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CAVITY GEOMETRY EFFECTS IN SMALL-SCALE HELICAL RECEIVERS

Summary

This study investigates the influence of cavity geometry on the performance of small-scale solar central receivers through a comparative opto-thermal analysis of cubical and semi-cylindrical cuboidal cavity configurations integrated with a helical absorber. A three-dimensional numerical model is developed to simulate solar flux distribution, heat transfer characteristics, and thermal losses under identical operating conditions. The analysis evaluates the impact of cavity geometry on thermal efficiency and flux uniformity, which together capture the trade-off between energy conversion and heat flux distribution.

Results show that thermal efficiency increases with non-dimensional pitch and attains a maximum at approximately 1.8 for the semi-cylindrical cuboidal cavity, compared to 2 for the cubical configuration. The optical efficiency of the system is approximately 83.1%. Although the semi-cylindrical cuboidal cavity improves flux uniformity due to enhanced redistribution of incident radiation, it exhibits comparatively higher total heat losses, resulting in lower thermal efficiency than the cubical cavity.

These findings highlight a trade-off between flux uniformity and thermal performance and provide design insights for optimising compact solar tower receivers.

Keywords: Cavity receiver, central receiver, cubical cavity, flux uniformity, helical absorber, semi-cylindrical cuboidal cavity, opto-thermal performance, small-scale solar tower, thermal efficiency

Field of application for the findings: Solar thermal power, concentrated solar power (CSP), renewable energy systems

Addressed audience: Researchers, design engineers, and professionals in solar thermal and energy systems

1. Introduction

Small-scale solar central receiver systems have gained increasing attention due to their potential for decentralised and cost-effective thermal energy generation. Kadohiro et al. (2025) demonstrated a dual-media cavity receiver capable of producing steam and air at temperatures above 800 °C. Studies such as Giostri et al. (2020) and Morosini et al. (2022) support integration with micro gas turbines and storage systems.

The central receiver plays a critical role in CSP systems by converting concentrated solar radiation into thermal energy. In cavity receivers, the absorber acts as a radiative–convective heat exchanger. Although helical heat exchangers are widely used in industry, their application in solar receivers remains limited.

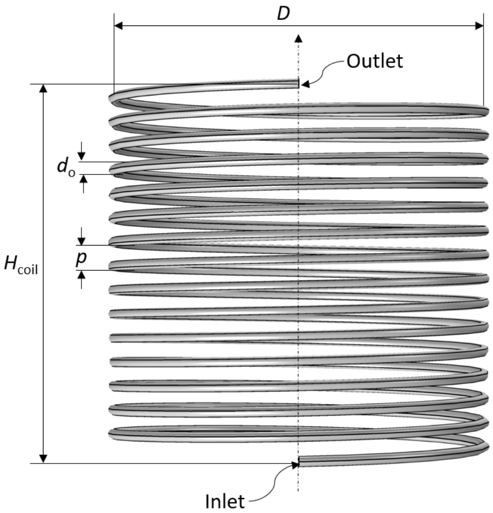
Shanker and Modi (2026) analysed a helical absorber in a cubical cavity. Building upon this, the present study investigates a semi-cylindrical cuboidal cavity (hereafter referred to as "hybrid cavity") to examine the influence of geometry on thermal performance, flux distribution, and optimal design parameters.

2. Methodology

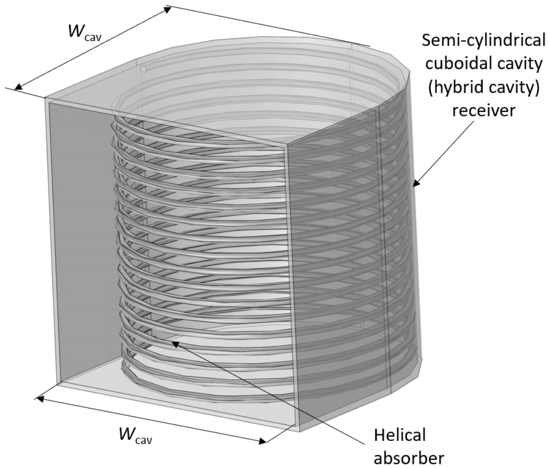
2.1 Receiver configuration

The proposed system consists of a helical absorber enclosed within a hybrid cavity (Fig. 1). The results are compared with the cubical cavity configuration reported in Shanker and Modi (2026).

The opto-thermal modelling approach follows Shanker and Modi (2026). The non-dimensional pitch (p/d_o) is the primary design variable.



(a)



(b)

Fig. 1: Schematic diagrams of (a) helical absorber and (b) hybrid cavity receiver.

2.2 Performance parameters

Instantaneous thermal efficiency:

$$\eta_{\text{th}} = \frac{\dot{Q}_{\text{u}}}{\dot{Q}_{\text{coil}} + \dot{Q}_{\text{cav}}} \tag{1}$$

Flux uniformity is quantified in terms of uniformity factor (UF) (Daabo et al., 2016) as :

$$UF = \left(1 - \frac{\dot{q}_{\text{peak}} - \dot{q}_{\text{mean}}}{\dot{q}_{\text{peak}}}\right) \times 100\% \tag{2}$$

where $\dot{q}_{\text{mean}}$ and $\dot{q}_{\text{peak}}$ denote the mean and peak heat fluxes on the absorber tube, respectively, while $\dot{Q}_{\text{u}}$, $\dot{Q}_{\text{coil}}$, and $\dot{Q}_{\text{cav}}$ represent the useful thermal power and the solar power incident on the absorber tube and cavity walls, respectively. Simulations are performed in COMSOL under identical operating conditions with systematic variation of the non-dimensional pitch.

3. Results and Discussion

The variation of thermal efficiency with non-dimensional pitch is shown in Fig. 2.

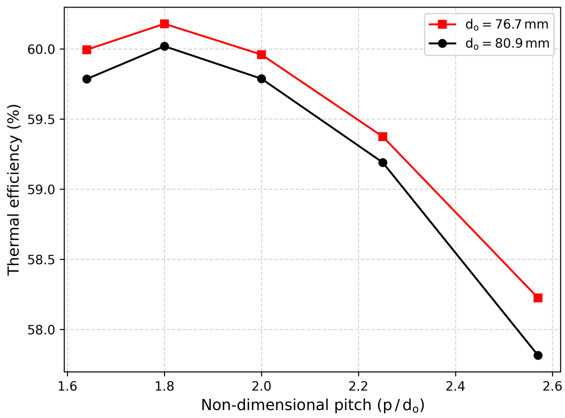
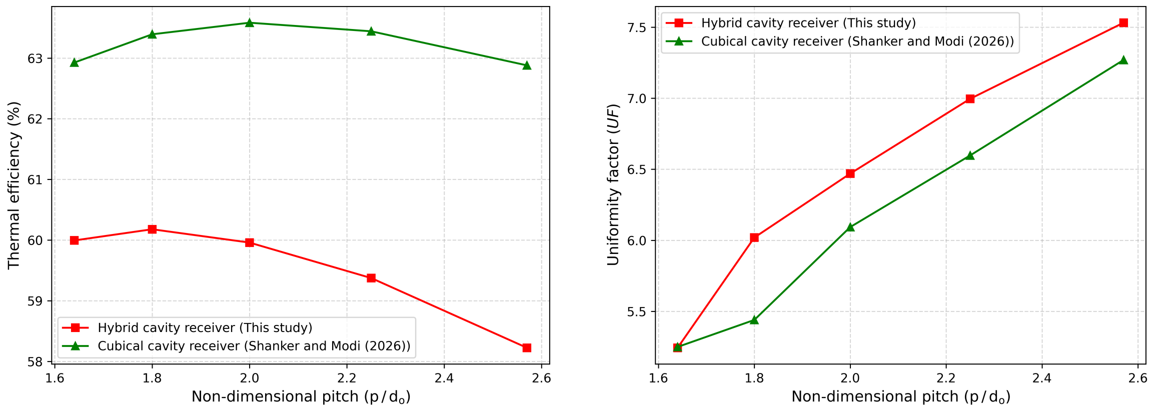


Fig. 2: Effect of non-dimensional pitch on thermal efficiency of the hybrid cavity receiver for different tube diameters (d_o).

The higher efficiency is observed for the smaller tube diameter for the entire range of the non-dimensional pitch studied. Thermal efficiency increases with pitch up to an optimal value of approximately 1.8, beyond which it decreases.

This behaviour is attributed to the trade-off between thermal and optical losses, which results in an optimal non-dimensional pitch of approximately 1.8. In contrast, the cubical cavity achieves optimal performance at a higher non-dimensional pitch of approximately 2 (Shanker and Modi, 2026), as shown in Fig. 3a. Overall, the cubical cavity receiver exhibits superior thermal performance compared to the hybrid cavity.

Despite this, the hybrid cavity demonstrates improved flux uniformity across most configurations (Fig. 3b) due to enhanced redistribution of incident radiation by its curved surfaces. An exception is observed at a non-dimensional pitch of 1.65, where both configurations exhibit similar flux distribution. This is attributed to minimal exposure of the cavity walls at this pitch, resulting in a negligible contribution to flux redistribution.



(a) **(b)**

Fig. 3: Comparison of cavity geometries (d_o = 76.7 mm): (a) thermal efficiency and (b) flux uniformity

Overall, the hybrid cavity receiver offers better, more uniform flux distribution, however the thermal performance of the hybrid cavity is inferior to that of the cubical cavity. The cubical geometry provides better confinement of radiation, resulting in lower total heat losses and higher efficiency.

These results highlight a fundamental trade-off between flux uniformity and thermal efficiency in cavity receiver design.

4. References

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