August 27-31, 2023
FLORENCE - ITALY
16th International
Conference on
Wind Engineering

Assessing the impact of interior scale geometry on pedestrian level winds and ventilation in cities

Kimberley Adamek [1], Girma Bitsuamlak [2]

[1]*Western University, London, Canada, kadamek2@uwo.ca*
[2]*Western University, London, Canada, gbitsuam@uwo.ca*

SUMMARY:
The impact of large scale and small-scale geometrical details on the wind environment is often examined separately when resolving wind issues. While it is efficient to focus on one scale at a time, it is also important to know the impact of one building on another - treating the city like an organism. This awareness would allow designers such as architects and planners to integrate wind criteria more thoroughly into design. A design framework using case studies to visualize the relationship between geometric scales and different criterion of wind can help bridge this gap. In this study specifically, the objective is to demonstrate the importance of interior geometry on the competing designs of PLW and ventilation on the exterior vicinity of a building. A study building with varying interior geometries located in an area of downtown Toronto is used as a case study and modelled in CFD. The change in the flow around the building is investigated to assess its optimality for PLW versus ventilation. In the future, additional case studies will be considered to formally layout the architectural building and urban design framework.

Keywords: Pedestrian level wind; ventilation; multi-scale urban design

1. INTRODUCTION

Inherently, cities are designed at multiple scales. From materials, rooms, levels, floors, cladding, building shape, street orientation, to block layout - all aspects of design, and how they relate to one another, impact people. The city itself is a micro-organism where each building plays a role in the sustainability and success of a community – mediating between people and weather. One of the more complicated elements to incorporate into architectural design or urban planning fields is wind. Specifically, it is difficult to fully understand how the many different details of a building change the flow field at different scales (i.e., materials change the flow field nearest to the surface and building shape alters a larger street scale area) and therefore we unconsciously design wind environments we experience. While wind engineering consultants are brought into earlier design stages, there is still a gap in knowledge of understanding wind at different scales of design on the design end. The impact and relationship of large scale and small-scale geometrical details on wind environment is mostly investigated separately. While it is efficient to focus on one scale at a time, it is also important to know the impact of one building on another - treating the city like an organism. Without doing this, we may focus too closely on a single issue; for instance, we may use building shape to improve pedestrian level wind conditions at street level. However, we may overlook that the same pedestrian area gathers pollutants from street traffic and with limited airflow becomes unusable for its main purpose, as seen in Figure 1. We might also focus too closely on one design scale, noticing that building shapes impact pedestrian wind levels, but not noticing how the window openings or interior spaces impact that pedestrian level wind as well. It is useful to create a framework using case studies to visualize the relationship between geometric scales and different criterion of wind. In this study specifically, the objective is to demonstrate the importance of interior geometry on the competing designs of pedestrian level winds (PLW) and ventilation on the exterior vicinity of a building.

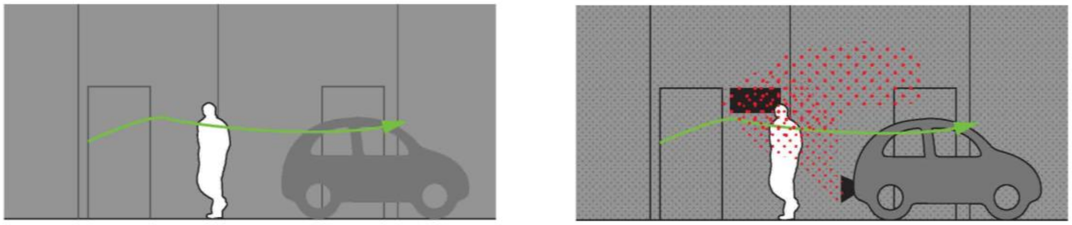

Figure 1. Competing objectives
(left) PLW, (right) Pollutants

2. METHODOLOGY

A computational fluid dynamics-based approach is used to create this framework and a case study to measure different metrics.

2.1. Case study

The physical geometry of a downtown area in Toronto, Ontario is used as the basis for this case study. The CAARC building(40x30x188m), has replaced a building of similar size (see Figure 2 red area) in this area to act as a representative case. The geometry includes all relevant surrounding buildings within a 350m radius centred on the CAARC building. The prevailing winds from the west and east-northeast have been simulated and the wind field assessed at a height of 1.5 m above the ground (pedestrian height). The case study is broken down into 4 cases where the interior space of the first level is altered as seen in Figure 2.

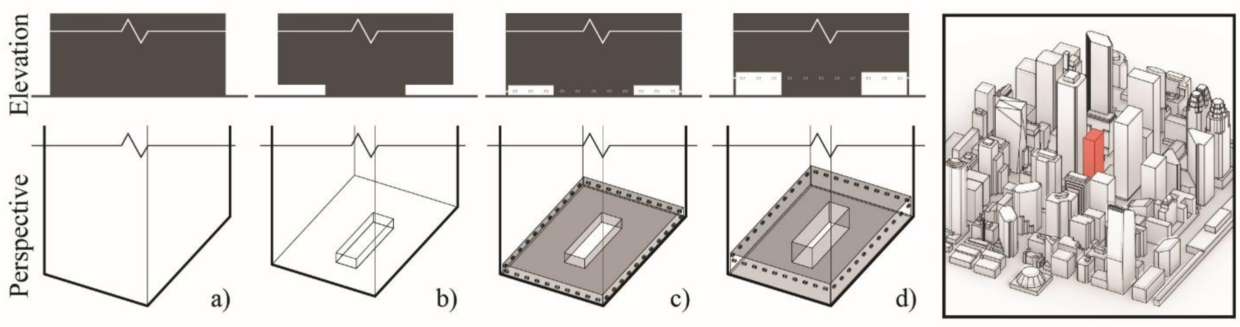

Figure 2. Four cases within urban context of Toronto
a) Base, b) Core, c) Single height interior with windows, d) Double height interior with windows raised

2.2. CFD setup

The 4 cases were simulated in the commercial CFD package STAR-CCM+ using RANS k-epsilon turbulence models. A mean wind velocity of 10m/s at a 10m height is used. The sides and the top of the computational domain have been assigned as symmetry plane boundary conditions, to eliminate the effect on the computational domain. The ground has been assigned an urban roughness and all building faces have been defined as no-slip walls. The computational domain has been discretized using polyhedral control volumes. A gradual mesh refinement is applied to the area of interest. There are approximately 2 million mesh cells for each model.

2.3. Criteria

Initially, the wind field will be solely monitored to determine the changes in velocity and impact distance between cases. Then, both pedestrian level wind criteria and exterior ventilation criteria as they relate to wind velocity will be used to determine the impact and efficiency of the geometrical changes in each case study.

2.3.1. Pedestrian level winds

Generally, there is a variation in criteria by experts as to which wind velocities are "comfortable". Therefore, a criterion that is widely used for Toronto-like areas by wind consultants based on recommendations by ASCE (2004), and Lawson (1973) has been selected. More details can be found in Adamek et al (2017).

2.3.2. Ventilation

The criteria for ventilation will be based on two factors - supply rates and draft rate. The supply rate determines the acceptable indoor air quality based on the acceptable outdoor supply rates, as per ASHRAE standard 62-2001. The airflow rate or air change rate near large openings will be evaluated against these criteria. The draft rate (also called thermal environmental conditions for human occupancy), outlined in ASHRAE standard 55-2010, measures the percentage of people dissatisfied with a given indoor draft speed. Incorporating this can minimize unwanted local cooling of the body due to air movement. Alternatively, the allowable indoor mean air speed (based on room temperature and turbulent intensity) will be utilized to monitor requirements

3. RESULTS AND DISCUSSION

The resultant contour plots for each of the four cases show the velocity magnitude on a horizontal plane located 1.5m from the ground and are calibrated to demonstrate the velocity from 0 m/s to 4 m/s as seen in Figure 3. In the overall view, the wind field acts quite similar based on the overall shape and orientation of the building itself. Upon closer inspection to specific areas, as seen in Figure 4, we can see variances in the flow of up to 10m away from the study building. These variances, at human scale, impact pedestrians inside and outside the building. In case B, by opening up the gorund floor, there is an increase in wind speed along the South and Northeast side of the building.

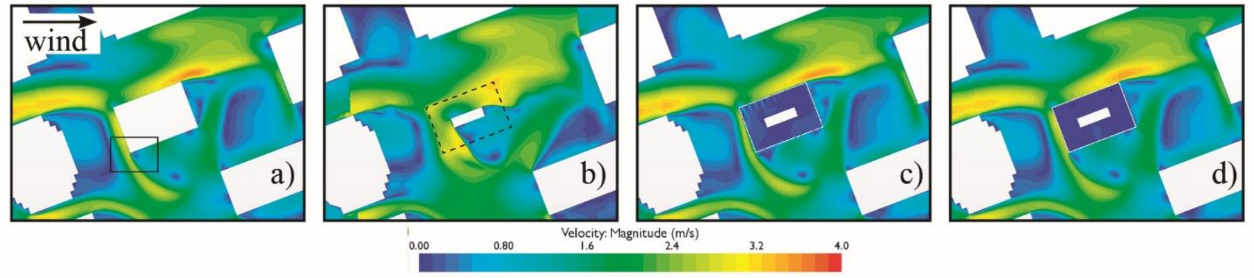

Figure 3. Case result (wind velocity at 1.5m above grade)

In case C, by introducing a row of windows on the first floor of the building, the flow stagnates on the south side while the higher velocities on the west side have increased in area. This could potentially improve PLW conditions but reduce ventilation quality. While the wind field is relatively consistent between cases A and D (even with the introduction of windows on the second level), it is possible that with a different wind direction – one that provokes downwashing along one face of the building, more significant changes might be seen.

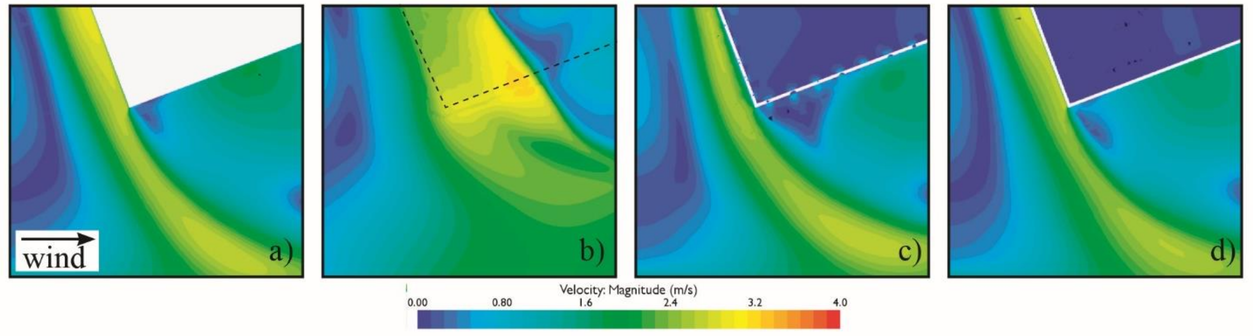

Figure 4. Close up of case result (wind velocity at 1.5m above grade)

4. CONCLUSIONS

This research highlights how the design of different scales of a building and adjacent buildings alters wind velocity conditions that can impact different wind criteria. The design of interior scales can impact winds typically attributed to overall building shape design. Further, the PLW and ventilation criteria will be assessed to evaluate the success of the differences in geometry. The plan is to determine if the change in interior spaces can significantly influence one criterion such as ventilation while not impacting PLW as much. A framework for assessing building geometry at multi-scales in relation to wind is necessary to anticipate wind flow fields and their associated wind criteria to create more robust buildings and cities. If incorporated into design, this framework, and others like it, can enable a new type of thinking and approach to wind in design. While not yet a standard in architectural practice, further developments in computational services, three-dimensional visualizations, and full-scale simulations can make these methods more accessible. The intent is that the visual nature of this research will improve the communication between wind engineers and architects and allow designers to consciously design with wind.

ACKNOWLEDGEMENTS

Thank you for various useful discussions with members of our research group at Western University, and to Sharcnet for their computational resources that allow this research to occur.

REFERENCES

Adamek, K., Vasan, N., Elshaer, A., English, E., Bitsuamlak, G. 2017. Pedestrian Level Wind Assessment through City Development: A Study of the Financial District in Toronto. Sustainable Cities and Society, Volume 35, Pages 178-190, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2017.06.004.

ASCE Task Committee on Outdoor Human Comfort (2004). Outdoor Human Comfort and Its Assessment, 68 pages, American Society of Civil Engineers, Reston, Virginia, USA.

Lawson, T.V. "The wind environment of buildings: a logical approach to the establishment of criteria." Report No. TVL 7321 (1973).