Building and Environment 116 (2017) 228–245

Contents lists available at ScienceDirect

Building and Environment

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

Field measurements of wind-driven rain on mid-and high-rise buildings in three Canadian regions

Hua Ge*, U.K. Deb Nath, Vincent Chiu

Department of Building, Civil and Environmental Engineering, Concordia University, 1455 de Maisonneuve, Montreal, Quebec, H3G 1M8, Canada

A R T I C L E I N F O

Article history:
Received 10 December 2016
Received in revised form
6 February 2017
Accepted 21 February 2017
Available online 22 February 2017

Keywords:
Wind-driven rain (WDR)
Field measurements
Semi-empirical WDR model
Environmental loads
Building façade

A B S T R A C T

Wind-driven rain (WDR) is an important boundary condition for the study of hygrothermal behaviour and durability of building envelopes. Understanding the WDR characteristics is important for establishing designs that minimize moisture related issues. Given the limited data available on field measurements of WDR, especially for mid- and high-rise buildings, a number of buildings have been instrumented with weather stations and driving rain gauges for WDR measurements on building façade in three Canadian cities (Vancouver, Montreal, and Fredericton). The high-resolution WDR data collected provide a valuable and unique dataset for improving semi-empirical WDR models and validating Computational Fluid Dynamic (CFD) models. This paper presents the experimental setup, spatial distribution of WDR on façades in terms of catch ratios and wall factors, and the comparison between measurements and calculated WDR using ISO standard 15927. The results show that the spatial distribution of WDR on façade is significantly influenced by building geometry, façade details, and its surroundings. The wall factors vary with both the width and height of the building façade. The ISO semi-empirical model typically overestimates WDR on buildings studied under Canadian climates.

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 [1,2]. Wind-driven rain, the amount of rainwater that impinges on the vertical surface of building envelopes under the influence of wind, is the result of complex interactions among wind, rain and buildings. 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 are normally determined or estimated by measurements, semi-empirical correlations, and Computational Fluid Dynamics (CFD) modelling. Each approach has its advantages and limitations [2]. 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 [2–5]. 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 [6]. 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 [7–9]. The importance of WDR has led to research efforts in this field in the past. In recent years, the application of numerical modelling [9–16] and efforts in collecting high quality and high resolution measurements [7,17–20] have advanced our understanding of this complex phenomenon such as the effect of building geometry, geometrical details, and local weather conditions [21–23].

* Corresponding author.
E-mail address: hua.ge@concordia.ca (H. Ge).

http://dx.doi.org/10.1016/j.buildenv.2017.02.016
0360-1323/

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 facades, which are determined based on long-term field measurements. Studies showed that WDR estimated using these semi-empirical models deviated largely from field measurements [18,19,24]. A detailed analysis between CFD modelling and semi-empirical models identified that semi-empirical models suffer from overestimation [25,26]. One of the main sources of discrepancies is the rain deposition factor or wall factor, a constant to account for the spatial distribution of WDR on façade. This factor suggested in these semi-empirical models is obtained over long-term field measurements on a limited number of buildings and it is reported as a constant value for a very limited number of locations on façade. The complex interaction among wind, rain and building, which results in the WDR distribution on façade, is taken into account by this single value in semi-empirical models. Therefore, semi-empirical model suffers from the lack of variation with various building geometries and wind and rain conditions.

The commonly used two semi-empirical models are ISO standard [6] and ASHRAE 160 [27]. As the most comprehensive semi-empirical WDR model, ISO provides wall factors for six typical building geometries, in which five buildings are low-rise, i.e. two-storey and three-storey buildings with steep or low-sloped roof and with/without overhang. There are only two values for a multi-story building with a low-sloped roof. ASHRAE 160's WDR model only specifies three values for rain deposition factor, one for walls below a steep roof, one for walls below a low-sloped roof, and 1.0 for walls subject to rainwater runoff. CFD modelling can provide detailed WDR loads on façade, however, given its complexity it still remains as a research tool and requires high quality measurements for validation. 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.

The objectives of this research are to generate a unique set of measurements to characterize the WDR distribution on mid- and high-rise buildings under Canadian climates, to provide data for assessing the appropriateness and improving semi-empirical models and to validate CFD models. This paper presents the field measurements of WDR on mid - and high - rise buildings in three Canadian regions. The following sections present the experimental setup, spatial distribution of WDR on façades in terms of catch ratios and wall factors, the comparison between measurements and calculated WDR using the ISO standard 15927, and conclusions.

2. Measurement setup

2.1. Test buildings

Three buildings located in three regions of Canada, Fredericton in Maritime region on the east coast, Montreal in Eastern Canada and Vancouver on the west coast, have been instrumented with equipment to characterize WDR loads on building façades. Details of these test buildings and the number of rain gauges that have been installed on different façades of test buildings are shown in Table 1.

The satellite images of the test buildings and their surroundings are presented in Fig. 1. Located at University of New Brunswick, Fredericton, the student residence is a seven-storey building with a low-sloped roof without any overhang (Fig. 1a). The height of the building is 22 m. A neighbouring building with a height of 22 m is located about 20 m away on the north-west side. On the west to south-west side is a parking lot with a long field of trees. These trees are about 40 m away from the building. There are a couple of low-rise houses on the south-east side, located over 100 m away from the building. On the north-east side is an open grass field with some low-rise constructions across the road, over 130 m away from the building.

The office building is thirteen-storey high located in downtown, Montreal, Quebec (Fig. 1b). It has a low-sloped roof without overhang. The height of the building is 45.6 m. On the south-west direction is a five-storey wing attached to the building. On the north-west side there is a five-storey building located about 25 m away. Further there exists a fifteen-storey building located about 60 m away. On the south-east side is a four-storey building located about 22 m away. On the north-east side the nearby building is three storeys high and located about 23 m away.

The six-storey residential building in Vancouver has a low-sloped roof and a short parapet (Fig. 1c). The building sits atop an escarpment with the east façade facing the direction of the escarpment and is surrounded by three-storey 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 faces facing the east, the prevailing wind direction during rain hours. It is a fairly open site within a suburban setting, which makes it an ideal building for wind-driven rain studies.

Table 1
Details of test buildings.

Buildings	Coordinates	Construction type	Geometry	Obstruction	No. of rain gauges	Picture
Student residence Fredericton, NB	45.94°N 66.65°W	Seven-storey	low-sloped roof without overhang	Moderate	7 (south-west) 6 (south-east) 2 (north-east) 1 (north-west)	
Office building, Montreal, QC	45.49°N 73.58°W	Thirteen-storey	low-sloped roof without overhang	Moderate	7 (south-west) 6 (south-east) 10 (north-east) 1 (north-west)	
Residential building, Vancouver, BC	49.26°N, 123.03°W	Six-storey	low-sloped roof without overhang	Moderate	18 (east) 11 (north) 1 (south) 1 (west)