## Climate Control of a Greenhouse with Concentrating Solar Power System

Piet Sonneveld, Iwan van Bochove,  HAN University of Applied Sciences, P.O. Box 2217, 6802 CE Arnhem, The Netherlands, piet.sonneveld@han.nl

**Abstract**

**There are several greenhouses built with solar panels integrated into the roof. In summer time this will operate very well, although broad shadow stripes can result in growth and yield differences. In winter the amount of sunlight is further limited by the solar panels and will result in further reduction of light accession to the cultivation space. As a result, the crops suffer from growth problems. These drawbacks are eliminated by the application of Concentrating Power Systems (CSP) with Fresnel lenses. A Fresnel lens works like a normal lens but is much thinner. When the sun shines, the lens receives both direct and indirect sunlight. The lens will concentrate all direct sunlight, which can be collected as thermal energy in the focal point. This absorbed radiation can be converted with an absorption cooler into cold water for cooling. This cold water can cool the greenhouse without the need of water use. The indirect solar radiation, the diffuse light will not focus and is therefore available as a fairly constant light source in the building or in the greenhouse. The capture of all direct radiation at high intensities will diminish the incoming heat load, which is useful for a better internal climate control of greenhouses and buildings. This lower heat load makes it easier to keep the greenhouse cool with the absorber. In this study the details of energy flows and thermal conversion with absorption cooler is determined. Calculation shows a 47% heat load reduction (from 337 W/m² to 157 W/m²) with the Fresnel lenses in the covering of the greenhouse. In the case of the collector in focus, only 48% of the captured direct radiation, available as thermal energy, is required to cool the greenhouse further with an absorption cooler. Cooling a greenhouse can result in up to 90% reduction in water consumption of the cultivation. The possibility of light regulation is  another important advantage the Fresnel lenses have. The light amount can vary between 15 – 77% of the incoming radiation. The access of the generated energy can be used for extra illumination (light and energy regulation) and/or energy supply and/or a desalination system.**

## INTRODUCTION

Due to solar radiation, the greenhouses in south European countries and countries located closer to the equator, generate too much heat load for most crops to grow. Therefore, cooling is needed (Stanghelini, 1987). Even natural ventilation during summer is not sufficient to remove the energy excess. In previous work a greenhouse with an integrated NIR filter, a fan and a pad system for cooling was presented. (Sonneveld et al. 1996). However these systems require a lot of water and dry air to achieve the desired cooling effect. 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 to separate direct and diffuse light with this lens can be used for exposure control in greenhouses and buildings. With this lens direct radiation can be used for energy generation or cooling and diffuse light for plant growth. With a Fresnel greenhouse design as presented in Fig. 1, two effects can be used to diminish the heat load. First of all removing direct radiation, which contains about 80% of all radiation, will diminish the heat input of the greenhouse with a large fraction. Secondly absorption in the focal area of the lens will collect this energy and convert this to thermal energy. This thermal energy can be used in an absorption cooler into cold water for cooling to remove the rest of the heat in the greenhouse.

The collection of 40-80% of the (direct) solar radiation is possible with a Fresnel lens as seen in Fig. 1. The leftover 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 collector can be placed out of focus, so that the total radiation entered into the greenhouse. So the lighting level is optimal to benefit to maintained horticultural application.

## MATERIALS AND METHODS
### Separation of visible and thermal radiation
With Fresnel lenses all direct radiation can be focused and collected with a thermal absorber. The remaining diffuse radiation will not focus. This diffuse radiation will pass the collector and is available as light source in the greenhouse. In a previous project the Fresnel lenses were integrated in a double glass construction (Sonneveld et al. 2011) as static lenses and the collectors were moving in trajectories to keep them in the focal area. In this study the complete Fresnel lenses with collector are continuous perpendicular oriented on the sun via tracking motors. Two advantages are:
1. Improved collecting of the direct radiation, especially in the morning and evening
2. Only small modifications are needed to fit it in a standard Venlo type greenhouse.

### Integration in the greenhouse system
A greenhouse will be developed as presented in Fig. 1 and is based on a Venlo type greenhouse with glass covering: beams and stability bracings will be made of steel. The length of the hood is 12.00 m at a width of 4.00 m. Two hoods are mounted on a lower ranked trellis girder. The cover with the glass rods has a slope of $21^{o}$ with the horizontal plane and are oriented to the east-west direction. The walls of the greenhouse will be covered with standard single glass of 4 mm thickness. In total 80 linear Fresnel lenses with a focal distance of 1.2 m and a size of 1.0 x 1.0 m are placed between the trellis girder and the gutters.

## RESULTS AND DISCUSSION
### The energy losses
Based on transmission and reflection measurements of the glass covering material used on greenhouses and Fresnel lenses an overview of the energy losses is made. The results of these energy losses are given in Table 1. The results are based on weather data of a clear day with 80% direct and 20% diffuse solar radiation. The losses for direct radiation are different from diffuse radiation therefore columns for both cases are presented. The contribution of the 8% reflection losses of direct radiation is weighted with the 80% of the

direct radiation contribution and the 13% reflection losses of diffuse radiation is weighted with the 20% of the diffuse radiation contribution. For the heat collector at the focal point of the lens 20% losses are supposed. At this manner the losses are calculated for all optical components of the greenhouse and counted, resulting in a total loss of 33% for direct radiation and 6.6% for diffuse radiation.

**The energy balance**
The incoming amount of diffuse radiation into the greenhouse is calculated by evaluating the 20% external diffuse radiation and the 80% external direct radiation. Starting with the diffuse radiation of 20 % minus the calculated loss of 6.6% gives 13.4% diffuse radiation. For direct radiation 1% of the reflection losses will enter the greenhouse and 1% reflections of the collector, giving totally 15.4%. These values are summarized in the first column of Table 2. In the second column the amount of thermal energy entering the greenhouse is calculated. These are the absorption values of the direct- en diffuse radiation and the heat losses of the thermal collector, resulting in total 21.4% of thermal energy. The third column of Table 2 gives the remaining yield of thermal energy available for the cooling process. This was calculated from the 80% direct radiation minus the 32.8% losses from Table 1 giving a net yield of 47.2%. These energy flows are presented as a Sankey-diagram in Fig. 2. Here an overview of the energy flows of a Fresnel greenhouse is presented.

**The extra cooling effect**
Compared with a standard greenhouse the heat load and the amount of solar radiation are strongly diminished. For a standard greenhouse a light transmission of $\tau_p = 80\%$ is supposed for direct radiation and $\tau_d = 70\%$ for diffuse radiation. In the case of 80% direct and 20% diffuse solar radiation as mentioned here before the average transmission becomes:

$\tau_{ag} = 0,8 \cdot \tau_p + 0,2 \cdot \tau_d = 78$ %. For a clear day at May the 3rd 2011 in Wageningen The Netherlands, with a maximum global radiation of 866 W/m$^2$, the results of the incoming radiation are seen in Fig. 3. In this figure $P_{gl}$ gives the global radiation during the day, $P_{gh}$ gives the radiation entering into the greenhouse and $P_{lgh}$ gives the corresponding cooling effect by transpiration of tomato crops (latent heat) as determined by previous publications (Stangelini 1987, Sonneveld et al.2006). The difference between the radiation entering into the greenhouse $P_{gh}$ (maximal 675 W/m$^2$) and the cooling effect by transpiration $P_{lgh}$ (maximal 337 W/m$^2$) is the cooling need of the greenhouse (338 W/m$^2$ maximal). The results for a Fresnel greenhouse are given in Fig. 4. The heat load into the Fresnel greenhouse with the collecor in focus is the contribution of diffuse light (15.4%) and the heat access as given in Table 2 (21.4%) total 36.8%, which give maximal $P_{fgh}$ of 315 W/m$^2$, this is more than 50% lower as in the case of the standard greenhouse. Here the cooling effect by transpiration of tomato crops is lower (maximal 158W/m$^2$). The heat load is than a factor 315/675=0.47 lesser compared to a normal greenhouse. Then the maximum cooling need of the Fresnel greenhouse is: 315-158=157W/m$^2$. This is an important advance of the Fresnel greenhouse The heat load is diminished from 337 W/m$^2$ to 157

W/m$^2$. This smal amount can be dissipated with an absorption cooler or an TASM. The available thermal output of the collector is more then sufficient to cool the greenhouse. Accoring the result in Table 2 and Fig. 2 the avalable thermal energy is 470 W/m$^2$, with a typical COP of an absorption cooler of 0.7, the cooling capacity is maximal 329 W/m$^2$. Only a factor 157/329= 0.48 is needed for cooling of the greenhouse.

**The effect of light regulation**
On the other hand it is interesting to know the amount of light and energies in the case that the collector is out of focus. In that case also the acquired direct light will enter into the greenhouse and is then according Table 1 and 2: Direct light 80-17=63% + 14% diffuse light=77%. This is also the total heat load at the collector out of focus, but the half of this part deminished by the evaporation coolling effect. In that case the collected thermal energy is zero as well as the generated amount of cooling energy. In fact the amount of light and energy can variating between this two cases, which can be shown in Fig. 5. Here an increase of light and thermal energy is shown at a higher out of focus ration of the collector. At the same time the collected thermal energy and cooling deminished linear. At nearly 30% out of focus the cooling energy is just sufficient to cool the energy from the extra light amount. The access of the generated energy can also be used for energy supply and/or a desalination system.

**CONCLUSIONS**
The property of Fresnel lenses to capture of all direct radiation at high intensities will diminish the incoming heat load. This is useful for a better internal climate control of greenhouses and buildings. In a Sankey-diagram the energy flows of a Fresnel greenhouse as presented. The lower heat load makes it easier to keep the greenhouse cool with the absorber cooler and will avoid the need for screens or lime coating of the glass to reflect or block a large part of the radiation. Calculation shows a 47% heat load reduction (from 337 W/m$^2$ to 157 W/m$^2$) with the Fresnel lenses in the covering of the greenhouse. In the case of the collector in focus, only 48% of the captured direct radiation, available as thermal energy, is required to cool the greenhouse further with an absorption cooler. Cooling a greenhouse can result in up to 90% reduction in water consumption of the cultivation. The possibility of light regulation is an important advance of the use of Fresnel lenses. The light amount can vary between 15 – 77% of the incoming radiation. The access of the generated energy can be used for extra illumination (light and energy regulation) and/or energy supply and/or a desalination system.

**Literature Cited**

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. PhD-Thesis Wageningen University.

Sonneveld P.J., Swinkels G.L.A.M., Kempkes F., Campen J. van, Bot G.P.A., 2006, Greenhouse with integrated NIR filter and a solar cooling system, Acta Hort. 719:589-596

Sonneveld P.J., Swinkels G.L.A.M., Tuijl B.A.J. van, Janssen H., Zwart H.F. de, Up scaling and Test results of an advanced Fresnel greenhouse, 2011, Acta Hort. 952:531-538

Sonneveld P.J, Swinkels, G.L.A.M, van Tuijl B.A.J, Janssen, J.H.H., van Campen J, Bot G.P.A. 2010. Energy performance of a concentrated photovoltaic energy system with linear Fresnel lenses integrated in a greenhouse, Solar Energy, Solar Energy, 85:432-442

Tripanagnostopoulos, Y. Souliotis, M. Tonui, J.K. and Kavga, A. 2004. Irradiation aspects for energy balances in greenhouses. Greensys2004 Int. conf.; Acta Hort. 691:733-740.

**Tables**

Table 1. Overview of the energy losses of a Fresnel greenhouse for the situation of 80% direct and 20% diffuse radiation.

| Part of the Greenhouse | Direct radiation (80%) | | Diffuse radiation (20%) | | Sum abs. losses (%) |
|---|---|---|---|---|---|
| | Losses rel.(%) | Losses abs.(%) | Losses rel.(%) | Losses abs.(%) | |
| Covering glass | 8 | 6.4 | 13 | 2.6 | 9.0 |
| Fresnel lens | 8 | 6.4 | 13 | 2.6 | 9.0 |
| Absorption | 5 | 4 | 7 | 1.4 | 5.4 |
| Conversion | 20 | 16 | | 0 | 16 |
| Total | | 32.8 | | 6.6 | 39.4 |

Table 2. Overview of the total energy yields and light and heat access of a Fresnel greenhouse.

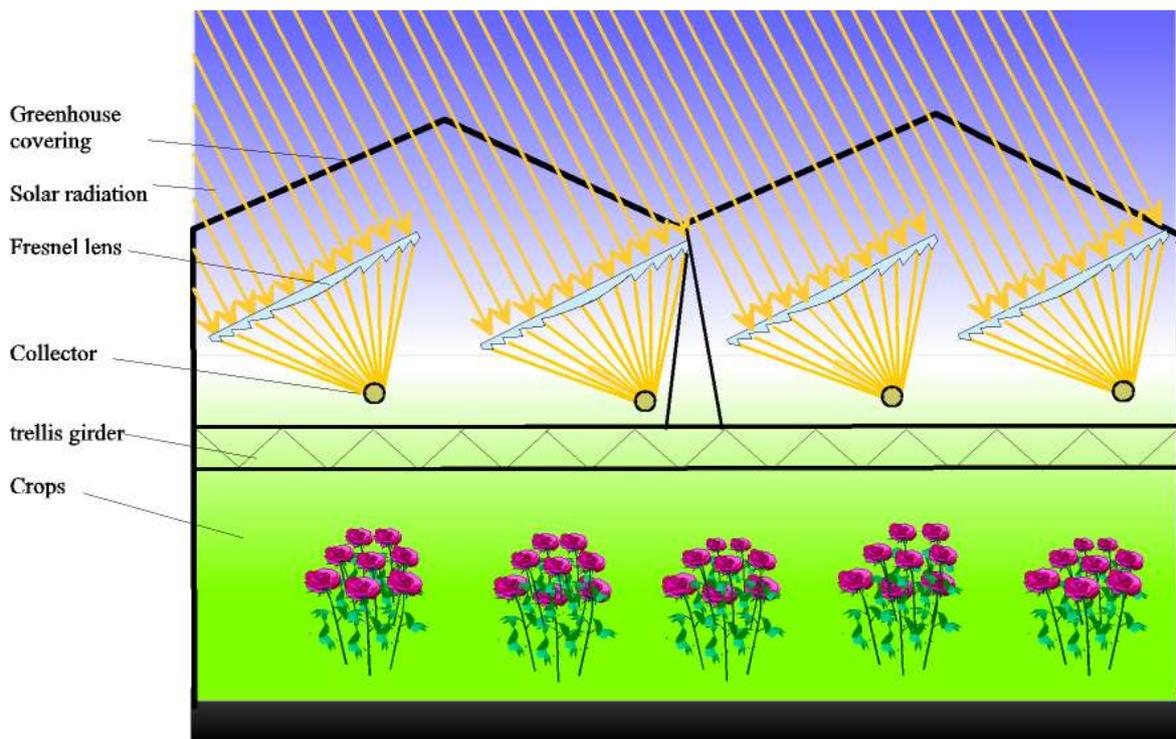| Contribution | Light access (%) | Heat access (%) | Heat yield (%) |
|---|---|---|---|
| Diffuus radiation | 13.4 | 1,4 | 15 |
| Direct radiation | 1 | 4 | 5 |
| Conversion | 1 | 16 | 17 |
| Total | 15.4 | 21.4 | 37 |

**Figures**



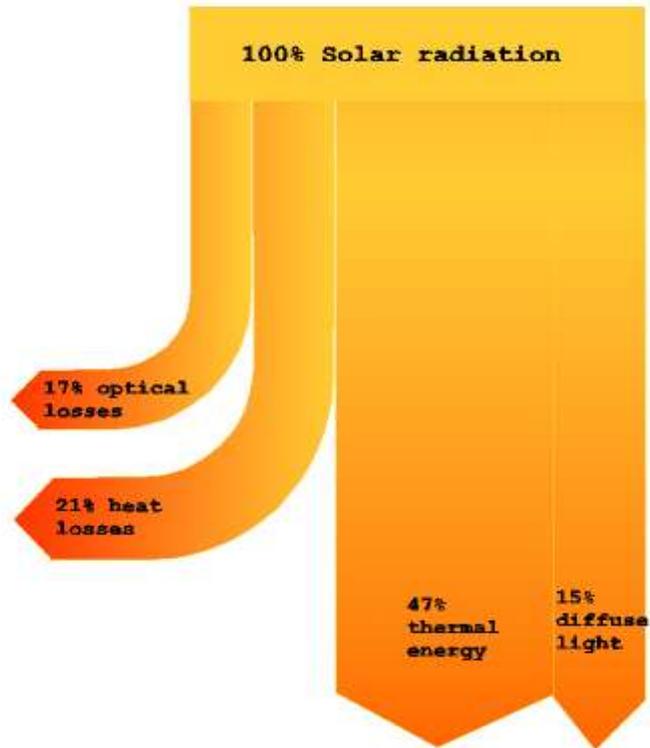Fig. 1.   Impression of a Fresnel greenhouse with tracking Fresnel lenses between the trellis girder and the gutter.

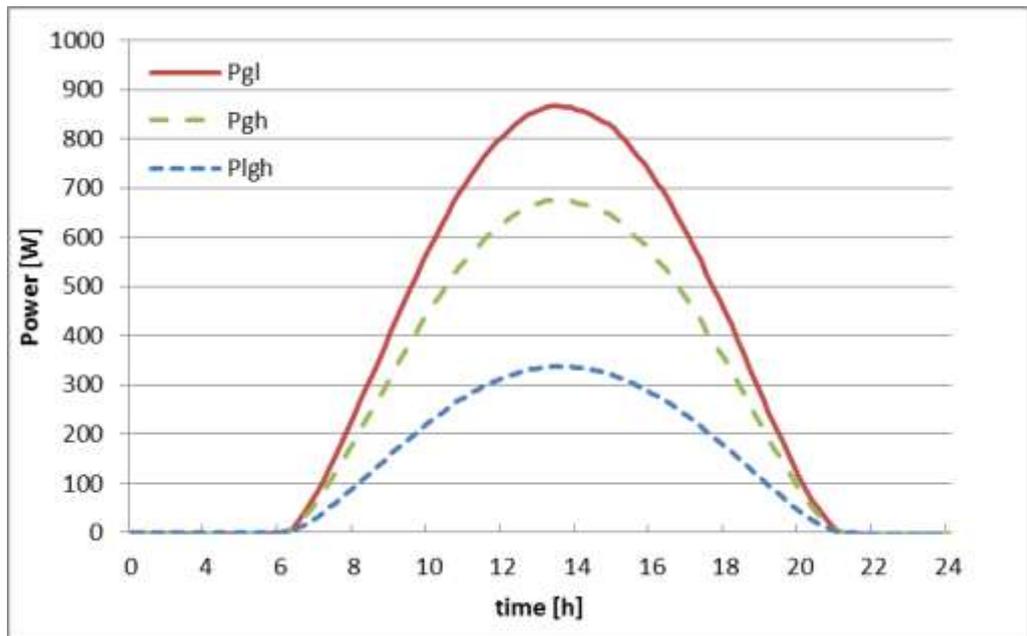Fig. 2. Overview of the energy flows in a Fresnel greenhouse (Sankey-diagram).



Fig. 3. Calculated results of the global radiation ($P_{gl}$) on a clear day May 3 the Netherlands (Wageningen), the heat load inside the greenhouse ($P_{gh}$) and the corresponding cooling effect by transpiration of tomato crops ($P_{lgh}$).
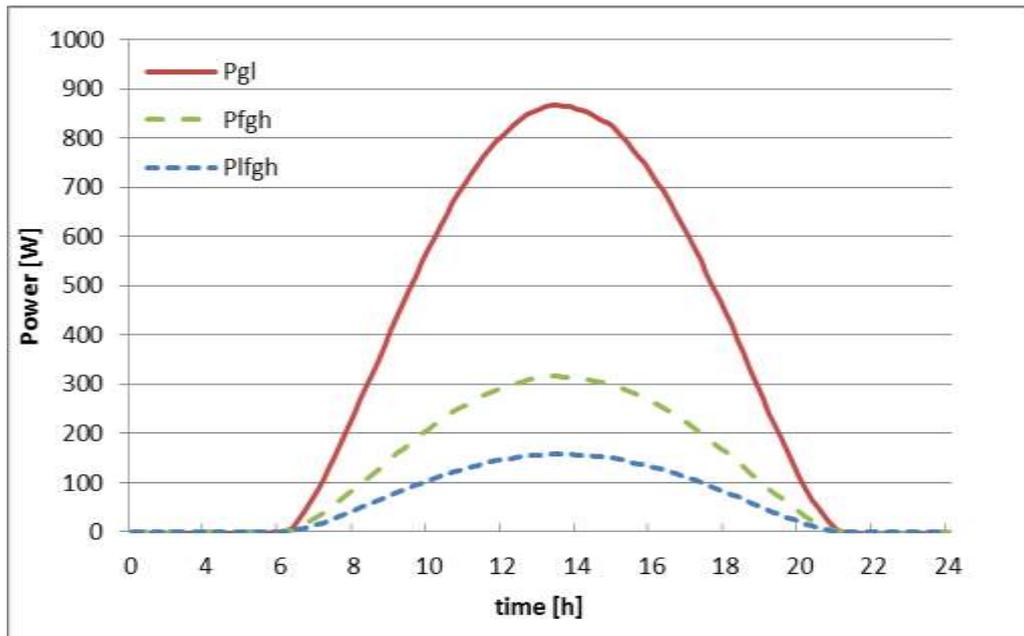
Fig. 4. Calculated results of the global radiation ($P_{gl}$) on a clear day May 3 the Netherlands (Wageningen), the heat load inside a Fresnel greenhouse ($P_{fgh}$) and the corresponding cooling effect by transpiration of tomato crops ($P_{lfgh}$).
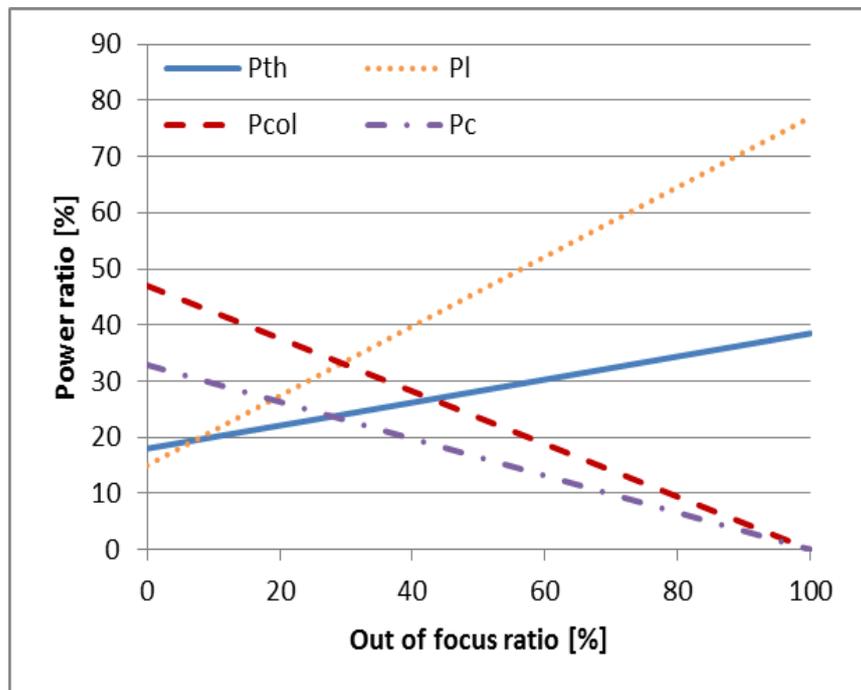


Fig. 5. Effects of different out of focus ratios of the collector on the energy flows
of: 1. Fraction thermal energy entering into the greenhouse $P_{th}$
2. Fraction thermal energy collected $P_{col}$
3. Fraction light energy entering into the greenhouse $P_l$
4. Fraction cooling energy with a COP of 0.7 $P_c$