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A Study on the Air Flow Velocity and Temperature Distribution Characteristics of Hybrid Smart Farm

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Abstract. The hybrid smart farm's internal fluid was assumed to be air. Four each FCUs and FANs were assumed to be on the left and on the right and one each FCU and FAN were assumed to be on the front for forced flows. Four cases where the FCUs and FANs were installed high or low were analyzed. To analyze the smart farm at room temperature, the internal initial temperature was set to 10°C and it was assumed that air at 15℃ would flow in through the FCUs at 0.5 m/s and flow out through the FANs. In addition, the internal temperature of smart farm was assumed to be optimal when it is constant in a range of 12~18℃ and the panels were assumed to be insulated. Analyses were conducted for four seasons too. By stably realizing consistent environmental management, smart farms' optimum conditions not only save the effort for ventilation repeated everyday but also enable the management of ventilation at the optimum thereby enabling high quality production. The present study is intended to examine sandwich insulation panel type smart farm systems through flow analyses. The positions of FCUs and FANs that are in charge of air inflows/outflows were adjusted to smoothen the air flows between the multiple array mushroom beds in four lines of seven layers and prevent environmental differences between upper and lower mushroom beds. The standard deviation of the smart farm where FCUs and FANs were positioned low was the smallest amounting to 0.298. Therefore, this smart farm was judged to be the optimum model because the temperatures around the shelves inside the smart farm became the most evenly distributed

Keywords Hybrid smart farm, Smart farm analysis model, Airflow velocity, Temperature distribution, Heat transfer characteristics

1 Introduction

Although the energy consumption in the agricultural sector accounts for only 1.8% of the national energy consumption, the importance of energy in agricultural product production is very high. In particular, energy inputs have been increasing due to the expansion of controlled horticulture and the progress of mechanization. In particular, in the case of thermophilic crops, since the ratio of energy used has been increasing remarkably over the last several years, energy saving is required. Although

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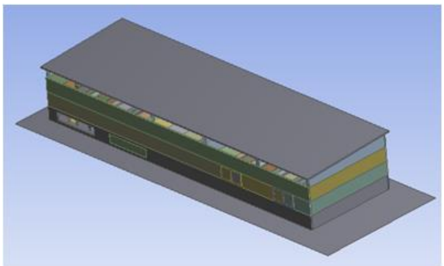
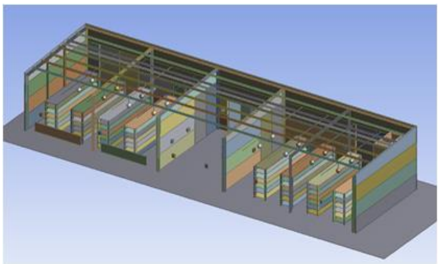
new & renewable energy that can substitute for energy saving facilities and fossil fuels for energy saving have been recently developed and supplied, the extent of supply has been insignificant. Therefore, the reasons why the supply cannot progress smoothly have been investigated and measures to increase the supply have been sought for.(1) In the current situation where fossil fuels may be exhausted globally and the prospect of international oil prices is uncertain, the necessity to reduce operating costs by reducing the dependence on fossil fuels or enhancing the efficiency of fuels has been coming to the fore.(2) In addition, as the situation where carbon emissions should be reduced has come, in the agricultural sector too, pressure toward the reduction of energy consumption has been increasing and this has become a constraint factor against the enhancement of agricultural productivity.(3) In addition, for energy cost saving and carbon emission reduction in response to global warming, the energy use structure in the agricultural sector should be re-reviewed in order to take measures such as increasing energy saving facilities that can enhance the efficiency of energy and increasing the use of new & renewable energy that can substitute for fossil fuels.(4) Han et a1.(5) conducted a study on the effects of changes in the amount of ventilation in mushroom cultivation houses on the growth and development of mushrooms and analyzed basic data. Cho et a1. (6) analyzed the heat transfer efficiency of the cross sections of vertical closed heat exchangers through numerical analysis that provides basic data on the effects of changes in the temperature and flow velocity on smart farms. They derived results indicating that the flow velocity of the air glowing in heat exchangers and temperature distributions are variables that have large effects on heat transfer efficiency. However, the results of previous studies have not reported the temperature distribution characteristics of energy farm hybrid small composite smart farms. Hybrid smart farms realize stable and consistent environmental management so that not only the effort for ventilation repeated everyday can be saved but also the amount of ventilation can be managed at the optimum thereby enabling high quality production. (7) The present study is intended to analyze air flows in hybrid smart farms and investigate the temperature distribution characteristics with a view to implementing optimum hybrid smart farms. In addition, the present study is also intended to adjust the positions of FCUs and FANs that are in charge of air inflows/outflows to smoothen the air flows between the multiple array mushroom beds in four lines of seven layers with a view to implementing uniform environments in the upper and lower mushroom beds.

2 Modeling and Analysis Conditions

Fig. 1 shows the entire smart farm analysis model and the inside shape of the model. As shown in Fig. 1 and 2, the internal fluid of the smart farm was assumed to be air and the internal beam material and its material properties are as shown in Table 1. To analyze smart farm at room temperature, the internal initial temperature was set to 10°C and it was assumed that air at 15°C came in through the FCUs and 0.5 m/s and went out through the FANs. In addition, the internal temperature of smart farm was assumed to be optimal when it is constant in a range of 12~18°C and the panels were assumed to be insulated. Analyses were conducted for four seasons too.

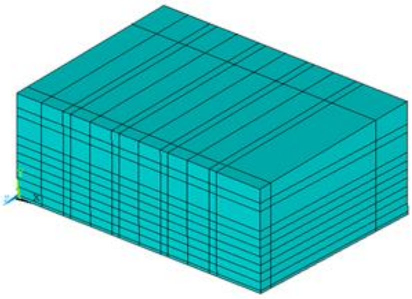


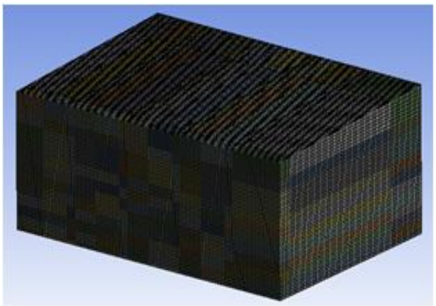


(a) Smart farm model (entire model) (b) Smart farm model (internal shape)

Fig. 1. Smart farm analysis model

Fig. 2 shows the parts for flow analysis of the actual model and analysis model of the smart farm. As shown in Fig. 2, the air layers inside the smart farm were analyzed and since the model was bilaterally symmetric, only the left part was modeled.





(a) Analysis model (b) Finite element model

Fig. 2. Actual model and analysis model of the smart farm (part for flow analysis)

Table 1 shows the material properties of air used in the flow analysis and the material properties of steel used in the structural analysis.

Table 1. Material properties of the fluid (air)

Fluid	Density[kg/m^3]	Molar Mass[kg/kmol]	Specific Heat Capacity[Jkg/(kg·K)]
Air	1.185	28.96	343

Table 2. Material properties of the structural steel

Material property model	Density [kg/m^3]	Modulus of elasticity [MPa]	Yield strength[MPa]	Poisson's ratio
Mushroom cultivation house	7850	210x103	250	0.3

As shown in Fig. 3, four each FCUs and FANs were assumed to be on the left and on the right and one each FCU and FAN were assumed to be on the front for forced flows and four cases where the FCUs and FANs were installed high or low were analyzed. As shown in Fig. 3, the analysis was conducted under the condition that air at 15℃ would flow in through the FCUs at 0.5 m/s and flow out through the FANs

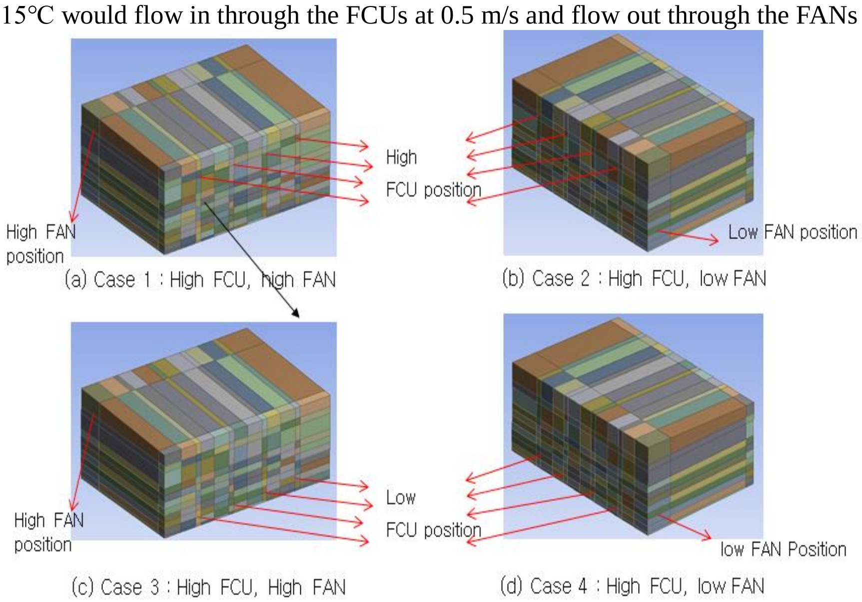
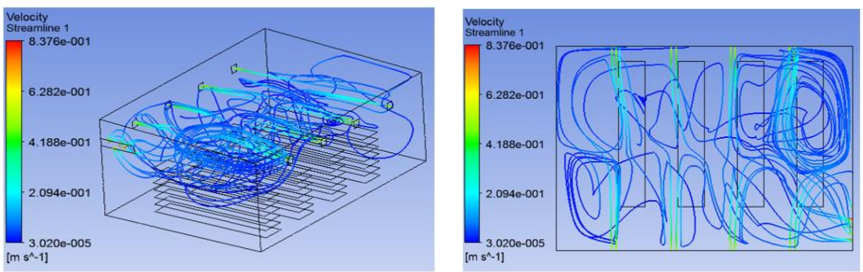


Fig. 3. Analysis conditions

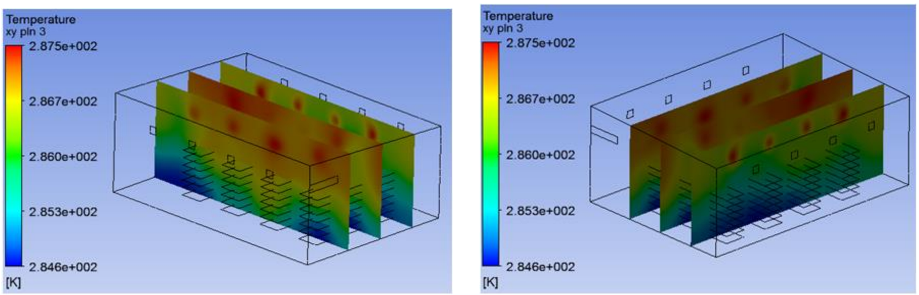
3 Flow and Heat Transfer Characteristics Analysis Results

Fig. 4 shows the flow characteristics of Case 1 and Fig. 5 shows the heat transfer characteristics of Case 1. As shown in Fig. 4, the air blown by the FCUs flows inside to go out through the FANs. The velocity shows a distribution in a range of 0~0.84 m/s. As shown in Fig. 5, the temperatures are high when the air is blown by the FCUs and heat was transferred to the entire space through convection. The temperatures showed a distribution in a range of 11.6~14.5 °C.



(a) Streamline distribution (diagonal view) (b) Streamline distribution (top view)

Fig. 4. Flow characteristics of case 1

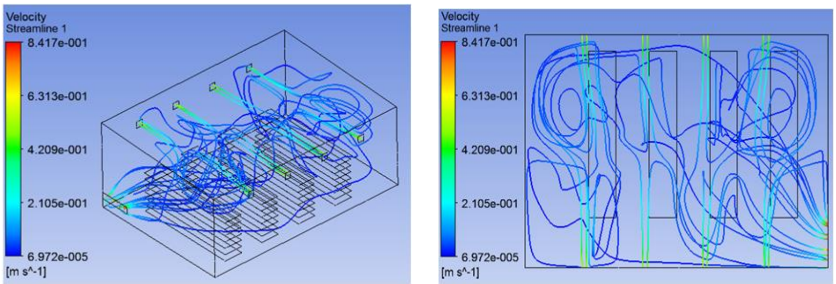


(a) Cross-sectional temperature distribution

(b) Cross-sectional temperature distribution

Fig. 5. Heat transfer characteristics of case 1

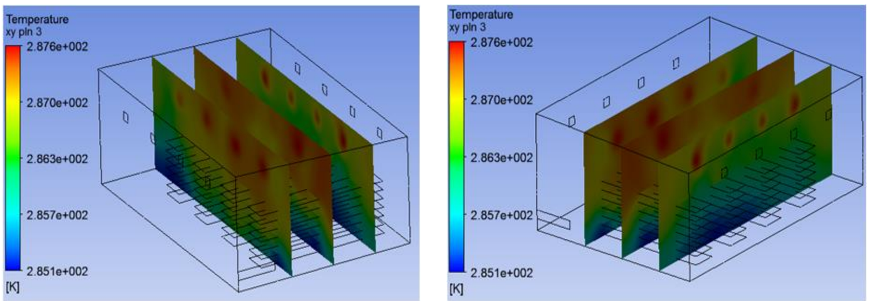
Fig. 6 shows the flow characteristics of Case 2 and Fig. 7 shows the heat transfer characteristics of Case 2. As shown in Fig. 6, the air blown by the FCUs flows inside to go out through the FANs. The velocity shows a distribution in a range of 0~0.84 m/s. As shown in Fig. 7, the temperatures are high when the air is blown by the FCUs and heat was transferred to the entire space through convection. The temperatures showed a distribution in a range of 12.1~14.6 ^{o}C.



(a) Streamline distribution (diagonal view)

(b) Streamline distribution (top view)

Fig. 6. Flow characteristics of case 2

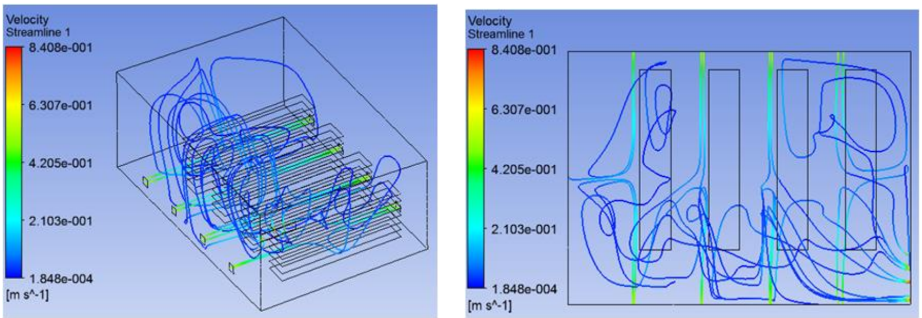


(a) Cross-sectional temperature distribution

(b) Cross-sectional temperature distribution

Fig. 7. Heat transfer characteristics of case 2

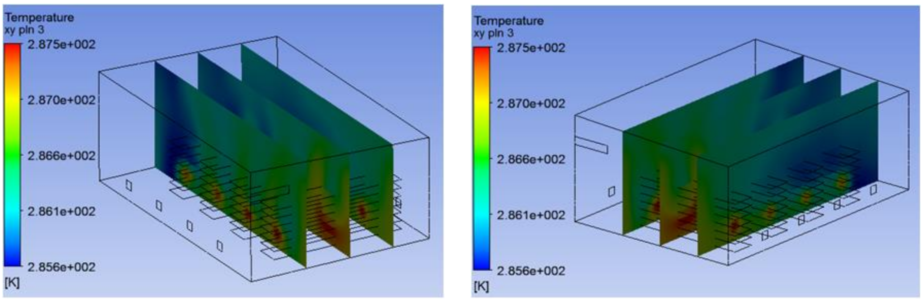
Fig. 8 shows the flow characteristics of Case 3 and Fig. 9 shows the heat transfer characteristics of Case 3. As shown in Fig. 8, the air blown by the FCUs flows inside to go out through the FANs. The velocity shows a distribution in a range of 0~0.84 m/s. As shown in Fig. 9, the temperatures are high when the air is blown by the FCUs and heat was transferred to the entire space through convection. The temperatures showed a distribution in a range of 12.6~14.5 °C.



(a) Streamline distribution (diagonal view)

(b) Streamline distribution (top view)

Fig. 8. Flow characteristics of case 3



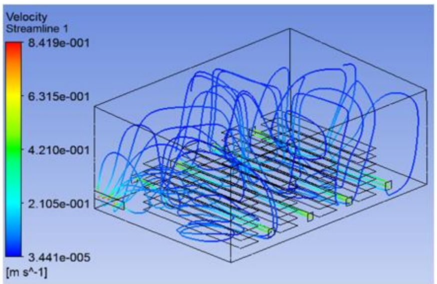
(a) Cross-sectional temperature distribution

(b) Cross-sectional temperature distribution

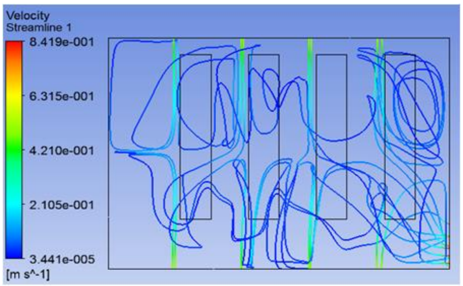
Fig. 9. Heat transfer characteristics of case 3

Fig. 10 shows the flow characteristics of Case 4 and Fig. 11 shows the heat transfer characteristics of Case 4. As shown in Fig. 10, the air blown by the FCUs flows inside to go out through the FANs. The velocity shows a distribution in a range of 0~0.84 m/s. As shown in Fig. 11, the temperatures are high when the air is blown by the FCUs and heat was transferred to the entire space through convection. The temperatures showed a distribution in a range of 12.0~14.2 °C. Air flows and heat transfer characteristics in smart farms were analyzed under four conditions. Case 1 showed a mean temperature of 12.983 °C and a standard deviation of 0.552, Case 2 showed a mean temperature of 13.370 °C and a standard deviation of 0.465, Case 3 showed a mean temperature of 13.438 °C and a standard deviation of 0.338, and Case 4 showed a mean temperature of 13.308 °C and a standard deviation of 0.298.

Therefore, the standard deviation of Case 4 where the FCUs and FANs were positioned low was the lowest as 0.298. Therefore, this smart farm is judged to be the optimum model because the temperatures around the shelves inside the smart farm become the most evenly distributed. However, Case 4 is shown to require excessive construction costs because of its structure. Since the primary role of FANs is ventilation and warm air always exists in the upper region, the relevant air should be discharge to prevent adverse effects on the crop. Among the results of analysis of flows of the four cases, those of Case 3 and Case 4 did not show any significant difference. Therefore, the application of Case 3 is also considered to show good results.

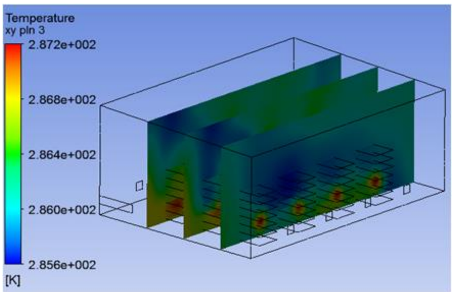


(a) Streamline distribution(diagonal view)

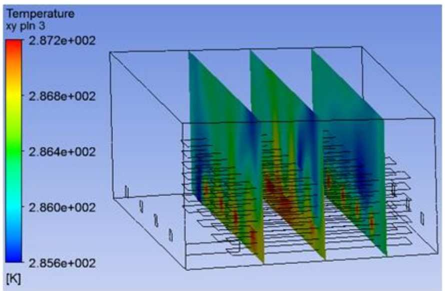


(b) Streamline distribution (top view)

Fig. 10. Flow characteristics of case 4



(a) Cross-sectional temperature distribution



(b) Cross-sectional temperature distribution

Fig. 11. Flow characteristics of case 4

4 Conclusion

The smart farm’s internal fluid was assumed to be air. To analyze smart farmat room temperature, the internal initial temperature was set to 10℃ and it was assumed that air at 15℃ would flow in through the FCUs at 0.5 m/s and flowout through the FANs. The air flow velocity and heat transfer characteristics of the smart farm were studied assuming that the internal temperature of smart would be constant in a range of

12~18℃ to obtain the following conclusions.

(1) Case 1 showed a mean temperature of 12.983 ºC and a standard deviation of 0.552, Case 2 showed a mean temperature of 13.370 ºC and a standard deviation of 0.465, Case 3 showed a mean temperature of 13.438 ºC and a standard deviation of 0.338, and Case 4 showed a mean temperature of 13.308 ºC and a standard deviation of 0.298.

(2) The standard deviation of Case 4 where the FCUs and FANs were positioned low was the lowest as 0.298. Therefore, this smart farm is judged to be the optimum model because the temperatures around the shelves inside the smart farm become the most evenly distributed.

(3) Case 4 is shown to require excessive construction costs because of its structure. Since the primary role of FANs is ventilation and warm air always exists in the upper region, the relevant air should be discharge to prevent adverse effects on the crop. Among the results of analysis of flows of the four cases, those of Case 3 and Case 4 did not show any significant difference. Therefore, the application of Case 3 is also considered to show good results.

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