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Application of Rain Intensity Dependent Rain Admittance Factor (RAF) in Hygrothermal Performance Assessment of Wall Systems

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ABSTRACT

Wind-driven rain (WDR) is one of the main moisture loading sources on the exterior enclosures. The direct impact of wind-driven rain on the hygrothermal performance of building envelope has been well documented. Rain admittance factor (RAF) and rain penetration values characterize the amount of water reaching the exterior surface and the exterior surface of the water-resistive barrier respectively based on measured horizontal rain intensity. In common RAF factor calculation from horizontal rainfall data procedures, such as ASHRAE 160, RAF values are not affected by the intensity of the rainfall. However, a previous study shows RAF coefficients are sensitive to the rainfall intensity. Thus it is important to investigate how the sensitivity of using horizontal rainfall intensity dependent RAF factors and the subsequent rain penetration relates to hygrothermal performance assessment of building envelope components. This study is based on five years of WDR and horizontal rainfall data collected at different orientations of façades at a two-story test building in a mild coastal climate. The data is categorized into two sets based on rain intensity. The correlation between the measured moisture content on the sheathing board of a building envelope at different points utilizing RAF values based on the proposed approach and the overall measured RAF values is studied using WUFI simulation. Results show that an average percentage difference between the moisture content values of a sheathing board using RAF values of the rain intensity dependent approach and the overall RAF measured value can be as large as 9 %.

KEYWORDS

hygrothermal performance, rain admittance factor, rain intensity, water penetration, wind-driven rain.

INTRODUCTION

Moisture ingression on building envelopes due to rain load along with vapour diffusion and built-in moisture is the main cause for moisture related problems such as corrosion, mould, rottenness and their consequential effects such as compromised structural integrity and health-related problems. Accumulated moisture in components of wall systems due to wind-driven rain (WDR) can be prominent in wet climates such as the coastal climate of British Columbia. Designers are expected to take the rain load effect into account on the overall hygrothermal performance of a building enclosure. Incorporating the wind-driven rain effect requires measuring or accurately estimating the number of raindrops that are impinging on the vertical building surfaces due to wind forces blowing towards the building.

Many factors affect the amount of wind-driven rain, including rain intensity, wind speed and direction, topography, building geometry, the orientation of the building assembly, and the location of the area of interest on the building elevation. However, the primary components to wind-driven rain intensity are rain intensity, wind speed and wind direction. Most wind-driven rain computational models are based on semi-empirical and numerical analysis methods. The most commonly used numerical analysis method is mainly developed by Choi in the 1990s (Choi, 1994a, 1994b, 1999). According to Hens (2015), the semi-empirical analysis method was developed in the 1950s by Lacy (Lacy, 1965) using experimental-based relations of raindrop size, raindrop speed, and horizontal rain intensity. The calculation of raindrop size and terminal velocity was based on Best's work (Best, 1950a, Best, 1950b). Recently, based on Lacy's findings, a semi-empirical estimation formula is developed by Straube and Burnett (2000).

To estimate the amount of wind-driven rain without direct field measurement at the location of interest, historical weather data can be used. To account for other factors, such as the building geometry, orientation of the building assembly, and the area of interest on the wall façade, semi-empirical studies have provided coefficients to be used in calculations. The two commonly used factors are *the wall factor*, W (BSI EN 13013-3, 1997), and *Rain Admittance Factor*, RAF (Straube and Burnett, 2000), which considers the building aspect ratio, the presence of a roof overhang and the area of interest within the wall facade. The wind-driven intensity on a vertical surface according to Straube and Burnett's method (Straube and Burnett, 2000) can be calculated as:

$$R_{wdr} = RAF \times DRF(V_t) \times \cos(\theta) \times U(h) \times R_h \qquad (1)$$

Where R_{wdr} is wind-driven rain intensity (mm), *RAF* is Rain Admittance Factor, *DRF(Vt)* is Driving Rain Factor (1/Vt), θ is the angle of the wind to the wall's normal, *U(h)* is the wind speed at the height of interest (m/s), R_h is horizontal rainfall intensity (mm/hr.m^2).

The driving rain factor (DRF) is a multiplicative inverse of terminal velocity. A droplet size, the main parameter in terminal velocity calculation (Dingle and Lee, 1972), can be estimated based on horizontal rain intensity (by Best 1950a).The last 3-terms on the right side of equation 1, $\cos(\theta) \times U(h) \times R_h$, represent free-field wind-driven rain under the rain intensity through a 1 m^2 area of the unobstructed vertical field.

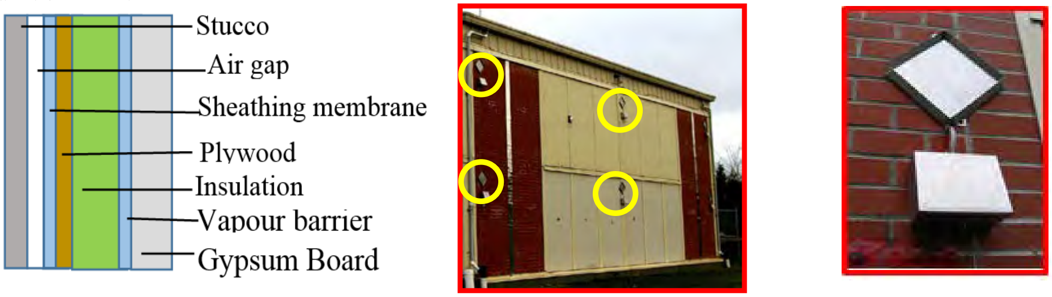
Commonly, a median droplet size is used while employing the Straube and Burnett model. A work by Cornick and Lacasse (2009) used the predominant raindrop diameter instead of the median drop size. Using the predominant raindrop diameter provides a lower terminal velocity and a higher WDR load (Van Den Bossche et al, 2013). A work by Van Den Bossche et al. (2013) stresses the drawbacks of using single rain droplet diameter and their simulation work shows using a median droplet in WDR calculation can introduce an error up to 20% as the horizontal rain intensity increases.

In this study, the dependency of the Rain admittance factor (RAF) on rainfall intensity for different orientations and elevations is examined. Based on the newly obtained RAF coefficients, the effect of RAF values variation between the existing RAF calculation and the proposed approach on hygrothermal performance of building enclosure is investigated.

WEATHER DATA ANALYSIS

In this study, fifty-seven months of weather data between January 2009 to September 2013 was collected at the BCIT's Building Envelope Test Facility in Burnaby (BETF), British Columbia, Canada. The horizontal rain intensity, vertical rain intensity, wind speed and directions are measured using a horizontal rain gauge, 15 wall rain gauges, and an anemometer. The data is used to calculate the free-field wind-driven rain, the Driving Rain Factor (DRF) and the Rain Admittance Factor (RAF) at different elevations and orientations.

An hourly data of horizontal rain, wind speed and direction is used to calculate the free-field wind-driven rain using Equation 1. The weather data is categorized into classifications based on rain intensity as class I (high horizontal rain intensity) and Class II (low horizontal rainfall). The effect of small wind speed is found to be less significant in the computation of RAF values, thus classifying the data based on wind speed is excluded in this paper. The horizontal rain intensity of above 2mm/hr is classified as high rain intensity class. Correspondingly, horizontal rain intensity below and equal to 2mm/hr is considered as low rain intensity scenario. In order to accommodate the sensitivity of data sensors, rain intensity and wind speed values below 0.1mm/hr and 0.5 m/s are unused. The vertical rain intensity measured at different locations and orientations, as shown in Figure 1b, is used to find a semi-empirical RAF value. Once the free-field wind-driven rain is calculated, the RAF values are obtained as gradients of vertical rain intensity (the wind-driven rain) and the free-field wind-driven rain.



a) b) c)

Figure 1 a) a rain-screen wall system b) rain gauge locations and c) vertical rain gauge

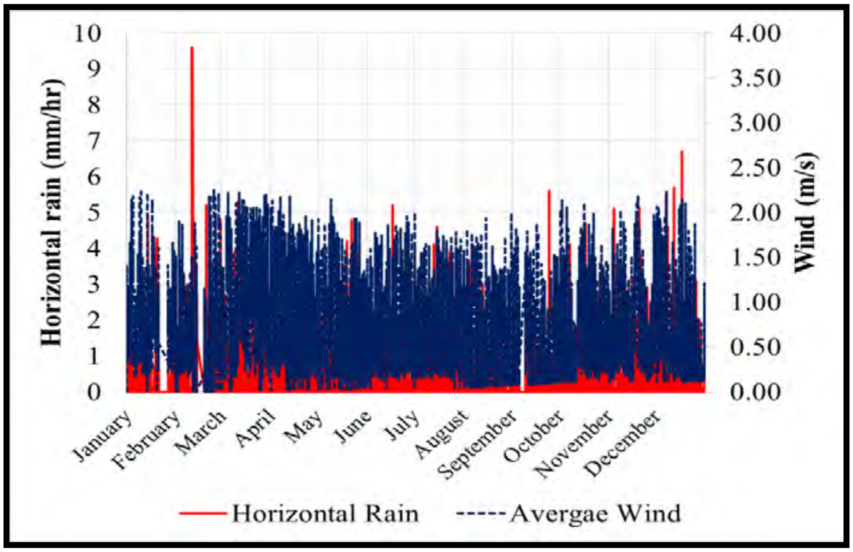
SIMULATION DESIGN

In order to study how the rain intensity dependant RAF values affect the hygrothermal performance of a building envelope, a WUFI simulation for rain screen wall system is conducted. The indoor conditions of relative humidity and temperature are set using ASHRAE 160P intermediate model.

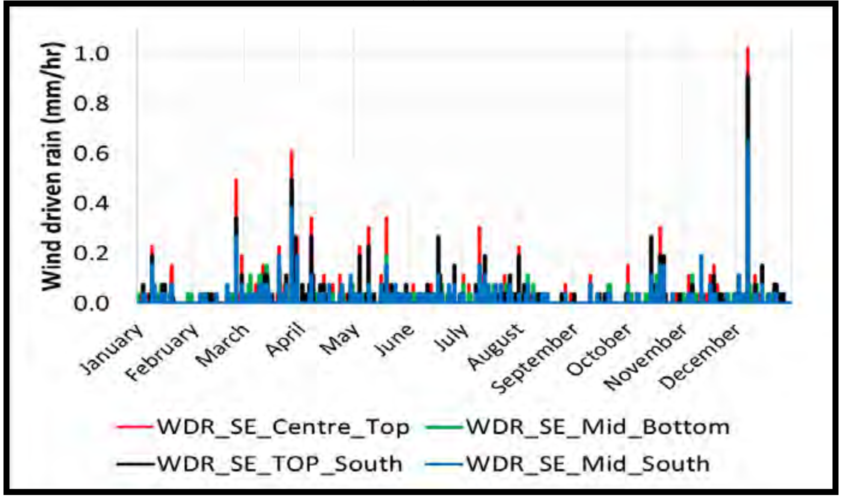
As shown in Figure 1a, the components of the wall system are regular Portland Stucco which is used as an exterior cladding, 10mm rain- screen air-gap, spun bonded olefin as a sheathing membrane (as a second plane of protection from precipitation and water intrusion), plywood sheathing board, 6 mil polyethylene sheet as a vapour and air barrier material, and gypsum board as an interior finishing layer. The initial conditions of 20^{o}C and 80% RH are used for all wall component members and the simulation is run for two consecutive years.

RESULTS AND DISCUSSIONS

The rain dependant RAF values were computed using the collected data of horizontal rain intensity, wind speed and direction and the wind-driven rain which is collected by vertical rain gauges at different elevations and directions of the BCIT Building Envelope Test Facility (BETF) walls. The horizontal and the vertical rain intensity values data used in this study are measured from January 1st, 2009 to September 30th, 2013. Figure 2 (a) shows the measured horizontal rain and wind speed of the year 2009. The wind-driven rain collected by vertical rain gauges on the South-East facing wall is shown in Figure2 (b). The selected elevations and the directions for the rain gauges are top-center, mid- centre, top-corner and mid-corner points of the four walls of the BETF. This data is used to simulate the hygrothermal performance of a rain screen wall located in Metro Vancouver.



(a)



(b)

Figure 2. One year measured data. a) Horizontal rain and wind speed, b) WDR at different wall locations.

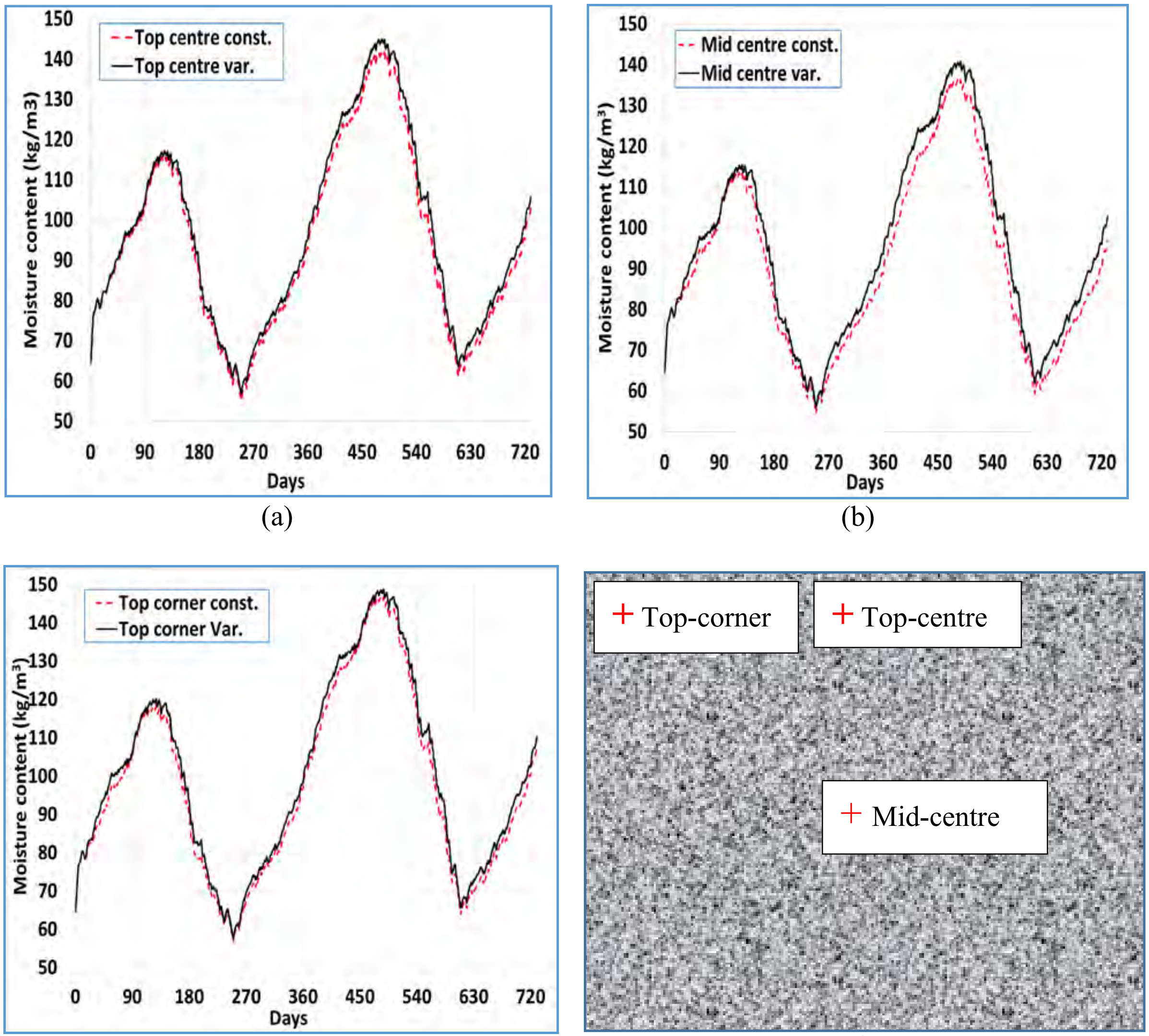
The horizontal rain intensity, the wind speed and direction data were used to calculate the free-field wind-driven rain and the DRF. The RAF values at each wall rain gauge location were determined by the slope of the plot of wind-driven rain intensity against the calculated free-field wind-driven rain (Tariku et al. 2016). The RAF values at the different locations on the walls are compared to the RAF values in literature and shown in Table 1.

Table 1. Calculated rain-dependent RAF and literature-based RAF values

Vertical Rain-gauge locations	Low rain Intensity	High rain intensity	BSI EN 13013-3, 1997
Top Centre	0.23	0.32	0.5
Middle Centre	0.23	0.31	0.4
Top Corner	0.26	0.38	0.5
Mid Corner	0.33	0.37	0.4

In order to study how this variation in RAF values affects the hygrothermal performance of building envelope, two types of simulations are conducted. The first simulation is using the measured variable RAF values based on the horizontal rainfall at the specific hour of interest. Thus in this simulation when the horizontal rain intensity class changes so does the RAF value used. In the second simulation category, the calculated constant RAF values are used.

Figure 3 shows the moisture content of the plywood sheathing board for a rain-screen wall system on three locations. As can be seen in the figure, the moisture content values for the Metro Vancouver weather data, the simulation based on constant RAF provides a lower moisture content value throughout the simulation periods of all three locations. The percentage difference of the water content of the plywood values between the two simulations for the gauges locations of top-centre, mid centre and top-corner has reached up to 5.8%, 9.0% and 6.2% respectively. The schematic diagram shown in Figure 3d shows the rain gauge locations used in the study.



(a) (b)

(c) (d)

Figure 3. Water content of the plywood for constant and rain intensity dependant RAF values at (a) top-centre (b) mid-centre and (c) top-corner

Considering the above figure is moisture content values of a sheathing in a rain-screen wall design with a moisture barrier, it can be deduced that the variation between the two models can be pronounced in the absence of rain gap and prolonged time period.

CONCLUSIONS

In this study, the variation of the proposed approach's RAF values from the existing literature calculation method is studied and the variation's effect on the hygrothermal performance of rain screen wall system is examined. Results show that there is a direct relationship between rain intensity and calculated RAF values. The total water content of the plywood sheathing for wall systems with rain screen is simulated for both constant and rain intensity dependent RAF values developed under this study. A percentage variation up to 9% is observed between the new approach and constant RAF model for studied wall systems at different elevations. These findings support the initial hypothesis of this study that applying a constant RAF value for any rain load can affect the overall hygrothermal performance study of building enclosures.

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