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The Effect of Parapets on Roof Mounted Solar Collectors

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Abstract

Wind-driven heat transfer accounts for a major portion of solar collector losses and is significantly influenced by local structures and geometry. Parapets are an extension of a wall at the edge of a roof or other building structure. Traditionally, they have served multiple purposes; as safety features to prevent falls from elevated walkways or roofs, as defensive structures in castles and, as architectural features that create the illusion of an aesthetically pleasing flat roof. More recently, they have been the subject of discussion as to their impact on the aerodynamic loading of roof structures. In this vein, several studies have shown that parapets can make a significant impact on the wind loads experienced by roof structures. Hence as solar collectors, both thermal and photovoltaic, become more prevalent in the built environment, there is a need to understand how parapet structures impact their performance.

In this study, the wind flow over an isolated low-rise flat-roof building was modelled using computational fluid dynamics. The aerodynamic loads on the roof were compared to experimental data to validate the simulation method. Subsequently, roof-mounted solar collectors, with tilt angles between 20°to 40°, and perimetric parapets, with heights between 0.4 and 1.2m, were added to the building. The results showed that the parapet height had a significant impact on the local wind velocity on the surface of solar collectors. From this, it is apparent that parapet structures can serve as windbreaks to reduce air movement over solar collectors and to potentially reduce the wind-driven heat loss from solar thermal collectors.

1. Introduction

As the solar renewable technology industry expands, there is an increasing demand for high energy yield. And climatic conditions amongst other factors are significant in determining energy yield. Aside from solar irradiance, ambient temperature and equivalent sun hours, wind speed is considered to have a major effect with regards to the thermal performance of solar thermal collectors and photovoltaic modules. For example, the poor thermal performance of unglazed solar collectors, linked to wind-induced heat loss is cited as a major setback although its economic potential is well documented (Molineaux, Lachal, & Guisan, 1994). Thus, wind-induced heat losses are detrimental to the performance of solar collectors whiles the opposite is the case with photovoltaic panels. As reported in (Mathew et al., 2018; Schwingshackl et al., 2013) the efficiency of photovoltaic panels reduce as their temperature increase.

Over the last decades, several studies have examined the possibility of improving these solar technologies, with the core objective of maximising energy yield at a minimal cost. Within that pool, some studies have investigated the prospects of architectural integration, colour, material, fluids, and cooling. Studies related to minimising the natural effect of wind, have however been limited to mitigating extreme wind pressures on structural support systems as opposed to performance. As most solar technologies are often mounted on roof surfaces, one of the most cost-effective options to enhance efficiency would be to regulate the effect of wind. Very little has however been done in this regard.

That said, considerable research has been carried out, primarily, on the effect of wind pressure probability distributions on roofs. Such studies have tended to demonstrate strongly that, parapets; a common architectural element on roofs can mitigate wind loads by influencing wind velocity at varying heights and configurations (Baskaran & Stathopoulos, 1988), (Surry & Lin, 1995)(Browne, Gibbons, Gamble, & Galsworthy, 2013; Kopp, Mans, & Surry, 2005b; Mans, Kopp, & Surry, 2005). Thus, attention in this area has been on the aerodynamic loads on the roof, and not the effect of local wind speeds on collectors.

Given the focus on the effect of parapets on roof loading, very few studies have explored their impact on roof-mounted collectors, particularly given that these are becoming more common. This present study is aimed at understanding the effect of parapets on the surface wind velocity of stand-alone solar collectors placed on low rise buildings.

2. Method

For this study, the aerodynamics around a solar collector mounted on a low rise building with a perimetric parapet was investigated using a commercial CFD code, ANSYS Fluent v.19.1.The height and width of the building were specified as 4 m and 16m respectively; representing a building height to a width aspect ratio of 1:4. This ratio was chosen, as previous experimental studies had been conducted on of a building with the same dimensions.

To model the flow around the building, a computational domain was created following best practice guidelines proposed by (Bert Blocken, Stathopoulos, Carmeliet, & Hensen, 2011), (Franke, Hellsten, Schlünzen, & Carissimo, 2007), as shown in Figure 1. The nominal height (H) of the building was used in the sizing of the domain, where H was measured from the base of the building to the leading edge of the collector. The upstream length of the computational domain was specified as 5H. This consideration was made to ensure a blockage ratio of less than 3 as stipulated in best practise guidelines. Lateral distance from the building was specified as 5H on both sides with a distance of 15H downstream of the building.

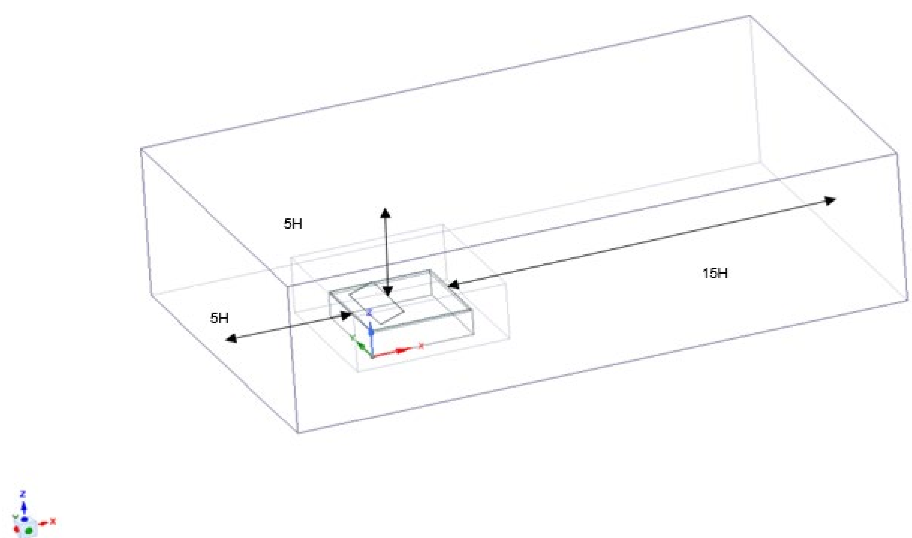


Figure 1: Computational domain with building, parapet and solar collector

To capture the flow details around the collector and roof surface, different mesh densities were specified near the collector and in the far-field. The initial enclosure around the building had a mesh resolution of 0.3 m while 0.5 m was specified throughout the rest of the computational domain. A mesh resolution of 0.05 m was specified for the collector. A mesh independence study was carried out and showed no significant variation in results. The final mesh statistics for all cases simulated were in the range of 4 to 5 million cells, with skewness less than 0.85 and orthogonal quality greater than 0.1.

On this basis, simulations were carried out for different scenarios; a standalone solar collector mounted on the flat roof of a low rise building without parapets, and, a standalone solar collector mounted on a low rise building with parapet heights of 0.4 and 1.2 respectively. These parapet heights were chosen to represent lower perimetric parapets ($h/(H+h) \leq 0.09$) and high perimetric parapets ($h/(H+h) \geq 0.23$), as documented elsewhere (Kopp, Mans, & Surry, 2005a).

Additionally, the parapets were modelled as 0.3m wide, as studies have shown parapets wider than 0.2m have no effect on wind loads (Baskaran & Stathopoulos, 1988). The collectors were assumed to be mounted 2 m from the edge of the building, with collector inclination angles between 20º to 40º. In conformance with good practice, a gap of 0.2 m was specified between the collectors leading edge and the roof surface.

To resolve the flow field, the realizable k-ε turbulence model was specified for the closure of the transport equation. This was chosen as it has shown to be adequate for the calculation of the mean wind speed upstream of building facades (Blocken, Defraeye, Derome, & Carmeliet, 2009). For the pressure-velocity coupling, the SIMPLE algorithm scheme was specified. Pressure interpolation in second-order and second-order discretisation schemes was specified for both the convection and the viscous terms of the governing equations. The solution was initialised by the values of the inlet boundary conditions, specified as a velocity inlet. The chosen convergence criterion was specified so that the residuals decrease to 10^{-5} for all the equations. Thus, the solution was considered converged when all the scaled residuals levelled off and reached a minimum of 10^{-5}. For the inlet boundary conditions, a velocity range of 2m/s to 10m/s was imposed. These values were specified based on the performance range of collectors at varying velocities as reported by (Soltau, 1992). However, for brevities sake, only the results from the free stream velocity of 6m/s are presented in this study. Finally, the bottom boundary was set as a non-slip wall, while the top and lateral boundary conditions were modelled as symmetry conditions.

3. Validation of the CFD Model

To validate the results of the simulation, the loads on the building without parapets or collectors was compared to work performed at the Tokyo Polytechnic University (TPU). In this respect, the pressure coefficients from this simulation were compared with the in-situ wind tunnel tests from Tamura (2012).

Because the building geometry in this work is the same as that used in the wind tunnel experimental work, a wind incidence approach of 45° was selected for validation. Figure 3.0 presents the mean pressure coefficients plots of the flat roof of a low rise building from the TPU aerodynamic database and the current CFD model. It was found that the CFD simulation was consistent with the results of the TPU database, thus providing a validation of the method.

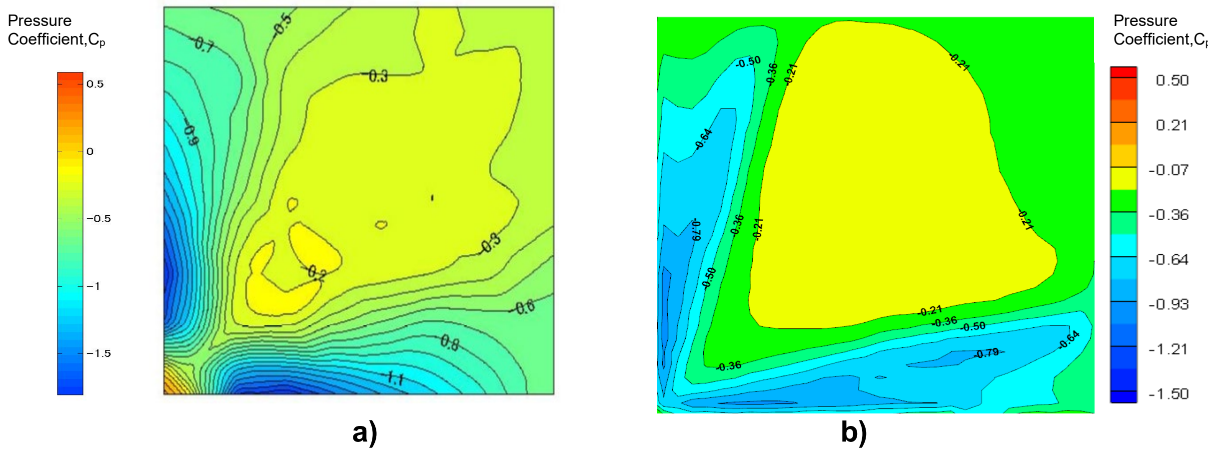


Figure 2: Mean wind pressure coefficients contour for a 45º wind direction: (a) the TPU aerodynamic database and (b) Results of the present CFD model

4. Results and Discussion

4.1 *Wind incidence and Parapet Height*

Having established the validity of the CFD method, Figure 3 shows the effect of wind on the collector surface (along the midplane of the simulation domain) expressed as contours of magnitude velocity for three scenarios i.e.; no parapet, a low and a high perimetric parapet. From this, the most striking observation that can be made from the contours is the fact that the wind velocity changes significantly with increasing parapet height. Specifically, a significant reduction in wind velocity occurs over the surface of the collector at higher perimetric parapet heights. One of the plausible reasons for this observation is the occurrence of flow separation at the edge of the parapet.

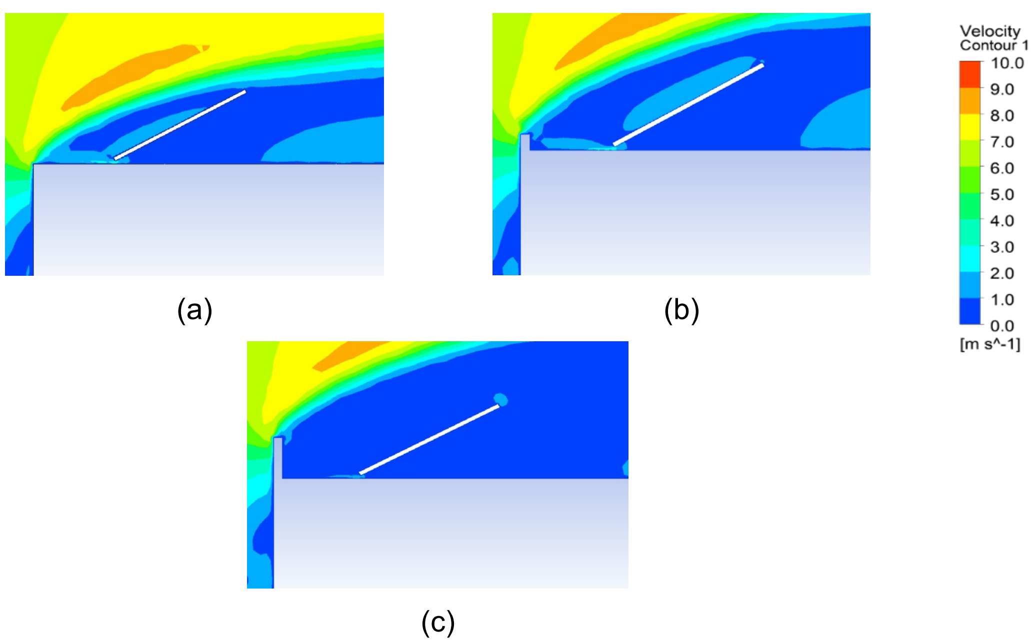
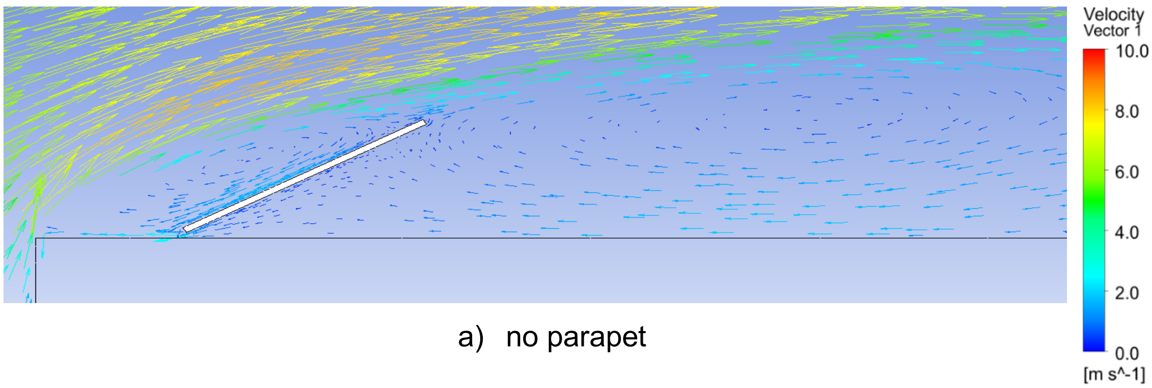
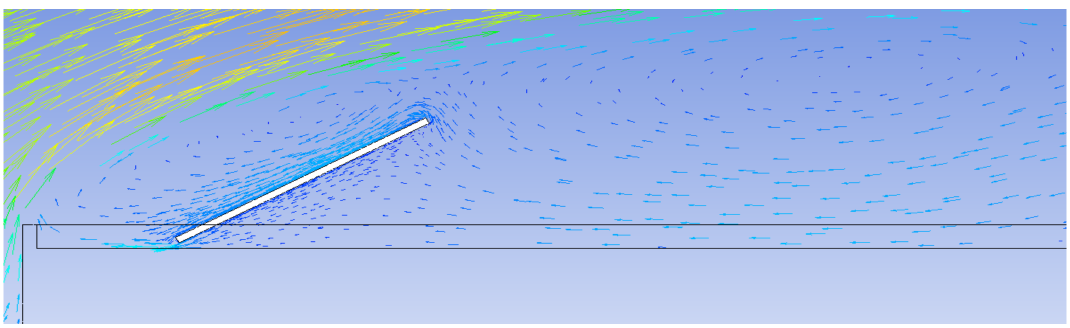


Figure 3: Velocity contours for a) no parapet b) 0.4m parapet and c) 1.2m parapet

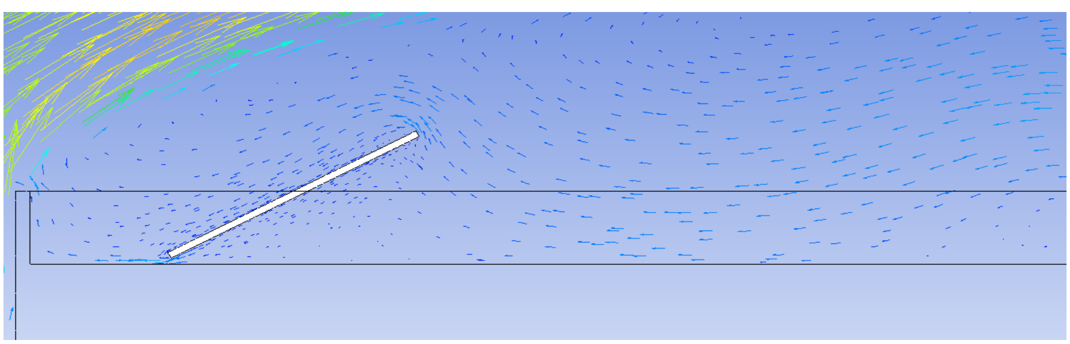
The velocity fields in Figure 3 provide a good qualitative representation of the mean velocity field over the panel. To obtain a better assessment of the flow behaviour and its variation on and around the collector, the velocity vectors are shown in Figure 4. Evidently, one can see a stagnation region on the surface of the collector, upstream of the roof. Whilst this is the case for the roof with no parapet, it appears this is more pronounced for the lower perimetric parapet. This observation is consistent with studies such as (Stathopoulos, Marathe, & Wu, 1999)(Baskaran & Stathopoulos, 1988) which have found that roof corner suctions increase significantly when parapets lower than 0.9 m high are applied to buildings. For the higher parapet, it appears the velocity is significantly reduced on the roof surface as there is little flow. This can be attributed to the fact that the aerodynamic jump at the eaves of the building, which typically favours the appearance of separation bubbles, is reduced at higher parapet heights.



a) no parapet



b) 0.4 m parapet



c) 1.2 m parapet

Figure 4: Velocity vectors for varying parapet heights

Moreover, the collector has a gap between its leading edge and the roof surface. These gaps serve as a pass-through for flow underneath the collectors to prevent a pressure differential on the surface and underneath the collector. Thus, they result in the bifurcation of flow at the leading edge of the collector, allowing for flow through the narrow gap between the underside of the collector and the roof of the building. The significance of such gaps in the structural support system of roof-mounted collectors is widely reported.

In instances where parapets have been added to buildings, Figure 4, shows a reduction in velocity and flow within the gap. A plausible explanation for this is the fact that as the flow approaches the collector for the building without a parapet, a resistance to flow due to the inclined projection of the collector is created. Consequently, this causes the flow to pass through the path of least resistance underneath the collector. For buildings with parapets, the leading edge of the collector is somewhat shielded, again, the flow tends to go through the path of least resistance at the leading edge of the collector. The presence of the parapet however present a region of stagnation around the leading edge.

4.2 *Effect of Collector Inclination Angle and Parapet Height*

Often, collectors are installed at angles of inclination equal to the latitude of the location. Several studies have investigated the drag and lift forces produced on such incline planes. For roof-mounted collectors, the inclination is also dictated by constraints associated with the building in line with the need to harness the best energy from the sun.

Figures 5 and 6, show the effect of varying perimetric parapet heights on the flow at different collector inclination angles. As shown in the figures, the change in velocity follows the same pattern for increments in parapet height. Low-velocity flow on the surface of the collector is observed in all cases upstream of the roof. This observation is consistent with the inference made in section 4.1. Concerning the change in inclination, however, the aerodynamic jump from the building eaves and parapet impinge directly on the trailing edge of the 40º inclined collector. This is because the collector‘s trailing edge is higher due to its inclination angle. This observation is also consistent with the anticipated interaction of vortices of separated flow along roof edges with inclined collectors reported in other studies.

Moreover, it is necessary to note that when the flow approaches the collector in all cases, its inclination induces a vertical component which reduces a fraction of the velocity. And this is even more pronounced in the 40º inclined collector, given its significant upward tilt. Finally from , for the roof without a parapet, see Figure 6a, there is an increased wind force on the surface of the collector. The flow separation from the edge of the building impinges on the collector at its leading edge, maintaining a higher wind velocity on the collectors surface. The above observation is, however, not the case for the collector with a 20º angle of tilt without the parapet.

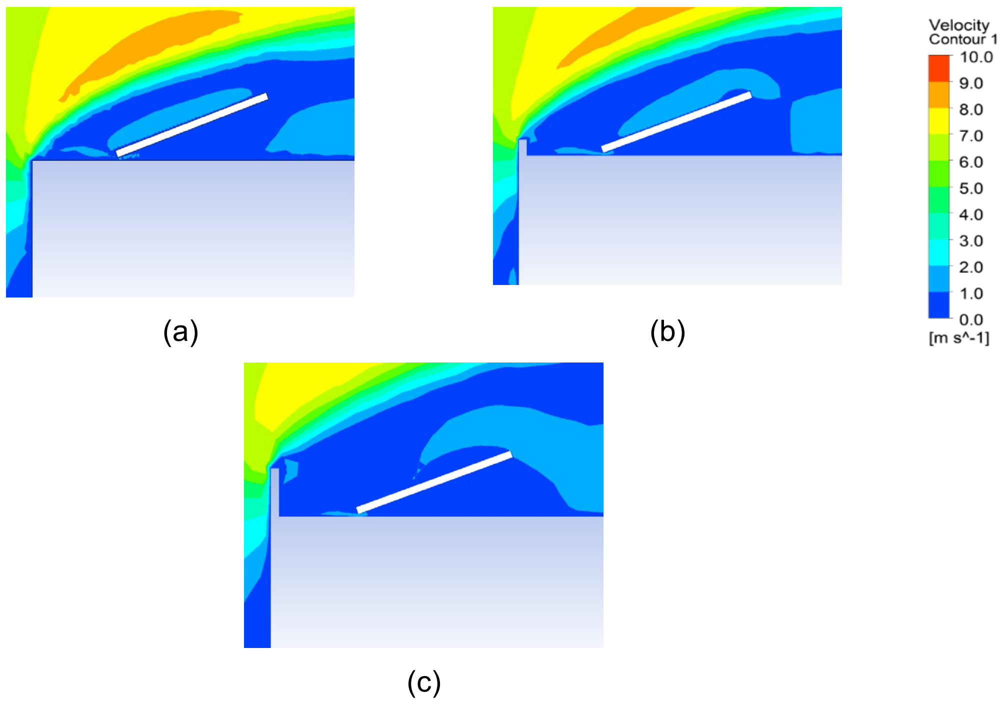


Figure 5: Flow over a collector at 20º inclination for a) no parapet b) 0.4m parapet and c) 1.2m parapet

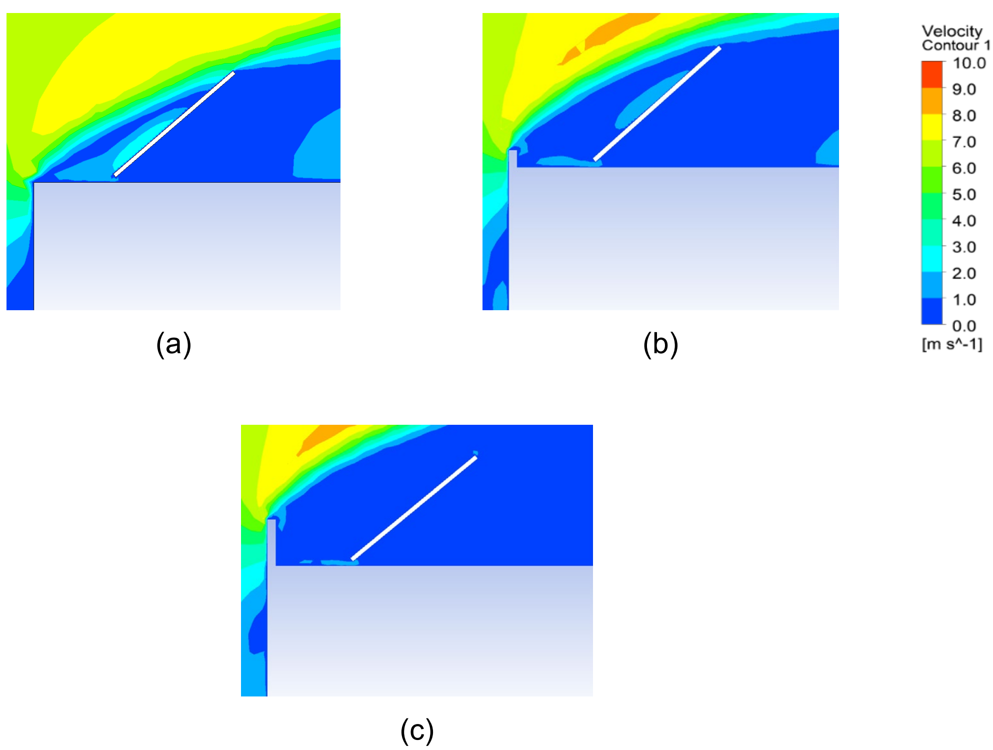


Figure 6: Flow over a collector at 40º inclination for a) no parapet b) 0.4m parapet and c) 1.2m parapet

5. Conclusion

The present study investigated the effect of the parapet on the local velocity of collector surfaces. Primarily, the study shows that wind velocity near the surface of a roof-mounted collector, which can affect the thermal performance of the collector, is reduced with an increase in parapet height. Nonetheless, the generation of higher suction pressures on the roof corner is of concern as this affect the structural support systems of the collectors.

Evidently, the placement of the collectors at certain heights above the roof surface has shown to allow for the infiltration of such flows. It would be interesting to understand how the parapet affects the performance of the collectors for different parapet heights and at varying wind incidence angles. Since the gap between the roof surface and leading edge of the collectors is pivotal in reducing the stagnation over the collector surface, it would also be worthwhile to get an understanding of the nexus between the gap, parapet height, collector local surface velocity.

Accordingly, the parapet height plays a significant role in reducing wind velocity on the surface of roof-mounted solar collectors, being that its influence is more noticeable in higher parapets.

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