

## ABSTRACT

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Solar energy could be one of primary sources of energy because it is ecologically clean and is freely available to everyone over the long periods of time. The most common use of solar energy includes its applications in thermal energy, particularly in the field of cooking or baking or drying by means of thermal collectors or by use of solar reflectors. Theoretically there are two types of reflectors in practice (a) Curved type reflectors (CTR) and (b) Flat plate type reflectors (FPTR). Although, the performance of a solar reflector depends largely upon the topology of a reflector unit. It is observed that the Thermal efficiency ( $\eta_{thr}$ ) is higher in case of CTR, compared to FPTR when CTR solar system is tracked precisely. CTRs undoubtedly exhibit superior performance characteristics, but they are burdened with intricate manufacturing processes, and often rely on requirement of non-indigenous technology for manufacturing of reflectors and control systems. From the literature, it has been observed that the cost associated with solar tracking mechanisms and CTRs contributes significantly to the overall system cost, making it less favourable for certain applications. In contrast, the FPTR presents a comparatively advantageous alternative due to its cost-effectiveness. This is attributed to the relative simplicity in manufacturing flat reflectors and the corresponding control systems, which substantially reduces production and operational expenses. With proper design and with little tracking, the flat type of reflecting geometry can also perform better (Kumar et al., 2010). Additionally, few literature have claimed that there is no specific methodology available to numerically analyse the FPTR and no such experimental study which give proper guidelines to test FPTR for specific solar applications.

In order to address this issue present study proposes a generalised methodology to evaluate various configurations of large-scale Flat plate solar reflecting system (FPSRS) under azimuthal sun alignment. The proposed method helps to evaluate performance of each single ray after it has been reflected by FPSRS's reflectors. The FPSRS is made up of different flat reflectors arranged into a funnel shape that resembles the inverted frustum of a square pyramid. A small-scale model of FPSRS having a Square-type configuration (STC) was built and exhaustive experiments are conducted for utilising the laser light in a controlled dark room environment to investigate the response of the FPSRS. To enhance the understanding of its behaviour and the reflection pattern, responses of the each rays were categorized into six different categories, from case A to case F. Furthermore, an Uncertainty ( $\chi$ ) analysis of the experimental setup is calculated to quantify the possible impact of manufacturing errors when scaling up the unit. The results of the uncertainty analysis for the FPSRS indicate that the maximum value of  $\chi$  in the path of the ray is 2.96% with considering  $\pm 1^\circ$

manufacturing error. The experimental findings obtained through the single-ray experimental approach are validated by comparing them to an earlier shadow experiment involving a solar system-augmented flat reflector designed for thermal applications, as conducted by A. C. Andres et al. (Carrillo-Andrés et al., 2022). Nevertheless, the results obtained from the experimental analysis of the ray path were cross-validated for a similar sized model in a CAD environment. The result shows a Maximum deviation ( $\delta_{\max}$ ) in the path of ray which is around 2.1% between the CAD model and the experimental results. The results of the analysis clearly establishes that the currently proposed use of FPSRS is capable to replace the traditional approach of use of fully tracking solar system, in terms of performance.

The current approach to analyse the performance of FPSRS involves discretizing the Top imaginary surface (TIS) into small rectangular surfaces through which the rays passes. Besides, it is observed from the literature that there is no specific guidelines to follow for selecting a particular mesh size, that gives sufficient accurate result for a given problem or for similar such problems. Present study also addresses this issue and proposes '*two-step guideline*' to determine an Optimum grid number (N). The above referred guidelines comprises of two steps, in the first step, a critical area in which the grid needs to be improved is identified through a mathematical approach. This is determined following Effective grid reduction ratio (EGR) method or Length of characteristics (LC) method. Subsequently, in the second step, 'N' is determined iteratively using the Coefficient variation of root-mean-square error (CVRMSE) method or the Coefficient of determination ( $R^2$ ) method. The applicability and effectiveness of the proposed approach are demonstrated through a case study of a numerical modelling of FPSRS with Ray tracing algorithm (RTA) in MATLAB environment. The RTA is developed using fundamental equations of lines and plane interaction and the same is derived for the equation of solar radiation as applied to three-dimensional analytical geometric equations. The results show that proposed guidelines lead to a remarkable 4.3% improvement in obtained N compared to the conventional approach.

The RTA was further employed to optimise the optical performance of the FPSRS and subsequently utilised for topology optimisation considering various configurations, after the successful validation of experimental results of FPSRS using RTA. Initially, RTA was applied to evaluate the optical performance of the FPSRS based on two parameters: the height-to-bottom (H/B) ratio and the reflector angle relative to the horizontal surface. This analysis was conducted for the FPSRS with a considering STC under two distinct solar radiation scenarios: Summer solstice (SS) and Winter solstice (WS). The results indicated that the optimal H/B ratio for optimum performance of the FPSRS ranges between 1.52 and 2. Further analysis was carried out to examine variations in the cross-sectional geometry of the FPSRS for three configurations: Octagonal type configuration (OTC), Hexagonal type configuration (HTC), and STC. These geometries were evaluated under both SS and

WS solar radiation conditions. The modifications to the FPSRS geometry using RTA revealed that transitioning from the STC to HTC resulted in a 2.9% variation in the Ray distribution profile (RDP) at the Base receiving surface (BRS) and improvement of 3.2% in Optical efficiency ( $\eta_{opt}$ ). However, the OTC demonstrated a distinct advantage, showing a 5.1% improvement in RDP over the HTC for lower-altitude solar rays. These findings confirm the suitability and efficacy of RTA in addressing topology optimisation challenges and highlight its potential in refining FPSRS configurations to enhance overall optical performance.

From this investigation, it is concluded that FPSRS can serve as a viable alternative for converting solar energy into thermal energy, proving highly beneficial for community cooking and baking processes. Furthermore, the experimental and numerical study of single-ray behaviour after reflection has resulted in to a completely a new era of solar beam radiation analysis. The findings aid in determining the thermal and optical efficiency of the FPSRS.