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The spell definition in ISO-15927 and its impact on the rain deposition on the building facade

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Abstract

Wind-driven rain (WDR) is one of the most important causes for water damage in buildings. Therefore, the first crucial step to assess the hygrothermal performance of the building envelope, is the appropriate estimation of the amount of rainwater striking the building's façade. ISO 15927 offers the annual average index –mainly to assess the moisture content of absorbent surfaces, and the spell index – more related to the likelihood of water penetration through joints. To calculate these indices, assumptions are made concerning the length of the period of 'no rain', called 'spell definition'. Obviously, the choice of this spell definition will characterise the WDR-amount. In this paper, WDR measurements of a 3-storey building in Vancouver, Canada are used to investigate how this spell definition affects the rain load. Different filter criteria are used to exclude errors due to measurement equipment. By means of the catch ratio as a dimensionless parameter, the results of the analysis for different spell definitions are compared to hourly and 5-min data. It is concluded that longer spell definitions result in lower catch ratios and an underestimation of the WDR load. Hourly data turns out to be a more conservative approach for WDR-assessment of this case study, but is able to represent the spread on the catch ratio most closely to the original 5min-dataset.

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Keywords: Wind-driven rain; meteorological data; calculation method; catch ratio; ISO 15927

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1. Introduction

Construction methods and building materials need to be robust enough to endure the exposure to varying weather conditions over their lifetime. The resistance against rain is one of the priorities of the building skin. Typically, Heat-Air-Moisture (HAM)-simulations make use of the hourly data that is available from meteorological weather stations (wind speed, wind direction and horizontal rainfall intensity). Several researchers showed that smaller frequencies (5min, 10min) are of more interest for research in the weather resistance of the building skin, because peak loads are not averaged. In the ideal case, the weather data to be used in HAM-simulations is collected on site, simultaneously with the collection of rain that reaches the building surface, i.e. the wind driven rain (WDR). Because this type of measurements are time and cost intensive and not always possible, designers and researchers often have to rely on semi-empirical formulas to calculate the WDR-intensity from meteorological information.

Nomenclature

U_{10}	wind speed at 10m height [m/s]	E	exposure coefficient
θ	angle of the wind direction to the normal of the building facade [°]	D	deposition factor
		C_R	terrain roughness coefficient
R_{hor}	horizontal rainfall intensity [mm/h]	C_T	terrain topography coefficient
R_{wdr}	wind driven rain intensity [mm/h]	O	obstruction factor
S_{hor}	horizontal rainfall amount [mm]	W	wall factor, depending on the type of roof
S_{wdr}	wind driven rainfall amount [mm]	η	catch ratio [-]

1.1. ISO 15927

Next to other semi-empirical formulas that are currently available to calculate the WDR, ISO 15927 [1] offers an elaborate approach that takes into account the surroundings and building geometry and uses hourly meteorological data (Eq. 1, the summation is taken over all hours in the spell for which cos θ is positive):

$$R_{wdr} = C_R . C_T . O . W . \frac{2}{9} \sum R_{hor}^{8/9} . U_{10} . \cos\theta \tag{1}$$

ISO 15927 is based on the British Standard BS8104, and therefore applies to climates similar to the United Kingdom. For different climates it is recommended to verify its validity by driving rain measurements of the considered region. Eq. 1 is used to calculate the 'spell index', which renders the maximum value of WDR to occur once every 3 year, but implicitly also allows to calculate the WDR intensity for any rain spell [2]. According to this standard, a 'spell' of driving rain, is defined as a period of driving rain during which the risk of penetration through masonry increases, i.e. when the input of water due to rain exceeds the loss due to evaporation. In case of masonry, the dry period between 2 spells should last at least 96h to reach this threshold. For rain penetration through doors, windows and other gaps, shorter-term inputs should be considered. Nonetheless, the standard does not give guidelines on how short these inputs have to be, nor does it distinguish between different types of cladding (e.g. wood sidings, plaster or metallic cladding) for which the threshold will probably be lower.

1.2. Case study: Wallace building

For the current study, WDR measurements are performed on a 3-storey building in Vancouver, BC, Canada. The building will be referred to as Wallace, named after its street. It is located near the coastline of Jericho beach and is mainly subjected to eastern wind. For this orientation, the terrain is characterized by single-family houses, as can be seen from the photo in Fig. 1(a). Three rain gauges (resolution 0.038mm) are installed on the eastern façade: one at the top edge of the building (Top gauge), one 2.4m lower (Bottom gauge), and the third one at the protruding balcony (Balcony gauge), at the same height as Top gauge (Fig. 1(b-c)). The data is collected every 5-minutes for 21 months (November 2006 - July 2008). Additionally, the wind speed and wind direction are gathered from a mast on the roof (at 11.53m), as well as the horizontal rainfall intensity (at 8.53m, resolution 0.1mm). More detailed information on the location and measurement equipment can be found in [3].

In this paper, it is investigated to what extent the definition of a rain spell affects the WDR-amount on a building based on the measurements on the Wallace building. A more elaborate analysis is reported for the conversion of the measurement data with a resolution of 5min, to hourly data as needed in ISO 15927. Finally, several filter criteria to exclude measurement errors from the dataset are discussed.

Fig. 1 (a) eastern surroundings of the building; (b) photo of east façade (c) drawing with location of rain gauges

2. Definition of a 'spell'

For masonry, ISO 15927 defines intermediate dry periods of at least 96h between two spells. This implies that shorter intermediate dry periods (less than 96h) are combined and averaged with rainy periods, leading to a decreased assessment in peak rain load. For the Wallace dataset, it is investigated to what extent the duration of the dry intermediate period affects the estimation of WDR. Eight possible 'no rain'-criteria are considered: *96h, 72h, 48h, 24h, 12h, 6h, 1h* and an imaginary long period of 10000h, making the whole dataset as 1 spell (named *all*).

2.1. Converting 5-min data to hourly data

Because the definition of a spell is hourly-based, the measurement data with a resolution of 5min must be converted. Moreover, an hourly time step is a more common input for HAM-software. For the horizontal rain and wind driven rain, every 12 sequential data points are summed up to get the hourly value. To convert the wind speed and wind direction, the averaging can be done either arithmetically or weighted. Arithmetic averaging (AA) is currently used by meteorological stations, whereas the weighted averaging (WA) technique is proposed in [4] and takes into account the co-occurrence of wind and rain and yields good results for WDR-calculations. For the interval j (=1hour), short-term data i (=5min) and number of data points n (=12) within the interval, the formulas used in each technique are [4, 5]:

(AA): $$U_{10,j} = \frac{\sum_i U_{10,i}}{n}, \quad \theta_j = \frac{\sum_i \theta_i}{n}$$ (WA): $$U_{10,j} = \frac{\sum_i U_{10,i} S_{hor,i}}{\sum_i S_{hor,i}}, \quad \theta_j = \frac{\sum_i U_{10,i} S_{hor,i} \theta_i}{\sum_i U_{10,i} S_{hor,i}}$$

For analyzing the impact of the spell definition on the WDR amount on a building, AA is used to find the wind speed and direction per hour. The catch ratio η is used as a dimensionless parameter for comparison between the different spell definitions. It is calculated for each spell k with l hours with the following formula [6]:

$$\eta_k = \frac{R_{wdr,k}}{R_{hor,k}} = \frac{\sum_l R_{wdr,j}}{\sum_l R_{hor,j}} \quad (2)$$

It should be noted that the catch ratio here is only used as a parameter to compare different spell criteria. If it would be the purpose to define a catch ratio to calculate a realistic WDR deposition on the facade, one should compare different averaging techniques to calculate $R_{hor,j}$ too. However, this is out of the scope of this paper.

2.2. Filtering out measurement errors

The rain events of Vancouver are characterized by rather long, non-intense rain of several days in winter time (November-March) whereas spring and summer are characterized by shorter rain events. In [7] it is stated that several errors associated with WDR-measurements may occur. Firstly, the adhesion water is more likely to evaporate from the collection area during events of light rainfall, which leads to lower values of η (error 1). For the rain gauges used at Wallace, the adhesion water was determined experimentally, with an average of 0.081mm, which is quite large compared to the resolution of the gauge (0.038mm/tip). Because light rainfalls are predominant in Vancouver, the presence of error 1 is frequently present in the studied dataset: the horizontal gauge often did register rain, while the vertical rain gauge did not register any rain at that moment, leading to η_i=0.(One should differentiate that 'zeros' also occur due to the time delay between the registration of the horizontal and vertical gauge and the lower quantities of R_{wdr}.) To correct the error caused by this adhesion water, it is necessary to know the evaporation time under ambient conditions. Because we only want to compare different spell criteria for the current study, it is decided to filter out the data which is mostly affected by this error. Therefore, an appropriate threshold for S_{hor} and S_{wdr} should be determined. In [7] it is suggested to consider the worst case scenario: complete water evaporation at each interruption of the rainfall by a dry period. For Wallace, the following case is assumed: during a short 1 hour rain event the horizontal rain gauge tips once (0.1mm). The vertical gauge tips an unknown number of times. Fig. 2a shows the possible catch ratios for the number of tips of the vertical gauge. (e.g. 2 tips, η_{meas} = 0.076/0.1 = 0.76; blue). If complete evaporation is assumed at the end of the hour, this causes an error which is indicated in Fig. 4a by the green points, e.g. 2 tips: η=(0.038*2+0.081)/0.1 = 1.57. From the moment 3 tips of the vertical rain gauge occur, the impact of the evaporation error becomes less than 100%, and only decreases for more intense rainfalls. Consequently, the filter criterion for the vertical gauge is set to 3 tips or S_{wdr} = 0.114mm. Although this criterion reduces the dataset with about 60-80% (Fig. 4b), about 30-45% of the reduction is already caused by removing the 'zero' catch ratios. On the other hand, for the analysis of the 5min measurement data, only 1 tip is requested for the vertical gauge in order to account for it, because the time interval is much smaller and consequently the chance for total evaporation within 5 minutes has reduced .

Errore. L'origine r ... ata.

a. b.

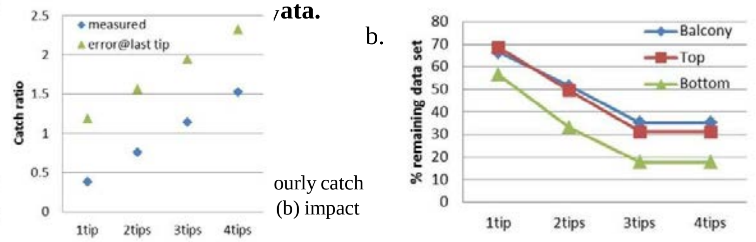

Fig. 2 (a) Impact of the e... ourly catch ratio, for different numbers of tips of the ve... (b) impact of filter criteria for vertical gauge on the...

A second error is related to the wind direction. It is assumed that wind at oblique angles to the building leads to disturbed flow patterns and raindrop trajectories, due to the presence of the rain gauge itself (error 2). Furthermore, the water is spread over a larger surface, increasing the evaporation risk. For wind blowing perpendicular to the wall's surface, it is supposed that this error/risk is negligible and thus the WDR-measurements at a perpendicular wind direction are more reliable.

In summary the following criteria are applied to the dataset (*event* can be a spell or 1 hour):

1. $S_{hor,event} \geq$ 0.1mm and $S_{wdr,event} \geq$ 0.114mm, $S_{hor,5min} \geq$ 0.1mm ,$S_{wdr,5min} \geq$ 0.038mm
2. Wind direction θ perpendicular to the façade: 80°≤θ≤100°

2.3. Effect of different spell definitions

Fig. 3 presents the spread of the catch ratios as the results of the analysis for different spell definitions and filter criteria. For reasons of comparison, the catch ratio range for the original dataset on a 5min base ('*5min*') is added, as well as the hourly averaged data (hourly AA ‘H_A’ or hourly WA ‘H_W’). Because the conclusions are similar for the top and bottom gauge, only the results for the balcony gauge are shown. It is clear that the spread of the catch ratio is largely depending on the spell definition. As expected, when the spell definition is very long (e.g. All, 96h, 72h) the dataset is divided into only a few but long spells, which results in none, one or only a few and low catch ratios. The minimum-maximum range becomes larger as the spell duration shortens because wind and rain peaks are more pronounced. For the filtered dataset (1,2 or 1+2) it can be stated that for shorter dry periods, and implicitly shorter spell durations, η shows an increasing trend. For unfiltered data the opposite is true, mainly because a lot of ‘zeros’ are still present in the dataset (partly due to error 1, as was mentioned in 2.2). Their impact is larger when spells are shorter, which results in a decreasing trend. This contrast between filtered and unfiltered data emphasizes the importance of filtering/correcting a measurement dataset of rain events.

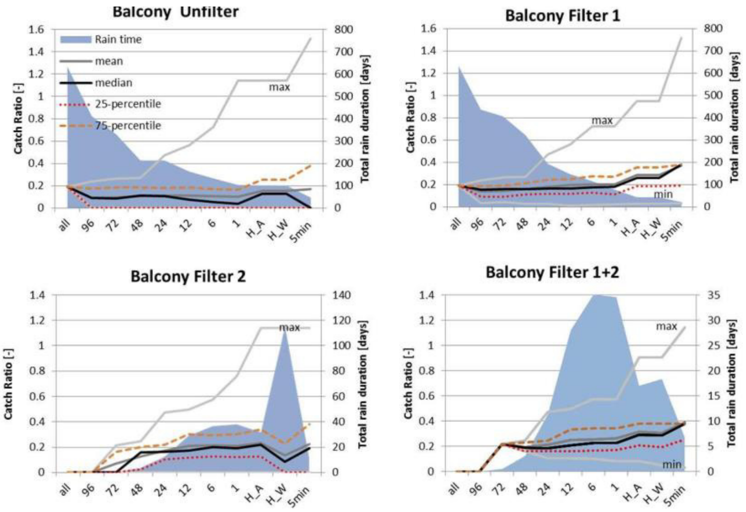

Fig. 3 Range of the catch ratios for the given dataset (here only for the balcony gauge), for different spell definitions and filter criteria
H_A: hourly arithmetic averaged data; H_W: hourly weighted average data; 5min; original measured data on 5min base

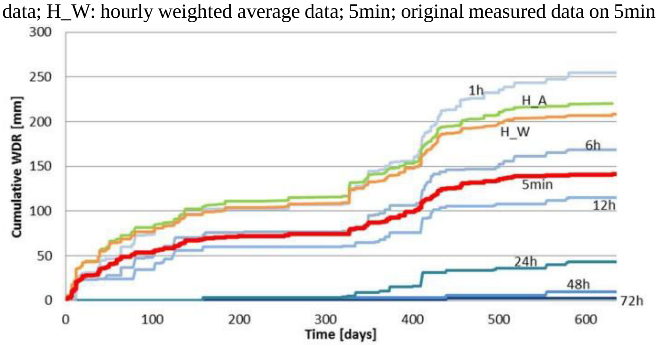

Fig. 4 Cumulative distribution function of the amount of WDR (at balcony gauge, filter 1+2) for different spell definitions. Shorter and more frequent rain events result in a higher total exposure. H_A: hourly arithmetic averaged; H_W: hourly weighted average; 5min: original data

Rain events perpendicular to the façade (filter 2) are expected to result in higher catch ratios, because the rain is spread over only a small area. This trend is clearly noticed when ‘filter 1’ and ‘filter 1+2’ are compared in Fig.3. The values within the 75-percentile are generally higher, and the curve of the median catch ratio becomes steeper. However, the value for the maximum catch ratio is generally lower when both filters are applied. This is because high wind speeds (>4m/s) - which results in higher η-values - occur on average at 164° from north, but are excluded by filter 2. For the filtered data, it is noticed that the hourly values and 5min values always result in higher median catch ratios than any of the spell definition (e.g. the median catch ratio for H_A is on average about 30-35% higher than the median catch ratio for any of the spell definitions).This means that short term data contains valuable information on the peak rain loads on the facade. The number of rain events, and thus the total rain time that is accounted for, decreases significantly when more filters are applied. For filter 1, on average about 60% of the events of the unfiltered dataset (or 87% of the total rain time) remains, but filter criterion 2 reduces this to only 12% (or 28% of the total rain time). When both filters are applied together, only 6% of the unfiltered rain events are left (or 13% of the total rain time). Although the number of events and so the total time span that is considered as 'raining' diminishes by filtering, it is still very long for the shorter spell definitions and much higher than the total rain time of the 5min-data (Fig 3, blue).

Fig. 4 presents the total wind driven rain amount over the considered period for the different spell definitions (filter 1+2). Shorter and more frequent rain events result in a higher total exposure for wind perpendicular to the façade during heavier rainfall. It is clear that definitions with long intermediate dry periods (*96h*,*72h*, *48h*, *24h*) severely underestimate the WDR amount, because the rain data is smoothed over long periods of time. *12h* and *6h* definitions follow the trend of the 5 min data most closely. On the other hand, *1h*-definition produces WDR-amounts similar to the hourly data, which is a better point of reference because the filter criteria are the same.

3. Conclusion

Calculating WDR according to the spell definitions (as defined in ISO 15927) always results in an underestimation of the catch ratios of the building façade. The data is smoothed over long periods of time, especially in case of long spell durations. It is shown that the application of filters has a large impact and increases the value of the measured catch ratios significantly.

Concerning the total WDR-amount, the definitions of *12h* and *6h* dry periods between two spells lead to the best approximation of the filtered measurement data (5min) of the studied Wallace building. Here, the lower catch ratios are compensated by longer rain spells. Nonetheless, the 5min data contains important information on the peak loads which is discarded by the spell definitions. Data on an hourly basis is able to represent partly the original catch ratio spectrum, but by averaging the wind speed and direction and filtering the data, the total amount of WDR is estimated much higher compared to the 5min data, which makes it a more conservative approach.

The choice for short term data with high peak loads (and catch ratios) or a dataset with longer spells and lower catch ratios but higher total WDR amount, might be depending on the assembly one wants to study, and the type of defect that has to be investigated. Both types of dataset can provide various information on the hygrothermal behaviour of the assembly, and it is worth looking at both of them instead of choosing just one scenario.

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