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DETEC
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Highly Concentrated Solar Radiation Measurement by means of an Inverse Method

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Introduction: This work focuses on the numerical analysis conducted on the prototype sensor for the measurement of highly concentrated radiative heat fluxes, based on an inverse heat transfer method, realized at the ENEA Portici Research Center, in collaboration with the DETEC department of the University of Naples Federico II.
Figure 1 shows a picture of the prototype sensor. It consists of a metallic disc, made of AISI 316 stainless steel, whose exposed surface represents the target of the concentrated radiative heat flux, a zirconia thermal insulating support, and a metallic support. Three K thermocouples are placed on the bottom hidden surface of the target for the temperature measurements.

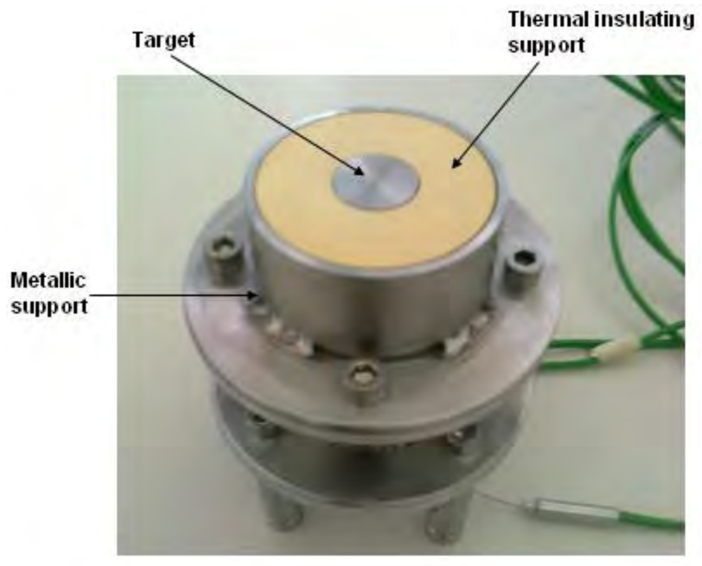

Fig. 1. Prototype sensor

Inverse heat transfer problem resolution procedure: Figure 2 shows the block diagram relative to the procedure used for the estimation of the concentrated radiative heat flux.

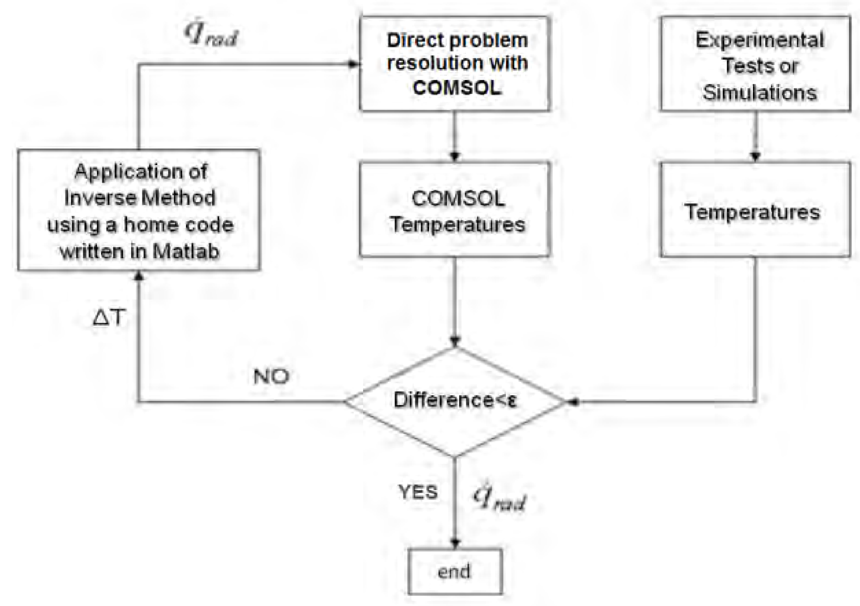

Fig. 2. Block diagram of the resolution of the inverse problem.

The implementation of the inverse method, based on the algorithm of Levenberg Marquardt, for the estimation of the concentrated radiative heat flux was performed using a home-made Matlab code. This procedure prescribes the iterative resolution of the direct problem performed using the COMSOL simulator.
Figure 3 refers to the 2D axisymmetric computational domain relative to the prototype sensor, and shows the two points on the hidden surface of the metal disc in which temperatures are numerically calculated and experimentally measured. The Comsol simulator solves the direct problem associated to the sensor in order to obtain the temperature values in the measuring points on the metal disc at certain instants of time. The calculated temperatures are then compared with those recorded during the experimental tests at the same instants. The difference between the computed and experimental temperatures are then used by the Matlab code to update the value of the radiative flux.

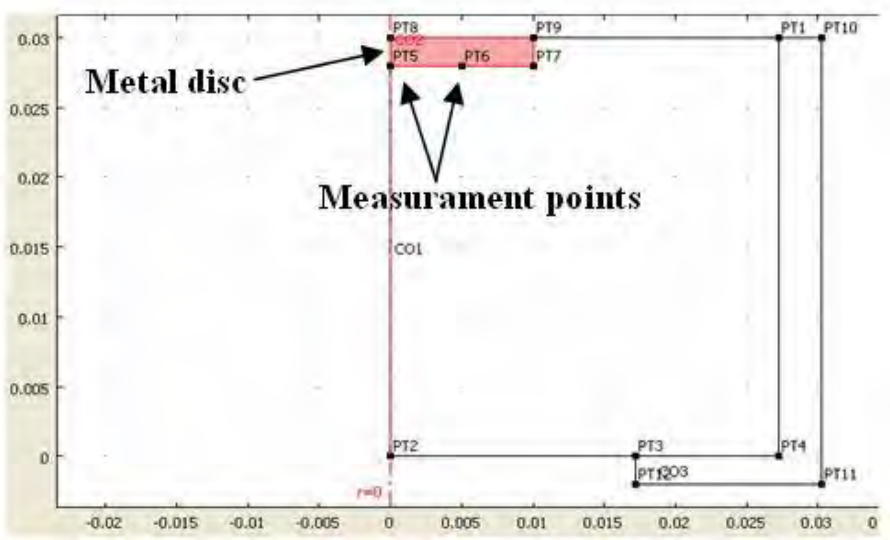

Fig. 3. Sketch of the 2D axisymmetric computational domain.

Numerical Analysis: The numerical analysis has been focused on the evaluation of the incidence of some characteristics relative both to the target exposed surface and the temperature measurements on the final estimate of the absorbed concentrated radiative heat flux coming from the resolution of the inverse problem, namely the emissivity of the target surface of the sensor, the synchronization error in the temperature measurements, and the measurement error of the thermocouples. In this numerical study the input temperatures to the inverse problem are not measured experimentally, but they are obtained from the numerical simulation of the prototype sensor realized by means of the software Comsol Multiphysics 3.5a. Figures 4-9 show the comparison between the simulated fluxes and the estimated ones.

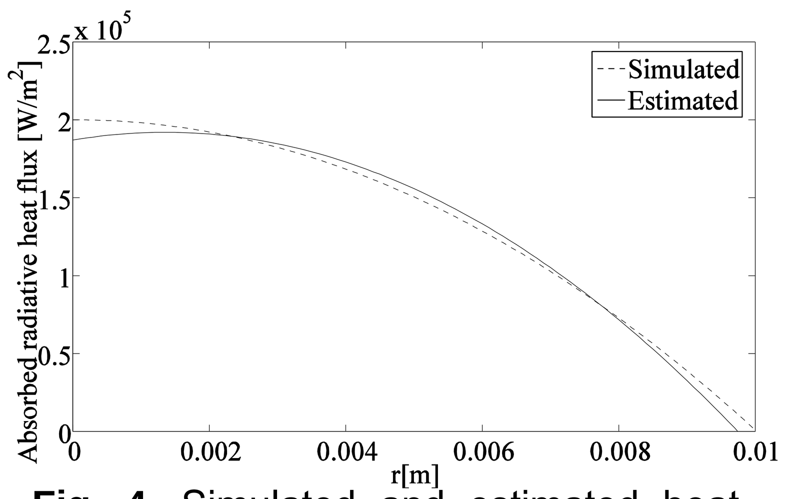

Fig. 4. Simulated and estimated heat fluxes of order 100 kW/m² with Δε=10%.

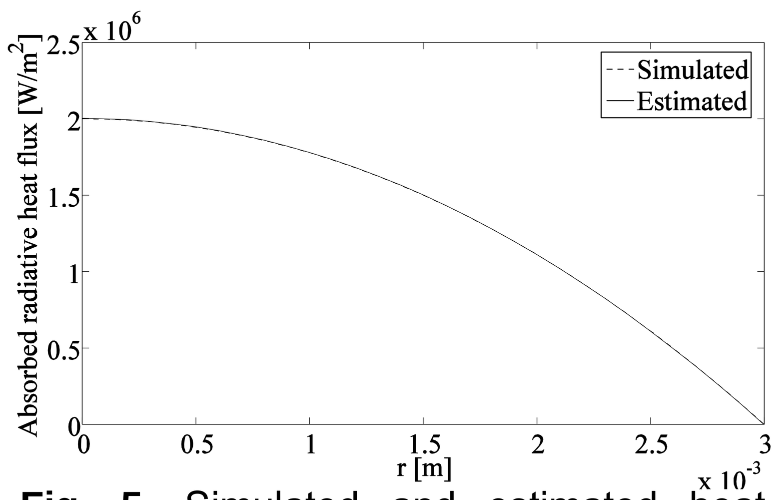

Fig. 5. Simulated and estimated heat fluxes of order 1000 kW/m² with Δε=10%.

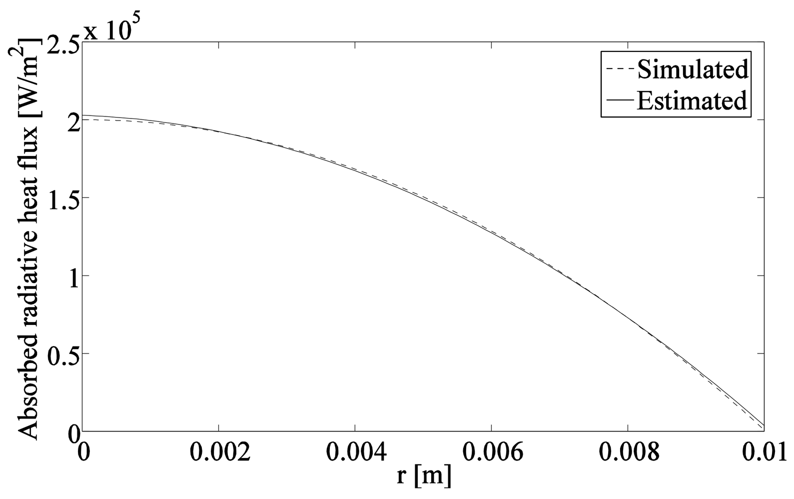

Fig. 6. Incidence of a synchronization error of 1 s with 100 kW/m².

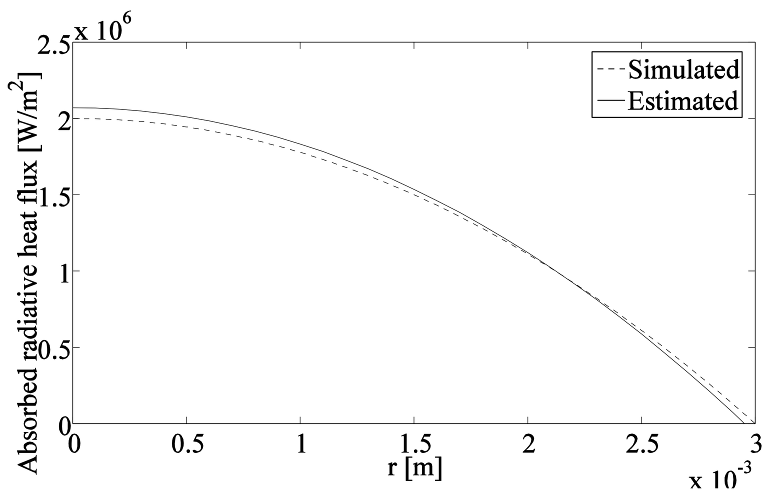

Fig. 7. Incidence of a synchronization error of 1 s with 1000 kW/m².

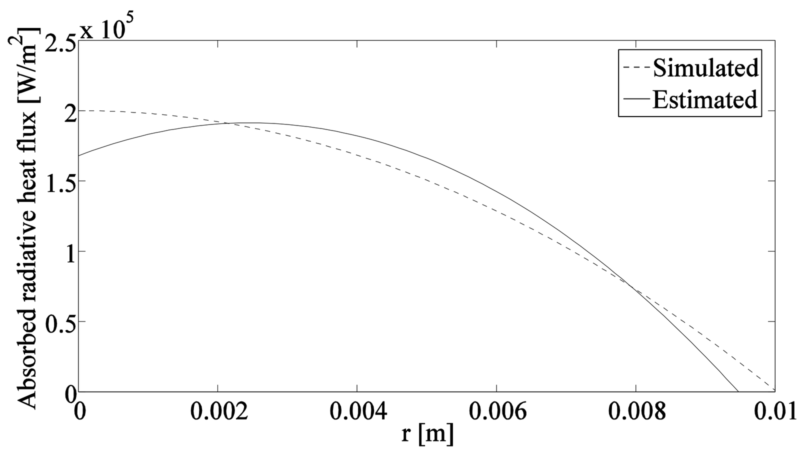

Fig. 8. Incidence of thermocouples error with 100 kW/m².

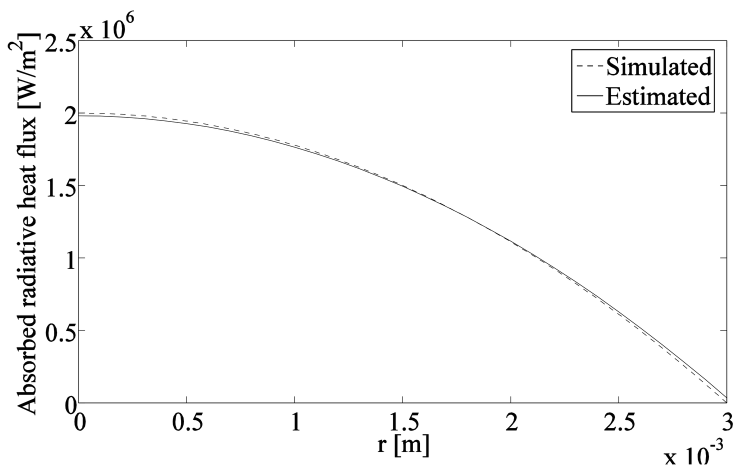

Fig. 9. Incidence of thermocouples error with 1000 kW/m².

Experimental tests: Figure 10 shows the test facility utilized for the experimental analysis, while figure 11 shows the prototype sensor during an experimental test. Two square lenses of different types, namely a prismatic lens and a hybrid (prismatic-fresnel) one, were used in order to provide a concentrated solar radiation on the sensor target surface. Table 1 reports for each of the two lenses the estimated and the experimental power on the target exposed surface.

Fig. 10. ENEA outdoor measuring station.

Fig. 11. Sensor housing.

	Acquisition instants [s]	Estimated power [W]	Experimental power [W]
Test 1 (prismatic lens)	100, 200	18.046	13.26
Test 2 (hybrid lens)	100, 200	12.23	12.29

Table 1. Estimated and experimental power.

Conclusions: As concerns the numerical analysis, it was found that, in the case of highly contentrated radiative heat fluxes of order 1000 suns, the prototype sensor is not very sensitive to the uncertainty related both to the value of the emissivity of the exposed surface of the target, and to the temperature measurements of the thermocouples. Furthermore, it emerged that the prototype works good also in the estimation of radiative heat fluxes with a lower concentration (100 suns) when synchronization errors are present. Finally, experimental results confirmed the consistency of the technique implemented for the estimation of highly concentrated radiative heat fluxes.