ANALYSIS OF WIND-DRIVEN RAIN EXPOSURE BASED ON LONG-TERM MONITORING

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OUTLINE

- INTRODUCTION
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- METHODOLOGY
- RESULTS AND DISCUSSION
- CONCLUSION

INTRODUCTION

- Exterior building envelopes are typically exposed to various climatic loads on the outside while maintaining quite stable conditions on the inside.
- The envelopes experience wetting and drying cycles from HAM transfer through the assemblies.
- Accumulated moisture may deteriorate envelope components when exposed for longer period of wetting than drying of assemblies.

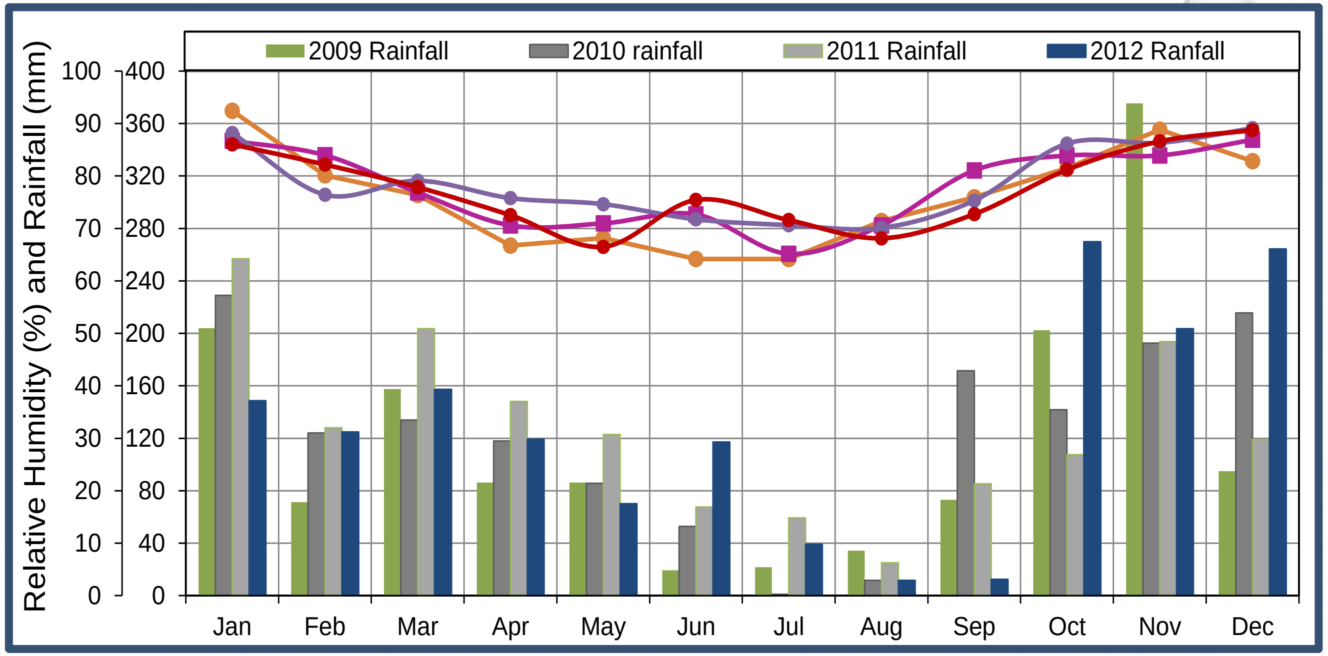
WIND-DRIVEN RAIN (WDR)

- WDR is one of the major moisture loading causes in coastal climate such as BC, Canada

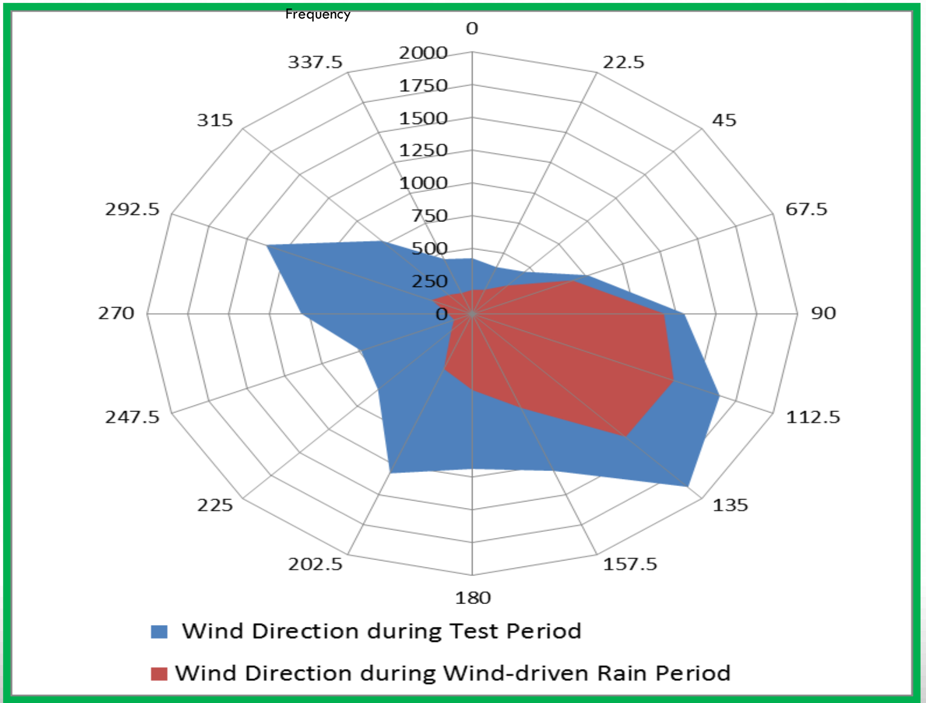
- Determining amount of WDR impinging to a building envelope surface is one of the critical steps in improved design that consider enhancing the drying capabilities of assemblies.
- Horizontal rainfall intensity, wind speed and wind direction are the most important factors to determine the magnitude of WDR.

BC Coastal Climate

- Mild temperature and wet climate
- Monthly horizontal rainfall:
- Max. 200 - 375 mm in Oct. - Jan.
- Min. 0 - 60 mm in Jul - Aug.
- Monthly average relative humidity:
- Max. 83 - 91% in Oct. - Jan.
- Min. 63 -70% in Jun. - Aug.



Monthly average outdoor relative humidity (RH) and accumulated horizontal rainfall.



- The prevailing wind direction was from south-east and secondary direction was from north-west in the whole period of the year.
- A prevailing wind from south-east direction during wind-driven rain period. As a result, south-east façade receives highest wind-driven rain.

BACKGROUND

- The common practice on WDR estimation involve using semi-empirical or numerical analysis methods.
- The semi-empirical analysis method was first developed in1950s by Best and Lacy using experimental-based study of the relationship between rain drop size, rain drop speed, and horizontal rain intensity.
- Edmund C. Choi's numerical analysis method, which was developed during the 90s, is one of the first WDR analysis method.

BACKGROUND

- Several research works on WDR estimation methods and validation works have been reported [Blocken and Carmeliet 2010; Hens, 2015; van Mook 2002] .
  - Further development on semi-empirical formula was recounted in the early 2000s by Straube and Burnett.
- Rain Admittance Factor (RAF) (Straube and Burnett, 2000) considers
- The building aspect ratio, the presence of a roof overhang, and the area of interest within the wall façade.
  - Wall Factor, or RAF is a factor which can be determined based on the slope of wind-driven rain intensity against the calculated free-field WDR.

WDR Calculation

- In addition to the horizontal rain intensity and wind data, several other parameters need be calculated first to estimate the **free-field WDR intensity**:

1) Median rain drop diameter: $d_{50} = 1.30\left(R_h{}^{0.232} \times 0.69^{1/n}\right)$

   coefficient n is 2.25, d_{50} is median raindrop diameter (mm), R_h is horizontal rainfall intensity (mm/hr.m^2).

2) Terminal velocity of raindrops:

$$V_t(d) = -0.166033 + 4.918441\mathrm{d} - 0.888016d^2 + 0.054888\mathrm{d}^3$$

   $V_t(d)$ is terminal velocity of raindrops, d is median raindrop diameter (mm).

3) WDR intensity:

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

   R_{wdr} is WDR intensity (mm), RAF is= Rain Admittance Factor, $DRF(V_t)$ is Driving Rain Factor = $1/V_t$, θ is angle of the wind to the wall's normal, U(h) is wind speed at the height of interest (m/s).

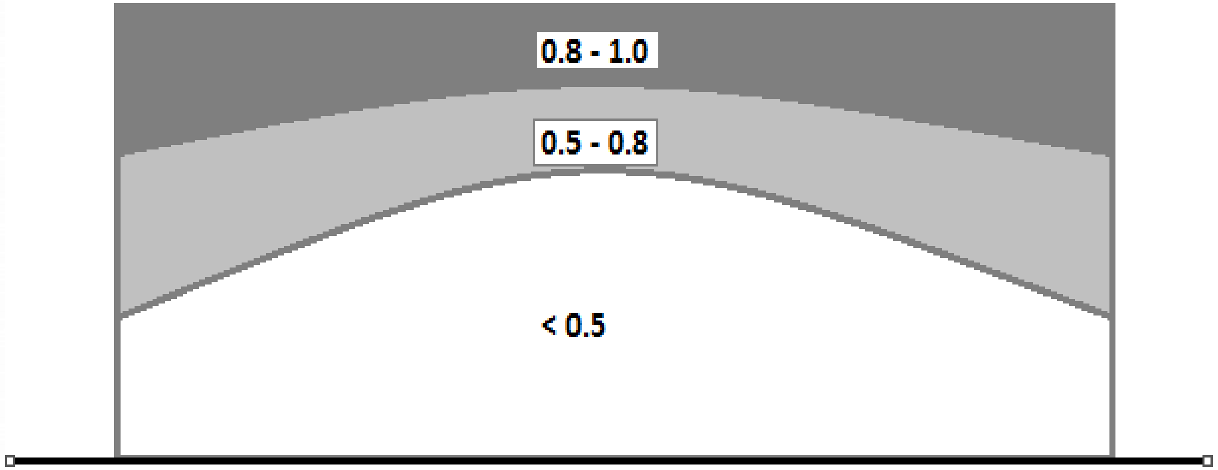
WDR Calculation

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

- The Factor, $cos(\theta) \times U(h) \times R_h$ represent a free-field WDR.
- $DRF(V_t)$, the driving rain factor, is the inverse of raindrops' terminal velocities.
- RAF as mentioned before, accounts for the obstructions to airflow around wall façade due to building aspect ratio, wall geometries, location of WRD on the façade.

- RAF includes considerations of a building aspect ratio, presence of a roof overhang and area of interest within the wall facade.

Wall factor (W) or Rain Admittance Factor (RAF) on a wall facade for a two-storey flat roof with a slope less than <20° (BSI EN 13013-3, 1997)



Wall factor (W) or Rain Admittance Factor (RAF) for a low-rise building with an aspect ratio much less than 1 (Straube and Burnett, 2000).

OBJECTIVE OF THE STUDY

- To measure and present five years of WDR data collected at different orientations of facades at a two-storey test building in a mild coastal climate.
- To compare and examine the sets of RAF values, in low and high field rainfall intensities, between the field data and values obtained by using the empirical methods of computation.

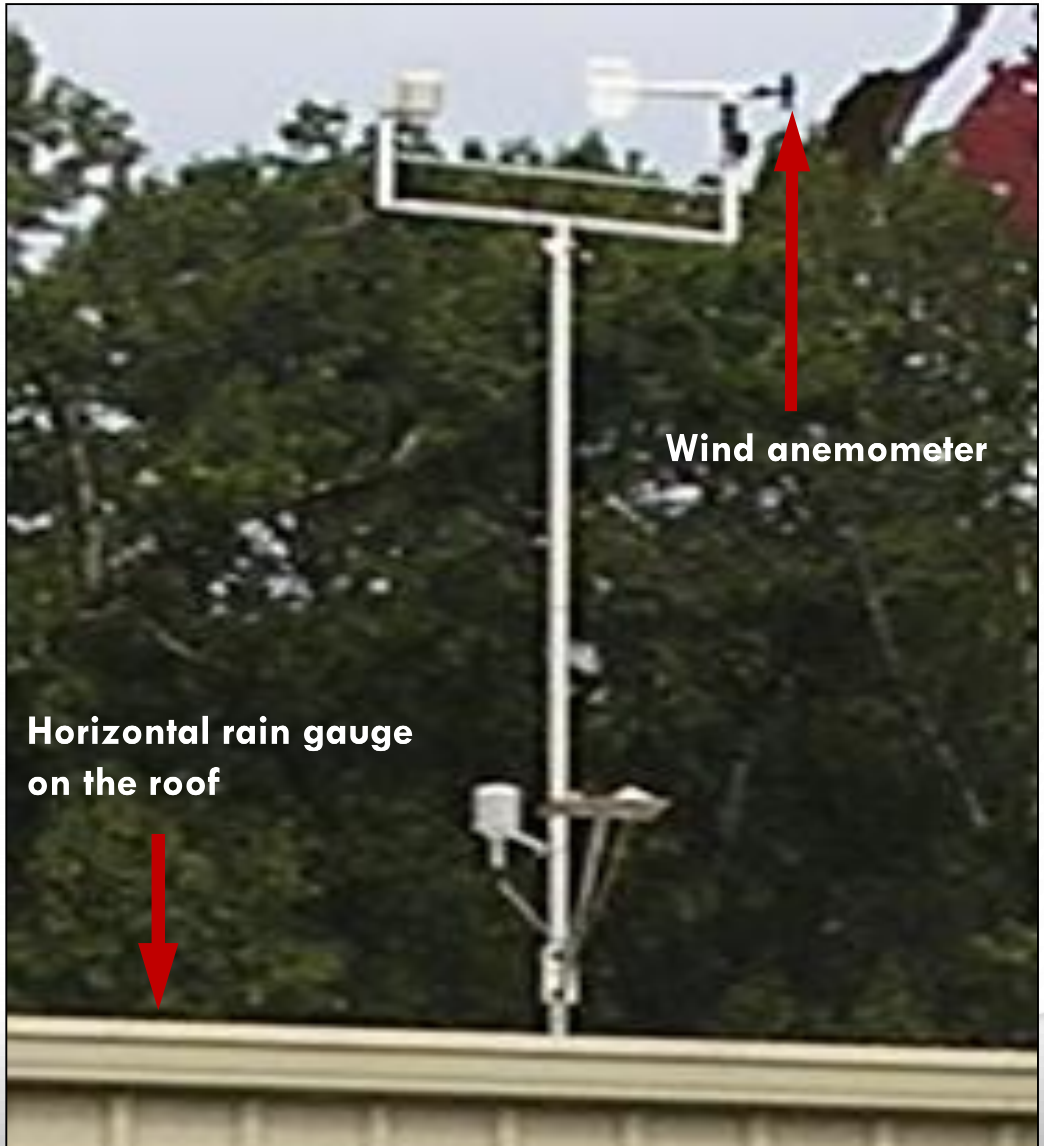
METHODOLOGY
BUILDING ENVELOPE TEST FACILITY

- The location of Building Envelope Test Facility

Building Envelope Test Facility at BCIT Campus. (Google Maps, 2015)

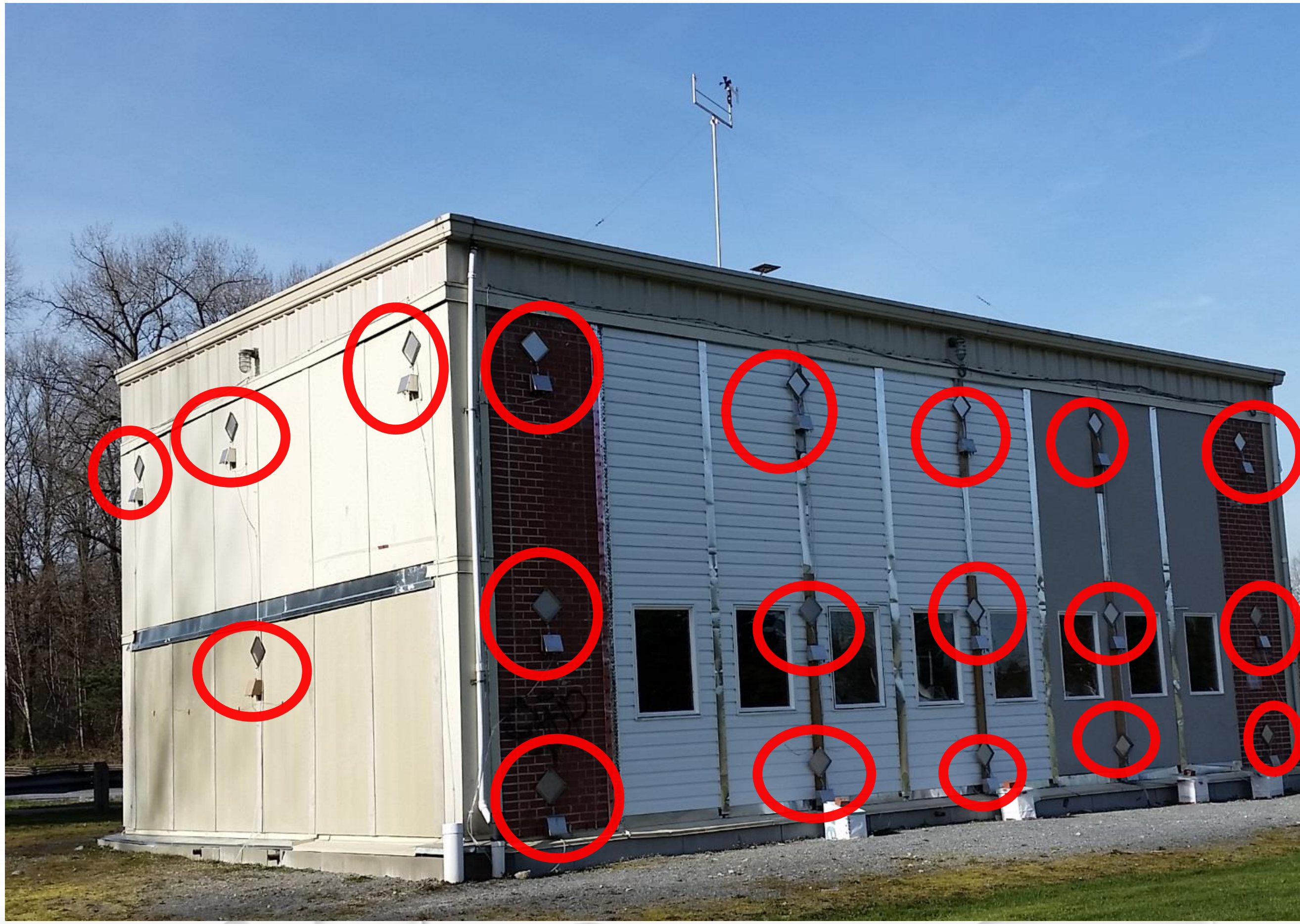
METHODOLOGY

- Horizontal rain intensity and wind speed and wind direction were collected from January 2009 to September 2013.
- These data are used to calculate free-field wind driven rain (WDR) and Driving Rain Factor (DRF)



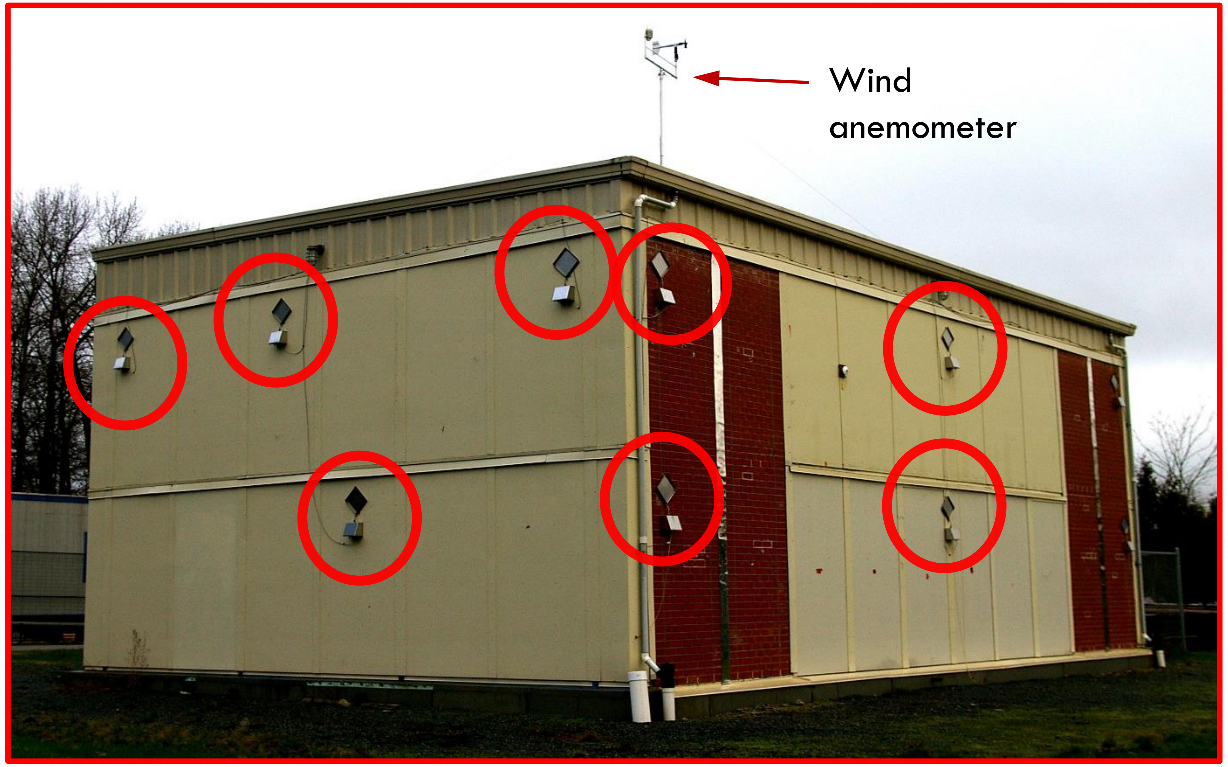
Methodology

- 15 wall rain gauges on all four wall facades and different locations are used to collect vertical rain intensity for over four years from January 2009 to September 2013.
- These field WDR data are used to estimate the RAF values against the calculated free-field WDR at the same façade and location.



Methodology:
Rain Gauges and Anemometer

- 15 wall rain gauges on four façades of Building Envelope Test Facility collect WDR.



A wind anemometer is installed on the rooftop weather station to measure wind speed and wind direction.

RESULTS :

Annual rain fall and rain hours

THE ANNUAL RAINFALL AND RAIN HOURS DURING 2009-2013:

	2009	2010	2011	2012	2013*
Total horizontal rain (mm)	1426	1475	1517	1539	992
Total number of rain hours	1478	1638	1593	1736	885
Average rain fall intensity (mm/hr)	0.96	0.9	0.95	0.88	0.96
Median rain intensity (mm/hr)	0.6	0.5	0.6	0.5	0.6
Average wind speed for the year (m/s)	0.82	0.85	0.81	0.81	0.84
Average wind speed during rain (m/s)	0.86	0.89	0.85	0.79	0.82
Median wind speed during rain (m/s)	0.65	0.72	0.68	0.56	0.57

*The data for 2013 is based on nine months' measured values (January to September).

RESULTS :
Annual rain fall and rain hours

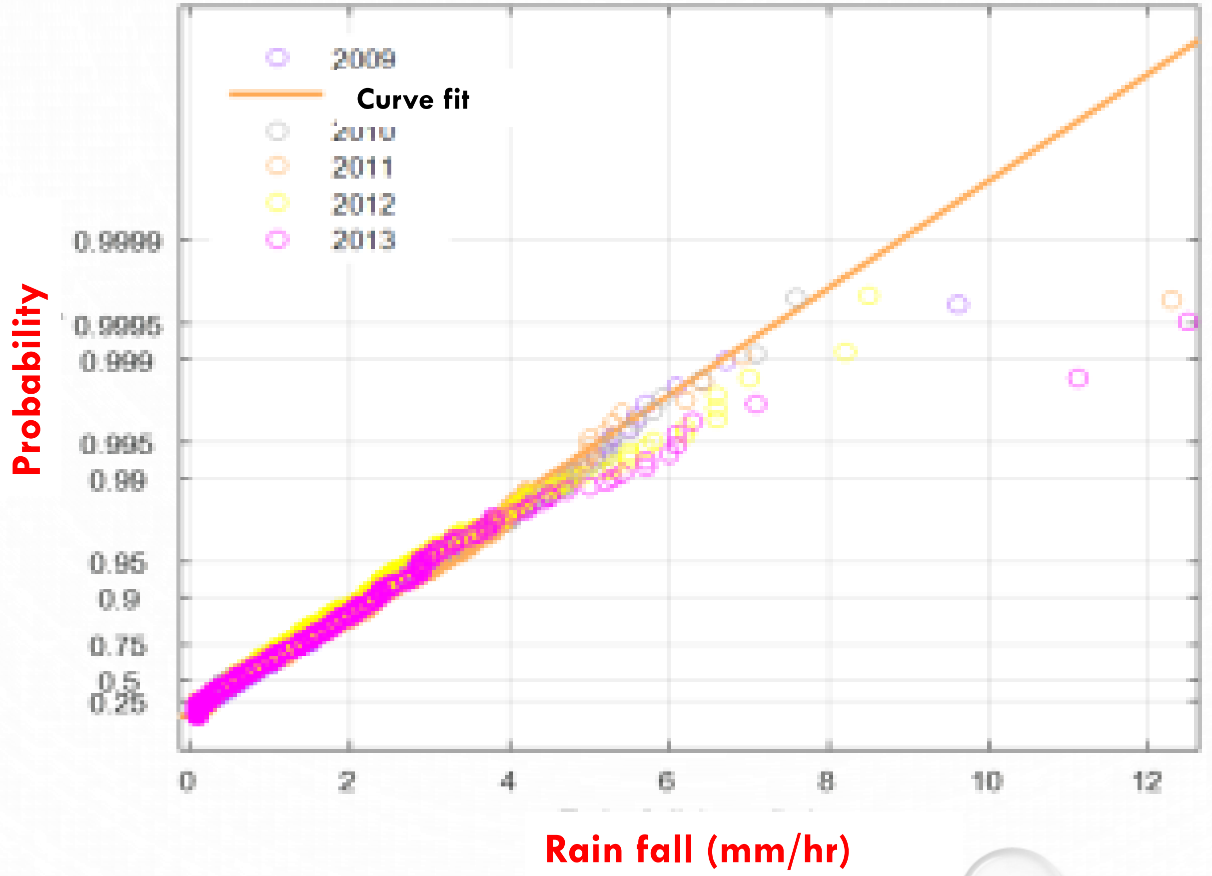
Comparison of the rainfall and rain hours among four years (2009-2012):

- The variations among the years in annual horizontal rainfall were within 8%.
- The variations among the years in rain hours were within 15%.

Results :

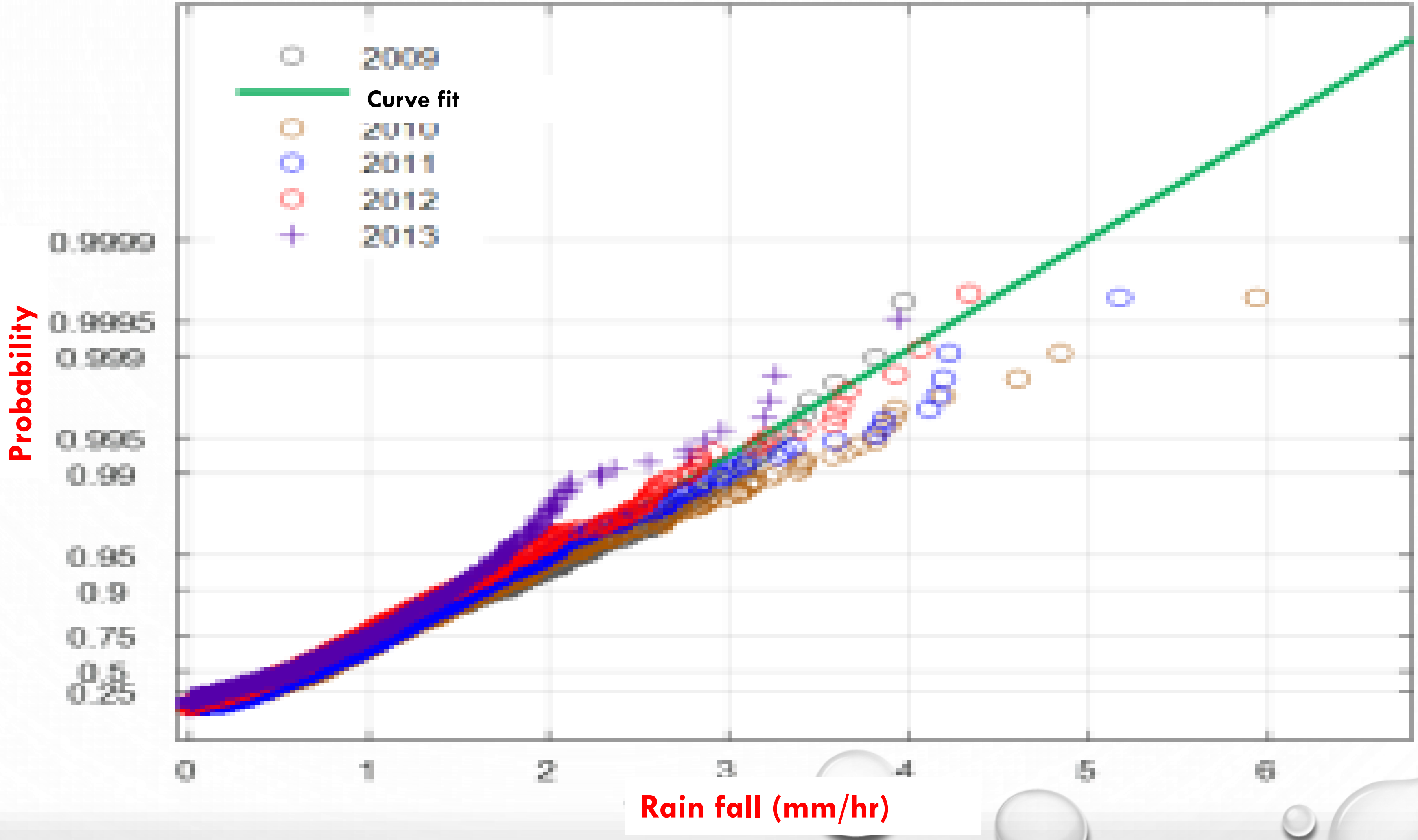
Horizontal Rainfall Distributions

- THE PROBABILITY OF HORIZONTAL RAINFALL DURING 2009-2013.



Results: Wind Speed Distributions

- The probability of wind speed while rain falling during 2009-2013.



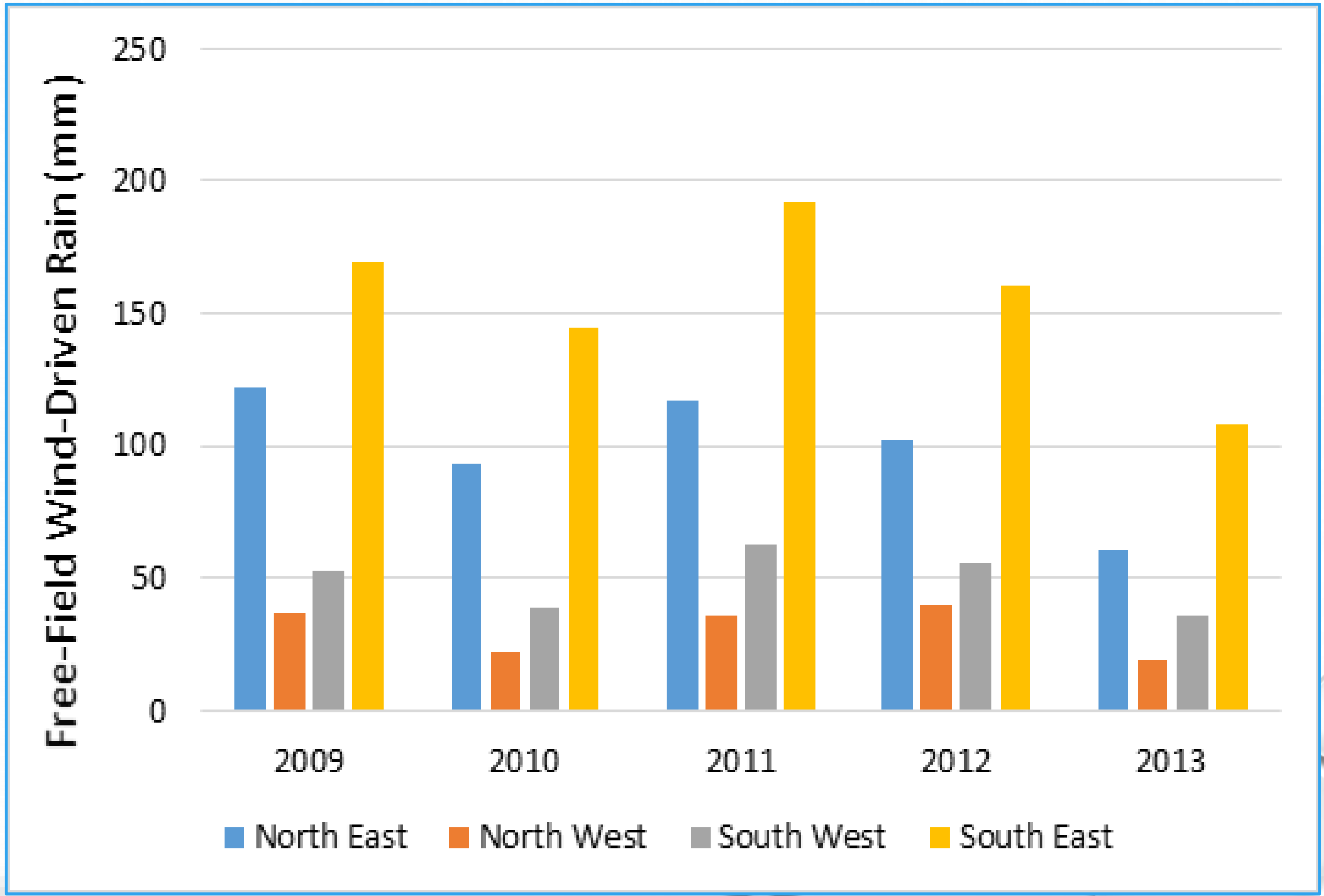
RESULTS:
DISCUSSION OF THE DISTRIBUTIONS

- The probability plots help to validate the selected distribution function (gamma function) for the rainfall and wind speed data.
- The mean rain intensities for five year varies between 0.88 – 0.96 mm/hr while median rain intensities was in the range between 0.50-0.60 mm/hr.
- The mean wind speed during rainfall periods varies between 0.79 – 0.89 m/s while median values is a range of 0.56-0.72 m/s.
- The statistical summary shows average rain intensities and wind speeds during rainfall don't differ significantly from year to year.

Results :

Directional Wind-Driven Rain

- Wind-driven rain measurement on all four orientations of test building:

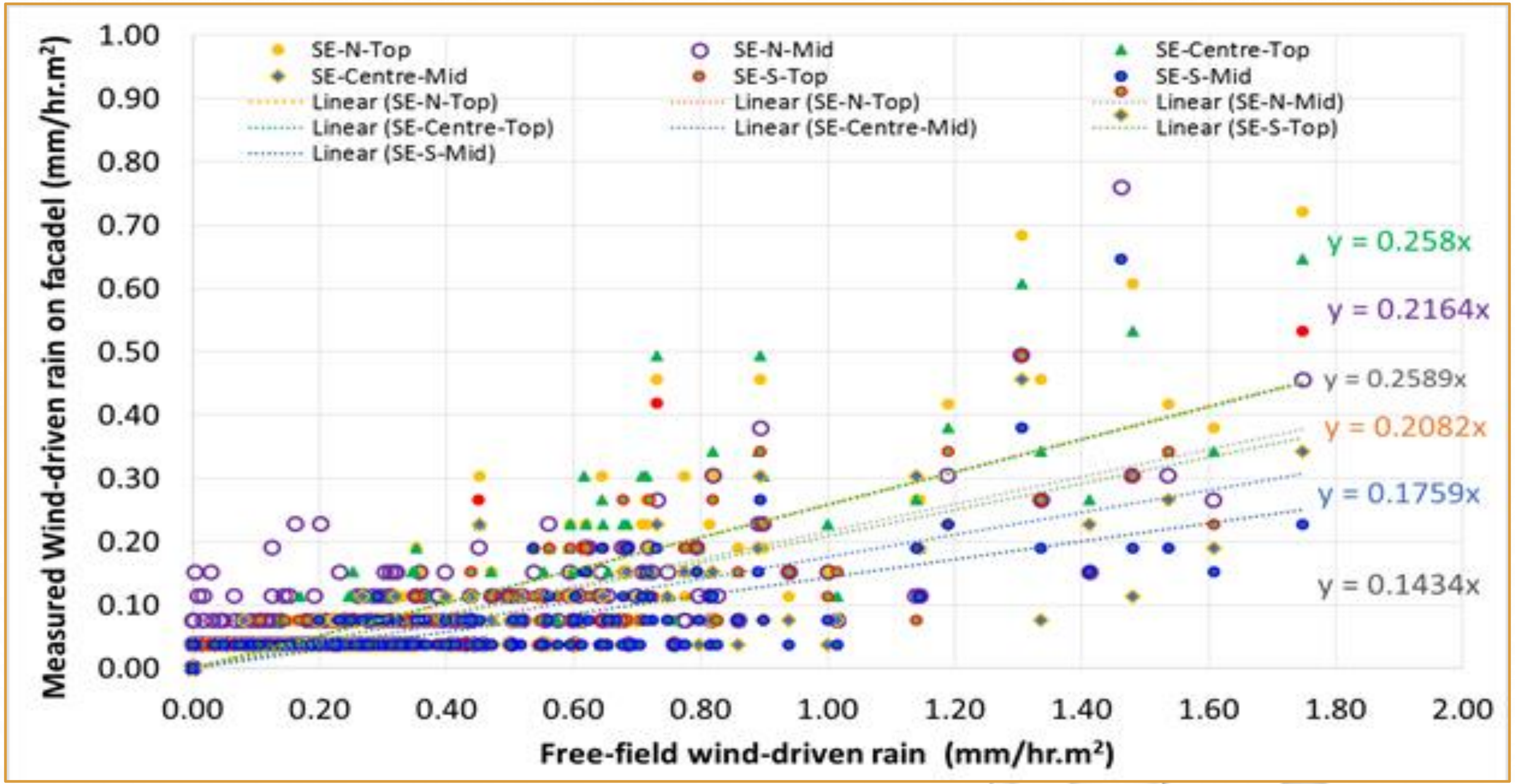


- Predominant direction from the strongest to weakest is:
  - Southeast,
  - Northeast,
  - Southwest
  - Northwest.
-

RESULTS:

RAIN ADMITTANCE FACTOR (RAF)

- A typical plot of hourly measured WDR against normalized wind speeds.



RESULTS:

Rain Admittance Factor (RAF)

- RAF values of 10 WDR locations on NE, NW and SE façades from 2009 - 2013

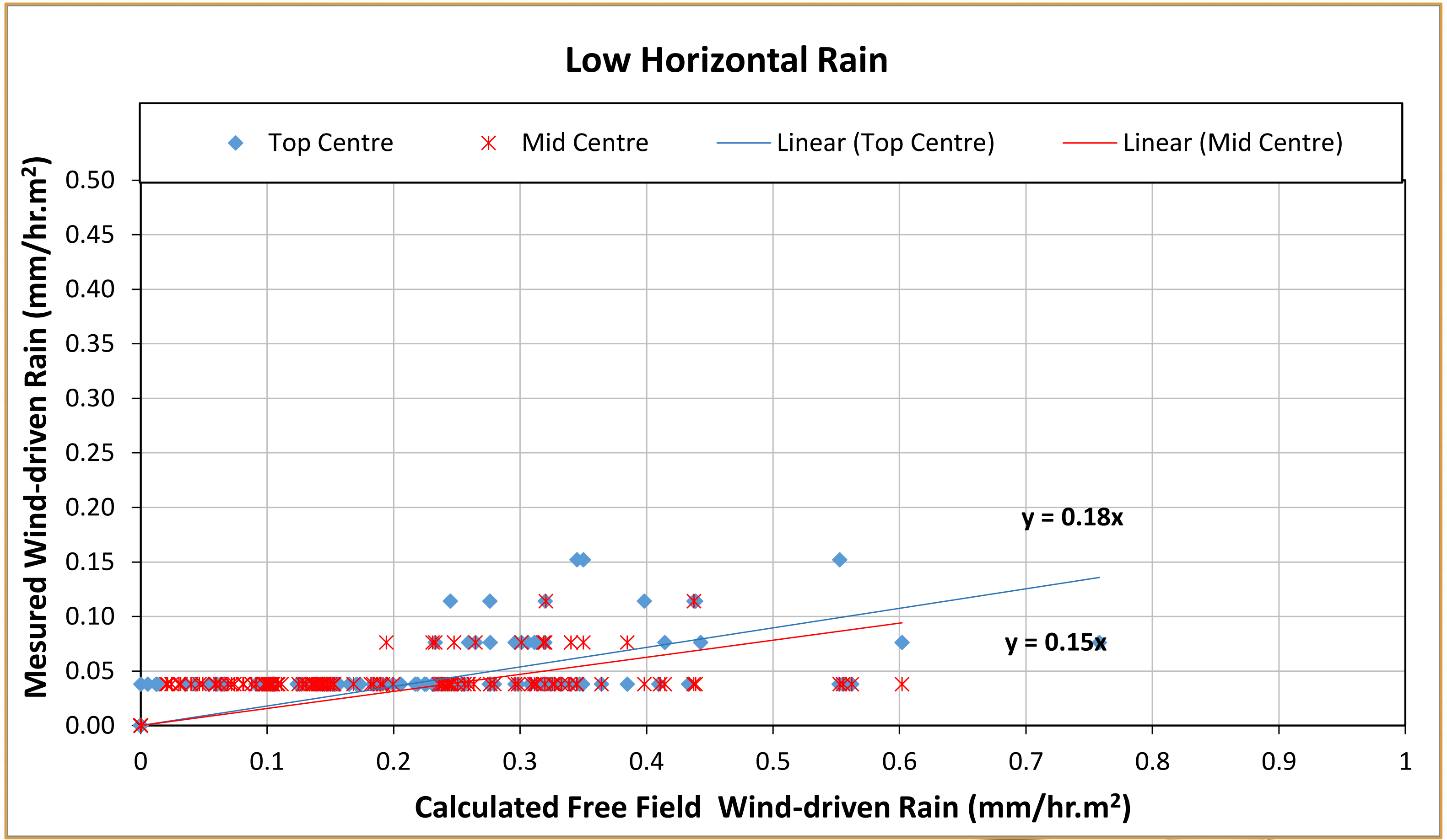
Wall Rain Gauge Name	2009	2010	2011	2012	2013	Average
NE Centre-Top	0.27	0.35	0.32	0.29	0.34	0.31
NW N-Top	0.38	0.40	0.36	0.36	0.36	0.37
NW Centre-Top	0.30	0.35	0.31	0.34	0.30	0.32
NW S Top	0.53	0.62	0.46	0.53	0.62	0.55
SE N Top	0.26	0.32	0.32	0.24	0.24	0.28
SE Centre-Top	0.26	0.34	0.23	0.17	0.19	0.24
SE S Top	0.21	0.32	0.30	0.26	0.33	0.28
SE N Mid	0.22	0.37	**	0.31	0.31	0.30
SE Centre-Mid	0.18	0.36	**	0.22	0.23	0.25
SE S Mid	0.14	0.21	0.18	0.14	0.27	0.19

RESULTS: Sensitivity of RAF

- To investigate the sensitivity of RAF to rainfall intensity, both measured and calculated free-field WDR are grouped into "high" and " low " horizontal rain categories.
- The 90% horizontal rainfall value, 2 mm/ hr, is used as a cut-off value:
  - Low category – 2 mm/hr and lower.
  - High category – above 2 mm/hr.

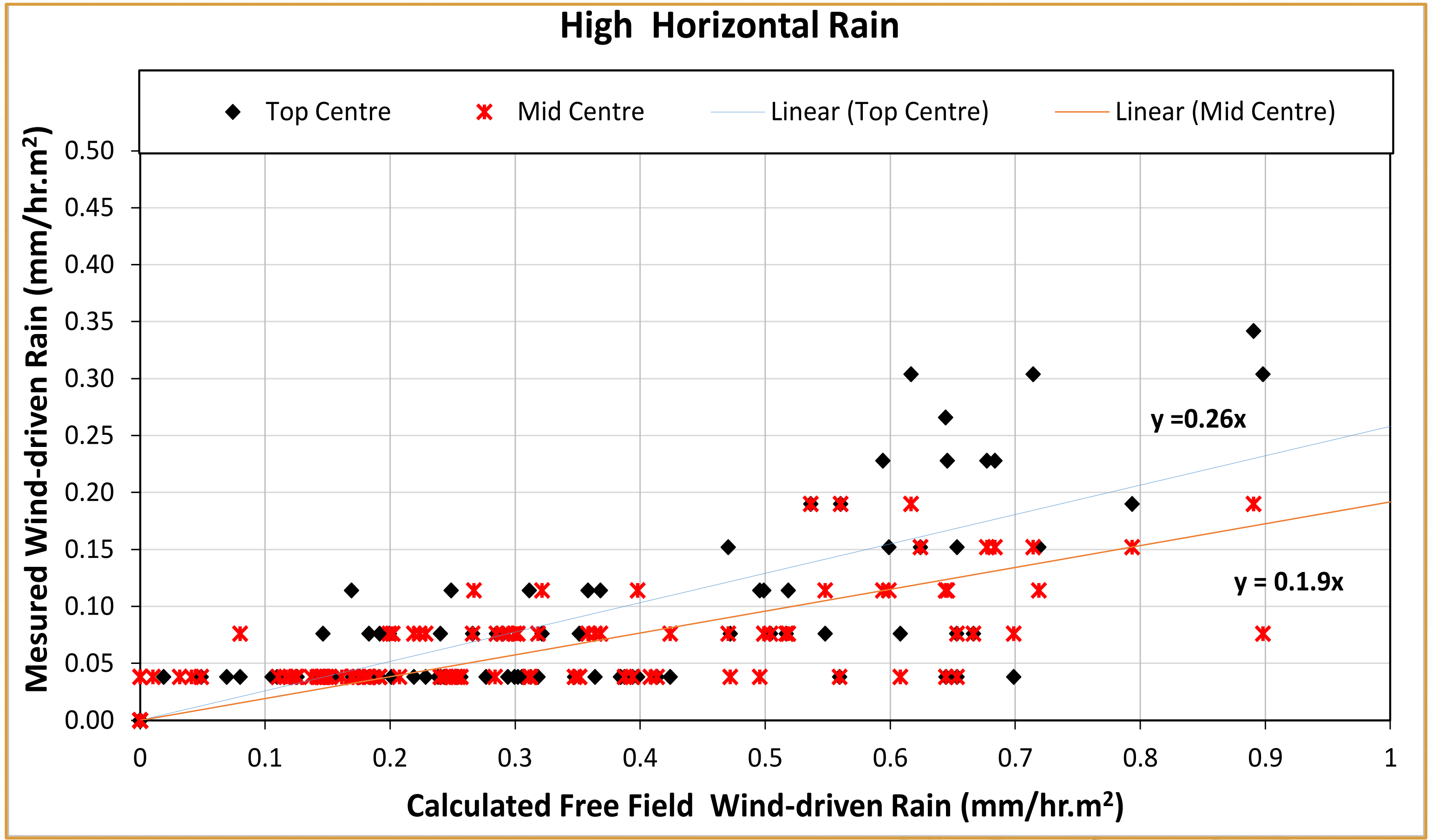
RESULTS: Sensitivity of RAF

- A plot of measured WDR at top-centre and mid-centre of SE façade against calculated WDR in low category:



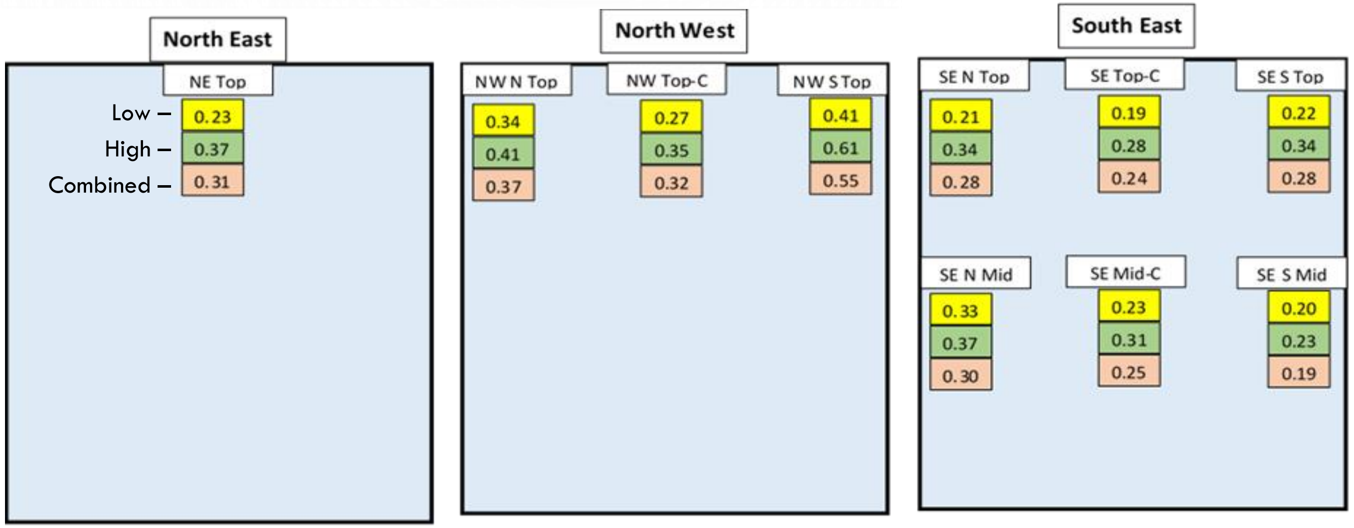
Results:
Rain Admittance Factor (RAF)

- A plot of measured WDR at top-centre and mid-centre of SE façade against calculated WDR in high category:



RESULTS:
COMPARISON OF RAF

- RAF values at 10 locations of wall rain gauges obtained by using discrete sets:



- Difference of RAF between “low” and “high” are higher at the upper locations than mid-section of facades, suggesting RAF at upper more sensitive than at mid height of facades.

RESULTS:
AVERAGE RAF VALUES

- Generally, the average RAF values at different locations and facades from 2009 - 2013 are in between the “low” and “high” RAF values.

Wall Rain Gauge Name	Low horizontal rain (< 2 mm/hr)	High horizontal rain (< 2 mm/hr)	All data
NE Centre-Top	0.23	0.37	0.31
NW N-Top	0.34	0.41	0.37
NW Centre-Top	0.27	0.35	0.32
NW S Top	0.41	0.61	0.55
SE N Top	0.21	0.34	0.28
SE Centre-Top	0.19	0.28	0.24
SE S Top	0.22	0.34	0.28
SE N Mid	0.33	0.37	0.30
SE Centre-Mid	0.23	0.31	0.25
SE S Mid	0.20	0.23	0.19

CONCLUSION

- The average rainfall, wind speed and WDR measurement were consistent from year to year.
- Overall, RAF's for high horizontal rainfall category are higher than that for low horizontal category.
- Slight variations in RAF's patterns on different orientations.
- The variations of mean rain intensities and wind speeds for five year are bigger than the variation of median rain intensities and wind speeds.

Further Study

- The authors aim to conduct sensitivity analysis to further investigate the effect of using horizontal rainfall intensity dependent RAF factors in a hygrothermal performance assessment of building envelope components.

THANK YOU!

ANY QUESTIONS?