

Temperature distribution on inclined roof-mounted PV modules under free convection conditions: A numerical study

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1. INTRODUCTION

With the rise in urban temperatures and the growing use of photovoltaic (PV) modules on residential rooftops, these systems are increasingly exposed to high thermal conditions. Previous studies indicate that rooftop PV module temperatures can often exceed 70 °C. Such elevated temperatures not only contribute to the warming of the urban microclimate but also reduce the lifespan and electrical efficiency of the PV modules.

The aim of this study is to evaluate the interaction between airflow and heat transfer on the upper and lower surfaces of roof-mounted PV modules installed at various roof pitches (slopes) – specifically 10°, 22.5°, and 45° – which are typical in urban areas depending on latitude. The analysis focuses on natural convection under no-wind conditions, where the module temperature is expected to reach its maximum.

2. APPROACH

A computational fluid dynamics (CFD) model was developed in ANSYS Fluent 2024 R2, following the methodology described by [1]. The computational domain was defined as a cylindrical volume with a radius of 40 m and a height of 40 m. A building was positioned at the center of the domain, with dimensions of 5 m in height, 16 m in width, and 7 m in depth. The roof slope was set to either 45°, 22.5°, and 10° to horizontal, representing typical configurations for residential buildings in Australia, see, e.g., [2]. The photovoltaic (PV) module was mounted 10 cm above the roof surface, with a 3–4 cm margin from the roof edges. A schematic of the computational domain is presented below.

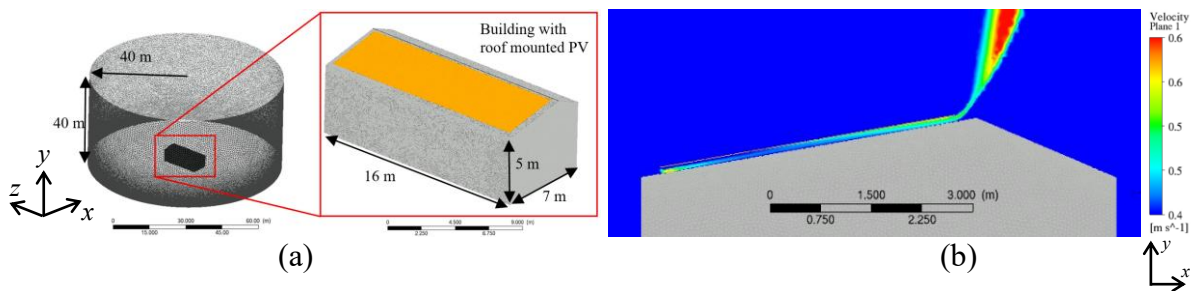


Figure 1. (a) Computational domain with mid-plane shown. (b) Velocity distribution at mid-plane.

The solver was configured using the ideal gas assumption to account for buoyancy effects. A surface-to-surface radiation model was applied, with the emissivity of both the PV module and the roof set to 0.9. The sky temperature was specified as 0 °C to represent radiative heat loss to the sky. A constant heat flux of 800 W/m² was imposed on the PV surface, corresponding to a typical solar irradiance on a clear summer day. The ambient temperature was set to 20 °C. The Shear Stress Transport (SST) turbulence model was employed, with simulations being performed under steady-state as well as unsteady conditions. Mesh convergence has been undertaken with 2% error relative to coarse mesh; 3cm mesh sizing on PV module and 5cm on roof was adopted.

2. RESULTS

Table 1 presents the temperature distribution on the surface of the PV module. The temperature variation ranges from 3°C to 4.8°C, depending on the roof slope. For more horizontal roof configurations, the buoyancy force in the channel between the PV module and the roof is reduced, resulting in higher PV module temperatures – consistent with the findings reported in [3].

Roof Slope	10°	23°	45°
Average PV temperature	64.8 °C	63.7 °C	62.5 °C
Maximum PV temperature	69.6 °C	67.5 °C	65.4 °C

Table 1. Area integrated temperature on the surface of the PV module.

As shown in Figure 2, the surface temperature of the PV module is non-uniform. Lower temperatures are observed near the inlet to the gap between the PV module and the roof compared to the rest of the module. This effect results in noticeable temperature variations, particularly at lower roof slopes, where localized hot spots are evident, as illustrated in Figure 2(a).

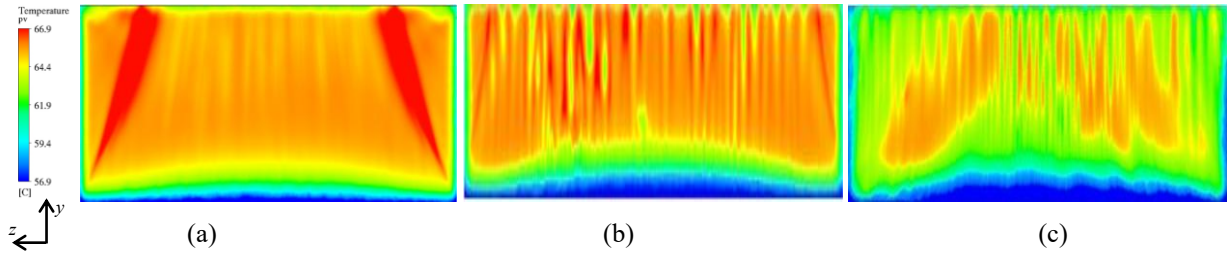


Figure 2. Instantaneous temperature of the module for roof slopes (a) 10°; (b) 22.5°; (c) 45°. (Not to scale.)

Additionally, the temperature contours shown in Figure 2 suggest the formation of streaks parallel to the flow, approximately 10% downstream from the inlet along the lower side of the module. These streaks may be attributed to instabilities in the external natural convection boundary layer adjacent to the isoflux surface, consistent with previous observations (e.g., [4]). The behaviour of the streaks varies with the roof slope.

4. CONCLUSIONS

Complex variations in the temperature distribution on the surface of the PV module were observed for the case of a single module mounted on the roof, with temperature differences of up to 5°C. Further investigation is required to evaluate the influence of module spacing and wind effects.

ACKNOWLEDGEMENTS

This research includes computations using the computational cluster Katana supported by Research Technology Services at UNSW Sydney.

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