

## Impact of radial and horizontal airflow fans on single-span greenhouse microclimate and yield

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### Abstract

No matter where they are located, horticultural plants may be grown thanks to greenhouse technology (Kumar et al. 2021). In order to maximise agricultural yields, the greenhouse structure allows for partial or complete control over climate variables such temperature, relative humidity (RH), carbon dioxide (CO<sub>2</sub>) concentration, solar radiation (SR), and vapour pressure deficit (VPD) (Sagar and Singh 2023). The main purpose of ventilation is to regulate the quality of indoor air by replenishing and diluting the air inside a space, changing the temperature, relative humidity, and airflow to attain appropriate thermal conditions. In contemporary commercial farming, controlling the microclimate and ventilation of greenhouses is essential since it minimises the need for excessive pesticides and herbicides, conserves water, and uses less energy (Akrami et al. 2020). In order to reduce the risk of disease and to achieve uniformity in critical factors like temperature, RH, VPD, and CO<sub>2</sub> level within greenhouses, fans must be placed to create air movement that mixes the air and facilitates the evaporation of moisture from leaf surfaces (Akpenpuun et al. 2022, Randhe et al. 2022). The horizontal airflow fan (HAF), which is placed horizontally above the crop canopy, is the most often utilised air circulation fan. The radial airflow fan (RAF), which is positioned vertically above the crop canopy and has one end that extends to the surrounding atmosphere, is a more modern invention. The impact of HAF on climatic factors has been the subject of several research. Nevertheless, little is known about the use of RAF and how it affects crop production and the distribution of microclimatic factors. This study's goals were to examine the efficacy of the HAF and RAF and look into how the RAF affected the distribution of microenvironment factors and strawberry production.

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### Introduction

This experiment was carried out in two arch-shaped greenhouses in Sangju Smart Farm Innovation Valley, Sangju-si (36°24'39"N and 128°9'32"E at an elevation of 60 meters amsl), Gyeongsangbuk-do, South Korea, from January to March 2023. Sangju's climate is classified as humid subtropical. The greenhouses had two polyolefin layers and a thermal screen layer covering them, and they were orientated east-west. They measured 52.8, 6.8, and 2.5 meters in length, width, and height, respectively, with 1.5 meters at the eaves. The first layer (thermal screen), second layer, and third layer had corresponding heights of 2.5, 2.8, and 3.05 m [Fig. 1(a) and (b)]. When the internal air temperature in the HAF greenhouse (HAF-GH) rose beyond the predetermined threshold of 20°C, the side vents opened automatically. The RAF greenhouse (RAF-GH) was different from the HAF-GH in that it had closed side vents and a chimney-like structure that extended to the surrounding environment. Based on predetermined humidity and temperature settings, this design made it easier for air to move between the greenhouse and the outdoors. The fans and sensors were placed (Fig. 1c). For this investigation, the approach described in Akpenpuun et al. (2023) was used.

**Statistical analysis:** To compare the microclimates in HAF-GH and RAF-GH, descriptive statistics, frequency distribution, and analysis of variance were used to the obtained data.

**Temperature:** The RAF-GH had more temperature fluctuation than the HAF-GH, with daily mean temperatures of 12.87±4.60°C, 14.88±5.89°C, and 1.62±6.51°C, respectively. 14.88°C is the average daily temperature.

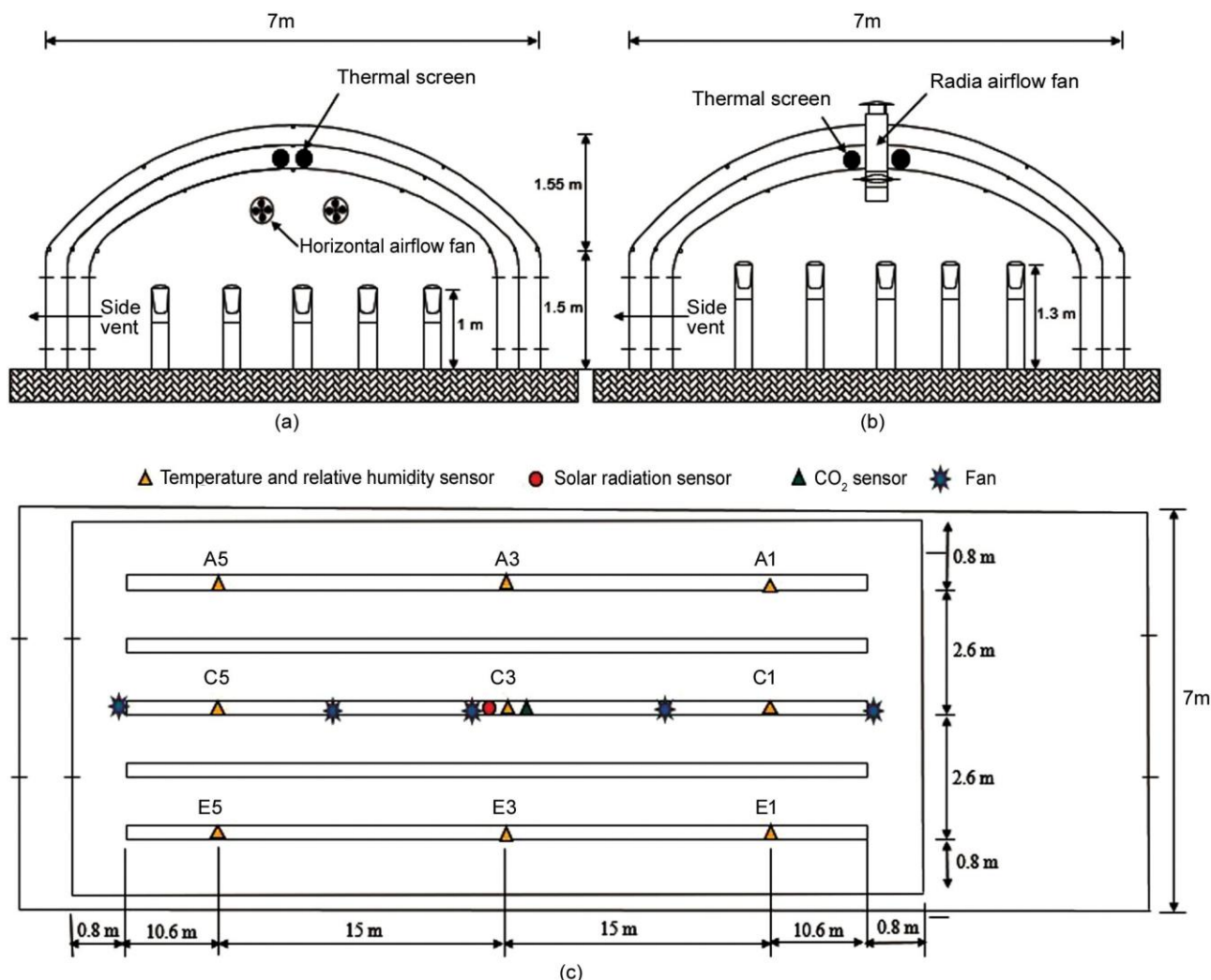


Fig. 1 Cross-sectional view of the experimental (a) horizontal airflow fan (b) radial airflow fan greenhouses, and (c) sensor and fan positions in the greenhouses.

in the RAF-GH is consistent with the results of Nascimento et al. (2023), who found that greenhouse strawberries had a daily mean temperature of 14.17°C. In the RAF-GH and HAF-GH, the average daily temperature was 20.22°C and 16.78°C, respectively. The ideal daily temperature ranges, according to Tang et al. (2020), are 18–24°C. In contrast, the HAF-GH and RAF-GH had mean nighttime temperatures of 10°C and 10.96°C, respectively, which fall within the ideal nighttime temperature range of 10–13°C as stated by Ogunlowo et al. (2021). The frequency of the ideal temperature range throughout the day was 42.29% in the HAF-GH and 43.53% in the RAF-GH. Similarly, 29.93% of nighttime temperatures in the HAF-GH were inside the ideal range, compared to 47.98% in the RAF-GH. According to the investigation, the RAF-GH is better for growing strawberries than the HAF-GH. The temperature data between HAF-GH and RAF-GH, both during the day and at night, seems to vary significantly, according to the ANOVA result (Table 1). The trend of mean hourly temperature changes in January, February, and March in the HAF-GH, RAF-GH, and external environment is shown in Fig. 2. The temperature trends showed a slow rise after 8:00, peaking between 12:00 and 4:00, and then a drop at night. Crucially, throughout the trial, the RAF-GH consistently reported higher temperatures than the HAF-GH throughout the day. The HAF-GH, on the other hand, reported somewhat lower temperatures at night. The different ventilation systems used in the two greenhouses are the reason for this temperature difference. The RAF's radial circulation system successfully averages the temperature by ensuring that thermal strata are thoroughly mixed throughout the greenhouse's height. On the other hand, since warmer air rises toward the greenhouse roof and colder air enters via side vents, the HAF only promotes mixing at the top stratum levels.

**Relative humidity:** The HAF-GH, RAF-GH, and external environment had mean daily RH values of 74.94±16.87%, 83.95±13.57%, and 61.19±19.97%, respectively. This demonstrates that RH varied significantly across the three habitats, with the exterior environment exhibiting the largest variance. Furthermore, the average daytime RH in

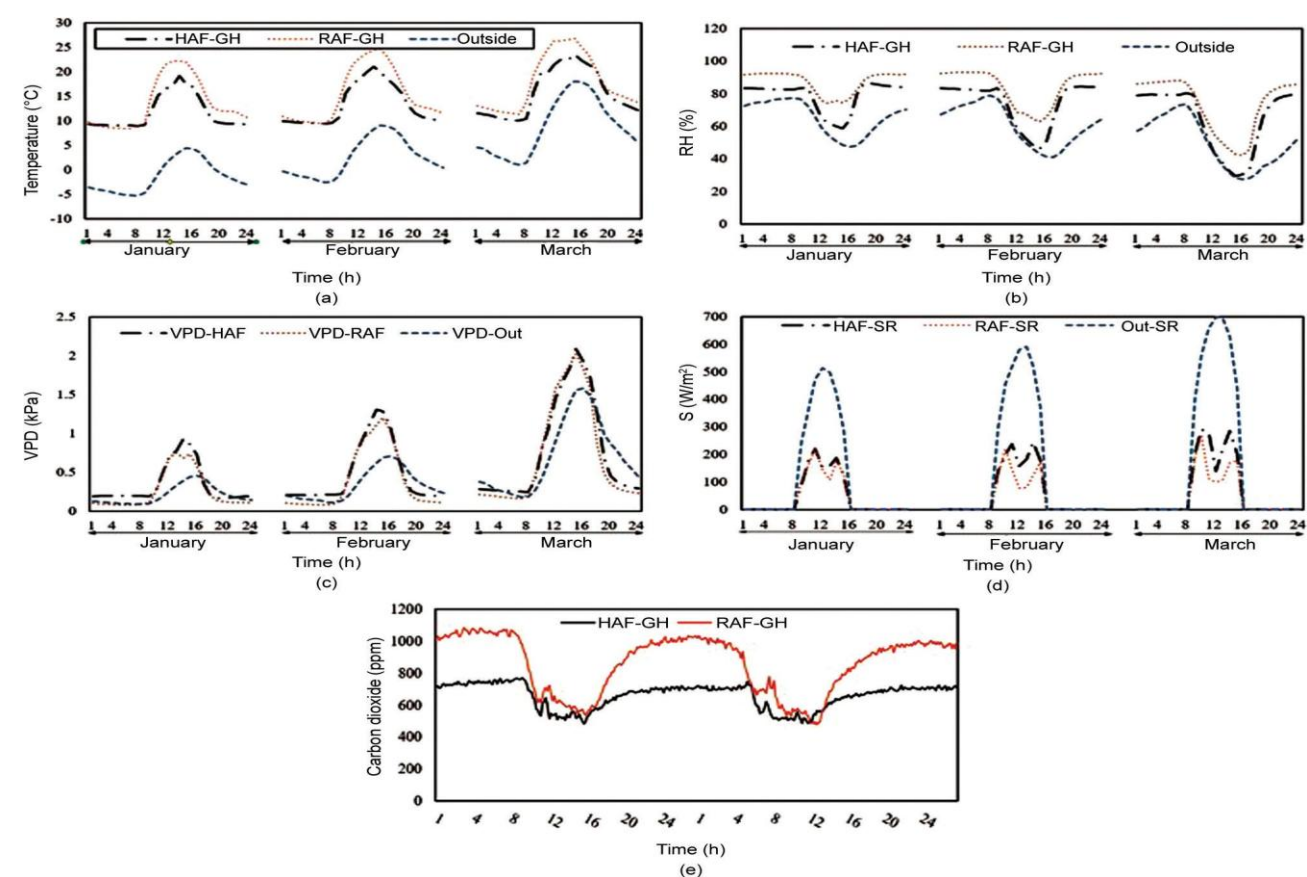


Fig. 2 Mean hourly variation of microenvironment parameters (a) temperature, (b) RH, (c) VPD, (d) SR, and (e) Carbon dioxide in the horizontal airflow fan, radial airflow fan greenhouses, and external environment.

The external environment was 53.20%, the HAF-GH was 64.44%, and the RAF-GH was 74.21%. Additionally, the HAF-GH, RAF-GH, and external environment had mean nighttime relative humidity of 82.67%, 91.11%, and 67.07%, respectively. When growing strawberries in double-layer greenhouses, Sim et al. (2020) and Khammayom et al. (2022) recorded RH 73.7 to 93.2% and 30 to 93%, respectively. Within the ideal RH range of 60–90%, the daytime RH frequency in the HAF-GH and RAF-GH was 52.01 and 65.34%, respectively. In the HAF-GH, the frequency of RH falling inside the ideal range at nite was 88.79%. Conversely, the RAF-GH found a lower

Table 1 ANOVA of day and night time temperature (T), RH, VPD, SR, and CO<sub>2</sub> between HAF-GH and RAF-GH at 95% confidence intervals

| Greenhouse       | Parameter       | Day-time     |          |            | Night-time   |          |            |
|------------------|-----------------|--------------|----------|------------|--------------|----------|------------|
|                  |                 | F-statistics | P-value  | F-critical | F-statistics | P-value  | F-critical |
| HAF-GH vs RAF-GH | T               | 1080.12      | $P<0.01$ | 3.84       | 692.57       | $P<0.01$ | 3.84       |
|                  | RH              | 588.75       | $P<0.01$ | 3.84       | 8178.56      | $P<0.01$ | 3.84       |
|                  | VPD             | 17.60        | $P<0.01$ | 3.84       | 25.44        | $P<0.01$ | 3.84       |
|                  | SR              | 183.35       | $P<0.01$ | 3.84       |              |          |            |
|                  | CO <sub>2</sub> | 203.56       | $P<0.01$ | 3.84       |              |          |            |

frequency of RH falling within the ideal range (31.99%). The findings clearly showed that the two greenhouse habitats had significantly different relative humidity levels throughout the day and at night. The different ventilation systems used in the two greenhouses are responsible for this divergence in RH profiles. These results highlight the different RH dynamics between the two settings at night, with RAF-GH exhibiting a stronger propensity for higher humidity levels over the ideal range. Deficit in vapour pressure: After 8:00, the VPD patterns in HAF-GH and RAF-GH (Fig. 2) gradually increased, peaking between 12:00 and 16:00. The VPD in HAF-GH, RAF-GH, and the surrounding environment surpassed 1.5 KPa in March during peak hours. The daily VPD ranges for the HAF-GH and RAF-GH were 0.03 to 3.42 KPa and 0.02 to 2.66 KPa, respectively. Additionally, the mean VPD throughout the day was 0.78 KPa and 0.19 KPa in the HAF-GH and 0.73 KPa and 0.10 KPa in the RAF-GH. For the majority of greenhouse crops, Sultan et al. (2021) suggested a VPD range of 0.45 to 1.25 KPa to support normal growth throughout the crop cycle. Compared to the RAF-GH, the HAF-GH had 3.07% less VPD readings within the acceptable range, suggesting that the RAF-GH's circumstances were more favourable for strawberry production. Two settings were substantially different, according to the ANOVA of the VPD data (Table 1) in the HAF-GH and RAF-GH. The results clearly showed differences in the VPD data between the two greenhouse settings during day and at night.

**Solar radiation (SR):** According to the descriptive analysis, the mean solar radiation in the HAF-GH, RAF-GH, and external environment was  $182.21 \pm 103.59$  W/m<sup>2</sup>,  $145.51 \pm 102.75$  W/m<sup>2</sup>, and  $457.73 \pm 213.91$  W/m<sup>2</sup>. In the HAF-GH, RAF-GH, and external environment, the highest SR values were 448.68 W/m<sup>2</sup>, 503.73 W/m<sup>2</sup>, and 856.98 W/m<sup>2</sup>. Yoshida et al. (2016) advised a range of 21.73–65.21 W/m<sup>2</sup> for strawberry growth; the HAF-GH had a frequency of 5.45%, while the RAF-GH had a slightly lower frequency of 4.42%. According to Tang et al. (2020), the ideal range of solar radiation for high-quality strawberries is 73.8 to 98.43 W/m<sup>2</sup>. In the HAF-GH and RAF-GH, the frequency of SR values falling within the suggested range was 7.69% and 18.53%, respectively. There were notable variations in SR between the two greenhouse settings, according to the ANOVA of SR (Table 1) of HAF-GH and RAF-GH. For HAF-GH, the lowest hourly mean SR values for January, February, and March were 89.14, 139.31, and 139.50 W/m<sup>2</sup>. On the other hand, during the same months, the equivalent SR values in the RAF-GH were 105.40, 78.53, and 98.76 W/m<sup>2</sup>.

**Carbon dioxide:** The HAF-GH and RAF-GH had mean daily carbon dioxide levels of  $643.12 \pm 121.65$  ppm and  $801.05 \pm 243.13$  ppm, respectively. RAF-GH continuously sustained greater CO<sub>2</sub> levels than HAF-GH throughout the trial. Interestingly, these CO<sub>2</sub> levels were higher than the 600 ppm threshold linked to the peak rate of photosynthesis, as suggested by Sim et al. (2020). In the RAF-GH, the frequency of CO<sub>2</sub> levels between 600 and 900 ppm was 33.19%, which was somewhat higher than the 30.56% seen in the HAF-GH. The HAF-GH and RAF-GH daytime and nighttime CO<sub>2</sub> ANOVA (Table 1) revealed a statistically significant difference between the two settings. Yield: The HAF-GH produced 328 kg of strawberries overall, whilst the RAF-GH produced 445 kg. The yield of RAF-GH was 117 kg higher than that of HAF-GH. According to the yield statistics, RAF may create more evenly mixed air under the same greenhouse conditions.

## SUMMARY

In order to maximise crop output and optimise growing conditions, the current research assessed and compared the distribution patterns of microclimatic factors inside greenhouses. At Sangju Smart Farm Innovation Valley in Sangju-si, South Korea, two adjacent greenhouses coated with two polyolefin layers and a thermal screen layer were used for the experiments, which took place between January and March of 2023. The radial airflow fan's unique design, which connects to the outside world and blends air evenly, proved to be more effective than the horizontal airflow fan. By improving the distribution of microclimate factors, radial airflow fans might have a significant impact on commercial production. This would raise greenhouse efficiency and, eventually, agricultural yields.

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