

CFD analysis of interior architectural details on interior air quality and exterior comfort

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SUMMARY

Wind assessments typically isolate interior ventilation and pedestrian-level wind (PLW) studies at different scales for computational efficiency, yet exterior and interior conditions interact. Few studies examine how interior geometries (window configuration, location, volume) simultaneously impact external PLW and internal ventilation. This study uses RANS CFD to assess the CAARC building in downtown Toronto with three interior first floor configurations, closed windows, and single and double-height spaces with single windows on each face. Simulations include two dominant wind directions (west and east-northeast) that document velocities at pedestrian height (1.5m) and interior air change rates. The results show that along with wind direction, interior volume significantly affects air change rate while opening windows impacts the exterior pedestrian level winds. Interior scale geometries can impact both interior and exterior wind topics, it is necessary to create a multi-scale framework to anticipate these coupled wind effects and enable conscious wind-integrated design in practice.

Keywords: *Pedestrian Level Winds, ACH, Interior flow, CFD, Framework*

1. INTRODUCTION

Wind assessments typically isolate specific scales for specific topics such as interior ventilation to window/room scales, pedestrian-level wind (PLW) to building scales specifically for computational efficiency. However, design changes at one scale can inadvertently affect another through air and go unchecked without iterative re-testing. In literature, the CAARC building is the standard model used mostly for external pressures and structural response but none considering interior nor near ground flow. Outside of the CAARC building, there are other studies that address PLW across urban scales and interior ventilation through window placement and airflow paths. While it is not common to find studies that examine how interior-scale geometries (window configuration, location, volume) impact both external PLW and internal ventilation simultaneously, occasionally low-rise studies consider exterior geometry effects on interior flow and some pair modeling strategies like building simulation with CFD (Computational Fluid Dynamics). However, larger scale and single use program that couple interior and exterior effects remain underdeveloped. This study aims to identify geometric relationships simultaneously affecting pedestrian comfort and interior air change rates, bridging the typical separation between exterior and interior wind assessment methodologies.

2. METHODS

The widely studied CAARC (Commonwealth Advisory Aeronautical Research Council) building (40x30x182m), with interior modifications, is used in place of a similar sized existing building

within the surroundings of downtown Toronto, Ontario, Canada. A computational fluid dynamics-based approach is used to measure wind flow due to different metrics of interior scale geometry.

2.1. Case Study

The study building used is based on the CAARC building with interior geometry modifications for each configuration. The first floor has been represented with a typical building core measuring 6x20.72m and the external walls have a thickness of 0.5m. The study building has replaced a building of similar size in a realistic city setting of Toronto, Canada and is set at the center of a 350m radius of surrounding buildings. Two different geometrical configurations have been tested to outline the impact of interior scale geometrical changes on the surrounding wind flow. The configurations include a building with enclosure (windows closed), a building with a single height (3m) interior enclosure (3227 m³ volume) with a single window placed on the center of each side wall measuring 1.6m x 3.125m centered on either 1.5m from the ground, and a double height 6.5m tall interior space (6992 m³ volume) with a single window placed on the center of each side 1.5m from the ground. (2.5% and 1.7% window to wall ratio) as seen in Figure 1c).

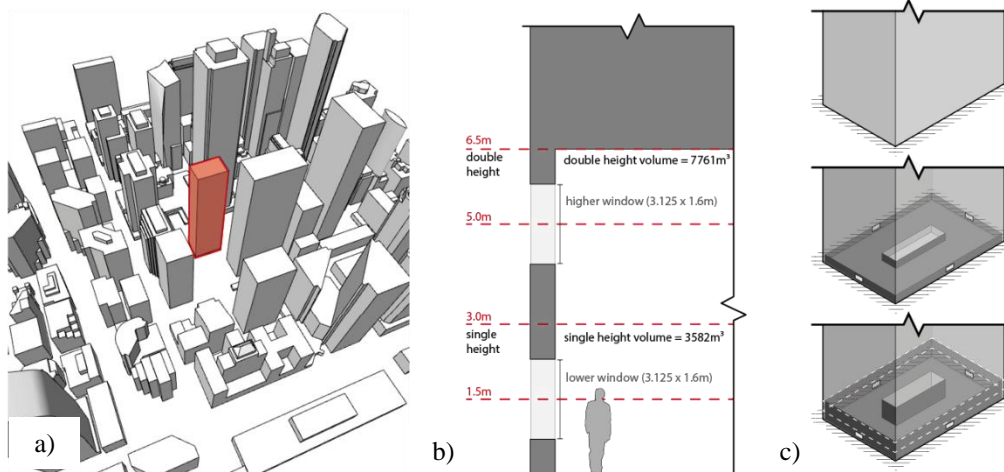


Figure 1: a) Study building with surroundings, b) section of interior, c) 3 Configurations

2.2. Meteorology

The dominant angles of attack (AOA) in the Toronto area are used in the study. The west winds, which approach the city at an oblique angle and the east-northeast winds that approach from a parallel direction aligned with the building faces have been simulated and the wind field assessed at a height of 1.5 m above the ground (pedestrian height). The reference wind speed is 10m/s at a 10m height.

2.3. Criteria

While this study aims to demonstrate the interior and exterior changes in flow due to small scale geometrical changes, it is important to note that the results will change per specific climate and criteria of geographic location. For the pedestrian level winds, there is a variation in criteria by experts and regions as to which wind velocities are “comfortable” due to climate specific qualities outside of wind speed itself. Therefore, a criterion that is widely used for Toronto-like areas by wind consultants based on recommendations by ASCE and Lawson documented by Janssen 2013 has been selected which includes: sitting ≤ 2.7 m/s, standing ≤ 4.1 m/s, walking ≤ 5.5 m/s, uncomfortable > 5.5 m/s. For interior air flow, ACH (air changes per hour) measures how many

times interior air is replaced with outdoor air in 1 hour (per a specified volume) will be used to determine quality of interior air. ACH is calculated by $ACH = \frac{CFM \times 60}{Room\ Volume\ (ft^3)}$. A higher ACH removes pollutants and other airborne debris and is highly dependent on the size of the space, the use of the space, and the density of people in that space. It is useful to consider the natural ACH value that can be achieved with a direct connection to exterior environment and how interior scale geometrical changes can alter the rate. For this study, a CFM (cubic feet per minute) for a commercial lobby space is used which is 7.5 per person.

3. COMPUTATIONAL SETTINGS

A full-scale model was used with steady RANS equations and a k-epsilon turbulence model. There are a total of 6 simulations (3 configurations with 2 wind directions each (W and ENE)).

This study used similar characteristics for the computational domain as those adopted by Franke et al. (2007), Dagneu and Bitsuamlak, (2013) as can be seen in Figure 2. The boundary conditions

include: the sides and the top of the computational domain have been placed sufficiently far from the study and the surroundings and assigned as symmetry plane boundary conditions, to eliminate the effect of those sides on the flow over the building. The ground and all building faces have been defined as no-slip walls, where the air velocity is set to be still at the surface. The log law was used to generate the ABL of 10m at 10m/s height using the suburban surrounding $z_0 = 0.3$ at the velocity inlet. The computational domain has been discretized using polyhedral control volumes. The grid is divided into six zones and refinements were added to surfaces as well. There were approximately 3,600,000 cells for each model.

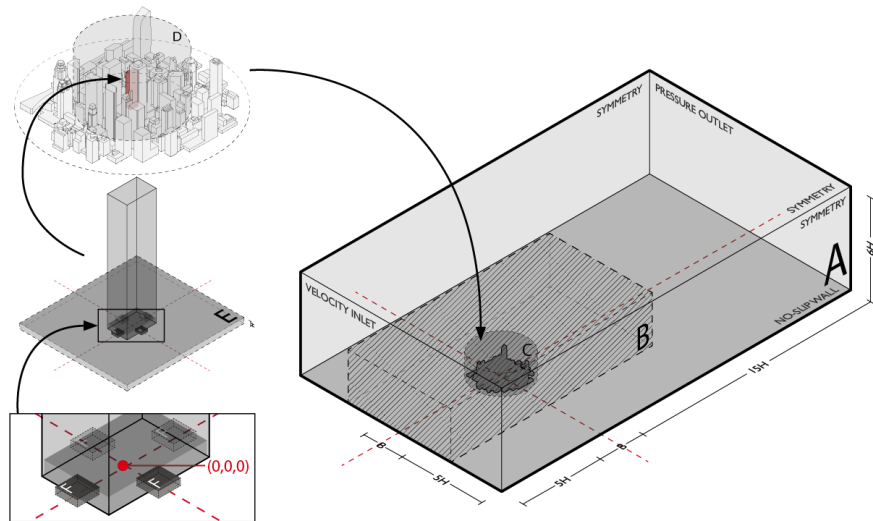


Figure 2: CFD Setup Details

4. RESULTS AND DISCUSSIONS

Figure 3. shows results for the three configurations of the exterior pedestrian level winds and the interior ACH value for the west wind angle of attack.

As West winds approach the solid building (C1) and the windows are opened on all sides of the building (C2), the winds on the north side of the building increase and the wind field west and south of the building changes direction and speed. When the interior volume (C2) doubles (C3), there are minimal changes in the exterior winds but a significant change in interior air flow. In C2, winds typically move faster from the North and West windows across to the East and South windows respectively. Most significantly, the ACH value is higher (1.45 to 6.33) in C2 even though

there are slower winds at 1.5m height. Overall, as the windows are open there is a significant impact on the exterior velocities and as the volume changes from a single height (C2 or double height space C3), there is a more significant impact on interior ACH levels and flow patterns in the interior space.

5. CONCLUSIONS

Interior volume most significantly affects air change rate (ACH), while the opening and closing of

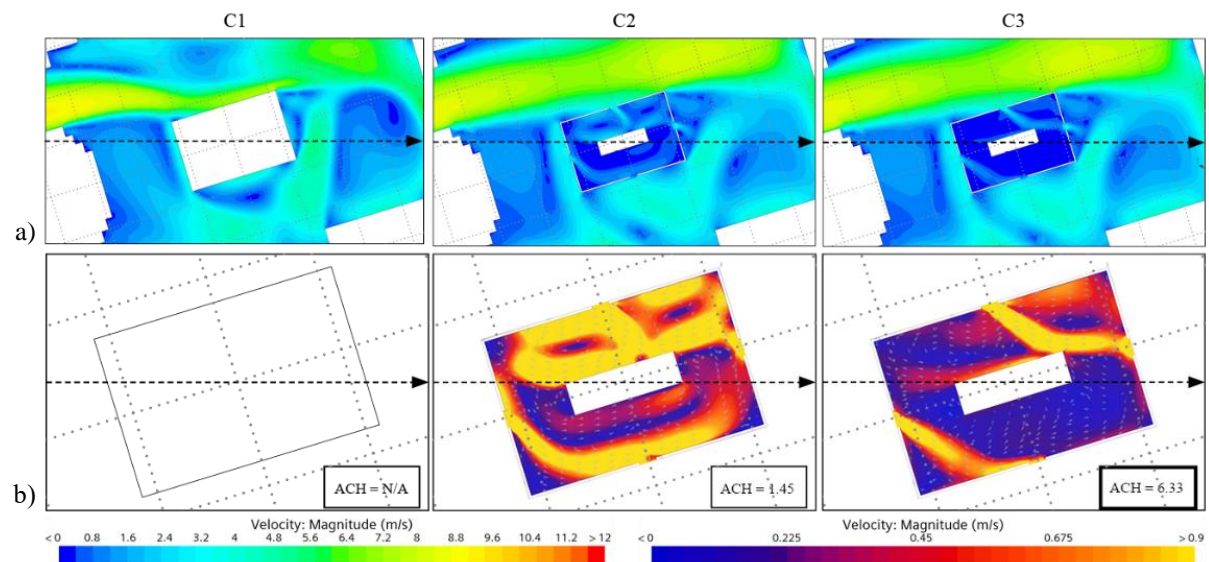


Figure 3: a) Pedestrian level winds. b) Interior air flow and ACH values

windows has a significant effect on the exterior surroundings. Interior volume, window configuration, and location should be considered in both interior and exterior design; simulations can prevent costly redesigns. Further investigation of isolated cases, additional wind directions, and varying window configurations would confirm findings. This research demonstrates that interior-scale geometric choices alter exterior wind conditions typically attributed to building shape alone. A multi-scale assessment framework is necessary to anticipate wind effects and create robust buildings and cities. Enhanced computational tools and visualization can improve wind engineer–architect communication, enabling conscious design with wind—advancing wind integration from specialized analysis toward standard architectural practice.

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