J. Wind Eng. Ind. Aerodyn. 143 (2015) 50–61

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

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

Influence of time resolution and averaging techniques of meteorological data on the estimation of wind-driven rain load on building facades for Canadian climates

Hua Ge *

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

ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form
22 April 2015
Accepted 23 April 2015

Keywords:
Wind-driven rain
Building facades
Semi-empirical models
Meteorological data
Averaging techniques
CFD-based catch ratio method

ABSTRACT

This paper investigates the influence of time resolution of meteorological data and the averaging techniques on the quantification of wind-driven rain amount on building facades for Canadian climates using three WDR models, i.e. the ISO and ASHRAE 160P semi-empirical models, and the CFD-based catch ratio method. A cubic low-rise building is used as a case study. Meteorological data i.e. wind speed, wind direction and rainfall intensity are collected at 5-min intervals at three building sites in Vancouver, Montreal and Fredericton. The 5-min data is used as the reference. The analyses show that when semi-empirical WDR models are used, the arithmetic averaging gives a better estimation while the weighted averaging tends to overestimate the WDR amount. When the detailed CFD-based catch ratio method is used, the weighted averaging technique provides a better estimation, however, the difference between the arithmetic and weighted averaging is within 3–7% for the three Canadian cities investigated. Therefore, the choice of averaging techniques depends on the WDR models to be employed and the 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 (Kumaran and Sanders, 2008). It is an important factor influencing the deposition of pollutants, erosion and surface soiling on building facades. Moisture accumulation in porous materials due to WDR can lead to frost damage, water penetration, moisture induced salt migration, cracking, and efflorescence, just to name a few (Blocken and Carmeliet, 2004).

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, etc. WDR loads are normally determined or estimated by measurements, semi-empirical correlations, and Computational Fluid Dynamics (CFD) modeling (Blocken and Carmeliet, 2004). Measurements have always been the primary tool in WDR research, but they can be time-consuming and expensive, and their use for the estimation of WDR load can be limited to the specific site where the measurements were taken. These limitations motivated researchers to establish semi-empirical correlations between WDR on facades and the standard meteorological parameters. The semi-empirical correlations were developed on a theoretical basis with coefficients that were determined from measurements. The semi-empirical models estimate the wind-driven rain 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, 2009). More detailed but more time consuming alternative is to use CFD modeling. CFD models provide the WDR results on any particular building as a function of horizontal rainfall intensity, wind speed and wind direction, however, its accuracy needs careful validation with high quality measurements (Blocken and Carmeliet, 2006, 2010; Blocken et al., 2010; Abuku et al., 2009).

The importance of wind-driven rain has led to research efforts in this field in the past. Wind-driven rain exposure as an issue has been investigated for Canada over the last decades and studies characterizing wind-driven rain loads specifically for Canadian climates have been reported by Boyd (1963), Robinson and Baker

* Tel.: +1 514 848 2424x8771.
E-mail address: hua.ge@concordia.ca

http://dx.doi.org/10.1016/j.jweia.2015.04.019
0167-6105/

(1975), Fazio et al. (1995), Zhu et al. (1995), Straube and Burnett (2000), Cornick and Lacasse (2005), and Krpan and Ge (2014). In recent years, the application of numerical modeling (Blocken and Carmeliet, 2006; Abuku et al., 2009; Kubilay et al., 2013) and efforts in collecting high quality and high resolution measurements (Blocken and Carmeliet, 2006; Nore et al., 2007; Kubilay et al., 2014) have advanced our understanding of this complex phenomenon such as the effect of building geometry, geometrical details, and local weather conditions (Blocken et al., 2009, 2011; Mohaddes et al., 2013; Blocken and Carmeliet, 2007, 2008). The impact of time resolution and averaging techniques of meteorological data on WDR quantification was investigated by Blocken and Carmeliet (2007, 2008). It was found that significant underestimations can occur if the high-resolution raw data was arithmetically averaged to obtain hourly data. The researchers suggested a weighted averaging technique using the rainfall amount as the weighing factor, which can significantly reduce the time resolution errors in estimating the WDR amount, especially for cumuliform rains, showers generated from unstable atmosphere. For stratiform rains, steady and persistent rain generated from stable atmosphere as a result of condensation process, the errors introduced by arithmetic averaging was not as significant. The influence of the averaging techniques on WDR amount was tested over a number of cities in Europe, USA and South Africa when wind angle was not considered. It was suggested that a minimum of ten-minute averaged data was required to obtain results that were acceptable for quantifying WDR intensity.

The weighted averaging method introduced by Blocken et al. (Nore et al., 2007; Blocken and Carmeliet, 2007) was to better represent the co-occurrence of wind and rain. The weighted hourly wind speed and rainfall intensity were used to determine the catch ratio from CFD generated catch ratio charts and then the WDR amount was calculated by multiplying the total horizontal rainfall amount by the catch ratio. Therefore, the weighted averaging method gives better results when the detailed CFD generated catch ratio approach is used. Guidelines for the required time resolution of meteorological input data for WDR calculation on buildings were outlined in a paper by Blocken and Carmeliet (2008). The paper suggested that similar conclusions could be applied to semi-empirical WDR models given that the semi-empirical relationship could be regarded as a simplified version of the CFD-based method.

Because of their easy use and simplicity, semi-empirical correlations are still the most commonly used approach of quantifying WDR load on building facades 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. On the other hand, the CFD-based approach can provide more detailed spatial distribution over the façade under specific weather conditions and is more sensitive to the time-resolution of meteorological data. How would the time resolution and averaging techniques influence the WDR calculation using semi-empirical models? That is one of the questions this study aims to answer.

The objective of this paper is to investigate the influence of time resolution of meteorological data and the appropriateness of different averaging techniques on the estimation of WDR load on building facades using different WDR models for Canadian climates. A low-rise cubic building is used as a case study. Three WDR models, namely ISO and ASHRAE 160P semi-empirical models, and the CFD-based catch ratio method, are studied. Meteorological data i.e. wind speed, wind direction and rainfall intensity are collected at 5-min intervals at three building sites in Vancouver, Montreal and Fredericton. The 5-min data is used as the basis for generating hourly averaged data and the WDR amount calculated using 5-min data is used as reference for comparison. Three averaging techniques, namely arithmetic, vector and weighted averaging, are used to convert 5-min data to hourly average. For semi-empirical WDR models, the airfield driving rain indices calculated using hourly average obtained from these three averaging techniques are compared to that calculated using 5-min reference data. For the CFD-based catch ratio method, the actual WDR amount at the top corner of the cubic reference building is calculated using arithmetic and weighted average for cases with and without considering incident wind angles.

Section 2 provides a brief introduction of the semi-empirical and CFD-based WDR models, averaging techniques investigated, the case study building, and the calculation procedure. Section 3 presents the results in terms of airfield WDR indices calculated by semi-empirical models and WDR amounts calculated by the CFD-based model using different averaging techniques. Comparison of WDR load calculated for the top corner of a low-rise cubic building by the semi-empirical models and CFD-based catch ratio method is also made. Discussion and conclusions are provided in Sections 4 and 5, respectively.

2. Methodology

2.1. Wind-driven rain models

2.1.1. Semi-empirical WDR models

The semi-empirical correlations were developed on a theoretical basis with coefficients determined from measurements and are commonly used because of their ease of use and simplicity although their accuracy is limited because the correction factors were developed based on measurements on a limited number of buildings and for specific climates. The semi-empirical model is based on the simplified assumption that the horizontal component of wind carries the rain drops through a vertical plane, and the amount of WDR through a vertical plane equals to the ratio of the horizontal component of wind speed to the rain drop's terminal velocity multiplied by the horizontal rainfall intensity (Eq. (1)).

$$R_{\mathrm{wdr}} = R_{\mathrm{h}} \cdot \frac{U}{V_{\mathrm{t}}} \tag{1}$$

Eq. (1) shows the correlation between rainfall intensity received on a horizontal surface, R_{h}, to the rainfall intensity received on a vertical surface, R_{wdr}, which is an imaginary vertical plane without the influence of building itself. U is the horizontal wind speed in m/s and V_{t} is the rain drop's terminal velocity in m/s. The terminal velocity is a function of the raindrop size, which is a function of the horizontal rainfall intensity. Empirical correlations were established based on measurements describing the relationship between rainfall intensity and raindrop size distribution (Marshall and Palmer, 1948; Best, 1950a; Markowitz, 1976; Mualem and Assouline, 1986) and the relationship between terminal velocity and raindrop sizes (Best, 1950b; Dingle and Lee, 1972; Gunn and Kinzer, 1949).

Empirical correlations were established based on measurements to correlate free field WDR to the wind speed and rainfall intensity (Eq. (2)) (Lacy, 1965).

$$R_{\mathrm{wdr}} = \alpha \cdot U \cdot R_{\mathrm{h}} \tag{2}$$

where α is the WDR coefficient, which is the inverse of the raindrop's terminal velocity. The WDR coefficient ranges between 0.20 and 0.25 s/m for average conditions based on measurements (Straube and Burnett, 1997).

To get the WDR on an actual building, the interaction between wind and building needs to be taken into account. The wind speed at a particular site needs to be converted from the wind speed recorded at the weather station at a relatively open area to the site by taking into account the effect of terrain, local topography, obstruction and building height. When wind approaches the actual