Optical Fiber as Solar Radiation Collector for Radiometric Measurements

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Introduction

Objective: Study the feasibility of using optical fibers as solar radiation collectors, as well as the influence of its various parameters.

¿What is solar irradiance?

Solar irradiance is defined as the radiant flux received by a surface per unit area. It is decomposed into two main components, Direct Normal Irradiance (DNI) when talking about the solar radiation coming directly from a small solid angle centered in the solar disk, and Diffuse Horizontal Irradiance (DHI), which refers to the radiation received from any path but the one directly from the sun. The sum of both components is known as Global Horizontal Irradiance (GHI).

¿Why is solar irradiance measurement important?

Data collection on solar irradiation is important for a wide variety of applications, such as agriculture, architecture or medicine; as well as for the energy generation field; allowing investors and companies to evaluate the potential of different spaces for the installation of photovoltaic or concentrated solar power (CSP) stations, and helping the real time monitoring of efficiency, status or potential problems in this type of power generation plants.

¿How is solar irradiance measured nowadays?

Following International Organization for Standardization (ISO) [1,2] and World Meteorological Organization (WMO) [3] norms, the device used for measuring DNI is the pyrheliometer, while DHI and GHI are measured with a pyranometer.

In the case of the pyrheliometer, it will be mounted into a solar tracker to ensure that the system is always oriented towards the sun, capturing the radiation coming from the solar disk. The captured radiation will be guided to a thermopile, converting the induced heat into a voltage signal [4]. The device also needs to guarantee that only the radiation coming from the solar disk is captured. For this reason, the field of view of the device must be sufficiently small. According to the World Meteorological Organization, a pyrheliometer should have a half-angle aperture of 2.5º, although other studies have explored half-angle apertures up to 10º [5].

System Description

The tip of the optical fibers is exposed to the solar light, guiding the optical power to a photodetector which transforms it into an electrical signal received at an optical power meter, generating a power trace.

The exposed tips were mounted on a solar tracker and placed next to a KIPP & ZONEN CHP1 pyrheliometer, generating a solar irradiance measurement used as a reference to evaluate the behavior of the different fibers.

Optical fiber tip alongside commercial pyrheliometer.

Photodiode, optical power meter and computer to store power traces.

After processing the optical power trace with a calibration algorithm already presented in [6,7], the optical fiber and photodiode-based radiometer, provided accurate direct solar radiation measurements.

Conclusions

The study presented demonstrates the feasibility of using optical fibers as radiation collector for radiometric measurements, reaching results comparable to conventional pyrheliometers when using the appropriate numerical aperture for measuring DNI.

Among the different optical fibers used in the different tests, it was proved that the size of the core of the fiber does not affect the accuracy of the device, although it does influence the ripple of the measurements.

When varying the different numerical apertures, only the fiber with the smaller Field of View (FoV) (0.1 NA) provided results comparable to the commercial pyrheliometer under all circumstances, while fibers with numerical apertures of 0.22 and 0.5 showed higher errors, especially under cloudy conditions.

Fibers with greater FoV could be used as solar radiation collectors in radiometers, measuring GHI from a section of the sky, as well as in other applications where the radiation coupled came from a wider angle.

The use of optical fibers as solar radiation collectors can be a viable and economical alternative for DNI measurement, with potential applications in solar power plant monitoring. Future research could focus on analyzing the different error sources; and a refinement of the calibration algorithm.

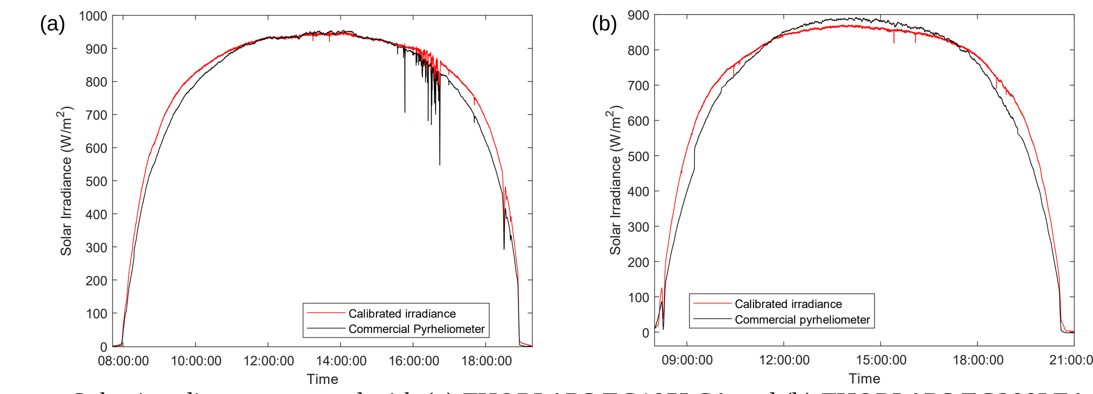
Results

The optical fibers detailed on the right table were used, connected to a photodiode THORLABS S140C, and the optical power meter PM320E. The results presented illustrate the measurements given by the proposed optical fiber and photodiode-based radiometer [6,7] when using different optical fibers as capturing element for solar radiation (red and blue lines) compared with the commercial pyrheliometer (black line).

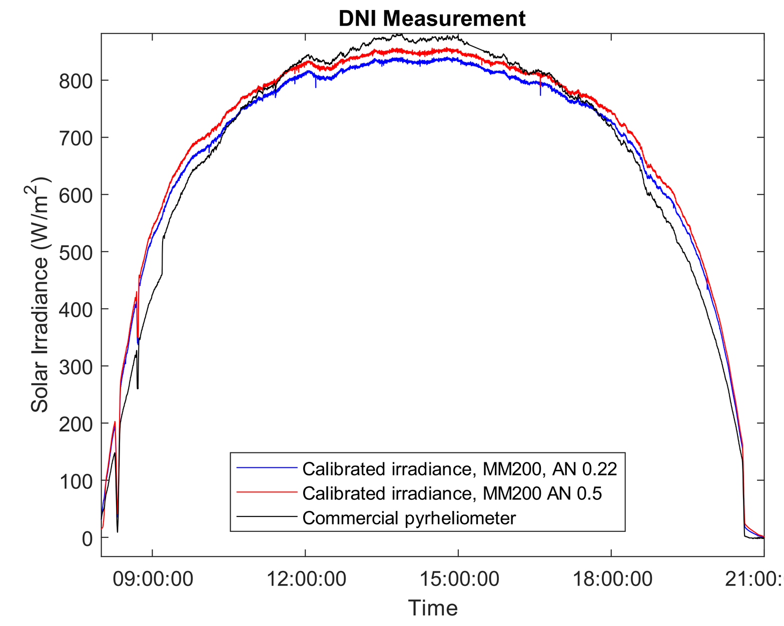
Fiber Model	Core Diameter (µm)	Numerical Aperture	Half-Acceptance Angle
FP200ERT	200	0.5	30º
FG200LEA	200	0.22	12.71º
FG105LCA	105	0.22	12.71º
FG105LVA	105	0.1	5.73º
FG050LGA	50	0.22	12.71º

Influence of the core diameter

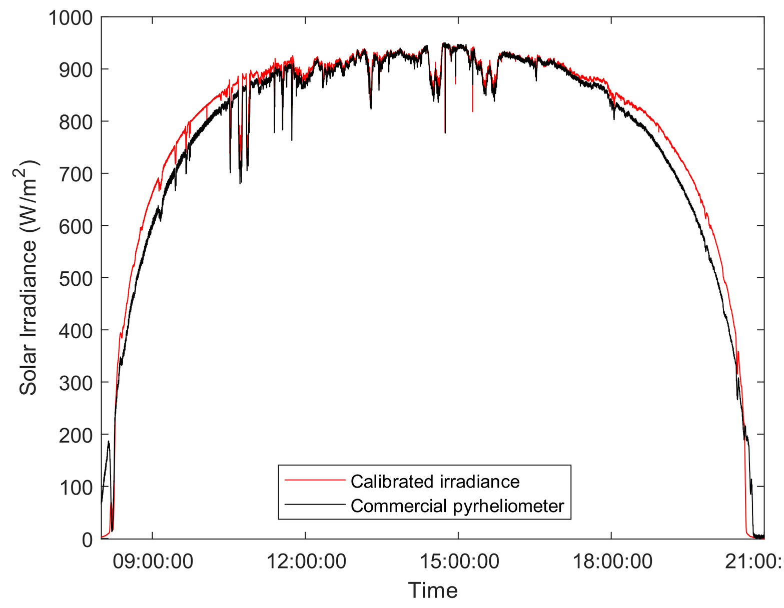
The comparison of the results obtained with fibers of different core diameter shows that the modification of this parameter does not affect the goodness of the results. The main implications when varying the core diameter of the fibers are related to the ripple, as the power coupled is near to the photodiode sensitivity limit when working with smaller core fibers.



Solar irradiance measured with (a) THORLABS FG105LCA and (b) THORLABS FG200LEA, with core diameter of 105µm and 200µm, respectively, during two mainly sunny days.



Solar irradiance measured with THORLABS FG200LEA (0.22NA) and THORLABS FP200ERT (0.5NA), during a completely sunny day.

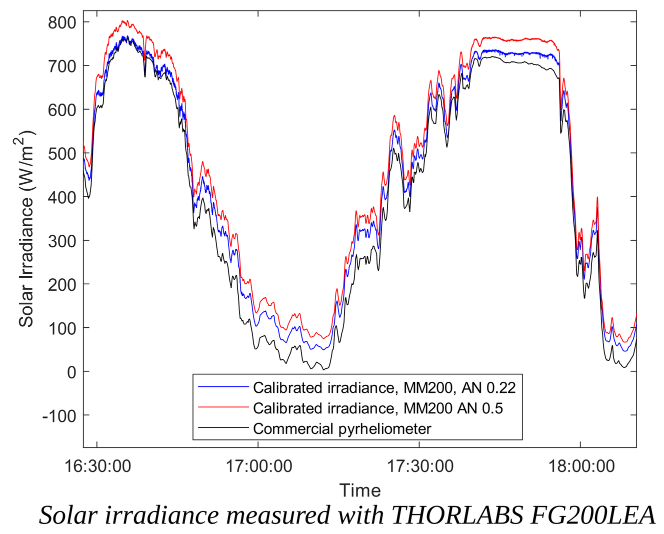


Solar irradiance measured THORLABS FG105LVA (0.1NA) during a completely sunny day.

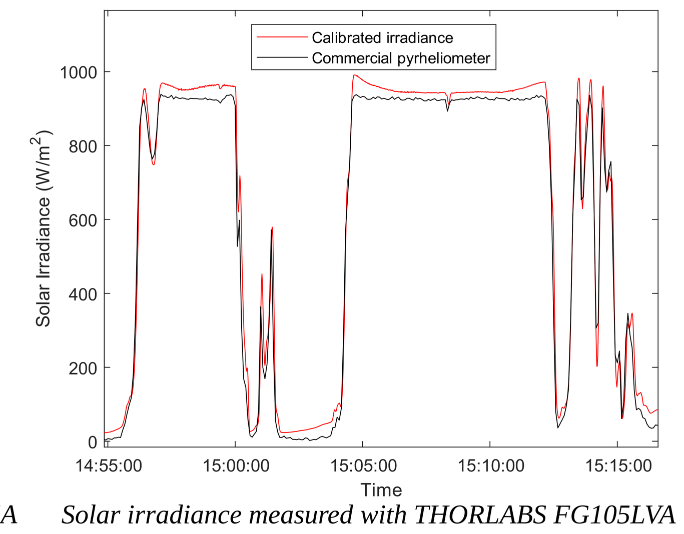
Influence of the numerical aperture

In the case of the fibers with greatest numerical aperture, the light captured and introduced into the fiber comes not only from the solar disk but also from a large section of the sky, including a significant DHI component in the DNI measurement. Although this is negligible for sunny days, when the behaviour is similar to the pyrheliometer, results are worse for cloudy days. This problem is also observed, but minimized, in the case of the fibers with 0.22 numerical aperture

For the smallest numerical aperture, corresponding to model FG105LVA, the aperture angle associated is in the range of other commercial devices. This time, it is observed that the results are approximately equal to the commercial pyrheliometer under all climatological conditions; reaching deviations of less than 1% during central hours of the day.



Solar irradiance measured with THORLABS FG200LEA (0.22NA) and THORLABS FP200ERT (0.5NA), during a cloudy period



Solar irradiance measured with THORLABS FG105LVA (0.1NA) during a cloudy period

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