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Reynolds number effect on low-rise buildings: A consistent inflow LES study

Naveen Shiju Joseph [a], R Panneer Selvam [b]

[a] *University of Arkansas, Fayetteville, Arkansas, USA, naveenj@uark.edu*
[b] *University of Arkansas, Fayetteville, Arkansas, USA, rps@uark.edu*

SUMMARY

A Reynolds-number (Re) effect study was conducted using four scaled models under identical inflow conditions with a Large Eddy Simulation (LES) framework. Unlike previous wind-tunnel studies where changes in model scale unintentionally altered terrain roughness, boundary-layer thickness, and turbulence; this work preserves identical inflow profiles, roughness, and turbulence across all scales, isolating the Re effect. The TTU low-rise building is used as the test case. Without separate inflow turbulence generators, differences in flow behavior arise solely from changes in Re. The analysis focuses on peak suction pressures, minimum surface pressure coefficients, and flow features around the building. Systematic variations in surface pressure patterns and vortex behavior in both the wake and windward regions were observed as Re increased. These findings also demonstrate the solver's ability to capture Re-dependent aerodynamics in low-rise buildings. The full paper will also include results with inflow turbulence generators.

Keywords: *Reynolds number effect, LES, Shear layer, low rise building, Wind Tunnel, inflow generator*

1. INTRODUCTION

Most Residential buildings are low rise buildings, which are vulnerable to damage during extreme wind event. Building codes include provisions to strengthen the wind resistance of buildings. Unlike high rise buildings, most of the damage occurs in Low rise buildings because of uplift forces on the top, which are created during extreme wind events. The sharp edges of the buildings such as roof edge or eaves cause a separation in flow of the wind, which further leads to a localized drop in pressure. This is what causes suction and results in uplift forces. The magnitude of this pressure depends on many parameters such as wind velocity, topography of surroundings, shape of the building, turbulence intensity of incoming wind and many others. One of the most important parameters is the Reynolds number (Re).

Wind tunnel tests and CFD simulations were conducted to examine the Re effect. Earlier wind tunnel studies (Djilali and Gartshore, 1991; Hillier and Cherry, 1981) had the assumption that flow features such as reattachment length and pressure distribution were independent of Re beyond (2-3) x 10^4. Hoxey et al., (1998) provided experimental evidence of Re sensitivity in separated flows on bluff bodies (in the field of building aerodynamics). This assumption was then built upon by Lim et al., (2007) by adding that Re effects are significant for even on mean flow quantities if the flow has the potential to generate vortices, like on roof edges. Under such conditions, the mean pressure coefficients on the roof will change, exhibiting clear Re dependence.

Replicating the atmospheric boundary layer in the wind tunnel requires matching (a) upstream parameters such as Jensen number(Jensen, 1958) and geometric scales and (b) turbulence intensities and spectral characteristics of test section of wind tunnel with that of the atmospheric boundary layer. Wind tunnels, though well established, struggles to satisfy both these conditions simultaneously. Fritz et al., (2008) reported that pressure coefficients vary by 10-40% in different wind tunnels even with the same inflow parameters. In addition, when comparing different scaled models, larger scaled models showed better agreement with field tests as reported in (Moravej, 2018). Although a statistical correction was used to obtain the mean pressure coefficient, the better accuracy of larger scaled models was attributed to Re being closer to field test's Re. The wind tunnel could not replicate the low frequency region of the spectra accurately. However, when both Re and inflow boundary conditions vary between tests, the source of the differences in pressure distribution becomes even more ambiguous. Variation in inflow turbulence, such as changes in turbulence intensity, boundary layer thickness, deviations in logarithmic velocity profile can all influence the changes in pressure distribution between different simulations. Thus, making it hard to pin down the factor responsible for the pressure variation between Re variation and variation in inflow conditions as discussed above.

To avoid this ambiguity, the current work uses an LES model to isolate the pressure change due to Re effect alone. This is the objective of the study. Re is changed systematically by changing scale ratio, while maintaining inflow boundary conditions identical across all Re. The logarithmic velocity profile, non-dimensional surface roughness and friction velocity are kept identical. As of now, no inflow turbulence generator is used. Results with inflow turbulence generators shall be included in the full paper. To the authors' knowledge, this is the first CFD study in building aerodynamics where Re is changed systematically under perfectly matched inflow conditions, allowing just the Re effect of low-rise building to be examined without wind tunnel limitations.

1.1. Identifying the Re effect

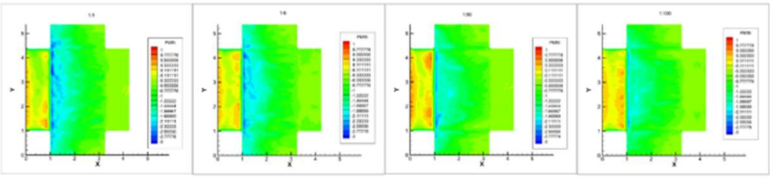
Re effect is present when changes in pressure coefficient distribution and flow structures happens solely due to change in Re while all inflow conditions remain identical as discussed in the previous section. Previous studies have shown that in low-rise buildings, Re effect strongly influences (a) the separation and reattachment process over the roof, with higher Re numbers having longer reattachment points(Akon and Kopp, 2016; Hudy et al., 2003; Ota et al., 1981), (b) the formation of windward wall shear layer (Akon and Kopp, 2016), (c) the variation in surface pressure coefficient and (d) the change in strength and lateral spread of vortices forming at roof and side walls (Richards and Hoxey, 2025). These mechanisms are particularly relevant for sharp edged bluff bodies such as low-rise buildings, where flow separation in roof and the shear layer in windward wall influence the vortex formation and ultimately the surface pressures. At lower Re number, shear layers are thicker, causing reattachment to happen sooner. Mean while higher Re number has thinner shear layers, causing stronger rollups which results in delayed reattachments and higher lateral spread of vortices (towards sidewalls). All these mechanisms ultimately lead to systematic changes in surface pressure distributions across different Res, even when the inflow boundary conditions are kept identical.

2. METHODOLOGY

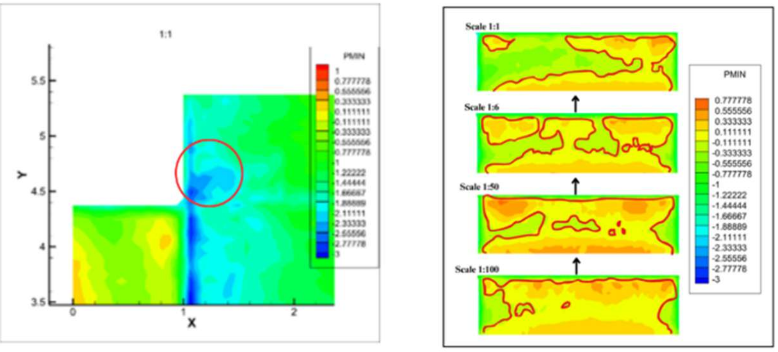
The different scaled models, z_0 value and reference velocities are obtained from Moravej, (2018). Scale ratios 1:1, 1:6, 1: 50 and 1:100 with Res 3.63 x 10^6, 5.99 x 10^5, 5.6 x 10^4 and 2.76 x 10^4 respectively. The building under consideration is the Texas Tech (TTU) building. Flow perpendicular to the front wall alone is considered here. The solver from Selvam, (2022) was used for the simulations. The Governing equations and solution procedures are in Selvam, (1997). The preliminary part is done without the inflow generators. As results, surface pressure distribution for mean and peak Cp; time series data of pressure on building surface and flow features around the building are obtained.

3. DISCUSSION

For all the 4 scale ratios, mainly 4 outputs were analysed. (a) Peak Cp across the centerline, (b)time series data for pressure at different points of buildings, (c) Minimum Cp distribution on building surfaces and (d) flow visualisation around the building. The minimum Cp fields show a clear Re dependence. The absolute minimum surface pressure coefficients, Min Cp for the four scale ratios were −3.201 (1:1), −2.845 (1:6), −2.8004 (1:50) and −2.498 (1:100); relative to the 1:1 case this corresponds to reductions of 11% in 1:6, 1:50 scale ratios and 22% reduction in 1:100 scale ratio. These minima occur progressively closer to the roof/side edges at higher Res, while the area and centroid of low-pressure regions shift laterally on the windward wall(Refer Fig1.(a) and (c)). Furthermore, at higher Re, strong suction(Min Cp of -2) extends onto the side walls too, which is consistent with field test results by Richards et al., (2025). At the edge of the side walls, negative pressures of -2.84 and -2.4 was found for scale ratios 1:1 and 1:6 respectively(Refer Fig1.(a) and (b)). This negative pressure in sidewalls was not observed in scale ratios 1:50 and 1:100. Similarly, the reattachment length increasing relatively for higher Re which was observed here is consistent with previous studies(Akon and Kopp, 2016; Hudy et al., 2003). The mean values of reattachment lengths were 2H, 1.75H, 1.1H and 0.9H(H=building height) for scale ratios 1:1, 1:6, 1:50 and 1:100 respectively. Additionally, positive pressure on the windward face remains more uniformly distributed at lower Re, matching trends reported by Lim et al., 2009. Observations of flow visualisations will be reported in detail in the full paper.



(a)Surface Min Cp distribution for 1:1.
1:6, 1:50 and 1:100



(b)Sidewall minimum pressure for 1:1 Scale ratio

(c)Windward wall pressure spread

Figure 1: Overview of the results

4. CONCLUSION

The present results, obtained under uniform inflow conditions without synthetic turbulence generator, already exhibit clear and systematic Re effects in both surface pressure fields and flow structures around the building. These findings demonstrate that the LES model is capable of capturing the essential aerodynamics associated with varying Re, even in the absence of imposed inflow turbulence. The full-length paper will extend this analysis by incorporating simulations with realistic turbulent inflow conditions, enabling a more comprehensive assessment of Re sensitivity and providing a broader comparison with wind-tunnel and full-scale studies. This is the first work in CFD to investigate Re effect on low rise building by systematically changing the scale ratio by keeping the inflow conditions identical.

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