The Prediction of Hourly Radiation on Plastic Surfaces of Lean-to Type Greenhouse

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摘 要

비닐하우스內에서의 환경처리를 위해서는 얼마나 많은 太陽輻射에너지가 비닐하우스 各面위에 도달하며 그것이 P. V. C. film을 通하여 얼마나 투과되는가 하는 問題를 해결하는 것이 重要하다. 太陽과 地球와의 幾何學的인 關係를 究明하여 太陽熱이 地球에 얼마나 도달하는가를 예측하여 實際 太陽輻射에너지 測定器로 測定한 값과 比較하였다. 그리고 P. V. C. film에서의 太陽輻射에너지의 입사각에 따른 투과율을 굴절율과 吸光係數를 감안하여 계산하였다. 그 結果는 다음과 같다.

1. P. V. C. film의 투과율은 입사각의 약 50도 될 때까지는 약 90%이며, 입사각이 50도를 넘어서면서 투과율은 급격히 감소한다.

2. 비닐하우스 지붕面의 每時間 推定에너지는 거의 測定輻射에너지와 같았다. 그러나 비닐하우스 前面에서의 每時間 推定값과 測定값은 어느정도 가까우나잘 맞는 편은 아니었고, 東쪽面과 西쪽面은 比較的 두 값이 잘 맞아 들어가는 便이었다. 故로 여기에 提示한 비닐하우스 各 面의 輻射에너지를 推定하기 위한 시뮬레이션 모델은 一般的인 形態의 비닐하우스에도 適用시킬 수있으리라고 思料된다.

I. INTRODUCTION

To improve the greenhouse environment, it would be of importance to know how much solar energy is collected by each greenhouse surface and how much solar radiation is transmitted through each surface.

Once it is known how much solar radiation is transmitted, it could be possible to predict the inside air temperature summing up the heat gain and loss on each surface at any time.

It would be meaningful to develop the model predicting the radiation on each surface of the greenhouse and compare the predicted and the measured radiation using the pyranometer.

1.1 Objective of the Study

(1) The primary objective of the study is to predict hourly insolation(irradiation) on the tilted surface to be made up of three components; beam radiation, diffuse solar radiation, and solar radiation diffusely reflected from the ground.

(a) the hourly angle of incidence, zenith angle on each surface of the greenhouse.

(b) the transmittance of the P.V.C. (polyvinyl chloride) film of the greenhouse as to varying the hourly angle of incidence.

(2) The secodary objective is to compare the predicted with the measured hourly insolation by pyranometer under clear sky day.

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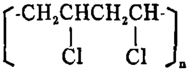
Ⅱ. SYSTEM DESCRIPTIONS

2.1 General Description of Greenhouse

Polyvinyl Chloride (P.V.C) 
$\left[-CH_2\underset{Cl}{\underset{|}{C}}HCH_2\underset{Cl}{\underset{|}{C}}H-\right]_n$ film was used for the structure cover and its beam transmission was about 80% (Ultra and visible solar wave range, infra-red wave range) and about 40% (New infra-red and infra-red wave range), however the transmittance of the total radiation was about 90% over all wave-length around mid-day standard time.

The lean-to type of greenhouse was used for this study because of the special location situation, but that type is not recommended for commerial application because of the reduced light.

The east and west wall frame was made of wood and the roof and the south wall frame was made of aluminum pipes.

The north wall was composed of three layers in series with 4cm styrofoam, 3cm glasswool, and 0.4cm plywood to prevent the heat loss.

The north wall was assumed to be completely insulated and was designed to work as a reflector, so a solar ray was reflected and absorbed by the soil surface.

The east-west orientation of greenhouse is generally considered to be much better than any other orientation to collect the greatest amount of radiation.

To provide for maximum transmission of radiant energy, the greenhouse should be constructed so that the angle of incidence is appoximately 0°.

For a zero angle of incidence in Jinju($\phi=35.17°$) the roof slope would need to be 42°. Such a house would be very expensive to build and maintain. Its roof area would be excessive in relation to the ground surface covered.

Hence, the slope of the roof was designed to be 32°, but it was measured to be 30° after construction. This slope of roof also supported by Morse and Carnecki (Duffie and Beekman, 1974)'s

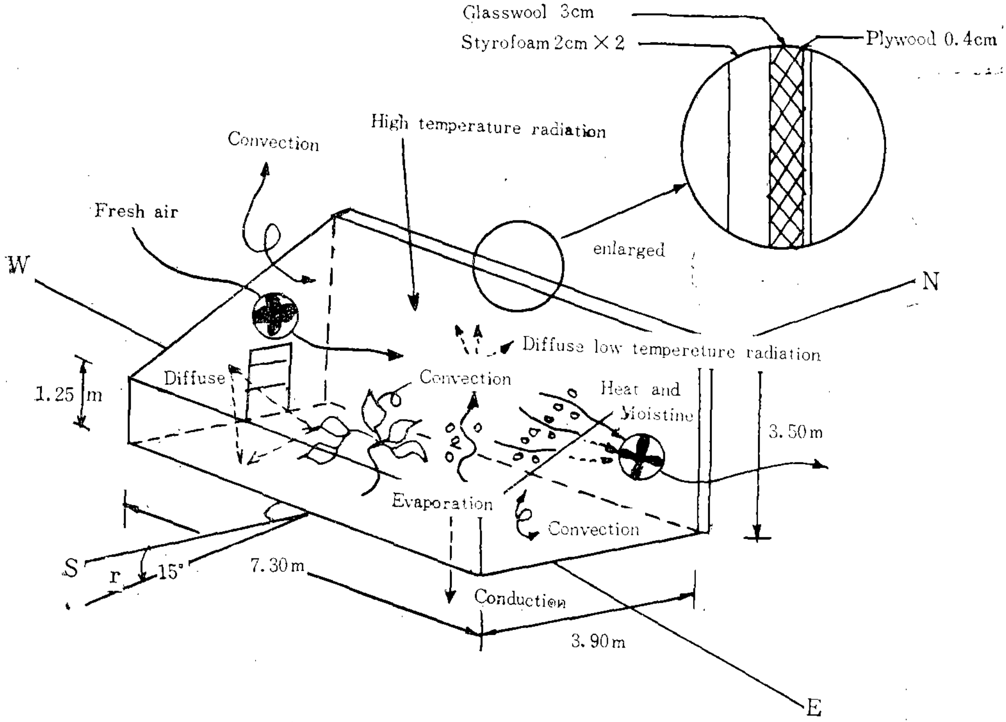


Fig. 2.1 Greenhouse thermal schematic

work ($s=0.9\phi$).

Ventilation system employed mechanical exhaust fans. The side incoming ventilative volume is 9m^3 per miniute(900rpm) and the volume of outgoing ventilation is 15m^3 per miniute (1500 rpm).

With exhaust fans of sufficient capacity, inside air temperature and water vapor ratio can be lowered.

Ⅲ. ESTIMATION OF HOURLY INSOLATION

3.1 Hourly Clear Sky Radiation on a Tilted Surface

For periods of an hour, the clear sky total radiation on a tilted surface is simulated. The value of 0.0036 in the equation is conversion factor from unit of W/m^2 to MJ/m^2·hr. The sun path on March 25, 1982 in Jinju and solar geometry on the greenhouse is given in Fig.3.1, 3.2 and 3.3, respectively.

$$I_t = I_{tb} + I_{td} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

where I_t = total hourly radiation at tilted surface

I_{tb} = beam hourly radiation at tilted surface

I_{td} = diffuse hourly radiation at tilted surface

For the roof surface,

$$I_{tb} = 0.0036(\mathrm{Gon})\ (\tau_b)\ (\cos\theta_z)/\cos\beta \cdots (1.1)$$

$$I_{td} = 0.0036(\mathrm{Gon})\ (\tau_d)\ (\cos\theta_z)/\cos\beta \cdots (1.2)$$

For the surface 2 (south facing wall)

$$I_{tb} = 0.0036(\mathrm{Gon})\ (\tau_b)\ (\sin\theta_z)(\cos x) \cdots (1.3)$$

$$I_{td} = 0.0036(\mathrm{Gon})\ (\tau_d)\ (\sin\theta_z)(\cos x) \cdots (1.4)$$

For the surface 3 and 4 (east facing wall and west facing wall)

$$I_{tb} = 0.0036(\mathrm{Gon})\ (\tau_b)\ (\sin\theta_z)(\sin x) \cdots (1.5)$$

$$I_{td} = 0.0036(\mathrm{Gon})\ (\tau_d)\ (\sin\theta_z)(\sin x) \cdots (1.6)$$

where G_{on} = extraterrestrial radiation

τ_b = atmospheric transmittance for beam radiation

τ_d = atmospheric transmittance for diffuse radiation

θ_z = zenith angle of the sun

β = slope, the angle between the plane surface in question and horizontal.

x = angle given in Fig. 3.3

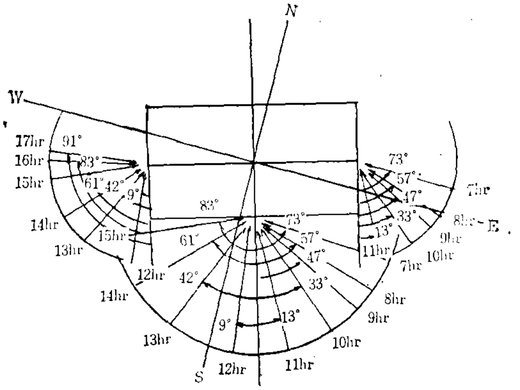


Fig.3.1 Sun path diagram on March 25, 1982 in Jinju(Latitude:32.17°)

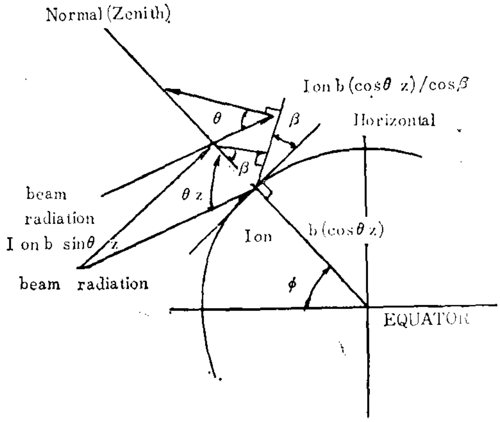


Fig.3.2 Vector geometry of solar radiation on the roof surface tilted to south·

3.2 Total Radiation on Fixed Sloped Surfaces

An improvement on this model has been derived by Liu and Jordan(1963) by considering the radiation on the tilted surface to be made up of three components: beam radiation, diffuse radiation, and solar diffusely reflected from the ground. A surface tilted at slope β from the horizontal has a view factor to the sky by $(1+\cos\beta)/2$. If the diffuse solar radiation is isotropic, this is also R_d. The surface has a view factor to the ground of $(1-\cos\beta)/2$ and if those surro-

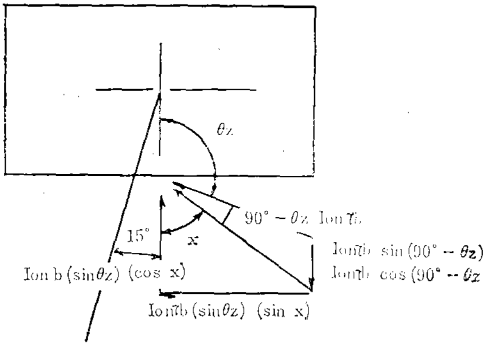


Fig.3. 3 Vector geometry of solar radiation on the surface of the greenhouse.

undings have reflectance of ρ for the total radiation, the reflected radiation from the surrounding on the surface on the tilted surface for an hour is then the sum of three terms;

For the roof surface,

$$I_T=I_{tb}\mathrm{FI}+I_d((1+\cos\beta/2)+(I_b+I_d)\rho((1-\cos\beta)/2)\cdots\cdots(2)$$

For the surface 2, 3, and 4

$$I_T=I_{tb}\mathrm{FI}+I_{td}/2+(I_{tb}+I_{td})/2\cdots\cdots(2.1)$$

where I_T = modified hourly radiation at tilted surface, total

FI = view Factor

Liu and Jordan suggest values of diffuse ground reflectance of 0.2 when three is no snow and 0.7 there is a fresh snow cover. The view factor of the vertical receiver, surface 2, 3 and 4 in this study is 0.5, because cos β is equal to zero ($\beta=90°$)

3. 3 Radiation Transmittance of Transparent Cover

The tansmission, reflectance, and the absorption of solar radiation by various parts of a solar collector are important in determining the hourly insolation transmitted into the greenhouse as a solar collector.

The transmittance, reflectance, and absorption are functions of the incoming radiation, and the thickness, refractive index (n) and the extinction coefficient (K) are the function of the wave length of the radiation.

3. 3. 1 Reflection of Radiation

Exactly the same expression results when the parallel component of polarization is considered. $r_\perp$ and $r_\parallel$ are not equal (except the normal incidence and transmittance of initially unpolarized radiation is the average transmittance of the two components

$$\tau_r=1/2((1-r_\parallel)/(1+r_\parallel)+(1-r_\perp)/(1+r_\perp)) \quad (3)$$

where τ_r = the transmittance considered the absorbing loss

$r_\perp$ = the perpendicular component of unpolarized radiation

$r_\parallel$ = the parallel component of unpolarized radiation

3. 3. 2 Absorption of Radiation

The absorption of radiation in a partially transparent medium is described by Boug uer's law, which is based on the assumption that the absorbed radiation is proportional to the local intensity in the medium and the distance the radiation travels in the medium, x,

$$dI_x=I_xKdx$$

where K = the proportionality constant, called the extinction coefficient, and assumed to be a constant in the solar spectrum

Integrating along the actual path length in the medium yields $L/\cos\theta_2$

$$\tau_a=I_\tau/I_0=EXP(-KL/\cos\theta_2)\cdots\cdots(4)$$

where τ_a = the transmittance considered the reflecting loss

I_τ = the radiation traveled in the medium x

I_0 = the local intensity in the medium

L = length of the medium

The tansmittance of a single cover becomes,

$$\tau=\tau_a\tau_r\cdots\cdots(5)$$

3. 4 Computer Program Structures

Simulation modelling is of little merit unless the resulting predictions are accurate. Therefore o test the model, comparisons were made betweent actual and predicted the hourly insolation.

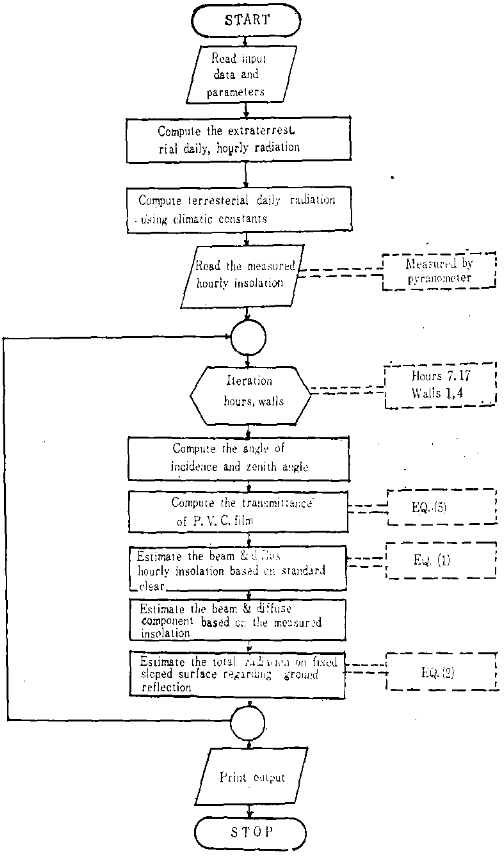


Fig.3.4 Flow chart of computer evaluation of the mathematical model

IV. EXPERIMENTAL PROCEDURE AND RESULTS

4.1 Experimental Procedure

The LI-200 SB Pyranometer Sensor manufactured by LI-COR, Ltd., was used for field measurements in solar radiation. Patterned after the work of Kerr, Thurntell and Tanner, the LI-200 SB features a silicon photovoltaic detector mounted in fully cosine-corrected miniature head. The pyranometer's spectural response does not cover the full range of solar spectrum, but the error induced is less than ±5% under most conditions of natural daylight. The LI-200 SB should not be used under vegetation or artificial lights because it has been calibrated for the daylight spectrum.

Light meter LI-185 B manufactured by LI-COR, Ltd., gives direct readout of measurements of solar radiation in air from the pyranometer, LI-200 SB.

The pyranometer was mounted just outside the outer cover on the cover frame and took the reading from light meter on each wall 1, 2, 3 and 4 every hour at daylight.

4.2 Results

The mathematical model was programmed for hourly insolation on each surface of the greenhouse. The output of the model were discussed in these sections.

4.2.1 Transmittance as a Function of the Angle of Incidence

The transmittance using eq. (5) were theoretically calculated. The transmittance were plotted in Fig. 4.1 with respect to the angle of incidence for transparent cover in greenhouse. Each relation of the angle of incidence, zenith angle of the sun, clear index(K), and transmittance is listed in Table 4.1, 4.2, 4.3 and 4.4.

4.2.3 The Prediction of the Hourly Insolation Based on Extraterrestrial Radiation

The prediction of the insolation based on extraterrestrial radiation theoretically using eq.s (1), (1.1), (1.2), (1.3), (1.4), (1.5), and (1.6), which are modified by researcher are plotted in Fig. 4.2, 4.3, 4.4, and 4.5

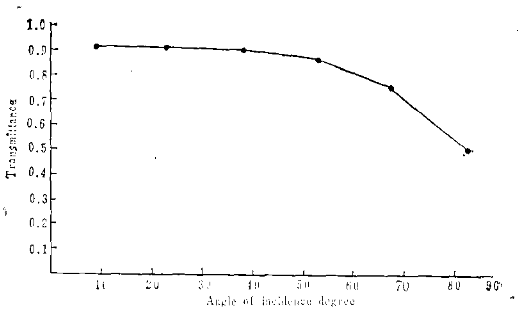


Fig.4.1 Transmittance as a function of the angle of incidence

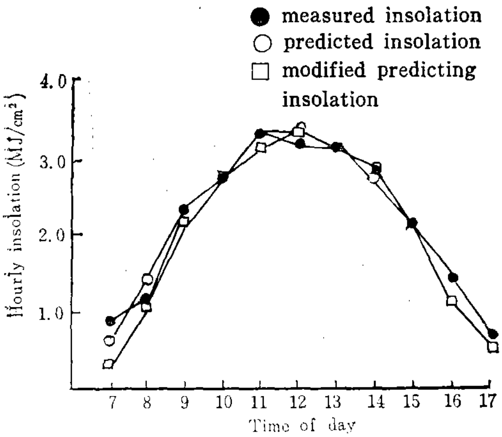


Fig.4.2 Comparison of the measured and predicted insolation on the roof surface of the greenhouse. (J=1)

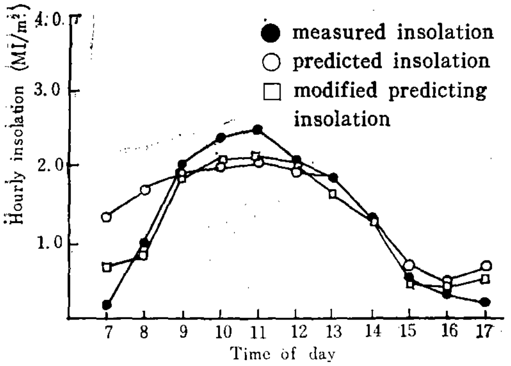


Fig.4.3 Comparison of the measured and predicted insolation on front surface of the greenhouse. (J=2)

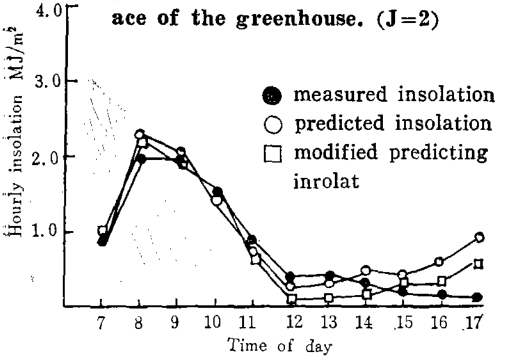


Fig.4.4 Comparison of the measured and predicted insolation on east facing surface of the greenhouse. (J=3)

V. CONCLUSIONS

Based on the simulation of the mathematical model, the hourly insolations are predicted on each wall of the greenhouse. The following conclusions are presented,

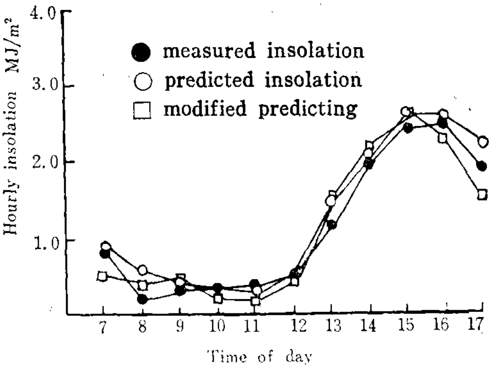


Fig.4.5 Comparison of the measured and predicted insolation on west facing surface of the greenhouse. (J=4)

Table-4.1 The Transmittance with respect to the angle of incidence, zenith angle, clear index for roof surface of the greenhouse.

time	angle of incidence (deg.)	zenith angle of the sun (deg.)	clearness index	transmittance
7	67.5	77.1	.33	.77
8	52.6	65.1	.34	.88
9	37.7	53.8	.54	.91
10	23.0	44.0	.58	.91
11	8.9	36.7	.66	.91
12	8.9	34.0	.67	.91
13	22.9	36.7	.72	.91
14	37.7	44.0	.81	.91
15	52.6	53.8	.83	.88
16	67.5	65.1	1.	.77
17	82.4	77.1	2.06	.52

1. The transmittance of the P.V.C. film is about 90% up to the angle of incidence 50°. The transmittance sharply decreases with increase of the angle of incidence at larger than 50°.

2. The predicted insolation is very close to the measured insolation for the roof surface. However the prediction on the front surface does not fit well. It needs modifing the model. And the predicted insolation for east and west facing surface fits quite well.

3. The following recommendations for further

Table-4.2 The tansmittance with respect to the angle of incidence, zenith angle, clear index for the front surface of the house.

time	angle of incidence (deg.)	zenith angle of the sun (deg.)	clearness index	transmittance
7	67.8	77.1	.07	.76
8	60.9	65.1	.37	.83
9	56.0	53.8	.66	.86
10	53.5	44.0	.77	.87
11	54.0	36.7	.83	.87
12	57.3	34.0	.80	.85
13	63,0	36.7	.88	.81
14	70.4	44.0	.88	.73
15	78.8	53.8	.63	.59
16	87.8	65.1	2.38	.39
17	97.0	77.1	0.0	.20

Table-4.3 The transmittance with respect to the angle of incidence, zenith angle, clear index for east facing surface

time	angle of incidence (deg.)	zenith angle of the sun (deg.)	clearness index	transmittance
7	26.0	77.1	.14	.91
8	40.0	65.1	.44	.90
9	54.4	53.8	.61	.87
10	69.0	43.9	.82	.74
11	83.7	36.7	1.65	.49
12	98.7	34.0	.0	.18
13	112.9	36.7	.0	.07
14	127.4	43.9	.0	.04
15	141.6	53.8	.0	.0
16	155.0	65.1	.0	.0
17	165.2	77.1	.0	.0

study are presented,

(1) The mathematical model presented in this study should be adjusted for the front surface of the greenhouse.

(2) To test the simulation model, it could be better to take 2-3 days hourly insolation measurements or just one day hourly insolation of a few months than to take only one day hourly insolation in March.

Table-4.4 The transmittance with respect to the angle of incidence, zenith angle, clear index for west facing surface

time	angle of incidence (deg.)	zenith angle of the sun (deg.)	clearness index	transmittance
7	154.0	77.1	.0	.0
8	140.0	65.1	.0	.0
9	125.6	53.8	.0	.10
10	111.0	43.9	.0	.06
11	96.3	36.7	.0	.21
12	81.7	34.0	.77	.53
13	67.1	36.7	.64	.77
14	52.6	43.9	.71	.88
15	38.4	53.8	.75	.91
16	25.0	65.1	.72	.91
17	14.8	77.1	.81	.91

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