Static Linear Fresnel Lenses as LCPV System in a Greenhouse

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Abstract. A low concentrating PV system with water cooling (LCPVT system) will result in electrical and thermal energy output from the solar energy excess entering a building or greenhouse. All the direct radiation could be converted, which corresponds to 75% of the incoming solar energy. This will significantly reduce the demand of cooling of the building. For an optimal performance it is beneficial to construct asymmetric roof elements with a steep inclination at the north side (the exact angle of course depends on the latitude of the building site). The Fresnel lens structure is oriented in upwards direction. In the current design, two of them are placed between an AR-coated double glass structure to prevent pollution and condensation on the lenses. Compared with a previous system, the number of lenses is reduced from 3 to 2 lenses, which reduces the costs of the system by limiting the number of receivers. By the upward facing of the lens structure, the focus quality is preserved over a much broader range of angles of incidence compared to a lens with downward facing structures. Each PMMA lens with a size of 1.20m x 1.60m is composed of 12 'tiles' for easy production. The focal distance of the lens is 1,875m and the concentration factor 50x. In most cases the focus line is thinner than 3 cm and the transmission is above 80%. The performance of these lenses with respect of the shape of the focal area and the position of the focal line has been analyzed with ray tracing techniques. From this analyses it was concluded that tracking of the receiver module is possible with two motors. One motor controls the distance between lens and receiver and one motor controls the translocation of the receivers parallel to the lens. The second conclusion was that the positions of the focal line are within the bounds of the greenhouse construction for almost the whole year. Only in winter, the focal line will be unreachable from time to time. A 480 m^2 greenhouse with the LCPVT system based on Static Fresnel lenses and a 40 m CPVT-module and a 200m CT-module is designed by Bode Project Engineering and constructed by Technokas in Bleiswijk the Netherlands.

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INTRODUCTION

An important issue of greenhouses and transparent systems in buildings is the different needs of solar energy to the system. In summer the excess of solar energy is easily too large and the system has to be cooled, while in winter all energy and light can be usefully applied in the building. A variable solar energy collector which absorbs 0 to 50% of the direct solar radiation is possible with the combination of a linear Fresnel lens and a thermal or photovoltaic module (CPVT module). The photovoltaic module has to be suitable for concentrated radiation. A normal Fresnel lens will focus to a point, while a linear Fresnel lens will focus to a line. In this system linear Fresnel lenses are applied, and since the system is constructed in a greenhouse, the remaining diffuse radiation is transmitted and used for plant growth. The possibility to separate direct and diffuse light with the Fresnel lens[1,2,3] can be used for control of light intensity in greenhouses and buildings. In case of low light intensities (morning, evening, cloudy weather and during winter), the CPVT modules can be removed from the focal line, so that the total radiation in the building is as high as possible. During bright sunshine, the receiver is placed in the focus and light levels will be tempered. For a number of greenhouse crops (especially ornamentals), this is a very favorable situation. The lenses can be combined with thermal, photovoltaic, or a hybrid technique and the concentrated solar energy is converted to warmed water, electricity or a combination of both[l]. Because of the small size of the CPV-module, unwanted light interception (e.g. of diffuse light and when brought out of focus) is limited. Capturing of this energy during periods with high intensities of solar radiation will result in better growth conditions for these plants. The system developed is suitable for a complete CPVT system and generates electrical and thermal energy. This energy yields enable the construction of more energy efficient buildings and greenhouses. For greenhouse without artificial illumination, energy savings of 50-75% are realistic. The exact energy saving percentage depends on the thermal isolation of the covering and the dehumidification system

MATERIALS AND METHODS

Integration in the greenhouse

Due to large efforts of Bode Project Engineering in the design stage and the accurate building of the greenhouse builder Technokas (both companies from de Lier, the Netherlands), a greenhouse was erected that supports Fresnel lenses, receivers and a tracking system in the roof structure.

The main structure of this prototype greenhouse with a size of 480m^2 (length is 30m and the width is 16m) consists of four asymmetric roof elements (see Fig. 1). Each roof element has a span of 4 m and an inclination of the south side of 36^o and on the north side of 54^o. This asymmetric roof is a result of maximizing the potential energy yield , while preventing direct light entering the greenhouse through the north facing roof (without lenses), giving the light conditions at the 52nd latitude. The spans, trellis girders, and stability bracings are made of steel. The walls of the greenhouse are covered with a 16 mm double wall polycarbonate sheet material. The span of

FIGURE 1. Impression of the 480 m² Fresnel greenhouse with 4 roof spans with Fresnel lenses mounted at the south facing roof segments.

the trellis girders is 8.00 m with two roof segments of 4.00 m. The trellis girders are 5.00 m interspaced. The ventilation windows are mounded in the north facing roofs and are implemented as sliding windows. This prevents unwanted shadows on the south oriented roof panes with the Fresnel lenses during ventilation. In total, 25 meter of linear Fresnel lenses are mounted in every roof (the first 2.5 meter on each side of the roof are cladded with diffuse glass). The lenses have a focal distance of 1.875 m, and a concentration factor of 50x. The lenses are divided in pieces of 1.20 × 1.54 m. and each such a lens is composed of 12 tiles. Two of these lenses are fitted between a double glass cladding panel. A tracking motor for the receiver movements is depicted in Fig.3 (left side). This motors are connected to gearboxes with a cogwheel rack. At

FIGURE 2. Details of the modular constructed Fresnellens. Each lens is assembled from 12 parts and two lenses are mounted in one double glass pane.

each 5 m this gearbox is mounted on the trellis girders and connected with the axis of the motor. This linear movement is transferred to steel cables, which bring

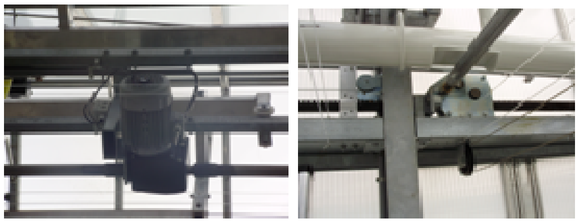


FIGURE 3. Details of the tracking motor (right) and the gearbox (left) of the tracking mechanism for linear movements.

the receiver to the right tracking position. Each receiver is connected with two steel cables: one for the distance to the Fresnel lens and one for movements parallel to the lens (see Fig. 4 left side).

FIGURE 4. Left: Details of the receivers inside the greenhouse with two receivers per roof. Right: the cultivation area with pot plants in the greenhouse (still only half filled).

Two types of receivers are applied in this greenhouse. There is 200 m of concentrated PVT modules(Fig. 5 right side). And there is 40 m of receiver with CPV cells (Fig. 5 left side, still in the workshop). The CPV cells are silicon solar cells suitable for concentration ratios up to 50×. The heat excess is removed with water cooled tubes , which are laminated under the CPV module.

Each CPV receiver starts and ends with a CT module because the first and last parts of the receiver are in the cover area without lenses. This solar collector tube (CT-collector, see Fig. 5 right side) is the same as the other 200 m of PVT

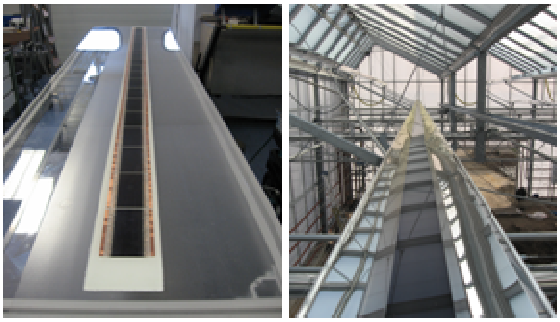


FIGURE 5. Right: details of the CPVT module in the workshop (total 40m) Left: details of the CT collector in the greenhouse (total 240m).

receiver. The CT-module consists of a black painted rectangular steel profile covered with AR-coated glass with an air gap of about 7 mm.

The development and testing of the new type of greenhouse with an integrated linear Fresnel lens, receiver CPVT-module and an innovative tracking system makes it possible to exploit the direct radiation in a solar energy system. Moreover, for a number of ornamental plants, removal of all direct radiation will drastically reduce the need for cooling and the need for screens or white wash, in summer conditions

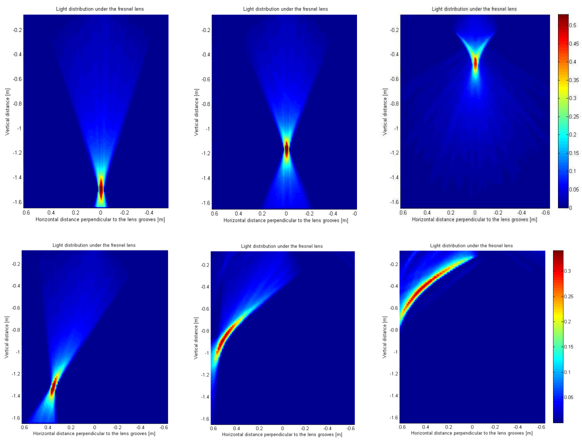
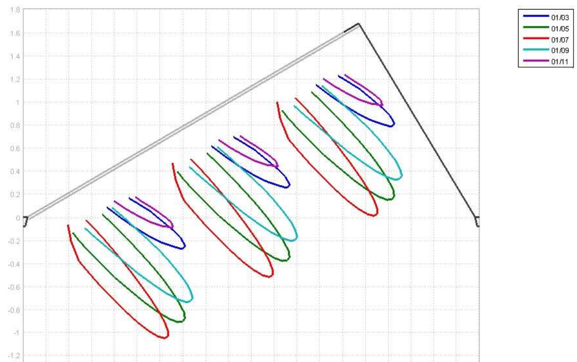


FIGURE 6. Intensities for different angles of incident φ and azimuth (θ=0 is in line with the groves of the lens) made with Raypro ray trace simulations.
a) θ= 0°, φ = 0°, b) θ= 0°, φ = 30°, c) θ= 0°,φ = 60°, d) θ=90°,φ=15°, e) θ= 90°, φ= 30°, f) θ=90°, φ= 45°.

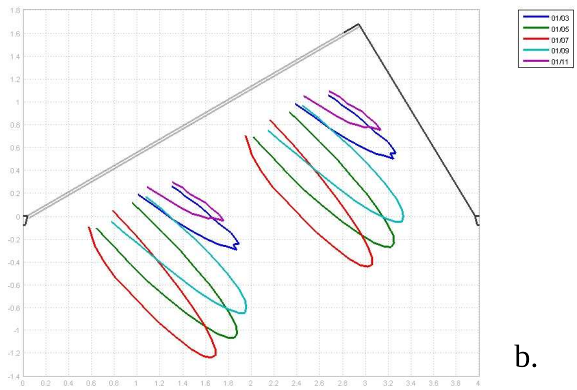
RESULTS

Ray trace simulations

With ZEMAX the structure and orientation of the Fresnel lenses was optimized as reported previously[5]. With the ray tracing computer program (Raypro) the radiation intensities near the focal line were determined as a function of the angle of incidence φ and the azimuth angle θ. The results are presented in Fig. 6. From these results a shorter distance of the focal line to the Fresnel lens can be noticed at increasing angles of incidence at an azimuth angle zero (radiation from the direction of the grooves). In the situation of azimuth angle 90°, the focal line moves with the angle of incident according to the Figs. 6d, e, f. At higher angles of incidence the focal area spreads out to larger areas.



a.



b.

FIGURE 7. Trajectories of the Focal line at different times during a year for different lenses with a size of:

a. three lenses and a focal distance of 1500mm
b. two lenses and a focal distance of 1875mm .

With the Raypro tool, also the focal position can be determined at different periods in the year. The results are presented in Fig. 7. These calculations are performed for the situation with three lenses in the south facing roof pane (Fig. 7a. focal distance of the lens is 1500mm) and for the case with two larger lenses per roof pane (Fig.7b. focal distance of the lens is 1875mm). Besides as information for selecting the optimal system, these results are used for the control software to track the module into the focal point. An area detector is used for the fine tuning of the tracking system. From this analyses it was concluded that tracking of the receiver module is possible with two motors. One motor controls the distance between lens and receiver and the other motor controls the movement parallel to the lens (and perpendicular on the groove direction).

Performance of the CPVT system

The performance of the CPVT system with linear PMMA Fresnel lens was determined with practical measurements. An overview of the energy yield of a prior and more or less comparable system is given in Fig. 8. For the Dutch climate conditions, a peak power of approximately 35 W/(m^2 lens) electrical and thermal peak power of 250 W/(m^2 lens) is expected at an outside radiation of 850 W/m^2 .The yearly energy production is estimated on 29 kWh/m^2 greenhouse) and the thermal yield on 144 kWh/(m^2 greenhouse) as mentioned in previous work[5,6].

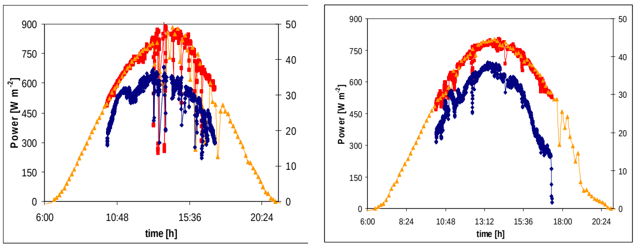


FIGURE 8. The generated electric power (Pnom) for the system with PMMA lenses and double glass combination and irradiation (Prad) as a function of time on August 4th (left) and August 5th (right) in 2009.

CONCLUSIONS

A 480m^2 greenhouse with a LCPVT system based on Static Fresnel lenses and both 40 m CPVT-module and a 200 m CT-module is constructed in Bleiswijk the Netherlands. The greenhouse construction is characterized by a asymmetric roof with a south facing roof with a slope of 36^o and a smaller north facing roof with a slope of 54^o. One pane contains two lenses. Compared with the previous system, the number of lenses is reduced from 3 to 2 lenses, which reduces the costs of the system by limiting the total length of the receiver. Also, now an AR-coated glass is used. Each PMMA lens with a size of 1.20 m x 1.54 m is composed of 12 divided elements for easy production. The focal distance of the lens is 1,875m and the concentration factor 50×. In most cases, the focus line is thinner than 3 cm and the transmission is above 80%.

The performance of these lenses has been analyzed with raytracing techniques with respect of the shape of the focal area and the position of the focal line. From this analyses it was concluded that tracking of the receiver module is possible with two motors. One motor controls the distance between lens and receiver and the other motor controls the movement parallel to the lens (and perpendicular to the groove direction). The second conclusion was that the positions of the focal line will be within the bounds of the greenhouse for most of the year. Only in winter there will be some periods where the receiver will not be able to reach the focal line.

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