Journal of Wind Engineering & Industrial Aerodynamics 176 (2018) 183–196

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Improved assessment of wind-driven rain on building façade based on ISO standard with high-resolution on-site weather data

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ARTICLE INFO

Keywords:
Wind-driven rain
Field measurements
Wind-tunnel measurements
Site wind conditions
Semi-empirical WDR model
Building façade

ABSTRACT

Wind-Driven Rain (WDR) is one of the major moisture sources that cause building envelope failures. The quantity and spatial distribution of WDR are important considerations for durable building envelope designs and are essential boundary conditions for hygrothermal modelling. Within a comprehensive research program of quantifying WDR exposure of buildings and the effectiveness of overhang on reducing WDR wetting, a six-storey building located in Vancouver, Canada was instrumented for field WDR measurements. One of the challenges in field WDR measurements is the validity of on-site wind measurements. The accurate measurements of on-site wind conditions are essential for correlating WDR on façade with on-site weather conditions and for generating the spatial distribution correction factor required in the semi-empirical WDR models. This paper focuses on discussing the procedure necessary for proper on-site wind measurements for quantifying WDR on façade based on field and wind-tunnel measurements. The proper procedure to calculate the spatial distribution correction factor, namely wall factor according to ISO standard, and its impact on the accuracy of the ISO model is also discussed. The accuracy of ISO model can be significantly improved by using more detailed wall factors calculated based on high-resolution on-site wind and rain measurements.

1. Introduction

Wind-driven rain (WDR) is one of the most important environmental loads and the main moisture source that affects the hygrothermal performance and durability of building envelopes (Kumaran and Sanders, 2008; Blocken and Carmeliet, 2004). The quantity and spatial distribution of WDR is affected by a wide range of parameters including wind speed, wind direction, rainfall intensity, wind angle, building geometry, location on building facades, and surrounding topography. WDR loads on facades are normally determined or estimated by measurements, semi-empirical correlations, and Computational Fluid Dynamics (CFD) modelling. Each approach has its advantages and limitations (Blocken and Carmeliet, 2004). Measurements have always been the primary tool for WDR study and provide the basic knowledge for understanding WDR, but they can be time consuming, expensive, and suffer from large errors (Blocken and Carmeliet, 2004, 2005a, 2006a; Blocken et al., 2009). Their use for the estimation of WDR load can be limited to the specific site where measurements were taken. These limitations motivated researchers to establish semi-empirical correlations between WDR on façades and the standard meteorological parameters. The semi-empirical correlations are developed on a theoretical basis with coefficients that are determined from measurements. The semi-empirical models estimate the WDR amount on a building façade by correlating available weather data i.e. wind speed, wind direction, and rainfall intensity collected at weather stations to the specific building site and façade location by introducing a number of correction factors to account for the specific terrain, topography, and building geometry, such as the procedure prescribed by ISO Standard 15927-3 (International Standard Organization (ISO), 2009). More detailed but more time-consuming alternative is to use CFD modelling. CFD models provide the WDR results on any particular building as a function of wind speed, wind direction, and horizontal rainfall intensity, however, its accuracy needs careful validation with high quality measurements (Blocken and Carmeliet, 2005b, 2007; Abuku et al., 2009). The importance of WDR has led to research efforts in this field in the past. In recent years, the application of numerical modelling (Abuku et al., 2009; Blocken and Carmeliet, 2006b; Huang and Li, 2010; Kubilay et al., 2013, 2014a, 2015a, 2017a; Pettersson et al., 2016) and efforts in collecting high quality and high resolution measurements (Blocken and Carmeliet, 2005b; Nore et al., 2007; Kubilay et al., 2014b; Deb Nath et al., 2015; Krpan and Ge, 2014) have

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https://doi.org/10.1016/j.jweia.2018.03.013
Received 15 December 2017; Accepted 15 March 2018

advanced our understanding of this complex phenomenon such as the effect of building geometry, geometrical details, and local weather conditions (Kubilay et al., 2015b, 2017b; Foroushani et al., 2013).

Because of their easy use and simplicity, semi-empirical correlations are still the most commonly used approaches for quantifying WDR load on building façades and are typically implemented in hygrothermal simulation programs. The accuracy of these semi-empirical models is affected by the correction factors such as the spatial distributions on façades, which are determined based on long-term field measurements. Studies showed that WDR estimated using these semi-empirical models deviated largely from field measurements (Kubilay et al., 2014b; Deb Nath et al., 2015; Chiu et al., 2015) and suffer from overestimation and the lack of variation with various building geometries and wind and rain conditions (Blocken and Carmeliet, 2010; Blocken et al., 2011). To improve the accuracy of semi-empirical models and provide datasets for validating CFD models, measurements on buildings with various geometries under different climatic conditions are valuable and essential for the advancement of research in WDR.

Within a comprehensive research program on quantifying WDR for mid-rise and high-rise buildings and the effectiveness of overhang, a number of buildings in three Canadian regions have been instrumented for WDR measurements (Ge et al., 2017a). One of the challenges in field measurements is the validity of on-site wind measurements. Ideally, a wind anemometer should be placed in front of the building in an open field to capture the approaching wind profile. However, due to the site limitation, it is often that wind anemometer has to be placed on the roof top and its height may also be restricted due to logistic limitation, therefore, the wind speed and wind direction measured at the anemometer height may be influenced by the building itself. The accurate measurements of on-site wind conditions are essential for correlating WDR on façade with the on-site weather conditions and for generating the spatial distribution correction factor required in the semi-empirical models. Therefore, correction of on-site wind measurements may be necessary. This paper focuses on discussing the procedure necessary for proper on-site wind measurements for quantifying WDR on façade based on field and wind-tunnel measurements. The proper procedure to calculate the spatial distribution correction factor, namely wall factor according to ISO standard, and its impact on the accuracy of the semi-empirical model is also discussed. A six-story building located in Vancouver, British Columbia, Canada is used as the case study building.

2. Methods

Both field measurements and wind-tunnel measurements have been carried out. The field measurements focus on quantifying WDR on façade and the effectiveness of overhang on reducing WDR wetting on façade with on-site wind and rain measurements. The wind-tunnel measurements focus on mean wind speed upstream, above and around the scaled building for verification of field wind measurements.

2.1. Field measurements of wind-driven rain

2.1.1. Test building

The test building is a six-story rectangular residential building with a low-sloped roof and a short parapet located in Vancouver, British Columbia (Fig. 1). The building sits atop an escarpment with the East façade facing the direction of the escarpment and is surrounded by 3-story residential buildings to its North and West and a highway to its East and South. The building is 39.2 m long, 15.2 m wide, and 19.8 m high. The building façades face the cardinal directions with one of the long façade facing the East, the prevailing wind direction. It is a fairly open site within a suburban setting, which makes it an ideal site for WDR studies. A customized retractable overhang structure is designed and installed on the East and North façade of the building to quantify the effectiveness of overhang.

2.1.2. Instrumentation

The parameters monitored include on-site weather conditions and

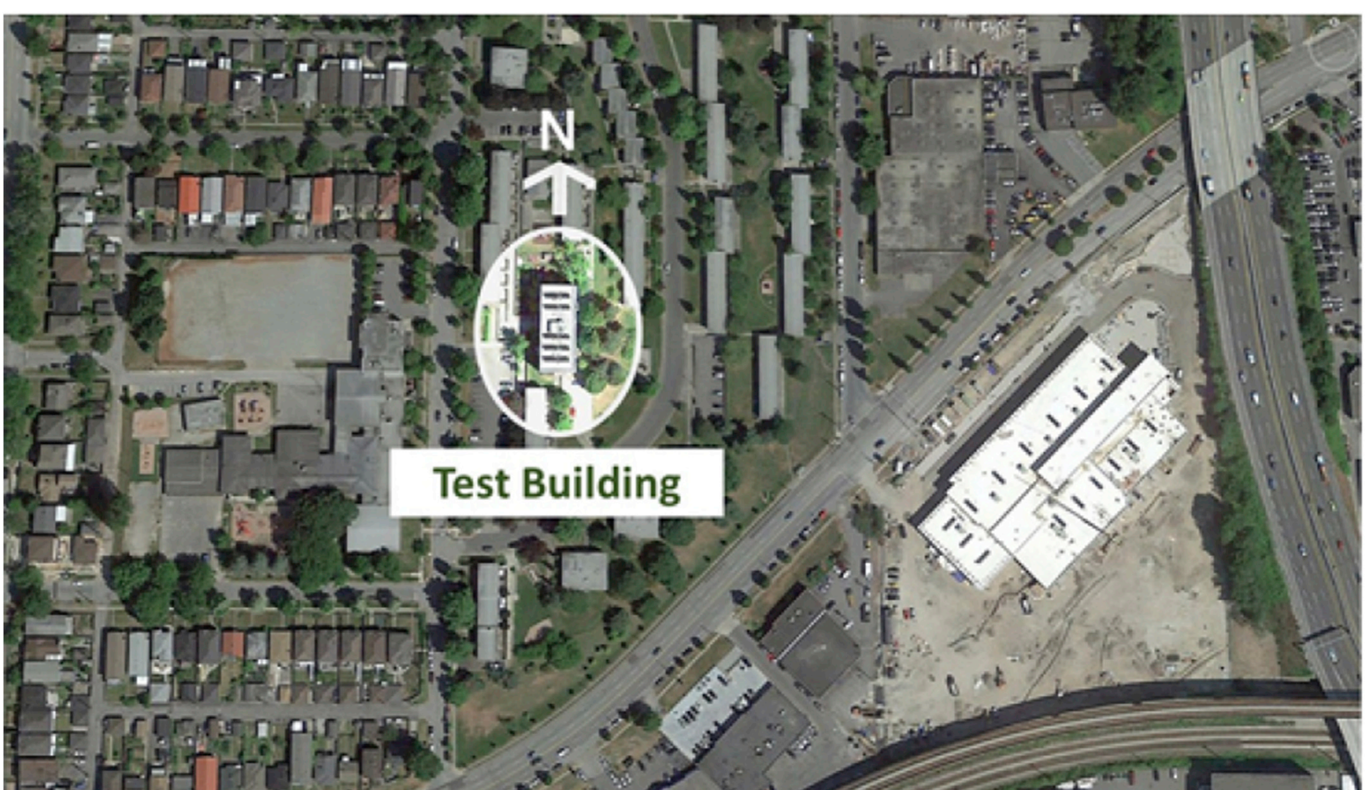

Fig. 1. Aerial view of the building site (from Google Maps).