Proceedings of the 18th UK Heat Transfer Conference

9-11 September 2024, Birmingham

UKHTC2024-059

STUDY OF NATURAL CONVECTION OVER VERTICAL AND INCLINED FIN ARRAYS

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1. ABSTRACT

Rectangular fins play a crucial role in many cooling applications, particularly in the realm of electronics, mechanical, and solar applications. This study focusses on the conjugate heat transfer analysis of natural convection over arrays of parallel fins attached to either vertical or inclined heated surfaces. This arrangement is relevant to the passive cooling of PV cells. The objective is to first validate the numerical method using experimental data for vertical arrays and then to apply the resulting methodology to the investigation of the effect of the angle of inclination.

2. INTRODUCTION

Photovoltaic (PV) panels, also known as solar panels, are widely utilized to convert solar energy into electrical power. However, their efficiency and operating life are significantly affected by their operating temperature, which tends to rise during prolonged exposure to sunlight. Elevated temperatures can lead to decreased performance and reduced lifespan of PV panels. Therefore, effective cooling strategies are essential to maintain optimal operating conditions and enhance energy conversion efficiency.

One promising method to mitigate temperature rise in PV panels is the implementation of passive cooling techniques, such as fins into the panel design. Fins are extended surfaces attached to the underside of the PV panel, which enhance heat transfer from the lower surface of the panel to the surroundings, through increased surface area.

This research aims to investigate the impact of inclination angle on the effectiveness of fin-based cooling for PV panels. Inclination angle refers to the angle of the panel relative to the vertical plane and plays a crucial role in solar energy capture. By altering the inclination angle, researchers can assess its influence on the fin cooling process and the operational temperature of the PV panel.

Understanding how inclination angle affects cooling is vital for optimizing the design of PV systems in different geographical locations and climates and informing the development of more efficient cooling strategies, ultimately enhancing the performance and longevity of solar energy systems.

3. METHODOLOGY

The numerical modelling has been carried our using the finite-volume computational fluid dynamics code, StarCCM+. It involves the numerical solution of the momentum and enthalpy transport equations through the finite volume approach, under laminar conditions. The pressure field is obtained through the SIMPLE algorithm, which enforces local mass conservation. The effects of buoyancy are included through the Boussinesq approximation, which involves the use of temperature-independent fluid properties. The mesh also extents to the

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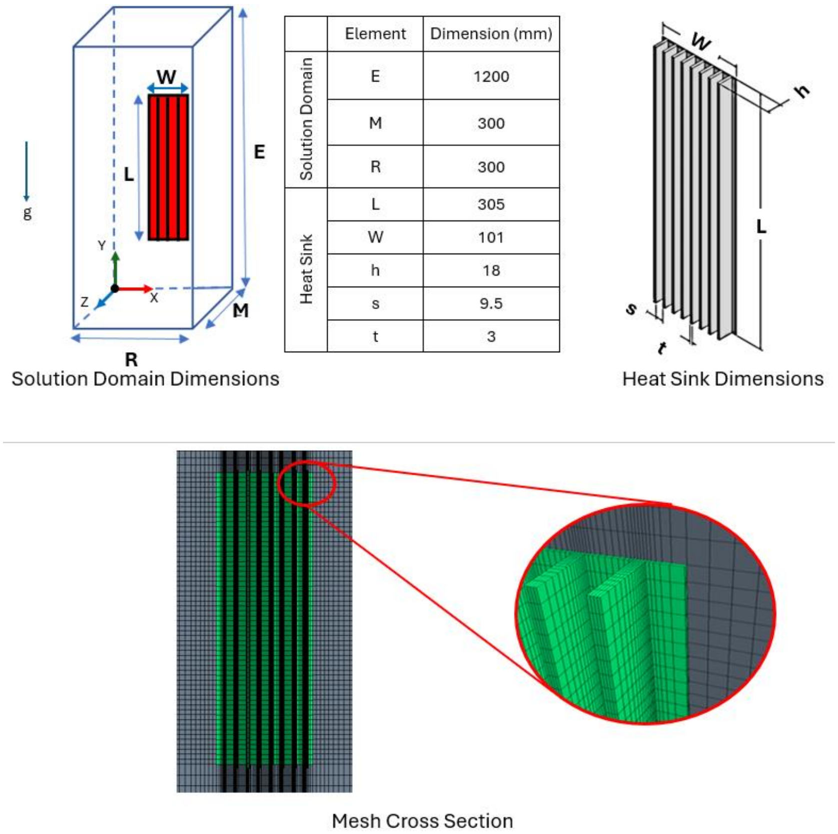
solid regions of the fin array and its base. The heat convection equation is then solved over the solid regions, with uniform wall heat flux thermal boundary conditions at the back of the base of the array, shown in Figure 1. The size of the solution domain is 1.2 m by 0.3 m by 0.3 m in the vertical, lateral (parallel to the heated wall) and wall-normal directions, respectively. A cartesian mesh has been used over the solution domain, as shown in Figure 1. Several mesh sizes were tested, ranging from 2.1×10^5 to 2.6×10^6 nodes. After 1.2×10^6 nodes, there was not a significant change in the measured parameters. The maximum error in temperature between measurements with 1.2×10^6 nodes and 2.6×10^6 nodes was less than 0.3%, indicating convergence of the outcomes beyond this mesh size. Therefore, the mesh size with 1.2×10^6 nodes was chosen to carry out all the simulations. For the two vertical boundary planes on the left- and right-hand sides of the flow domain, symmetry boundary conditions have been imposed. The flow boundary conditions for the upper and lower boundary planes and for the vertical plane opposite to the heated surface are set as pressure outlets, which allow air to flow in and out of the domain based on the prevailing conditions inside. For the thermal field ambient temperature boundary conditions are imposed. Several orientations have been simulated by changing the gravitational vector angle. These orientations were (0°, ±30°, ±60°, ±75°, and ±90°), where zero degrees represents the vertical case. Positive angles represent the finned side facing upwards, and negative angles represent cases with the finned side facing downwards.



	Element	Dimension (mm)
Solution Domain	E	1200
	M	300
	R	300
Heat Sink	L	305
	W	101
	h	18
	s	9.5
	t	3

Fig. 1 The dimensions of the fluid and solid domains and the mesh used in the numerical simulation.

4. RESULTS

First, the code is validated through comparisons of the current predictions for of a vertical heated plate cooled by a fin array, with experimental measurements [1] and empirical equations [2]. The resulting comparisons between the numerical simulations and experimental data, shown in Figure 2(a), demonstrate that for the vertical orientation, over a range of heating rates, there is close agreement between the predicted and measured average surface temperatures. The same comparison is also presented in Figure 2(b) in dimensionless form, indicating a range of modified Rayleigh number from $1x10^{10}$ to $3x10^{10}$.

For the other orientations ($\pm 30°, \pm 60°, \pm 75°, and\ \pm 90°$), detailed comparisons have also been carried out. This includes temperature and velocity field contours, Nusselt number calculations, representations of velocity vectors, and comparison of surface temperatures, as presented in Figure 3, which reveals that for angles even as large as -60° and +60° to the vertical, there is very little change in surface temperature for a given heating rate. Additionally, the downward-facing horizontal orientation (angle of -90°) demonstrates higher temperatures due to the greater accumulation of hot air over the surface and the consequent decreased heat transfer rate due to low temperature difference. This could be enhanced by extending the height of the fins.

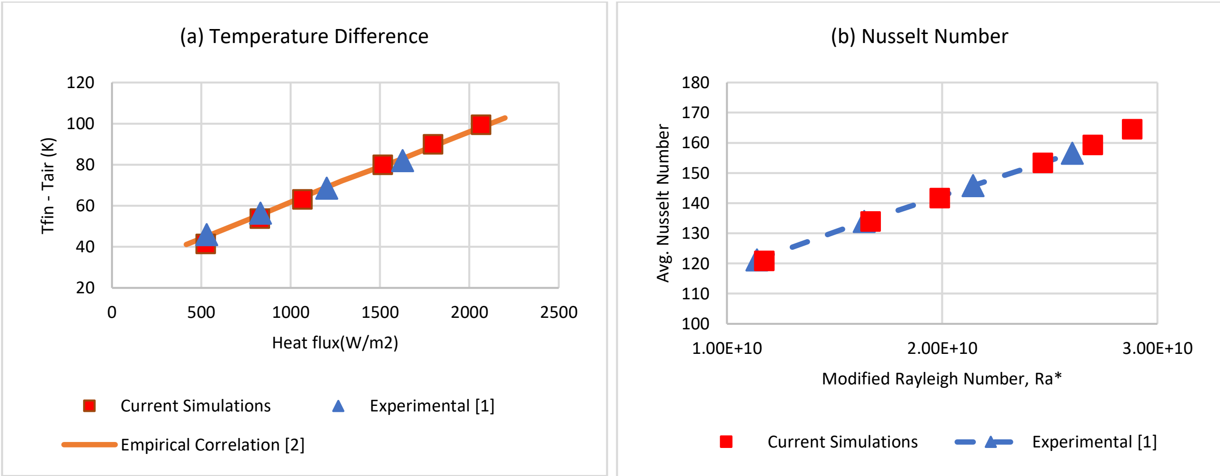


Fig. 2 Vertical plate orientation comparisons between the predicted, measured and empirical variations of surface temperature with heating rate (a) Temperature difference (b) Nusselt number.

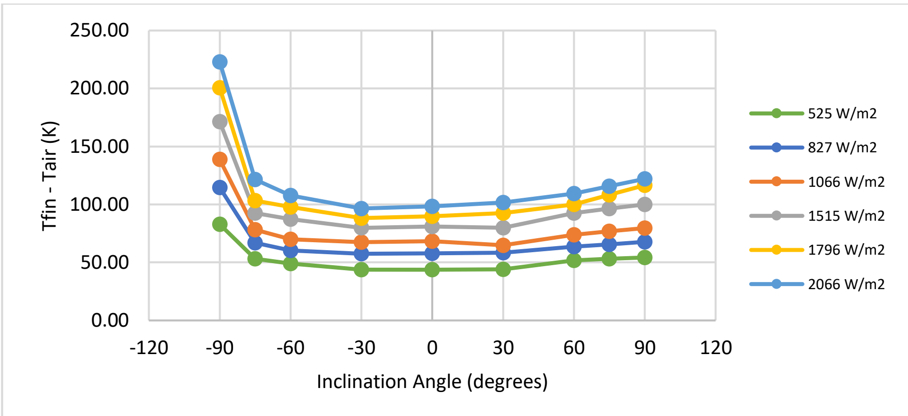


Fig. 3 Predicted variations of surface temperature with heating rate and orientation. An angle of 0° denotes the vertical orientation.

5. CONCLUSIONS

In conclusion, this study first demonstrates the validity of CFD for the computation of laminar natural convection from a vertical fin array, and then extensively examines the impact of the inclination angle, through consideration of the angle effect on a variety of flow and thermal parameters. While, as expected, the vertical configuration (θ= 0°) results in the strongest heat transfer, and hence lower surface temperature, for a wide range of angles, the reduction of heat transfer with angle remains modest, which is very significant for solar panel cooling arrangements. In the full presentation, a wider range or comparisons will be presented, which provide further insights to the physical processed present and their effects on the thermal characteristics.

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