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Parapets to mitigate wind loads on green roofs

(An adaptation from ANSI/SPRI RP-14, Wind Design Standard for Vegetative Roofing Systems)

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Introduction

Continuous urban densification, and the need to optimize space, has led to the prevalence of green roofs and walls on existing and new developments in Singapore in recent years. It is therefore important to have in place design and management guidelines that promote landscape excellence and safety for green roofs and walls. To this end, the Centre of Urban Greenery & Ecology has launched nine CUGE Standards since 2010. In the pipeline is one addressing wind loads on skyrise greenery.

While Singapore's urban wind conditions are generally considered mild, there exist genuine concerns regarding the safety of green roofs under exceptional wind conditions. With increasing altitude, rooftop systems will experience stronger wind impact and uplift especially along rooftop perimeter and corners, thereby posing greater potential risk. This Research Technical Note discusses how building roofs can be designed to reduce this risk.

The use of parapets can improve the wind performance of the green roof systems

Rooftop parapets, the vertical surface demarcating rooftop edges, when sensibly designed and constructed, are possible passive architecture-solutions. It is generally agreed that opaque roof parapets of adequate height (>1m) can improve green roof systems' resistance against wind uplift, by reducing the mean and peak pressure coefficients in the corners and perimeters of the roof.

Parapet heights

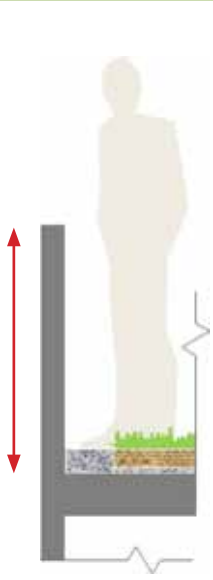
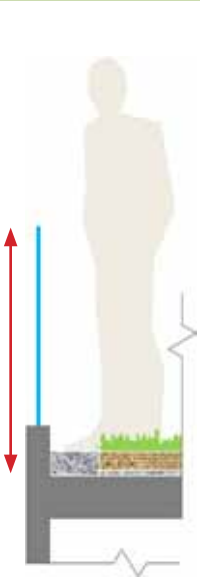
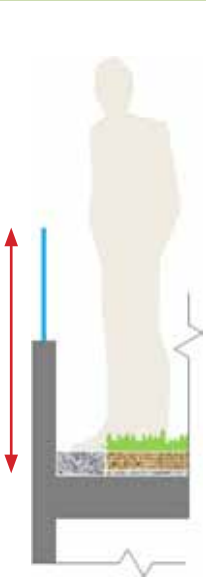
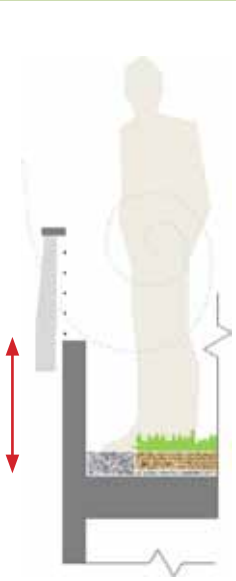
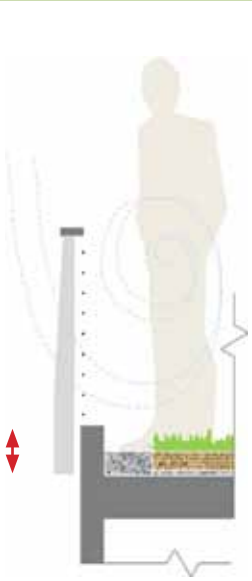
Parapet heights, for both accessible and non-accessible green roofs, whenever possible, should ideally be no less than 1m (1000mm) - from top of the green roof system finish level to the top of parapet - to provide the following benefits:

- Improved resistance against wind uplift and;
- Worker safety, when carrying out roof maintenance work; especially along the roof perimeter and roof corners.

Parapets Materiality

There are many roof parapet design possibilities. (See examples below)

Examples of parapet designs

Solid parapet designs			Porous parapet designs	
Concrete	Glass	Concrete & Glass	Concrete & Rail	Rail
				

↕ The red arrow denotes the effective height of the parapet, that is solid and impervious to wind forces, that contributes to improving green roof's resistance against wind uplift.

- With the exception of the rail portion of the parapet, the above-mentioned parapet types are considered solid surfaces.
- Generally, to reduce wind-induced suction pressures on low-sloped roofs, consider solid parapet design(s), recommended at no less than 1m height, to achieve a more favorable* pressure distributions across the low-sloped roof. (* - That is, the maximum wind suction is reduced, with suction peak broadened.)
- The general engineering understanding is that the taller the roof parapet, the less non-uniform the wind pressure distribution. This is especially true for low-sloped roofs of taller buildings (estimated at 20m height and taller) [(1)].
- A registered Professional Engineer (PE) must determine the following:
  - Engineering of the parapet design (dimensions + materiality + loading capacity) and;
  - The estimated improved resistance against wind uplift.
- Note that, depending on the building's architecture design, the parapet materials, dimensions (i.e. height) and opacity may not be uniform along the entire rooftop edge. The registered PE will have to consider holistically when estimating/mapping wind loads across green roof.

Singapore's urban wind conditions

Wind speeds in Singapore

The table below presents the relevant wind speed estimates in Singapore.

Wind speed		relevant Code of Practice
33m/s	basic wind speed (3 second gust speed)	Code of Basic Data for the Design of Buildings. Loading. Wind Loads – CP3 Chapter V Part 2
22m/s	basic wind speed (hourly mean speed)	Loading for buildings. Code of Practice for Wind Loads – BS 6399:Part2
20m/s	basic wind speed	Actions on structures. General actions – Wind actions – SS EN 1991-1-4
SS ENs will be the only prescribed design standards with effect from 01 Apr 2015.		

Sumatra squall (maximum recorded gust speed)

Maximum gusts of up to 26 metres per second (93 km/h) have been recorded during the passage of a Sumatra squall (gusts are temporary increase in wind speed). For more information about Singapore's weather, please refer to the National Environment Agency (NEA) website, www.nea.gov.sg.

Wind directions in Singapore

- The prevailing monsoon winds directions in Singapore are from the northeast (December till early March) and the southwest (June till September). The Sumatra squall is described in *The Weather and Climate of Singapore*, by the National Environment Agency, as follow:

  "Sumatra squall lines are often associated with the southwest monsoon, but they actually can occur all year round. They can even occur during the northeast monsoon. One common misconception about the monsoons is that the winds blow constantly and unrelentingly from one direction only. This is not true, … Even during the northeast monsoon there can sometimes be brief periods when winds over Singapore will change direction and blow from the west or southwest."

- Wind conditions in the city centre is therefore complex, as a result of the varying urban volumes of adjacent buildings and structures, which can block, channel and/or concentrate the wind as it passes through, and may not concur with the clear directionality as studied in wind tunnel tests. This lack of clear wind directionality must be considered when simulating/estimating using Computational Fluid Dynamics (CFD) study.

Suggested parapet heights for flat extensive green roof at various heights (in Singapore)

(roof inclination no steeper than 7 degrees)

The following two tables are suggestions on the roof solid-parapet heights (with the associated green roof minimum loads and placements), in order to achieve adequate resistance against wind uplift, based on the:

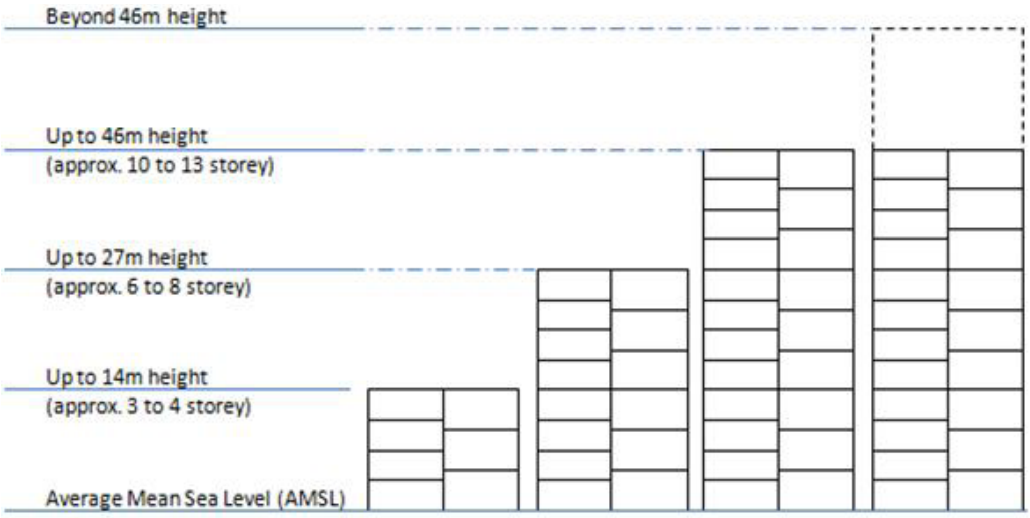
- Expected Singapore's wind speeds (Please see previous page on Wind Speeds) and;
- General green roof heights, observed in Singapore (broadly categorized below).

These two tables should be read in con-junction with ANSI/SPRI RP-14, *Wind Design Standard for Vegetative Roofing Systems*.

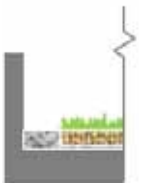
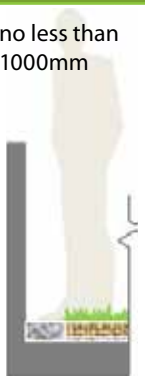
Suggested taller parapet heights, the associated minimum green roof system's loads & placements

(Adapted from ANSI/SPRI RP-14)

Roof Heights



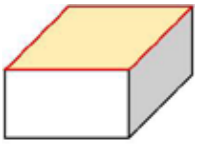
Suggested taller Parapet Heights

for extensive green roof on different roof heights	no less than 50mm (50 – 450mm)	no less than 450mm (450mm – 1m)	no less than 1000mm	Registered PE to design
				

The suggested parapet heights assume the following:

- Wind conditions and speeds are within the ranges recorded in Singapore (not more than 33m/s).
- In Exposure B (Dense built urban conditions)

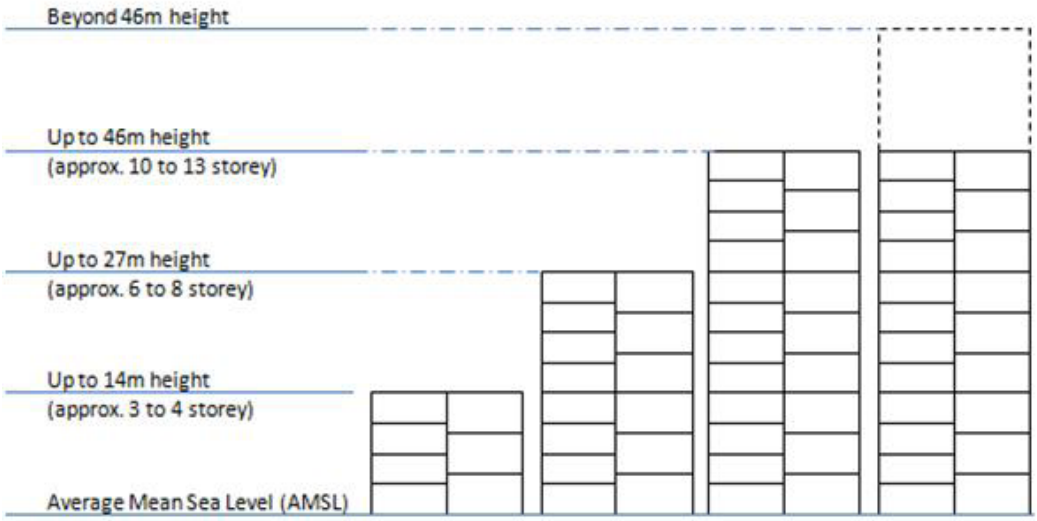
Minimum loads & placements (of the green roof systems) on the roof, to avoid excessive wind uplift, for the above suggested taller parapet heights, are as follow:

		Interlocking system	Independent system
Field of roof 	Green roof Ballast dry weight (inorganic)	49 kg/m^2 (min)	88 kg/m^2 (min)
	Concrete paver weight	49 kg/m^2 (min)	88 kg/m^2 (min)

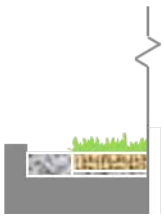
Suggested shorter parapet heights, the associated minimum green roof system's loads & placements

(Adapted from ANSI/SPRI RP-14)

Roof Heights



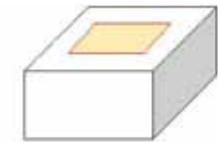
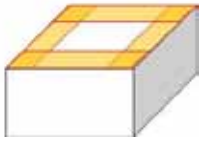
Suggested shorter Parapet Heights

for <u>extensive</u> green roof on different roof heights	no less than 50mm (50 – 300mm)	no less than 50mm (50 – 300mm)	no less than 300mm (300 – 450mm)	Registered PE to design
				

The suggested parapet heights assume the following:

- Wind conditions and speeds are within the ranges recorded in Singapore (not more than 33m/s).
- In Exposure B (Dense built urban conditions)

Minimum loads & placements (of the green roof systems) on the roof, to avoid excessive wind uplift, for the above suggested shorter parapet heights, are as follow:

		Interlocking system	Independent system
Field of roof 	Green roof Ballast dry weight (inorganic)	49 kg/m^2 (min)	88 kg/m^2 (min)
	Concrete paver weight	49 kg/m^2 (min)	88 kg/m^2 (min)
Corners and Perimeters of roof 	Green roof Ballast dry weight (inorganic)	64 kg/m^2 (min)	104 kg/m^2 (min)
	Concrete paver weight	49 kg/m^2 (min)	104 kg/m^2 (min)

NOTE: Roof corners and perimeters are no less than 2.6m in width along roof edges

- In general, taller roof parapet height improves the green roof systems' resistance against wind uplift. With shorter roof parapet height, wind uplift along roof perimeter and roof corners are expected to be higher, and must be counteracted with 'heavier' green roof systems.
- Alternatively, green roof systems along the roof edges and roof corners can be appropriately anchor-tied onto the roof against the calculated wind uplift, as advised by the registered PE and the green roof consultant.
- In situations where wind uplift on the roof is a genuine issue and erecting opaque perimetrical roof parapet is not an option, proprietary systems such as the AeroEdge patented fascia systems can be considered.

The CUGE Standard, CS E10:2014 – Guidelines on Design Loads for Skyrise Greenery, which will be released later this year, will present more details on the wind loads on skyrise greenery.

References

ANSI/SPRI RP-14, Wind Design Standard for Vegetative Roofing Systems

T. Stathopoulos, A. Baskaran (1988) 'Turbulent wind loading of roofs with parapet configurations', Canadian Journal of Civil Engineering

C. Blessing, A.G. Chowdhury, J. Lin, P. Huang. (2009) 'Full-scale validation of vortex suppression techniques for mitigation of roof uplift', Engineering Structures, Volume 31, Issue 12: 2936-2946.

J. Lstiburek (2011), 'Parapets—Where Roofs Meet Walls', Building Science Insights, BSI-050. http://www.buildingscience.com/documents/insights/bsi-050-parapets-where-roofs-meet-walls

[1] 1ed – Walter J. Rossiter, 2ed – Thomas J. Wallace (2007), Roofing Research and Standards Development, 6th Volume

M. Fong (2012), The Weather and Climate of Singapore, Meteorological Service Singapore

NEA website