HARMONISING WIND COMFORT: COMPARATIVE ANALYSIS OF PEDESTRIAN WIND COMFORT USING OPEN-JET AND BOUNDED-TYPE WORKING SECTIONS

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ABSTRACT

This paper presents the findings of wind tunnel testing conducted for a high-rise tower within a typical urban context with the aim to compare the pedestrian wind comfort conditions obtained from two different wind tunnel configurations – a closed-circuit wind tunnel with a bounded-type working section and the open-jet wind tunnel where the working section is located outside the mouth of the tunnel. Models of the proposed development and surrounding buildings, constructed at a 1:400 scale, were independently fabricated in India and Canada. Each model was equipped with omni-directional Irwin Sensors to record wind speeds. Wind data from Bankstown Airport served as the regional reference for climate and the Lawson Criteria was used to assess the wind comfort conditions. Both tunnels are routinely calibrated to replicate approach wind speeds and turbulence profiles as closely as possible. For the tests, the boundary layer profile applied to all 36 wind directions tested was equivalent to a Terrain Category 3. The comparison of test results reveals consistent pedestrian wind comfort conditions between the two working section setups. Minor variations, occurring in localised areas, show at most a difference of one wind comfort category. These discrepancies, attributed to inherent variability from independent construction and testing by different teams in distinct facilities, occur when measurements are close to the criteria threshold. Importantly, an analysis of the velocity ratios indicates no systematic bias favouring either wind tunnel, suggesting that for routinely calibrated wind tunnels neither the open-jet nor the bounded-type working sections consistently produce windier or calmer results.

INTRODUCTION

The importance of understanding and assessing the wind environment around buildings has gained significant attention in recent years. As urban areas grow denser and high-rise developments become more common, ensuring pedestrian wind comfort and safety has become a critical aspect of urban planning and architectural design (Stathopoulos, 2009). Inadequate consideration of wind effects can lead to uncomfortable or even hazardous conditions for pedestrians, as well as adverse impacts on building performance and energy consumption.

Atmospheric Boundary Layer (ABL) Wind Tunnels remain a cornerstone of wind environment assessment and are typically a requirement of the planning process to assess wind conditions around a site. These facilities simulate natural atmospheric conditions by generating a boundary layer that closely replicates real-world wind patterns and can resolve the various length and time scales of natural wind if properly calibrated (Holmes, 2007). ABL wind tunnels can generally be classified into two main types: open-jet and closed-circuit wind tunnels. In an open-jet wind tunnel, air flows through the test section and is released into the atmosphere. Conversely, a closed-circuit wind tunnel recirculates air within an enclosed loop.

An alternative classification can be based on the placement of the test section either inside the tunnel, leading to a bounded-type working section, or outside the tunnel such as is commonly done for open-jet tunnels. A key issue that follows the placement of the working section of the tunnel pertains to blockage which is defined as the maximum projected area of the near field simulation (subject building and the surrounding context) and the wind tunnel cross sectional area (AWES QAM 2019). Blockage is a complex issue in environmental wind engineering due to the variability of building shapes and surrounding contexts. In bounded flow, care must be taken to avoid high blockage effects (typically should be lower than 10% per the AWES QAM 2019) as this can artificially accelerate wind speeds within the tunnel. On the other hand, in the case of open-jet tunnels with the working section outside the tunnel mouth, the typical definition of blockage is not applicable. However, these must be designed to prevent potential decelerations of winds as these exit the tunnel. While studies have been undertaken comparing the results from the two different setups that show a good agreement in the overall wind responses, these are often limited to the effects of wind loading on the building (Lamberti *et al.* 2020; Cook *et al.* 2006) and not the effect of the building on the local wind environment.

To this end, this paper investigates the pedestrian wind environment results obtained from the two types of working sections: a conventional bounded-type working section within a closed-circuit wind tunnel and an open-jet configuration where the working section is situated outside the tunnel. The study aims to compare the results from these different setups and address any possible implications of blockage effects on wind comfort predictions for a high-rise tower within a typical urban context.

EXPERIMENTAL SETUP

The development under assessment was a high-rise building located within a typical urban context. To evaluate the wind environment around this development, 1:400 scaled models of the site and its surroundings were constructed independently by the model-making teams in India and Canada. The wind tunnel models included all relevant surrounding buildings and topography within a radius of approximately 480m, centered at the development site. Each model was equipped with omni-directional 'Irwin' wind speed sensors, following the same sensor layouts to ensure consistency.

These models were then tested in their respective wind tunnels at two facilities: the open-jet wind tunnel at RWDI's facility in Trivandrum, India, and the closed-circuit wind tunnel with a bounded-type working section at RWDI's facility in Guelph, Canada. The open-jet wind tunnel features an outlet duct that is 2m high and 2.4m wide, directing air towards an open working section containing a 3m diameter turntable. The closed-circuit wind tunnel has a bounded working section that is 2.4m high and 3.6m wide, with a 3m diameter turntable. Note that at a 1:400 scale the surrounding model occupies a diameter of 2.4m atop these turntables. Wind tunnel test models are shown in Figure 1.

Both wind tunnels are routinely calibrated to produce the same wind speed and turbulence profiles in the atmospheric boundary layer beyond the modelled areas. The boundary layer profile used in the assessment, applied to all 36 wind directions tested (10-degree increments), is classified as Terrain Category 3 based on Australian Standards. Furthermore, the wind statistics recorded at Bankstown Airport, corrected for terrain, were analysed for the period between 1993 and 2018 (inclusive) for the summer and winter seasons to be used as reference to calculate full-scale wind speeds on site. The full-scale winds were then compared with the Lawson Criteria for pedestrian wind comfort (Lawson 1973) to assess wind conditions around the site for the two test configurations.

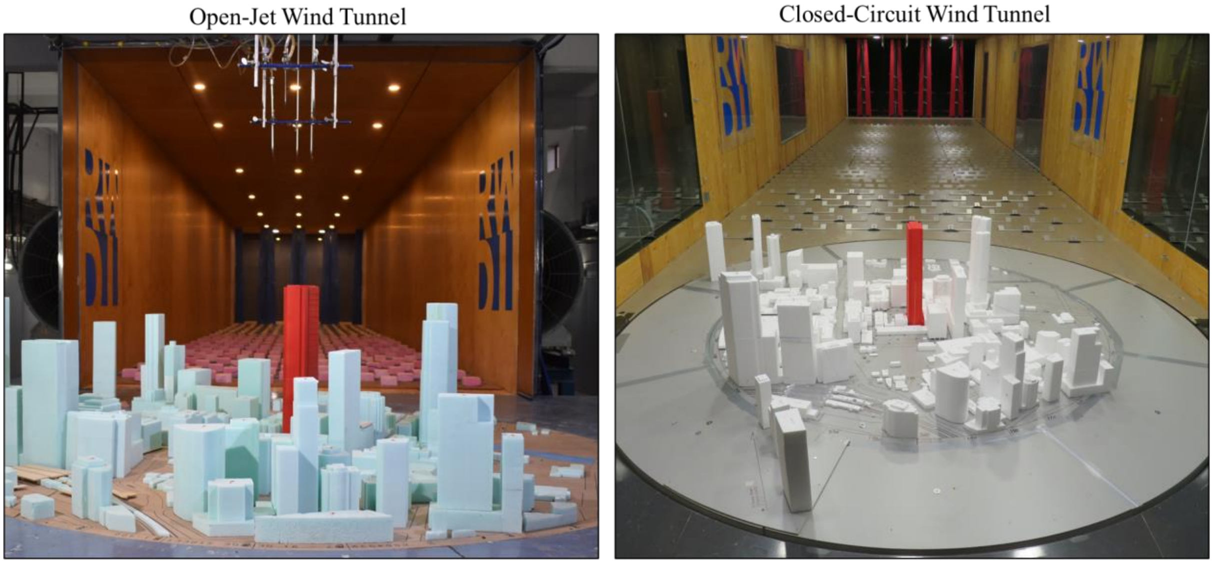

Figure 1. Photographs of Study Models in the Wind Tunnels

RESULTS AND DISCUSSIONS

Figure 2 presents the wind conditions around the site for both the summer and winter seasons, comparing results from the open-jet and bounded-type working sections. The data is illustrated using dot plots that categorise space usage according to the Lawson Criteria for wind comfort.

The comparison shows that wind comfort predictions are generally consistent between the two wind tunnels. Minor variations, highlighted in Figure 3, indicate differences of at most one wind comfort category in localised areas. These variations manifest as either slightly windier or calmer conditions and occur in regions where the numerical wind speeds are close to the threshold between categories. The median percentage change between the two sets of results is approximately 7% when considering all sensors. For typical sensors, the variation in measurements was found to be between 2% - 5%.

Such differences are not unexpected, given the slight inherent variability arising from the independent construction of the models by two different teams and their testing in different facilities. Crucially, there is no significant, systematic bias in the results that would suggest either type of wind tunnel consistently produces windier or calmer conditions. This finding supports the reliability and comparability of both testing approaches.

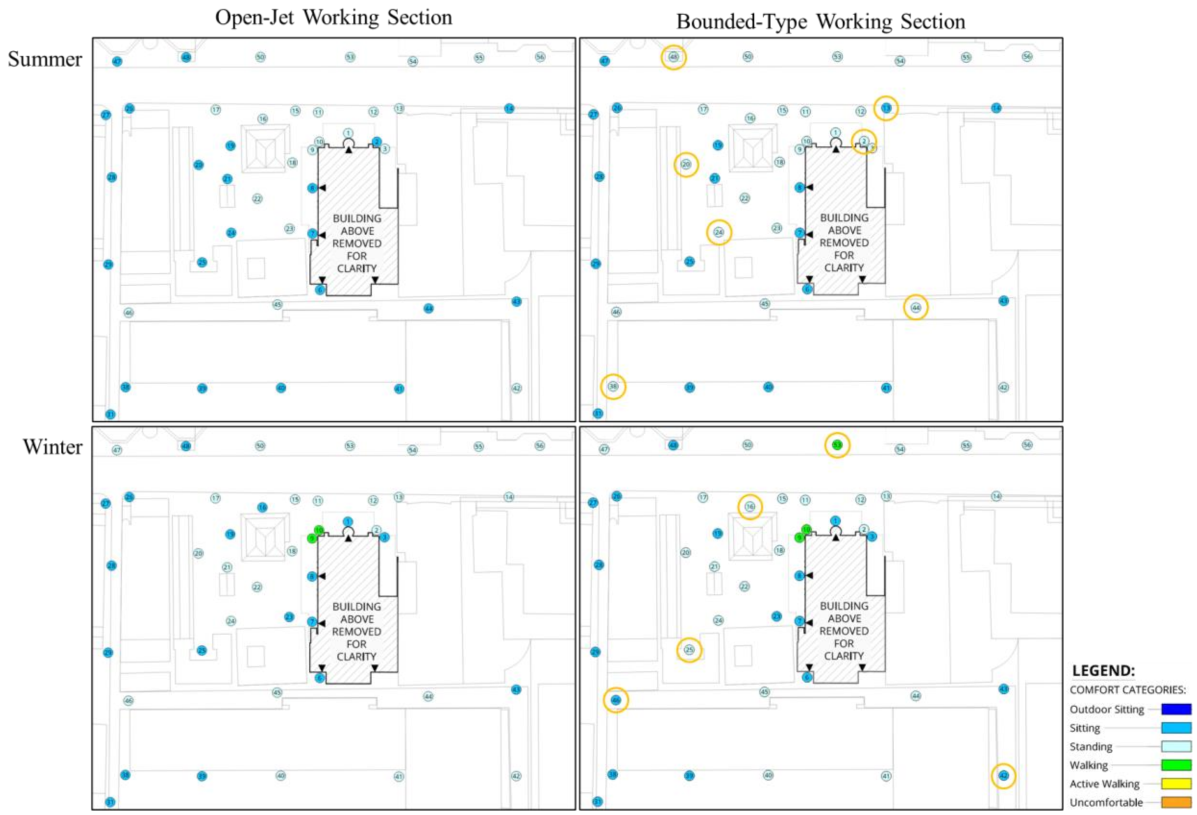

Figure 2. Comparison of Wind Comfort Conditions for Open-Jet and Bounded-Type Working Sections with Areas of Differences Marked

Figure 3 illustrates the mean wind speed coefficients for the 36 wind directions assessed at key sensor locations where the largest differences in wind speeds were observed. The variation in mean velocity is relatively consistent for Sensors 25, 38, and 53. However, Sensor 48 shows a larger change for winds approaching from the east sector (110-170 degrees).

Upon closer inspection, it was found that this discrepancy originated from a missed awning on the surrounding building in the model used for the test in the closed-circuit wind tunnel (Figure 4). This omission resulted in slightly higher exposure to east winds, thus altering the velocity distribution profile from the directions noted. The typical variation of wind velocity as a function of wind direction, however, remains similar between the two wind tunnels for all other directions. Hence, the overall impact of this discrepancy on the comfort prediction is small.

It is noteworthy that even minor omissions in the details incorporated into surrounding models can result in variations in wind comfort predictions. If higher wind recordings from the wind tunnel were to coincide with strong winds from a different meteorological station, it could lead to a prediction of adverse wind conditions. However, as the meteorological data for this assessment was obtained from Bankstown Airport, where typically mild winds prevail due to its inland location, the overall wind environment predictions remain largely unaffected. This underscores the importance of accurate details in the model, though it does not materially impact the comparison of tunnel types in this instance.

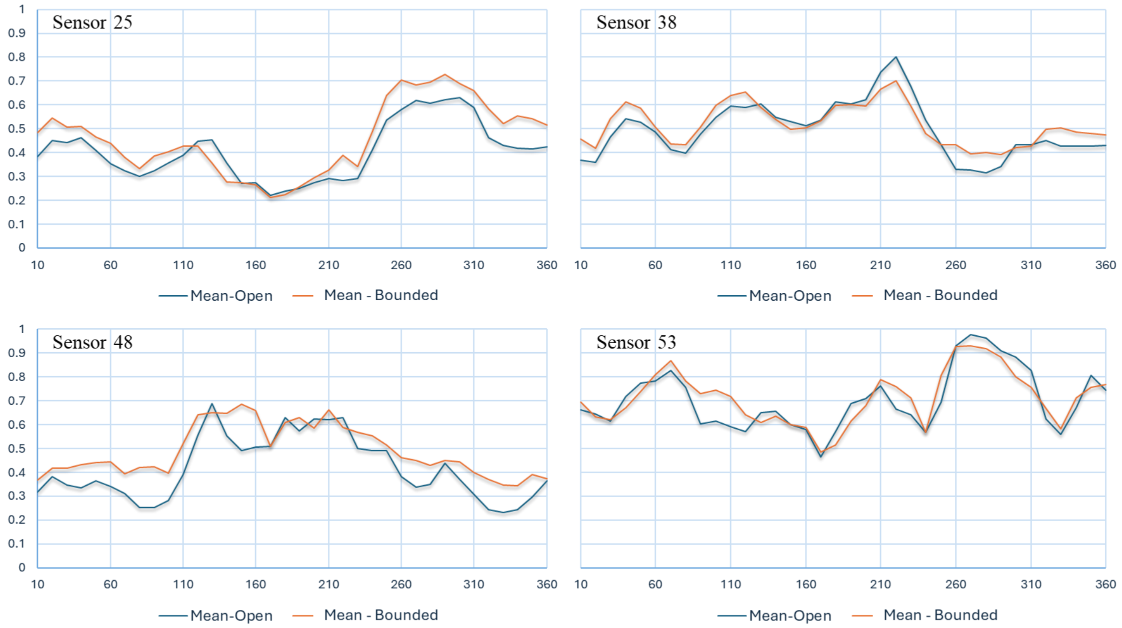

Figure 3. Mean Velocity Coefficients obtained from the Open-Jet and Bounded-Type Working Sections for Key Sensor Locations

Open-Jet Working Section Bounded-Type Working Section

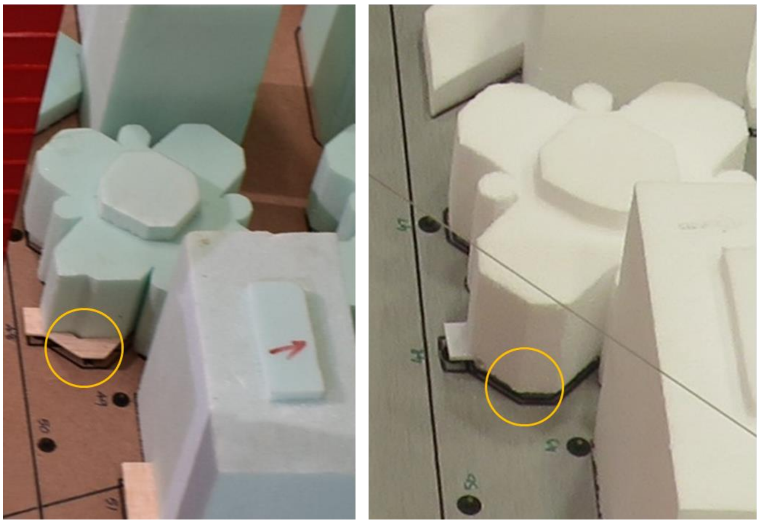

Figure 4. Missing Awning on the Surrounding Building Impacting Comfort Predictions

CONCLUSION AND RECOMMENDATIONS

This study investigated the pedestrian wind environment around a high-rise development within a typical urban context using two different setups for a working section of a wind tunnel: an open-jet working section and a bounded-type working section. The main objective of the study was to assess the comparability of wind comfort predictions from these two setups and to understand the impact of blockage effects on the results.

The wind tunnel tests were conducted on 1:400 scale models, independently constructed and tested at facilities in India and Canada. Both wind tunnels were calibrated to replicate the same wind and turbulence profiles ensuring consistent test conditions. The wind comfort predictions were evaluated against the Lawson Criteria using wind data from Bankstown Airport.

The results show that wind comfort predictions are consistent between the open-jet and bounded-type working sections. Minor variations were observed in localised areas with differences of at most one wind comfort category for measurements that were close to the threshold for the category. These variations were attributed to inherent variability in model construction and testing. Despite these minor differences, there was no significant systematic bias favouring either wind tunnel setup and no apparent impact of flow decelerations on predictions obtained from an open-jet tunnel.

Based on the findings, the following recommendations are made for future studies and practical applications for assessment of wind comfort using wind tunnels:

- Ensure a high level of detail in the construction of surrounding models. Typically, wind tunnel tests for urban microclimate studies do not incorporate smaller architectural elements on surrounding buildings, often because comparisons are made between the existing and proposed sites to assess the building's impact on the local wind environment. However, this approach may not accurately predict actual site wind conditions. Including appropriate details, such as awnings or other substantial features, especially in areas where sensors are placed within the surrounding context, is crucial to an accurate estimation of wind conditions. It is recommended that these considerations be included in the next revision of the AWES Quality Assurance Manual.
- It is important to be mindful of blockage effects, and test setups should be designed to minimise these impacts. This can typically be achieved through the use of open-jet tunnels or by ensuring that a bounded-type working section is designed to be blockage-tolerant with the surrounds offset sufficiently from the walls of the tunnel to reduce potential wall effects.
- Maintain regular calibration of wind tunnels to ensure consistent replication of atmospheric boundary layer profiles. This is essential for the accuracy and reliability of the wind comfort predictions.
- Conduct cross-validation using different wind tunnel setups when possible to enhance the reliability of wind comfort predictions. This approach is particularly useful for high-rise projects, as it allows for the verification of results across different testing environments.

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