Thermal performance of unglazed roof-mounted solar thermal collectors

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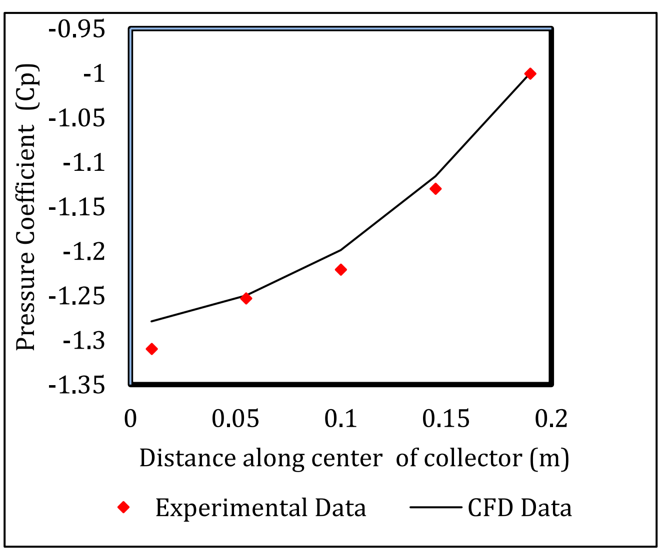
1. INTRODUCTION

Unglazed solar collectors, consist of absorbers of embedded channels where the fluid circulates without any covering material. Due to this, they are noted for very high heat losses, primarily, induced by high convective heat loss and radiant heat transfer to the surrounding. The magnitude of these losses has led to unglazed collectors been relegated to low-temperature applications. Primarily, linearity exists between the local wind velocity and the wind-induced convective heat transfer coefficient, evident in the Hottel Whillier-Bliss equation correlations (Duffie, Beckman, and McGowan 1985; Hottel and Whillier 1958) used in evaluating collector useful energy. Nonetheless, as solar collectors are largely roof-mounted, conventional literature has tended to focus on the effect of wind on the support structure of collectors (Kopp, Farquhar, and Morrison 2012; Maffei et al. 2014), as opposed to energy yield. Other literature related to wind loads on roofs, however, show parapets; a common architectural element on roofs can mitigate wind loads by influencing wind velocity (Browne et al. 2013; Mans, Kopp, and Surry 2005; Stathopoulos and Baskaran 1987)

2. APPROACH

In this work, an investigation of the convective heat transfer from an unglazed collector was carried out using numerical simulations, validated by experimental work. The numerical simulations were conducted using a 3D Reynolds-Averaged Navier-Stokes (RANS) Computational Fluid Dynamics (CFD) software (ANSYS 2019). Experiments were carried out in the atmospheric boundary-layer wind tunnel of the University of Auckland on a model scale of 1:20. The length scale of 1:20 was chosen so as to properly model the parapets and collector as well as to measure the wind presssure on the respective surfaces. The wind pressure coefficient was determined from several pressure tapping points on the model, after which results were compared with the pressure coefficient at the same location on the simulated model. The validation showed a good agreement between the experiment and numerical simulations in terms of the pressure coefficient distribution on the collector and parapet surface as shown in Figure 1.0.



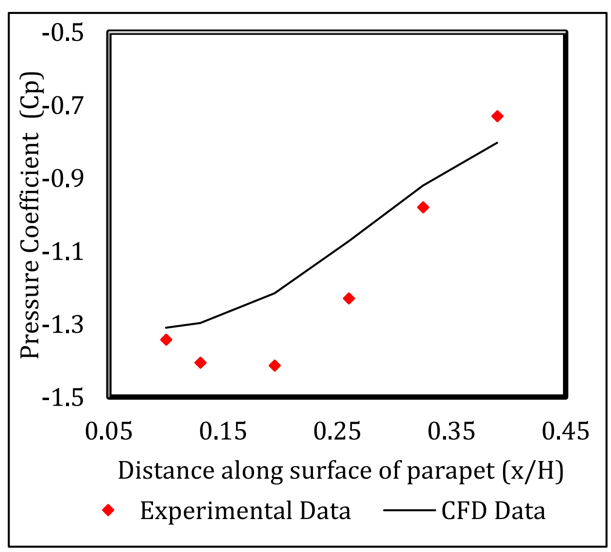


Figure 1.0: Comparison of experimental and numerical data for low parapet (h/(H+h)≤ 0.09) at 5m/s.

3. RESULTS

To determine the effect of the parapets in minimising velocity, two perimetric; low (h/(H+h)≤ 0.09) and high (h/(H+h) ≥ 0.23) parapets (where h is the parapet height and H is the building height) (Kopp, Mans, and Surry 2005), were considered at varying wind velocity of 2m/s to 10m/s, and wind incidence of (0º, 45º). The effect of the change in aspect ratio and Reynolds number on the average Nusselt number was determined. It is found that, the local wind velocity around the collector is influenced mainly by the parapet height. The parapets result in the creation of a shallow cavity, characterised by streamline plots which show the generation of a recirculation bubble upstream of the collector, as seen in Figure 2.0.

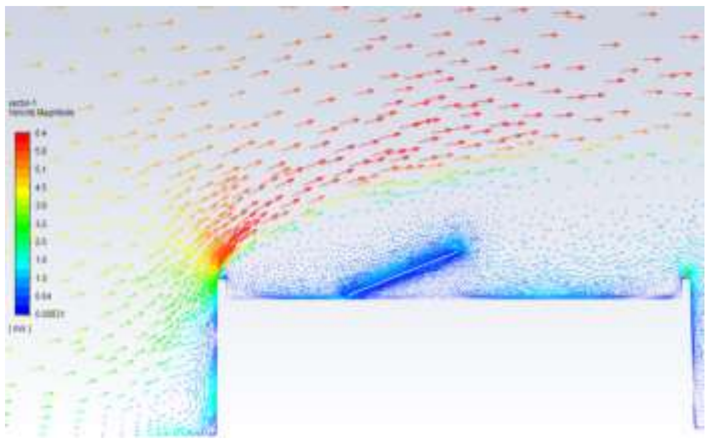


Figure 2.0: Flow visualisation around roof mounted collector with perimetric parapet.

As shown in Figure 3.0, the average Nusselt number on the collector also increases uniformly with the Reynolds number. Thus, an increase in wind velocity resulted in increased convective heat loss; similar to an observation reported by Soltau (1992). Regarding the aspect ratio, a third scenario of a flat roof with no parapet was considered. The aspect ratio was determined from the relation (L/h) where L is the length of the cavity of the roof and h the height of the parapet. For the flat roof, the aspect ratio was defined at infinity (∞). Evidently, the Nusselt number decreases at a lower aspect ratio irrespective of wind incidence (Figure 3 and 4). This is primarily due to vortices created behind the parapets at higher heights ; consistent with that reported for shallow cavities by Mesalhy, Abdel Aziz, and El-Sayed (2010).

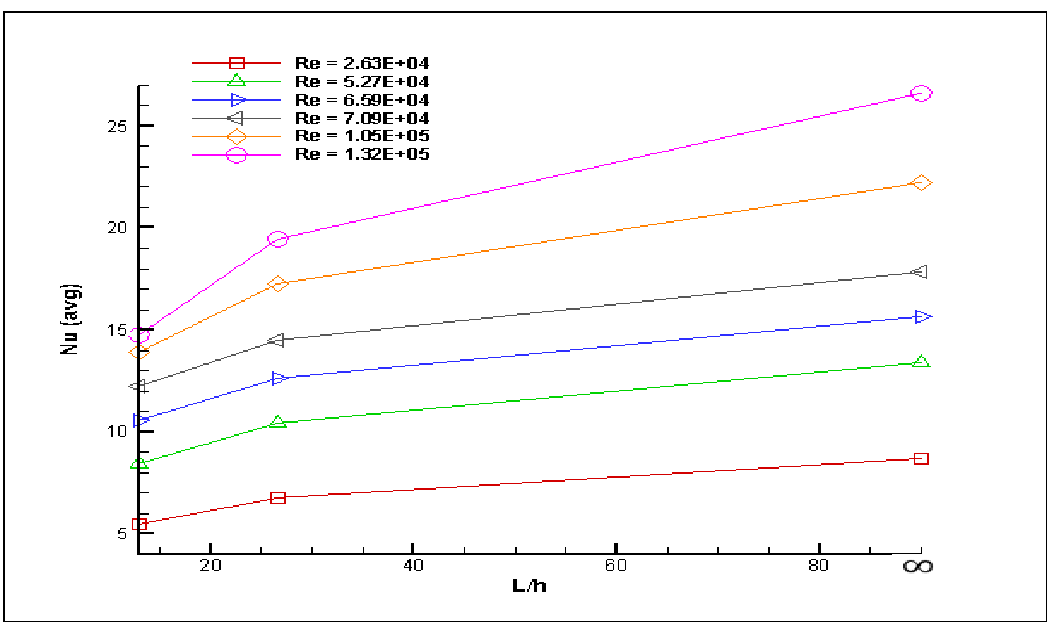


Figure 3.0: Effect of changing aspect ratio on average Nusselt number at 0 wind incidence

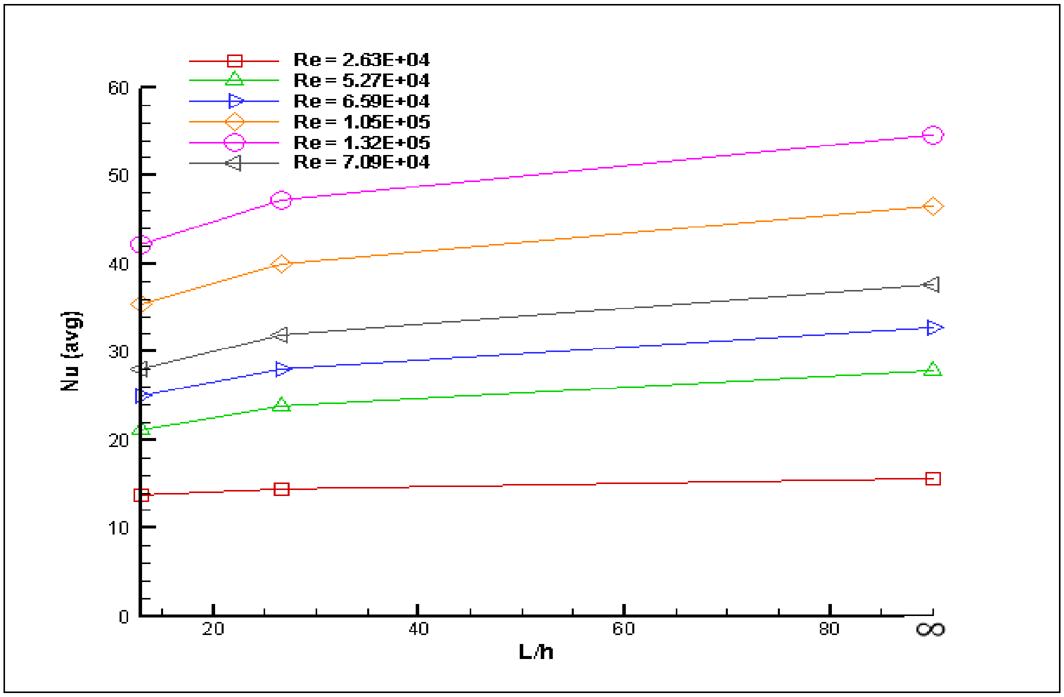


Figure 4.0 : Effect of changing aspect ratio on average Nusselt number at 45º wind incidence

Since collectors are installed to face different geographical locations based on latitude, the impact of the directional dependence of wind flow speeds over roof-mounted collectors is significant. Accordingly, the Reynolds number at varying wind incidence angles were determined. As shown in Figure 5.0, with a change in wind incidence, there is an increase in Nusselt number for the same aspect ratio. This is due to the flow separation that occurs at the windward and leeward face of the collector simultaneously.Given the above, it is worth noting that perimetric parapets can significantly reduce heat loss of unglazed solar thermal collector, thus improving performance and their use in other large scale applications.

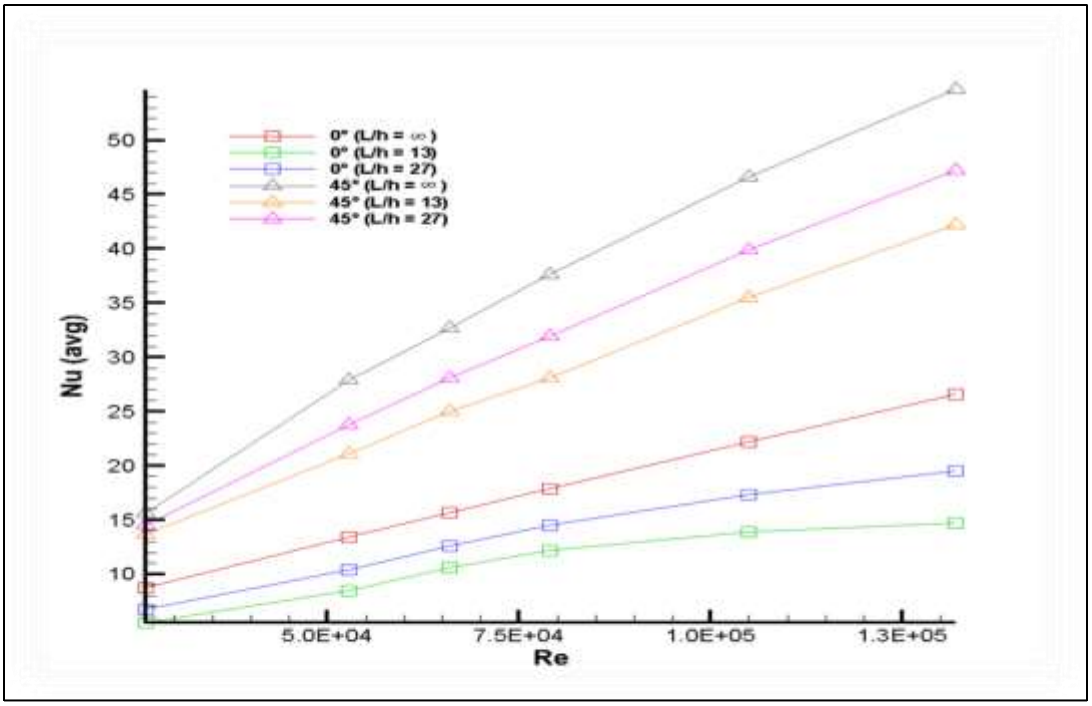


Figure 5.0: Effect of change Nusselt number at varying wind incidence angles .

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