# A Fresnel Lenses Based Concentrated PV System in a Greenhouse

P.J. Sonneveld[a], G.L.A.M. Swinkels, B.A.J. van Tuijl, H.J.J. Janssen and T.H. Gieling
Wageningen UR Greenhouse Horticulture
PO Box 16, 6700 AA Wageningen
The Netherlands

**Keywords:** concentrators, energy options, solar cell

**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 exploit 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) that do 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 removal 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 requires cooling due to the high heat load of the concentrated radiation (concentration factor of 50×). All parts are integrated in a greenhouse structure with a size of about 36 m$^2$ and the electrical and thermal yield is determined for Dutch climate circumstances.**

## INTRODUCTION

In northern Europe, with colder winter climate conditions, energy saving is an important issue. Moreover during summer cooling is needed by natural ventilation to remove excess energy. In the southern countries with higher global radiation and higher outdoor temperatures during summer, cooling of greenhouses is even more important (Stanghelini, 1987). With a Fresnel greenhouse design presented in Figure 1, cooling can be combined with energy supply. First developments applying linear Fresnel lenses where presented by Jirka et al. (1999) and Tripanagnostopoulos et al. (2004). 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. With this lens direct radiation can be used for energy generation and diffuse light for plant growth. 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) as seen in Figure 1. 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%.

[a] piet.sonneveld@wur.nl

## MATERIALS AND METHODS

### Separation of Visible and Thermal Radiation

The basic idea of using Fresnel lenses in the covering of the greenhouse is splitting the diffuse and direct radiation and converting the last mentioned part in useful electrical and thermal energy. The remaining diffuse light part is sufficient for the growth of most pot plant cultures. In Figure 2A 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 does not result in a good picture of the instantaneous ratio between diffuse and direct radiation. Therefore, these data are given in a separate graph of Figure 2B. On the basis of these hourly data a maximum direct radiation of 69% is shown compared with the total radiation. From this we can deduce the maximum screenings percentage.

In addition to the 69% direct radiation, which can be eliminated, the maximum transmission of diffuse light through the greenhouse covering is 80%. With a transmission of 80% for diffuse light through the greenhouse construction, the diffuse light transmission for the entire greenhouse for 64%. So for another 36% decline for the diffuse light fraction, then the maximum screenings percentage becomes: 69+31×0.36=80%. On a clear day (900 W $m^{-2}$ irradiation) the crop incident power is the left 20%: 180 W $m^{-2}$. This part can be increased by setting the module out of focus. On a cloudy day with an irradiation of 400 W $m^{-2}$ all the incoming radiation can be entered to the cultivation system. In that case this irradiation is 280 W $m^{-2}$.

### 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 length of the hood is 6 m at a width of 6 m. The covering with the glass rods has a slope of 30° 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 we chose a symmetrical greenhouse because in the case of an asymmetric greenhouse the path of the focal point comes in the north part of the greenhouse covering. The ventilation windows are mounted in the part of the roof oriented in the north direction. The walls of the greenhouse are 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 1×1 m are placed on the south side of the greenhouse with a size of 6×6 m. The lenses are separately placed within one double glass panel of 1×3 m (total 4 glass panels) shown in Figure 3. A photograph of the entire greenhouse is given in Figure 4.

### The PV/T Module and Tracking

In the greenhouse under each array of Fresnel lenses three collectors are placed as can be noticed in Figure 5. On one of these collectors a PV/T 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 1500×30 mm, which is placed in the focal point of the linear Fresnel lens (concentration factor of about 50×) as can be seen in Figure 6. Due to the high optical concentration factor of 50×, 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 loss is acceptable for horticulture. The solar cells have to be cooled with air or water to remove the excessive heat. The 30 mono-crystalline NR solar cells are placed in series and have a total length of 1.55 m. These cells are suitable for concentration factors up to 100× and are performed with parallel diodes. The modules are mounted and suspended with thin steel cables. These cables are wound around two steel shafts which are driven by two electric motors. This structure will enable the modules in the right position for large surfaces (1000-10000 $m^2$) with only two electric motors. In Figure 5 the construction of the PV/T modules is shown. The tracking of the module in the focal line of the linear Fresnel lens was based on a 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 Figure 7.

## RESULTS AND DISCUSSION

### Measurement of the Yield of the System

The electric yield of the system was measured with electronic resistors. 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 5-10 A, 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 of the measurements on 5 August 2009 are depicted in Figures 7 and 8. Both positions of the electric motors where the module will be held in the focus on 5 August 2009 are depicted in Figure 7. R1 is the position of the motor which regulates the vertical movement and R2 is the position of the motor which contributes to the horizontal movement. The generated power on 15 August 2008 is depicted in Figure 8. A peak value of the generated power of 37.5 W $m^{-2}$ is measured during this day. The thermal yield was determined on 170 W $m^{-2}$ at an incident radiation of 733 W $m^{-2}$. From these data the yearly yields are calculated with typical Dutch climate data as given in Figure 2A. The yearly total electric yield is determined on 29 kW $m^{-2}$ and the thermal yield on 144 kW $m^{-2}$. In Figure 9 the yield of the electric energy is given as a function of time. There are possibilities to increase the yield of the system. In Table 1 on overview is given for the transmission of perpendicular radiation, the used cells for the module and the yearly yield of the electric energy. From this Table an increase of output can be noticed by the use of AR coated glass, a good lamination between the lens and the glass and the use of triple-junction cells. In that case the yearly yield can be increased to 240 kW $m^{-2}$.

## CONCLUSIONS

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 exploit all direct radiation in a solar energy system is described. The basic idea of this horticultural application is to develop a greenhouse for pot plants that are typical shadow plant that do 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 6×6 m 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 electrical energy is determined at 29 kWh $m^{-2}$ and the thermal yield at 144 kWh $m^{-2}$. The generated energy can be used for energy supply, extra cooling with a pad and fan system and/or a desalination system.

## ACKNOWLEDGEMENTS

This research is funded by the Ministry of Agriculture, Nature and Food quality (LNV), Dutch Product Board for the Horticulture (PT) and the Dutch organization SenterNovem (EOS).

### Literature Cited

de Zwart, H.F. 1996. Analyzing energy-saving options in greenhouse cultivation using simulation model. Ph.D. Thesis, Wageningen University. IMAG rapport 96-5.

Jirka, V., Kučeravý, K., Malý, M., Pech, F. and Pokorný, J. 1999. Energy flow in a greenhouse equipped with glass raster lenses. Renewable Energy 16:660-664.

Stanghelini, C. 1987. Transpiration of Greenhouse Crops. Ph.D. Thesis, Wageningen

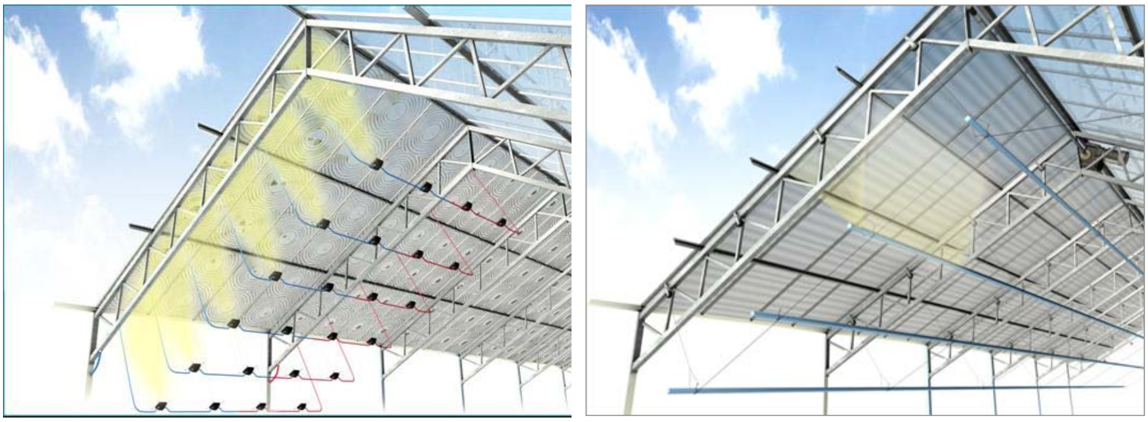
University.
Tripanagnostopoulos, Y., Souliotis, M., Tonui, J.K. and Kavga, A. 2004. Irradiation aspects for energy balances in greenhouses. Acta Hort. 691:733-740.
Zondag, H.A., Vries, D.W., de Velden, W.G.J., van Zolingen, R.J.C. and van Steenbergen, A.A. 2002. The thermal and electrical yield of a PV-Thermal collector. Solar Energy 72:113-128.

## Tables

Table 1. Light Transmissions and estimated annual yield based on amount of light transmission and direct radiation.

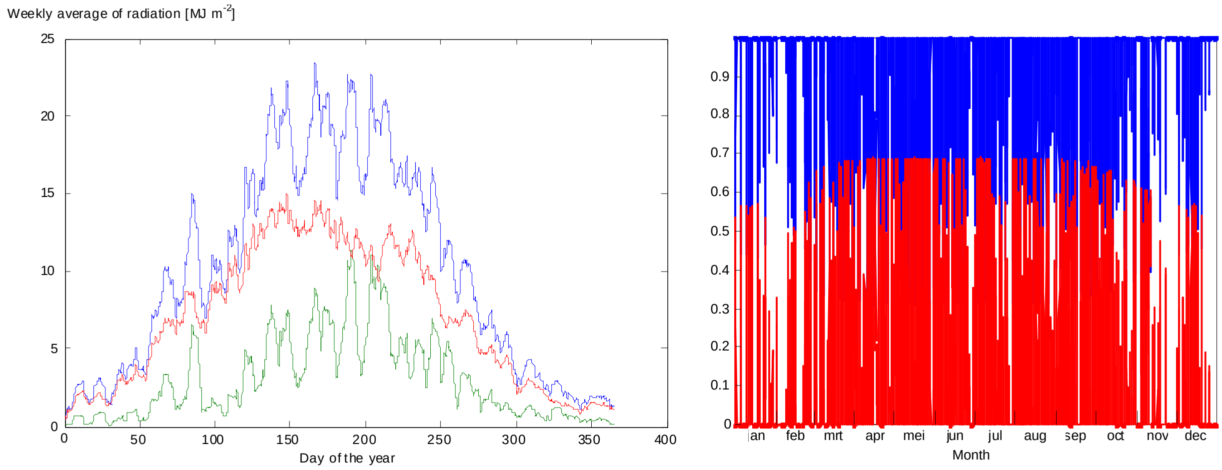
| Type covering | Transmission perpendicular (%) | Transmission greenhouse perpendicular (%) | Yearly yield electric (kWh m$^{-2}$) | |
|---|---|---|---|---|
| | | | Si-PV cel | Triple-junction-cel |
| Single PMMA Fresnel lens | 93 | 74 | 53 | 106 |
| PMMA Fresnel lens as double sheet | 81 | 64 | 45 | 90 |
| PMMA Fresnel lens between double glass | 53 | 42 | 30 | 61 |
| PMMA Fresnel lens laminated between AR coated double glass | 90 | 72 | 51 | 102 |

## Figures



A. B.

Fig. 1. Impression of a greenhouse hood with: A. Normal Fresnel lenses and PV/T modules. B. Linear Fresnel lenses and PV/T modules. The lenses are integrated between double glass (Drawing Bode Project and Engineering Bureau).




A. B.

Fig. 2. A. Daily average global radiation (blue) in the Netherlands divided into diffuse (red) and direct part (green) measured in De Bilt (The Netherlands); B. Diffuse and direct radiation in the Netherlands determined from hourly means (red = fraction direct radiation, blue = fraction diffuse radiation).

Fig. 3. Placement of the three Fresnel lenses of 1×1 m between double glass (size of 1×3 m).

Fig. 4. The Fresnel greenhouse in Wageningen at the real size of 6×6 m.

Fig. 5. The three collectors of the system inside the greenhouse, with details of the suspension and steering construction of the solar cell modules.

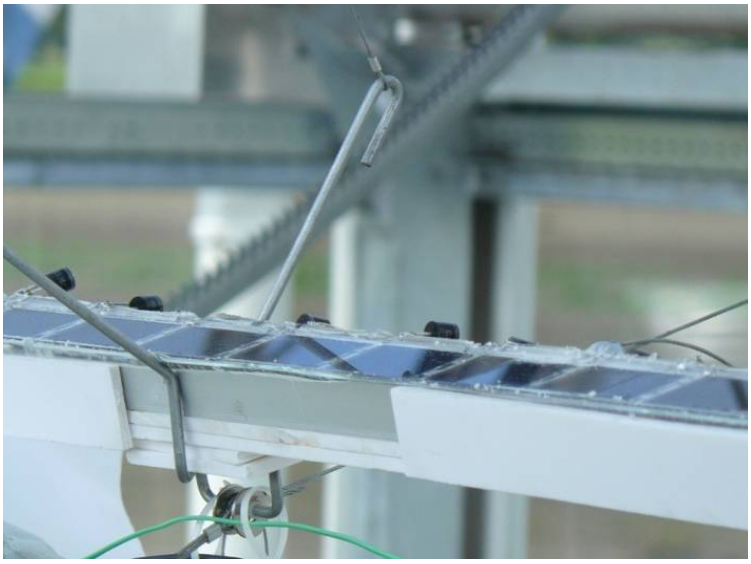


Fig. 6. The TPV module of the system with the silicon cells inside the greenhouse.

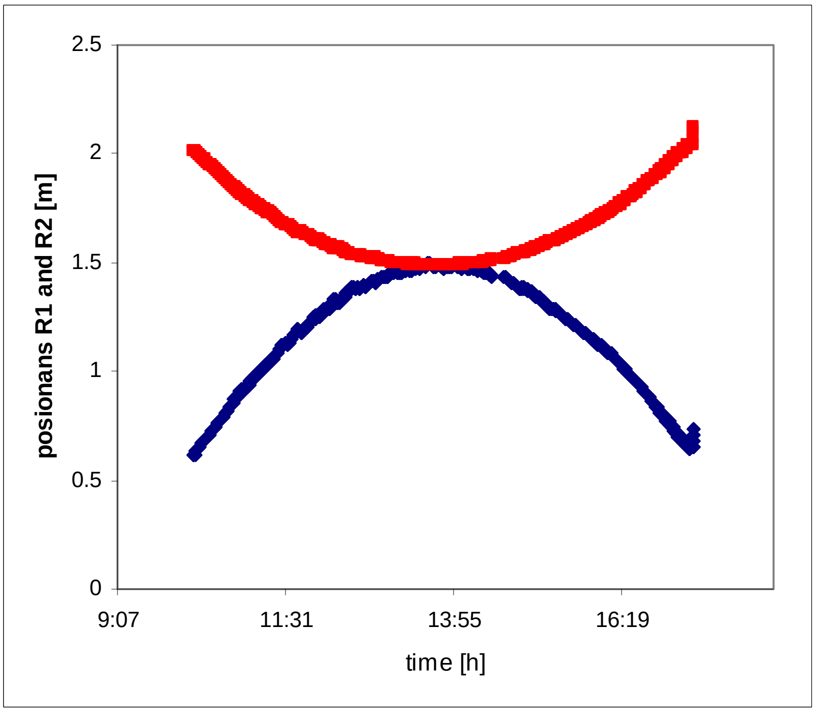



Fig. 7. Both positions of the electric motors where the module will be held in the focus on 5 August 2009. R1 (top) is the vertical position and R2 (bottom) is the horizontal position.

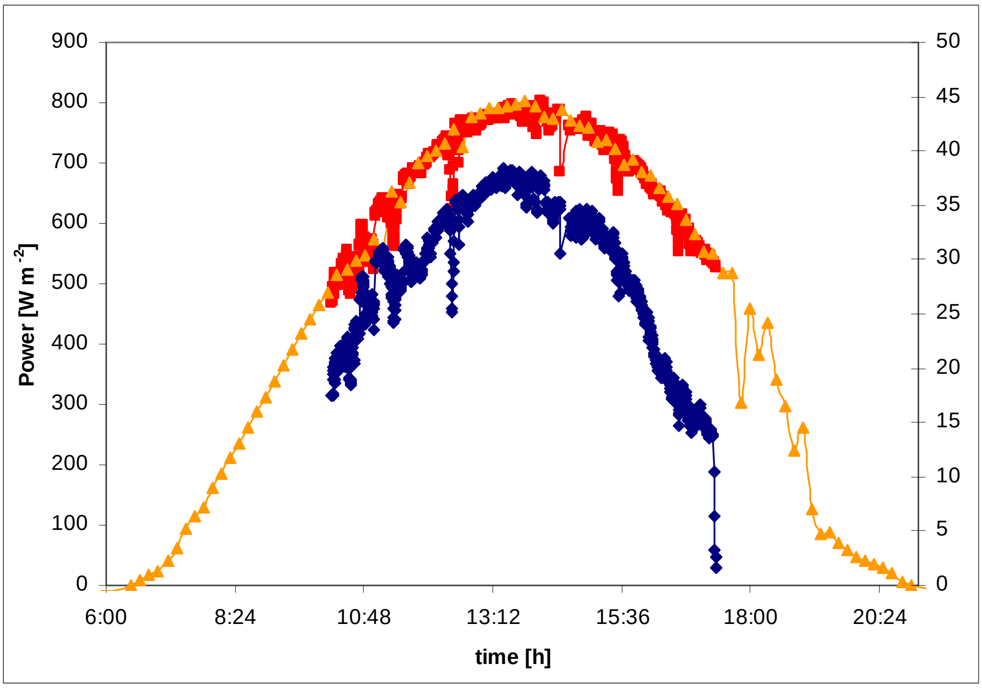



Fig. 8. Generated electric power (Pnom) and incident radiation (Prad) on the location Wageningen measured on 5 August 2009.

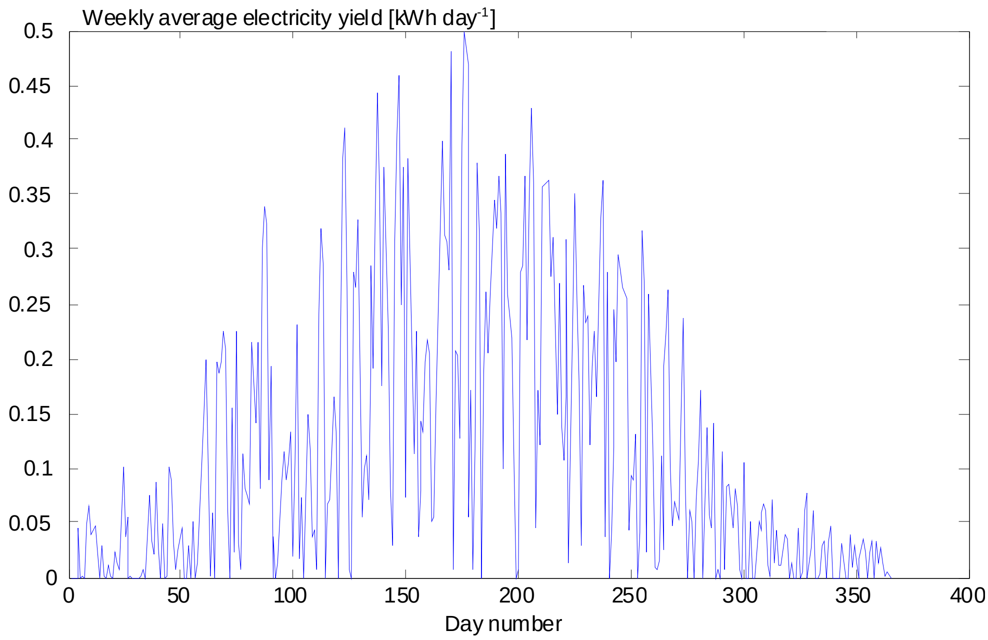



Fig. 9. Week average of the electrical power output as a function of the day number.