Sustainable solar energy greenhouse

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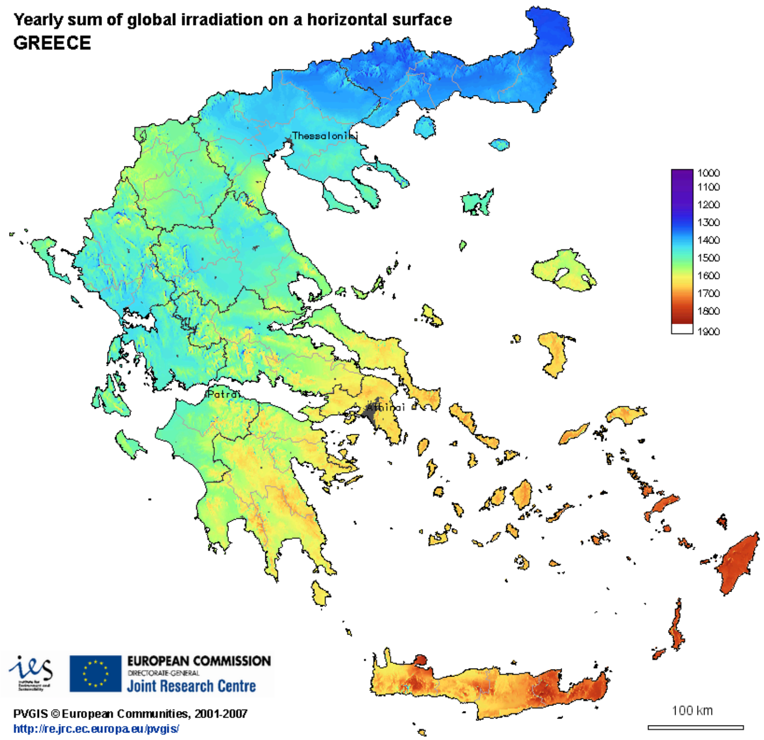
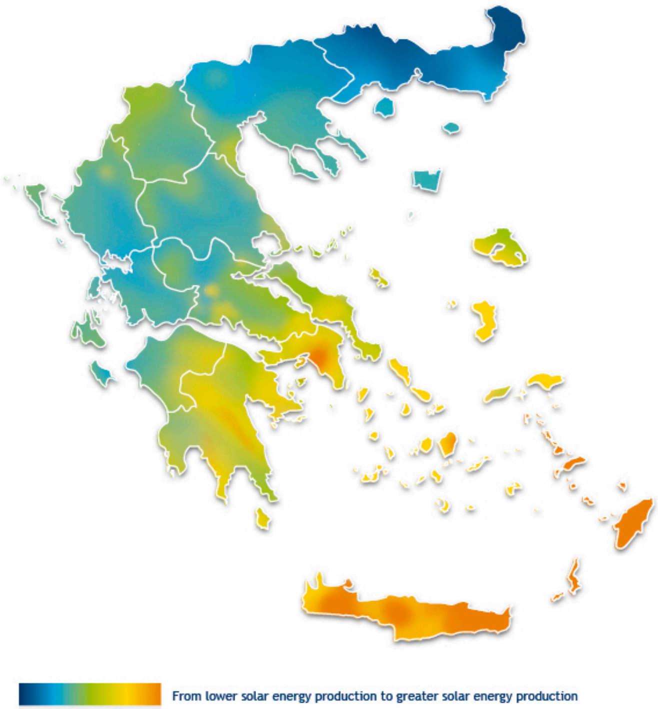
Background





Average annual solar radiation (Left) and solar energy production (right) in Greece.

Greenhouses

Greenhouses are like large solar thermal collectors, used in agriculture . They are used for plant growing and production avoiding low ambient temperatures and high wind velocities. Light and heat which are required are provided by solar energy.

Temperature and illumination are strongly interactive parameters that affect plant growth with the greater part of the incoming solar radiation being used to increase the greenhouse temperature, affecting plant growth.

Temperature conditions in greenhouse

- In air inside greenhouse solar radiation influences the temperature of the plant and its dynamic evaporation-transpiration.
- In the ground it influences the growth of the root and its function in absorbing nutritional elements, as well as the size of the leaf surface of young plants after germination.
- The greenhouse inside temperature depends on the solar input and the ambient air temperature.
- 10°C–25°C is accepted (21°C–24°C during the daytime and 18°C–19°C during the nighttime).
- e.g. vegetable species suspend their photosynthetic processes at temperatures above 30°C . When the temperature inside the greenhouse rises to 27 °C, the ventilation is necessary.
- In typical Mediterranean greenhouses the inner air during summer at noon is about 35-40°C, with the transparent cover being at a little higher temperature (about 45-50°C).
- in locations with hot or mild climatic conditions additional heating during the winter and cooling during the summer are necessary.

Illumination conditions in greenhouse

- Illumination varies according to the time of day, the month and the season but in high levels is not always beneficial.
- From September to October solar radiation intensity is at an acceptable level but during winter the illumination in the greenhouse is at a lower level and it is strongly dependent on the quality of the covering material
- During cloudy days when the plants are still at an early stage of growth, additional illumination is needed.
- When the period between seeding and transplanting occurs in September and October (during the winter period), the intensity of illumination is reduced due to the short days, clouds and low sun altitude. On the other hand, when the seeding is from December to January and the final planting starts from March, the developing growth fits in with the months when there is increasing solar radiation and consequently there is higher luminosity inside the greenhouse.

Environmental control

Several methods have been proposed for the control of the environmental factors in greenhouses (irradiation, temperature, humidity, etc), depending on the climatic conditions of the application and the technical details of the structures.

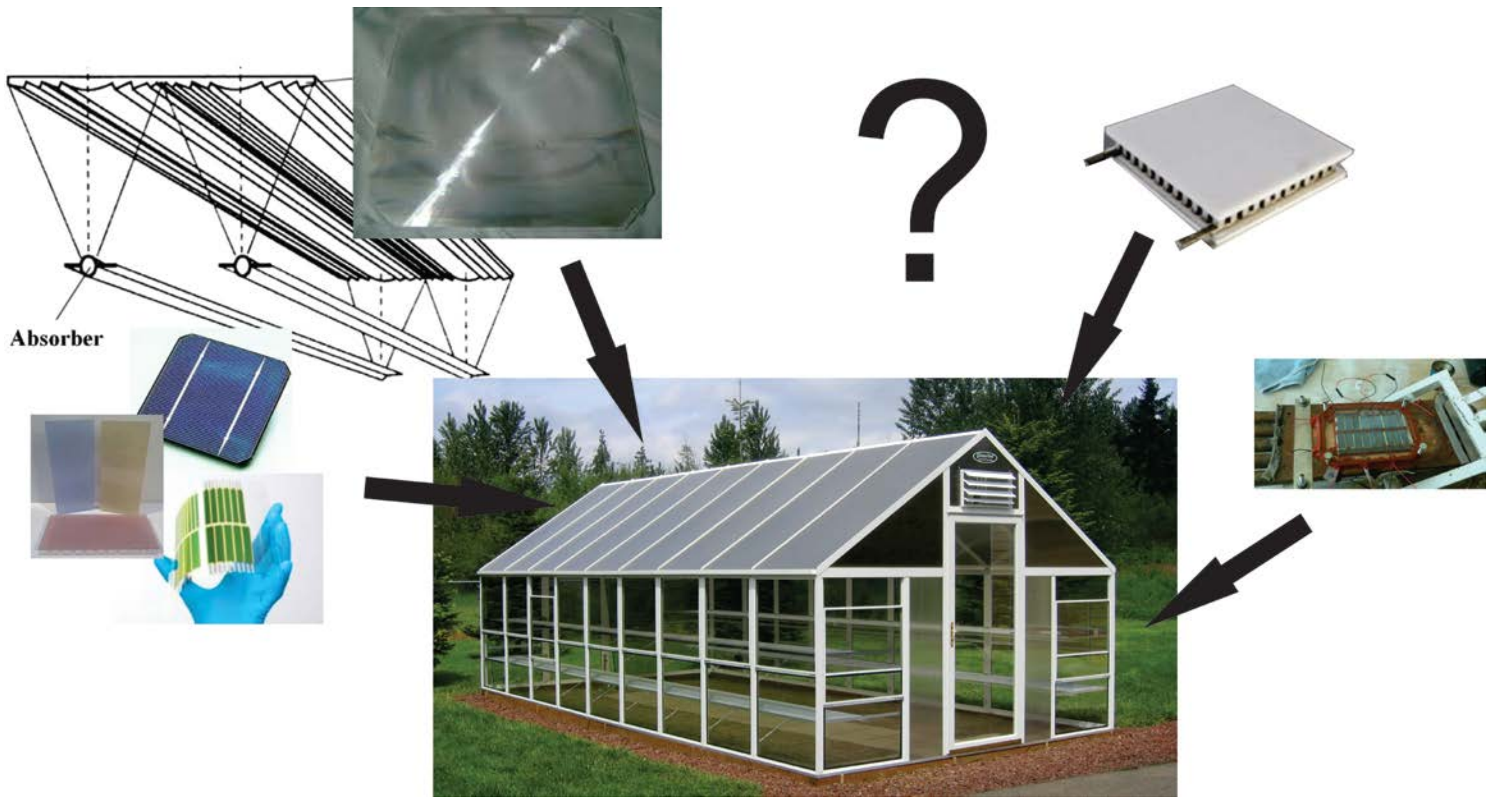
Covering

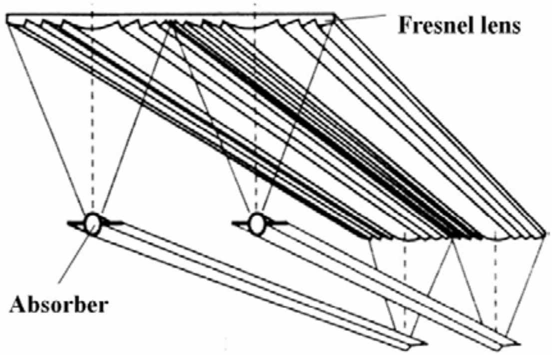
The transparent cover of greenhouses determines the internal microclimatic conditions. The covering materials reflect and absorb part of the incident solar radiation, which depends not only on the time and the latitude of the location, but also on the kind of the material and the angle of incidence

- Glass (PC, PMMA, GRP, PVC, RDPE, EVA) is considered a suitable material due to its very good optical and thermal properties and stability as well
- Regarding cost, glass and plastic covers are of almost equal cost after about ten years of operation
- Plastics are **cheaper** than glass, but most of them have **lower performance** regarding **illumination** and **thermal** properties.

A transparent cover, alternative to the usual glass panes for greenhouses, is the glass type Fresnel lenses

Problem statement

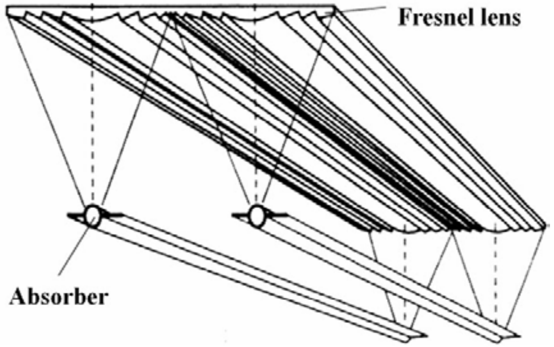




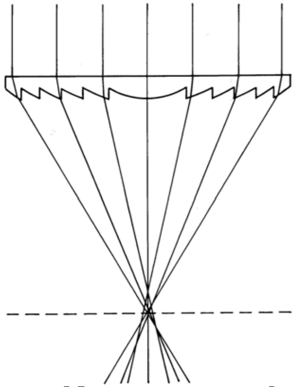
Fresnel lenses

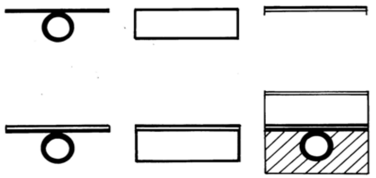
Optical devices concentrating solar radiation and they are used in several solar energy systems. They can be combined with thermal collectors and photovoltaics because of their attractive features, such as low volume and weight, small focal length and low cost, compared to ordinary thick lenses.

- Have been firstly introduced by Jirca et al (1998) as transparent covering material for lighting and energy control in internal spaces of buildings and greenhouses.
- As a transparent covering material for greenhouses has given interesting results in medium latitude countries, such as the Czech Republic (Jirka et al., 1998, 1999), but it can be also considered useful for application to greenhouses in lower latitude countries like Greece and other Mediterranean countries.
- The transmitted beam solar radiation through the transparent cover can be received by linear absorbers leaving the rest (mainly the diffused radiation) to be distributed in the greenhouse for the plant's needs.
- Several types of Fresnel lens have been investigated, consisting of linear or circular grooves.
- Two dimensional type Fresnel lenses (linear geometry lenses) are more practical than the 3D type (circular geometry lenses) and as they can have an East–West lens axis orientation, they need less movement for system orientation to the sun.



Linear FL



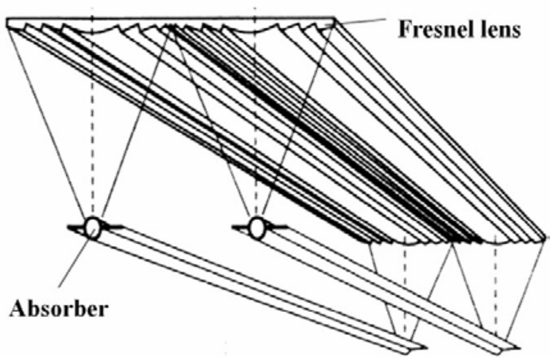


Small width absorbers receiving mainly the direct solar radiation, hence controlling the illumination inside the greenhouse. The absorbed energy can be taken away from the glazed space to achieve lower illumination level. They can be used as glazing on greenhouse roofs, by which illumination and temperature control in greenhouses can be achieved (Souliotis et al, 2006; Tripanagnostopoulos et al, 2007).

- Low volume and weight, they have smaller focal length and low cost than the thick ordinary lenses.
- the collection of 60%-80% of the transmitted solar radiation through the transparent cover leaves the rest amount to be distributed in the interior space for the illumination needs.

- They can be used with absorbers (**Concentrating Photovoltaic Thermal** (CPVT), CPV or **Concentrating Thermal** (CT) absorbers (Tripanagnostopoulos et al., 2007; Chemisana et al., 2011; Sonneveld et al., 2011))of small width (5-10 cm), depending on the selected concentration ratio, properly moved to truck the concentrated beam solar radiation and can adapt the illumination control during day.
- The absorbers extract the concentrated solar radiation in the form of heat and electricity, for later use (Tripanagnostopoulos et al., 2004).
- In low intensity solar radiation, or during cloudy days, the absorbers can be out of focus leaving the light to come in the interior space .
- In case of linear FL application east-west axis mounting (horizontal) it can remain stable all day and orientation adjustments can be in steps every few days or weeks.

- An additional agriculture application of FLs for remote, rural areas such as **water disinfection** and **drying** is proposed in this work as an extension of a previous work (Tripanagnostopoulos and Rocamora, 2007).



Parameters and needs of the system

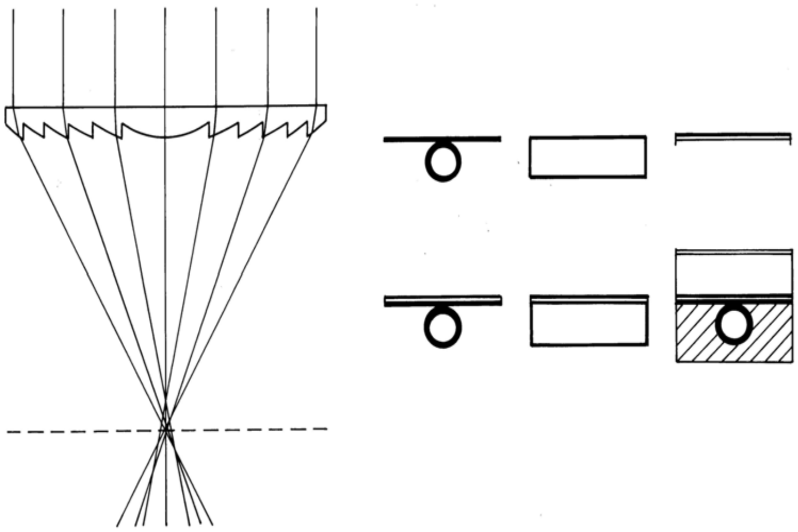
Parameters:

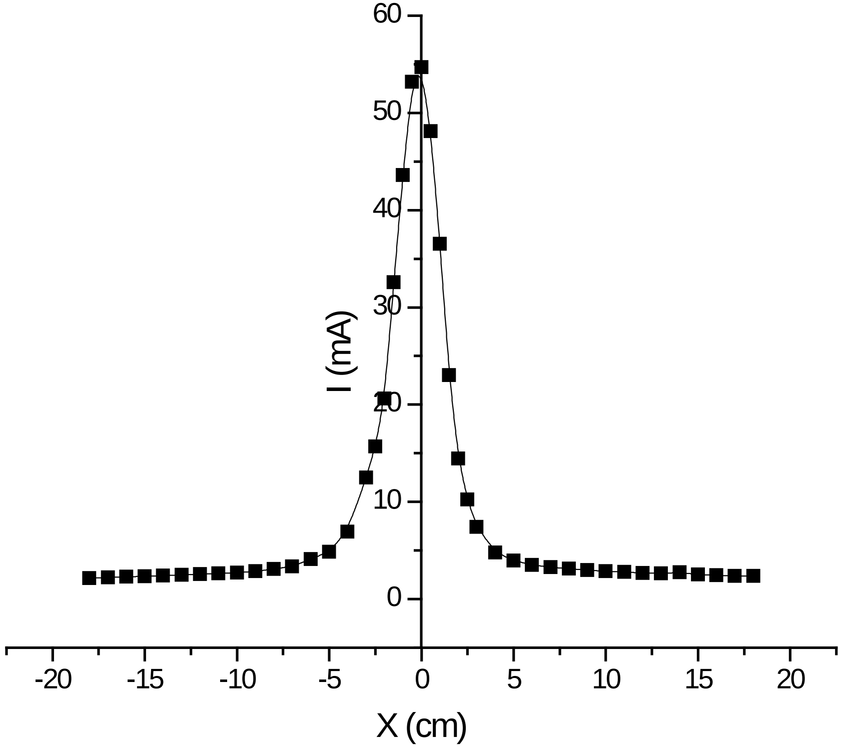
- Radiation (Shading or un-focus Fresnel).
- Temperature (Cooling or heating).
- Ventilation for heat extraction (Passive and active).

Needs

- Electricity (Operation of fans, window-opening motors, artificial lighting, irrigation, automation equipment among others).
- Heat.
- Winter: Heating, Heat extraction by water.
- Summer: Heat extraction by ventilation.

Experimental results from a linear Fresnel lense



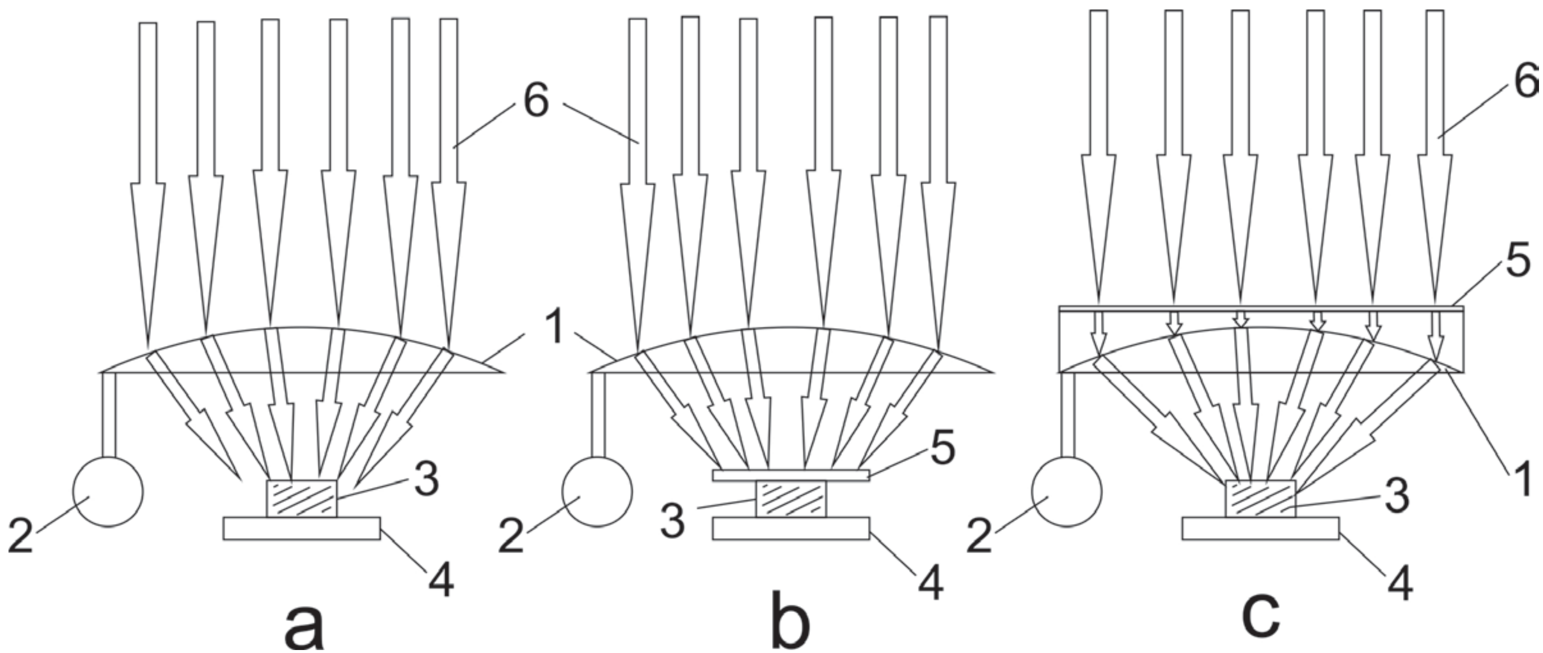


Instead of a PVT absorber a TEG absorber can be used

Use of Thermoelectric generators under solar concetration

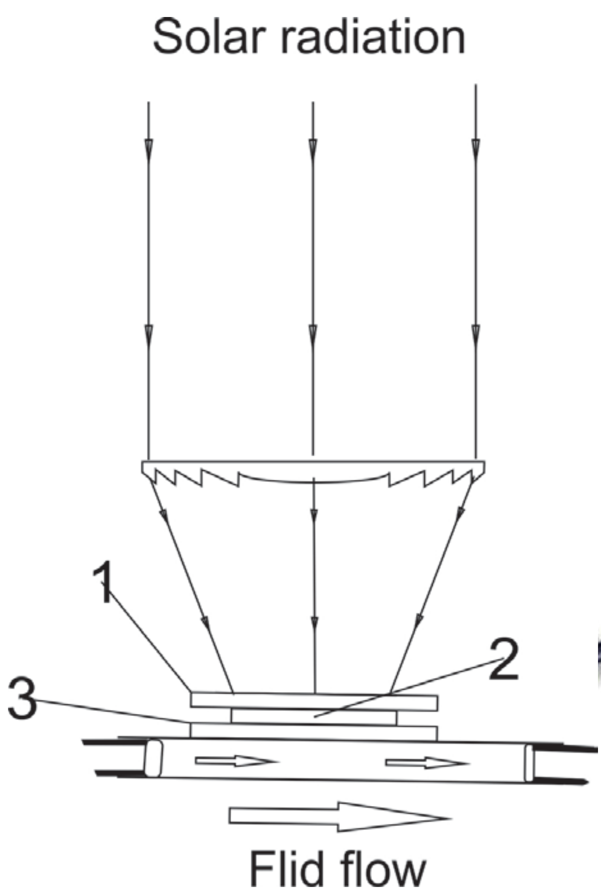
- Solar energy can be converted in energy and heat by different devices, in our previous work we analazide the possibility of use TEG in different configurations (E.A. Chávez-Urbiola, 2012) to produce heat on electric power by solar concentration o by using waste heat (S. Dubey, 2008) and how can it be improved (Tripanagnostopoulos, 2007).
- An TEG can be used alone directrly under the absorber (E.A. Chávez-Urbiola 2013) or with a PV cell, using the PV like the absorber (Yu.V. Vorobiev, 2013) or just another heat engine like Stirling .

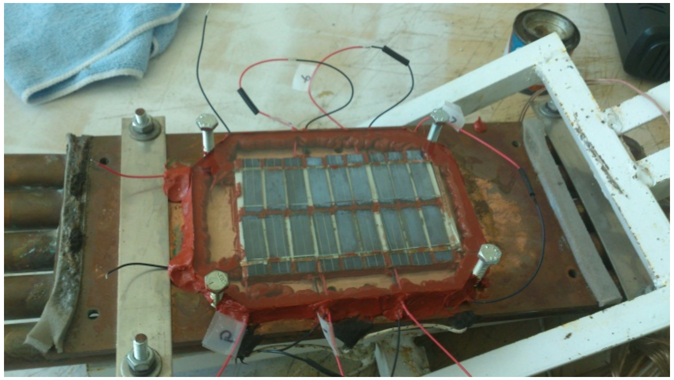
Preliminary experiments using TEG and solar concentration.

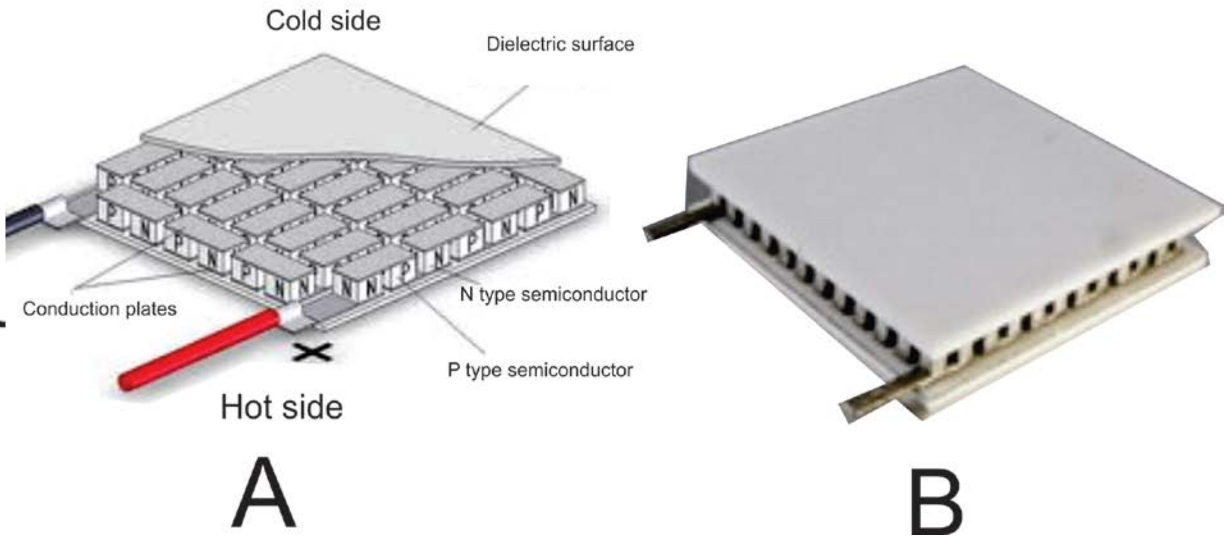


Schematics of the different possible conbinations of the absorber.

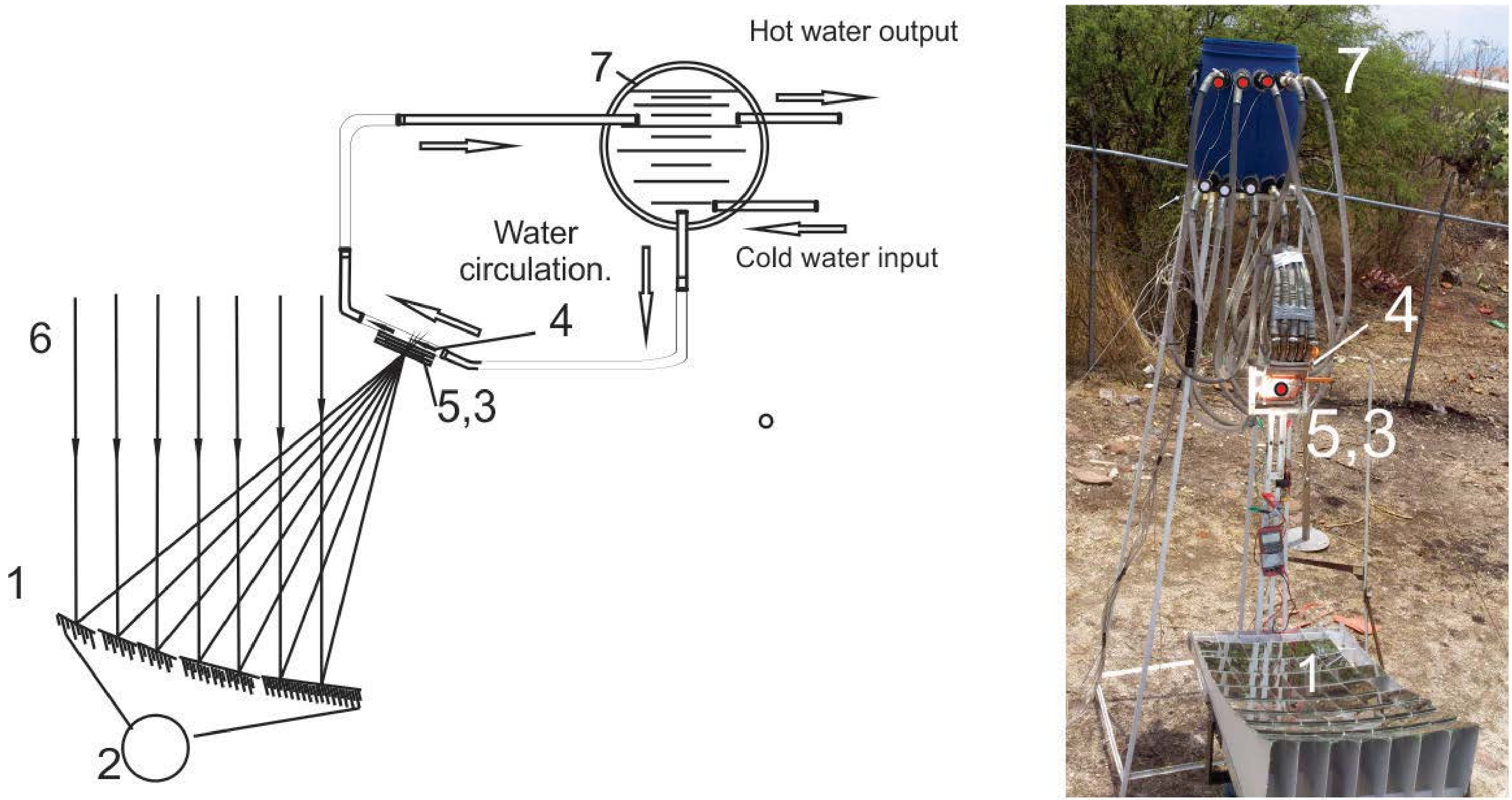
Thermoelectric generators





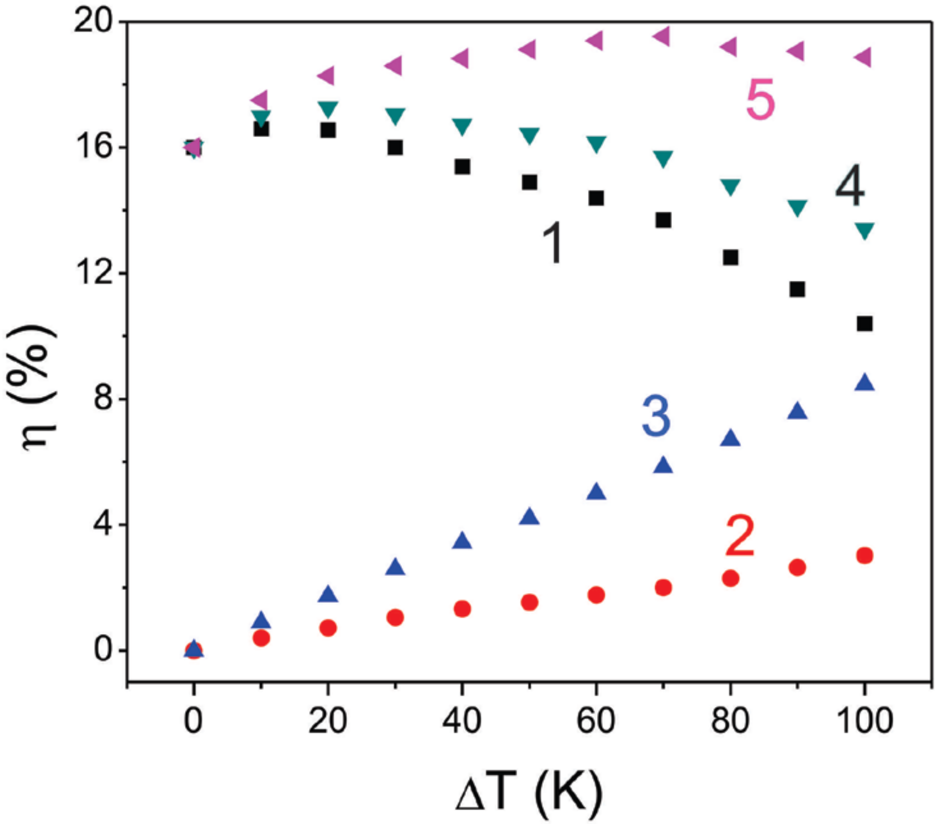


Studied prototype



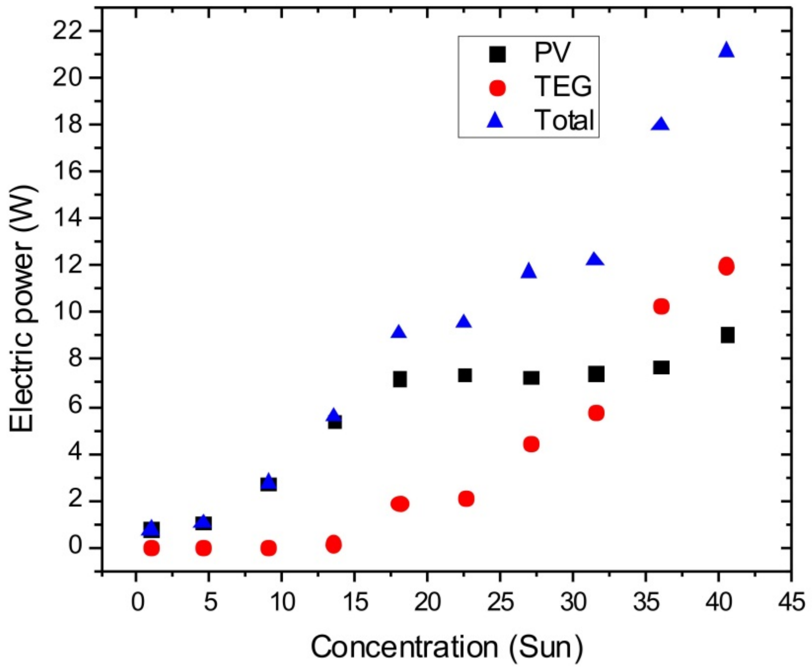
a) b)

Electric efficiency PV + TEG

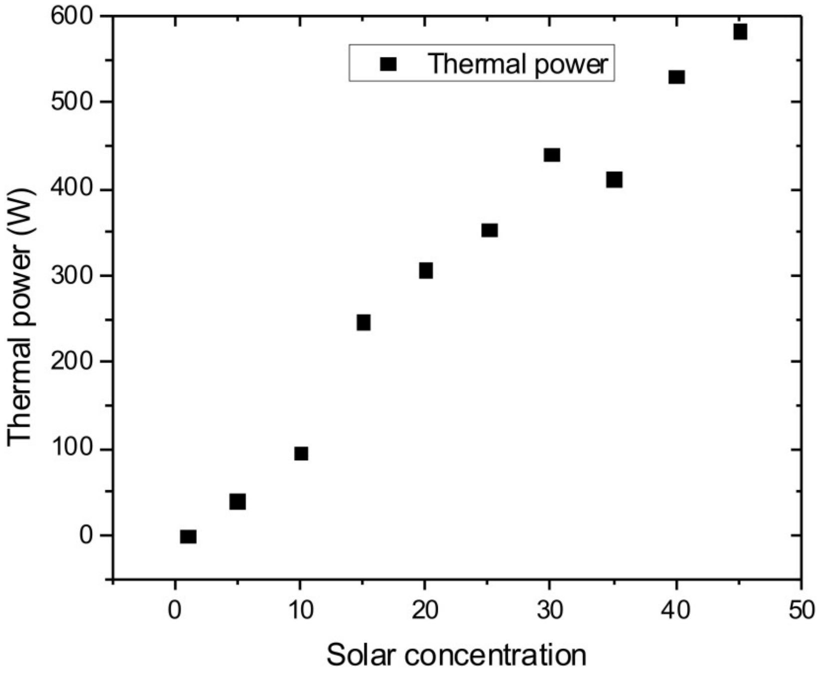


Si PV cell (1) TEG with a figure of merit (Z) of 0.7 (2) and 4 (3). In 4 and 5 total efficiency of PV + TEG are shown wit Z=0.7 and Z=4 respectively.

Total power output



a)



b)

a) Shows the total electric power generated and the thermal power in b).

Expected results in greenhouses

- With a concentration of 5-6X a TEG electrical efficiency around 2% can be reached but with a thermal efficiency of 50% , using only the TEG directly over the absorber.
- If PV cells are used as absorber over the TEG, an electrical efficiency of 8-10% can be reached over PV cell (Crystalline silicon) and 2% in TEG, with a slight lower thermal efficiency.

- Use of the suggested system for water disinfection

Use of solar thermal collectors for water disinfection

Horticulture represents an important percentage of Greenhouse production in Mediterranean regions.

The high demand of water combined with its scarcity make necessary to **recirculate irrigation effluents**.

The use of drainage water in hydroponics can achieve savings of 20-30% in water and agrochemicals, reducing also soil contamination.

Disinfection requierements

Water disinfection is necessary to eliminate pathogens, as many horticultural products are to be consumed raw.

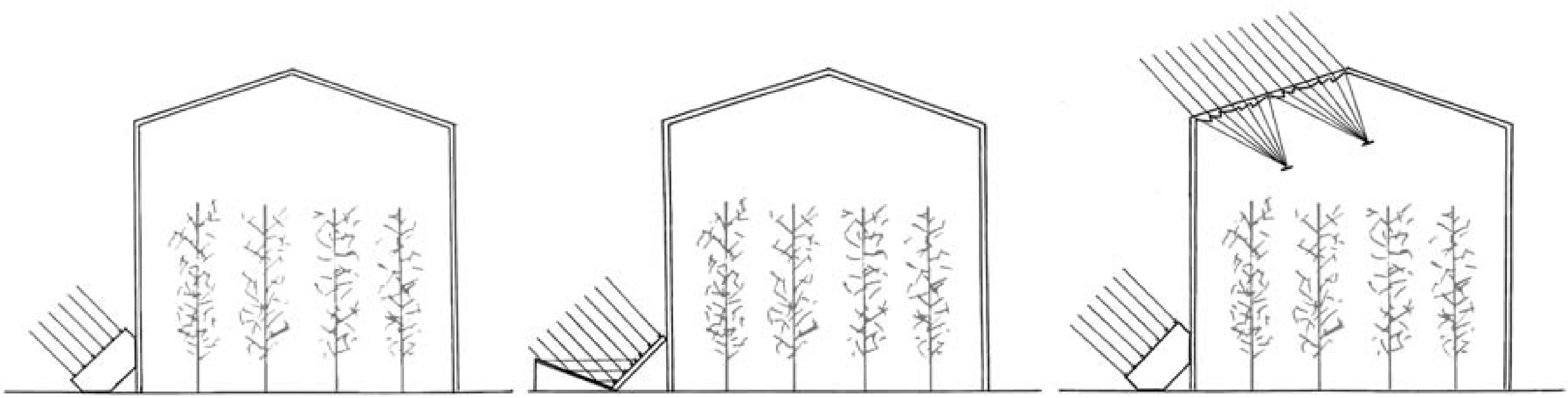
Temperatures above 50 °C are lethal to some pathogens, and temperatures of 65 °C maintained along the sufficient time can disinfect the water.

Current methods (heat exchangers, UV lamps and ozone injections) are energy demanding.

Disinfection requierements

Solar energy is usually applied for domestic hot water and space heating and is obviously used to the greenhouses, as they operate like large solar thermal collectors.

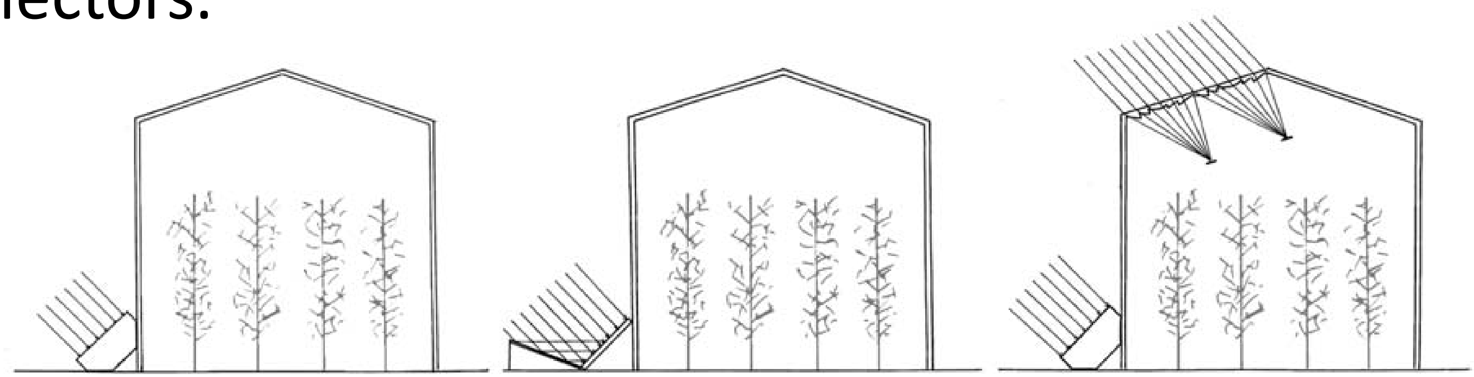
In regions with high values of radiation all over the year, solar thermal collectors can provide the energy required for heating water up to lethal temperature for pathogens.



Disinfection requierements

Several ways to disinfect water have been developed. All the mentioned methods of disinfection consume large amounts of energy (gas or electricity), that increases the costs of the disinfection.

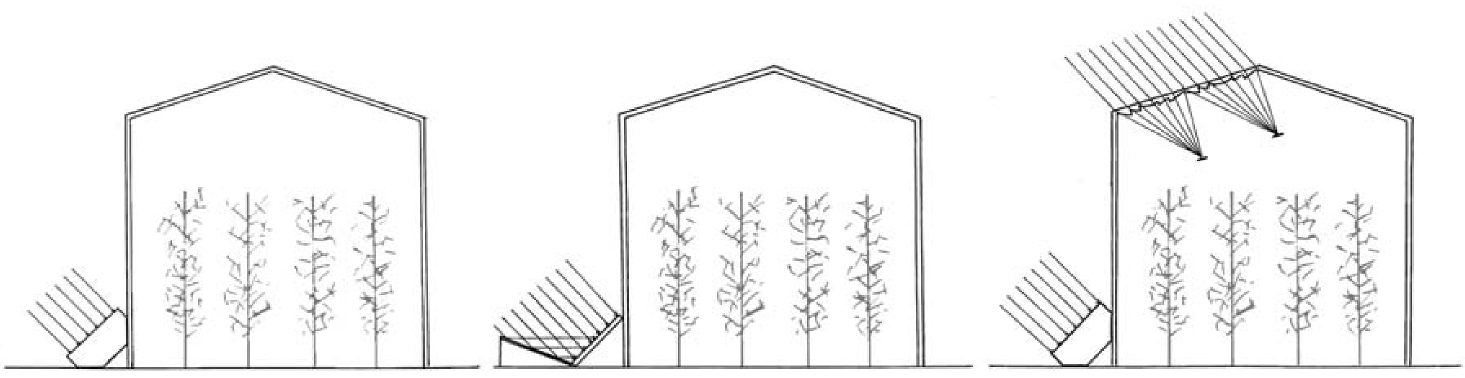
Nevertheless, in Mediterranean conditions, solar energy can be effectively used for water disinfection as solar radiation can heat water up to temperatures able to inactivate plant pathogens by means of suitable solar collectors.



Disinfection requierements

This work aims at applying thermal solar energy for heating water so as to reach the temperature able to disinfect water for its recirculation in greenhouses.

From experiments in our laboratory with the Fresnel Lens there have been recorded absorber temperatures in the range of 60-80 °C with a good efficiency (about 60%-50%).



Conclusions

- The use of Fresnel Lenses is suitable for its application in greenhouses for thermal and electrical power generation.
- Due to the fact that 3 hours is enough for an effective disinfection treatment at 65 °C, thermal power generated could be used for water disinfection.
- The use of TEG in between the solar absorber and the heat extraction unit can provide extra electrical power, but the solar concentration need to be improved at least up to 20X for its efficient use.
- The use of less temperature dependent solar cell like solar absorbers (Like GaAs) under FL solar concentration will lead to a more efficient and affordable system.

Thanks!

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