Figure 13 shows the change in average wind speed at each measuring point in a greenhouse, with the vector component value of wind direction in an east-west direction. As the figure shows, the same rule was presented in the three working conditions: when the wind direction vector in the east-west direction increases, the average wind speed in the greenhouse increases. As illustrated in Table 9, the inclusion of side windows significantly influences the effect of wind direction on indoor wind speed. In Case A, the vector component ranges from 34% to 99%, resulting in a modest increase of only 0.15 m/s in the indoor average wind speed. In Case B, the vector component spans from 34% to 99%, but the indoor average wind speed rises by 1.21 m/s this time. Likewise, in Case C, where the vector component remains at 34% to 99%, the indoor average wind speed experiences an increase of 1.03 m/s.

This indicates that the design should consider the prevailing wind direction in the Yangtze River Delta region for greenhouses with side windows. Aligning the greenhouse with this wind direction can take better advantage of wind utilization during the summer months.

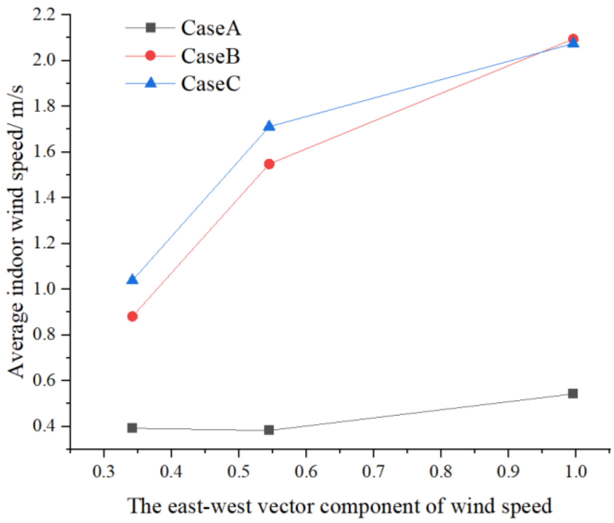


Figure 13 Comparison of Vector Component Proportion And Average Wind Speed
Source: Simulations

Journal of Information System and Technology Management JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

Table 9: Comparison Of Vector Component Proportion And Indoor Wind Speed

	200° outdoor wind direction	147° outdoor wind direction	265° outdoor wind direction
Vector component percentage/ %	0.34	0.55	0.99
The average wind speed of each measuring point in Case A/ m/s	0.39	0.38	0.54
The average wind speed of each measuring point in Case B/ m/s	0.88	1.55	2.09
The average wind speed of each measuring point in Case C/ m/s	1.04	1.71	2.07

By comparing wind speed values' standard deviation under different wind speed conditions, as shown in Table 10, it was found that in Case B, all indoor wind speeds were most evenly distributed in various wind directions.

Table 10: Standard Deviation Of Each Measuring Point Under Three Working Conditions At Different Wind Speeds

	200° outdoor wind direction	147° outdoor wind direction	265° outdoor wind direction	total
Standard deviation of measuring points in Case A/ m/s	0.31	0.31	0.54	1.16
Standard deviation of measuring points in Case B/ m/s	0.3	0.26	0.47	1.03
Standard deviation of measuring points in Case C/ m/s	0.53	0.44	0.69	1.66

Source: Simulations

Conclusion

Findings

This paper studies air flow in the Yangtze River Delta's narrow, long, single-span greenhouses. (1) The study found that under the influence of weak wind climate in the Yangtze River Delta in summer, many airflow stagnation areas exist in the narrow and long single-span greenhouses without side windows, and the airflow needs to be improved. The greenhouse was simulated using CFD, and the turbulence calculation used the $k-\varepsilon$ Standard Turbulence Model. Experimental data verified the CFD model; the RMSE and MAE values were 1.55 and 1.09,

Journal of Information System and Technology Management
JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018
and the model was effective. Without side windows, the average indoor wind speed was 0.38m/s. There were 9 points with less than 0.3m/s in the greenhouse among 22 measuring points. The gas flow in the greenhouse needs to be improved.

(2) Redesign simulation experiments were conducted by introducing side windows to the greenhouse at 45° and 90°, respectively. Adding these side windows significantly enhanced the gas flow within the greenhouse. For the 45° side windows, the average wind speed at each measuring point was recorded at 1.55 m/s, while the 90° side windows resulted in an average of 1.71 m/s. In both configurations, no measuring point registered a wind speed lower than 0.3 m/s. The standard deviations for Cases A, B, and C were 0.31 m/s, 0.26 m/s, and 0.44 m/s, respectively. Case C demonstrated superior air flow improvement capabilities, while Case B exhibited the most uniform indoor air flow distribution across all working conditions.

(3) Under varying wind speed conditions, it was demonstrated that the side window configuration significantly enhances the gas flow within the greenhouse. At an outdoor wind speed of 0.7 m/s, the average value at each measuring point in Case B increased by 0.65 m/s compared to Case A, while Case C exhibited an increase of 0.84 m/s. Similarly, at an outdoor wind speed of 1.5 m/s, Case B showed an average increase of 1.52 m/s over Case A, and Case C increased by 1.87 m/s. Case C demonstrated superior air flow improvement capabilities. Furthermore, analyzing the standard deviations of wind speeds at various measuring points under each condition revealed that Case B offered the most uniform distribution of indoor air flow.

Three angles 147°, 200°, and 270° were selected for comparative simulation experiments focusing on the impact of wind direction. The inclusion of side windows notably influenced the effect of wind direction. Specifically, the average indoor wind speed increased when the wind direction vector aligned with the east-west axis. In Case A, the east-west direction vector component rose from 34% to 99%, resulting in a modest indoor wind speed increase of just 0.15 m/s. In contrast, Case B exhibited a similar vector increase but achieved a significant rise in average indoor wind speed of 1.21 m/s. Case C, while also experiencing the exact vector change, saw an average indoor wind speed increase of 1.03 m/s.

Suggested Improvement Measures

(1) In light of the characteristics of the weak wind climate experienced in the Yangtze River Delta region during summer, it is advisable to incorporate side windows into the design of narrow, elongated single-span greenhouses to enhance ventilation. Various side window configurations yield different indoor ventilation outcomes. Case C demonstrates superior airflow performance, while Case B achieves the most uniform indoor air distribution. A suitable side window opening can be selected based on specific planting requirements.

(2) To maximize the benefits of outdoor wind, it is advisable that when constructing greenhouses with side windows in the Yangtze River Delta region, the orientation of the side windows should be positioned as perpendicular to the prevailing summer wind direction as possible. This approach will enhance air circulation and improve airflow within the greenhouse.

Contribute

This study had enriched the understanding of the air flow characteristics of single-span greenhouses in the Yangtze River Delta region to a certain extent and the Suggested improvement measures would provide positive guidance for the use of these greenhouses.

Limitations and Prospects

The research findings were primarily derived from CFD model simulations. Although experimental data have validated the simulation model, discrepancies between the simulations and real-world conditions are to be expected. Additionally, the study predominantly concentrated on speed, a relatively simplified analysis aspect.

Future research could employ experimental methods to investigate the impact of side windows on the internal airflow of narrow and long single-span greenhouses in the Yangtze River Delta region, while also considering a broader range of influencing factors.

Acknowledgement

The authors express their deepest gratitude to Universiti Teknologi Mara (UiTM) for providing the resources and support necessary to conduct this research. Thanks to the academic supervisors for invaluable guidance, technical expertise, and encouragement throughout this study.

References

Abdel-Ghany, A. M., Picuno, P., Al-Helal, I., Alsadon, A., Ibrahim, A., & Shady, M. (2015). Radiometric characterization, solar and thermal radiation in a greenhouse as affected by shading configuration in an arid climate. *Energies*, *8*(12), 13928-13937. doi: https://doi.org/10.3390/en81212404

Abdel-Ghany, A. M., & Al-Helal, I. M. (2011). Analysis of solar radiation transfer: A method to estimate the porosity of a plastic shading net. *Energy Conversion and Management*, *52*(3), 1755-1762.doi: https://doi.org/10.1016/j.enconman.2010.11.002

Abid, H., Ketata, A., Lajnef, M., Chiboub, H., & Driss, Z. (2024). Impact of greenhouse roof height on microclimate and agricultural practices: CFD and experimental investigations. *Journal of Thermal Analysis and Calorimetry*, *149*(11), 5483-5495.

Ansys Fluent Theory Guide (2021). ANSYS. Inc.

Akrami, M., Javadi, A. A., Hassanein, M. J., Farmani, R., Dibaj, M., Tabor, G. R., & Negm, A. (2020). Study the effects of vent configuration on mono-span greenhouse ventilation using computational fluid dynamics. *Sustainability*, *12*(3), 986. doi: https://doi.org/10.3390/su12030986

Barlin, D., & Bello-Ochende, T. THE EFFECT OF VENT CONFIGURATION ON NATURAL CIRCULATION OF FLOWS AND HEAT TRANSFER IN A GREENHOUSE. Department of Mechanical Engineering, University of Cape Town.

Chu, C. R., & Lan, T. W. (2019). Effectiveness of ridge vent to wind-driven natural ventilation in mono-slope multi-span greenhouses. *Biosystems Engineering*, *186*, 279-292.

Fatnassi, H., Leyronas, C., Boulard, T., Bardin, M., & Nicot, P. (2009). Dependence of greenhouse tunnel ventilation on wind direction and crop height. *biosystems engineering*, *103*(3), 338-343.

Kim, H. K. (2024). Evaluating the ventilation performance of single-span plastic greenhouses with continuous screened side openings. *Agronomy*, *14*(7), 1447.

Journal of Information System and Technology Management JISTM
EISSN: 0128-1666
Volume 10 Issue 39 (June 2025) PP. 265-284
DOI: 10.35631/JISTM.1039018

Kim, S. H., Kim, H. K., Lee, S. Y., & Kwon, J. K. (2022). Effect of different heights of side vents on microclimate in a single-span greenhouse during natural ventilation. *Journal of Bio-Environment Control*, *31*(2), 90-97.

Li, Y., Zhao, S., Dai, A., Zhang, J., Fan, Z., & Ding, T. (2024). Study on the Natural Ventilation Model of a Single-Span Plastic Greenhouse in a High-Altitude Area. *Agronomy*, *14*(9), 2166.

Lyu, X., Xu, Y., Wei, M., Wang, C., Zhang, G., & Wang, S. (2022). Effects of vent opening, wind speed, and crop height on microenvironment in a three-span arched greenhouse under natural ventilation. *Computers and Electronics in Agriculture*, *201*, 107326. doi: https://doi.org/10.1016/j.compag.2022.107326

Mao, Q., & Li, H. (2024). Simulation of ambient temperature and humidity distribution in an eight-span greenhouse under different wind conditions and corn height. *Case Studies in Thermal Engineering*, *61*, 105099.

Ogunlowo, Q. O., Akpenpuun, T. D., Na, W. H., Rabiu, A., Adesanya, M. A., Addae, K. S., ... & Lee, H. W. (2021). Heat and mass distribution analysis in a single- and multi-span greenhouse microclimate. *Agriculture*, *11*(9), 891.

Rasheed, A., Lee, J. W., Kim, H. T., & Lee, H. W. (2019). The efficiency of different roof vent designs on natural ventilation of a single-span plastic greenhouse. *Journal of Bio-Environment Control*, *28*(3), 225-233.

Sun, M., Wang, J., & He, K. (2020). Analysis of the urban land resources carrying capacity during urbanization—A case study of the Chinese YRD. *Applied Geography*, *116*, 102170.

Teitel, M., Ziskind, G., Liran, O., Dubovsky, V., & Letan, R. (2008). Effect of wind direction on greenhouse ventilation rate, airflow patterns, and temperature distributions. *Biosystems Engineering*, *101*(3), 351-369.

Turcotte, D.; Schubert, G. (2002). Geodynamics (2nd ed.). New York: Cambridge University Press.

Villagran, E., Leon, R., Rodriguez, A., & Jaramillo, J. (2020). 3D numerical analysis of the natural ventilation behavior in a Colombian greenhouse established in warm climate conditions. *Sustainability*, *12*(19), 8101. doi: https://doi.org/10.3390/su12198101

Yoon, J., Song, H., & Jang, E. S. (2024). Computational fluid dynamics analysis of ventilation characteristics with various design parameters in single-span greenhouses. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *46*(1), 11938-11951.

Yu, G., Zhang, S., Li, S., Zhang, M., Benli, H., & Wang, Y. (2023). Numerical investigation for natural light and ventilation effects on 3D tomato body heat distribution in a Venlo greenhouse. *Information Processing in Agriculture*, *10*(4), 535-546.

Zhang, J., Zhao, S., Dai, A., Wang, P., Liu, Z., Liang, B., & Ding, T. (2022). Greenhouse natural ventilation models: how do we develop them with Chinese greenhouses? *Agronomy*, *12*(9), 1995.