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Building Performance: A new Look at The Operability of Exterior Doors from Wind Force and Stack Effect Perspectives

Rose Babaei [1], Vincent Tang [1], Hanqing Wu [1]

[1]*Rowan Williams Davies & Irwin Inc., Guelph, Ontario, Canada,* *Rose.Babaei@rwdi.com*
Vincent.Tang@rwdi.com
Hanqing.Wu@rwdi.com

SUMMARY:
Doors are among the most frequently used features in the built environment. Performance of exterior doors should be evaluated based on ease of operation, user safety concerns, as well as energy efficiency. Multiple factors contribute to the operability and safety of doors, including the door type, weight, where the hinges/handles are located, resistance/assistance by door hardware, and the air pressure differentials across the doors. The focus of this study is to investigate the factors contributing to the pressure differentials across the door panels, namely, wind-induced exterior pressures, building pressurization and the stack effect. The combined effects of these factors determine the usability of the exterior doors, user safety, internal building flows and the associated energy loss. In this regard, various scenarios of door operations were modelled in the wind tunnel and wind pressures and speeds were measured. Conceptual aerodynamic solutions for enhancing the performance of doors were also considered and their efficiency was evaluated, in addition to other solutions such as different door types, operation systems and measures aimed at reducing the stack effect pressures.

Keywords: Building Aerodynamics; Door Operability; Wind Force; Stack Effect; Building Performance

1. INTRODUCTION

When it comes to the interaction of buildings, as bluff bodies, with winds, most of the time, the attention is given to the pressure distribution on higher building elevations and the wind-induces along-wind/cross-wind accelerations arising from buffeting and vortex shedding. However, the pressure distributions at the base of buildings are also of significant importance as they directly affect the accessibility and usability of building entrances. Additionally, the wind gusts around a building base can potentially pose safety issues for the users if the high-speed gusts are caught by outward-swinging open doors to stretch them open further or slam shutting them. In extreme cases, this will result in door damages and body injuries (Chang and Drury, 2007).

The operability of swinging doors depends on multiple factors that include both the physical characteristics of doors and the pressure difference across them (Chang, 2004). The latter factor is driven by the interior air pressures, interconnection between doors and the wind-induced exterior pressures. For tall buildings in harsher climates with distinct interior heating/cooling seasons, the effect of temperature difference inside and outside of a building on the pressure difference, which is known as stack effect, becomes significant (Ricketts and Straube, 2014). The wind-induced pressures, on the other hand, can cause door operability problems for buildings of all heights regardless of regional temperature.

In the current study, the operability for exterior swing doors is investigated from wind and stack effect perspectives. Door operability issues largely depend on the design specifications and can be solved through proper design modifications or mitigation efforts applicable to both inside and outside of buildings. Thus, the engagement of a wind engineering and stack effect professional in the evaluation of potential door accessibility/safety issues at the early design stages is of great benefit in avoiding the future problems that are more challenging and costly to solve. Failure to address these issues will create serious problems for building performance, ranging from accessibility challenges to undesirable airflows and energy loss.

2. BACKGROUND

2.1. Wind impact on the ease of operation of external swing doors

Wind flows can create positive pressures on the windward side of buildings and suction or negative pressures on the roofs and other sides, especially around building corners causing difficulty in opening or closing swing doors (Wang et al., 2014). For an outward-swing door, a high positive pressure outside (acting inward on the door) will cause difficulty in opening the door. Alternatively, a high negative pressure outside will cause the door to stay open or swing open quickly. The opposite would be true of inward-swing doors, whereby a high negative pressure would create resistance to opening, while a high positive pressure is likely to cause the doors to stay open or swing open quickly. The interconnection between doors is another contributor to door operability challenges which could exacerbates the pressure issues. The wind-induced force (F_{wind}) on a swing door is a product of the wind-induced pressure on the door (P_{wind}) and the door area (A=H×W). To counteract this force and open the door at the handle, the hand force of the user (F_{hand}) should be equal to or greater than the wind force. In Figure 1(a), the way these forces act on a swing door is schematically illustrated. The magnitude of the hand force is a function of the difference between the external wind-induced pressures and the internal pressures, door dimensions and the handle distance from the door edge (d).

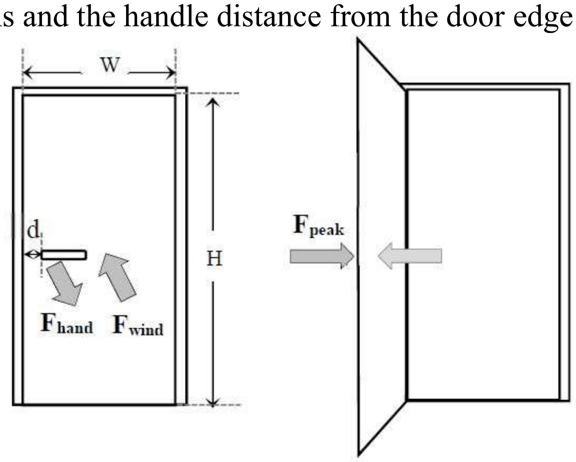

Figure 1. (a) Wind force acting on a swinging door and (b) peak wind forces due to the gust exposure

2.2. Wind impact on the safety aspects of swing doors

An opened outward-swing door can be considered as a flat plane entirely exposed to the winds flowing parallel to the building façade. The resultant peak wind-induced force exerted on the door (F_{peak}) can be calculated using the maximum net pressure across the door and the door dimensions. This force can also be estimated by the gust wind speeds measured near the entrance in a typical wind-tunnel study, together with the door dimensions and a known pressure coefficient. Such forces could be strong enough to seriously damage the door frame/hardware and cause safety concerns for users. Figure 1(b) schematically shows the peak wind force acting on an opened door.

2.3. Stack effect pressures

Stack effect is a phenomenon that can exist in all buildings and is induced by the pressures originated from indoor to outdoor temperature differences (buoyancy forces). Figure 2 illustrates normal versus reverse stack effect phenomenon which, respectively, occur during the cooling and heating seasons. Pressures arising from stack effect along with the external wind-induced pressures determine the door operability conditions and air infiltration/exfiltration through the building openings including doors. While stack effect issues are more significant for tall buildings, in extreme cold/hot climates, such issues can adversely impact the door operability even for short buildings.

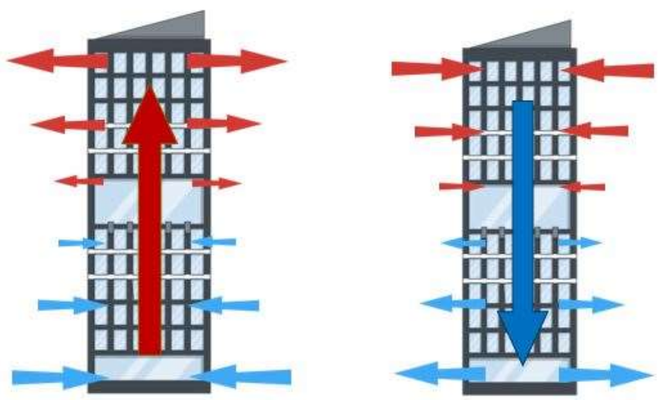

Figure 2. Stack effect driven pressures in the winter (left) and summer (right)

3. METHEDOLOGY

To assess the wind pressure distribution along the building base and measure the wind speeds at door locations, a 1:300 scale models of a 100m tall, L-shaped structure was constructed for the wind tunnel testing (Figure 3). This building form allowed creating areas of highly positive and negative pressures, representing the most common scenarios in the wind-building interactions. Further testing included single/double fully-opened doors at different locations with pressure taps instrumented at the typical height of a door center on the façades and on both sides of the open doors to obtain the net pressures acting on them.

To measure the mean and gust wind speeds around the building perimeter, Irwin sensors were utilized. They measured wind speeds at elevation equivalent to 1.5m above ground at full scale, or the middle height of a door of 3m high. For each wind direction, the peak forces along with wind gust speeds from Irwin sensors can be used to obtain the drag coefficient for opened single/double doors at different locations. Having this information is helpful in deriving a general guideline to predict the potential door safety issues for various wind climates, building orientations with respect to prevailing winds and door locations.

Another major aspect of the current study is to evaluate the effectiveness of typical solutions often recommended for improving the door operability/safety conditions. The purpose is to optimize the mitigation strategies based on design specifications and frequent wind directions and avoid implementing features or design changes that are of no benefit given the particular wind conditions causing the issue. In this regard, conceptual wind control elements in the form of canopies and wind screens were applied at different door locations and their impacts were quantified.

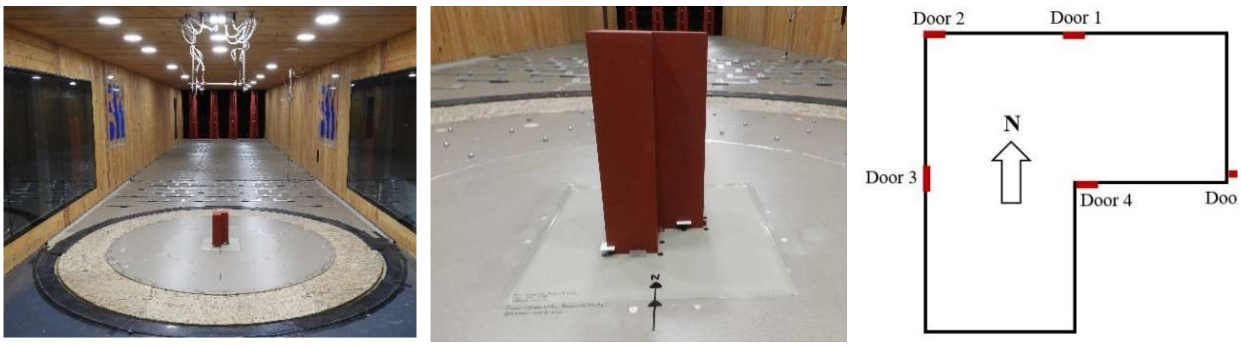

Figure 3. Wind-tunnel study model and door location

Since the wind speed and pressure data measured in the wind tunnel are in the form of ratios of local values to those at a reference gradient height, the wind tunnel results were analyzed using long-term wind records from different meteorological stations to draw region-specific conclusions. Statistical analysis was performed for each climate to obtain the probability of extreme wind forces and gusts. Similarly, stack effects were quantified for different climate regions, compartment, and general façade leakage. The combined impact of these forces was used to determine the door operability with respect to the available accessibility criteria.

4. CONCLUSIONS

Wind tunnel tests incorporating various door operation scenarios were conducted. The results were evaluated in combination with the stack effect related pressures. The performance of exterior doors was determined as a function of regional climate, door type, compartmentalization of the interior space and the specific use of the building. The effectiveness of wind control solutions moderating the wind-related accessibility/safety issues was investigated. The maximum force factors and return periods of peak forces were analyzed for different door operation scenarios.

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