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Application of LES for the assessment of components and cladding loads: comparison to wind tunnel data and wind loading provisions

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SUMMARY:
Using computational methods, such as Large-Eddy Simulation (LES), can overcome some potential challenges in modelling wind loads on low-rise buildings. Simulation of components and cladding (C&C) loads is one of the most challenging parts of realizing that potential. Typically, LES validation is conducted at individual points. However, this study aims to take the validation further by comparing the area-averaged cladding loads, following the practice in design codes, with experimental data and wind-loading provisions. Comparison with wind tunnel experiments suggests that the general characteristics, such as strong suction under separation bubbles and corner vortices and positive pressures on the windward walls, match reasonably well. The mean, standard deviation, and peak values of the pressure coefficients were also compared at every tap/probe location. Some load overestimation was observed, corresponding to the overestimated turbulence intensity and mesh-sensitive corner locations using LES. Future studies will consider inflow and mesh improvements along with additional wind directions. The effect of tap or probe density on components and cladding loads will also be investigated.

Keywords: Components and Cladding load; LES; building aerodynamics; low-rise buildings

1. INTRODUCTION

The Large-Eddy Simulation (LES) of components and cladding (C&C) wind load on low-rise buildings is crucial in assessing the applicability of LES for design purposes. Most previous studies (e.g., Geleta and Bitsuamlak 2022) compare the local surface pressure coefficients at specific tap locations. Although these comparisons are crucial, C&C loads must ultimately be specified as area-averaged loads and compared to wind loading provisions. The current study aims to reproduce a wind tunnel experiment of a flat-roof low-rise building in LES and compare both to wind loading provisions.

2. WIND LOAD EVALUATION METHODS

The simulation case considered in this study is a 1:50 scale model of the Texas Tech University (TTU) low-rise building. The building has a height, width, and length of $4m$, $9.14m$, and $13.71m$, respectively, as shown in Fig.1a. Both LES and wind tunnel cases use 456 taps/probes distributed across the building surface to sample the local pressure (Fig.1b). Two exposure conditions targeting full-scale $z_0 = 0.01m$ (Exposure 2, E2) and $z_0 = 0.089m$ (Exposure 3, E3) are considered in wind tunnel and LES cases. The profiles and spectra in comparison to ESDU 1975 values are shown in Fig. 2. Most of the values from both the experiment and LES are close to ESDU except for the velocity profile and turbulence intensity (TI) close to the ground surface. With further iteration of inflow correction, this gap is expected to close in future research. The simulation duration is 30 seconds for both LES and BLWT (truncated to match the LES).

The wind tunnel experiments were conducted at the Boundary Layer Wind Tunnel Laboratory of Western University. Sample pictures of the model and tunnel set-up are shown in Fig.1c. The LES models uses the same scale as the wind tunnel model. Different meshes were used for different wind directions to appropriately capture the change in the building aerodynamics. The inflow was generated using a synthetic method (Melaku and Bitsuamlak 2021) targeting the ESDU profiles. All LES parameters except for the inflow are same as used in Geleta and Bitsuamlak 2022.

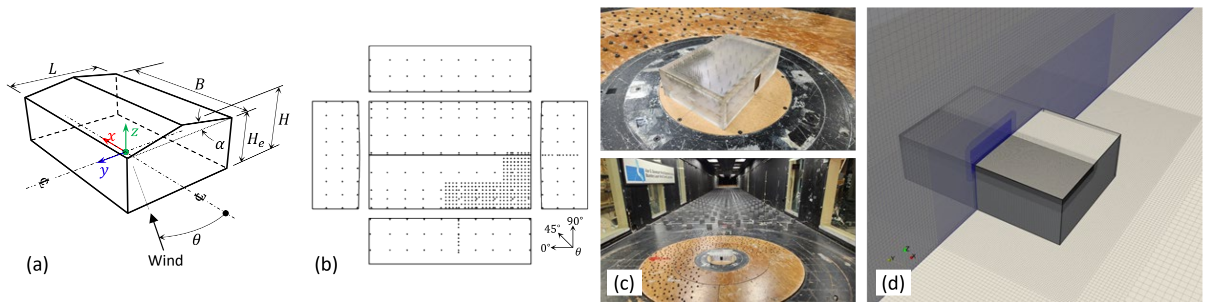

Figure 1. (a) Building geometry, (b) tap/probe layout, (c) typical experimental set-up, and (d) typical LES mesh.

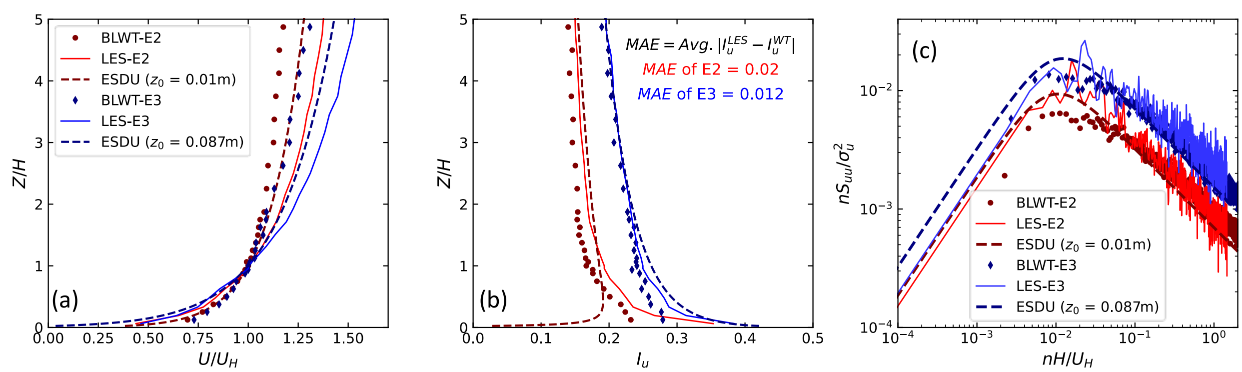

Figure 2. Comparison between BLWT, LES, and ESDU with (a) mean velocity profile, (b) turbulence intensity profile, and (c) longitudinal reduced turbulence spectra.

3. RESULTS AND DISCUSSION

3.1. Local pressure

The Mean C_p distribution across all surfaces in exposure E2 is compared between BLWT (top row) and LES (bottom row) in Fig. 3. The overall visual distribution of the values is considerably similar for all wind directions. A scatter plot comparing the two with Mean, Standard deviation, and Peak of C_p is given in Fig. 4. Apart from a few points, all three quantities show good agreement (i.e., NMAE under 8% except for E2 45° with 12%). The 45° cases have a relatively high deviation from BLWT. Most of the deviations are overestimations by LES, which is in line with the difference seen in the roof-height TI.

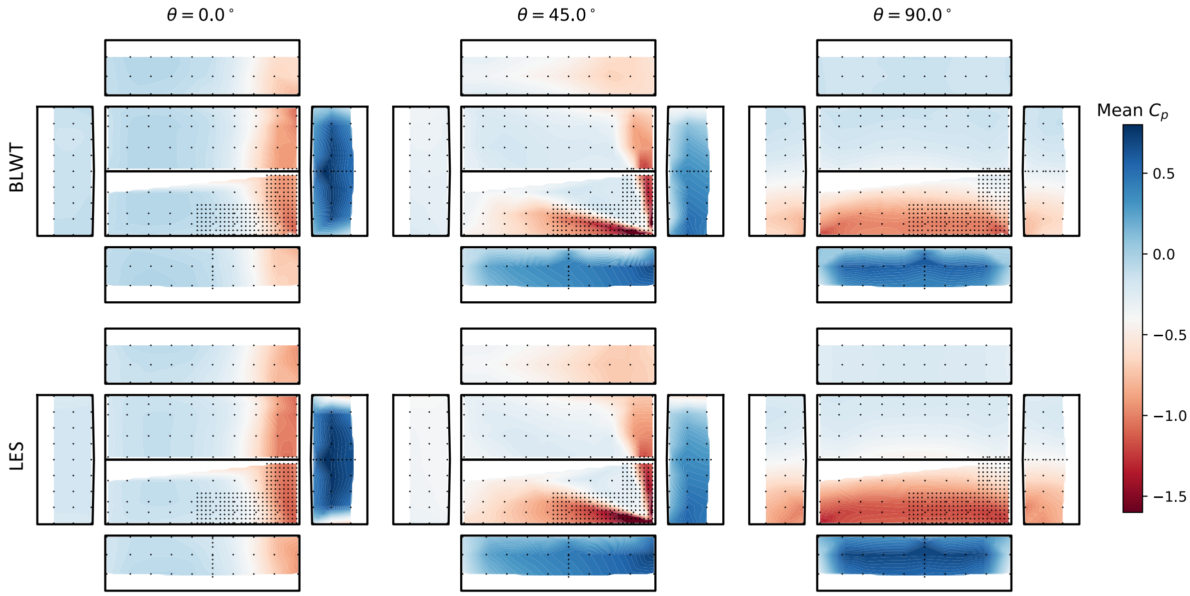

Figure 3. Mean C_p comparison between BLWT and LES for exposure E2.

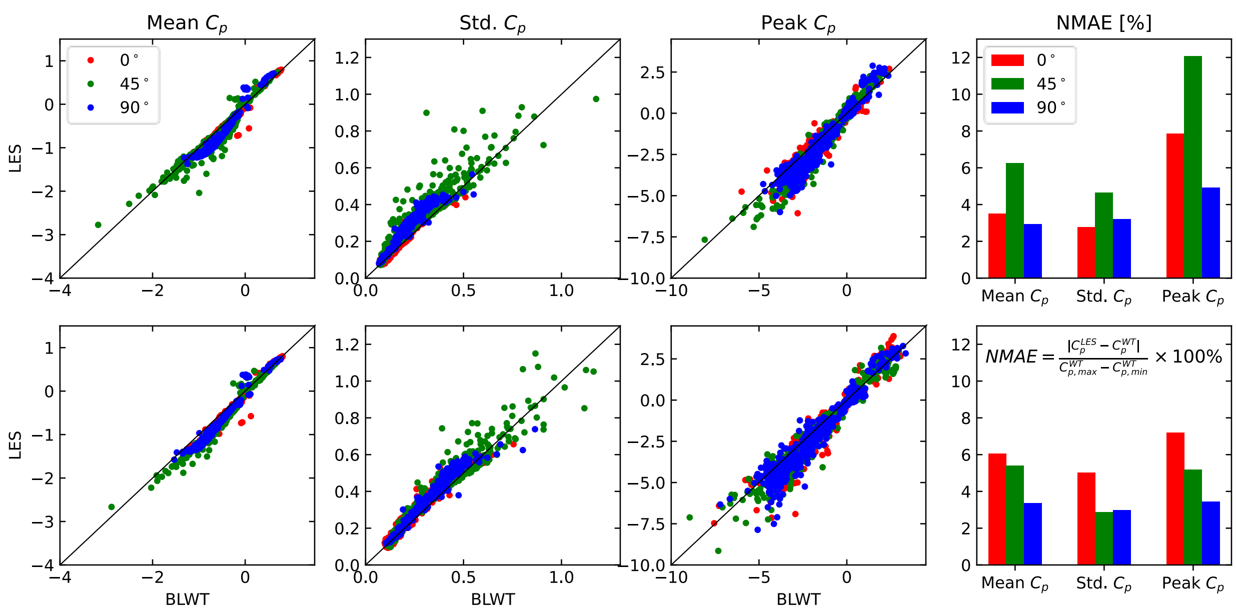

Figure 4. Scatter plots comparing BLWT and LES through Mean C_p, Standard deviation of C_p, and Peak C_p in exposures E2 and E3 with the corresponding Normalized Mean Absolute Error (NMAE) values.

3.2. Area averaged component and cladding load

The local time histories collected at all taps/probes were simultaneously weight-averaged over varying sizes of squares. The full-scale equivalent panel areas are 0.11, 0.2, 0.325, 1.25, 1.7, and 3.25 m^2. The area averaging is conducted by dividing the roof into corner, edge, and field zones.

Assuming the current results correspond to full-scale 1hr, a Durst factor of 1.53 is used to convert C_p to 3s gust equivalent gust pressure coefficinets (GC_p). In general, the negative C&C loads from LES are higher than those from BLWT. This is consistent with the differences in TI for most cases, but the corners may be affected more by the mesh density in oblique wind directions. The ASCE 7-22 (ASCE/SEI 2021) provisions are all higher than the BLWT results, but LES results of smaller averaging areas exceed those of ASCE 7-22.

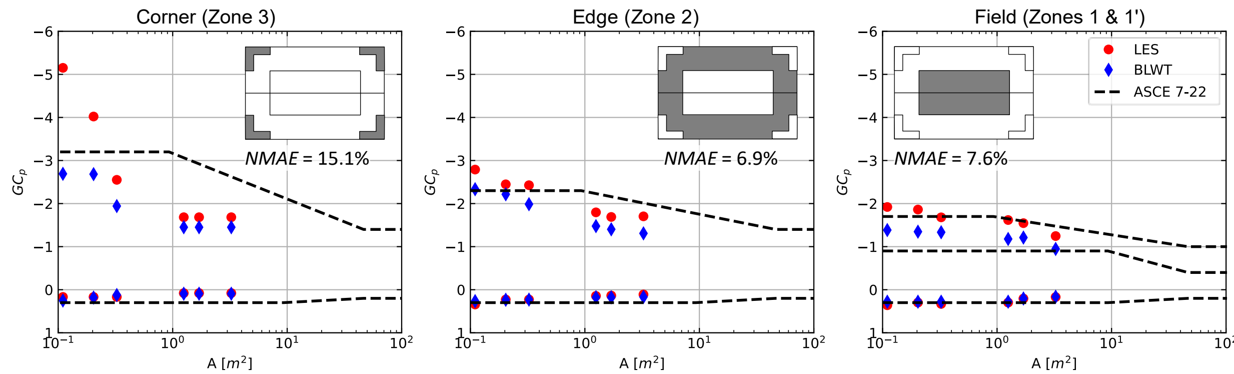

Figure 5. Comparison of 3s gust GC_p C&C load between BLWT, LES, and ASCE 7-22.

4. CONCLUSIONS

Detailed LES models targeting BLWT tests were used to simulate the local and area-averaged C&C loads on a low-rise building. The wind field was reproduced with a MAE in TI of up to 0.02. The NMAE values of the local peak loads were mostly within 8% except for one case of 12%. The difference was pronounced more (to 15%) in the C&C loads because it is governed by the highest loads at a few points. This difference is mostly attributed to the overestimated TI and the quality of mesh at the corners. Even though the local loads were In the future study, improvements to the inflow to better match the TI and mesh quality in the corners for oblique wind directions is crucial. Additional wind directions will be added to complete the comparison.

ACKNOWLEDGEMENTS

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