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Performances issue's analysis of an innovative low concentrated solar panel for energy production in buildings

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Abstract

The buildings are the causes of about a third of primary energy consumption in Europe and generally, they satisfy their energy needs by the connection to the outside with a complex distribution system.
The main sources for this energy production comes from the combustion of non-renewable fuels as natural gas or coal; this way presents a relevant impact on the environment at different levels. Solar energy could allow reducing the building's impact on the global primary energy consumption and consequently on the environment, but generally the solar systems are selective about their output or only thermal or only electricity. In this contest, the low concentrated solar technology could be an interesting way to combine the two outputs with easy integration in the building with low impact on the architecture.
The paper describes the analysis performed on a low concentration solar system; this unit has four linear semi-parabolic concentrators and the sun tracking is on only one rotational axes.
The work starts from an analysis of influence of the sun angle on focus's position on the receiver by a rays trace code. This is important because the concentrator is only alienated with one sun angle thus the sun's rays are not perpendicular with the input surface. A performance analysis, using the previous out coming, are performed on a complete system with the using of the sun position during the years for a reference location. The study compares two direction for the tracking: Est-West and South-North, some different distances between the concentrators and different tilt angles.

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Nomenclature

CPV	Concentrated PhotoVoltaic
PV	PhotoVoltaic
α	Solar Altitude angle
γ	Solar Azimuth angle
i	Incidence angle
Tilt	Angle between the ground and the panel

1. Introduction

In recent years, many Concentrated PhotoVoltaic systems (CPVs) and thermal concentrator systems have been developed [1]. A solar concentrator system has been introduced and developed in order to reduce the silicon needed for photovoltaic electrical energy production, with the possibility to produce electrical energy and thermal energy at the same time to reduce the needed surface. The main idea that are based these systems is to replace the photovoltaic active surface with reflective or refractive surface that are much less expensive. Moreover, by using the replaced materials is possible to increase the conversion efficiency of the overall system. The solar radiation is focused through mirrors or lenses onto a limited surface of photovoltaic material. On the other hand, the use of concentrating solar systems required mechanical and electronic systems to track the sun that increase the cost of the system and conditions the performance. This implies a more accurately and frequent maintenance programs.
Operation at high concentration factor can reduce electrical energy production caused from high operative cell's temperature because their efficiency drastically when the temperature is over the 60°C. The solution is the introducing of a water circuit that allows limiting the temperature.
Generally, a thermal solar concentrator works at generally over 130° - 150° C to allow a good efficiency of the system [2–4], so it is over the allowed operative temperature limit of the solar cells. Thus, the development of PV/T is a trade-off between the production of electrical and thermal energy.
In PV/T solar concentrator, the thermal energy production is achieved by the recovery of the heat generated by the solar cells and this quote of energy is used to produce hot water.
The aim of this work is the preliminary performance analysis on the capability to make available a concentrated solar flux on the receiver.
Many possible errors influence the correct focus, e.g. the constructive quality of the concentrator and the tracking error. These problems are performance influencing for high concentration system, but a 20X system is able to endure bigger focus errors.

1.1. The device description

The analyzed system, Fig. 1, is a linear solar concentrating system [5] using low profile parabolic reflector to concentrate the solar radiation into a string of mono-crystalline cells [6] with a 20x concentration factor.
The cells are cooled by means of water flowing through counter flow two pipes placed in the aluminum solar receiver; this solution is able to reduce the cell's temperature and it provides a thermal energy recovery for the producing of domestic hot water, this solution is implemented by other system as in Rosell et al. [7].
The device is a linear parabolic concentrators, it is made in glass- fiber and it uses a specific reflective film.
The receiving area for each concentrators could be from 0.30 to 0,40 m^2, it depends from the length of each concentrator; the theoretical maximal energy input could be from 0,30 to 0.40 kW when the system is perfectly aligned.
The tracking system is mono-axial system, and the main direction is est-west, the panel is inclined of 12° with the horizontal plane, it is the angle of a generic domestic roof in Tuscany. This configuration involvements a not perfect alignment with the sun of the receiver but it is a known limit of the single tracking axis [8–10].
All photovoltaic linear concentrator, that uses a one axis simpler tracker, presents the effect of "end-losses" issue [11]. A part of the receiver is not illuminated thus it reduced the performance of the system. This situation is critical for the

solar cell, because the not illuminated cells block the electric circuit to the others but for the thermal aspect, the shady zone reduces only the receiving zone thus the available energy.
The some devices, four or more, are mounted on a frame that allows realizing a solar module that presents a footprint equivalent a commercial solar module, about 2.4 m^2. This solution uses only one tracking system for all the devices.

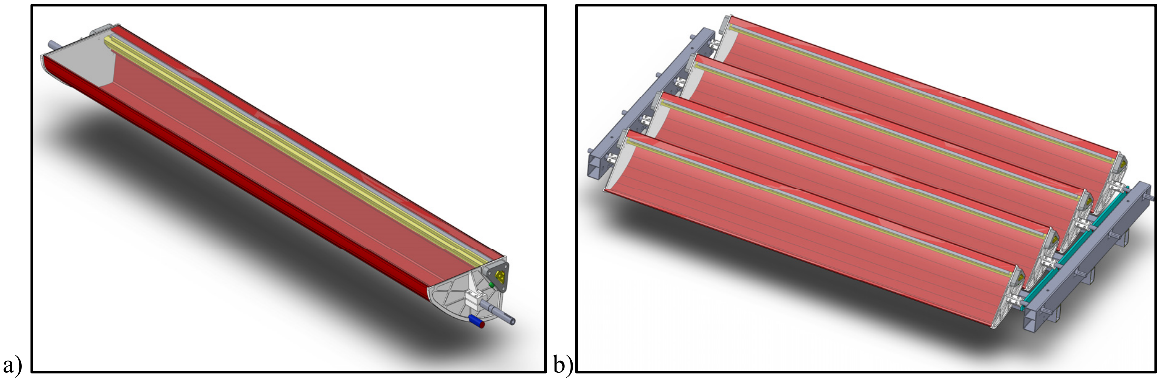

Fig. 1: a) The device and b) A combined configuration of the device

2. Ray tracing analysis

The study starts to investigate the effect of a generic focus error on the available energy for the receiver; these errors could be produced by the tracking system or by the constructive tolerance of the reflective surface.
The errors are represented by little rotations or translations, respect a fixed Cartesian system, from the condition of perfect focus, see Fig. 2, which is when the rays are parallel with the Z-axes. The X-axis is main axis for the tracking. The study is a numerical ray traces analysis applied on a sliced section of the concentrator, this way reduces the computational cost. The code generates a defined numbers of rays from a surface, and it tracks the path of each ray considering the optical law; e.g. the reflection. The receiver cell is a surface that works as a perfect absorber; the reflective surface considers the proprieties of the commercial Alanod Miro film.
The number of the tracked rays that influence directly the execution time thus the reducing of computational domain allows performing many simulations in little time.

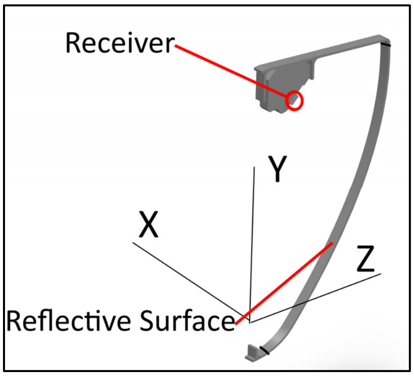

Fig. 2: Image of sliced section and Cartesian coordinate system

The slice deeps 10 mm but the receiver considers 30mm as three adjoining elements, this configuration evaluates the cases where the focus moves on next portion of the receiver.

2.1. Rotation analysis

The analysis performs some disturbances on the parabola's position while the receiver and the ray direction is maintained fixed. The angle range is from -2° to +2° degree respect each axis.

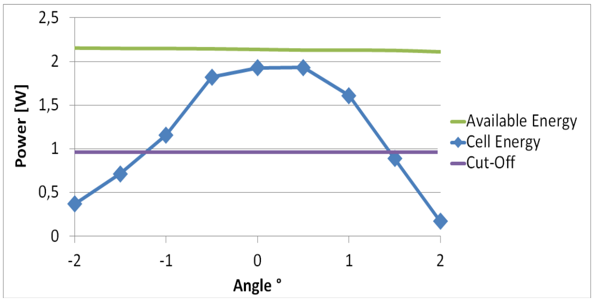

Fig. 3: X Axis rotation cases

The graph of Fig. 3 shows the effect of the rotations around the X-axis. The green line show the available energy for the cell, the blue line is the energy that light the cell. The violet line is the cut-off, this condition occurs when the cell is lighted for less of its 50%. The operative range is from -1° to 1.4° with a flat response from -0.5° to +0.5°.
The image of Fig. 4 and Fig. 5 show the effect of a rotation around Y-axis and Z-axis, in these cases the study considers the possibility that an energy share can get on the adjacent cells. In the images, these cells are defined Cell +X or Cells –X. The rotation effect on the main cell is a linear decline but the next cells recovers the lost energy so the global performance are not sensitive to rotation of two degree.

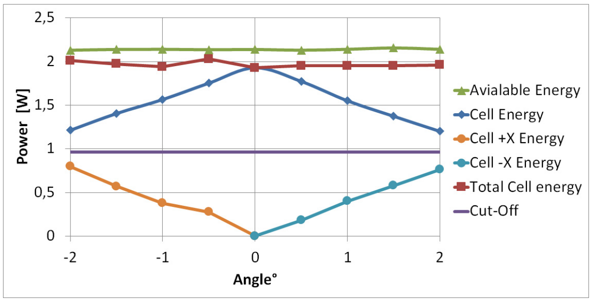

Fig. 4: Y Axis rotation cases

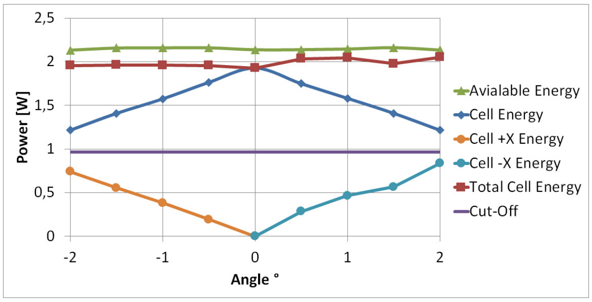

Fig. 5: Z Axis rotation cases

2.2. Translations analysis

Other important ways for the focus error generation are the translations on Y and Z directions. Errors on the X direction do not influence the performances, because this study evaluates errors about millimeter but the actual dimension, in X direction, is about 1800 mm. The graphs of Fig. 6 and Fig. 7 report the low sensitivity to the translations, in fact in a range of -4mm to +4 mm the cell power is over the 75% of the maximum.
The issue is that the plane YZ is the rotation plane on X-axis and the previous analysis shows a limit of one degree before the cut-off and this is equivalent a combined translation of one mm.

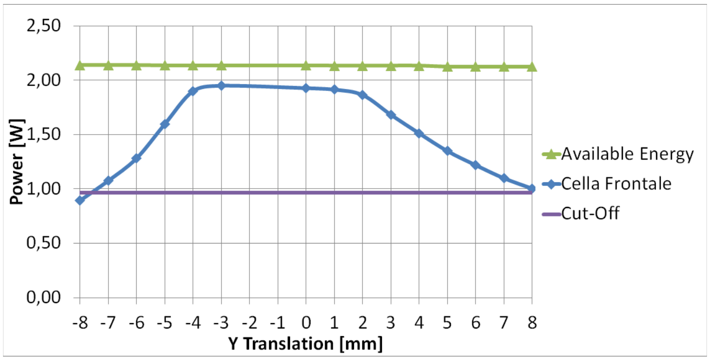

Fig. 6: Y Translation cases

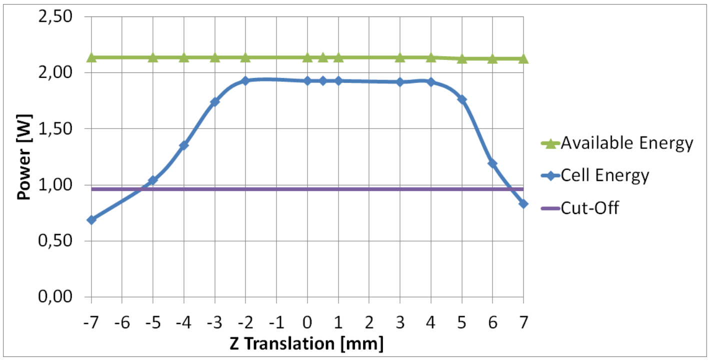

Fig. 7: Z Translation cases

3. Tracking orientation analysis

The investigated device uses only a mono-direction tracking so the performance issue analysis now focus to individuate the better tracking directions for different cases, when the device is south oriented and it is flat with the ground. The analysis uses the ENEA data for the sun position in Florence, Italy [12].
There are two possibility for the rotation axis:

1. The North-South so the Sun Est-West position is tracked
2. The Est-West so the Sun altitude is tracked.

This analysis considers a configuration with five parabolic concentrators and the global peak electric power is 210W with a 19% efficiency.
The mono axis tracking implies the presence of an incidence angle "*i*" between Sun and the concentrator.
This angle is evaluated by two equation for the two tracking orientations:

1. Est-West: $i = \text{arsen}(\text{sen}(\pi/2 - \alpha) * \cos\gamma)$
2. Sun altitude: $i = \text{arsen}(\text{sen}\,\alpha * \cos\gamma)$

Where the angle α is altitude and the angle γ is the azimuth of the Sun in a specific time, from graph of Fig. 8.
This graphs show the monthly average value of the sun position for every hours. In the azimuth's graph, the angle 0 referees to the south direction; in the altitude, the angle 0 is the horizon.

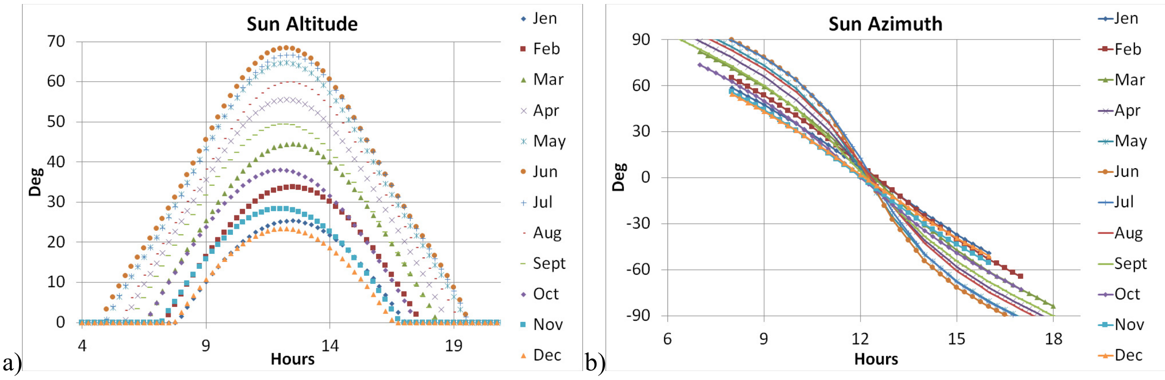

Fig. 8: a) Sun altitude angles and b) Sun Azimuth angles in Florence, Italy

The actual device is limited length thus the end-wall effect is present [5,11] thus a preliminary ray trace analysis evaluates a function between the angle *i* and the reduction of available energy for the concentrator. The graph of Fig. 9 reports the available energy in function of the angle *i*, the energy value is referred to the case with the sunrays perpendicular to the panel.

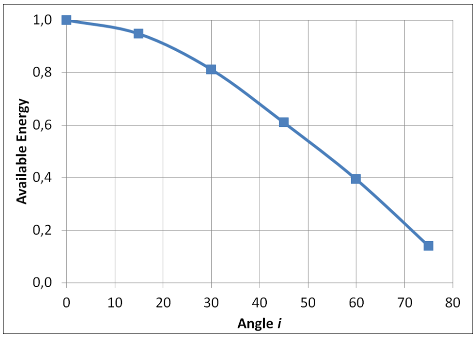

Fig. 9: Available Energy Vs Angle *i*, respect maximal available

The energy evaluation is produced through the equivalent hour of maximal power output; the procedure calculates the average value of sun hours using the sun position angles, the incident angle on the device and the available energy curve, after it considers the 19% of efficiency of PV cells.
Output from this evaluation shows an electric energy production of 867 kWh the Est-West tracking and 653kWh for the Sun altitude cases.

3.1. Shading between devices effect

Until now, the analysis does not consider the effect of showing between the devices as they are at infinite distance, but when a device is half shady it is in cut-off condition thus it does not produce electric energy.
So the procedure is extended the evaluation of shading, the graph of Fig. 10 shows the effect on the case with Est-West tracking, the values are referred at the case at infinite distance, the Fig. 11 shows the case with Sun altitude tracking. The Est-Wet case is the more penalized because the minimum loss is the 30% when the distance is about the 60% of the aperture of one device. The Sun altitude case, see Fig. 11, shows a lower influence in fact the worst-case losses only the 23%.

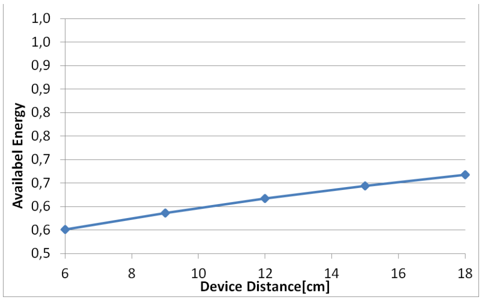

Fig. 10: Available energy Vs device distance, Est-West case

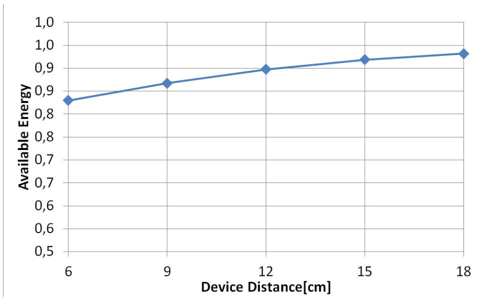

Fig. 11: Available energy Vs device distance, Sun altitude case

3.2. Tilt angle effect

The second effect that needs to be considered is the tilt angle; the device is developed for residential use where it could be installed on a roof. For simplification the tilt angle is added directly to the sun altitude angle, this is a formal error but its effects are influencing only in the cases with high azimuth absolute angle where the device does not work.
The graph of Fig. 12 reports the comparison between the two tracking way about the electric energy production in a years. The Est-Wet case presents its peak between 40-60°; it is an expected result because the reference latitude is 42°.
The Sun altitude case shows an insensibility for angle bigger than 40° but, for smaller angles, the production presents an evident decay. However, the typical roof angle is between 16 and 25° thus the Est-west tracking presents a bigger production.

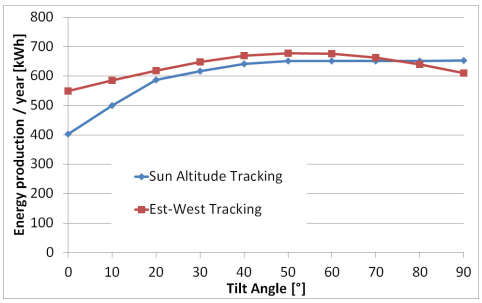

Fig. 12: Effect of the tilt angle on electric energy production for one years

4. Conclusions

The paper presents a multi-method approach for evaluating of some performance issues in a solar concentrated system. This device presents a mono-axial tracking direction and a low concentration level, the utilization target is the residential buildings. In this contest, small concentration systems present many performance issues because the cost to produced energy must be comparable with flat panel thus there are limitations on the manufacturing quality.

This paper focus to individuate the performance issues and to define some parameters that are able to guaranty an acceptable energy production.

The first analysis shows the maximum possible error on the focus positions, these errors are the combine of construction errors and tracking errors. The more impacting limit is on main axes rotation, a one-degree error is able to bring the cell at the cut-off condition.

The second analysis is focus on the tracking direction contemplating the distance between the devices and the tilt angle. Generally, the Est-West tracking is able to produce more energy than a Sun altitude tracking, but this tracking direction is better for high tilt angles.

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