Analysis of Thermal and Light Properties of Greenhouse Considering Greenhouse Sheets Characteristics in Hot and Humid Area in Asia

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Abstract Food market in Asia is expanding at dramatic rate. In the near future, there will be about 400 million rich people who will eat raw vegetables as well as Japanese people, which is a great business opportunity for the farmer in Japan who has the know-how to produce high-quality vegetables. However, the weather conditions in Asia, especially in south-east Asia, can induce poor growth of plants because of its distinctive high temperature and humidity. In this case, putting a light shielding material on the outside of film can be a good method for cooling the greenhouse. In this study, the authors investigated the effects of some greenhouse shielding sheets on the environment of greenhouse in hot and humid regions of Asia. Consequently, it became possible to analyze the degree of suppression of the temperature rise of the greenhouse due to absorption of heat rays using shielding materials for the greenhouse at high temperature and its mechanism. It was suggested that focusing on the physical value of the film such as absorption rate is important by this simulation.

1 Introduction

Today, Japan is lagging far behind countries such as Netherlands in agricultural products export and energy use in agriculture. In recent years, with the increase of population and the economic level in Asia, interest on Japanese food that is considered to be safe, secure and delicious is increasing. It is said that in the near future, there are about 400 million rich people who will eat raw vegetables as well as Japanese people. This is a good opportunity for Japan that has know-how to produce high-quality vegetables to expand its exports.

There are some problems in the cultivation by plant factory, especially greenhouse type of plant factory, in hot and humid area. So, there are very few cases for hot and humid areas. Since the outside temperature is so high, it is not possible to expect sufficient cooling effect by ventilation. Watering, which is the cooling method using the vaporization heat, is also insufficient because water does not evaporate much because of the high humidity in Southeast Asia. Also, the instability and unsafety of groundwater is a problem for the secure of sufficient water for watering. There is also a problem in the cooling method by introducing shielding material. When shielding material is introduced, it is expected that the rise of temperature by the heat from sunlight decreases because the heat energy entering the greenhouse from sunlight decreases. However, by introducing shielding material, the heat shielded by the film is absorbed into the film that causes the rise of temperature of film. The heated film emits heats to the greenhouse that can eventually cause the rise of temperature in the greenhouse. Also, shielding sunlight can cause the shortage of the amount of light which is necessary for the growth of plants that can induce poor growth of plants. (Hamamoto *et al*., 2000)

The purpose of this study was to investigate the effectiveness of shielding material as a cooling method by simulation, aiming at efficient environmental control in the future using greenhouses in hot and humid area. In particular, calculations were performed assuming different films in the simulation, and the temperature in the greenhouse and the heat generated in the greenhouse for each factor were compared. A model was built for this test to predict the temperature of each element of the greenhouse from outside weather conditions. The temperature and the heat generated for each factor were calculated by the model for the case that uses conventional materials and that uses shielding materials respectively. Through the comparison of the calculation results, we discussed the effectiveness of using shielding materials as an environmental control method.

2 Temperature Prediction Model

2.1 Building a model

In this study, A model that inputs are the outside temperature and solar radiation and output is the

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temperature of each element of the greenhouse was built. First, the greenhouse was divided into mesh. The part of the greenhouse was cut out , and classified into each element such as film and air, and divided each element into mesh.

In previous study, when calculating the temperature of greenhouse, it is often to calculate by solving the heat balance formula of the whole greenhouse. (Local Independent Administrative Agency Hokkaido Research Organization Building Research Department Northern Regional Building Research Institute, 2017) This means that the temperature of the greenhouae is homogenous. However, the temperature of the upper part of the greenhouae and the lower part of the greenhouae is usually different. So, in this study, the temperature of the greenhouse was calculated in more detail by dividing the elements of the greenhouse into mesh. The elements of the greenhouse are those that shown in Figure 1, air outside the greenhouse, film, pipe, air inside the greenhouse, leaves, and soil.

It was assumed that the greenhouse is three meters wide and three meters high. The height of leaves is 2.55 meters high. The thickness of the film is 0.00013 meters.

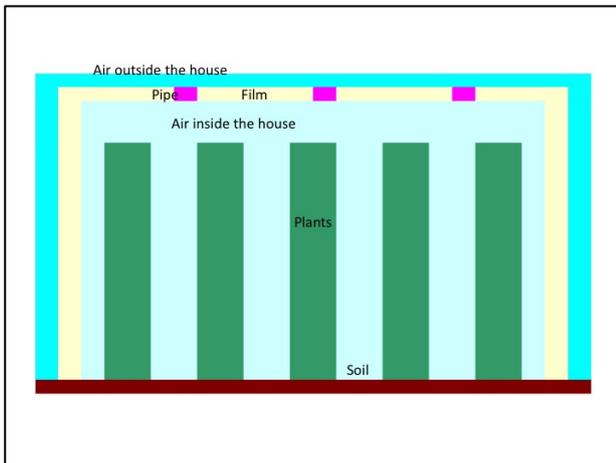The temperature of each mesh is the output of this model.

Figure 1. Element and division of the greenhouse

Next, the authors explain about the method to calculate the temperature of each mesh. The calculation of the temperature is based on heat conduction equation [Thermal diffusion equation] like the equation shown in formula 1. The temperature was calculated by dividing the change of temperature in unit time into the change by the heat conduction and the change by the heat from the external factor such as solar radiation.

$$\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) + \frac{1}{\rho c} \frac{\partial q}{\partial t} \qquad (1)$$

Here, α[m²/s] is the thermal diffusivity of each mesh and ρ [g/m³] is the density of each mesh, and c [J/K/g] is the specific heat of each mech. These are unique values according to the physical properties of the mesh. And, q

[J] is the heat that enter each mesh. The heat from the eternal factor is calculated by defining the transition of the heat in the greenhouse as shown in Figure 2.
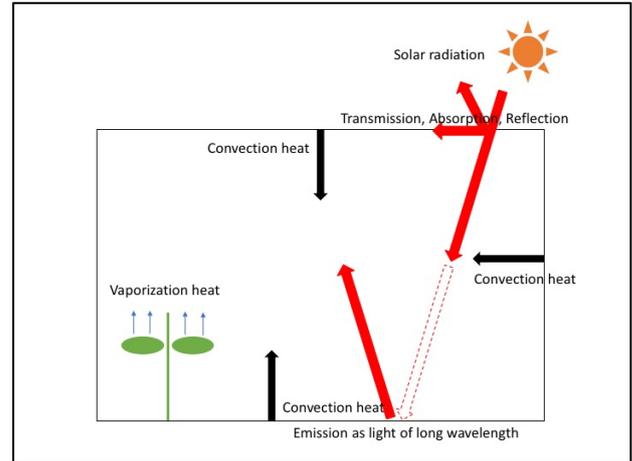

Figure 2. Definition of the flow of the heat

The authors considered the heat from the solar radiation, the convection heat generated by contacting between solid parts and gas parts, and the vaporization heat of water generated by the evaporation by plants as the heat from the eternal factor. (Iwakiri, 1971; Togari *et al.*, 1992) The convection heat generated by contacting between solid parts and gas parts was calculated based on the equation shown in Formula 2.

$$q_{con} = h * S_{wall} \cdot (T_{wall} - T_{air}) \qquad (2)$$

Formula 2 shows one example of convection heat that the heat generated by the difference between the temperature of the wall and the temperature of the air inside the greenhouse. Here, h (W/m²/K) is the heat transfer coefficient between the air and the wall, S_{wall}[m²] is the area in which the air and the wall are in contact, T_{wall} [°C] is the temperature of the wall, T_{air} [°C] is the temperature of the air of the specific point inside the greenhouse. The vaporization heat of water generated by the evaporation by plants was calculated based on the equation shown in Figure 3.

$$q_{plant} = -r \cdot w_{plant} \cdot S_{plant} \qquad (3)$$

Here, r [J/g] is the vaporization heat of the water per gram, and w_{plant}[g/s] is the amount of water evaporated by the leaves per one square meter, S_{plant} [m²] is the leaf area. To calculate the heat enters the greenhouse by solar radiation, the flow of solar radiation was assumed as shown in Figure 3. The light by solar radiation is transmitted, absorbed, and reflected by the film once. The light transmitted is absorbed by the ground. And some percent of light absorbed by the ground is emitted as the light of long wavelength, and that is transmitted, absorbed, and reflected by the film again. The rate of

transmission, absorption, and reflection of light is determined by the physical property values. When considering of the physical value, it is also important to consider both the rate of short wavelength and rate of long wavelength.

This is because the light that plants can use the light whose wavelength is from 300 nm to 700 nm for photosynthesis. So, it is so important how much lights whose wavelength is from 300 nm to 700 nm is in the greenhouse to manage the environment in the greenhouse. Based on the flow of the light mentioned above, it would be reasonable to design the film to cut the light of short wavelength when entering the greenhouse to release heat as much as possible while securing a certain amount of light entering the greenhouse. This is because the light released by the ground whose wavelength is long is to be transmitted through the film. When considering the growth of plants in the greenhouse, the film should be designed so that it can also transmit the light of short wavelength when sunlight enters the greenhouse. So, it is necessary to consider the physical value of the film not on the whole, but on each short wavelength and long wavelength.

In this study, the temperature in the greenhouse was calculated based on two types of the film, "shielding type" and "traditional type". The film that is easy to transmit light whose wavelength is necessary for plant photosynthesis and that does not easily transmit light whose wavelength is longer than 700 nm was examined for "shielding type". The traditional film transmits almost all light, but the film of shielding type efficiently passes only the necessary light into the greenhouse. Therefore, the suppression of the rise of temperature in the greenhouse is expected. On the other hand, since part of the is absorbed by the film, the temperature of film rises compared to the traditional type, which may contribute to the temperature rise in the greenhouse.
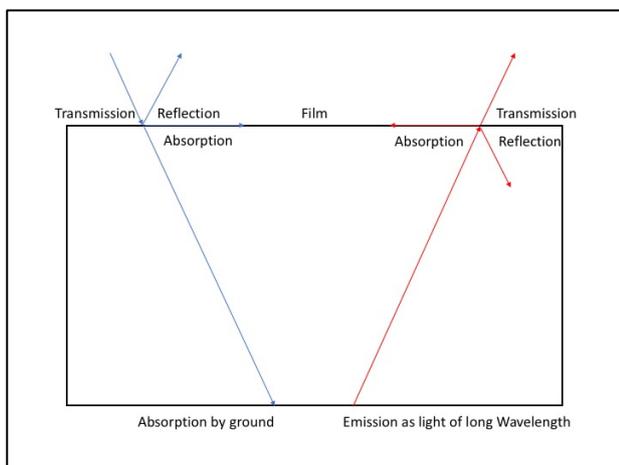

Figure 3. Flow of solar radiation

2.2 Preparation of the input data for calculation

The inputs of this model were outside temperature and solar radiation, so the weather data of the area was prepared from the literature values. The area to be

examined was Jakarta in Indonesia, and the period to be examined was from May to October. Also, for the comparison, the weather data of Tokyo in Japan for the same period was prepared.

The daytime was assumed for twelve hours. And based on the monthly average maximum temperature, average minimum temperature and average integrated solar radiation, the transition of the daily temperature and solar radiation was prepared . The example of the transition of the daily temperature and solar radiation are shown in Figures 4 and 5.
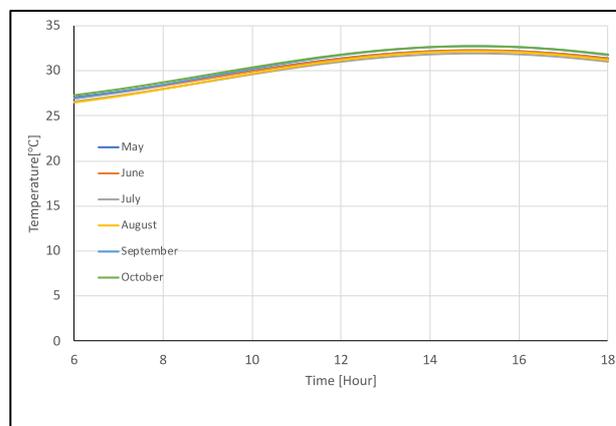

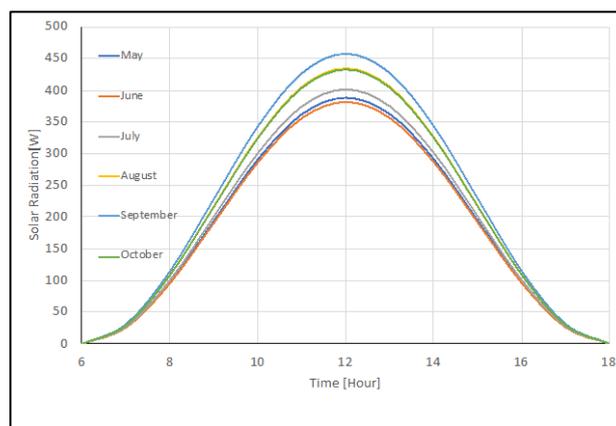**Figure 4.** Transition of temperature in Jakarta

Figure 5. Transition of solar radiation in Jakarta

3 Result and Discussion

Based on the date above, the transition of the daily temperature inside the greenhouse was calculated. The result of calculation for each case the film of "shielding type" and the film of "traditional type" are shown in Figures 6–9. Here, the film of "shielding type" is the one designed to shield the light of long wavelength relatively, and the film of "traditional type" is the one that designed to transmit both light of short and long wavelength.

As the Figures above show, there was not much significant improvement by considering the shielding.

So next, to verify the factor of this result, the transition of the amount of the heat according to the factors that entered the mesh which is in the central part of the greenhouse was analyzed. Since there are a lot of data, only the month in which the temperature in the greenhouse was most improved in Jakarta which is September is described. Figure 11 shows the case of "shielding type" and, Figure 12 shows the case of "traditional type".
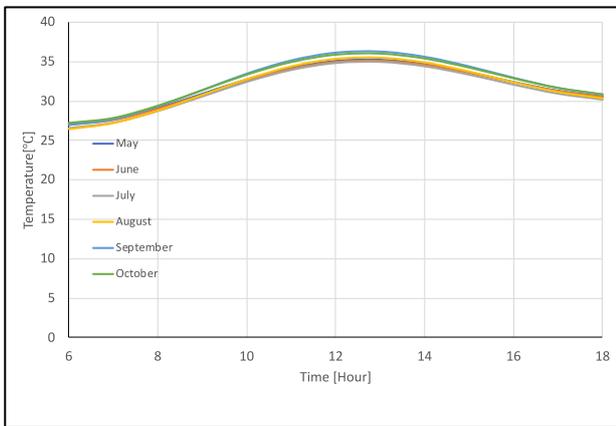

Figure 6. Results of transition of temperature in Jakarta, "shielding type"
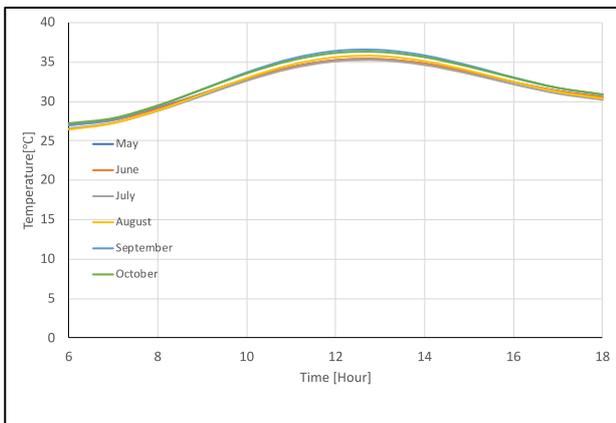
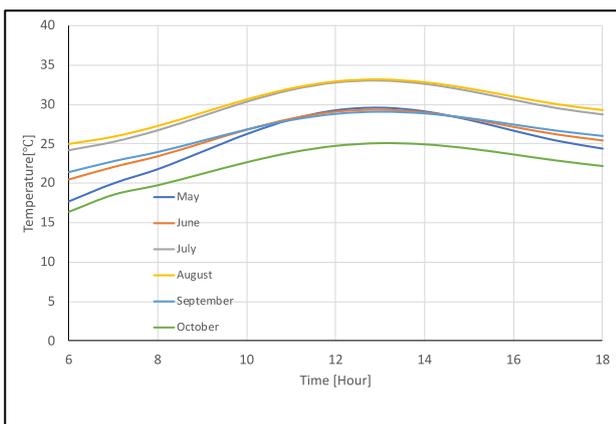**Figure 7.** Results of transition of temperature in Jakarta, "traditional type"

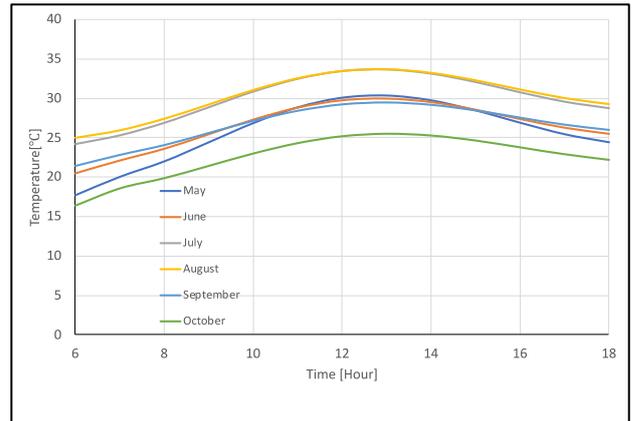**Figure 8.** Results of transition of temperature in Tokyo, "shielding type"

Figure 9. Results of transition of temperature in Tokyo, "traditional type"

As can be seen from the transition of the amount of the heat according to the factors that entered the mesh of the central part of the greenhouse in Figure10 and Figure11, it was suggested that the film was warmed because some part of the light shielded was absorbed by the film, and as a result the heated film contributed to the rise of temperature in the greenhouse.

Figure 12 shows the total amount of the heat per day that entered the mesh of the central part of the greenhouse according to the factors for each case of simulation. As the figure shows, the dominant factor of the heat generation is the convection heat from the film for "shielding type", and is the solar radiation for "traditional type".

From this result, the authors think it is also important to consider the rate of absorption rate of the film as well as the rate of transmission. To solve this problem, the authors would like to propose introducing the system that removes the heat of the film such as water curtain. However, the system like water curtain can affect the other physical value of the film, so it should be careful to introduce such system. And such system that uses water has some problems in the using groundwater in Southeast Asia.
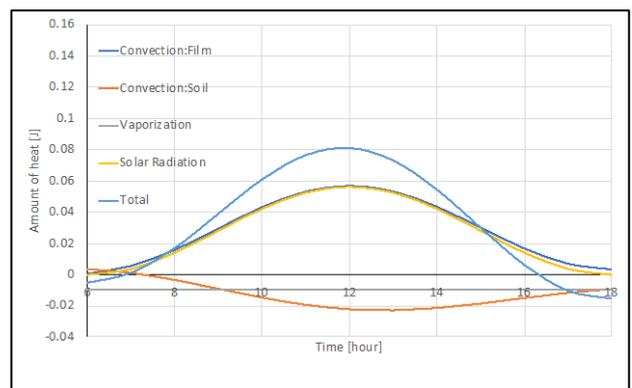
Figure 10. Transition of the amount of the heat according to the factors "shielding type"
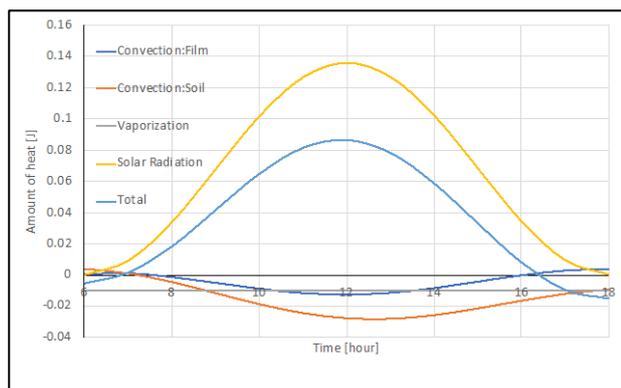

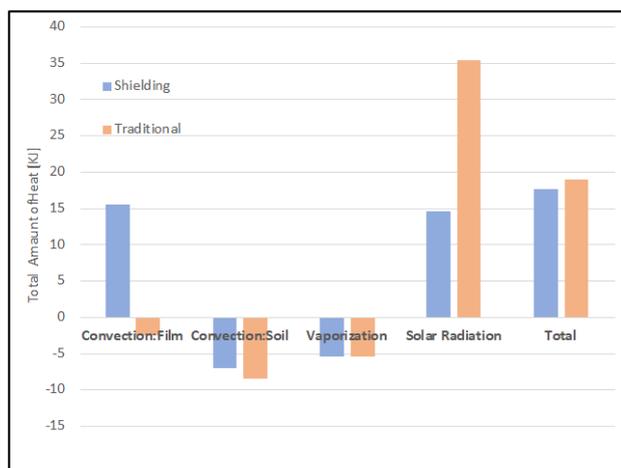**Figure 11.** Transition of the amount of the heat according to the factors "traditional type"

Figure 12. Comparison of the total amount of the heat according to the factors

Also, when lowering the rate of transmission and absorption, the rate of reflection is getting higher. As seen in Figure3, the light enters the greenhouse is absorbed once, and emitted as the light of long wavelength, and some that reflected on the film leaves in the greenhouse that warms the air inside the greenhouse. So, the authors think transmitting the light emitted from the ground is as important as shielding the solar radiation first. These problems are conflicting, so it is necessary to choose the better physical values according to the environmental requirements of the plant cultivated in the greenhouse. For example, in the film of "shielding type", the amount of light for photosynthesis in daytime is about 75% compared to the film in "traditional type". This amount of the light sometimes means good condition for some plants, but means bad for some plants.

So, to examine the effect of shielding, the authors think it is important to consider the plants in the greenhouse and its constraint condition for cultivation.

4 Conclusion

In this study, the authors built a model and performed the simulations to examine the effectiveness of shielding materials as a cooling method for controlling the environment in greenhouse in hot and humid area. As a result, it became possible to analyse the degree of temperature suppression due to heat ray absorption of the shielding material and the heat generated in the house for each factor in the greenhouse. The suppression of the temperature in the greenhouse was not very much, but it was confirmed that the main factor of heat generation in the greenhouse was changed by shading.

Specifically, it was confirmed that when using a traditional film, the heat of sunlight entering the greenhouse is the main factor of heat generation in the greenhouse, but when using a film with shielding materials, the heat generated from the film is the main factor. This result suggested that when using shielding materials, part of the energy of sunlight entering the film is absorbed by the film, so the effect of shielding is not sufficient unless a treatment such as removing the absorbed energy is performed.So, it would be necessary to remove the heat absorbed in the film in order to obtain the sufficient effect of the shading materials. These results suggest that when controlling the greenhouse environment using film, it is important to consider physical properties of the film according to the wavelength, and take measures such as removing heat by water.

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