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Validation of an efficient block-coupled solver and automated workflow for urban wind flow modelling

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SUMMARY:
Despite being by far the most computationally demanding application in Urban Physics Modelling (UPM), Computational Fluid Dynamics (CFD) is widely used in industry to predict the impact of new developments on local urban microclimate and evaluate the effect of design changes on high-rise structures. Multiple CFD analyses at different wind conditions and for various building configurations are carried out in a single wind study. In an attempt to reduce the computational cost of those simulations, streamline the process chain moving from input geometry and climate data to results and overall cut the turnaround time at design stages, ENGYS has recently developed a novel simulation framework based on two main key ingredients: i) an efficient pressure-velocity block-coupled solver aimed at reducing runtimes ii) a multi-instance framework (MIF) that can handle multiple design conditions in a single execution without need for external scripting. In this work, the accuracy of the proposed simulation framework and methodology is validated against wind tunnel (WT) data provided by NOVA Fluid Mechanics (NOVA FM) for pedestrian comfort, safety, and mean pressure wind loading applications in both full-scale and model-scale conditions. The results obtained throughout the course of the study suggest that the newly developed process chain constitutes an efficient and reliable tool that could potentially set new standards in UPM.

Keywords: wind microclimate, multi-instance, coupled solver

1. INTRODUCTION

As the Architecture, Engineering and Construction (AEC) industry is rapidly transitioning to a digital era, attention has been drawn to the utilization of CFD methodologies for performing several UPM investigations such as pedestrian comfort assessment, wind loading analysis on buildings, pollutant dispersion and wind driven rain deposition. However, sufficiently assessing the urban microclimate of a built-up area, requires the examination of different site configurations and weather scenarios with a plethora of repetitive experiments, all of which entail high computational costs. Aiming to optimize and facilitate the whole process, ENGYS has proposed a novel, more cost-effective toolchain as part of the latest developments introduced in its main product HELYX. The core of this newly developed technology lies in the MIF, a simulation platform that provides full support for preparing, running and postprocessing multiple CFD experiments in a single execution. By erasing the need for external scripting, the MIF provides both expert and non-expert users with a convenient, more user-friendly way to perform urban microclimatic studies. Despite the degree of automation, the implementation remains accessible to end users for customisation. Combined with the efficient pressure-velocity block-coupled solver, which ensures fast convergence rates, this toolchain offers a significant decrease in the overall computational and setup costs for conducting demanding wind engineering analyses.

The aim of the current study is to quantify the improvements introduced by the proposed technology in terms of computational efficiency and accuracy for pedestrian comfort, safety and mean wind loading analysis. For all the tests, the Reynolds Averaged Navier Stokes (RANS) equations are solved along with k-omega SST and k-epsilon turbulence models and the results are validated against experimental data obtained from WT testing.

2. VALIDATION & VERIFICATION STUDY

The validation and verification study conducted by SoftSim Consult is based on two sets of testing data which were provided by NOVA FM: i) WT Atmospheric Boundary Layer (ABL) testing results for 9-11 Palmerston Road development situated in London, UK (see Figure 1) and ii) WT ABL testing results for Petra Tower development situated in Asuncion, Paraguay. Both experiments were conducted in the University of Genoa, Department of Civil, Chemical and Environmental Engineering wind tunnel facility on 1:400 scale models (WinDyn, 2023).

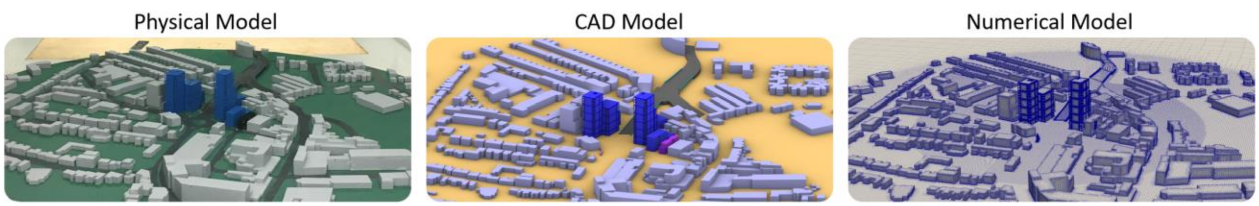

Figure 1. Physical, CAD and numerical models from the 9-11 Palmerston Road experiment.

2.1. Pedestrian Comfort and Safety Assessment

For pedestrian comfort and safety assessment validation, WT testing data for 9-11 Palmerston Road development were used for three different site configurations: existing site conditions, proposed within existing surroundings, and proposed within consented surroundings. The experimental data were recorded for 16 wind directions (every 22.5 degrees), using 82 Irwin probes. Figure 2 presents CFD results of worst seasonal comfort assessment at the 82 measurement locations, 73 of which demonstrated good correlation with the experimental data.

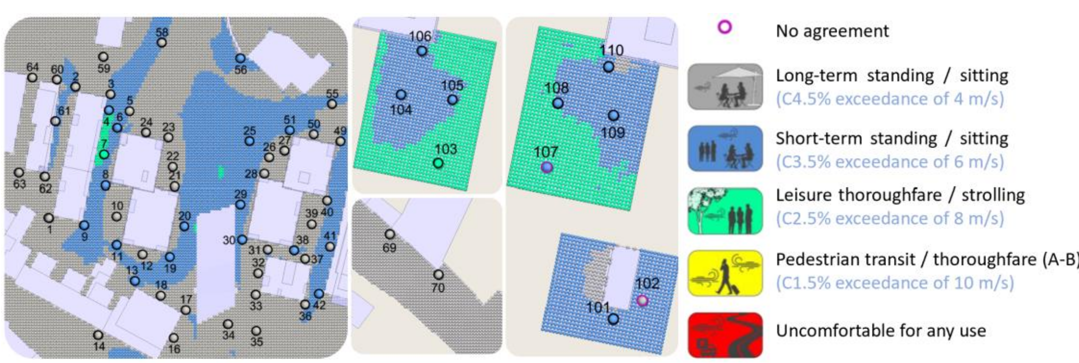

Figure 2. Lawson LDDC Criteria CFD Results – Worst seasonal comfort**.**

2.2. Mean Wind Loading Analysis

In the context of mean wind loading analysis, the proposed technology is validated based on WT testing data for Petra Tower developments for a single site configuration. The experimental data were recorded using 365 pressure taps for 36 wind directions (every 10 degrees). Figure 3 presents comparative results of the pressure coefficients calculated at 16 different locations, placed at a vertical distance of 25 meters from the ground level.

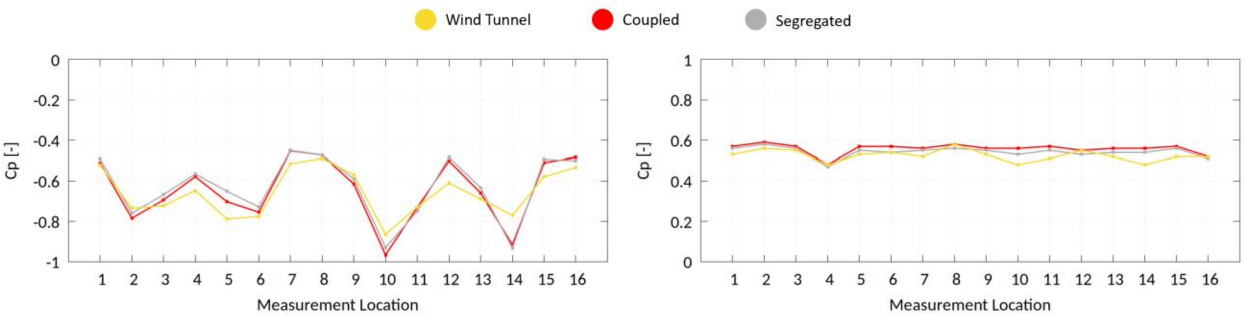

Figure 3. Pressure coefficient calculated at 16 locations, placed at +25 m above ground level.

2.3. Coupled-solver Convergence Rate Quantification

Throughout the course of the study, the block-coupled solver algorithm consistently demonstrated faster convergence rate compared to the segregated solver. Figure 4. presents comparative results of the velocity field convergence rate measured at four different locations.

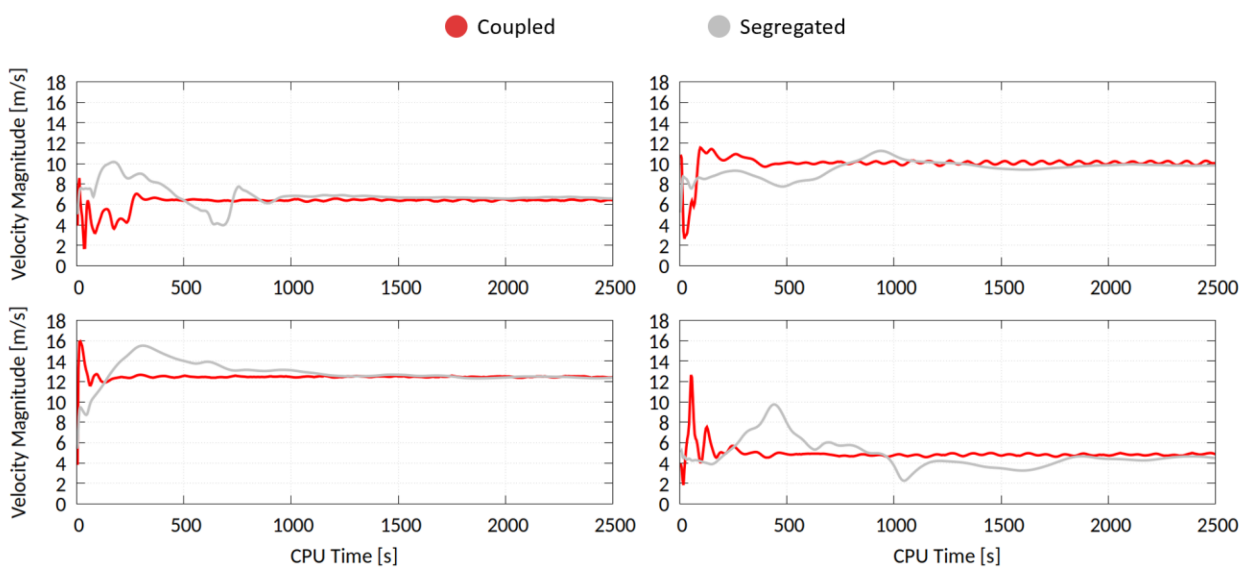

Figure 4. Velocity field convergence rate – segregated vs. block-coupled solver.

3. CONCLUSIONS & FURTHER WORK

The current paper offers an extensive validation study which highlights the efficiency and reliability of the novel simulation tool introduced by ENGYS:

- Good correlation has been observed between WT testing data and simulation results for the pedestrian comfort and safety assessment. For the measurements marked as “no agreement”, marginal deviation (within 20% of the WT testing data) for the probability of exceedance was observed.
- Amongst k-epsilon and k-omega SST models that were employed for pedestrian comfort and safety assessment, the latter consistently demonstrated better performance in terms of accuracy.
- Pressure coefficient was over-predicted at most of the measurement locations.
- The compromise in accuracy observed for the mean wind loading analysis, due to RANS model's inability to capture the oscillating behaviour of the flow, underlines the fact that Unsteady RANS or Large Eddy Simulation (LES) modelling approaches should be considered for accurately modelling this type of application.
- The utilization of MIF along with the block-coupled solver has resulted in significantly lower turnaround time for a complete urban microclimatic assessment.

In the context of this validation and verification study, a pollutant dispersion analysis has already been completed using data provided by AIJ (Yoshie et al., 2012) and will be presented in a separate publication. As part of supplementary work, wind driven rain deposition will also be validated using field measurements (Briggen et al. 2009, Blocken et al., 2012).

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