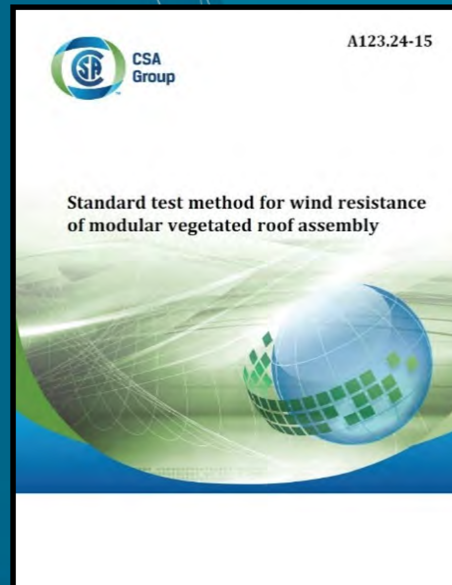
NRC·CNRC NRC.CANADA.CA

# Application de la norme CAN/CSA A123.24 pour évaluer la résistance au vent des toitures végétalisées


CSA Group
A123.24-15
Standard test method for wind resistance of modular vegetated roof assembly

Mauricio Chavez
CNRC - Construction

27 March, 2024

National Research Council Canada Conseil national de recherches Canada Canada

## Équipe

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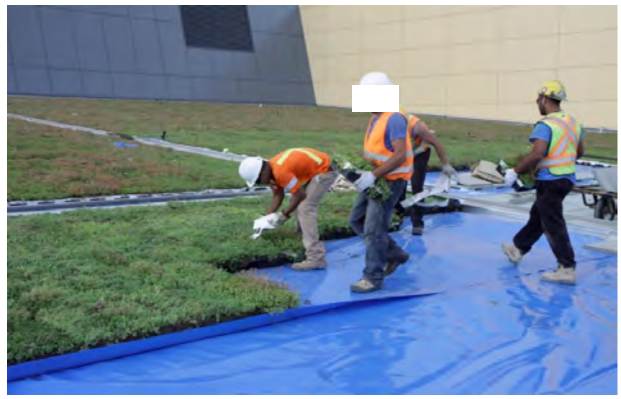
**Suda Molleti**
**Steven Ko**
**Amor Duric**
**Jeff Tompkins**
**David Van Reenen**

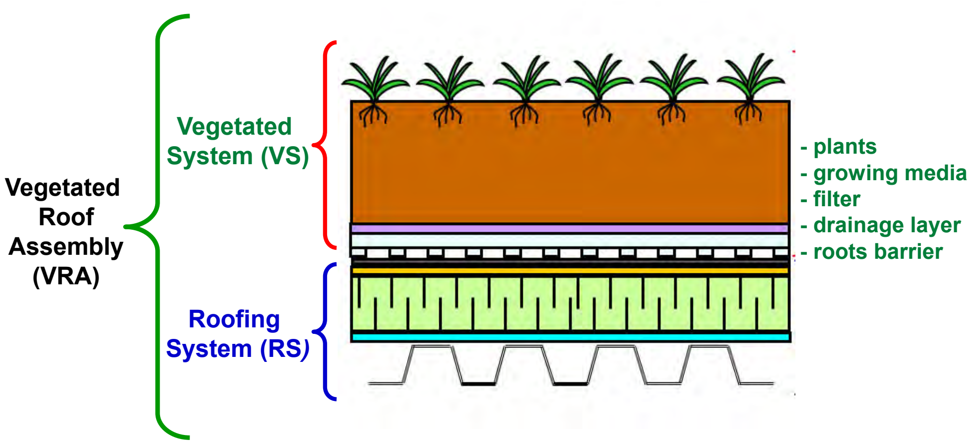
courtesy LiveRoof Ontario Inc.

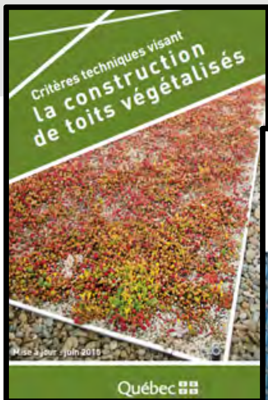


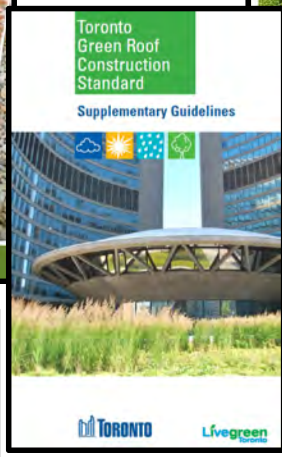
courtesy LiveRoof Ontario Inc.



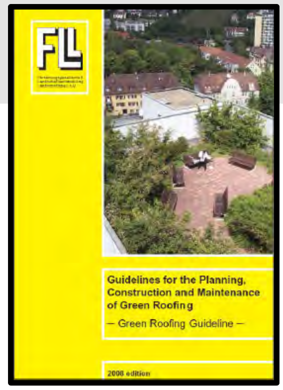
# Vegetated Roof Assembly (VRA)
# Assemblage de toiture végétalisée

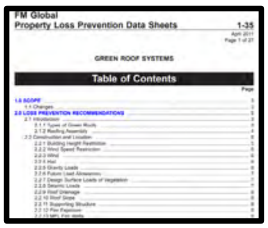


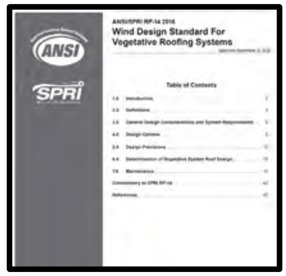










## 4. Résistance au soulèvement dû au vent et à l'érosion

**4.1.** Le calcul des forces de soulèvement dû au vent doit être réalisé selon les exigences du Code.

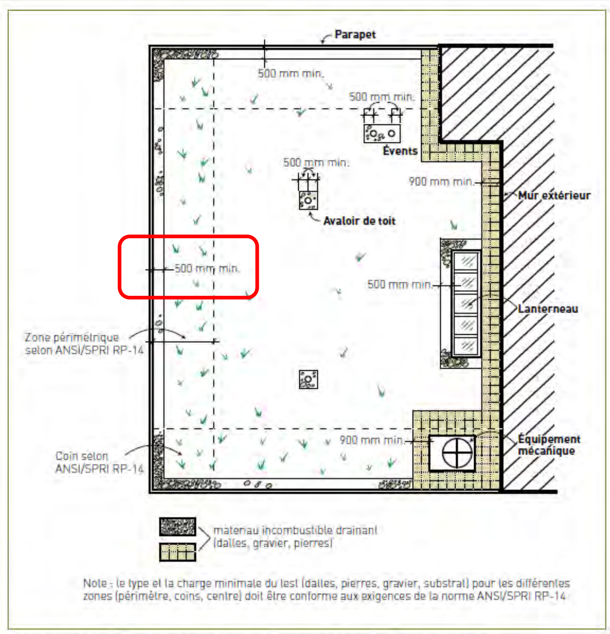
**4.2.** Sous réserve des points 4.3 et 4.4, le toit végétalisé doit être conçu pour résister aux effets de soulèvement par le vent selon les critères de la norme ANSI/SPRI RP-14, «Wind Design Standard for Vegetative Roofing Systems», tout en respectant les recommandations du manufacturier de la membrane d'étanchéité.

**4.3.** La hauteur du parapet mesurée au-dessus du substrat ou du lest doit être calculée selon la norme ANSI/SPRI RP-14 et ne doit pas être inférieure à 150 mm.

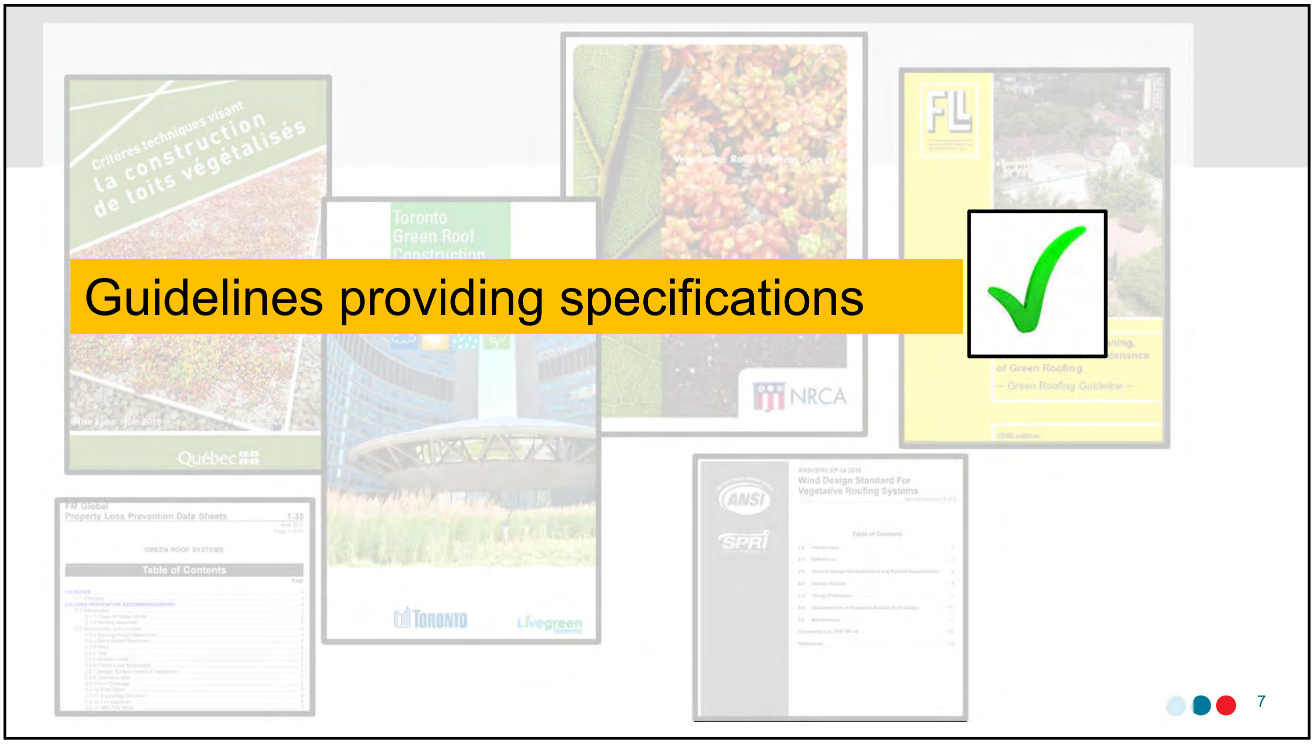
**4.4.** Une zone libre de végétation d'une largeur d'au moins 500 mm et recouverte de lest de pierre ou de dalles de béton conforme aux règles de l'art et respectant la norme ANSI/SPRI RP-14 est requise entre le parapet et le couvert végétatif.

**4.5.** Des mesures de retenue conformes aux règles de l'art doivent être prises pour éviter l'érosion du substrat et pour contrer l'arrachement des plantes par le vent jusqu'à ce que le couvert végétatif ait atteint sa maturité.

**4.6.** Seules les membranes d'étanchéité à pleine adhérence ou les membranes fixées mécaniquement sont permises sur le bassin sur lequel le toit végétalisé est construit.




Zones libres de végétation et zones pour la résistance au soulèvement dû au vent


Critères techniques visant
la construction
de toits végétalisés
Québec
Toronto
Green Roof
Construction
NRCA
FLL
of Green Roofing
Wind Design Standard For
Vegetative Roofing Systems
ANSI
SPRI
FM Global
Property Loss Prevention Data Sheets
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TORONTO
Livegreen
Guidelines providing specifications
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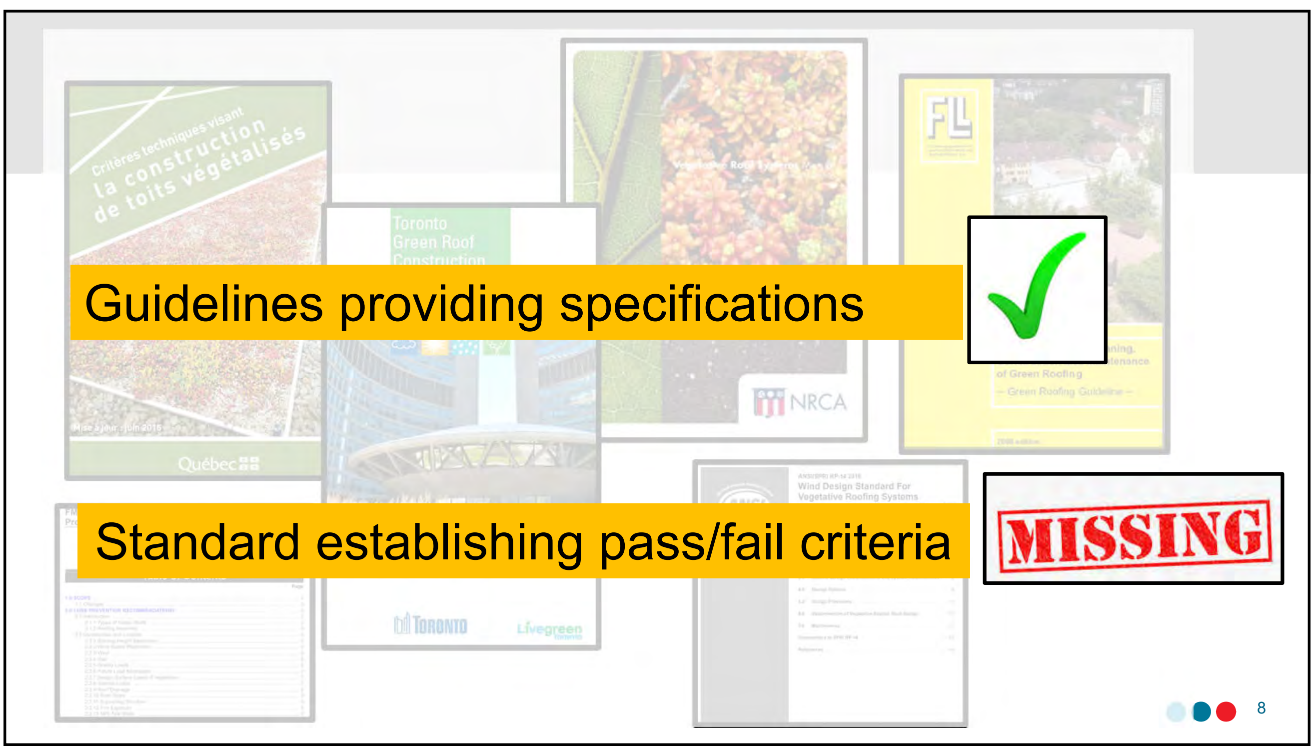
Critères techniques visant
la construction
de toits végétalisés
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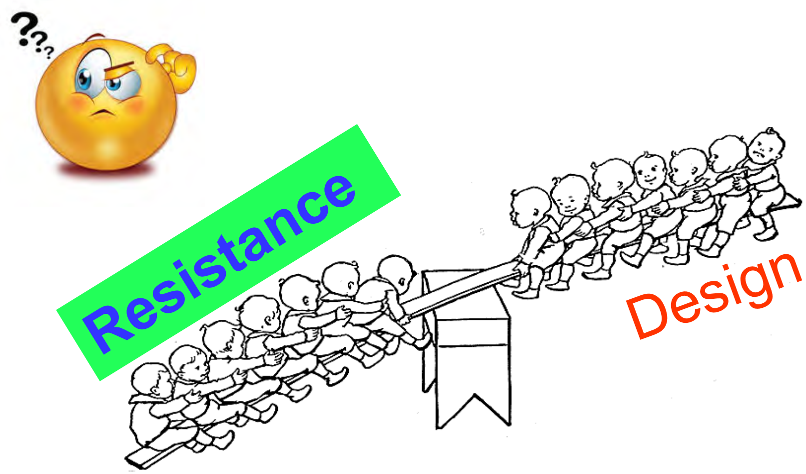
Toronto
Green Roof
Construction
NRCA
FLL
of Green Roofing
Wind Design Standard For
Vegetative Roofing Systems
TORONTO
Livegreen
Guidelines providing specifications
Standard establishing pass/fail criteria
MISSING
8

## Resistance vs Design of roof top add-ons

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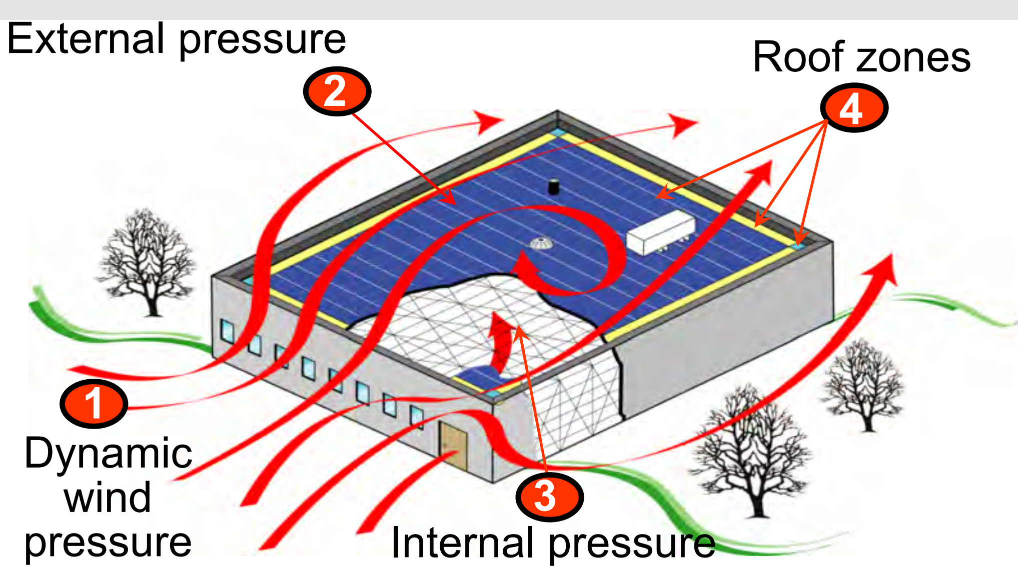
## Design of roof claddings

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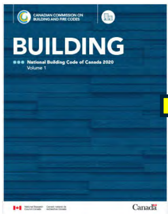
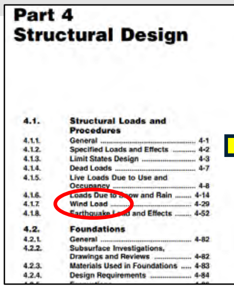
# Building Aerodynamics





**Part 4**
**Structural Design**

| | | |
|---|---|---|
| 4.1. | Structural Loads and Procedures | |
| 4.1.1. | General | 4-1 |
| 4.1.2. | Specified Loads and Effects | 4-2 |
| 4.1.3. | Limit States Design | 4-3 |
| 4.1.4. | Dead Loads | 4-7 |
| 4.1.5. | Live Loads Due to Use and Occupancy | 4-8 |
| 4.1.6. | Loads Due to Snow and Rain | 4-14 |
| 4.1.7. | Wind Load | 4-29 |
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| 4.2. | Foundations | |
| 4.2.1. | General | 4-82 |
| 4.2.2. | Subsurface Investigations, Drawings and Reviews | 4-82 |
| 4.2.3. | Materials Used in Foundations | 4-83 |
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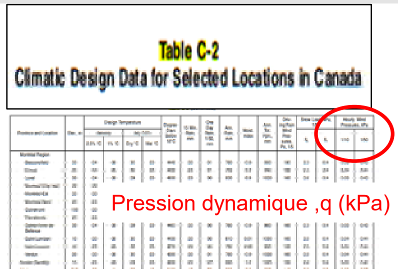
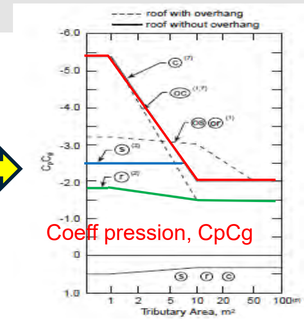



Pression dynamique ,q (kPa)




Coeff pression, CpCg

**4.1.7. Charge due au vent**

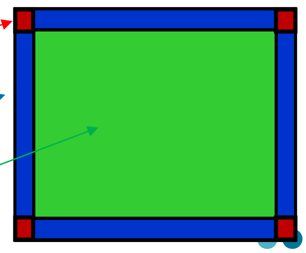
$$p = I_W \boxed{q} C_e C_t \boxed{C_g C_p} \quad \text{(kPa)}$$

$$p_i = I_W q C_{ei} C_t C_{gi} C_{pi}$$

-2.8 kPa (corner)

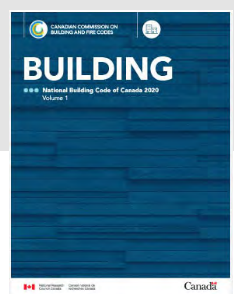
-1.4kPa (edge)

-1.1kPa (interior)





# Wind uplift resistance




**5.2.2.2. Charges dues au vent**

(Voir la note A-5.2.2.2.)

**1)** Le présent article s'applique à la détermination de la charge due au vent prise en compte dans le calcul des matériaux, composants ou ensembles de construction, y compris leurs assemblages, séparant des milieux différents ou exposés au milieu extérieur, si ces éléments :

a) sont soumis à une charge due au vent; et

b) doivent être conçus de façon à résister à une charge due au vent.

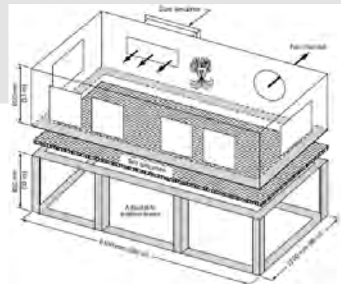
**2)** Sous réserve du paragraphe 3), la charge due au vent décrite au paragraphe 1) doit représenter la totalité de la charge spécifiée due au vent calculée selon l'article 4.1.7.1.

**3)** Si l'on peut démontrer au moyen d'essais ou d'analyses qu'un matériau, composant ou ensemble de construction ou assemblage décrit au paragraphe 1) est exposé à des charges dues au vent inférieures à la totalité des charges dues au vent spécifiées, la charge décrite au paragraphe 1) ne doit pas être inférieure à la valeur établie au moyen d'un essai ou d'une analyse.

**4)** Sous réserve du paragraphe 5), la résistance à l'arrachement sous l'action du vent des couvertures à membrane doit être déterminée conformément à la norme CAN/CSA-A123.21, « Méthode d'essai normalisée de la résistance dynamique à l'arrachement sous l'action du vent des systèmes de couverture à membrane » (voir la note A-5.2.2.2. 4)).

**5)** Les couvertures à membrane ayant une performance déjà éprouvée pour les charges dues au vent prévues ne sont pas visées par le paragraphe 4) (voir la note A-5.1.4.1. 5)).

## Wind uplift resistance

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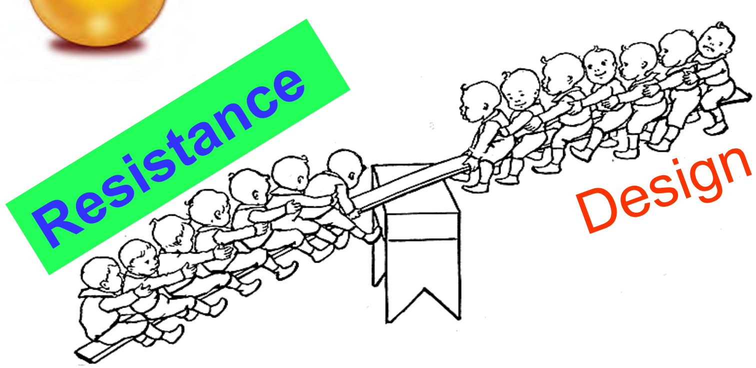
## Resistance vs Design of VRA

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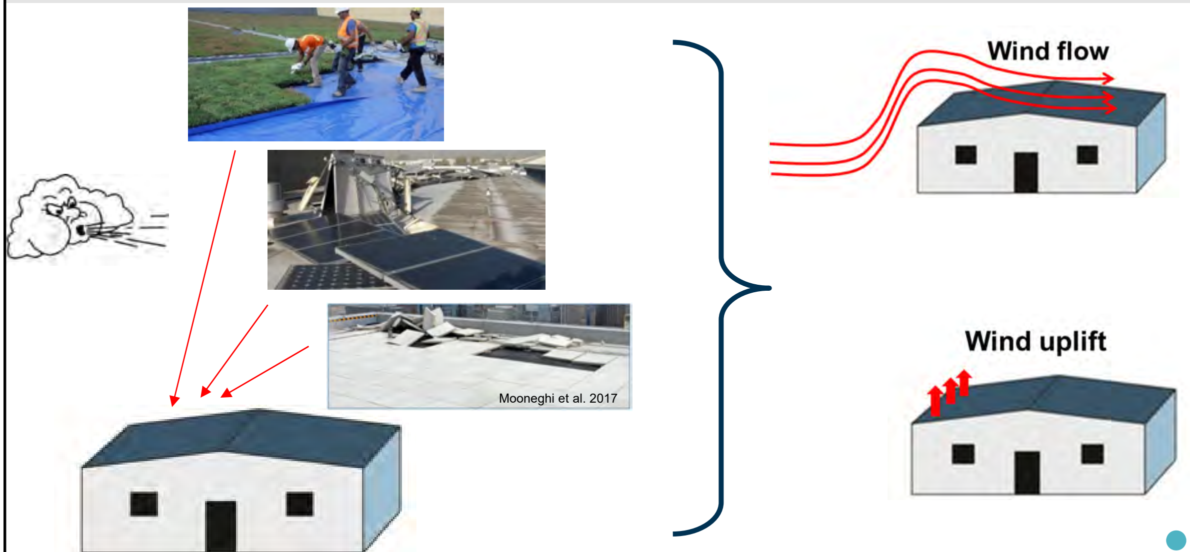
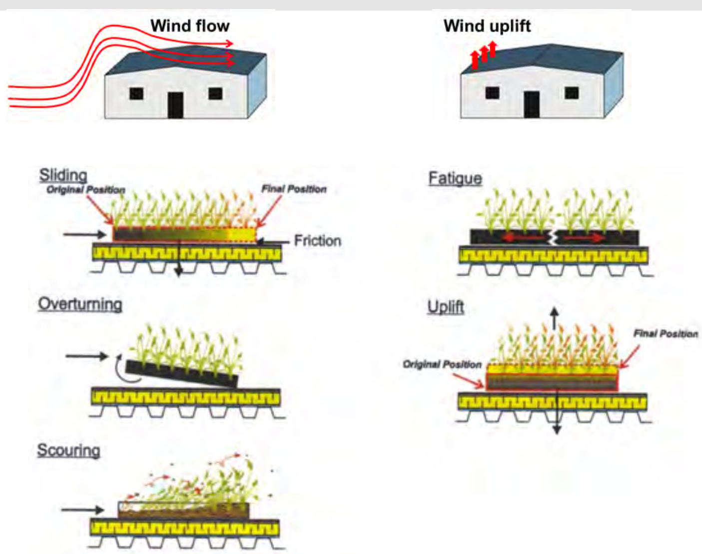
## Wind resistance of roof top add-ons





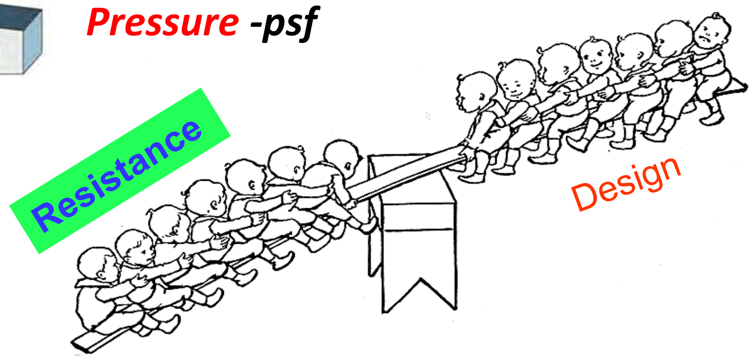

## Wind Resistance of Roof top add-ons

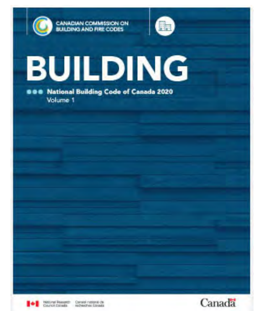


## Evaluating VRA wind resistance


*Wind Speed - mph*


*Pressure -psf*

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VRA

Modular VRA: MVRA

Built-in-place VRA: BVRA

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CANADIAN ROOFING
crca
CONTRACTORS' ASSOCIATION
CLEB
une entreprise d'UL
armtec
bioroof SYSTEMS
LiveRoof
SOPREMA
vitaroofs
ADVANCED LIVING ROOF SYSTEMS
TORONTO
Xeroflor
Ottawa
CSA Group
A123.24-15
Standard test method for wind resistance of modular vegetated roof assembly
2015 – MVRA only


CANADIAN ROOFING
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Ottawa
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ZinCo
SOPREMA
HYDROTECH
CSA GROUP
CSA A123.24:21
National Standard of Canada
Standard test method for wind resistance of vegetated roof assembly
2021 - MVRA AND BVRA
Standards Council of Canada
Conseil canadien des normes
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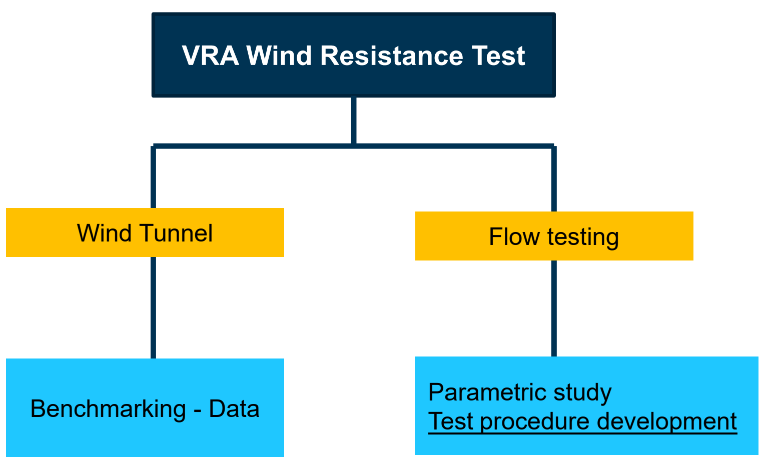
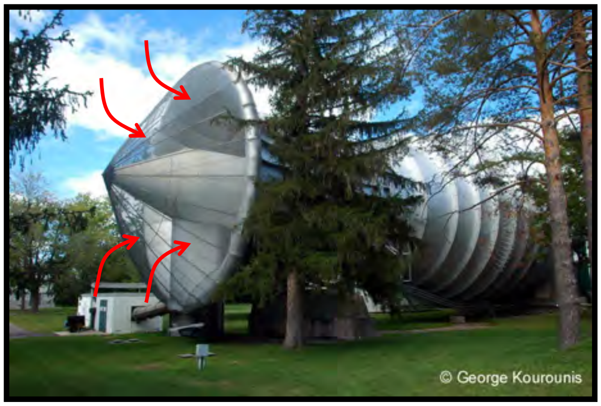
# Flow Resistance





## NRC wind tunnel




- 10' x 20'
- Open-circuit tunnel
- 100 mph wind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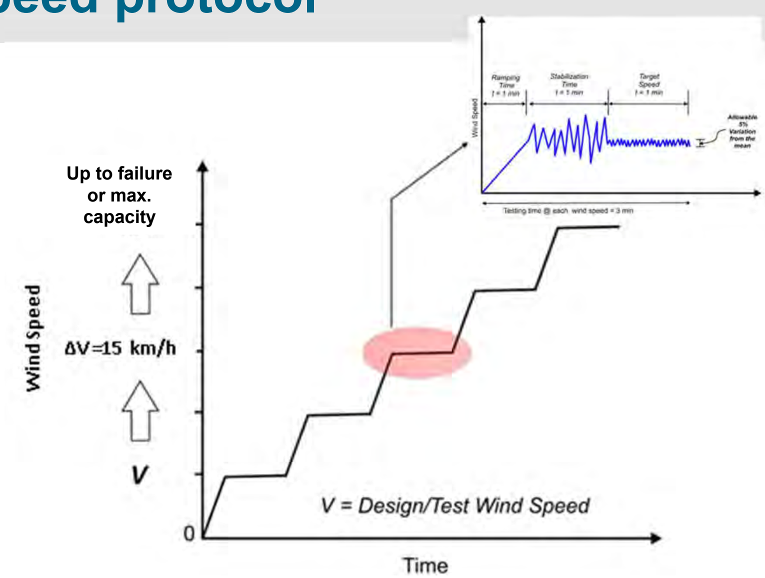
## Wind speed protocol

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## MVRA

wind



## MVRA – failure mode


wind

# MVRA – failure mode


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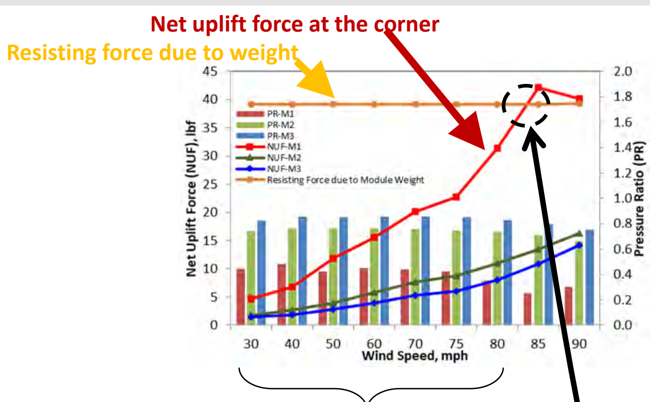
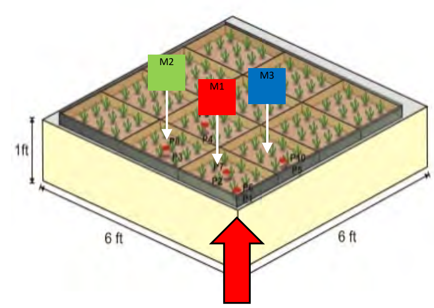
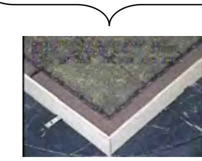
# MVRA- failure mode



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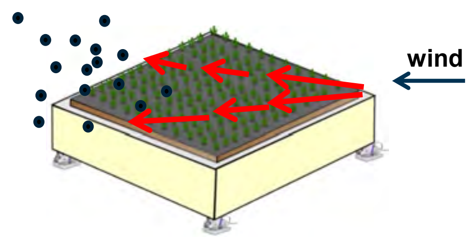
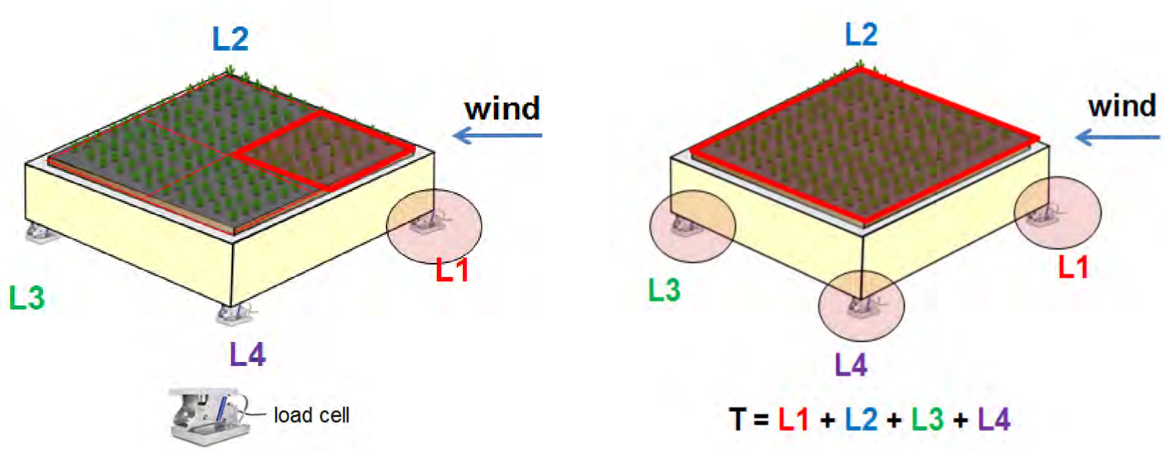
## BVRA

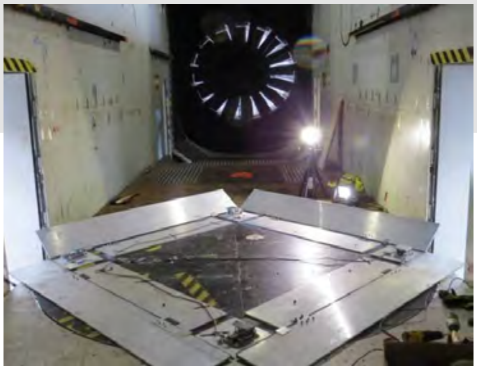


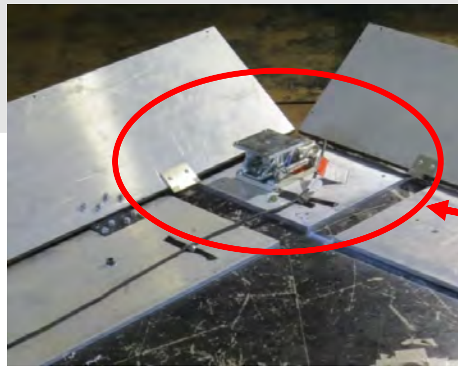

- Intensity depends on wind speed
- **Growing media loss (erosion)**
- Continuous process



## BVRA







Load cell

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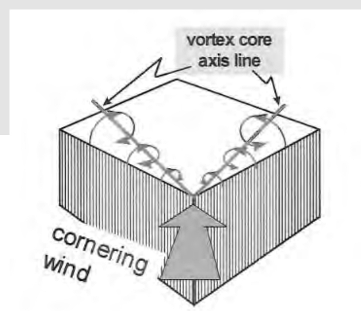
## BVRA – failure mode


Wind

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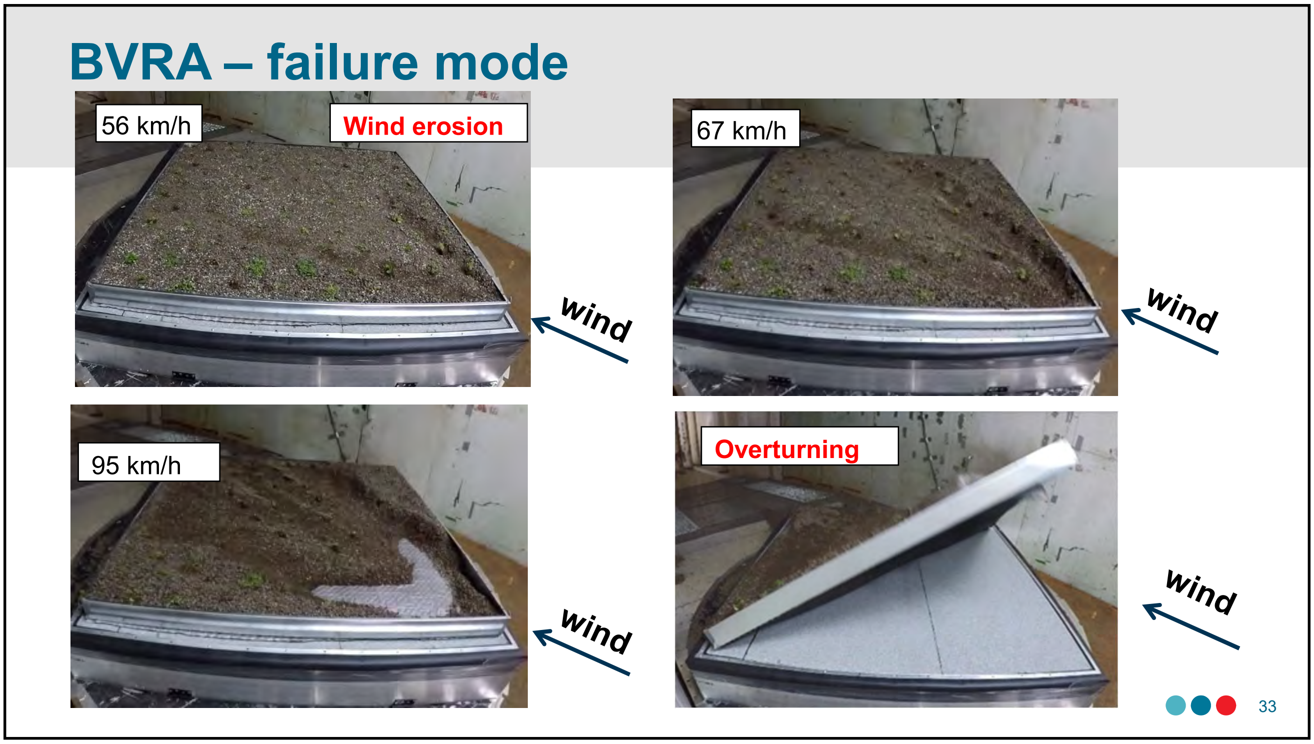
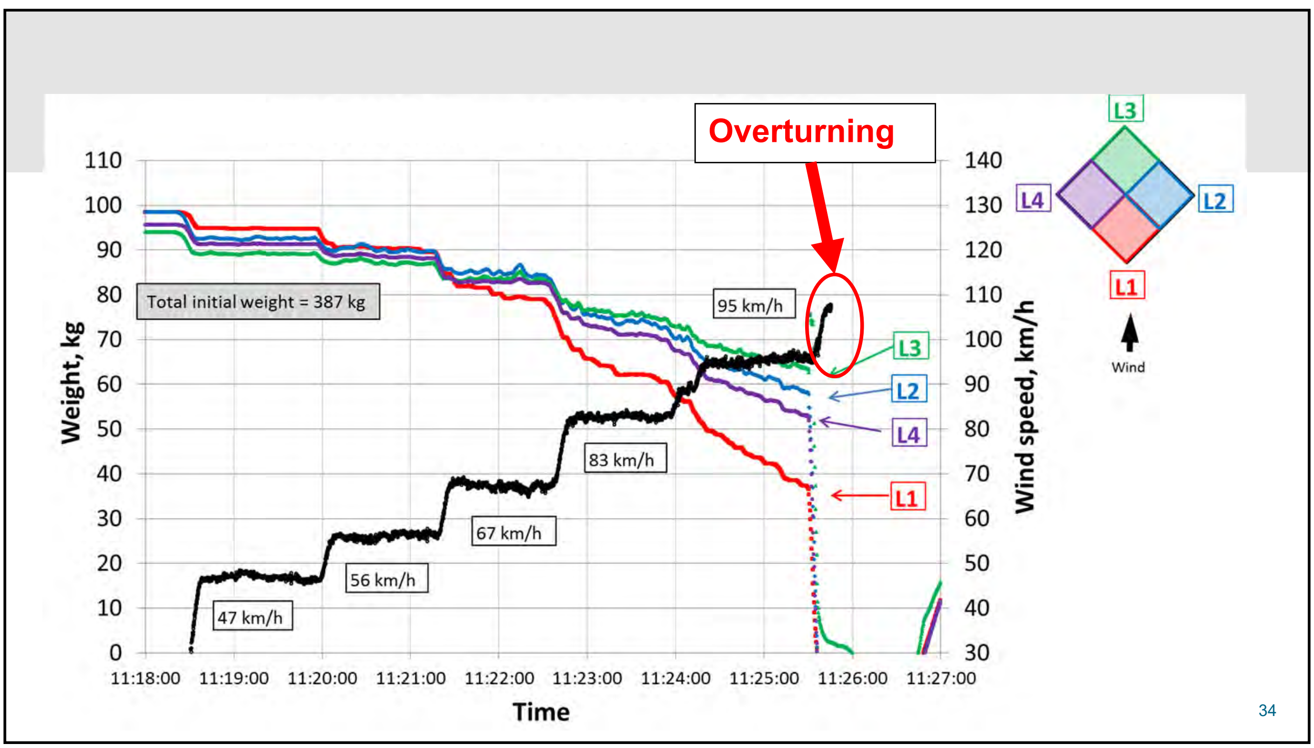
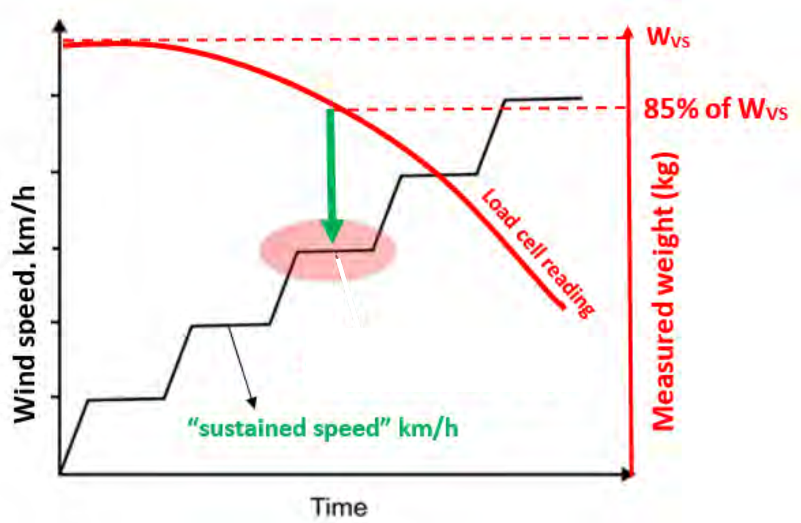


BVRA – failure mode
56 km/h
Wind erosion
67 km/h
95 km/h
Overturning
wind
wind
wind
wind
33

Overturning
Total initial weight = 387 kg
47 km/h
56 km/h
67 km/h
83 km/h
95 km/h
L1
L2
L3
L4
Wind
Weight, kg
Wind speed, km/h
Time
11:18:00
11:19:00
11:20:00
11:21:00
11:22:00
11:23:00
11:24:00
11:25:00
11:26:00
11:27:00
34

## Wind speed protocol + failure



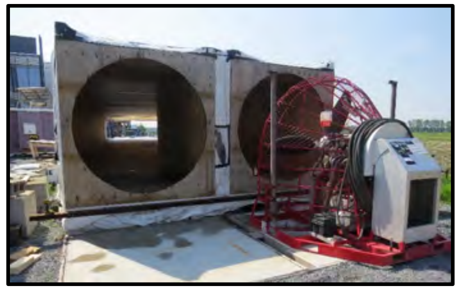



**Flow Resistance**

In a commercial lab

In collaboration with CLEB une entreprise d'UL

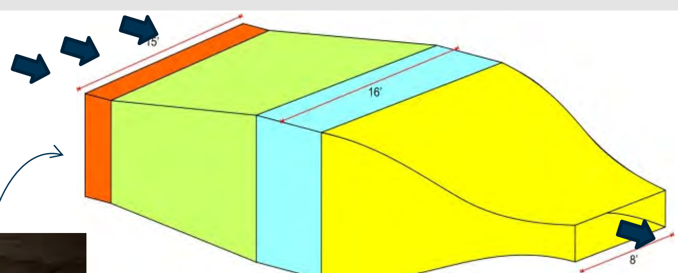
## Wind flow facility

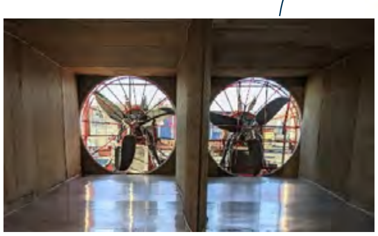


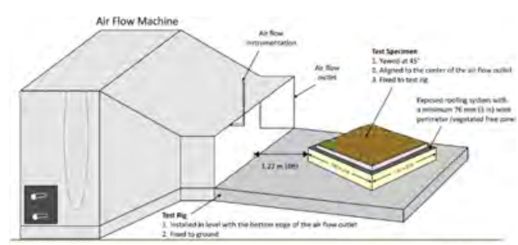
- 150 mph (240 km/h)



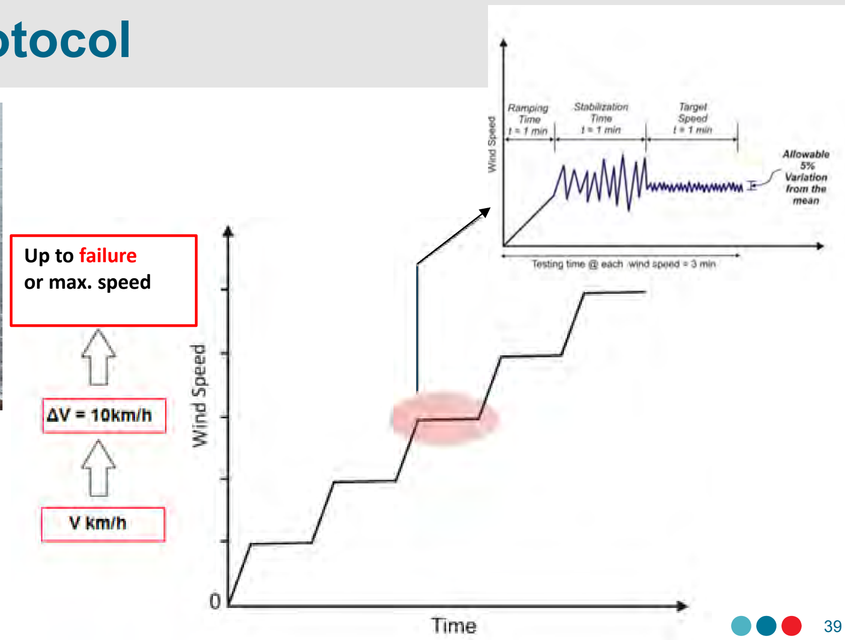
## Wind flow facility





## Wind speed protocol

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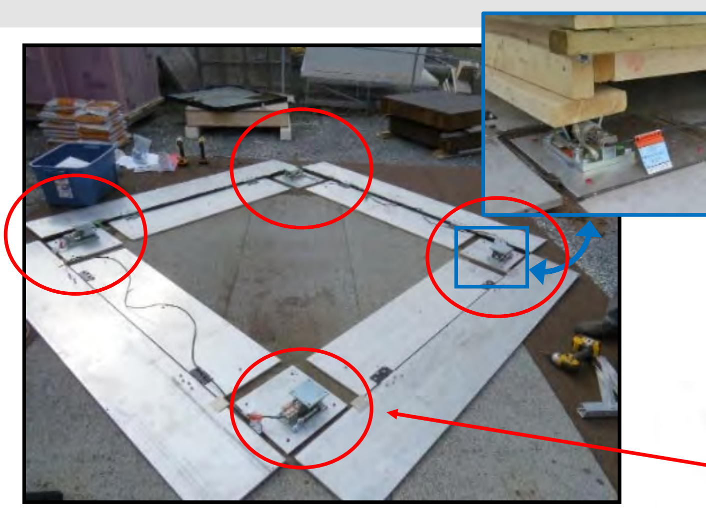
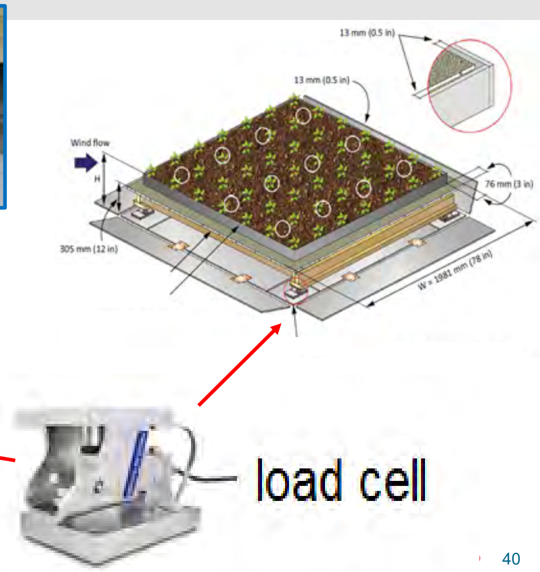
## Load cells



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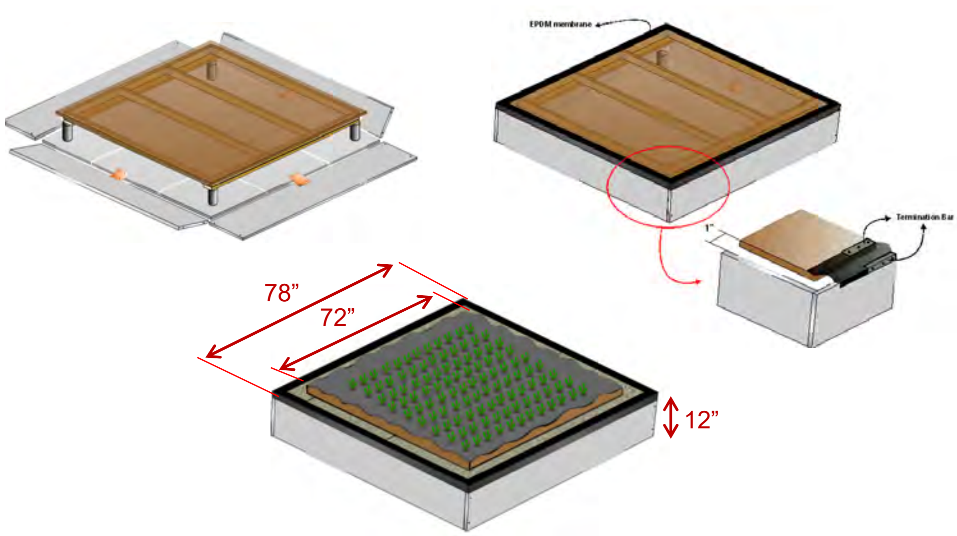
# BVRA construction

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# BVRA installation

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## BVRA challenges



Resistance ?

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## Effect of vegetation growth

"as-built"

"12-weeks"

"1-year-grown"

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## Built-in-place :BVRA

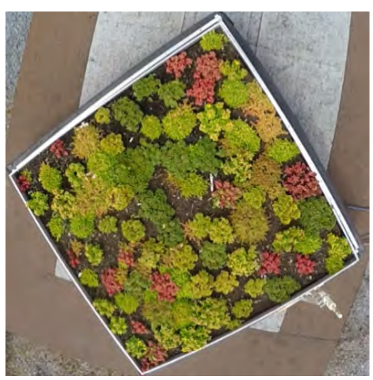
- -more than 40 specimens
- -same plants (sedum)
- -irrigation plan
- -no fertilizer
- -no replacement after a year



## Built-in-place VRA: BVRA

**As-built**

**12-weeks**

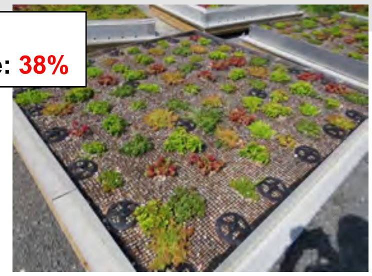


**1-year**

## 12-weeks

**Source 1**
**Coverage: 68%**

**Source 2**
**Coverage: 38%**



**Source 3**
**Coverage: 78%**

**Source 4**
**Coverage: 90%**

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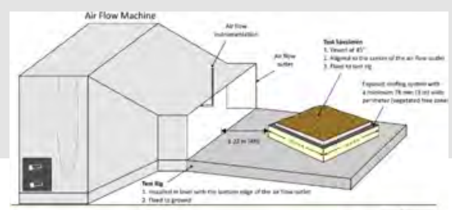




**Video 1 (source_1- as built )**

**Video 2 (source_1- after 1 year )**

**Video 3 (source_2- as built )**

**Video 4 (source_2- after 1 year )**

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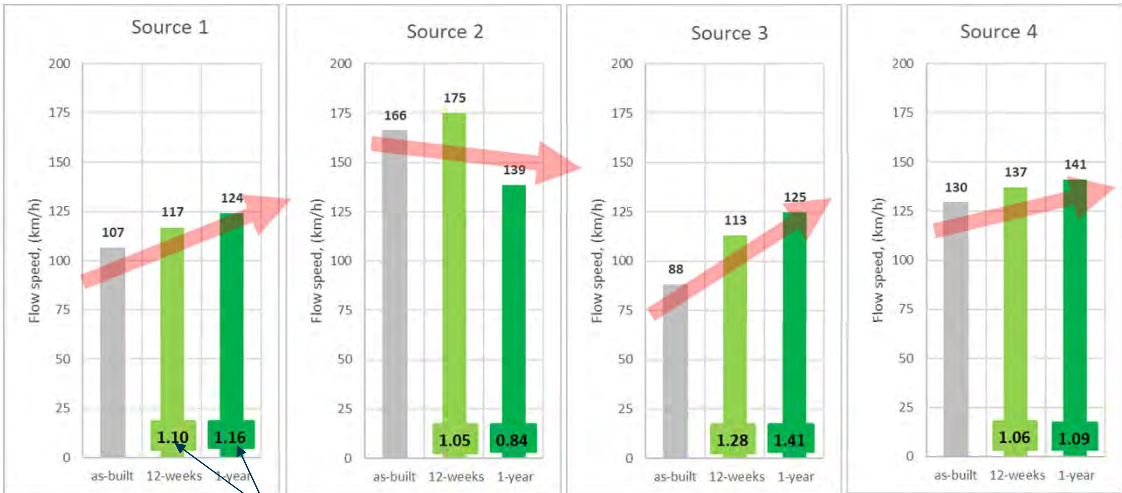
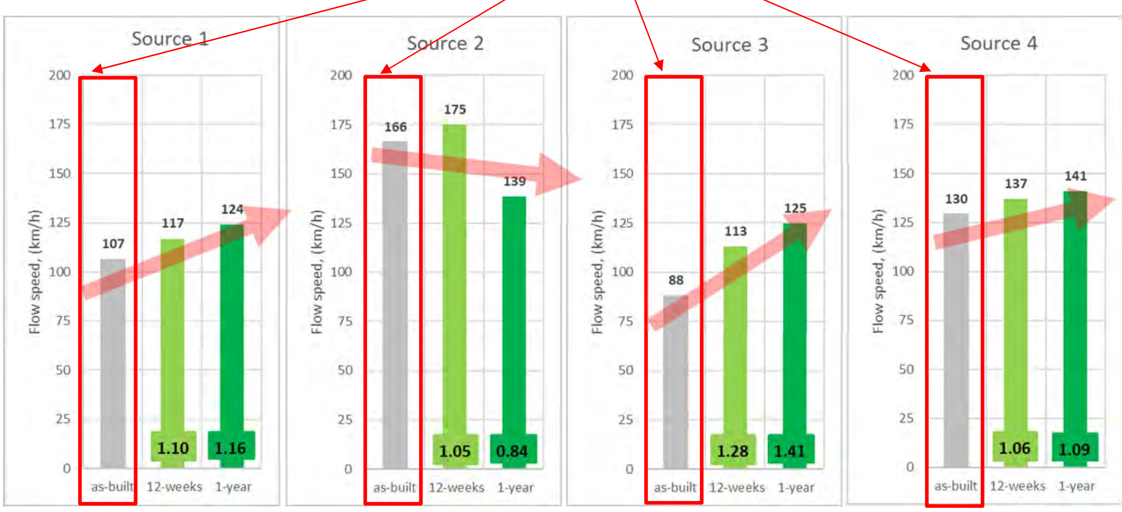
# Effect of vegetation growth




Growth Modify Factor, **GMF**

49

The standard can be based on the “As-built” performance and predict the 1 year performance




density "as-built" **0.80** g/cm$^3$ **1.43** **0.43** **0.75**

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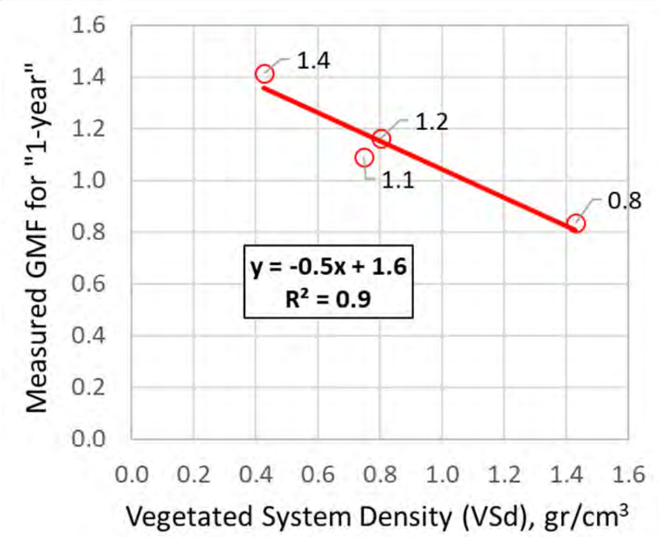


$$GMF = 1.6 - \frac{\rho}{2}$$

ρ (g/cm$^3$), density "as-built"

(*) GMF no greater than 1.3

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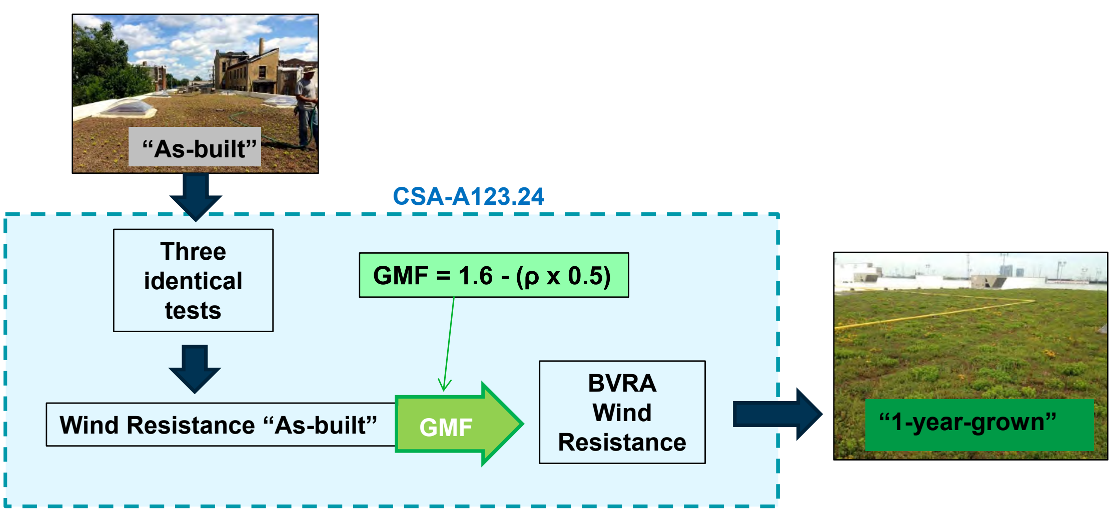
## Standard approach

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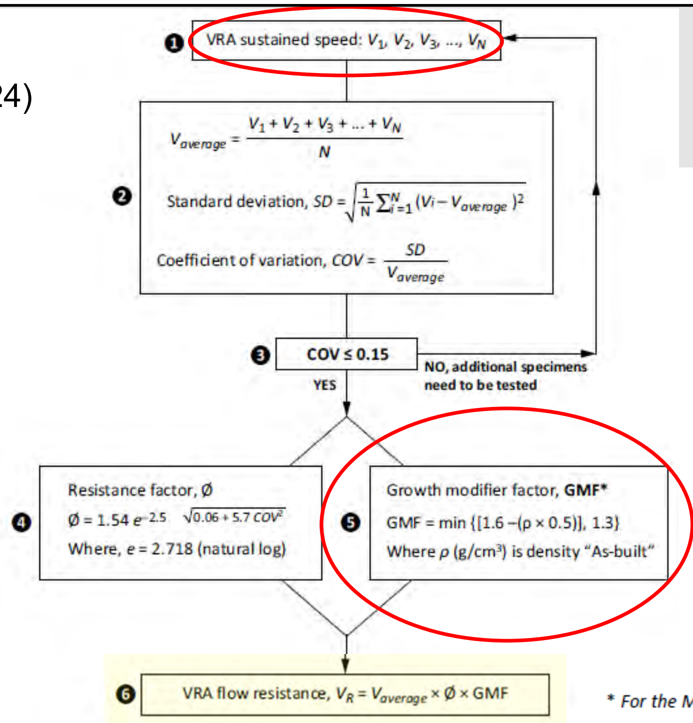
Flow chart
(from CSA123.24)




Tests "as-built"

To account for the vegetation growth: **GMF**

Depends on "as-built" density

* For the MVS: GMF = 1.0.

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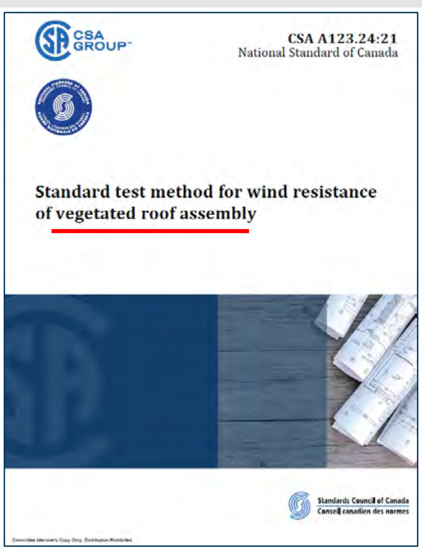
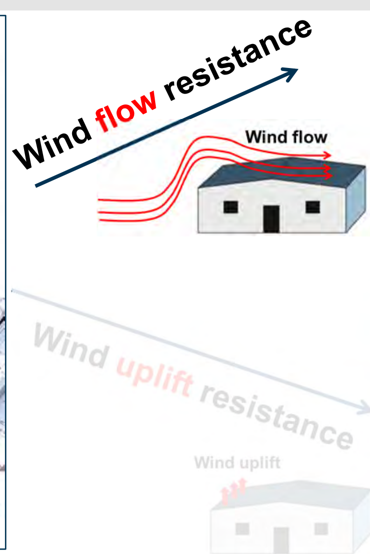
# VRA wind resistance







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VRA wind resistance
CSA GROUP
CSA A123.24:21
National Standard of Canada
Standard test method for wind resistance of vegetated roof assembly
Standards Council of Canada
Conseil canadien des normes
Wind flow resistance
Wind flow
Wind
Wind uplift resistance
Wind uplift
55


VRA wind resistance
CSA GROUP
CSA A123.24:21
National Standard of Canada
Standard test method for wind resistance of vegetated roof assembly
Standards Council of Canada
Conseil canadien des normes
Wind flow resistance
Wind flow
Wind
Wind uplift resistance
Wind uplift
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# Wind Uplift Resistance

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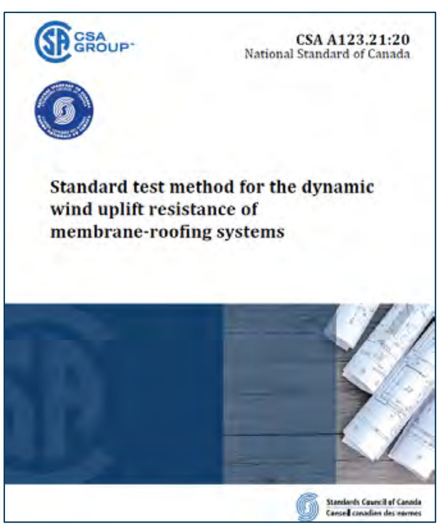
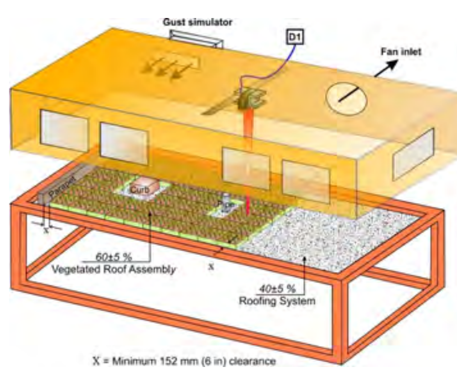
## Wind uplift resistance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## Wind uplift resistance


CSA GROUP
CSA A123.21:20
National Standard of Canada

Standard test method for the dynamic wind uplift resistance of membrane-roofing systems

Standards Council of Canada
Conseil canadien des normes

MARS (Not applicable to VRA)

AARS ✓

PARS ✓

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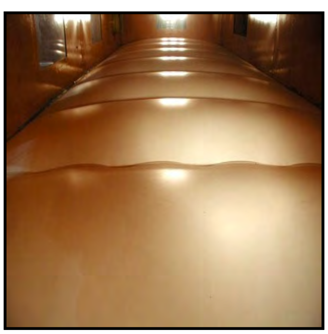
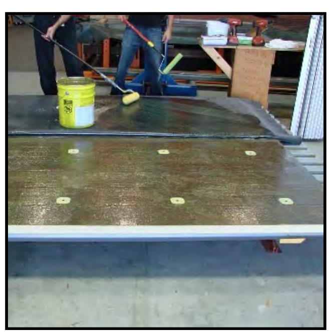
## Wind uplift resistance

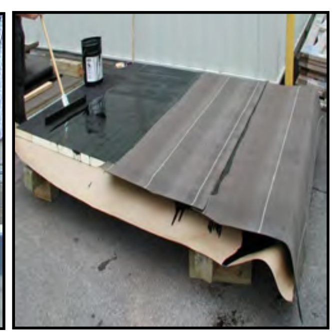
MARS ✗

PARS

AARS







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# Wind uplift resistance

Wind uplift

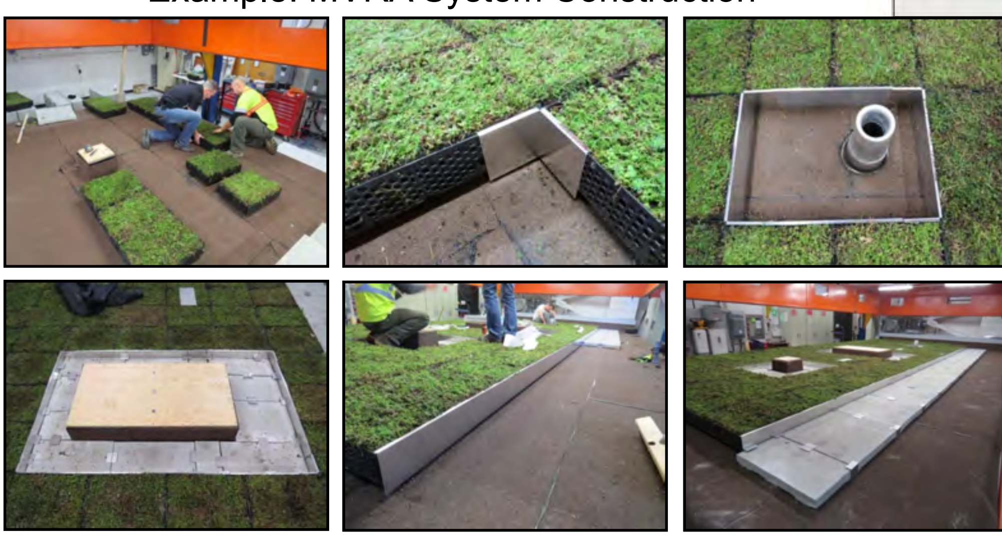
Roofing System Construction



# Wind uplift resistance

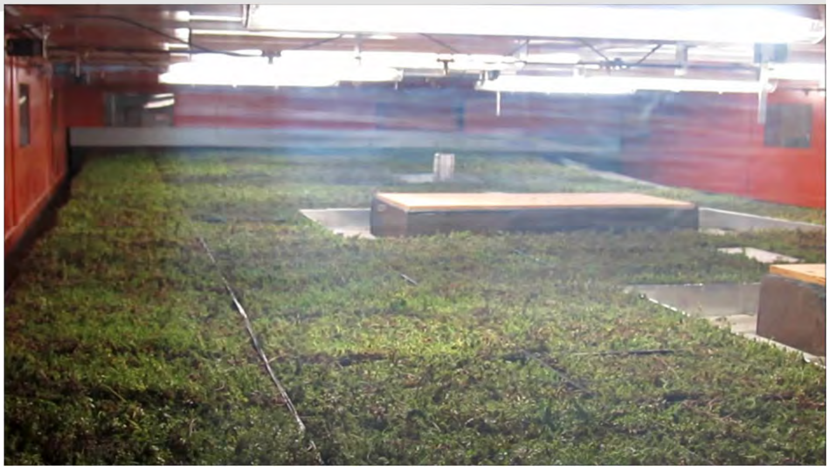
Wind uplift

Example: MVRA System Construction



## Typical uplift testing

Wind uplift

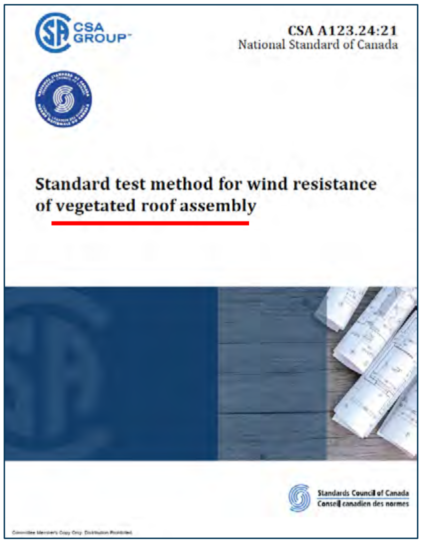




## Failure mode

Wind uplift

## VRA wind resistance


CSA GROUP
CSA A123.24:21
National Standard of Canada

Standard test method for wind resistance of vegetated roof assembly

Standards Council of Canada
Conseil canadien des normes

Wind **flow** resistance



Wind **uplift** resistance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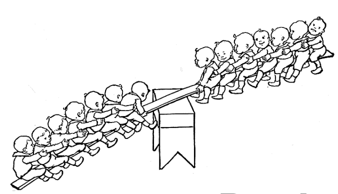
## Application

**3 steps**

1- Design wind data (pressure and wind speed) from **Code**

2- Resistance by testing using **CSA 123.24**

3- Code **VERIFICATION**:



Resistance $_{(Pr,\ Vr)}$ > Design $_{(Pd,\ Vd)}$

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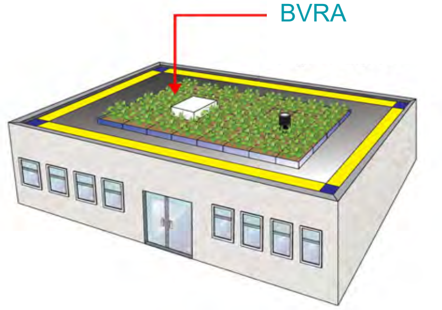
# Application

A building-owner wants to install a BVRA on a building.

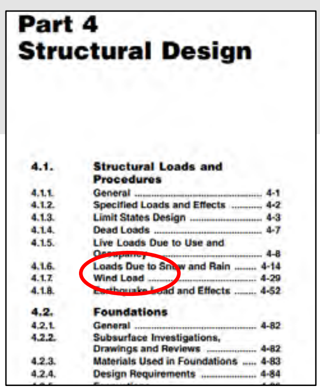
Two options of **BVRAs** (Source_1 and Source_2)






# 1- Design


Design wind uplift



Part 4
Structural Design

4.1. Structural Loads and Procedures
4.1.1. General ........ 4-1
4.1.2. Specified Loads and Effects ........ 4-2
4.1.3. Limit States Design ........ 4-3
4.1.4. Dead Loads ........ 4-7
4.1.5. Live Loads Due to Use and Occupancy ........ 4-8
4.1.6. Loads Due to Snow and Rain ........ 4-14
4.1.7. Wind Load ........ 4-29
4.1.8. Earthquake Load and Effects ........ 4-52
4.2. Foundations
4.2.1. General ........ 4-82
4.2.2. Subsurface Investigations, Drawings and Reviews ........ 4-82
4.2.3. Materials Used in Foundations ........ 4-83
4.2.4. Design Requirements ........ 4-84

Design wind speed

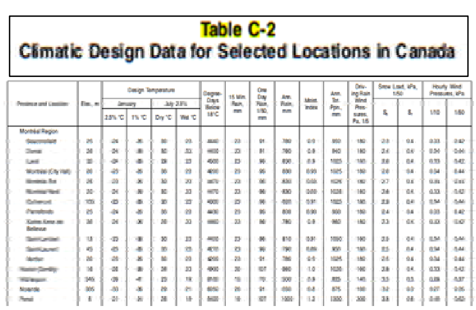
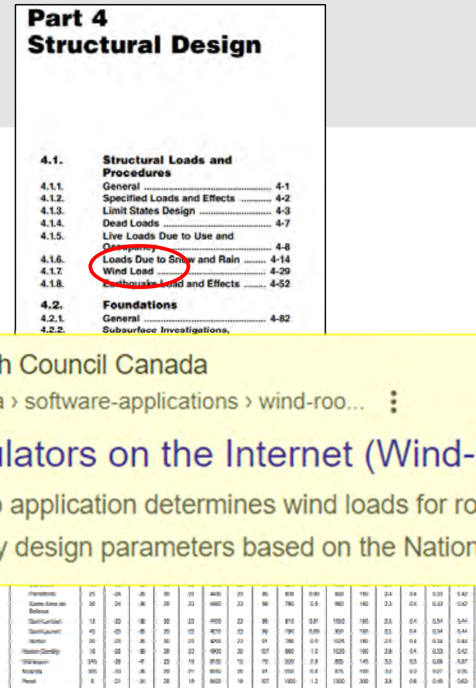


Table C-2
Climatic Design Data for Selected Locations in Canada

# 1- Design


Design wind **uplift** →




National Research Council Canada
https://nrc.canada.ca › software-applications › wind-roo...

Wind-Roof Calculators on the Internet (Wind-RCI)

Apr 5, 2023 — This web application determines wind loads for roof cladding and modular vegetated roof assembly design parameters based on the National ...



# 2- Resistance UPLIFT


Resistance wind **uplift** →

| | BVRA- Source_1 | BVRA- Source_2 |
|---|---|---|
| Failure Mode | Membrane delamination | Membrane delamination |
| Sustained pressure | 90 psf (4.3 kPa) | 105 psf (5.0 kPa) |
| Wind Uplift resistance | **90*0.65 = 59 psf (2.8 kPa)** | **105*0.65 = 68 psf (3.3 kPa)** |

**Lab results**

## 2- Resistance FLOW





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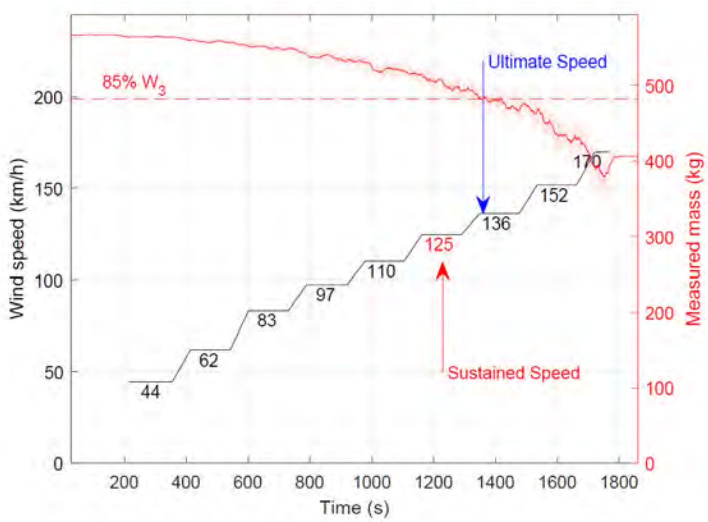
## 2- Resistance FLOW: typical result

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## 2- Resistance Wind Flow


1. Obtain $W_1$, $W_2$, $W_3$ and calculate $W_{average}$
2. Calculate Coefficient of Variation, COV
3. COV ≤ 15% — NO, more data needed / YES
4. Determine Resistance Factor, Ø
5. Determine Growth Modifier Factor, GMF
6. BVRA Wind Resistance, $W_R = W_{average}$ x Ø x GMF

Lab work!



## 2- Resistance WIND SPEED

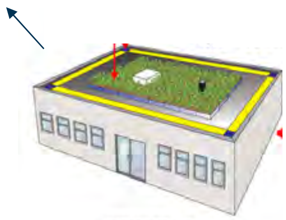
| | | Source_1 | Source_2 | |
|---|---|---|---|---|
| (i) Three identical tests ($W_1$, $W_2$, $W_3$) | $W_{average}$ | 112 km/h | 148 km/h | 1 |
| (ii) Standard deviation, | SD | 14.86 | 9.90 | 2 |
| (iii) Coefficient of Variation, COV | | 11% | 6% | 3 |
| Resistance factor, | Ø | **0.64** | **0.70** | 4 |
| Average "as-built" density, ρ (g/cm³) | | 0.80 | 1.00 | |
| GMF = 1.6 - (ρ x 0.5) | | **1.20** | **1.10** | 5 |
| $W_R = W_{average}$ x Ø x GMF | | **86 km/h** | **114 km/h** | 6 |

COV ≤ 15% ✓

Lab results

## 3- Verification

**Pd = -2.5kPa**
**Vd = 108 km/h**

Design wind data
from Building Code

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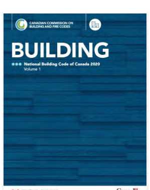
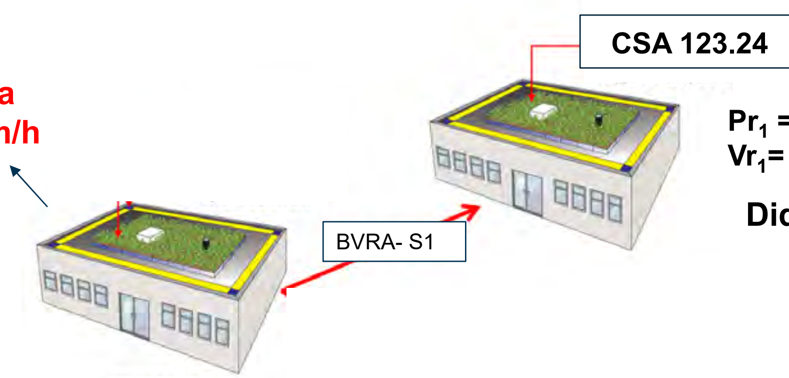
## 3- Verification

**Pd = -2.5kPa**
**Vd = 108 km/h**




Design wind data
from Building Code

**$Pr_1$ = -2.8kPa**
**$Vr_1$= 86 km/h**

**Did NOT meet**

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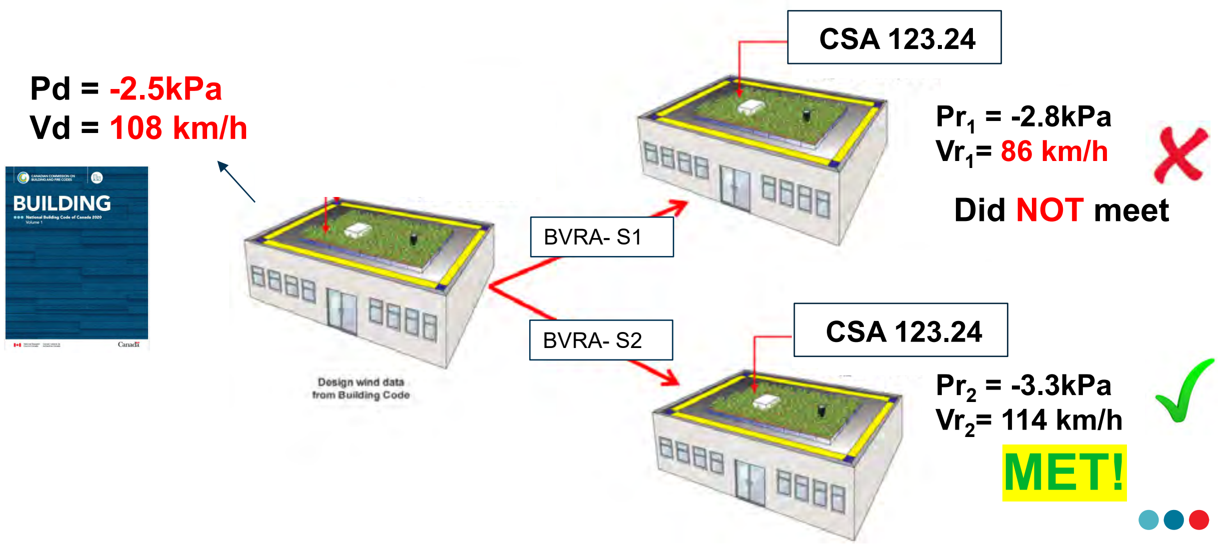
# 3- Verification

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Journal of Architectural Engineering / Volume 27 Issue 3 - September 2021

## New Test Methodology for Wind Resistance Evaluation of Built-In-Place Vegetated Roof Assembly

Appupillai Baskaran, M.ASCE[1]; Mauricio Chavez[2]; and Sudhakar Molleti[3]

**Abstract:** The North American Vegetated Roof Assembly (VRA—a.k.a. green roofs) market is dominated by two different types: modular vegetated roof assemblies (MVRAs) and built-in-place vegetated roof assemblies (BVRAs). In MVRA, the vegetation is pregrown in transportable trays and installed on the roof, whereas in the BVRA, the vegetation develops on the roof. In 2015, the National Research Council of Canada (NRC), in collaboration with the green roof industry and roofing industry, set the national standard for the wind resistance evaluation of MVRA. Practitioners and building authorities have widely used this standard. In 2017, NRC and the industry collaborators started a new research project on BVRA to expand the current standards. The wind performance of BVRA is highly dependent on the growth stage of the vegetation. This variable was investigated by testing four BVRA sources (S1, S2, S3, and S4) at three different growth stages, namely, *as-built*, *12 weeks*, and *1 year* of growth. The interaction between the approaching wind speed and the BVRA response was monitored by installing load cells underneath the test mock-up. The load cells were intended to capture the growth media loss as the wind flow develops over the BVRA mock-up. The wind speed at which the vegetated system's (VS) weight reaches 85% of the initial weight was used to compute the BVRA wind performance. The tests conducted at the three growth stages permitted developing an empirical growth modifier factor (GMF). The GMF is a practical engineering solution to estimate the wind performance of a *1-year* BVRA using the *as-built* performance data. The paper presents the development of this new testing methodology and the standardization process. **DOI:** 10.1061/(ASCE)AE.1943-5568.0000475. *© 2021 American Society of Civil Engineers.*

**Author keywords:** Built-in-place vegetated roof assemblies; Green roofs; Wind erosion; Wind resistance; Standard development; Building code.

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CRCA magazine fall/winter 2021


## NBCC

Canadian Board for Harmonized Construction Codes 1754

### Proposed Change 1754

| | |
|---|---|
| **Code Reference(s):** | **NBC20 Div.B 5.2.2.2. (first printing)** |
| Subject: | Vegetated Roof Assemblies |
| Title: | Requirements for Wind Resistance of Vegetated Roof Assemblies |
| Description: | This proposed change introduces a requirement for the testing of the dynamic wind uplift resistance and wind flow resistance of vegetated roof assemblies in accordance with the CAN/CSA-A123.24:21 standard. |
| Related Code Change Request(s): | CCR 1151 |

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## NBCC

**PROPOSED CHANGE**

[5.2.2.2.] 5.2.2.2. **Determination of Wind Load**

[5] 5) Membrane roofing assemblies with proven past performance for the anticipated wind loads need not comply with Sentence (4). (See Note A-5.1.4.1.(5).)

[6] --) The wind resistance of vegetated roof assemblies shall
[a] --) conform to existing provincial or territorial regulations, or
[b] --) in the absence of the regulations referred to in Clause (a), be determined in accordance with the requirements of CAN/CSA-A123.24:21, "Standard test method for wind resistance of vegetated roof assembly" (see Note A-5.2.2.2.(6)(b)).

**Note A-5.2.2.2.(6)(b) Vegetated Roof Assemblies.**
When a vegetated system is added on the top of a membrane roofing assembly, a vegetated roof assembly (VRA) is formed. The test methods described in CAN/CSA-A123.24:21, "Standard test method for wind resistance of vegetated roof assembly," determine both the wind uplift resistance and the wind flow resistance of the VRA. If the wind uplift resistance of the membrane roofing assembly used in the VRA has already been determined in accordance with the requirements of CAN/CSA-A123.21, "Standard test method for the dynamic wind uplift resistance of membrane-roofing systems," as required by Sentence 5.2.2.2.(4), then this resistance can be used as an acceptable conservative wind uplift resistance of the VRA; in such cases, only the wind flow resistance of the VRA has to be determined in accordance with CAN/CSA-A123.24:21. If, however, any variations in the components or methods of construction of the membrane roofing assembly used in the VRA are made after the wind uplift resistance was determined in accordance with the requirements of CAN/CSA-A123.21, then the wind uplift resistance of the VRA must be determined in accordance with CAN/CSA-A123.24:21.

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NRC·CNRC

NRC.CANADA.CA

# Questions?

mauricio.chavez@nrc-cnrc.gc.ca

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Canada