Estimating wind loads on low-rise buildings using CFD

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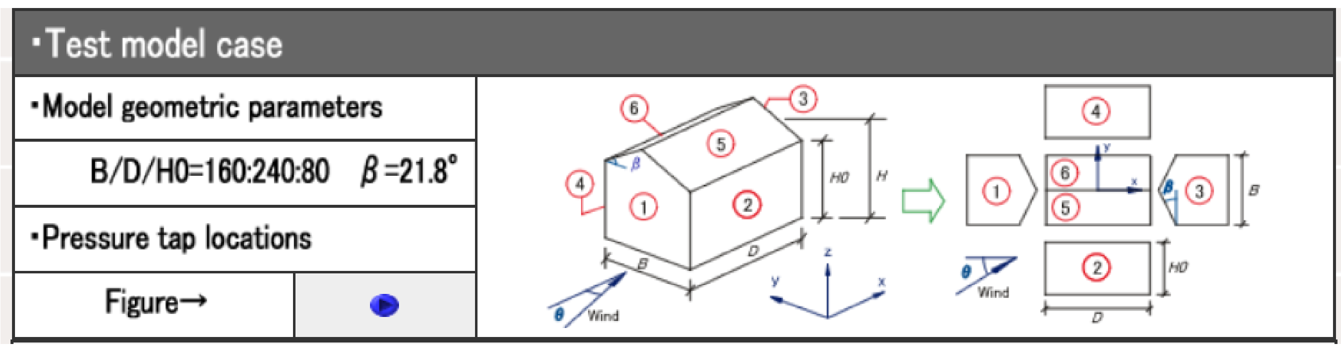
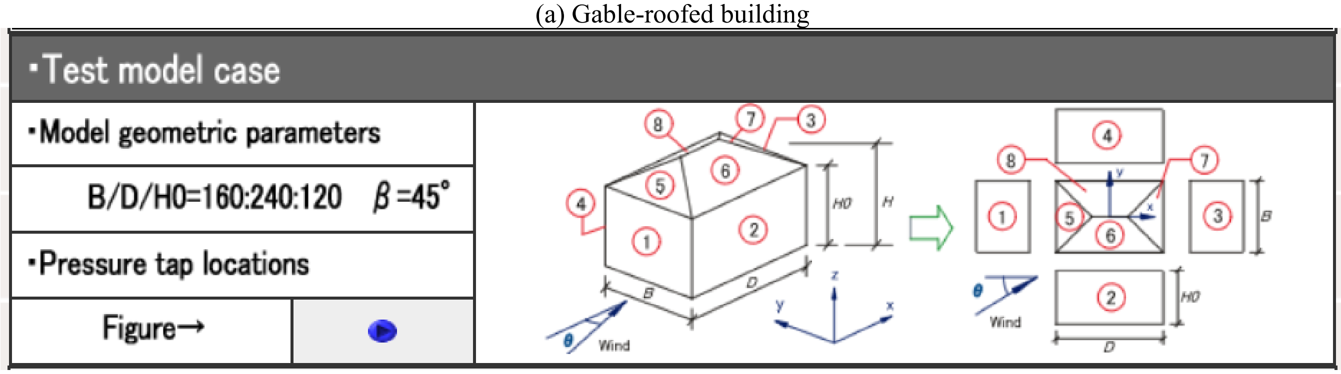
This report provides the procedure and results of using Large Eddy Simulation (LES) for estimating wind loads on low-rise buildings. The NHERI-SimCenter/WE-UQ tool is used to generate CFD models. Three models of flat-, gable-, and hip-roofed buildings are created and seven wind directions with a 15° increment are considered for each building, which results in 21 simulation cases in total. For each case, the peak and statistical moments of surface pressure coefficients are validated wind boundary layer wind tunnel data. The comparison demonstrates that the pressure coefficients have satisfactory agreement with the wind tunnel measurements. The codes for preprocessing, postprocessing, and the CFD models are available at https://github.com/xinlong-du/LES_TPU. All input and output data including time series and peaks for pressure coefficients as well as the validation results can be found in the shared folder https://drive.google.com/drive/folders/1cyt3wIw4ElbOEb96UFZSvfjZzz2FCCk6?usp=sharing.

1. Reference experimental study and prototype buildings

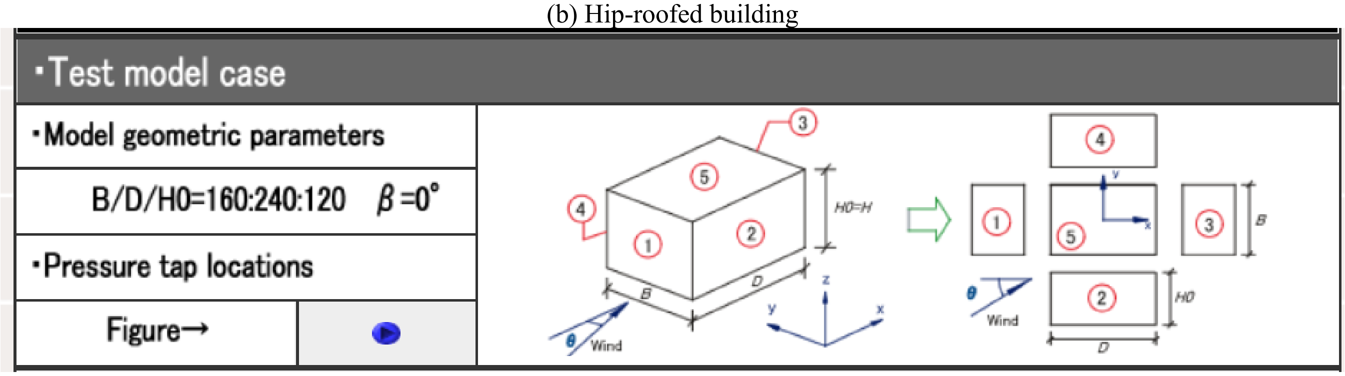
The aerodynamic database developed by the Tokyo Polytechnic University is used for validation of the LES results (TPU, n.d.). We focus on isolated low-rise buildings without eaves. The wind tunnel tests of one gable-roofed, one hip-roofed, and one flat-roofed buildings are selected from the TPU aerodynamic database and replicated using LES in model scale. The length scale was 1:100. The test wind velocity was about 7.4 m/s. Seven wind directions were considered from 0° to 90° with a 15° increment. Figs. 1-3 provide the geometric information of the three prototype buildings (see the definition of 0° wind direction in the figures). More details of the wind tunnels tests can be found in the cited TPU webpage.



(a) Gable-roofed building



(b) Hip-roofed building



(c) Flat-roofed building

Fig. 1. Three prototype buildings used in LES simulations

2. Description of the CFD models

The CFD models are generated using the NHERI-SimCenter/WE-UQ tool. To facilitate comparison with the experimental data, LES simulations are performed in the model scale. Seven LES simulations are conducted for each prototype building shown in Fig. 1 with each simulation corresponding to a wind direction, which results in 21 simulations in total. All simulations are conducted using OpenFOAM-10 installed on the Stampede3 cluster of Texas Advanced Computing Center. The computational domain is shown in Fig. 2 along with the building model. Other information of the computational domain, boundary conditions, mesh, and numerical setup can be found in the provided GitHub repository. Readers can load the json file using WE-UQ to access all details of the CFD model.

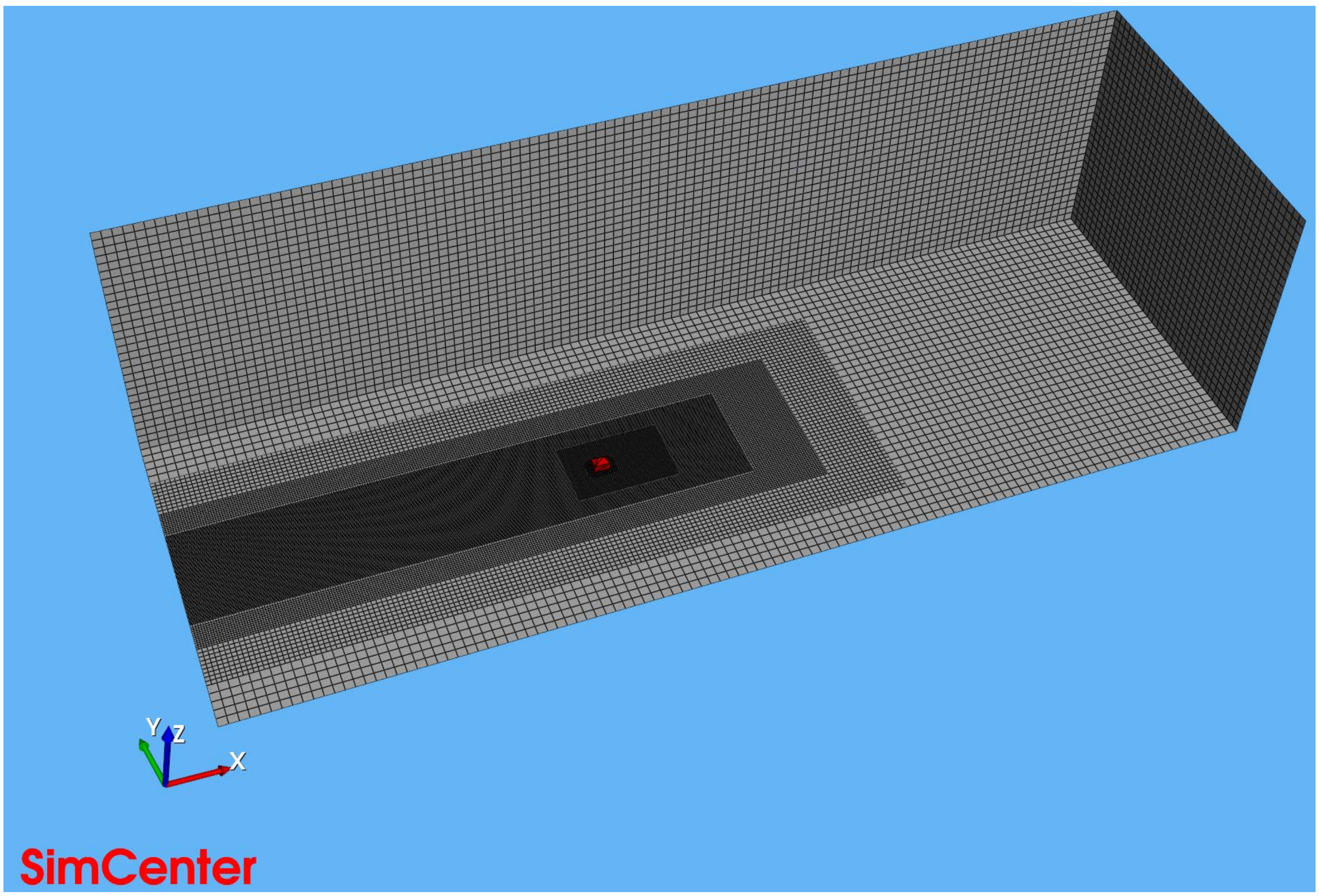
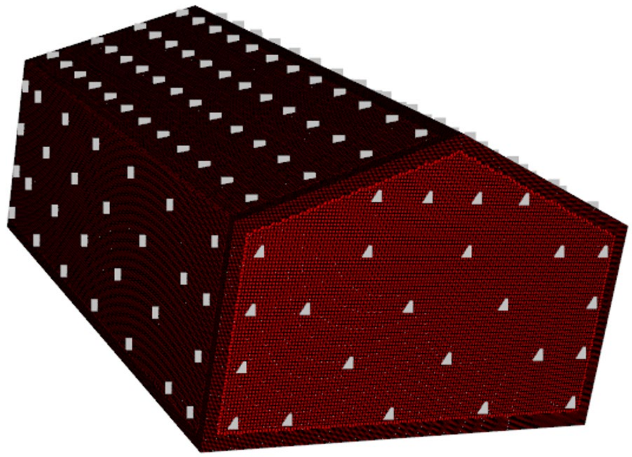
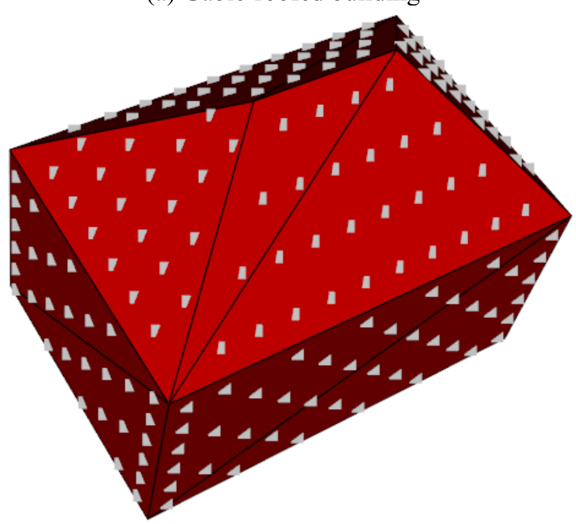


Fig. 2. Computational domain and the building model

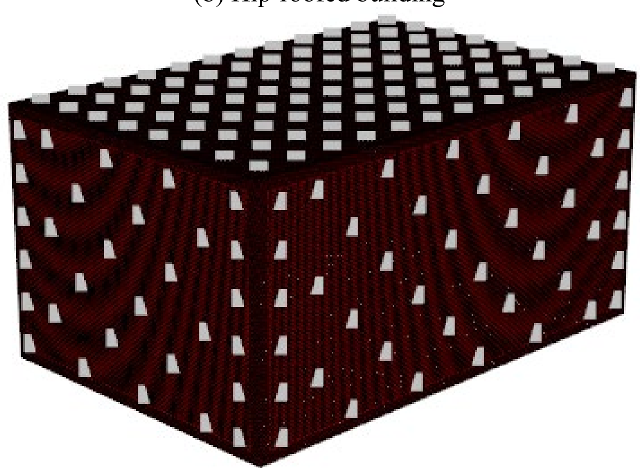
Probes are placed at the surface of the building model to record pressure data during the simulation. The probes are at the same location on the building surface as the pressure taps used in the wind tunnel tests. There are 200 probes for the gable-roofed building and 240 probes for the hip-roofed and flat-roofed building. The locations of probes are shown in Fig. 3. The coordinates of the probes are also provided in the shared folder in Google Drive and can be imported to the CFD model using WE-UQ.



(a) Gable-roofed building



(b) Hip-roofed building

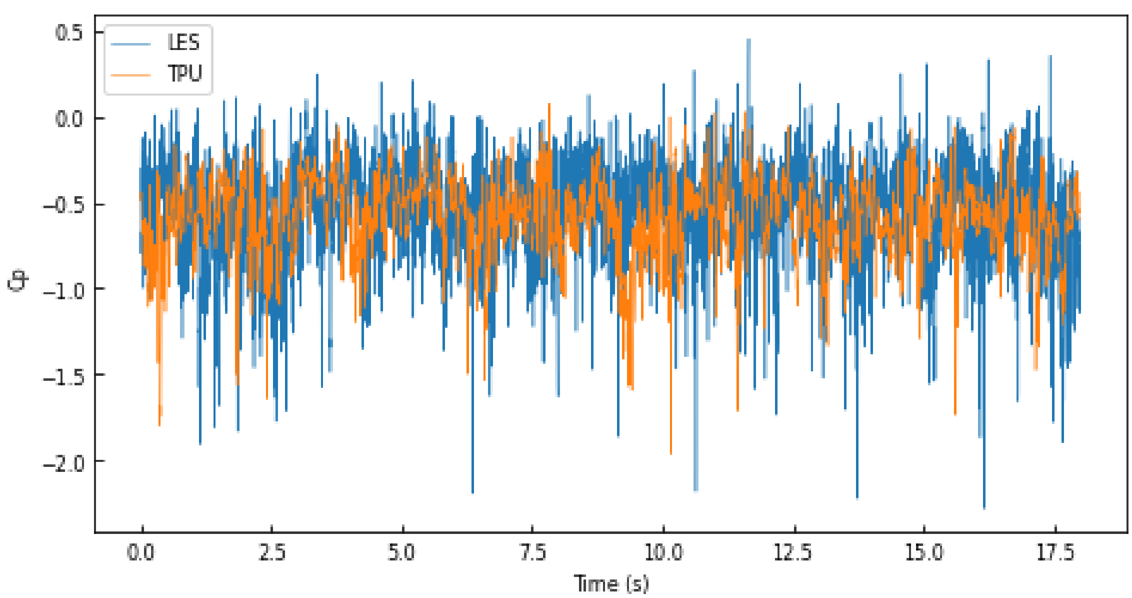


(c) Flat-roofed building

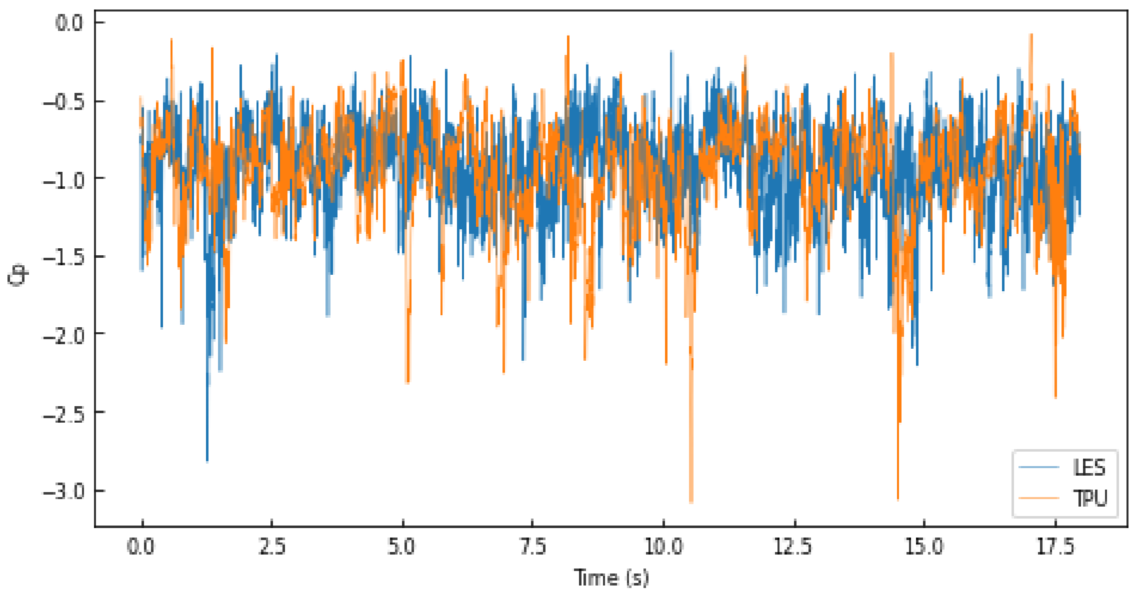
Fig. 3. Locations of probes along with the geometry of the building

3. Validation against wind tunnel tests

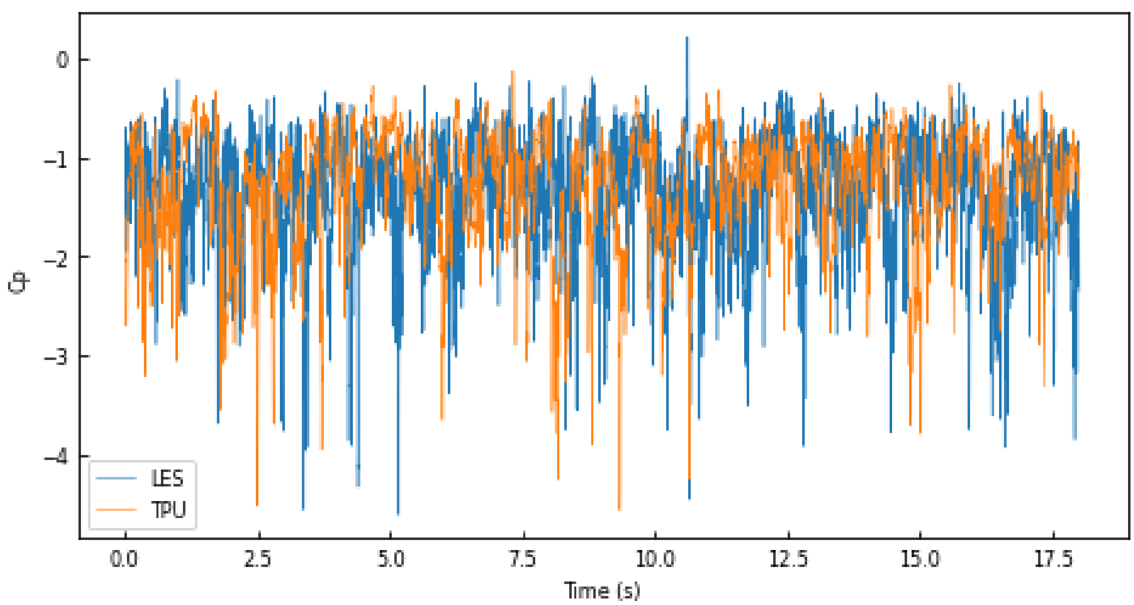
Each LES simulation was run for 19 s and the first 1 s duration was removed to exclude the initial transient stage. Therefore, the validation process uses 18 s data in model scale from both CFD and wind tunnel tests, which translates to a 10-min duration in full scale if the velocity scale is roughly 1:3. The validation of all 21 cases can be done by running the *validation.py* code in the shared folder. Since the 1-hour peaks of Cp are of interest for the design of a building, these peak data of all cases and the comparison of peaks between LES and wind tunnel results are provided in the shared folder. In this report, we only display the results of one wind direction for each building: the gable-roofed building with a 90° wind direction, the hip-roofed building with a 15° wind direction, and the flat-roofed building with a 0° wind direction. Fig. 4 shows the time series of Cp of pressure tap 1 of the selected cases, while Fig. 5 compares the histograms of Cp of the same pressure tap. Fig. 6 and Fig. 7 compares the mean and standard deviation of Cp of all pressure taps. It is seen that LES can provide reasonable results of Cp in terms of its mean, standard deviation, and statistical distribution, while the LES predictions for the flat-roofed building is less accurate than other two buildings.



(a) Gable-roofed, 90° wind direction, pressure tap 1

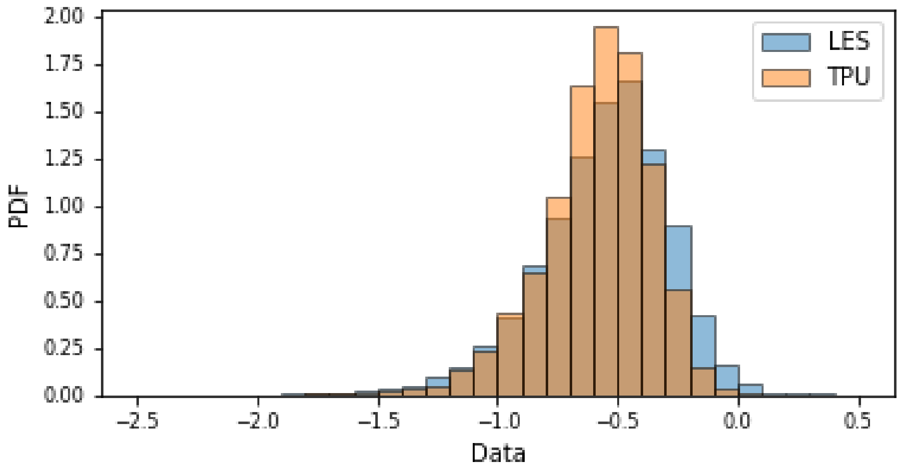


(b) Hip-roofed, 15° wind direction, pressure tap 1

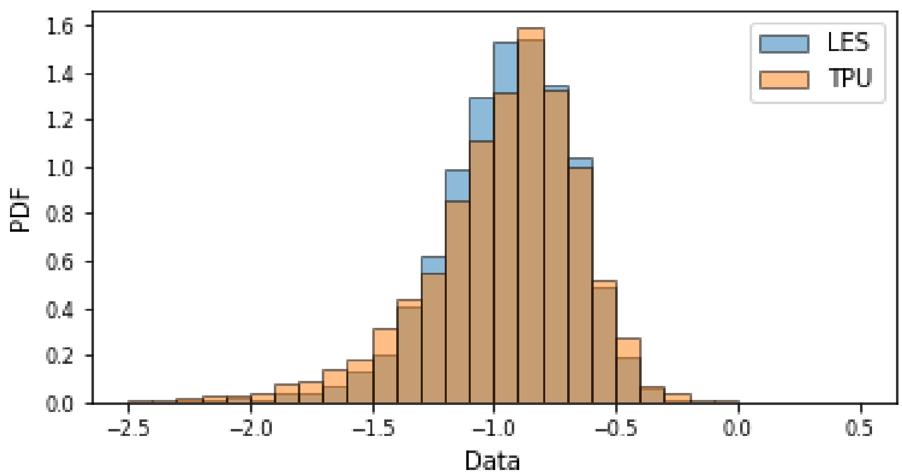


(c) Flat-roofed, 0° wind direction, pressure tap 1

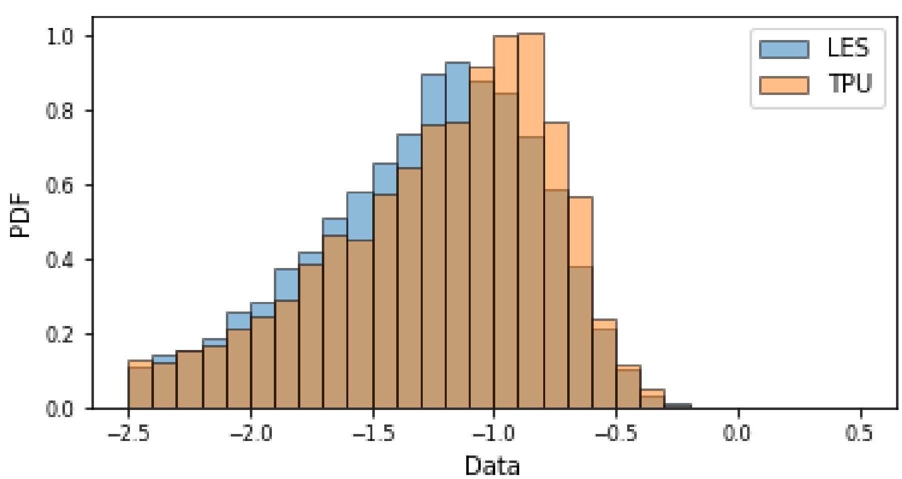
Fig. 4. Comparison of time series of Cp from LES and wind tunnel data



(a) Gable-roofed, 90° wind direction, pressure tap 1

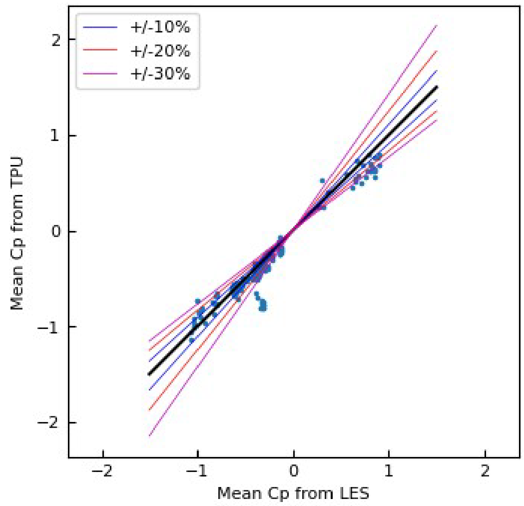


(b) Hip-roofed, 15° wind direction, pressure tap 1

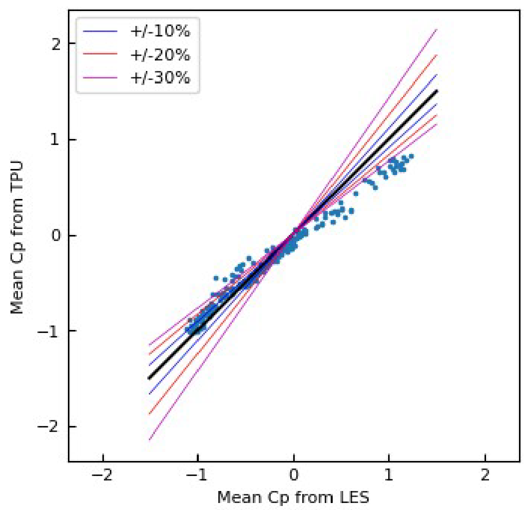


(c) Flat-roofed, 0° wind direction, pressure tap 1

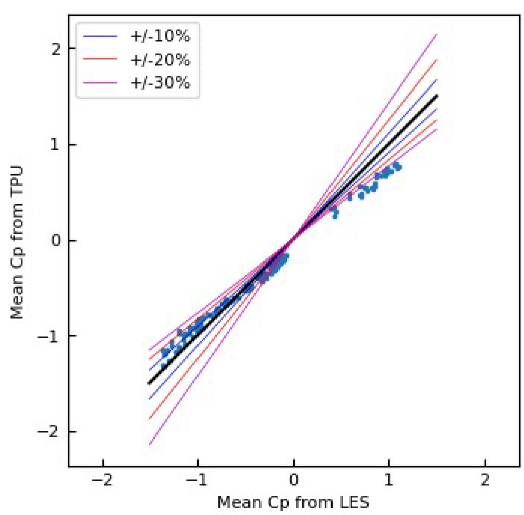
Fig. 5. Comparison of histograms of Cp from LES and wind tunnel data



(a) Gable-roofed, 90° wind direction

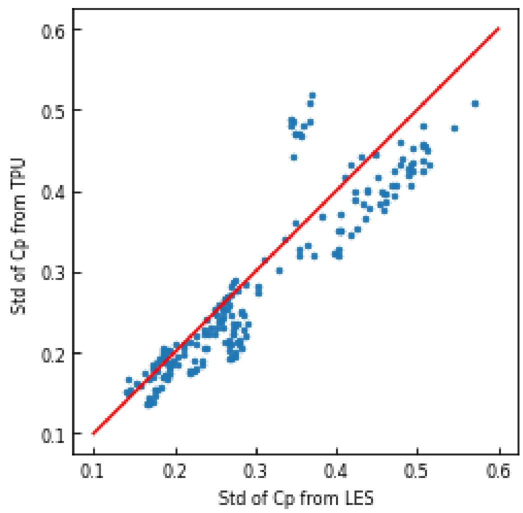


(b) Hip-roofed, 15° wind direction

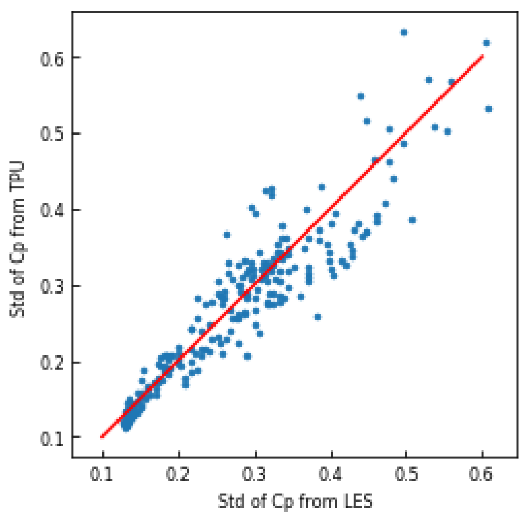


(c) Flat-roofed, 0° wind direction

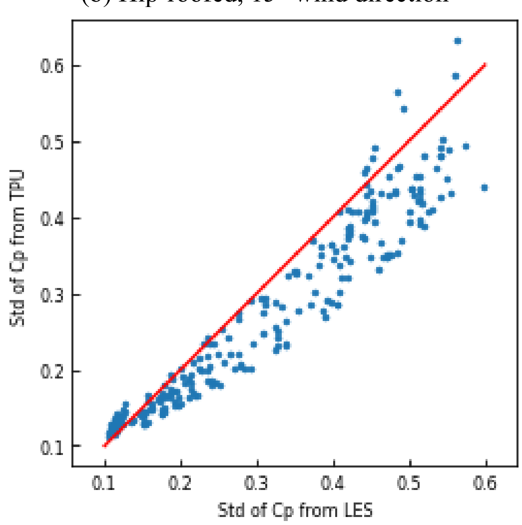
Fig. 6. Comparison of mean values of Cp from LES and wind tunnel data (with error intervals)



(a) Gable-roofed, 90° wind direction



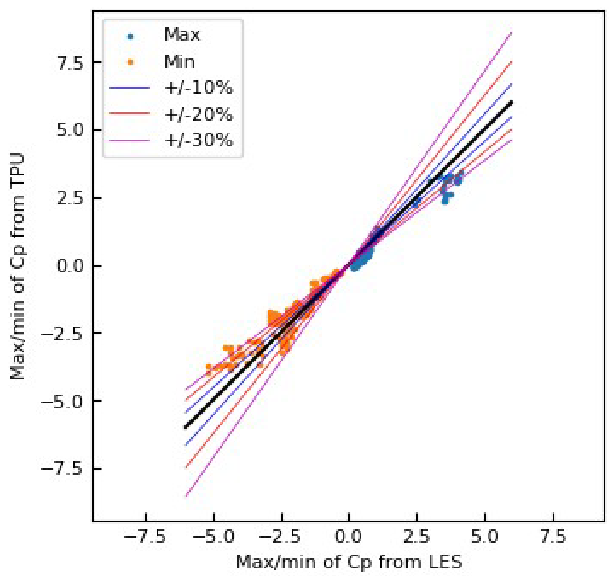
(b) Hip-roofed, 15° wind direction



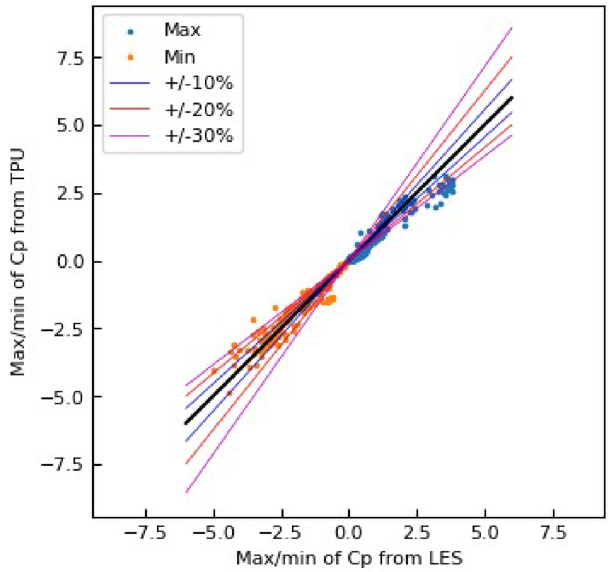
(c) Flat-roofed, 0° wind direction

Fig. 7. Comparison of standard deviation (std) of Cp from LES and wind tunnel data

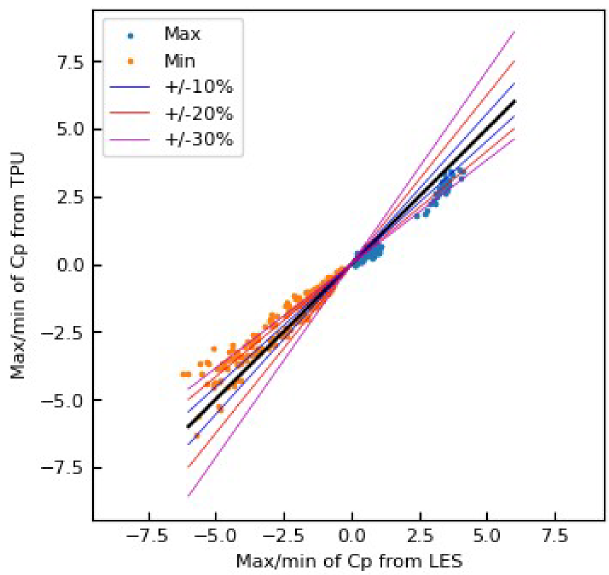
In order to estimate stable peak values of Cp from a sample time series, the peak estimate method developed by Sadek and Simiu (2002) is used in this work. The MATLAB functions provided in the referenced NIST website (NIST, n.d.) are converted to Python codes and can be found in the GitHub repository. One-hour peaks in full scale of all pressure taps are estimated based on the 18 s LES and wind tunnel data (10-min duration in full scale). Fig. 8 compares the 1-hour peak values of Cp from LES and wind tunnel data for 3 cases, while results for all other cases can be found in the shared folder. As peaks are the most important variables that will be used in design, Fig. 8 also shows the ±10%, ±20%, and ±30% error intervals. It is seen that the errors of peaks are within 30% for most of the pressure taps in the 3 cases, which also holds for other cases that have been studies in this work.



(a) Gable-roofed, 90° wind direction



(b) Hip-roofed, 15° wind direction



(c) Flat-roofed, 0° wind direction

Fig. 8. Comparison of 1-hour peaks of Cp from LES and wind tunnel data (with error intervals)

4. Conclusions

Comparison between the LES and wind tunnel data demonstrates that LES can make reasonably good predictions for mean, standard deviation, and statistical distribution of pressure coefficients. The errors of the 1-hour peaks estimated from LES simulations are generally within 30%. The accuracy of the predictions for the hip-roofed and gable-roofed buildings is better than that for the flat-roofed buildings, which may be due to the fact that the wind flow around the flat-roofed building is more turbulent and involves more separation and reattachment.

References

Sadek, F., and Simiu, E. (2002). Peak Non-Gaussian Wind Effects for Database-Assisted Low-Rise Building Design. *Journal of Engineering Mechanics*, *128*(5), 530–539. https://doi.org/10.1061/(ASCE)0733-9399(2002)128:5(530)

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