A FRESNEL LENSES BASED CONCENTRATED PV SYSTEM IN A GREENHOUSE

Sonneveld, P. J., G.L.A.M. Swinkels, B.A.J. van Tuijl, H. Janssen and Th. Gieling
Wageningen UR Greenhouse Horticulture, P.O. Box 16, 6700 AA Wageningen, The Netherlands,
email: piet.sonneveld@wur.nl

ABSTRACT: The scope of this investigation is the development and testing of a new type of greenhouse with an integrated linear Fresnel lens, receiver module and an innovative system for tracking to exploiting all direct radiation in a solar energy system. The basic idea of this horticultural application is to develop a greenhouse for pot plants (typical shadow plants) who does not like direct radiation. Removing all direct radiation will drastically reduce the need for cooling under summer conditions and the need for screens or lime coating of the glass to reflect or block a large part of the radiation. The remove of all direct radiation will block up to 81% of the solar energy, which will reduce the needed cooling capacity. The second measure is the integration of a solar energy system. When the (linear) Fresnel lenses are designed between double glass coverings and integrated in the greenhouse, the focused solar energy on the Thermal Photovoltaic (TPV) cell in the focus point delivers electric and thermal energy. The TPV module mounted in the focal point require cooling due to the high heat load of the concentrated radiation (concentration factor of 50 x). All part are integrated in a greenhouse structure with a size of about 36m^2 and the electrical and thermal yield is determined for Dutch climate circumstances.

Keywords: Fresnel, Concentrators, Energy Options, PV System, Solar Cell.

1 INTRODUCTION

Fresnel lenses are optical devices that can be used for concentration of solar radiation. These lenses are thinner, have lower weight and a smaller focal length than the thicker standard lenses. The possibility of direct and diffuse light with this lens to separate the Fresnel lens is used for exposure control in greenhouses and buildings.

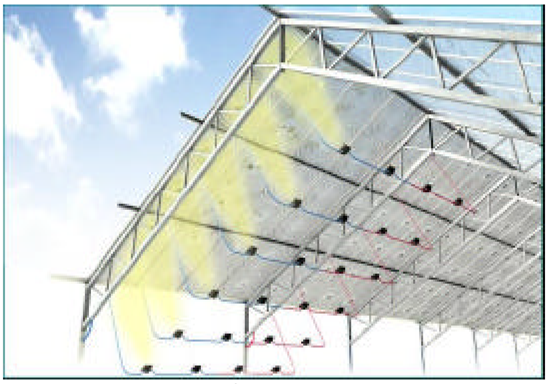

Figure 1: Impression of a greenhouse hood with normal Fresnellenzen integrated between double glass (Drawing Bode Project and Engineering).

With this lens direct radiation can be used for energy generation and diffuse light for plant growth. The reception of this energy, the weather conditions at high intensities of solar irradiation better. Especially for plants that are often lower light intensities questions provides interesting possibilities. The collection of 40-80% of the (direct) solar radiation is possible with the combination of linear and linear Fresnel lens photovoltaic module (PV module). The left diffuse radiation is used for exposure of the plants in the greenhouse. In the case of low intensities (morning, evening, cloudy weather and during winter) of solar radiation, the PV module can be removed from the focal point, so that the total radiation in the greenhouse is as much as possible. So the lighting level is optimal to benefit to maintained horticultural application. The Fresnel lens can be combined with thermal, photovoltaic, or a hybrid technique, the concentrated energy is released in the form of hot water, electric energy or a combination of both. With thermal absorbers, about a return of 50% and PV cells achieved an efficiency of up to 30%.

2 METHODS AND RESULTS

2.1 Separation of direct and diffuse radiation

The basic idea of using Fresnel lenses in the covering of the greenhouse is splitting the diffuse and direct radiation and converts the last mentioned part in useful electrical and thermal energy. The remaining diffuse light part is sufficient for the growth of the most pot plant cultures.

In figure 2 the average global radiation in the Netherlands appears divided into diffuse and direct.

These graphs give a good indication of the average daily radiation sum. However the daily averaged radiation sum do not result in a good picture of the instantaneous ratio between diffuse and direct radiation. Therefore, these data is given in a separate graph of Fig. 3 On basis of this hourly data it is shown a maximum direct radiation of 69% compared with the total radiation. From this we can deduce the maximum screenings percentage:

In addition of the 69% direct radiation, which can be eliminated, the maximum transmission of diffuse light through the greenhouse covering is 80%. So for another 31% decline, then the maximum screenings percentage becomes: 69 + 31x 0.80 = 81%. With a transmission of 80% for diffuse light through the greenhouse construction, the diffuse light transmission for the entire greenhouse for 64%. On a clear day (900W irradiation) is the crop incident power: 171W. This part can be increase to allow entering more direct light into the greenhouse. At a cloudy day with an irradiation of 400W all the incoming radiation can be entered to the cultivation system. In that case this irradiation is: 280W.

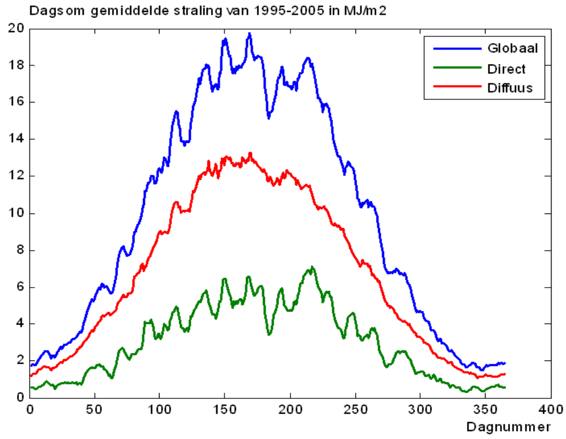

Figure 2 Daily average global radiation in the Netherlands divided into diffuse and direct part.

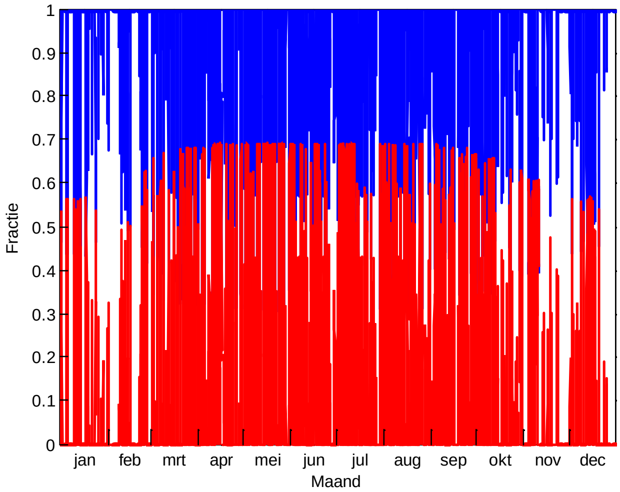

Figure 3 Diffuse and direct radiation in the Netherlands determined from hourly means. (red = fraction direct radiation, blue = fraction diffuse radiation)

2.2 Integration in the greenhouse system

The main structure of the (prototype) greenhouse will be comparable to a traditional wide span greenhouse: beams, and stability bracings will be made of steel. The span of the span is 6.00 m with a width of 6.00 m. The covering with the glass rods have a slope of 30^{o} with the horizontal and are oriented to the south direction. In the north direction the glass rods have the same slope with the horizontal. In this case there is chosen for a symmetrical greenhouse because in the case of an asymmetric greenhouse the path of the focal point becomes in the north part of the greenhouse covering. The ventilation windows are mounded in the part of the roof oriented in the north direction. The walls of the greenhouse will be covered with standard single glass of 4 mm thickness. In total 12 linear Fresnel lenses with a focal distance of 1.2 m and a size of 1.0x1.0 m are placed on the south side of the greenhouse with a size of 6 x 6 m. The lenses are separately places within one double glass panel of 1.0 x 3.0 m (total 4 glass panels) see Fig. 5.

Figure 5 Placement of the Fresnel lenses (placed between double glass).

Figure 6 The Fresnel greenhouse at real size of 6 x 6 m.

In Fig. 6 The complete greenhouse is depicted.

2.3 The TPV module and tracking

In the greenhouse under each array of Fresnel lenses three collectors are placed as can be noticed in Fig. 7. On one of these collectors a TPV module is placed for the conversion to electrical energy. The monocrystalline Si-cells, suitable for concentrated radiation, are laminated to a module with a size of 1500 x 30 mm, which is placed in the focal point of the linear Fresnel lens (concentration factor of about 50x) as can be seen in Fig. 8. Due to the high optical concentration factor of 50 x, the required PV area is a lot smaller compared to a normal silicon PV system. This will result in an area of the PV cells of about 2% of the total greenhouse area. Therefore the light loses are acceptable for horticulture. The solar cells have to be cooled with air or water to remove the excessive heat. The thirty mono crystalline NR solar cells are placed in series and have a total length of 1.55 m. These cells suitable for the concentration factors up to 100x and are performed with parallel diodes. The modules are mounted and suspended with thin steel cables. These cables are excited by two steel shafts which are driven by two electric motors. This structure will enable the modules in the right position for large surfaces (1000-10000m^2) with only two electric motors. In Fig. 9 the

Figure 7 The three collectors of the system inside the greenhouse

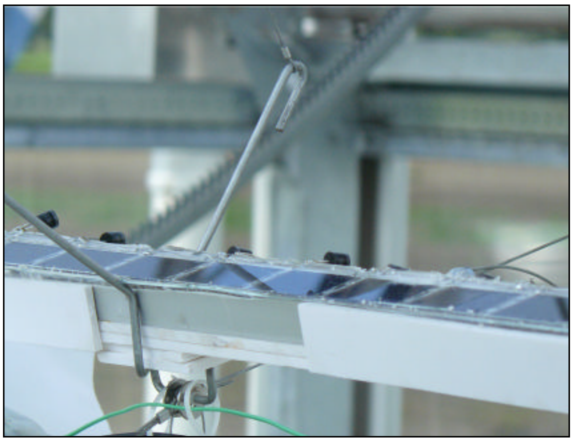

Figure 8 The TPV module of the system with the silicon cells inside the greenhouse

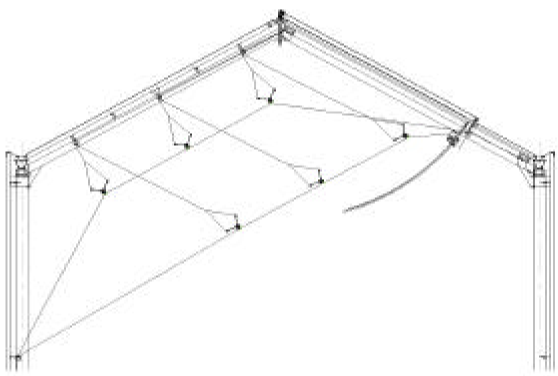

Figure 9 Cross section of the hood with details of the suspension and steering construction of the solar cell modules, with the lowest and highest position of the modules is shown.

construction with the lowest and highest position of the modules is shown. The tracking of the module in the focal line of the linear Fresnel lens was based on calculated position designed and fine tuned with respect to maximum power level. The typical positions of both electric motors for the module position during one day can be seen in Fig.9

2.4 Measurement of the yield of the system

The electric yield of the system was measured with the module as described under 2.3. The effect of shadow lines on the modules was diminished by placing parallel diodes. The first measurements show a combination of the shadow effect, the voltage loss over the diodes and the high currents of typical 5-10A, which results in a very low fill factor of 0.5. In the future however, better diodes or electronics will result in a higher fill factor. Therefore the yield is calculated with a fill factor of 0.7. The results on the measurements on July 31 2008 is depicted in

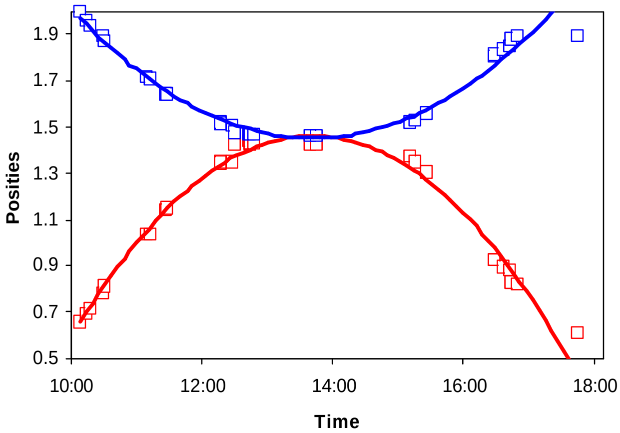

Figure 10 Both positions of the electric motors where the module will be held in the focus on August 15, 2008. R1 is the position of motor which regulate the vertical movement and R2 is the position of the motor which contribute to the horizontal movement.

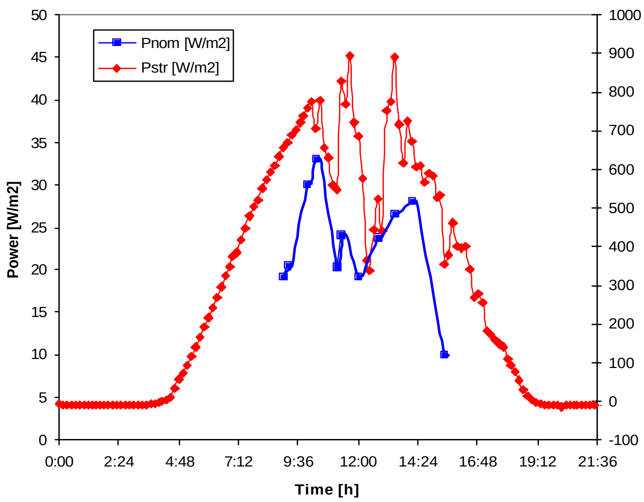

Figure 11 Generated electric power (Pnom) and incident radiation (Prad) on the location Wageningen measured on July. 31. 2008

Figure 11. A peak value of 35W/ m^2 is measured during this day. The thermal yield was determined on 170 W/m^2 at an incident radiation of 640 W/m^2. From this data the yearly yields are calculated with typical Dutch climate data as given in Fig. 12. The

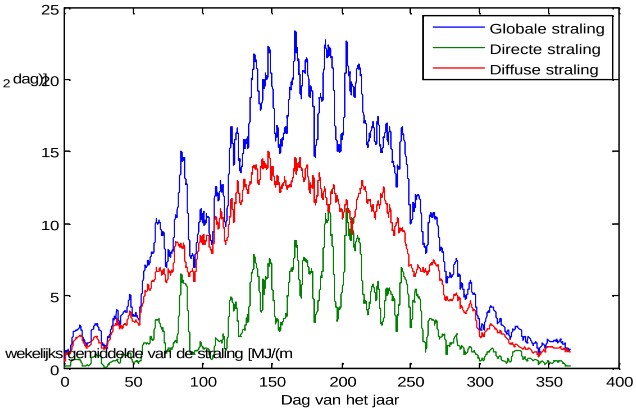

Figure 11 Daily radiation sums (global, direct and diffuse part) for a year measured in De Bilt.

yearly total electric yield is determined on 29 kW/m^2 and the thermal yield on 144 kW/m^2. In Fig. 12 the yield of the electric energy is given is a function of time. There are possibilities to increase the yield of the system. In Table I on overview is given for the transmission of perpendicular radiation, the used cells for the module and

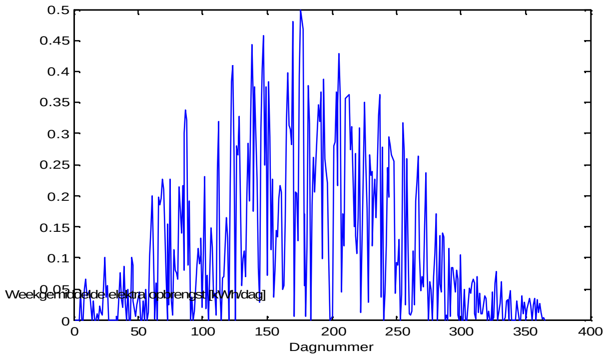

Figure 12 Week average of the electrical power output as a function of the day number.

the yearly yield of the electric energy. From this Table an increase of out put can be notices by the use of AR coated glass a good lamination between the lens and the

Table I Light Transmissions and estimated annual yield based on amount of light transmission and direct radiation

Type covering	Transmission perpendicular (%)	Transmission greenhouse perpendicular (%)	Yairly yield Electric [kWh/m^2]	
			Si-PV cel	Tri-j-cel
Single PMMA Fresnel lens	93	74	53	106
PMMA Fresnel lens as double sheet	81	64	45	90
PMMA Fresnel lens between double glass	53	42	30	61
PMMA Fresnellens laminated between AR coated double glass	90	72	51	102

glass and the use of triple-junction cells. In that case the yearly yield can be increased to 100 KW/ m^2.

3 SUMMARY

The development and testing of a new type of greenhouse with an integrated linear Fresnel lens, receiver module and an innovative system for tracking to exploiting all direct radiation in a solar energy system is described. The basic idea of this horticultural application is to develop a greenhouse for pot plant that is typical shadow plant who does not like direct radiation. Removing all direct radiation will drastically reduce the need for cooling under summer conditions and the need for screens or lime coating of the glass to reflect or block a large part of the radiation. Calculation shows a maximum light reduction of 81% with this covering in the greenhouse. The PV cells are mounted in a framework and controlled in position with two electric motors. The system with a size of 6 x 6m is integrated in a greenhouse. A peak power of approximately 40 W/m^2 electrical and thermal peak power of 170 W/m^2 is expected with an illumination of 900 W/m^2.The produced energy is determined on 29 kW/m^2 and the thermal yield on 144 kW/m^2 and can be used for energy supply and/or extra cooling with a pad and fan system and/or a desalination system.

4. ACKNOWLEDGEMENTS

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