The influence of building parapets on the wind induced heat loss from solar thermal and photovoltaic collectors.

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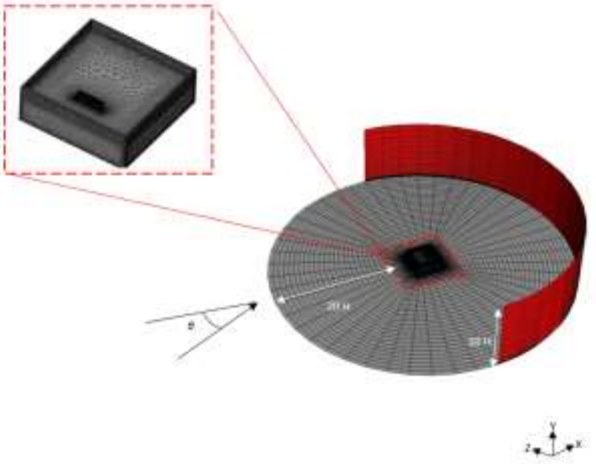
The wind has a major effect on the performance of unglazed solar thermal collectors, as well as photovoltaic (PV) devices. For unglazed solar thermal collectors, the simple steady-state correlations first proposed by [1] and modified by [2] show that wind velocity can significantly affect heat loss. Thus, given the link between the collector heat loss and useful energy yield, it can be argued that wind velocity is one of the essential determinants of the collector's performance. That said, the integration of technologies such as PV panels and solar collectors to buildings has seen considerable growth over the years. Given the fact that most of these systems are mounted on rooftops of low-rise buildings where the flow motion is characterized by distinct flow behaviour, significant research interest has been drawn to the effect of wind loads on their structural support systems. Amongst these, perimetric parapets have been shown to alter wind loads on PV structural support systems and roof-top arrays [3]. However, their effect on collector wind-induced heat loss has not been investigated in detail. Consequently, there is a need to critically examine how parapets affect the wind-induced heat loss of solar thermal collectors, considering their location relative to different parapet heights. Essentially, given that the effect of increasing wind velocity on PV panels affects performance, an understanding of the foregoing could provide a significant opportunity to advance the application of parapets as passive windbreaks that minimises wind loads while enhancing the performance of solar thermal collectors or PV panels.

In line with addressing the above, it was decided to undertake a simulation study followed by experimental validation of the method. A 3D RANS Computational Fluid Dynamic (CFD) simulation of wind flow around a roof-mounted standalone solar collector was undertaken in full scale at steady-state inlet conditions. The computational domain was modelled as circular with observance of domain dimension recommendations by the European best practice guidelines of COST Action 732 [4], Figure 1a. A mesh independence study was carried out to determine the dependence of the flow field on the refinement of the mesh. The inflow and outflow boundary conditions were specified based on equations proposed by [5] to represent the Atmospheric Boundary Layer (ABL), in $k-\varepsilon$ models. These were applied on the Fluent solver via a User-Defined Function (UDF). The k−ε turbulence model--realizable was used for the closure of the transport equation with the SIMPLE algorithm scheme set for the pressure velocity coupling. Simulations were undertaken for collector locations of 4m, 8 m and 12 m at varying collector inclinations. The height of the parapet was varied based on a proposed classification by [6]. Where $h/(H+h) \leq 0.17$ and $h/(H+h) > 0.23$ denote lower and higher parapets, respectively; h is the height of the parapet while H is the height of the building.



a. Domain boundary representation on the building and ground surfaces

b. Photograph of model and collector in a wind tunnel

Figure 1. Numerical and experimental set-up

It was then decided to validate the results through a wind tunnel experiment, Figure 1b. Experiments were undertaken at the boundary layer wind tunnel of the University of Auckland. Investigation into different test models by [7] has shown that mean wind loads do not have a pronounced effect on the model size within the geometric scale of 1:10 to 1:50. Only the high parapet was considered in this case for the validation of numerical results. To compare the results, the non-dimensional pressure coefficient $C_{pi(t)}$ at the specific tap was used. The location was determined from pressure taps fitted across the respective surfaces. Distribution of the mean pressure coefficient C_p on the collector, parapet, and roof surface for the exact location in the experiment and numerical simulation were then compared as shown in Figure 2. As can be seen in Figure 2 (a), the comparison of the data on the collector and roof surface draws a similar distribution of the pressure coefficient. Having established the validity of the simulation, analyses were undertaken for flow behaviour and wind-induced heat loss at varying parapet heights and operational conditions. For brevity, presented in this study are results for the unglazed collector without back insulation at operational conditions of β= 20º, V=5m/s and θ=0º. β, V and θ are the collector inclination, wind velocity and wind incidence, respectively. As a first step to examining the effect of parapet height, the flow behaviour and wind velocity around the collector is presented. As can be seen in the velocity streamlines, Figure 3, a flow division is noticed in all cases with a stagnation point at the windward side of the building. Flow separation is also observed at the edge of the roof under all conditions. Without the perimetric parapets (see Figure 3a, recirculation is formed in front of the collector with a reattachment in its wake region. For both the low parapet and high configuration, see Figure 3 b and c, respectively, a backflow is observed from the leeward side of the building onto the roof; this is due to flow reattachment and vortices on the leeward side of the building. Moreover, the vortices above the roof create considerable suction in the cases with parapets as widely documented. When put in context, higher wind velocities can be seen in the wake region of the collector for low parapet and high parapet configurations compared to that of the no parapet configuration.

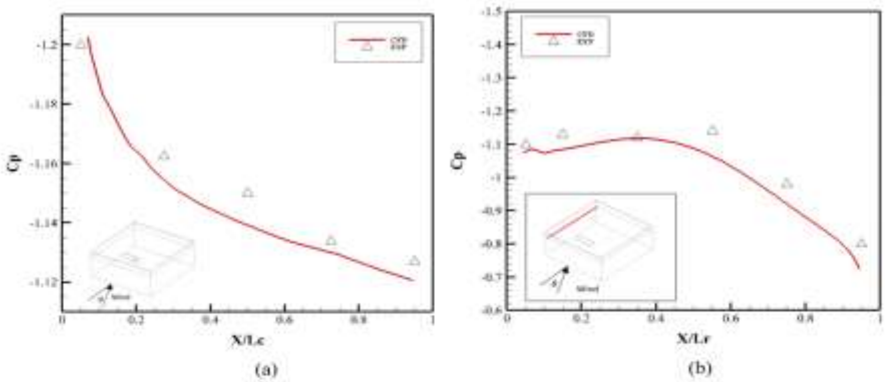


Figure 2.0: Comparison of C_p prediction of CFD simulation and experimental data for (a) collector upper surface and (b) roof surface

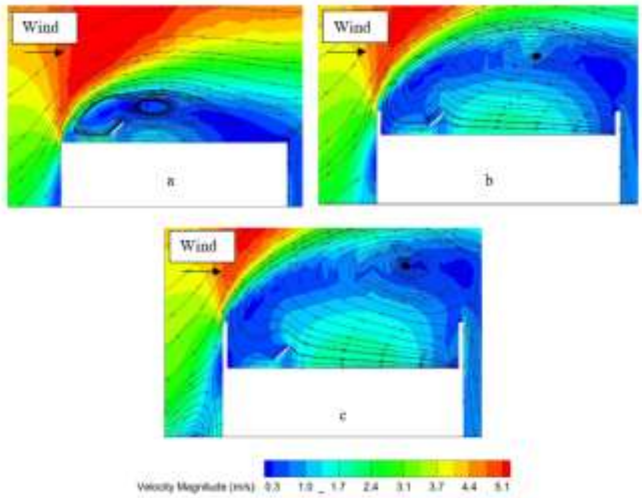


Figure 3: Streamwise velocity path lines and contours show the collector's main flow features at varying parapet heights.

A common assumption in the use of velocity in heat loss calculations is that of a single reference velocity against the local velocity on the collector's surface. Now, given that parapets affect wind velocity and flow behaviour on roof surfaces, the understanding of local velocity (V_l) on the collector surface and how that affects wind-induced heat loss is consequently vital. Here, we examine the change in local wind velocity on the collector's surface by relating that to the local heat loss. It must be noted that the convective heat transfer is expressed as a Nusselt number, Figure 4a. As depicted in Figure 4 (b), the absence of a perimetric parapet results in higher local velocity on both the front and back of the collector. Especially from the leading edge on the front region of the collector, higher velocities are noticed, which translate to significant heat loss. In Figure 4c, there is a clear trend of decreasing local velocity, which translates to heat loss at the surface of the collector when compared to that of the no parapet condition. Once again, the wind velocity reduces towards the trailing edge of the collector peaking after that. Comparatively, we infer that the heat loss on the surface of the collector under the no parapet conditions is higher than that of the low parapet. The case of the higher parapet is different in several aspects. Here (Figure 4d), far lower velocities are observed on the front region of the collector compared to that of the other cases. Also, the velocity at the wake region of the collector's trailing edge depicts a mix of velocities compared to the other cases. When the average Nusselt values (Nu_{avg}) values across the front and back of the collector are computed, it becomes apparent that increasing the parapet height results in significant heat losses. Seemingly, this can be tied to the presence of the parapet, which alters the flow behaviour and wind velocity, as reported in this study.

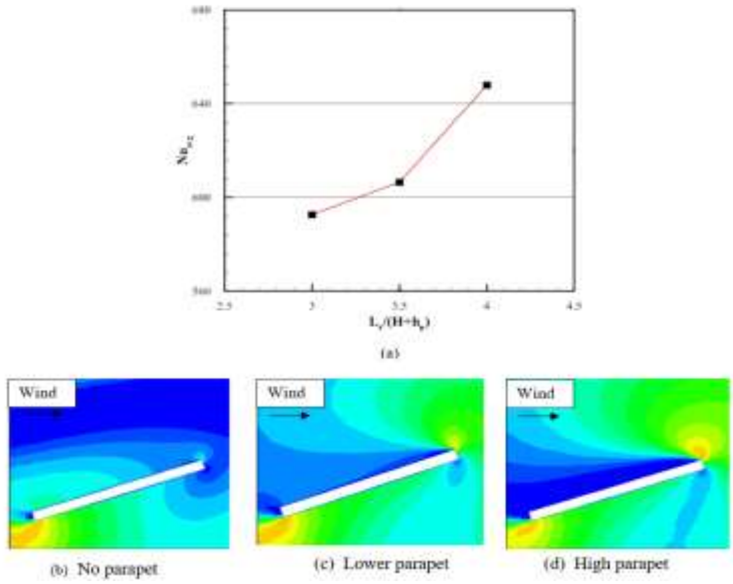


Figure 4: (a) Average Nusselt number at varying parapet height ((θ=0°, β= 20°, V=5m/s; collector located 25 per cent of roof cavity to incoming wind); L_r is the length of the roof cavity, H the height of the building and h height of the parapet h_p. (b-d) Velocity contours for local velocity around the collector.

Parapets are installed on many buildings to minimise wind loads on roof surfaces. However, it is evident they are a compromise between reducing wind loads and wind-induced heat loss, which can be advantageous to solar thermal collectors and detrimental to PV panels. In this study, we focussed on the effect of parapets on wind-induced heat loss. An unglazed standalone solar thermal collector with no back insulation was considered, and the effect of increasing the parapet height and collector location was studied. The numerical results were validated against an experimental study. We found that an increase in the parapet height significantly changes the wind-induced heat loss, shaped by wind velocity and flow behaviour. Essentially, this suggests that parapets may alter velocity for cases where higher performance is desired.

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