Journal of Wind Engineering & Industrial Aerodynamics 179 (2018) 190–199

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

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

Calculation of the driving rain wall factor using ray tracing

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ARTICLE INFO

Keywords:
Wind driven rain
Wall factor
ISO standard
Ray tracing

ABSTRACT

The current study presents a simplified method towards the improvement of the ISO Standard for the wind driven rain (WDR) assessment; given that the corresponding semi-empirical ISO model only provides wall factor values for a limited number of façade configurations, potential variations along the building façades such as protrusion of windowsills, extrusions or roof overhangs are only partially accounted for and as a result, significant overestimations of driving rain impingement at the respective spots, located in the 'rain shadow' may occur. In order to encounter this limitation for areas in the rain shadow, the present study proposes the use of the ray tracing method so as generate a building specific wall factor at a significantly low computational cost. Both validation and application results showed that the method can capture the distinct effect of the overhang and the windowsills in terms of rain sheltering while on the other hand, dynamic characteristics of the wind and more complex phenomena cannot be handled.

1. Introduction

Wind-driven rain or driving rain corresponds to the rain that has a horizontal velocity component due to wind in addition to the vertical velocity component. A great number of scientific studies have dealt with the WDR research since it is considered as one of the most important moisture sources for building facades, affecting thus the hygrothermal performance and the durability of the constructions (Blocken and Carmeliet, 2004). Given that each porous material is characterized by a threshold value for moisture content, severe damages can occur when the water content exceeds this value, increasing the risk of water penetration, frost damage, discoloration and structural degradation (Kyllingstad et al., 2010). Moreover, as multiple diverse parameters such as building geometry, site topography, wind speed and direction, horizontal rainfall intensity, raindrop trajectories and particle size govern the intensity of WDR, its assessment becomes a rather difficult and complex task (Giarma and Aravantinos, 2014). There are three main categories of methods regarding the evaluation of WDR impingement on a building façade (Blocken and Carmeliet, 2010):

(i) Field measurements of WDR through the use of the suitable gauges, having a vertical aperture to collect the amount of the WDR,
(ii) Semi-empirical models such as the ISO Standard (ISO, 2009) and the Straube and Burnett model (Straube and Burnett, 2000), having a theoretical basis but also guided by experimental data,
(iii) Numerical simulations based on Computational Fluid Dynamics models, initially introduced by Choi (1991) (Choi, 1994),) and extended by Blocken and Carmeliet (2002), able to simulate complex interactions between wind, rain and buildings with high accuracy.

The above mentioned categories have been thoroughly investigated and explored in literature reviews performed by Blocken and Carmeliet (2004) (Blocken and Carmeliet, 2010),). Experimental data through measurements have always provided the basis for model development and model validation; however they can be time consuming, and rather prone to errors. Reported errors associated with WDR measurements refer to evaporation of adhesion water from the collection area, evaporative losses from the part of the gauge where rain is stored, splashing of drops, condensation etc. (Blocken et al., 2013). Given the latter limitations of the onsite measurements, researchers have established semi-empirical methods for the assessment of wind driven rain. The development of these relationships is based on theoretical basis but the provided coefficients are chosen so as to fit experimental data. A brief overview of the ISO Standard is given in section 2. Finally, numerical methods using CFD simulations are vastly being used when a detailed

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https://doi.org/10.1016/j.jweia.2018.06.008
Received 1 November 2017; Received in revised form 6 June 2018; Accepted 14 June 2018

determination of the spatial and temporal WDR exposure is requested, as complex interactions between building geometry and wind profile can be handled. The need of high accuracy on WDR estimations firstly arises from its strong effect on the hygrothermal performance of the building façades. Considering that even more severe rainfall intensities are expected in the future due to the forecasted climate change, the accurate determination of the impinging intensity is of crucial importance when it comes to the durability of the constructions, the definition of adaption measures and thus the reduction of maintenance costs etc. (Sanders and Phillipson, 2003). Moreover, information on the WDR surface wetting pattern is used as boundary condition in the building envelope heat-air-moisture (BEHAM) transport models, suggesting that better approximation of the surfaces' wetting pattern will lead to more accurate calculations of heat, air and moisture transfer within the elements of the building envelope (Kubilay et al., 2013).

Despite the fact that numerical calculations have considerable advantages as they allow the consideration of multiple parameters that influence WDR impingement on building facades, they are highly time consuming and often too complex for practical use. On the other hand, semi-empirical methods provide a simple and low time consuming approach to WDR estimation; yet, rather rough estimates can be offered (Blocken and Carmeliet, 2004). In a prior study of Blocken et al. (2011), the results of two different semi-empirical models were compared with the outcome of CFD simulations for two case study buildings, for which onsite WDR measurements were available; the analysis revealed a strong agreement between measurements and CFD simulation results, presenting an average discrepancy of 20%–25%, while larger differences, up to a factor 2 to 5 were found for the semi-empirical models. Another important limitation of the corresponding models constitutes the provision of wall factors coefficients only for a few building types, whereas potential variations on the building façades are only partially accounted. While two building configurations having roof overhangs are given, no examples of windowsills' protrusions or other façade discontinuities are provided.

Given the above mentioned limitation and aiming on the improvement of the performance of the ISO Standard 15927-3, the target of this study is to present simple methodology that combines the Standard with a computer graphics method so as to create building specific wall factor coefficients, in which architectural differentiations along the façade, protrusions or roof overhangs are considered. The wall factor coefficient, defined as "*the ratio of the quantity of water hitting a wall to the quantity passing through an equivalent unobstructed space*" (ISO, 2009), strongly influence the amount of WDR reaching the building façade (Chiu et al., 2015); Its accurate estimation constitutes a necessary step towards a more precise quantification of the rain water hitting the façade, enabling the determination of strategies that would protect highly exposed areas and reduce moisture-related construction issues and increased renovation costs ((Chew, 2005), (Zavadskas et al., 2004)).

It has to be emphasized that the motivation of the study arose from the potential of the semi-empirical models to become even more valuable in practical WDR assessment where low computational cost is requested, provided that their main drawbacks are handled. The proposed methodology relies on the ray tracing method already applied for solar radiation calculations ((Petrasch, 2010), (Mousazadeh et al., 2009)). More precisely, for a given angle of rain incidence and a given wind direction the trajectories of rain droplets will be considered as straight paths. The different masks, corresponding to areas being in the 'rain shelter' or fully exposed, will be then combined with the general wall factor provided by the ISO standard, creating a building specific wall factor. Driving rain intensity in a vertical facade can be then calculated for the new wall factor, using the eq. (1) at a low computational cost. The novelty of the method lies thus on the possibility to use 3d models and automatically calculate the wetting pattern given the angle between the wind direction and the surface model.

Ray Tracing is a computational method which has been widely used in Graphical Processing Units (GPU) in computers; it consists a rendering technique for creating an image by drawing the trajectory of light as pixels in an image plane and simulating the effects of its interaction with virtual surrounding objects (Glassner, 1989). Because of the development in graphical computing, driven by the gaming and mobile industry, GPU computing is evolving rapidly (Liang et al., 2014), giving the possibility to use the technology in other sciences.

The paper is structured in the following way: Section 2 presents a brief overview of the ISO Standard 15927 while in section 3, the proposed methodology for creating a building specific wall factor is provided. Furthermore, the first part of section 4 is devoted on the presentation of the validation results using existing measurements data while in the second part, the results of the application of the proposed method in a residential building is presented. Finally, in section 5, the limitations of the proposed methodology are discussed.

2. The ISO standard 15927-3 – a brief overview

The ISO Standard 15927-3 of 2009, entitled 'Hygrothermal performance of buildings — Calculation and presentation of climatic data — Part 3: Calculation of a driving rain index for vertical surfaces from hourly wind and rain data' (ISO, 2009) is based on the British Standard BS8104 (BSI, 1992). It is one of the semi-empirical models that have been established for the investigation of WDR relationships. The model, a detailed description of which is provided in (Blocken and Carmeliet, 2010), suggests an approach for the calculation of wind driven rain intensities on a building façade, while accounting for the surroundings and building geometry and considering hourly wind and rain data. More precisely, the Standard 15927 provides a method to assess the following quantities: the annual average index which reflects the moisture content of an absorbent surface and the spell index which is related to the possibility of water penetration through joints. According to the standard, a spell is defined as follows: a *period during which WDR occurs, and that is preceded and followed by at least* 96 h *with airfield hourly index ((2/9) *U10*Rhor$^{8/9}$cosθ) smaller than or equal to zero* (ISO, 2009). The amount of WDR in the worst likely spell in a 3-year period, is given by equation (1).

$$Rwdr = \frac{2}{9} * \left(CR * CT * O * W * Rhor^{0.88} * U10 * \cos\theta \right) \quad (1)$$

Where:

- C_R is the roughness coefficient, accounting for the change on mean wind speed due to the height above ground,
- C_T is the topography coefficient, accounting for the increase of wind speed over escarpments and hills,
- O is the obstruction factor, referring to near facade obstacles,
- W is the wall factor
- R_{hor} is the unobstructed horizontal rainfall intensity,
- U_{10} is the reference wind speed at 10 meters height,
- θ is the angle between the wind direction and the surface normal

The eq. (1), provided by the ISO Standard for the calculation of the 'spell index', renders the maximum value of WDR to occur once every 3 year; nevertheless, this formula could be theoretically used to describe wind driven rain intensity for any spell within a year (Blocken et al., 2011). It can be thus claimed that the ISO 15927-3 consists a rather easy procedure to follow when aiming at the assessment of WDR intensities on building facades; however, it only provides rough estimates of the WDR exposure. As it was created for the climatic conditions of United Kingdom, a model validation through driving rain measurements is also recommended, in case of application in different climates (Blocken and Carmeliet, 2004). Another significant limitation of the model is that the wall factor is only given for a limited number of façade configurations without accounting of potential variations along the façade ((Kyllingstad et al., 2010), (Blocken et al., 2011)). In other words, micro scale effects of