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Performance Analysis of Fan Configurations for Greenhouse Cooling under Abu Dhabi Climatic Conditions, A Case Study from Al Kuwaitat Research Station, Al Ain, UAE

Ali AlShrouf[a]*, Nora Al Numai[b] ,Jouke Campen[c]

[a,b]*Lead Researcher, Al Kuwaitat Research Station, Abu Dhabi Agriculture and Food Safety Authority Al Ain, Abu Dhabi, United Arab Emirates*
[c]*International Project Manager, Wageningen University and Research – Greenhouse Horticulture, PO Box 644, 6700 AP Wageningen, Netherlands*
[a]*Email: ali.alshrouf@adafsa.gov.ae*
[b]*Email: noura.alnuaimi@adafsa.gov.ae*
[c]*Email: jouke.campen@wur.nl*

Abstract

This short communication presents an evaluation of cooling efficiency in an agricultural greenhouse located at Al Kuwaitat Research Station, Al Ain, UAE, under the climatic conditions of Abu Dhabi. The study focused on comparing fan configurations, with particular attention to the performance of upper fans. Among the tested scenarios, running only the upper fans (Scenario 2) demonstrated the most effective cooling performance, as indicated by significant temperature differences recorded across multiple sensors. This enhanced cooling effect is likely due to improved airflow patterns and heat dissipation facilitated by the strategic placement of the upper fans. To ensure the accuracy and continuity of temperature data, sensors were regularly maintained and calibrated, and a redundant system was implemented to prevent data loss. These measures helped avoid gaps in the dataset, which are critical for reliable analysis. The findings highlight the importance of fan configuration and data integrity in optimizing greenhouse climate control under arid conditions.

Keywords: Evaporative cooling; Desiccant dehumidification; Hybrid systems; Greenhouse; Microclimate; Humidity; Temperature decrease; Natural ventilation; Vent configuration; Wind effect; Airflow pattern; Ventilation energy-saving; Horizontal airflow fan; Radial airflow fan; Variable air volume.

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* *Corresponding author.*

1. Introduction

In the UAE's arid climate, managing heat inside greenhouses is a critical challenge. Excessive temperatures can severely impact plant health, reduce crop yields, and increase the risk of disease. To address this, cooling systems-particularly those using fans-are essential for maintaining optimal temperature and humidity levels. Recent research has explored how different fan configurations influence cooling performance. The study by [1] provides valuable insights into how fan type affects greenhouse microclimate. By comparing horizontal airflow fans (HAFs) and radial airflow fans (RAFs), the researchers found that RAFs offer superior temperature and humidity uniformity. This is particularly important in the UAE, where uneven cooling can lead to localized heat stress, affecting plant growth and increasing susceptibility to pests and diseases. The findings support the use of RAFs in single-span greenhouses, especially for crops sensitive to microclimate fluctuations.

Another approach involves Variable Air Volume fan-pad systems, as studied by [2], which allow dynamic control of airflow based on cooling demand. This flexibility is crucial in the UAE, where daytime temperatures fluctuate rapidly. While higher fan speeds improve cooling, they also raise energy consumption, making it essential to find a balance. Their study highlights the need for smart control systems that adjust fan speed in response to real-time temperature and humidity data, optimizing both climate control and energy efficiency. Author in [3] at North Carolina State University compared naturally ventilated (NV) and fan-ventilated greenhouses (FV). In the UAE, NV systems may struggle due to low wind speeds and high ambient temperatures, making FV systems more effective. When paired with evaporative cooling pads, FV systems provide consistent cooling, which is vital for maintaining crop productivity. However, the cost and energy requirements of FV systems must be weighed against their performance benefits

In terms of cooling technologies, as shown in [4] conducted a comprehensive review of evaporative cooling methods, including fan-pad, fogging, and roof cooling systems. Among these, fan-pad systems remain popular due to their simplicity and effectiveness. However, their performance depends on water quality**,** pad maintenance**,** and ambient humidity levels**.** In extremely dry conditions, fogging may offer supplementary cooling, but it requires precise control to avoid over-humidification. Looking at integrated solutions, [5] examined hybrid systems that combine evaporative cooling with desiccant dehumidification. These systems are particularly suited for the UAE's hot and dry climate, where controlling both temperature and humidity is essential. Desiccant units help remove excess moisture, improving air quality and reducing the risk of fungal diseases. Although more complex and costly, hybrid systems offer enhanced energy efficiency and climate stability, making them ideal for high-value crops.

Innovative approaches are also emerging. A solar-powered fan-chiller tube bank system was evaluated in [6]. which aligns with the UAE's push toward sustainable agriculture. The system demonstrated high energy and water use efficiency, but its economic feasibility varied depending on crop type and market value. This suggests that such systems may be best suited for premium crops or research facilities, where long-term sustainability outweighs initial investment.

Fan selection and maintenance are equally important. As noted in [7], emphasized the importance of selecting fans with a high Ventilation Efficiency Ratio. In the UAE, where cooling demands are high, choosing efficient fans can significantly reduce operational costs. Accessories like cones and shutters further enhance airflow and reduce backpressure, improving overall system performance. This highlights the need for engineering-based fan selection, rather than relying solely on cost or availability. Authors in [8] stressed on the role of regular maintenance in ensuring fan performance. In dusty environments like the UAE, cleaning guard screens, adjusting belt tension, and inspecting motor function are critical to prevent efficiency losses and equipment failure. A proactive maintenance schedule can extend fan lifespan and reduce energy waste, making it a cost-effective strategy for greenhouse operators.

Finally, ventilation systems directly affect the greenhouse microclimate. As demonstrated in [9], ventilation rate and vent configuration significantly affect temperature, humidity, and energy consumption. In the UAE, optimizing these parameters can help maintain a stable microclimate while minimizing energy use. For example, roof vents combined with side vents can enhance natural airflow, reducing the need for mechanical cooling during milder periods. Supporting this, [10] showed that combining roof and side vents improves air renewal and reduces internal temperatures, which enhances plant transpiration and overall growth. This is particularly relevant in the UAE, where stagnant air can lead to heat buildup and poor CO_2 exchange. Strategic vent placement can improve air circulation, reduce thermal gradients, and support healthy crop development.

In the agricultural sector, the utilization of greenhouses has become essential for crop production, allowing farmers to create controlled environments that optimize plant growth. One critical aspect of greenhouse management is the regulation of temperature, as excessive heat can lead to heat stress in plants, affecting their development and productivity. To address this issue, various cooling strategies are employed, including the use of fans to improve air circulation and lower temperatures within the greenhouse.

Temperature regulation plays a significant role in ensuring the well-being of plants, especially in environments where heat stress can hinder productivity. In this study, we aim to evaluate the cooling efficiency of agricultural greenhouses by comparing the effects of running either the upper fans alone or both the upper and lower fans concurrently.

This study trail seeks to evaluate the cooling efficiency in agricultural greenhouses by comparing the effectiveness of running either the upper fans alone or both the upper and lower fans simultaneously. By analyzing the impact of different fan configurations on temperature distribution and water and energy consumption, we aim to provide insights that can enhance cooling practices and optimize greenhouse climate management.

In the context of the UAE’s arid climate, managing internal greenhouse temperatures is a critical challenge due to the extreme heat, which can adversely affect plant health, reduce crop yields, and increase vulnerability to pests and diseases. To mitigate these effects, fan-based cooling systems play a pivotal role in maintaining optimal temperature and humidity levels. The present study investigates the impact of different fan configurations on internal temperature regulation, using a network of sensors distributed across various heights and locations within the greenhouse.

The study focuses on evaluating the cooling efficiency in agricultural greenhouses by analyzing the impact of different fan configurations on temperature regulation and humidity control.

Key Objectives of the Study:

1. Assess the effect of fan configuration on temperature control and air circulation in agricultural greenhouses.
2. Evaluate the energy efficiency and water usage of running upper fans only versus upper and lower fans together.
3. Investigate the overall impact of fan operation on cooling efficiency and crop productivity.

2. Materials and Methods

In the experimental setup, a single greenhouse compartment was equipped with non-ventilated temperature sensors to monitor temperature variations. This study was conducted at Al Kuwaitat Research Station in Al Ain, United Arab Emirates, which operates under the Abu Dhabi Agriculture and Food Safety Authority (ADAFSA). Sensors were strategically positioned at four locations within the greenhouse, with two different heights at each position to capture vertical temperature gradients. The lower sensors were installed at a height of 1.3 meters, while the upper sensors were placed at 2.9 meters. All sensors were connected to a data logger, recording temperature data at five-minute intervals throughout the study period.

Fan Operation: The study included conducting experiments where both upper and lower fans were operated in one-week time slots as the currently farmer used method (control treatment), while only upper fans were run in another set of one-week time slots. Additionally, a third week slot involved running the upper and lower fans alternately on a daily basis. Throughout the entire duration of the experiment, outside weather parameters were recorded at 5-minute intervals, while maintaining consistency in all other variables under observation.

Temperature and relative humidity readings were be recorded at different locations within the greenhouse to analyze the distribution of heat and airflow patterns. Also, a daily water consumption was recorded in the cooling system as much as the energy consumption to compare the overall effectiveness of the two fan configurations as compared with the currently used one (Control).

Analysis: Statistical methods will be employed to compare the effect of the running of different fan setup on the internal temperature and humidity.

3. Results and Discussion

3.1. Outside Temperature

As the various scenarios were running on different durations, each scenario likely experiences fluctuating outside temperatures which can significantly impact the internal temperature of the greenhouse, as well as the water and power consumption within the greenhouse. Figure 1 Illustrated average hourly outside temperatures during the durations of the three scenarios. Among the results, scenario 2 exhibited the highest trend in outside temperatures, while scenario 1 displayed the lowest temperatures. Additionally, scenario 3 experienced moderate outside temperatures compared to scenarios 1 and 2.

Figure 1: Hourly outside temperature through each scenario duration

the varying outside temperature trends across the three scenarios are critical for understanding and interpreting the overall performance of the greenhouse in terms of its internal climate control, resource consumption (water and power), and ultimately, crop productivity. These external conditions serve as a fundamental baseline for evaluating the efficiency and effectiveness of the greenhouse's design and operational strategies under different environmental loads.

3.2. Internal Temperature Impact

To illustrate the variations among the various scenarios in terms of internal temperature, the comparison of hourly greenhouse temperature with the outside temperature is visually shown in the figures 2-5 for the different sensors which were distributed over the greenhouse.

The figures clearly display the fluctuations in internal temperature across the different scenarios and time of the day, despite occasional drops and sensor failures leading to missing data during certain scenarios, the collected data underscores the influence of various fan configurations on the greenhouse environment. Scenario 2 mostly shows the most preferable difference between internal and external temperatures, indicating the effectiveness of running only the upper fans in maintaining optimal conditions within the greenhouse. This suggests a potential of adjusting fan configurations can have a substantial impact on temperature regulation and overall cooling efficiency in agricultural greenhouses.

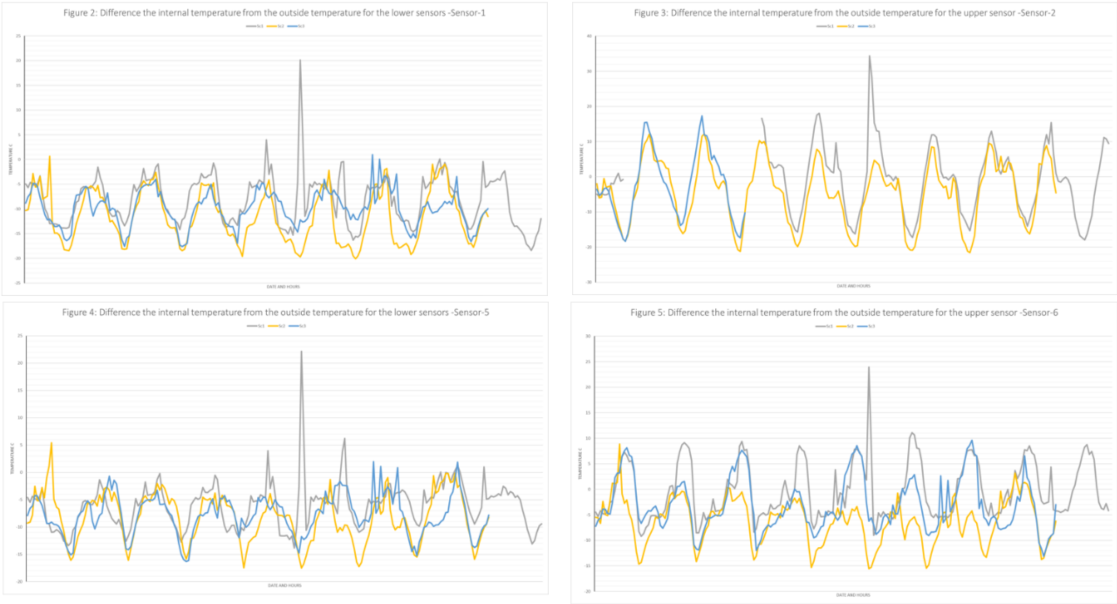

Figure 2, 3, 4,5: Difference the internal temperature from the outside temperature for the lower sensors- sensor 1,2,5,6

The upper sensors placed at an elevated height of 2.9 meters during scenario 1 exhibit moderate temperature variances, implying a notable cooling impact when both upper and lower fans are in operation. In scenario 2, substantial temperature variations are evident, particularly for Sensor-4 and Sensor-6, indicating improved cooling efficacy with solely the upper fans activated. In scenario 3, Sensor-2 and Sensor-6 display moderate differences, whereas Sensor-4 and Sensor-8 have missing or unreliable data, posing challenges in accurately evaluating cooling efficiency.

The lower sensors (placed at 1.3 m height) demonstrate increased temperature variances, suggesting efficient cooling when both upper and lower fans are functioning in Scenario 1. In Scenario 2, Sensor-1 and Sensor-5 display significant temperature discrepancies, highlighting superior cooling performance with only the upper fans activated. Within Scenario 3, Sensor-1, Sensor-5, and Sensor-7 exhibit good cooling efficiency, although Sensor-3's unreliable data hold back an accurate assessment of Scenario 3's effectiveness.

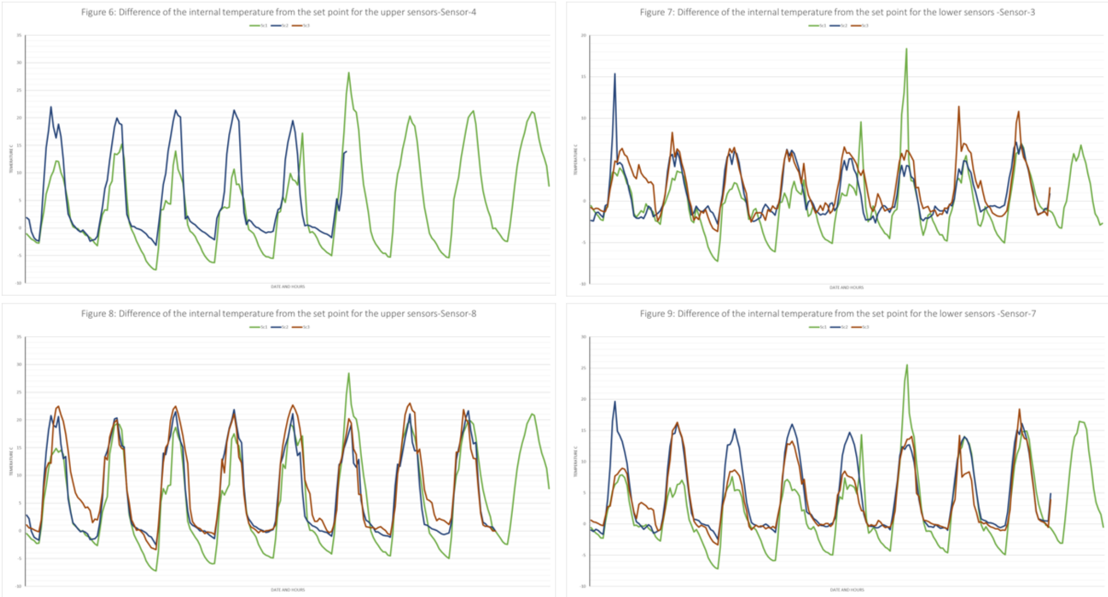

Figure 6, 7, 8,9: Difference the internal temperature from the outside temperature for the lower sensors- sensor 4,3,8,7

Throughout the application of each scenario, numerous fluctuations were noted, triggering the calculation of average hourly differences for statistical analysis. The tables below illustrate these averages across all application slots for comprehensive assessment. The alpha values suggest the degree of statistically correlation between the average hourly differences of internal temperature in different scenarios, with some sensors showing stronger correlations than others.Table 1 showed the average hourly differences of greenhouse internal temperature from Set Point Throughout each scenario duration, the results across all lower sensors, Scenarios 2 and 3 show a higher hourly internal temperature than Scenario 1, indicating less temperature control when only upper fans are in use or with an alternate fan configuration. This difference, although with a slight deviation, does not raise the greenhouse temperature to a level intolerable by plants. Scenario 2 displays more efficient cooling in the pad front sensors than Scenario 3 but less efficiency in the fan front sensors based on the total average. Nevertheless, the upper positioned sensors do not show significant differences compared to Scenario 1.

Table 1: Average Hourly Differences of Greenhouse Internal Temperature from Set Point Throughout Each Scenario Duration

Approach	Sensor-2	Sensor-4	Sensor-6	Sensor-8	Sensor-1	Sensor-3	Sensor-5	Sensor-7
Scenario 1	6.9	4.5	7.2	6.0	-0.6	-0.2	1.6	2.7
Scenario 2	7.7	5.3	6.1	6.9	0.8	0.9	4.1	4.9
Scenario 3	8.3	0.0	8.1	8.0	1.2	1.6	3.3	3.9
α								
Scenario 1 * Scenario 2	0.36	0.34	0.19	0.26	**0.00**	**0.00**	**0.00**	**0.00**
Scenario 1 * Scenario 3	0.33	-----	0.33	**0.01**	**0.00**	**0.00**	**0.00**	**0.04**

Table 2 indicates that Scenario 2 was the most significant cooling efficiency, with all sensors displaying larger negative temperature differences compared to Scenario 1. Similarly, Scenario 3 also exhibits decreased internal temperatures across most sensors, indicating enhanced cooling. The statistical analysis confirms significant differences between Scenario 1 and both Scenario 2 and Scenario 3 for all sensors, emphasizing the effectiveness of the alternative scenarios in maintaining a cooler internal greenhouse environment with improved temperature control.

Table 2: Average Hourly Differences of Greenhouse Internal Temperature from Outside Temperature Throughout Each Scenario Duration

Approach	Sensor-2	Sensor-4	Sensor-6	Sensor-8	Sensor-1	Sensor-3	Sensor-5	Sensor-7
Scenario 1	-1.0	-3.1	-0.2	-1.5	-8.2	-7.8	-6.0	-4.9
Scenario 2	-4.5	-6.7	-6.2	-5.4	-11.5	-11.4	-8.2	-7.5
Scenario 3	-2.7	----	-3.0	-3.0	-9.9	-9.5	-7.8	-7.2
α								
Scenario 1 * Scenario 2	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Scenario 1 * Scenario 3	0.25	----	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

3.3. Relative Humidity

The relative humidity (RH) data collected from different sensors in the study assessing the effect of fan configuration in agricultural greenhouses provides valuable insights into the environmental conditions within the greenhouses.

Operating both upper and lower fans can facilitate better air mixing, potentially leading to more uniform relative humidity levels throughout the greenhouse. This combined operation of fans may help in preventing localized humidity build-up or stagnation. While running only the upper fans might result in different air movement patterns compared to the control treatment, which could lead to variations in relative humidity distribution within the greenhouse. Alternating the operation of upper and lower fans daily may introduce changing airflow patterns, this dynamic airflow could impact how relative humidity levels fluctuate within the greenhouse, influencing the overall climate conditions for plant cultivation.

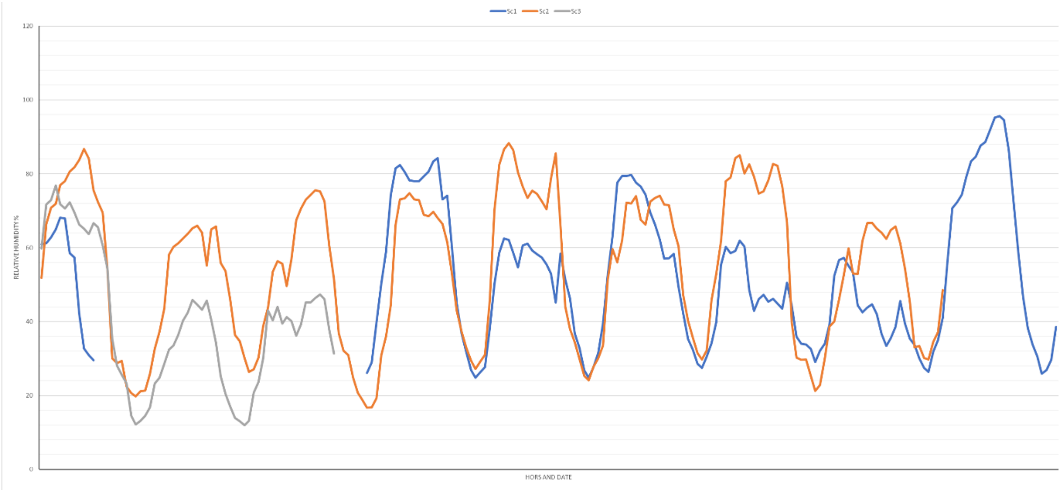

Figure 10: Relative humidity comparison for lower sensor-2 for the three-fan configuration scenario

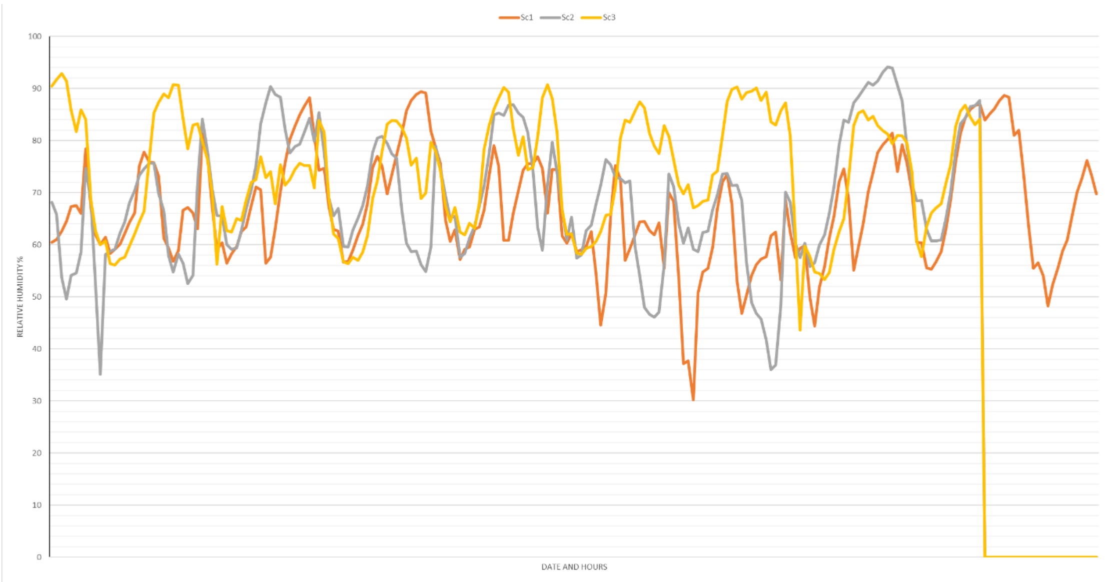

Figure 11: Relative humidity comparison for lower sensor-3 for the three-fan configuration scenario

The inequality in relative humidity levels between the upper and lower sensors within the greenhouse is a logical observation, attributed to the natural behavior of air movement. As heavier, moisture-laden air tends to sink, the upper sensors registering lower relative humidity align with this principle.

The results of the average hourly relative humidity (RH) readings from eight sensors within a greenhouse across three distinct scenarios showed undefined trend or specific nature of these scenarios, the data reveals important insights into RH variability and its implications for environmental control strategies.

3.4. Water Consumption Cooling

For more valuable insights for evaluating the impact of fan configurations on water consumption and cooling efficiency in agricultural greenhouses. The collected data for the daily water consumption in the pad and fan cooling system revealed that Scenario 2, where only the upper fans are in operation, shows a lower water usage of 7.67 m3/day, representing 85.25% of Scenario 1. The reduced water consumption in Scenario 2 indicates that operating only the upper fans leads to more efficient cooling compared to the combined operation of upper and lower fans in Scenario 1. In Scenario 3, where the upper and lower fans are alternated daily, the water usage increases to 11.18 m3/day, which is 124.30%

Table 3

Scenario	m3/day	% of Scenario 1
Scenario 1	9.00	100.00%
Scenario 2	7.67	85.25%
Scenario 3	11.18	124.30%

The data indicates a trade-off between water consumption and cooling efficiency based on the fan configuration. Scenario 2 shows potential for water savings. Finding the right balance between water usage and cooling efficiency is crucial for greenhouse operations.

3.5. Power consumption

Results for the power consumption showed Scenario 2 consumed 45.59 KW/day, representing 50.15% of Scenario 1's power consumption. The lower power consumption in Scenario 2 suggests that operating only the upper fans leads to significant energy savings compared to running both upper and lower fans in Scenario 1, despite the outside temperature during the implementation of the scenario 2 is higher than the other two scenarios.

Table 4

Scenario	KW/day	% of Scenario 1
Scenario 1	90.91	100.00%
Scenario 2	45.59	50.15%
Scenario 3	95.39	104.93%

Scenario 3, where upper and lower fans are alternated daily, had a power consumption of 95.39 KW/day, equivalent to 104.93% of Scenario 1's power usage. The higher power consumption in Scenario 3 indicates that the alternating fan operation may require more energy to maintain the desired cooling effect compared to continuous operation in Scenario.

4. Study Constraints

Despite the valuable insights gained from this study, several limitations should be acknowledged. First, intermittent sensor failures and data gaps-particularly in Scenario 3-restricted the completeness and reliability of the dataset, affecting the consistency of comparative analysis across all sensor locations. Additionally, the study was conducted over a limited time frame, which may not fully capture seasonal variations or long-term performance trends under fluctuating climatic conditions typical of the UAE. The experiment was confined to a single-span greenhouse structure, which may limit the generalizability of the findings to multi-span or differently designed greenhouses with varied airflow dynamics. External environmental factors such as wind speed, solar radiation, and ambient humidity were not fully controlled, potentially influencing internal temperature readings independently of fan configurations. Furthermore, while the study focused on thermal performance, it did not incorporate crop-specific physiological responses, which are essential for evaluating the agronomic impact of microclimate changes. Lastly, energy consumption data for each fan configuration were not comprehensively measured, limiting the ability to assess the trade-offs between cooling efficiency and operational cost.

5. Conclusion

Optimal Scenario: Based on the available data, Scenario 2 appears to offer the best cooling performance overall. The considerable temperature differences observed in multiple sensors when only the upper fans are running suggest enhanced cooling efficiency compared to other scenarios. The significant temperature differences seen across multiple sensors when only the upper fans are active suggest enhanced cooling effectiveness compared to other scenarios.

The substantial temperature difference in Scenario 2 may be attributed to the strategic use of upper fans, potentially enhancing airflow patterns and heat dissipation within the greenhouse. This configuration likely optimizes cooling efficiency while minimizing energy consumption.

Effective Fan Configuration: Running only the upper fans seems to be more effective in maintaining a significant temperature difference between the internal and external environments, indicating better cooling performance in the greenhouse.

Avoiding any sensor failures which might lead to gaps in the recorded data, affecting the accuracy of temperature readings and analysis which results in missing values in the dataset. These missing values can disrupt the continuity of the data and hinder the assessment of temperature variations.

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