

# SuPeRBE Training Material

Macro Area of Expertise MAE10:

**Macro Area of Expertise MAE10:**

**Hazard: Storms (E)**

Macro Area of Expertise MAE10.5:

**Building Element: Roof (E5)**

**Risk Category: Structure (E5.1)**

**Level of competence: 3**



## Storms

Windstorms are caused by rapid changes in atmospheric pressure, which are often associated with stronger currents and more dynamic weather systems. Damage caused by summer convective storms and winter cyclonic winds, which damage roofs and trees, is becoming increasingly common.

### What makes it worse?

- Unstable atmospheric conditions
- Intense precipitation, hailstorms
- Unsuitable shape/condition of buildings, loose elements

### What can we do?

- Aerodynamic shape of the building
- Reinforcement of structures
- Window protection
- Backup power sources, equipment protection





# Storms

## Roof

### Why does it make it worse?



- Storm winds create strong suction (uplift) on roofs, highest at edges and corners
- Failure usually starts at weak points: fixings, terminations, edges, penetrations, skylights
- Poor anchorage breaks the load path (covering → structure), leading to progressive detachment
- Once the roof covering is compromised, water ingress escalates damage very quickly
- Rigidly connected roof extensions can transfer storm loads and propagate failure into the main roof

### What can we do better?



- Use roof systems tested and certified for wind uplift resistance appropriate to local design wind speeds
- Strengthen detailing in critical zones (edges/corners) with higher fastening density and robust edge restraint
- Improve roof penetration and termination details (flashings, collars, sealing systems) to prevent initiation points
- Separate lightweight extensions (verandas/canopies) from the main roof using structural non-continuity and movement joints



## Storms

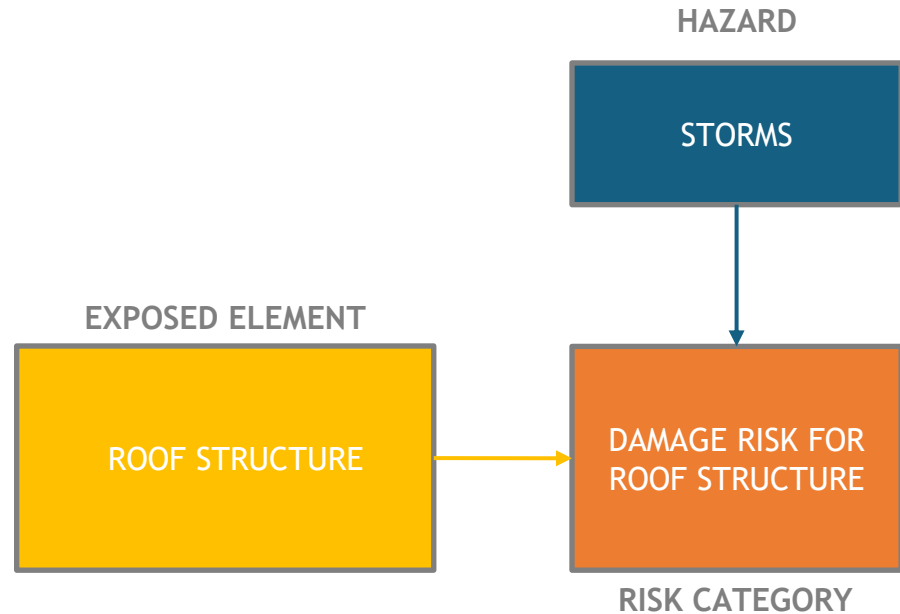
### Roof

Roof design under storms strongly influences the building's **exposure** and **vulnerability** and is a primary lever for **Storm adaptation measures**

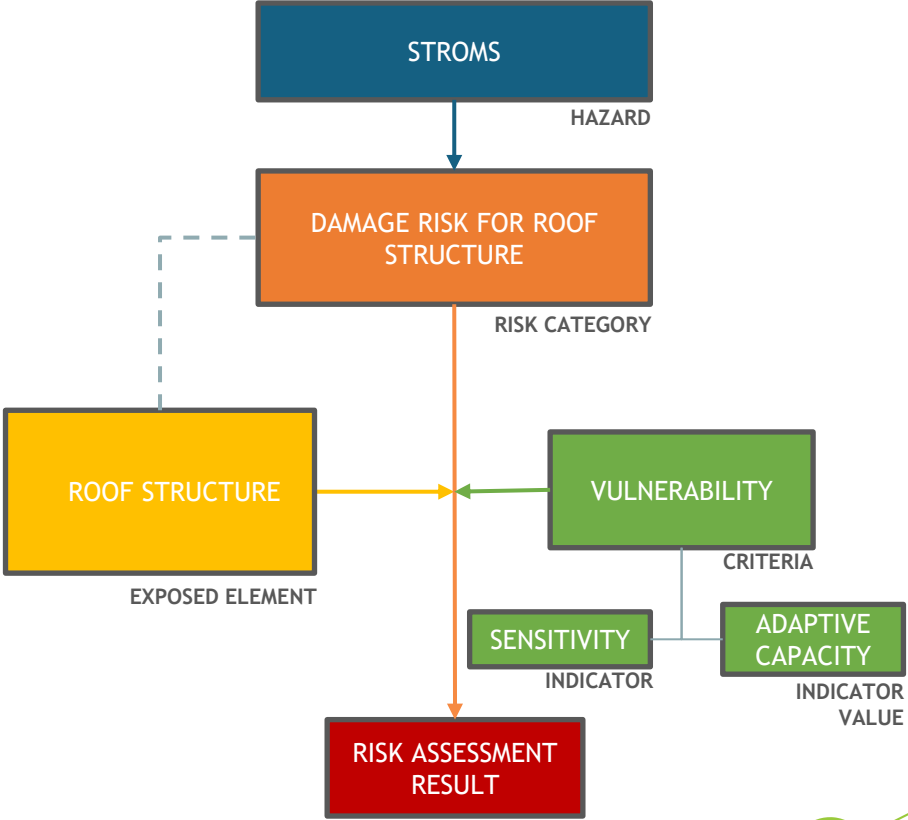
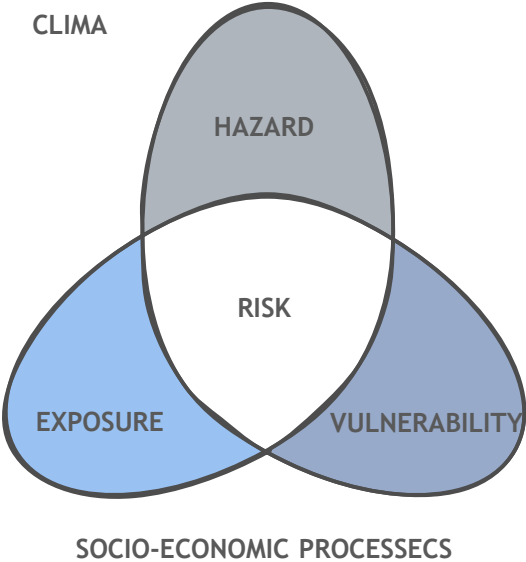
- **Exposure** - increases or decreases depending on how strongly wind pressures act on the roof (geometry, height, edges/corners, presence of rooftop equipment and extensions) and how easily wind can lift roof layers or enter through weak roof details
- **Vulnerability** - how the roof system (covering + fixings + structure + connections) maintains integrity under wind uplift, impact (hail/debris), and lightning, and whether local failures are contained without progressing into widespread structural damage or water ingress
- **Adaptation measures** - focus on a continuous uplift load path and robust detailing (especially edges/corners and penetrations), tested/certified roof systems for local design winds and hail, secure anchorage of rooftop equipment, compliant lightning protection, and structural separation of vulnerable extensions to prevent damage propagation.

# RISK ASSESSMENT FOR DAMAGE RISK FOR ROOF STRUCTURE

- **Hazard:**  
Storms
- **Exposed element:**  
Roof structure

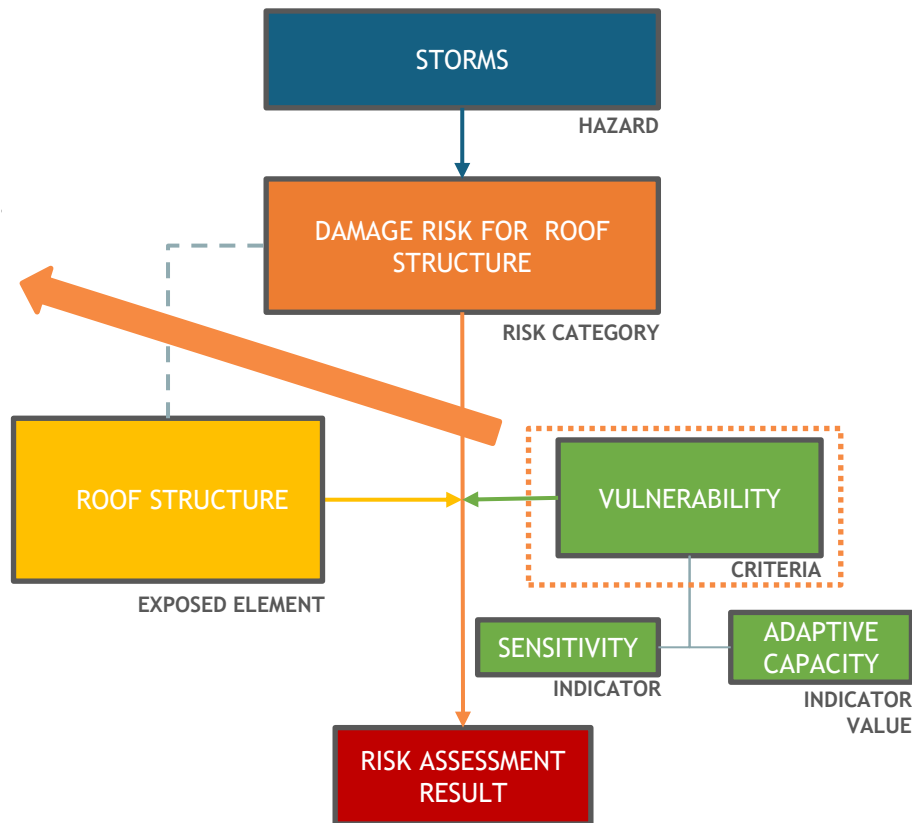


# IMPACT CHAIN



# CRITERIA

| E5.1 Roof Structure                                  | INDICATOR                                                                       |
|------------------------------------------------------|---------------------------------------------------------------------------------|
| E5.1.1 Storm-Resilient Roof Structure                | Wind load capacity of the roof structure                                        |
| E5.1.2 Wind Uplift Resistance                        | Resistance of roof materials to wind uplift forces                              |
| E5.1.3 Steel-Reinforced Fireplaces/Chimneys for Wind | Quality and share of chimneys/fireplaces reinforced                             |
| E5.1.4 Hail-Resistant Roofing                        | Impact resistance of roof elements against hail                                 |
| E5.1.5 Lightning Protection of Rooftop Equipment     | Compliance with lightning protection standards                                  |
| E5.1.6 Non-Continuity of the Structure               | Physical non-continuity between the main roof structure and attached extensions |



## E5.1.1 STORM-RESILIENT ROOF STRUCTURE

### Description:

This criterion evaluates the wind load capacity of the roof structure to ensure it can withstand storm wind pressures without structural damage or failure, reducing risk to building occupants and maintaining functionality during and after storms.

### Objective:

To ensure the roof's primary structural system and its connections (e.g., rafters/trusses, purlins, decking support, anchors and hold-downs) have sufficient wind load capacity to resist storm-related wind pressures without structural damage or failure, thereby protecting occupants and maintaining building functionality during and after extreme wind events.

### Relevance:

With more frequent and severe storms, roof uplift and suction pressures—especially at edges and corners—can trigger progressive failures, water ingress, and major disruption to building operation. Verifying adequate roof wind load capacity in line with EN 1991-1-4 and local design wind speeds is a key resilience measure that reduces safety risks, limits damage and downtime, and supports continuity of use under storm conditions.

## E5.1.1 STORM-RESILIENT ROOF STRUCTURE

### Indicator:

Wind load capacity of the roof structure, expressed in  $\text{kN/m}^2$ , representing the verified maximum wind pressure (including uplift/suction where governing) that the roof structural system and critical connections can resist without structural failure, based on structural design calculations and wind load assessment according to EN 1991-1-4 and local design wind parameters.

### Benchmarks: HIB

Critical value (1): Wind load capacity  $< 1.0 \text{ kN/m}^2$

Optimal value (0): Wind load capacity  $\geq 2.5 \text{ kN/m}^2$

### Calculation:

The indicator is determined as the certified/verified wind load capacity ( $\text{kN/m}^2$ ) of the roof structure derived from structural design documentation and wind action calculations in accordance with EN 1991-1-4. The reported value should represent the governing (lowest) verified resistance among critical roof zones (typically edges/corners) and critical components/connections along the load path, relative to the site's local design wind conditions.

## E5.1.1 STORM-RESILIENT ROOF STRUCTURE

### CALCULATION STEP-BY-STEP

- Obtain structural design documentation and wind load assessment reports demonstrating roof wind actions and resistances in accordance with EN 1991-1-4, including local design wind speed assumptions and exposure/terrain settings.
- Confirm roof geometry and relevant wind pressure coefficients/zones (field, edge, corner) used in the assessment and identify whether uplift/suction governs the design.
- Identify the critical roof structural components and connections forming the complete load path (roof deck/supports → purlins/rafters/trusses → bearings/walls → anchors/hold-downs) and extract their verified wind pressure resistance limits.
- Determine the governing wind load capacity ( $\text{kN/m}^2$ ) as the minimum verified resistance among the critical roof zones and the weakest controlling element/connection (often anchors/hold-downs or edge/corner zone design).
- Verify that the calculated/declared capacity aligns with construction documentation and (where available) site inspection records confirming the installed roof structure and fixings match the design (structural drawings, specifications, calculation reports, product certificates).

## E5.1.2 WIND UPLIFT RESISTANCE

### Description:

This criterion evaluates the resistance of roof materials and their anchoring systems to uplift forces caused by wind during storms, reducing the risk of roof covering detachment and damage.

### Objective:

To ensure roof covering materials and their anchoring/fixing systems (e.g., membranes, tiles, sheets, fasteners, adhesives, ballast) provide reliable resistance to wind uplift forces during storms, preventing detachment of roof layers and maintaining the roof's protective function and building integrity.

### Relevance:

During high-wind events, roof coverings are often the first elements to fail due to suction pressures, especially at roof edges and corners. Detachment can rapidly escalate to water ingress, debris hazards, damage to the structural roof deck, and major disruption to building operation. Using tested, certified uplift-resistant roof systems—properly installed for local design wind speeds—is therefore a critical resilience measure that reduces storm damage, improves safety, and supports continuity of use.

## E5.1.2 WIND UPLIFT RESISTANCE

### Indicator:

Resistance of roof materials to wind uplift forces (qualitative), reflecting whether the roof covering system and its anchoring/attachment method are tested, certified, and correctly installed to withstand wind uplift pressures appropriate to local design wind speeds and roof zone effects (field/edge/corner).

### Benchmarks:

Critical value (1): Roof materials lack uplift resistance or certification, or show significant installation deficiencies, implying high failure risk.

Optimal value (0): Roof materials and anchoring systems are tested and certified for wind uplift resistance appropriate to local design wind speeds, with robust, verified installation.

### Calculation:

The indicator is determined through a documentation and inspection-based verification of: (1) whether the specified roof covering system (including all components and fixings) has valid wind uplift test evidence/certification for the relevant wind hazard conditions, and (2) whether installation quality and detailing on site match the certified system requirements. The outcome is reported qualitatively by comparing the verified evidence against the benchmark definitions.

## E5.1.2 WIND UPLIFT RESISTANCE

### CALCULATION STEP-BY-STEP

- Compile roof system information: roof covering type, build-up, fixing/anchoring method, roof geometry and critical zones (field/edge/corner), and local design wind speed context used for design.
- Review product/system test reports and certifications (supplier test data, third-party certificates) demonstrating wind uplift resistance for the complete roof system (covering + insulation + substrate interface + fasteners/adhesives/ballast), appropriate to the site wind conditions.
- Confirm that certifications/tests are applicable to the installed configuration (substrate type, fastener pattern/density, adhesive type/coverage, seam/weld details, edge restraint details, parapets/terminations).
- Verify installation quality using quality control documentation and site inspection reports (or site inspection where available), checking critical failure points: edge/corner detailing, terminations, penetrations, seam integrity, fastener spacing, adhesive curing/coverage, and compatibility of components.
- Assign the qualitative result by matching evidence to benchmarks.

## E5.1.3 STEEL-REINFORCED FIREPLACES/CHIMNEYS FOR WIND

### Description:

This criterion evaluates the quality and share of fireplaces and chimneys that are steel-reinforced to improve their resistance to wind loads during storms, reducing the risk of detachment or collapse.

### Objective:

To ensure fireplaces and chimneys are adequately steel-reinforced and properly detailed/installed to resist storm wind loads, reducing the likelihood of cracking, detachment, overturning, or collapse of these typically slender roof-level elements and preventing associated hazards.

### Relevance:

Chimneys and fireplace stacks are exposed elements that experience high wind pressures and vibration effects, especially above roof level where wind speeds increase. Failures can create serious life-safety risks (falling masonry/debris), damage roof coverings and structural elements, and lead to water ingress and operational disruption.

## E5.1.3 STEEL-REINFORCED FIREPLACES/CHIMNEYS FOR WIND

### Indicator:

Quality and share of chimneys/fireplaces reinforced (qualitative), reflecting whether all fireplaces/chimneys are steel-reinforced and anchored in accordance with local wind load requirements, and whether reinforcement detailing and installation quality are verified (reinforcement continuity, anchorage, connections at roof interface, and workmanship).

### Benchmarks:

Critical value (1): No reinforcement or significant deficiencies present, implying high failure risk during storms.

Optimal value (0): All fireplaces/chimneys are steel-reinforced in accordance with local wind load requirements, with verified quality of detailing and installation.

### Calculation:

The indicator is determined through documentation and inspection-based verification of the presence, extent (share), and quality of steel reinforcement in chimneys/fireplaces relative to local wind load requirements. Evidence from structural design and reinforcement detailing is checked against as-built installation records/inspections. The outcome is reported qualitatively by matching the verified condition to the benchmark definitions.

## E5.1.3 STEEL-REINFORCED FIREPLACES/CHIMNEYS FOR WIND

### CALCULATION STEP-BY-STEP

- Identify and inventory all fireplaces/chimneys on the building (location, type, height above roof, material, and any attachments/bracing).
- Review structural design documentation and wind load basis for these elements (local wind load requirements and relevant design assumptions), and extract reinforcement requirements for each chimney/fireplace.
- Check reinforcement detailing drawings for the specified steel reinforcement arrangement (bar sizes/spacing, vertical and horizontal reinforcement, confinement/ties, continuity, laps, corrosion protection where relevant) and anchorage/connection details to the roof/structure (base anchorage, straps, brackets, tie-ins).
- Verify the share reinforced: confirm whether reinforcement is present in all chimneys/fireplaces and whether the installed configuration matches the design intent, using site inspection reports and construction quality control documentation (photos, checklists, as-built notes).
- Assess the quality of detailing and installation by focusing on typical failure points: reinforcement continuity at transitions, anchorage at base, roof penetration detailing, restraint against lateral movement, cracking/signs of poor workmanship, and compliance with specified materials and dimensions.
- Assign the qualitative result by matching evidence to benchmarks.

## E5.1.4 HAIL-RESISTANT ROOFING

### Description:

This criterion evaluates the impact resistance of roof elements against hail to minimise damage, water ingress, and repair needs during hailstorms.

### Objective:

To promote the selection and proper installation of roofing elements with verified hail impact resistance, so the roof can withstand hailstorms with minimal damage, preventing punctures/cracking and reducing the likelihood of water ingress and the need for emergency repairs.

### Relevance:

Roofs are increasingly exposed to impact damage from hail storms that can compromise waterproofing, insulation performance, and overall building durability. Hail damage can lead to rapid deterioration, leaks, mould risk, and significant repair costs and downtime. Using tested and certified hail-resistant roof elements—installed in a robust manner—supports resilient building operation, limits storm-related losses, and maintains occupant safety and comfort.

## E5.1.4 HAIL-RESISTANT ROOFING

### Indicator:

Impact resistance of roof elements against hail (qualitative), reflecting whether the installed roof elements (e.g., coverings, membranes, skylights/rooflights, insulation cover boards, protective layers) are tested and certified for hail impact resistance according to applicable standards and whether installation quality ensures the roof build-up performs as intended under hail exposure.

### Benchmarks:

Critical value (1): Roof elements are not hail-resistant or lack certification/testing, implying high damage risk during hailstorms.

Optimal value (0): Roof elements are tested and certified for high hail impact resistance, with robust installation ensuring protection against severe hail.

### Calculation:

The indicator is determined through documentation and inspection-based verification of evidence of hail impact performance for the installed roof elements. Product certificates and supplier technical data are checked to confirm compliance with applicable hail-impact standards, and installation-quality documentation/site inspections are used to confirm that the installed system matches the tested/certified configuration. The outcome is reported qualitatively by comparing verified evidence against the benchmark definitions.

## E5.1.4 HAIL-RESISTANT ROOFING

### CALCULATION STEP-BY-STEP

- Identify the roof elements relevant to hail vulnerability (roof covering type, membranes, rooflights/skylights, flashings, protective layers/cover boards, exposed insulation, and accessories), including their locations and exposure.
- Collect manufacturer test certificates and supplier technical data sheets confirming hail impact resistance and the applicable test standard/classification (e.g., EN 13583 or equivalent) for each relevant roof element/system.
- Verify applicability of the certification to the installed configuration (product variant, thickness, substrate/support layer, fastening method, seams/joints, and any protective layers) and confirm that the certified performance corresponds to the expected local hail severity (where local guidance exists).
- Review installation quality documentation and site inspection reports (or conduct inspection where available) to confirm robust detailing and workmanship at typical weak points: joints/seams, terminations, penetrations, rooflights, edges, and transitions.
- Check for evidence of deviations from certified configurations (unapproved substitutions, incorrect thickness, inadequate support, poor fixing patterns) that could reduce impact resistance in practice.
- Assign the qualitative result by matching evidence to benchmarks.

## E5.1.5 LIGHTNING PROTECTION OF ROOFTOP EQUIPMENT

### Description:

This criterion evaluates the compliance of rooftop equipment (e.g., HVAC units, antennas, solar panels) with lightning protection standards to reduce the risk of damage and hazards during storms.

### Objective:

To ensure all rooftop equipment (e.g., HVAC units, antennas, PV systems, roof-mounted controls) is integrated into a compliant lightning protection and grounding system, minimising the risk of lightning-related damage, fire, electric shock hazards, and loss of critical building services during storms.

### Relevance:

Rooftop equipment is highly exposed and can act as a strike point or a pathway for surge currents into the building. Without proper air-termination, bonding, surge protection, and verified grounding, lightning can damage equipment, cause fires, disrupt power and communications, and create hazards for occupants and maintenance staff. Ensuring compliance with lightning protection standards strengthens storm resilience, supports continuity of operation, and reduces repair costs and safety risks.

## E5.1.5 LIGHTNING PROTECTION OF ROOFTOP EQUIPMENT

### Indicator:

Compliance with lightning protection standards (qualitative), reflecting whether all rooftop equipment is protected according to applicable lightning protection standards (e.g., lightning protection system design, bonding/equipotential connections, grounding, and—where relevant—surge protective devices), supported by verified documentation and evidence of functional grounding.

### Benchmarks:

Critical value (1): No lightning protection for rooftop equipment or significant deficiencies (e.g., missing bonding/grounding, incomplete coverage, absent certification/testing).

Optimal value (0): All rooftop equipment is protected according to lightning protection standards, with verified documentation and functional grounding.

### Calculation:

The indicator is determined through documentation and inspection-based verification of the lightning protection provisions for rooftop equipment. Design documentation and lightning protection plans are reviewed to confirm that rooftop equipment is included in the protection concept (air-termination, down conductors, bonding, grounding, and surge protection where applicable). Installation certificates and grounding test records are checked to confirm correct installation and functional performance. The outcome is reported qualitatively by matching the verified condition to the benchmark definitions.

## E5.1.5 LIGHTNING PROTECTION OF ROOFTOP EQUIPMENT

### CALCULATION STEP-BY-STEP

- Compile an inventory of all rooftop equipment requiring protection (HVAC, antennas, PV arrays/inverters, roof-mounted controls, communications equipment, metallic frames/supports, roof penetrations associated with equipment).
- Review lightning protection system (LPS) documentation and plans to confirm rooftop equipment is covered: placement of air terminals/mesh, routing of down conductors, equipotential bonding points, and the grounding arrangement.
- Verify that each item of rooftop equipment is correctly bonded to the LPS/equipotential system (bonding conductors, clamps, connections to metallic frames/rails, bonding of cable trays and metallic services) and that protection is consistent with applicable standards and the designed protection level.
- Confirm the presence of appropriate surge protection measures where relevant (e.g., SPDs on power/data lines serving rooftop equipment), based on the design documentation and installation records.
- Check installation certificates and commissioning/inspection reports confirming compliance, and review grounding test certificates (e.g., earth resistance/continuity measurements) demonstrating functional grounding.
- Use site inspection records (or site inspection where available) to verify as-built conditions: integrity of conductors, corrosion/loose connections, correct routing/protection of cables, and clear labelling/maintenance access.
- Assign the qualitative result by matching evidence to benchmarks.

## E5.1.6 NON-CONTINUITY OF THE STRUCTURE

### Description:

This criterion evaluates the physical non-continuity between the main roof structure and attached extensions (e.g., covered terrace, veranda, patio) to reduce the risk of progressive structural damage during storms.

### Objective:

To promote structural separation (non-continuity) between the main roof structure and attached extensions (e.g., covered terrace, veranda, patio), so that wind-induced movements or failures in an extension do not transfer loads into the main roof, thereby reducing the likelihood of progressive structural damage during storms.

### Relevance:

Extensions are often lighter, more exposed, and more vulnerable to wind uplift and lateral loads than the main building roof. If they are fully continuous with the main roof structure, storm loads or failure of the extension can propagate into the primary structure, causing disproportionate damage, leaks, and loss of functionality. Ensuring physical non-continuity (e.g., separation joints, independent supports, controlled connections) is a practical resilience measure that limits damage spread, improves safety, and supports faster post-storm recovery.

## E5.1.6 NON-CONTINUITY OF THE STRUCTURE

### Indicator:

Physical non-continuity between the main roof structure and attached extensions (qualitative), reflecting whether extensions are structurally independent or physically separated from the main roof structure (e.g., independent framing/supports and separation joints allowing independent movement), as verified through design documentation and site inspection.

### Benchmarks:

Critical value (1): Full continuity with the main structure, implying high risk of damage propagation during storms.

Optimal value (0): Extensions are structurally separated from the main roof, ensuring independent movement and reduced damage risk during storms.

### Calculation:

The indicator is determined through a design and inspection-based assessment of whether roof extensions are structurally independent from the main roof. Architectural and structural drawings are reviewed to identify separation details (movement joints, independent supports, discontinuous framing, controlled connections) and to confirm that loads from the extension are not directly transferred into the main roof system. Site inspection records are used to verify that the separation is implemented as designed. The outcome is reported qualitatively by matching the verified condition to the benchmark definitions.

## E5.1.6 NON-CONTINUITY OF THE STRUCTURE

### CALCULATION STEP-BY-STEP

- Identify all roof extensions (covered terraces, verandas, patios, canopies) and document their geometry, supports, and connection locations to the main building.
- Review architectural drawings and construction details to confirm the intended separation strategy (e.g., expansion/movement joint, gap with flashing, independent roof layer/covering transitions, independent drainage where relevant).
- Review structural design documentation to determine the load path of each extension (independent columns/walls/foundations vs. reliance on main roof members), and check whether framing members are continuous into the main roof or structurally discontinuous.
- Verify the connection detailing at the interface: look for evidence of independent supports and controlled/sliding connections (where required) rather than rigid, continuous structural ties that would transmit storm loads and movements.
- Use site inspection records (or site inspection where available) to confirm as-built conditions match the design: presence of separation joint/gap, correct flashing/waterproofing at the joint, and absence of unplanned rigid connections (e.g., through-bolting, continuous rafters, continuous decking).
- Assign the qualitative result by matching evidence to benchmarks.

## HAZARD LIKELIHOOD

| Hazardous event |                                                                      | Slow-on set process |                                                | Hazard Value (HV) |
|-----------------|----------------------------------------------------------------------|---------------------|------------------------------------------------|-------------------|
| Frequent        | Likely to occur often in a life time (every 10 years)                | Very likely         | Very likely to occur in the next 10 years      | 1 - 0,9           |
| Probable        | Likely to occur several times in a lifetime (every 25 years)         | Likely              | Likely to occur in the next 10 years           | 0,89 - 0,66       |
| Occasional      | Likely to occur some times in a lifetime (every 50 years)            | As likely as not    | As likely as not to occur in the next 10 years | 0,65 - 0,33       |
| Remote          | Unlikely but still possible to occur in a lifetime (every 100 years) | Unlikely            | Unlikely to occur in the next 10 years         | 0,32 - 0          |

**Hazard Value (HV)** = This information is provided by SECAPs or by experts' judgment

For example, Hazard Value (HV) = **0.8 (Probable)**

## NORMALISATION

Once all indicator values for the selected criterion are calculated, normalization converts them to a common 0-1 scale. This ensures each indicator contributes proportionately to the overall resilience score, regardless of its original unit. Normalization enables meaningful data synthesis, cross-context benchmarking, and more transparent, objective decision-making in resilience assessments.

### EXAMPLE:

For E5.1.1 Storm-Resilient Roof Structure  
with an indicator value of **1,3 kN/m<sup>2</sup>**

Where:

$X_i = 1,3$

$X_{max} = 2,5$

$X_{min} = 1$

$$x_{norm} = \frac{x_{max} - x_i}{x_{max} - x_{min}}$$

$x_{norm} = (2,5 - 1,3) / (2,5 - 1) = 0,86$  (Critical)

### NORMALISATION INTERVAL

| Normalisation values | Description                                  |
|----------------------|----------------------------------------------|
| 0,0 - 0,2            | Optimal (no improvement necessary)           |
| > 0,2 - 0,4          | Rather positive                              |
| > 0,4 - 0,6          | Neutral                                      |
| > 0,6 - 0,8          | Rather negative                              |
| > 0,8 - 1,0          | Critical (could lead to severe consequences) |

## OVERALL VULNERABILITY (VULNERABILITY VALUE - VV)

| CRITERION                                            | Normalised value | Weight |
|------------------------------------------------------|------------------|--------|
| E5.1.1 Storm-Resilient Roof Structure                | 0,5              | 0,20   |
| E5.1.2 Wind Uplift Resistance                        | 0,21             | 0,15   |
| E5.1.3 Steel-Reinforced Fireplaces/Chimneys for Wind | 0,35             | 0,15   |
| E5.1.4 Hail-Resistant Roofing                        | 0,95             | 0,10   |
| E5.1.5 Lightning Protection of Rooftop Equipment     | 0,21             | 0,10   |
| E5.1.6 Non-Continuity of the Structure               | 0,4              | 0,20   |

Normalised score  Weight 

$$VV = \sum_{i=1}^n (I_i \times W_i)$$

$$VV = 0,50 \times 0,20 + 0,21 \times 0,15 + 0,35 \times 0,15 + 0,95 \times 0,10 + 0,21 \times 0,1 + 0,4 \times 0,2 = 0,38$$

Vulnerability Value (VV) = 0,38

Vulnerability Level =  
**RATHER POSITIVE**