

RANS for wind microclimate assessments: systematic testing of common modelling deficiencies against full-scale data

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SUMMARY

Pedestrian-level wind (PLW) assessments have become a routine component of the UK planning process for major urban developments, particularly in dense urban environments such as London. In this context, computational fluid dynamics (CFD)—and Reynolds-averaged Navier–Stokes (RANS) modelling in particular—has emerged as the dominant assessment tool, owing to its flexibility, comparatively low computational cost, and suitability for rapid design iteration. Despite widespread adoption, current guidance provides limited quantitative criteria by which the reliability of RANS-based PLW simulations can be evaluated, particularly in the absence of wind tunnel testing. This study investigates whether simple, adoptable success metrics can be defined for RANS-based pedestrian wind modelling that improve agreement with full-scale measurements while remaining compatible with industry constraints. Using rare full-scale data from eight pedestrian-level locations in a dense urban environment, a structured parametric study examines the influence of mesh quality, geometric fidelity, near-wall treatment, turbulence modelling, domain extent, and atmospheric boundary layer consistency. The work aims to distinguish avoidable modelling deficiencies from inherent RANS limitations and to support more transparent and defensible planning-led wind microclimate assessments.

Keywords: RANS, Wind Microclimate Assessment, Pedestrian Level, Parametric Study

1. INTRODUCTION

1.1. Pedestrian-level wind assessment in UK planning practice

In the United Kingdom, pedestrian-level wind (PLW) assessments are now a routine component of the planning process for major urban developments. Wind Microclimate Assessments (WMAs) are commonly submitted alongside environmental statements and design-and-access documentation, and their conclusions can materially influence both planning outcomes and design schedules. This is particularly evident in dense urban environments such as London, where complex building arrangements frequently give rise to wind discomfort or safety concerns at pedestrian level.

In this context, CFD—and steady-state RANS modelling in particular—has become the dominant assessment tool within industry practice. Its widespread use is driven by perceived flexibility, relatively low computational cost, and compatibility with iterative design workflows. As a result, the majority of WMAs submitted in the UK rely primarily, and often exclusively, on RANS-based CFD predictions.

1.2. Current guidance and the absence of quantitative controls

The City of London Wind Microclimate Guidelines, which are widely referenced across the UK, explicitly recognise both CFD and wind tunnel testing as acceptable methodologies for pedestrian wind assessment when appropriately justified. However, while these guidelines define assessment

criteria and reporting requirements, they do not prescribe quantitative controls on CFD model quality. In particular, they provide no explicit thresholds for mesh resolution, geometric fidelity, turbulence modelling, near-wall treatment, or atmospheric boundary layer (ABL) consistency.

As a result, practitioners and planning officers are left without simple, defensible metrics by which the reliability of a RANS simulation can be judged, unless a supporting wind tunnel study is available for the largest developments. In practice, many WMAs are therefore produced and reviewed in the absence of explicit methodological benchmarks, leading to significant variability in modelling quality across the industry.

1.3. Market pressures and the risk of methodological degradation

This lack of quantitative guidance has become increasingly consequential. The rapid expansion of cloud-based computing and open-source CFD software has substantially lowered the barrier to entry for numerical wind modelling. While this democratisation has clear benefits, it also enables the production of CFD studies by users with limited computational wind engineering training. In the UK planning context, this has the potential to undermine consultants who have invested in validated and robust workflows, by promoting a perception of CFD as a quick and inexpensive box-ticking exercise.

The UK market for WMAs is therefore characterised by a large volume of RANS-based PLW assessments that are rarely validated against full-scale data and are evaluated by planning officers who may lack specialist expertise in CFD. Furthermore, the absence of clear best-practice thresholds has fostered a confrontational culture around third-party reviews, leading some councils—most notably the City of London—to actively avoid expert review processes.

1.4. Disconnect between academic research and industry practice

A further complication is that practitioner-led studies are seldom published in the peer-reviewed literature. Consequently, much of the applied knowledge underpinning industry practice remains inaccessible to the research community. Conversely, much of the academic literature focuses on idealised geometries, wind tunnel validation, or large-eddy simulation (LES) studies that are not directly transferable to the constraints of planning-driven assessments.

This disconnect has left a notable gap in the literature. While the limitations of RANS modelling for complex urban flows—particularly in wake-dominated regions and for gust-related quantities—are well documented, there is limited guidance on how practitioners and regulators might distinguish between poorly configured RANS simulations and those that, while imperfect, deliver bounded and defensible predictions.

1.5. Objectives and scope of the present study

Against this backdrop, the present study addresses the following practical question: can simple, adoptable success metrics be defined for RANS-based pedestrian wind simulations that improve reliability without rendering routine practice infeasible? The study does not seek to demonstrate that RANS can replicate all aspects of pedestrian-level flow physics, nor to challenge the value of higher-fidelity approaches. Instead, it focuses on identifying conditions under which RANS performs acceptably and translating those conditions into metrics that are intelligible to both practitioners and non-specialist reviewers.

2. FULL-SCALE MEASUREMENTS

Full-scale measurements are used as the primary reference for validation. Eight pedestrian-level locations were instrumented in 2017 with three-dimensional sonic anemometers within a dense urban environment characterised by channelling effects, corner accelerations, and wake interference. Two high-wind days were selected to ensure relevance to pedestrian comfort and safety thresholds and to minimise uncertainty associated with low-wind variability.

Measured quantities include mean wind speed, turbulence statistics, and Gust Equivalent Mean (GEM) values at pedestrian height. These data provide a rare opportunity to evaluate RANS-based CFD predictions directly against real urban flows under controlled synoptic conditions.

3. NUMERICAL MODELLING FRAMEWORK

3.1. General modelling approach

CFD simulations are configured to replicate the measured inflow conditions corresponding to the selected events, rather than to generate long-term Lawson Criteria exceedance maps. Steady-state RANS is employed throughout, reflecting standard industry practice in UK WMAs.

The modelling approach follows established best-practice guidance for steady RANS applied to the built environment. However, the study deliberately incorporates modelling deficiencies commonly observed in industrial practice within a structured parametric framework, with the aim of identifying failure modes and defining practical thresholds.

3.2. Parametric study design

The study focuses on six modelling aspects that are both influential for solution quality and routinely configurable in applied studies. The intention is not to exhaustively explore parameter space, but to identify combinations and limits that reduce the risk of unreliable outcomes.

Table 1: Proposed parametric study items and indicative ranges.

No.	Parameter category	Metrics / variables	Tentative values or ranges
1	Mesh resolution and topology	Total cell count; skewness; non-orthogonality; prism growth rate	~2–5M, ~10–20M, ~60–100M cells; skewness < 0.85; non-orthogonality < 70°; growth 1.1–1.3
2	Geometric fidelity	Alignment; surface faceting; ground–building junctions	Misalignment $\pm 0.5^\circ$ – 2° ; facet size 0.5–2.0 m; gaps 0–0.2 m
3	Near-wall prism layers	Number of layers; first-layer height; y^+	5–20 layers; $y^+ \approx 1$ (low-Re) and 30–100 (wall functions)
4	Turbulence model compatibility	Closure type; wall treatment; discretisation	realisable k – ϵ ; k – ω SST; first/second order
5	Surroundings extent	Domain size; inclusion radius	Upstream 5H–10H; downstream 10H–20H; radius 300–800 m
6	Roughness and ABL consistency	z_0 ; k_s ; inlet–wall matching	$z_0 = 0.03$ – 1.0 m; matched shear stress profiles

3.3. Evaluation metrics

Simulation results are evaluated against full-scale measurements using velocity ratios, bias, correlation metrics, and GEM-based classification consistency. Particular emphasis is placed on identifying failure modes that are likely to arise in uncontrolled industry practice.

4. DISCUSSION AND CONCLUSION

The results are interpreted in the context of current planning-led CFD practice. Rather than framing discrepancies solely as evidence of fundamental RANS inadequacy, the analysis differentiates between unavoidable modelling limitations and deficiencies arising from poor configuration choices. This distinction is critical for both practitioners and regulators seeking to assess the credibility of CFD-based WMAs.

This study demonstrates that explicit, adoptable success metrics can be identified for RANS-based pedestrian wind simulations using full-scale validation data. While RANS cannot capture all aspects of complex urban flow physics, appropriate modelling choices significantly improve reliability within realistic industry constraints. By translating these conditions into clear, auditable metrics, the work supports a more transparent and defensible approach to pedestrian wind assessment that acknowledges both the limitations of RANS and its continued central role in planning practice.

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