The effect of wind on extensive lightweight vegetated roofs

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Abstract. Nowadays, Lightweight vegetated roofs are becoming increasingly popular due to their light weight, low maintenance and water consumption. Even though they are mostly extensive greenery (staghorn bushes, mosses, etc.) they can provide urban areas with a few benefits. In particular, they can make an important contribution to improving the urban microclimate and reducing the negative urban heat island effect. They also contribute to the conservation of biodiversity by providing alternative refuges for a range of animals. However, due to their light weight, these lightweight systems may not withstand adverse weather conditions well, especially at the beginning of their construction. Wind resistance can cause them to erode and wind erosion of the growing medium can occur, especially when the root network is not yet sufficiently anchored in the vegetation system. Roof sections may be rotated, displaced, or even overturned, especially in the outer parts of the roof. The effects of wind action can also be influenced by the slope of Lightweight roofs. Roofs with a pitch of less than 30° may be subject to stronger wind suction effects. Existing research shows that, for example, roofs with a pitch greater than 35° have better resistance to wind pressure. This paper discusses different variants of existing solutions to the given problem.

1 Introduction

Lightweight extensive green roofs are an effective solution for any type of roof, including pitched roofs. The ideal pitch is 2° to 45° but can be implemented up to 60°. They are characterized by a substrate thickness of 60-100 mm and a low weight, which is around 55-100 kg/m^2 in saturated conditions.[1] They do not require special care or maintenance.

They consist mainly of vegetation composed of mosses, succulent plants, thick-leaved plants (sedum) or thin vegetation of herbaceous grasses. This vegetation is characterised by its unpretentiousness. It requires little water and tolerates large temperature fluctuations. It is important that rainwater runoff works to prevent rotting of the plant roots.

Lightweight extensive vegetation roofs are systems specifically developed for lightweight structures that help bring nature into urban areas. Increasing urbanization has resulted in a decline in insects that are important for plant pollination. Based on a study carried out in the city of Córdoba in central Argentina, it was found that the design of green roofs should favour native plants to improve the protection of insects in cities. Testing was conducted on 30 roofs

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on two installed blocks of a modular extensive system with native or exotic plant species of 6 species each. A total of 35,257 insect species from 12 orders were registered during the testing. Two types of traps were used to capture insect samples. Flower abundance and plant cover were also measured. Native plants supported significantly higher total insect abundance (number of individuals per species) on both trap types, regardless of the level of urbanization, abundance of flowers, or plant cover on each roof. [2]

The disadvantage of lightweight vegetated roofs (mostly modular) is their poorer ability to resist wind forces. The wind creates suction or negative pressure (vertigo) which acts in different ways on different parts of the structure.

2 Types of lightweight vegetated roof structures

A lightweight vegetated roof consists of a roof system and a vegetation system. (Fig.1) All lightweight extensive vegetation roofs are designed to minimize weight on the surface. They can be implemented on existing or new buildings. They are not intended for public use. Access to their surface is quite difficult due to their lightweight construction. However, access to the roof for maintenance should be considered at the first stage of design. Later, when rooting occurs, the mature vegetation is already independent and requires only minimal maintenance.

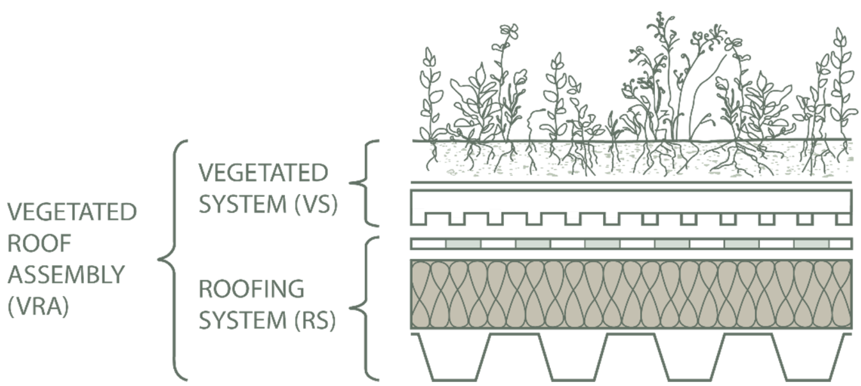

Fig. 1. Defining a VRA, Source: S. Molleti, A. Baskaran, F. De Souza, *Development of a Standard Test Method to Determine the Wind Resistance of Vegetated Roof Assemblies,* National Research council, Ottawa, Canada (2015), modified by the author.

For ultra-light roofs, the vegetation layer should ideally not exceed 70-80 kg/m², but at the same time the necessary conditions for the plants must be ensured.

The figure shows the basic types of vegetation systems according to the way they are established. (Fig.2) Plants can be either planted in situ or pre-grown in the form of vegetation blankets or pre-grown in modular trays.

2.1 Methods of placing plants in vegetation systems:

- Modular systems - the vegetation is pre-grown, and the components form a fitting arrangement.
- Pre-grown mats with growing medium and plants rolled onto rooftop systems
- Build-up system - implemented on-site where each component of the system (i.e. drainage layers, filter fabric, growing media and plants) is installed separately.

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Each type of vegetation system has its own advantages. It is important that it suits the building design and roof system (e.g. roof pitch) in resisting wind forces. [3]

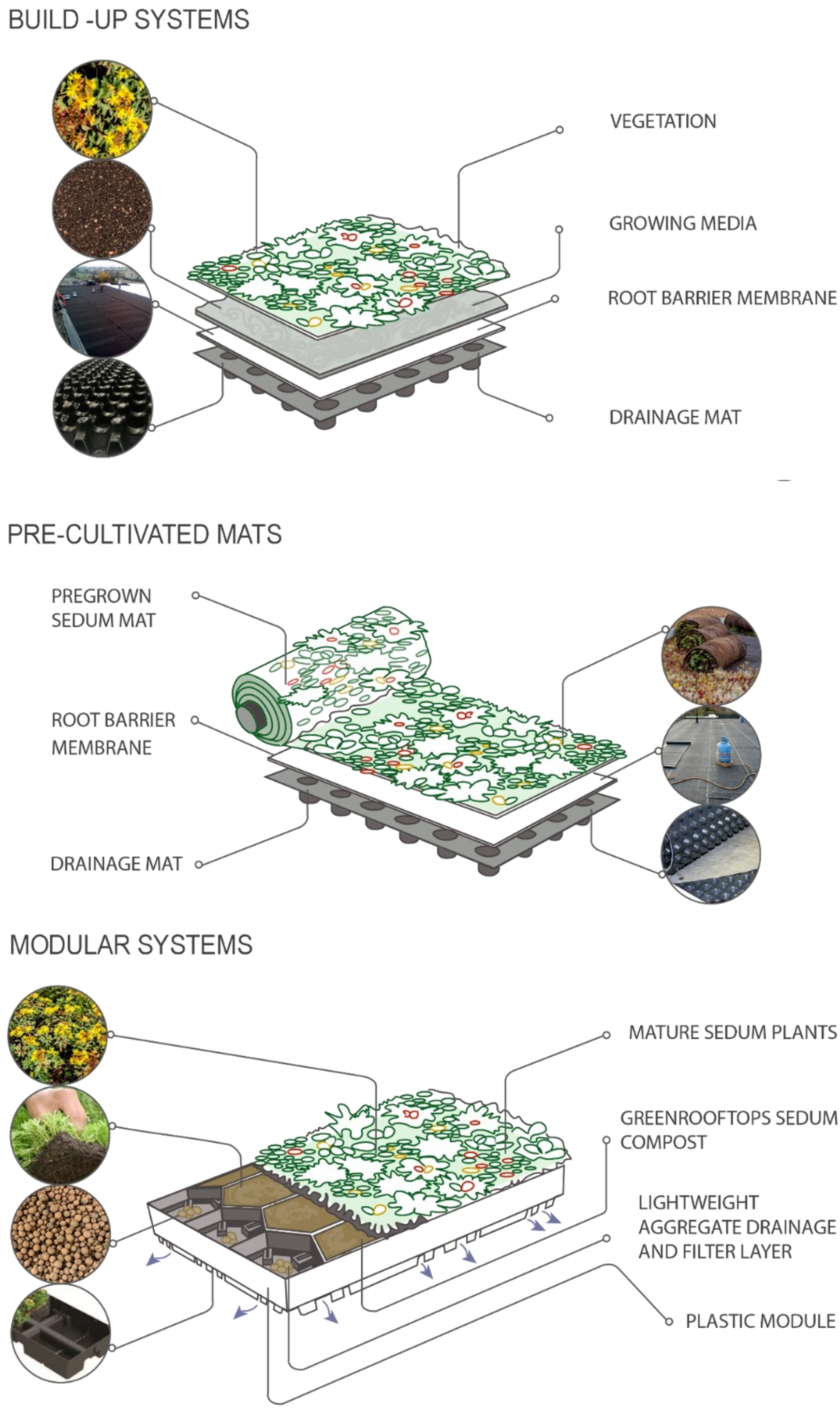

Fig. 2. Methods of placing plants in vegetation systems, Source: from the author's archive.

The substrate consists of, for example, expanded perlite and volcanic clay. Another technology is to replace the substrate with a layer of mineral wool or pre-grown vegetation mats.

Roofs are divided into flat roofs with a pitch of 0-2°, 2-5° and pitched roofs of 5-25° and 25-45°. The roof pitch depends on the implementation technology, which must be chosen optimally for each pitch.

For slopes greater than 10°, the layers of elements must be stabilised. The risk of erosion is relatively high here. The geographical location and the conditions of the building's location are also important. For example, the location to different cardinal points can have different effects on the development of vegetation. [4]

3 The effects of wind on vegetation systems

Wind action on roof systems creates suction or negative pressure and affects them in various ways. Wind suction is influenced by the height of the building, the pitch of the roof, the attachment and type of vegetation system and the weather conditions in the area (average wind strength). The edges, corners and inner surfaces of the roof respond differently to wind suction. The location of the attic may also have an influence. Air eddies may form at the edges of the roof.

Unlike conventional roofs, vegetated roofs are better able to resist wind forces due to their permeable surface. Vegetation and growing media have an irregular open structure which reduces the negative effects of wind. Vegetated roofs are most susceptible to damage during the establishment period, when the vegetation is not yet firmly rooted in the growing medium, particularly in the corner and edge areas of the roof where wind forces are strongest. [5]

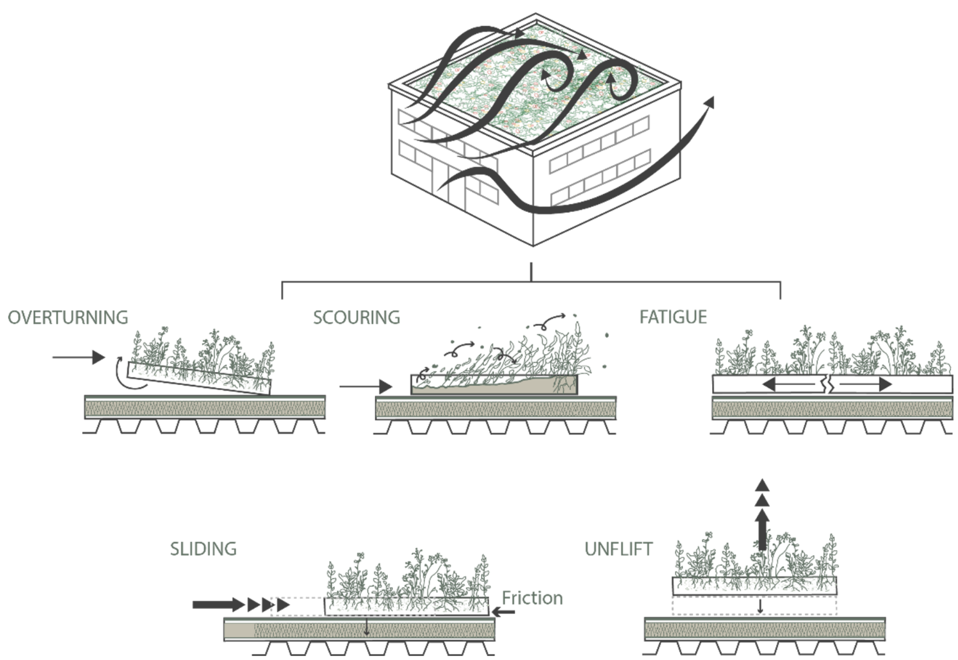

Fig. 3. Wind aerodynamics and failure mechanisms of a VRA. Source: B. Appupillai, Ch. Mauricio, M. Sudhakar, *New Test Methodology for Wind Resistance Evaluation of Built-In-Place Vegetated Roof Assembly,* Journal of Architectural Engineering, (2021), doi: 10.1061/(ASCE)AE.1943-5568.0000475, modified by the author.

4 Methods for testing the effect of wind on VS.

At present, there is still no consensus in the testing field on what and how to test vegetated roofs for wind conditions.

Testing focuses on two issues. One is damage to the system from blow-off during high winds or severe storms, where the safety of occupants may be compromised. The second issue is damage to the vegetation at the beginning of implementation and during the growing season of the plants. [6]

Testing is carried out in several ways:
- In situ testing with natural wind application.
- Wind tunnels
- Mathematical simulations

4.1 In situ testing

In situ testing appears to be the most accurate. The disadvantage is the long testing time for real situations in specific geographical conditions. The disadvantage is that no extreme wind situations may be recorded after the testing period.

4.2 Wind tunnels

Wind tunnels are used for testing scaled models with the possibility of setting a graded wind speed. However, it is difficult to replicate the exact profile of atmospheric wind in a wind tunnel due to its complex flow.

4.3 Mathematical simulations

Mathematical simulations are used, for example, to create numerical wind tunnels in various software (e.g. FLUENT). The results from the numerical tunnel need to be validated against measured results in real conditions. [7]

5 Examples of normative requirements for wind protection in different countries

For example, in Canada, CSA A123.21 (Standard Test Method for Dynamic Resistance to Wind Uplift of Membrane Roofing Systems) was developed through the GIEDSC (Special Interest Group on Dynamic Evaluation of Roofing Systems) research program to ensure that roof systems are tested for resistance against the wind. Testing must be performed by an accredited laboratory. [8]

Green roofs in Germany are designed according to FLL (German - Guidelines for Planning, Implementation and Maintenance of Green Roofs) and DIN 1055-4 (Wind Load). The wind permeability of vegetated roofs is considered in the calculations. The pressure is equalized between the top and bottom layers of the substrate and thanks to this the roof can be designed with a lower "reduction factor" depending on the vegetated roof system used. The calculation is based on the assumption that the vegetation layer is in a dry state. [9]

In the fig.4 we can see the vegetation roof solution designed to withstand the wind. The solution is based on FLL and DIN 1055-4 standards. The following measure considers the securing of the roof during the one-year growth phase and the securing of the edge and corner areas.

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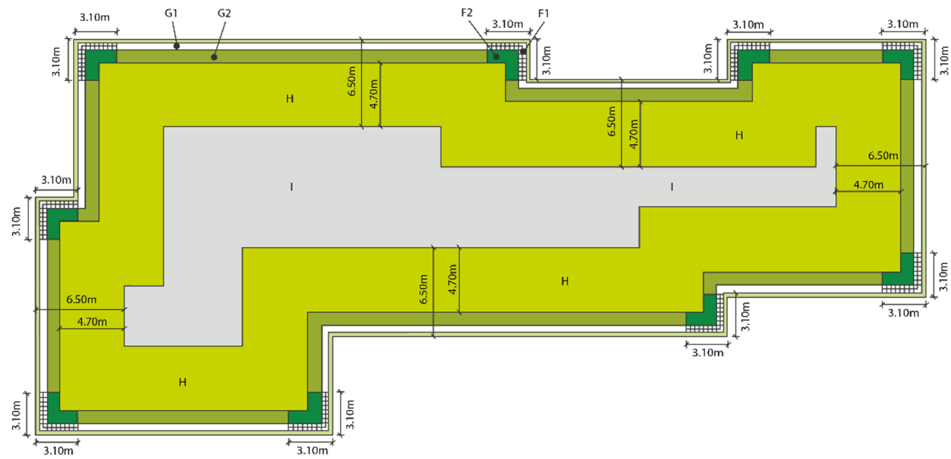
PRACTICAL EXAMPLE: WIND EROSION PROTECTION PLANNING



Surface distribution and weights required to ensure wind erosion and wind suction protection:

F - 1.02 kN/m²		G - 0.68 kN/m²		H - 0.40 kN/m²	I - 0.24 kN/m²
F_1	F_2	G_1	G_2		
- 4 cm erosion protection board EPS filled with gravel 16/22 - 2 cm gravel 16/22 - Filter fleece FIL 105 - Drainage board FKD 25 - RMS 300 = 1.09 kN/m² wet	- Veg. mat - 9 cm substrate E-light - Filter fleece FIL 105 - FKD 25 - RMS 300 = 1.58 kN/m² wet	- 5 cm gravel 16/22 - Filter fleece FIL 105 - FKD 25 - RMS 300 = 0.90 kN/m² wet	- Veg. mat - 6 cm substrate E-light - Filter fleece FIL 105 - FKD 25 - RMS 300 = 1.15 kN/m² wet	- Seeding - 6 cm substrate E-light - Filter fleece FIL 105 - FKD 25 - RMS 300 = 1.05 kN/m² wet	- eeding - 6 cm substrate E-light - Filter fleece FIL 105 - FKD 25 - RMS 300 = 1.05 kN/m² wet

Fig. 4. Practical example of wind erosion protection planning, Source: Landscape Development and Landscaping Research Society e.V., - FLL, *Green Roof Guidelines – Guidelines for the planning, construction, and maintenance of green roofs*, **150,** Germany (2018).

6 Conclusion

As the climate warms, the world is seeing stronger winds, heavier rainstorms, and more frequent storms. Based on international climate models, it can be assumed that these phenomena will occur more and more often in our geographical conditions. The risk increases with greening implemented on higher and higher buildings, where the wind acts more strongly. This situation requires higher requirements for protecting roofs from damage by strong winds.

For the safe construction of vegetated roofs, it is necessary to calculate the wind suction, considering the properties of the vegetation (vegetation, water content in the substrate, the distribution of plants and many others). In most countries, until now, these requirements for vegetation roofs are replaced by simplified computational models that do not consider the irregular open structure of the vegetation system due to the large number of variables. Further research is needed in this area, including an experimental approach (in situ, laboratory experiment) including data validation using numerical simulation.

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References

1. *Lightweight roof*, Online, (2022). Available from: https://odu-green-roof.com/lightweight-roof/
2. M. S. Fenoglio, E. González, J. Tavella, H. Beccacece, M. L. Moreno, D. Fabian, A. Salvo, E. L. Estallo, A. Calviño, *Native plants on experimental urban green roofs support higher community-level insect abundance than exotics,Urban Forestry & Urban Greening,* **86,** (2023), ISSN 1618-8667
3. S. Molleti, A. Baskaran, F. De Souza, *Development of a Standard Test Method to Determine the Wind Resistance of Vegetated Roof Assemblies,* National Research council, Ottawa, Canada (2015)
4. ZinCo GmbH, *PLANUNGSHILFE - Systeme für begrünte Schrägdächer,* Nürtingen Germany, https://www.zinco.de/planung
5. B. Appupillai, Ch. Mauricio, M. Sudhakar, *New Test Methodology for Wind Resistance Evaluation of Built-In-Place Vegetated Roof Assembly,* Journal of Architectural Engineering, (2021), doi: 10.1061/(ASCE)AE.1943-5568.0000475
6. A. Baskaran, S.K.P. Ko, and S. Molleti, *A Novel Approach to Estimate the Wind Unflip Resistance of roofing Systems, Building and Environment*, **44**, (2008), Canada
7. Wing-Hong Onyx Wai, Wen-Qing Hu, Chi-Wai Li, Jie-Min Zhan, *Effects of Green Roof on the Wind Field of a Low-rise Building,* Procedia Engineering, **126**, (2015), ISSN 1877-7058
8. CSA Group, *CSA A123.21:20 - Standard test method for the dynamic wind uplift resistance of membrane-roofing systems,* (2020)
9. Landscape Development and Landscaping Research Society e.V., - FLL, *Green Roof Guidelines – Guidelines for the planning, construction, and maintenance of green roofs*, **150,** Germany (2018)