Proposed Statement of Work
Development of Wind-Driven Rain Climatology and Coincidental Wind Speed Return Period Maps for Florida and Surrounding Coastal Areas.

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Introduction

Rain water intrusion, in its various forms, persists as one of the most costly and prolific forms of damage to buildings in the United States (Carll, 2000; ASTM, 2009; HUD, 2015). For exterior walls, rain water intrusion is closely related to the presence of wind to cause rain water impingement on walls. More importantly, the coincidental presence of wind also causes wind pressure differentials that force water behind claddings and into or through wall assemblies or components. This mechanism of rain water intrusion is prolific and is the cause of substantial economic impact, loss of building resiliency and useful life, and even has structural safety implications.

In the most severe and obvious cases, the damage is immediate and extensive as in tropical storms and hurricanes, even without the presence of significant damage to the structure or its exterior finishes. This form of damage can extend to building contents which escalates the cost impact. Less obvious forms of damage occur more insidiously from routine thunderstorms and other wind-driven rain events that impact most of the United States. Thus, water may be driven into assemblies without noticeable damage to building interiors. Consequently, the damage accumulates and progresses unnoticed until significant rot or corrosion or mold damage occurs within building assemblies. In the worst-cases, structural damage may go undetected and progress until exposed by a loading event resulting in failure or collapse. This collective impact of wind-driven rain impacts the durability and resiliency of essentially all of the U.S. building stock. Yet, there is no risk-consistent basis for dealing with this wind-driven rain hazard as it varies across Florida and more broadly the United States.

In the absence of a scientific understanding of wind-driven rain hazard as a risk-consistent basis for controlling the potential for rain water intrusion, building codes and construction practices have been developed in an inconsistent fashion based on experience and traditional practices. These practices may work well in some climates (e.g., dry southwest), but perform poorly in others (e.g., Northwest coast, Gulf and Atlantic Coasts, and inland regions impacted by frequent thunderstorms). In addition, newer alternative materials and methods for weather resistance may be developed on the basis of "equivalency" to these accepted practices without a risk-consistent or uniform set of performance requirements. Thus, they become subject to the same lack of risk consistency in preventing water intrusion due to wind-driven rain.

The above described problem and consequences will continue and persist without the development of a wind-driven rain climatology that properly represents the variation in wind-driven rain hazard across Florida. This need must be addressed in a manner that can be implemented to determine appropriate and consistent performance metrics for design and evaluation (testing) of building enclosures for weather resistance not only in Florida but across the U.S. This proposal is aimed at addressing this climate hazard need in a scientifically robust and practical manner.

Background

Interest in addressing wind-driven rain is not new and past attempts to resolve this concern have failed, largely due to the lack of a well-defined hazard basis to justify solutions to the problem. For example, a recent U.S. model building code proposal, numbered FS93-18, attempted to establish a risk-consistent basis for addressing wind-driven rain resistance of building envelopes (ICC, 2018). However, the proposal failed in large part due to the use of an old wind-driven rain "index map" which does not properly account for the coincidental occurrence of rain and wind. In other cases, annual rain fall data have been used as a basis for roughly describing regions of the U.S. with differing water intrusion hazard, although without consideration of coincidental wind speed necessary to produce rain impingement and pressure differentials that force intrusion. A risk-consistent basis for defining the variation in wind-driven rain hazard across Florida, which can subsequently be extended across the country, is needed to support building code advancement.

Various standards and criteria for evaluation of critical building envelope weather-resistant components, such as windows and water-resistive barriers, are generally prescriptive and vary significantly in the degree of water-intrusion resistance required for building code approval (ABTG, 2015). This lack of consistency in criteria creates uncertain and varied performance for different types of products and materials that are intended to serve the same purpose. Hence, market and product develop problems have developed and now persist because of the lack of a risk-consistent and uniform basis for defining performance requirements for components that provide weather-resistance to building envelopes. A risk consistent basis for defining the variation in wind-driven rain hazard across Florida, where the risk is anticipated to be the highest, and the U.S. is needed to support appropriate standards and criteria for assessing and specifying building products, materials, and assemblies.

As addressed in the proposed research approach (next section), progress has been made in other countries on the matter of defining wind-driven rain hazard. For example, Canada uses a driving-rain wind pressure (DRWP) parameter based on analysis of climate data in a manner similar to that proposed herein. As an application example, the DRWP is used to evaluate and specify window and door products suitable to a given climate in Canada (CSA, 2009). If appropriate, a similar coordinated effort is needed here to ensure building envelope components are specified in a manner consistent with the environment in which they are intended to be used. This research proposes to deliver the data (including wind-driven rain hazard maps) necessary to guide such an effort across Florida and surrounding hurricane-prone locations.

The mapped data will present wind speed return periods based on analysis of weather station data for annual extreme wind speeds that simultaneously occur with a relevant range of threshold values for *coincidental rainfall rates*. The threshold rainfall rates are intended to bracket conditions considered representative of that minimally necessary to initiate consequential leakage into or through building envelopes. The wind speed data will be adjusted as necessary to align with baseline design conditions (e.g., open, flat terrain, 33-ft above ground) such that standardized wind design provisions such as ASCE 7 (ASCE, 2016) can be used to determine pressure differentials across a building envelope that are coincidental with rainfall of a given threshold rate.

Tasks and Objectives

Task 1 Data Acquisition

Obtain 1-minute wind and precipitation data from all available Automated Surface Observing System sites in Florida and adjoining states from NOAA archive. Process and archive data for analysis. Obtain once-per-hour data from same set of sites for comparison.

Task 2 Obtain siting information

Siting information is necessary to align our the raw windspeed data to baseline design conditions (e.g., open, flat terrain, 33-ft above ground).

Task 3 Extreme value analysis

Develop coincident wind-rain partial duration series from 1-minute data series and fit appropriate extreme value distribution to data from each station. Distributions will be selected based on goodness of fit tests. Compute coincident rain intensity wind speed occurrence probabilities.

Task 4 Comparison with once-per-hour data

Compare magnitudes of coincident extreme wind speed rainfall intensity recurrence probabilities based on once-per-hour and one-per-minute observations. Determine trade-offs between the longer period of record available for the hourly samples and the higher sampling frequency (but shorter record) of the 1-minute data.

Task 5 Develop risk maps

Mapping software will be used to produce extreme wind speed risk maps for different rainfall intensity thresholds. Station specific values will be spatially interpolated and contoured.

Research Approach

Our work will be guided by the equation described in International Standard Organization (ISO), 2009) to compute wind driven rain (WDR) based on airport meteorological observations. In ISO (2009) WDR is given by

$$WDR = \frac{2}{9}\sum R^{\frac{8}{9}}\, v\ cos\theta, \tag{1}$$

where R is rainfall intensity (mmh^{-1}), v is 10-meter windspeed (ms^{-1}) and θ is the angle of the wind direction normal to the building facade. The $cos(\theta)$ term, is assumed to equal 1 in the more generalized case that ignores building face orientation. In addition, in the above form, the equation assumes that factors describing the influence of terrain roughness, topography, local obstructions and the spatial distribution of the WDR are equal to one. Since these factors are likely to differ between airport and building locations, relevant adjustments based on site characteristics will be provided.

The summation accounts for the period during which rainfall accumulates and some directional component of the wind impacts the same face. This and similar semi-empirical equations have been applied in the United Kingdom (Orr and Viles, 2018), Sweden (Nik et al., 2015), Greece (Giarma and Aravantinos, 2014), Brazil (Domínguez-Hernández, et al., 2017) and Spain (Perez-Bella et al, 2013) to develop country-scale maps of WDR. A study for US stations (Cornick and Lacasse, 2009) also used driving-rain wind pressure (DRWP); defined as:

$$DRWP = 0.5\rho_{air}v^2 \ , \tag{2}$$

where ρ_{air} is air density and v is wind speed.

Traditionally these national assessments of WDR have relied on meteorological data collected at hourly resolution. This is problematic in that it is likely that the highest wind speeds and rainfall intensities occur at shorter time scales and thus are not reflected in the hourly data. Blocken and Crameliet (2010) advocate for the use of 10-minute resolution data, although in some cases hourly data (reflecting the average of 10-minute measurements) was found to be adequate. Ge (2015) showed that while the correlation between WDR obtained from hourly data and that using

5-minute data was high (> 0.95), values based on hourly were on the order of 6% higher than the 5-minute reference.

Here we propose to use data from the national Automated Surface Observing System (ASOS) at 1-minute temporal resolution. Such data are available back to 2000, at more than 100 stations in Florida and adjacent hurricane-prone states (Fig. 1). The relevant data at these sites consist of minute-by-minute reports of 2-minute average wind, maximum 5-second windspeed and 1-minute rainfall accumulation. Using these data, we will be able to identify nearly coincident periods of high winds and rainfall, correcting a major deficiency in previous attempts to characterize the wind-driven rain hazard in the U.S. If needed, we will also be able to aggregate 1-minute data over longer averaging period, to assess differences between this new data resource and previous climatologies based on hourly records. Based on this comparison, we also propose to examine whether a strong enough relationship exists between the more desirable 1-minute wind-driven rain data and that using only hourly data. If such a relationship is feasible, the period of record available for analysis could be extended back to at least 1950 at most stations. Otherwise, only the shorter (approximately 20 years) 1-minute data will be used to develop extreme wind driven rain climatology. This will be a sufficiently long record to assess recurrence probabilities on the order of 25 to as much as 50-years.

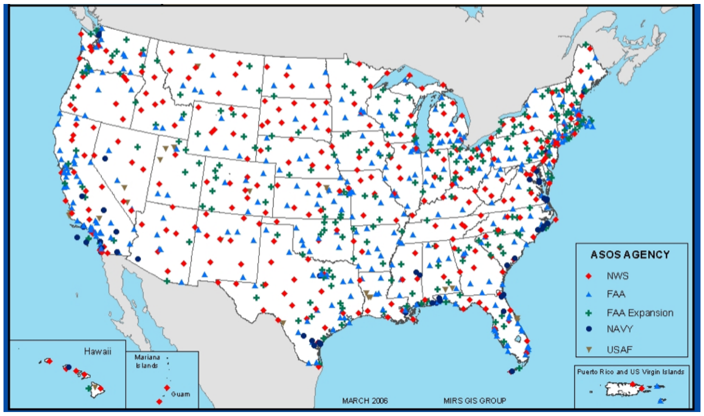

Figure 1. Locations of ASOS network stations.

To assess extreme WDR exposure, we will concentrate on developing extreme wind speed climatologies that are conditional upon the occurrence of rainfall within pre-specified interval categories (e.g. 0.1 – 0.2, 0.20-0.3, etc.). First, we will generate partial duration series (i.e. a list of the *n* largest independent wind events, where *n* is the length of the available period of record at a station. A preliminary example of such data is shown in Figure 2. Using this partial duration series (PDS), return periods will be generated by fitting an appropriate extreme value distribution to the data. Previously (e.g. Orr and Viles, 2018) the Gumbel distribution has been used to assess the recurrence probability of extreme WDR events. We will test other distributions such as the Generalized Extreme Value (GEV) distribution to determine which provides the best fit to these data. The outcome of this extreme value fitting procedure will be an estimate of the likelihood of an event (recurrence interval) that can be converted to the probability of exceeding a specific value in a given year. The extreme windspeeds computed for each rainfall intensity category will serve can be input into Equations 1 and 2 to obtain measures of extreme WDR and DRWP or can be used directly to guide product testing and/or develop risk maps analogous to those in ASCE 7, but conditional on rainfall occurrence and intensity.

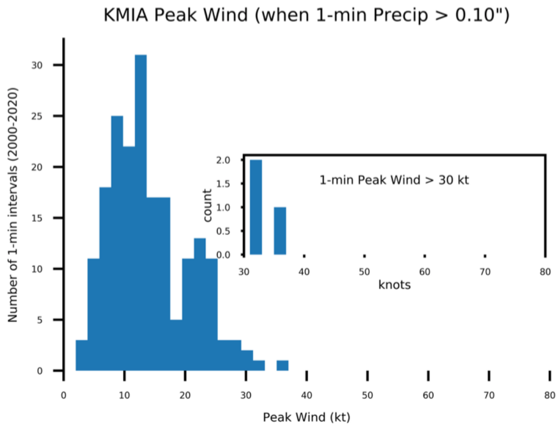

Figure 2. Histogram of 1-min samples of 5-second maximum wind speed (kt) when the coincident 1-minute rainfall accumulation is at least 0.10 inches. The insert shows the distribution of the 20 independent partial duration series events.

Deliverables

We will work with users in the fenestration and insurance industries to determine the most applicable set of deliverables and practical products. Given previous work, the envisioned deliverables would likely include

1) Quality control algorithms to identify erroneous data values. We will implement a set of limit checks to flag data values that exceed published 1% recurrence probabilities of rainfall and windspeed. These flagged values will be manually screened to assure their veracity.

2) A set of contour plots, one for each station (e.g. Fig. 3). These plots will document the mean recurrence intervals consistent with mean recurrence intervals used to develop ASCE 7 Chapter 26 wind speed maps, of simultaneous wind-speed (x-axis) and rainfall intensity (y-axis) during the available 20-year record of 1-minute observations. In the example plot, one could compare the risk of a high wind speed occurring coincident with a relatively lower rainfall intensity (lower right portion of the figure) with that of a more modest wind speed threshold but higher rainfall intensity (upper left portion of figure)

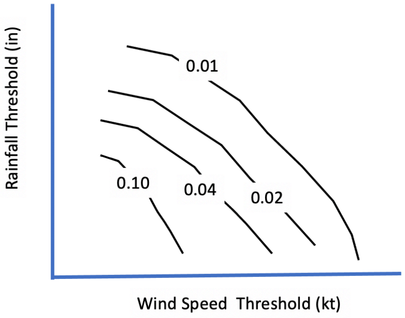

Figure 3. Example contour plot showing the mean annual recurrence probabilities of different wind speed and rain intensity combinations.

3) An analysis contour plots analogous to those in deliverable 2, but for the longer record of once-per-hour rainfall and windspeed observations. This will allow direct comparison between the probabilities computed using data with different temporal sampling resolutions as well as an assessment of the effect of the longer period-of-record.

4) Contoured maps showing a specific wind speed recurrence interval values conditional on rainfall intensity covering Florida and adjacent coastal areas (e.g. Fig. 4). For example the 4% annual probability of 5-second windspeed ***conditional upon*** the occurrence of rainfall within an intensity category.

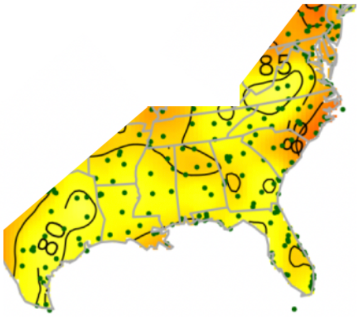

Figure 4. Prototype contoured map showing extreme wind speed associated with a specific coincident rainfall intensity.

5) Interim and final reports will be compiled and submitted

Implementation Targets

This project does not include implementation of the findings. However, it will produce the data (e.g., probabilistic wind-driven rain maps) to allow stakeholders to make the necessary implementation decisions in an informed manner. For example, the coincidental wind speed maps (with a given threshold of coincidental rainfall) will provide various levels of hazard (return periods) such that wind-pressures associated with rain wetting can be determined and compared to existing envelope design and evaluation criteria (or lack thereof). The deliverables cannot make this judgment in determining what magnitude of wind-driven rain probability adequately aligns with past successful practice (and resolves unsuccessful practice). But, regardless of the judgement used to "calibrate" to past successful practice, the use of results from this research will ensure that a reasonably uniform, risk-consistent basis for overall building envelope assembly and component design and evaluation will be achieved across the Southeast U.S.

Preliminary Budget Estimate

While it is expected that the research plan may be refined based on input from additional stakeholders and funding sources and additional literature review, the cost of the research plan and deliverables as described above is estimated to range from $110,000 to $120,000.

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