The Catalonia Institute of Construction Technology

# ITeC CRITERIA

## Simplified calculation procedure for verifying the glued connection in external wall cladding systems for ventilated façades

Image by SIKA SAU

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# 1. Introduction

Verification of glued connection is a fundamental factor in ventilated façade systems in which the cladding element (panel) is glued to the metallic profile of the subframe (typically composed of vertical profiles and brackets fixed to the supporting structure). This glued connection consists of an adhesive system, mainly composed of the adhesive bead and the primer for the pre-treatment of the surfaces to be connected (other ancillary components such as foam tape and surface cleaning agents may also be part of the adhesive system).

Procedures to perform this verification, even if they are relatively simple, can only be found in each adhesive manufacturer's technical documentation. This procedure has not yet been established in a generalised way and considering the Spanish regulation.

Having been detected this need and based on the acquired experience in ITeC on this type of façade systems assessment, here is provided a simplified calculation procedure for verifying the glued connection in external wall cladding systems.

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## 2. Scope

This document has been developed to be applied in ventilated façade external wall cladding systems composed of discontinuous elements (panels, boards, tiles, slabs, lamas, etc.) fixed by means of an adhesive system to a metallic vertical profile.

The calculation procedure hereafter developed for the glued connection is only part of the verifications that must be done on a ventilated façade external wall cladding system. Therefore, resistance and stability of the following components have not been considered here:

- Cladding elements.
- Subframe vertical profiles.
- Subframe brackets.
- When relevant, ancillary mechanical cladding fixings.
- Mechanical fixings between the profiles and the brackets.
- Anchorage between the brackets and the supporting structure.
- Supporting structure.

# 3. Adhesive system for external wall claddings in ventilated façade

An adhesive system for external wall claddings in a ventilated façade is composed of the following components (see figure 3.1):

1. Adhesive: paste generally based on silane modified polymers, polyurethanes, silicones or hybrid polymers.

   An adhesive must be specified by:

   - type of material,
   - minimum bead dimensions (minimum thickness and minimum width),
   - its physical properties: density or specific mass, shrinkage, hardness, flow resistance, thermogravimetric analysis, etc., and,
   - its design mechanical properties: tensile stress, static shear stress, elastic modulus and displacement under dynamic shear stress.

2. Pre-treatment:

   - Primer: liquid product applied on the cladding element and profile surfaces to be bonded to improve the adherence.
   - Cleaning agent: generally liquid and volatile product used to clean the cladding element and profile surfaces to be bonded.

   Pre-treatment products must be specified by considering the product and material type of the surfaces on which the use is intended.

3. <u>Two-sided foam tape</u>: tape with a double purpose; on the one hand, it is used for the initial fastening of cladding elements until the adhesive cures completely and on the other hand, it is used to assure the correct adhesive bead thickness.

   The foam tape must be specified by the type of material and its dimensions.

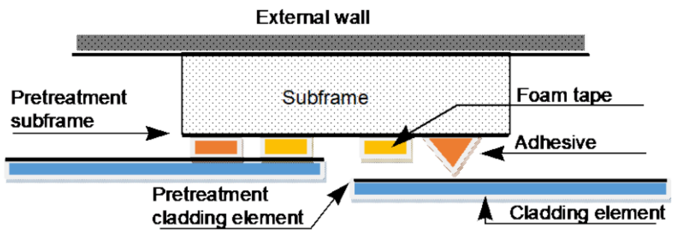



Figure 3.1: Adhesive system composition.

Mechanical properties of an adhesive system must be defined and provided by the manufacturer.

This definition must be based on the values obtained by tests following the harmonised methodologies established in the reference documents at European level for this type of systems. E.g. EAD 250005-00-0606 *Adhesive for wall cladding* or the future EAD on *Kits for external wall claddings glued to the subframe.*

If a manufacturer of an adhesive system has the corresponding ETA (European Technical Assessment) available, based on any of the EAD documents indicated in the previous paragraph, all the necessary data for the calculation will be contained in such ETA document.

It is very important to consider that design values defined by the manufacturers are values based on the premise that the glued connection failure is due to adhesive cohesion and never due to adherence between the adhesive and the cladding element or due to substrate (cladding element or profile) cohesion. This is the main role of the primer of an adhesive system in the glued connection final behaviour.

To ensure the adherence, manufacturers carry out peel-tests on all the surfaces types on which the adhesive is intended to be used. These peel-tests must also be carried out after accelerated ageing cycles on the specimens.

# 4. Calculation of the glued connection

The resistance of the glued connection to the following actions must be verified:

- Dead load (see clause 4.1).
- Wind load (see clause 4.2).
- Load for movements due to environmental conditions (see clause 4.4).

A calculation example of the glued connection resistance is given in Annex 1.

## 4.1. Dead load

Calculations to verify the resistance of the glued connection due to the cladding element dead load must be carried out for each project.

The design limit value to be considered in these calculations is the shear stress design value ($\tau_{des}$) defined by the manufacturer, value that has to be assessed considering the shear static load test results for the glued connection, indicated in the harmonised procedures at European level.

For the calculations, the following equations can be used depending on the value to be determined:

- maximum acceptable dead load (eq.1), or
- minimum bead width (eq.2).

$$Q_{pp} \cdot \gamma_{pp} \leq \frac{\tau_{cal} \cdot b_{min} \cdot N_b \cdot \gamma_1}{L_{clad}} \cdot 10^5 \qquad \text{(eq.1)}$$

$$b_{min} \geq \frac{Q_{pp} \cdot \gamma_{pp} \cdot L_{clad}}{\tau_{cal} \cdot N_b \cdot \gamma_1} \cdot 10^{-5} = b_{shear} \qquad \text{(eq.2)}$$

Where:

- $Q_{pp}$ (in kg/m²) = cladding element maximum dead load.
- $b_{min}$ (in mm) = minimum width of the bead.
- $b_{shear}$ (in mm) = width due to shear stress on the bead.
- $\tau_{cal}$ (in MPa) = calculation value of the permanent shear strength:

$$\tau_{cal} = \tau_{des} \cdot \gamma_t \cdot \gamma_{age} \qquad \text{(eq.3)}$$

- $\tau_{des}$ (in MPa) = design value of the permanent shear strength defined by the manufacturer.

- $\gamma_t$ = reduction factor depending on the intended use temperature. To be defined by the manufacturer or stated from test values according to procedures established at European level.

- $\gamma_{age}$ = freduction factor due to other ageing conditions (fatigue, freeze-thaw, etc.). To be defined by the manufacturer or stated from test values according to procedures established at European level.

- $N_b$ = total number of beads (bond-lines) per cladding element. It is important to take into account that profiles could include one or two adhesive beads (bond-lines).

- $L_{clad}$ (in mm) = cladding element length. Dimension perpendicular to the beads (bond-lines).

- $\gamma_1$ = reduction factor due to effective adherence.

$$\gamma_1 = \frac{h_{eff}}{H_{clad}} \qquad \text{(eq.4)}$$

- $h_{eff}$ (in mm) = applied length of the beads.

- $H_{clad}$ (in mm) = cladding element width. Dimension parallel to the beads (bond-lines).

- $\gamma_{pp}$ = dead load safety factor. According to DB SE from CTE (Spanish regulation); $\gamma_{pp}$ = 1,35.

## 4.2. Wind suction load

Calculations to verify the resistance of the glued connection due to the wind suction load must be carried out for each project.

The design limit value to be considered in these calculations is the tensile stress design value ($\sigma_{des}$) defined by the manufacturer, value that has to be assessed considering the tensile stress test results for the glued connection, indicated in the harmonised procedures at European level.

For the calculations, the following equations can be used depending on the value to be determined:

A. maximum admissible wind suction load, for:

- the scenario with two profiles per cladding element (see figure 4.1a) or external profiles (eq.5a), or
- the scenario with three or more profiles per cladding element (see figure 4.1b) (eq.5c), or

B. minimum bead width, for:

- the scenario with two profiles per cladding element (see figure 4.1a) or external profiles (eq.6a), or
- the scenario with three or more profiles per cladding element (see figure 4.1b) (eq.6c).

$$(Q_e \cdot \gamma_Q)_{ext} \leq \frac{\sigma_{cal} \cdot b_{min} \cdot n_{b\text{-}ext} \cdot \gamma_1}{K_{ext} \cdot l_b + l_{ext}} \cdot 10^3 \qquad \text{(eq.5a)}$$

$$(Q_e \cdot \gamma_Q)_{int} \leq \frac{\sigma_{cal} \cdot b_{min} \cdot n_{b\text{-}int} \cdot \gamma_1}{K_{int} \cdot l_p} \cdot 10^3 \qquad \text{(eq.5b)}$$

$$Q_e \cdot \gamma_Q \leq \min\left[\ \text{(eq.5a)}\ ;\ \text{(eq.5b)}\ \right] \qquad \text{(eq.5c)}$$

$$(b_{min})_{ext} \geq \frac{Q_e \cdot \gamma_Q \cdot (K_{ext} \cdot l_p + l_{ext})}{\sigma_{cal} \cdot n_{b\text{-}ext} \cdot \gamma_1} \cdot 10^{-3} \qquad \text{(eq.6a)}$$

$$(b_{min})_{int} \geq \frac{Q_e \cdot \gamma_Q \cdot K_{int} \cdot l_p}{\sigma_{cal} \cdot n_{b\text{-}int} \cdot \gamma_1} \cdot 10^{-3} \qquad \text{(eq.6b)}$$

$$b_{min} \geq \max \left[ \text{(eq.6a)} ; \text{(eq.6b)} \right] = b_{str} \qquad \text{(eq.6c)}$$

Where:

- $Q_e$ (in kN/m²) = wind suction load.

- $K_{ext}$ or $K_{int}$ = constant depending on the number of profiles (see table 4.1).

| Scenario | $K_{ext}$ | $K_{int}$ |
|---|---|---|
| 2 profiles | 0,50 | --- |
| 3 profiles | 0,375 | 1,25 |
| 4 o more profiles | 0,40 | 1,10 |

**Table 4.1:** Equation constants depending on the number of profiles.

- $b_{min}$ (in mm) = minimum width of the bead.

- $b_{str}$ (in mm) = width of the bead due to tensile stress load.

- $\sigma_{cal}$ (in MPa) = tensile stress calculation value:

$$\sigma_{cal} = \sigma_{des} \cdot \gamma_t \cdot \gamma_{age} \qquad \text{(eq.7)}$$

- $\sigma_{des}$ (in MPa) = tensile stress design value defined by the manufacturer.

- $\gamma_t$ = reduction factor depending on the intended use temperature. To be defined by the manufacturer or stated from test values according to procedures established at European level.

- $\gamma_{age}$ = reduction factor due to other ageing conditions (fatigue, freeze-thaw, etc.). To be defined by the manufacturer or stated from test values according to procedures established at European level.

- $n_{b\text{-}ext}$ = number of beads (bond-lines) by extreme profile.

- $n_{b\text{-}int}$ = number of beads (bond-lines) by intermediate profile.

- $l_p$ (in mm) = distance (span) between vertical profiles.

- $l_{ext}$ (in mm) = distance between the extreme profile and the cladding element border. Dimension perpendicular to beads (bond-lines).

- $\gamma_1$ = reduction factor due to effective adherence (see eq.4).

- $h_{eff}$ (in mm) = applied bead length.

- $H_{clad}$ (in mm) = cladding element width. Dimension parallel to beads (bond-lines).

- $\gamma_Q$ = wind load safety factor. According to DB SE from CTE; $\gamma_Q$ = 1,50.

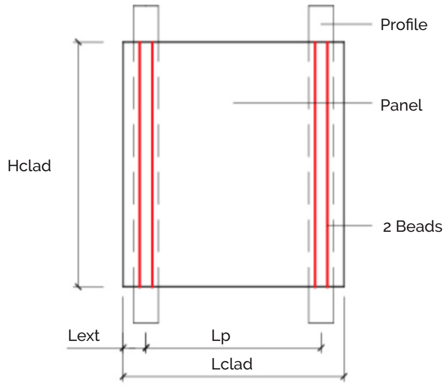
## 4.3. Weight and wind combination verification

Dead load and wind action combination is verified according to the bead minimum width data obtained from equations eq.2 and eq.6c.

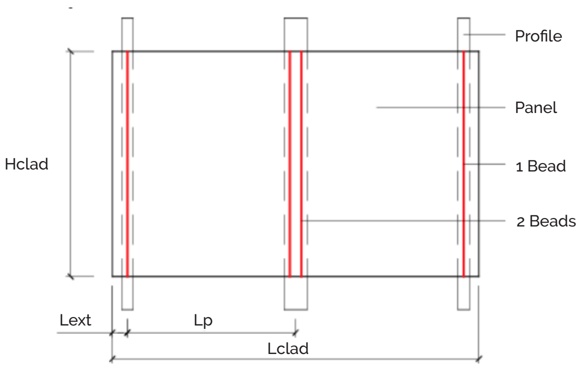
$$b_{min} \geq b_{total} = \sqrt{b^2_{shear} + b^2_{str}} \qquad \text{(eq.8)}$$

**Figure 4.1:** Possible bead layouts on vertical profiles.

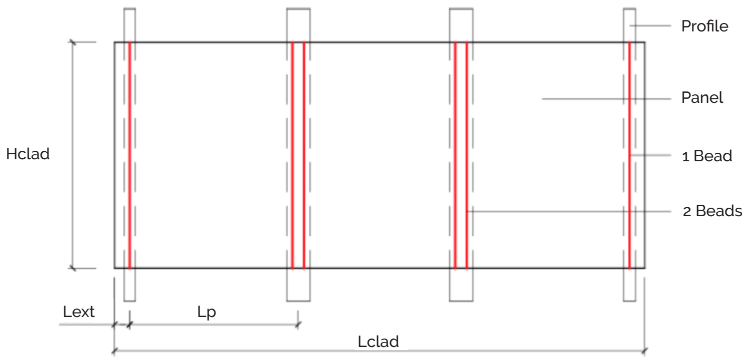
(a) Two profiles per cladding element with two beads per profile



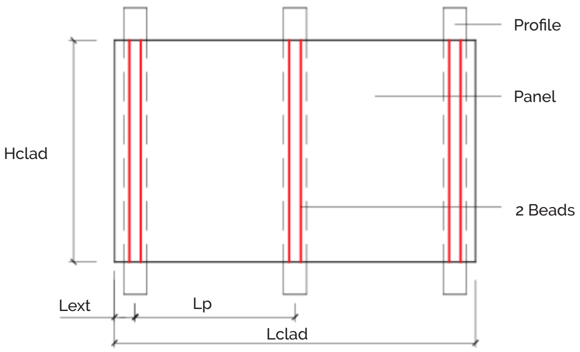

(b) Three profiles per cladding element with one bead in the extreme profiles



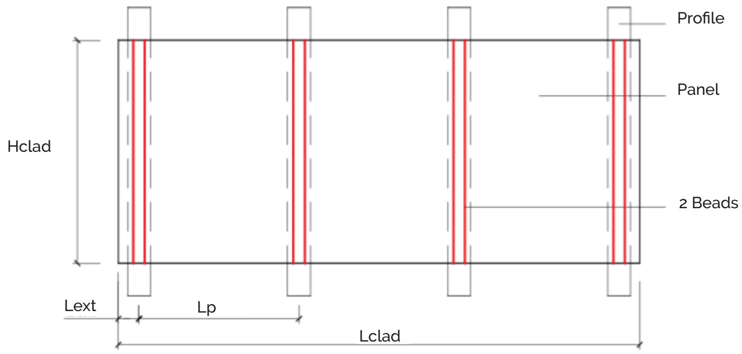

(c) Four or more profiles per cladding element with one bead in the extreme profiles




(d) Three profiles per cladding element with two beads in the extreme profiles




(e) Four or more profiles per cladding element with two beads in the extreme profiles



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## 4.4. Actions due to environmental conditions

Air temperature and humidity variations (relative humidity or humidity due to rain), may cause differential movements in cladding elements and vertical profiles, which must be absorbed by the glued connection shear displacement.

The design limit value to be considered in these calculations is the shear displacement design value ($d_{s,des}$) to be defined by the manufacturer by considering ($d_{s,C\_lim}$ afrom shear stress tests, or $\Delta L_{t,des}$ from tensile stress tests), value that must be assessed considering the shear stress test or the tensile stress test results for the glued connection, indicated in the harmonised procedures at European level.

For displacement calculation, the following equation can be used (eq.9a)[1].

$$d_s \geq \sqrt{\Delta L^2_v + \Delta L^2_h} \qquad \text{(eq.9a)}$$

Value "$d_{s,des}$" can be obtained from one of the following methods:

- Method 1: by considering shear stress tests with uniformly applied shear load[2].

$$d_s = d_{s,des} = 40\% \times d_{s,C\_lim} \qquad \text{(eq.9b)}$$

- Method 2: by considering trigonometry movements (see the justification in Annex 2).

$$d_s^2 = (t + \Delta L_{t,des})^2 - t^2 \qquad \text{(eq.9c)}$$

1 When considered as necessary by the designer, under the support of the manufacturer, displacements combination indicated in the equation (eq.9a) may be neglected, which means that this may be verified independently: $d_s \geq \Delta L_v$ and $d_s \geq \Delta L_h$.

2 Method based on the KOMO® specification document, clause 4.1.3 of BRL 4101, section 7.

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Where:

- $d_s$ (in mm) = limit value for the absolute shear displacement of the adhesive.

- $d_{s,des}$ (in mm) = design value for the shear displacement of the adhesive. Value to be defined or provided by the adhesive manufacturer.

- $d_{s,C\_lim}$ (in mm) = characteristic value of the shear displacement corresponding to the limit of the elastic field of the glued connection. Value to be obtained from shear stress test when the value "$d_{s,des}$" has not been defined or provided by the manufacturer.

- $\Delta L_v$ (in mm) = vertical differential displacement.

- $\Delta L_h$ (in mm) = horizontal differential displacement.

- $\Delta L_{t,des}$ (in mm) = design value of the tensile deformation corresponding to the limit of the elastic field of the glued connection. Value to be defined or provided by the adhesive manufacturer

- t (in mm) = adhesive bead thickness.

The differential displacements $\Delta L_v$ and $\Delta L_h$ depend on the cladding elements and vertical profiles linear thermal expansion values, as well as the dimensional variation due to changes in environmental relative humidity for specific cladding element materials (e.g. HPL laminated, agglomerated stone, etc.).

$$\Delta L_v = \left| \Delta L_{v,T^a} \pm \Delta L_{v,RH} \right| \qquad \text{(eq.10a)}$$

$$\Delta L_h = \left| \Delta L_{h,T^a} \pm \Delta L_{h,RH} \right| \qquad \text{(eq.10b)}$$

*Note: Positive sign (+) indicates the worst case, movements in opposite directions. Negative sign (-) indicates the best case, movements in the same direction.*

In the case of linear thermal expansion, differential displacements can be calculated according to the following equations:

$$\Delta L_{v,T^a} = \left| \left[ (\alpha_{clad} \cdot \Delta T_{clad}) - (\alpha_p \cdot \Delta T_p) \right] \cdot \frac{H_{clad}}{2} \right| \quad \text{(eq.11a)}$$

$$\Delta L_{h,T^a} = \left| \left[ (\alpha_{clad} \cdot \Delta T_{clad}) - (\alpha_w \cdot \Delta T_w) \right] \cdot \frac{L_{clad}}{2} \right| \quad \text{(eq.11b)}$$

*Note: Negative sign (-), movements in the same direction, due to temperature in both cases.*

Where:

- $L_{clad}$ (in mm) = cladding element length. Dimension perpendicular to the beads (bond-lines).
- $H_{clad}$ (in mm) = cladding element width. Dimension parallel to the beads (bond-lines).
- $\alpha_{clad}$ (in mm/(mm · °C) = cladding element linear thermal expansion coefficient.
- $\alpha_p$ (in mm/(mm · °C) = profile linear thermal expansion coefficient.
- $\alpha_w$ (in mm/(mm · °C) = external wall linear thermal expansion coefficient.
- $\Delta T_{clad}$ (in °C) = cladding element temperature difference.

$$\Delta T_{clad} = T_{0,clad} - T_{1,clad} \quad \text{(eq.12)}$$

- $\Delta T_p$ (in °C) = profile temperature difference.

$$\Delta T_p = T_{0,p} - T_{1,p} \quad \text{(eq.13)}$$

- $\Delta T_w$ (in °C) = external wall temperature difference.

$$\Delta T_w = T_{0,w} - T_{1,w} \quad \text{(eq.14)}$$

- $T_{0,i}$ (in °C) = temperature in the cladding element, profile or external wall, when the adhesive is applied. As a reference, $T_{0,i}$ = 10 °C, may be considered, assembly temperature according to clause 3.4.2 from DB SEAE from CTE (Spanish regulation).

- $T_{1,i}$ (in °C) = cladding element, subframe or external wall service temperature. As a reference, the criteria indicated in clause 3.4.2 from DB SE-AE from CTE (Spanish regulation) may be considered.

In case of cladding element movements due to dimensional variation caused by fluctuations in environmental relative humidity, differential displacements can be calculated according to the following equations:

$$\Delta L_{v,RH} = VD_v \cdot \frac{H_{clad}}{2} \qquad \text{(eq.15a)}$$

$$\Delta L_{h,RH} = VD_h \cdot \frac{L_{clad}}{2} \qquad \text{(eq.15b)}$$

Where:

- $VD_v$ (in mm/m) = cladding element cross dimensional variation due to humidity.

- $H_{clad}$ (in m) = cladding element width. Dimension parallel to the beads (bond-lines).

- $VD_h$ (in mm/m) = cladding element longitudinal dimensional variation due to humidity.

- $L_{clad}$ (in m) = cladding element length. Dimension perpendicular to the beads (bond-lines).

Depending on the external wall cladding system final design, some movements can be neglected. E.g. wall horizontal movement when it includes movement joints.

# Annex 1 - Example for glued connection calculation

## A.1.1. Input data

External wall cladding system in ventilated façade that includes HPL Panel (acc. to EN 438-7) and aluminium subframe. Components data are:

- Adhesive system:
    - Adhesive bead minimum thickness: $t_{min}$ = 3 mm.
    - Adhesive bead minimum width: $b_{min}$ = 12 mm.
    - Tensile design stress: $\sigma_{des}$ = 0,15 MPa.
    - Shear design stress: $\tau_{des}$ = 0,12 MPa.
    - Design displacement: $\Delta L_{t,des}$ = 1,0 mm.
    - Reduction factor by temperature: $\gamma_t$ = 0,60.
    - Reduction factor by other ageing: $\gamma_{age}$ = 0,10 (shear); $\gamma_{age}$ = 0,50 (tensile).
    - Reduction factor by effective adherence (see eq.4): $\gamma_1$ = 1,0.
- HPL Panel:
    - Thickness: $t_{clad}$ = 10 mm.
    - Density: $\rho_{clad}$ = 1500 kg/m$^3$.
    - Dimensional stability due to humidity: $VD_h = VD_v$ = 0,25% = 2,5 mm/m.
    - Cladding element movements due to temperature are neglected: $\alpha_{clad}$ = 0.

• TCladding element temperature when applying the adhesive:
$T_{0,clad}$ = 10 °C (value from clause 3.4.2 DB SE-AE CTE).

• Cladding element service temperature:
$T_{1,clad}$ = 76 °C = 46 °C (value for Zone 4, clause 3.4.2 DB SEAE CTE) + 30 °C (incremental term due to solar radiation when a light cladding element is southoriented, clause 3.4.2 DB SE-AE CTE).

- Aluminium profile:

• Thermal expansion coefficient: $\alpha_p$ = 23 μm/(m · °C)

• Profile temperature when applying the adhesive:
$T_{0,p}$ = 10 °C (value from clause 3.4.2 DB SE-AE CTE).

• Profile service temperature: $T_{1,p}$ = 46 °C (value for Zone 4, clause 3.4.2 DB SE-AE CTE). No incremental radiation term is considered due to its location inside the chamber and thus, exposed to shadow.

Other system data:

- External wall movements due to temperature: $\alpha_w$ = 0.

- Wind suction load: $Q_e$ = 2,5 kN/m$^2$ (estimated value for very exposed conditions).

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## A.1.2. Dimensional limit of the panel subject to humidity and temperature variations

(eq.11a) $\Delta L_{v,T^{o}} = (0 \times (76\text{–}10) - 23{\cdot}10^{-6} \times (46\text{–}10)) \times H_{clad}/2 = 4{,}14{\cdot}10^{-4} \times H_{clad}$ [mm]

(eq.11b) $\Delta L_{h,T^{a}} = (0 \times (76\text{–}10) - 0) \times L_{clad}/2 = 0 \times L_{clad}$ [mm]

(eq.15a) $\Delta L_{v,HR} = 2{,}5{\cdot}10^{-3} \times H_{clad}/2 = 1{,}25{\cdot}10^{-3} \times H_{clad}$ [mm]

(eq.15b) $\Delta L_{h,HR} = 2{,}5{\cdot}10^{-3} \times L_{clad}/2 = 1{,}25{\cdot}10^{-3} \times L_{clad}$ [mm]

(eq.10a) $\Delta L_{v} = |\, 4{,}14{\cdot}10^{-4} \times H_{clad} - 1{,}25{\cdot}10^{-3} \times H_{clad} \,| = 8{,}36{\cdot}10^{-4} \times H_{clad}$ [mm]

*Negative sign is used because both movements are considered as expansion.*

(eq.10b) $\Delta L_{h} = |\, 0 + 1{,}25{\cdot}10^{-3} \times L_{clad} \,| = 1{,}25{\cdot}10^{-3} \times L_{clad}$ [mm]

<u>Calc-01:</u> Considering movement combination (eq.9a) and supposing that

$\Delta L_{v} = \Delta L_{h} \leq d_{s} / \sqrt{2} = \sqrt{((t + \Delta L_{t,des})^{2} - t^{2})}/\sqrt{2}$; thus:

$\sqrt{((3{,}0 + 1{,}0)^{2} - 3{,}0^{2})} / \sqrt{2} \geq 8{,}36 \cdot 10^{-4} \times H_{clad}$ ; **$H_{clad} \leq 2237$ mm**

$\sqrt{((3{,}0 + 1{,}0)^{2} - 3{,}0^{2})} / \sqrt{2} \geq 1{,}250 \cdot 10^{-3} \times L_{clad}$ ; **$L_{clad} \leq 1496$ mm**

<u>Calc-02:</u> Considering there is no movement combination:

$\sqrt{((3{,}0 + 1{,}0)^{2} - 3{,}0^{2})} \geq 8{,}36 \cdot 10^{-4} \times H_{clad}$ ; **$H_{clad} \leq 3164$ mm**

$\sqrt{((3{,}0 + 1{,}0)^{2} - 3{,}0^{2})} \geq 1{,}250 \cdot 10^{-3} \times L_{clad}$ ; **$L_{clad} \leq 2116$ mm**

## A.1.3. Dead load

$Q_{pp} = \rho_{clad} \times t_{clad} = 1500\ kg/m^3 \times 10\ mm = 15\ kg/m^2$

$\gamma_{pp} = 1{,}35$

$\gamma_{age} = 0{,}10$

(eq.4) $\gamma_1 = 1{,}0$

(eq.3) $\tau_{cal} = 0{,}12\ MPa \times 0{,}60 \times 0{,}10 = 0{,}0072\ MPa$

**System with two vertical profiles per cladding element:**

$N_b = 4$

<u>Calc-01:</u> Considering $L_{clad} = 1496$ mm (limit value for environmental conditions with movement combination)

(eq.2) $b_{shear} = (15\ kg/m^2 \times 1{,}35 \times 1496\ mm \times 10^{-5}) / (0{,}0072\ MPa \times 4 \times 1) = 10{,}52\ mm < 12\ mm = b_{min}$;
=> OK

<u>Calc-02:</u> Considering $L_{clad} = 2116$ mm (limit value for environmental conditions without movement combination)

(eq.2) $b_{shear} = (15\ kg/m^2 \times 1{,}35 \times 2116\ mm \times 10^{-5}) / (0{,}0072\ MPa \times 4 \times 1) = 14{,}88\ mm > 12\ mm = b_{min}$;
=> not OK

<u>Calc-03:</u> Considering $b_{shear} = b_{min} = 12$ mm

(eq.1) $L_{clad} \leq (0{,}0072\ MPa \times 12\ mm \times 4 \times 1 \times 10^5) / (15\ kg/m^2 \times 1{,}35) = 1706\ mm > 1496\ mm$ => OK if movement combination is considered, the bead 12 mm enable greater lengths than the ones that environmental conditions limit;

or $< 2116$ mm => not OK if no movement combination is considered in environmental conditions.

Therefore, the limit will be in 1496 mm with movement combination or in 1706 mm by minimum bead width.

**System with three vertical profiles per cladding element:**

$N_b$ = 6 (two beads per profile, including the end profiles)

<u>Calc-01:</u> Considering $L_{clad}$ = 1496 mm (limit value for environmental conditions with movement combination)

(eq.2) $b_{shear}$ = (15 kg/m² x 1,35 x 1496 mm x $10^{-5}$) / (0,0072 MPa x 6 x 1) = 7,01 mm < 12 mm = $b_{min}$ => OK

<u>Calc-02</u>: Considering $L_{clad}$ = 2116 mm (limit value for environmental conditions without movement combination)

(eq.2) $b_{shear}$ = (15 kg/m² x 1,35 x 2116 mm x $10^{-5}$) / (0,0072 MPa x 6 x 1) = 9,91 mm < 12 mm = $b_{min}$ => OK

<u>Calc-03</u>: Considering $b_{shear}$ = $b_{min}$ = 12 mm

(eq.1) $L_{clad}$ ≤ (0,0072 MPa x 12 mm x 6 x 1 x $10^5$) / (15 kg/m² x 1,35) = = 2560 mm > 1496 mm o > 2116 mm; => OK, the bead 12 mm enables greater lengths than the ones that environmental conditions limit.

## A.1.4. Wind suction load

$Q_e$ = 2,5 kN/m² (estimated value for a very exposed condition)

$\gamma_Q$ = 1,50

$\gamma_{age}$ = 0,50

(eq.4) $\gamma_1$ = 1,0

(eq.7) $\sigma_{cal}$ = 0,15 MPa x 0,60 x 0,50 = 0,045 MPa

**System with two vertical profiles per cladding element:**

$K_{ext}$ = 0,50 (table 4.1)

$l_{ext}$ = 20 mm

$n_{b-ext}$ = 2

Calc-01: Considering $L_{clad}$ = 1496 mm (limit value for environmental conditions with movement combination)

$l_p = L_{clad} - 2 \times l_{ext}$ = 1456 mm

(eq.6a) $b_{str}$ = (2,5 kN/m² x 1,50 x (0,50 x 1456 mm + 20) x $10^{-3}$) / (0,045 MPa x 2 x 1) =
= 31,2 mm > 12 mm = $b_{min}$ => not OK **-> redefine $b_{min}$ = 32 mm**

Calc-02: Considering $L_{clad}$ = 2116 mm (limit value for environmental conditions without movement combination)

$l_p = L_{clad} - 2 \times l_{ext}$ = 2076 mm

(eq.6a) $b_{str}$ = (2,5 kN/m² x 1,50 x (0,50 x 2076 mm + 20) x $10^{-3}$) / (0,045 MPa x 2 x 1) =
= 44,01 mm > 12 mm = $b_{min}$ => not OK **-> redefine $b_{min}$ = 45 mm**

Calc-03a: Considering $b_{str}$ = $b_{min}$ = 12 mm

(eq.5a) $L_{clad} = l_p + 2 \times l_{ext} \leq$ ((0,045 MPa x 12 mm x 2 x 1 x $10^3$) / (2,5 kN/m² x 1,50) – 20) / 0,50 +
+ 2 x 20= 576 mm < 1496 mm o << 2116 mm => not OK;

Calc-03b: Considering $b_{str}$ = $b_{min}$ = 32 mm

(eq.5a) $L_{clad} = l_p + 2 \times l_{ext} \leq$ ((0,045 MPa x 32 mm x 2 x 1 x $10^3$) / (2,5 kN/m² x 1,50) – 20) / 0,50 + 2 x
x 20 = 1536 mm > 1496 mm => OK; however < 2116 mm => not OK under these conditions.

Calc-03c: Considering $b_{str}$ = $b_{min}$ = 45 mm

(eq.5a) $L_{clad} = l_p + 2 \times l_{ext} \leq$ ((0,045 MPa x 45 mm x 2 x 1 x $10^3$) / (2,5 kN/m² x 1,50) – 20) / 0,50 + 2 x
x 20 = 2160 mm > 1496 mm => OK; and also > 2116 mm => OK.

Calc-04: Considering $b_{min}$ = $b_{str}$ = 12 mm, obtention of the maximum length between profiles ($l_p$).

(eq.5a) $l_p \leq$((0,045 MPa x 12 mm x 2 x 1 x $10^3$) / (2,5 kN/m² x 1,50) - 20) / 0,50 = 536 mm

System with three vertical profiles per cladding element:

$K_{ext}$ = 0,375 (table 4.1)

$K_{int}$ = 1,25 (table 4.1)

$l_{ext}$ = 20 mm

$n_{b\text{-}ext}$ = 1

$n_{b\text{-}int}$ = 2

Calc-01: Considering $L_{clad}$ = 1496 mm (limit value for environmental conditions with movement combination)

$l_p$ = ($L_{clad}$ – 2 x $l_{ext}$)/2 = (1496 – 2 x 20) / 2 = 728 mm

(eq.6a) $b_{str)ext}$ = (2,5 kN/m² x 1,50 x (0,375 x 728 mm + 20) x 10⁻³) / (0,045 MPa x 1 x 1) =
= 24,4 mm > 12 mm = $b_{min}$ => not OK **-> redefine $b_{min}$ = 25 mm**

(eq.6b) $b_{str)int}$ = (2,5 kN/m² x 1,50 x 1,25 x 728 mm x 10⁻³) / (0,045 MPa x 2 x 1) =
= 39,92 mm > 12 mm = $b_{min}$ => not OK **-> redefine $b_{min}$ =40mm**

(eq.6c) $b_{str}$ = 40 mm

Calc-02: Considering $L_{clad}$ = 2116 mm (limit value for environmental conditions without movement combination)

$l_p$ =($L_{clad}$ – 2 x $l_{ext}$)/2 = (2116 – 2 x 20)/2 = 1038 mm

(eq.6a) $b_{str)ext}$ = (2,5 kN/m² x 1,50 x (0,375 x 1038 mm + 20) x 10⁻³) / (0,045 MPa x 1 x 1) =
= 34,1 mm > 12 mm = $b_{min}$ => not OK **-> redefine $b_{min}$ =35mm**

(eq.6b) $b_{str)int}$ =(2,5 kN/m² x 1,50 x 1,25 x 1038 mm x 10⁻³) / (0,045 MPa x 2 x 1) = 54,1 mm >
> 12 mm = $b_{min}$ => not OK **-> redefine $b_{min}$ = 55 mm**

(eq.6c) $b_{str}$ = 55 mm

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Calc-03a: Considering $b_{min} = b_{str} = 40$ mm

(eq.5a) $L_{clad} = 2 \times l_p + 2 \times l_{ext} \leq 2 \times (((0{,}045 \text{ MPa} \times 40 \text{ mm} \times 1 \times 1 \times 10^3) / (2{,}5 \text{ kN/m}^2 \times 1{,}50) - 20) / 0{,}375) + 2 \times 20 = 1616 \text{ mm} > 1496 \text{ mm}$ => OK

(eq.5b) $L_{clad} = 2 \times l_p + 2 \times l_{ext} \leq 2 \times ((0{,}045 \text{ MPa} \times 40 \text{ mm} \times 2 \times 1 \times 10^3) / (2{,}5 \text{ kN/m}^2 \times 1{,}50 \times 1{,}25)) + 2 \times 20 = 1576 \text{ mm} > 1496 \text{ mm}$ => OK

Calc-03b: Considering $b_{min} = b_{str} = 55$ mm

(eq.5a) $L_{clad} = 2 \times l_p + 2 \times l_{ext} \leq 2 \times (((0{,}045 \text{ MPa} \times 55 \text{ mm} \times 1 \times 1 \times 10^3) / (2{,}5 \text{ kN/m}^2 \times 1{,}50) - 20) / 0{,}375) + 2 \times 20 = 2192 \text{ mm} > 2116 \text{ mm}$ => OK

(eq.5b) $L_{clad} = 2 \times l_p + 2 \times l_{ext} \leq 2 \times ((0{,}045 \text{ MPa} \times 55 \text{ mm} \times 2 \times 1 \times 10^3) / (2{,}5 \text{ kN/m}^2 \times 1{,}50 \times 1{,}25)) + 2 \times 20 = 2152 \text{ mm} > 2116 \text{ mm}$ => OK

Calc-04: Considering $b_{min} = b_{str} = 12$ mm, obtention of the maximum length between profiles ($l_p$).

(eq.5a) $l_p \leq ((0{,}045 \text{ MPa} \times 12 \text{ mm} \times 1 \times 1 \times 10^3) / (2{,}5 \text{ kN/m}^2 \times 1{,}50) - 20) / 0{,}375 = 330 \text{ mm}$

(eq.5b) $l_p \leq (0{,}045 \text{ MPa} \times 12 \text{ mm} \times 2 \times 1 \times 10^3) / (2{,}5 \text{ kN/m}^2 \times 1{,}50 \times 1{,}25) = 230 \text{ mm}$

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# A.1.5. Dead load and wind combination verification

System with two vertical profiles per cladding element:

Calc-01: Considering $L_{clad}$ = 1496 mm (limit value for environmental conditions with movement combination)

(eq.8) $b_{total} = \sqrt{((10{,}52\ mm)^2 + (31{,}2\ mm)^2)} = 32{,}92\ mm > 32\ mm = b_{min}$ **-> redefine $b_{min}$ = 33 mm**

Calc-02: Considering $L_{clad}$ = 2116 mm (limit value for environmental conditions without movement combination)

(eq.8) $b_{total} = \sqrt{((14{,}88\ mm)^2 + (44{,}01\ mm)^2)} = 46{,}46\ mm > 45\ mm = b_{min}$ **-> redefine $b_{min}$ = 47 mm**

System with three vertical profiles per cladding element:

Calc-01: Considering $L_{clad}$ = 1496 mm (limit value for environmental conditions with movement combination)

(eq.8) $b_{total} = \sqrt{((7{,}01\ mm)^2 + (39{,}92\ mm)^2)} = 40{,}5\ mm < 35\ mm = b_{min}$ **-> redefine $b_{min}$ = 41 mm**

Calc-02: Considering $L_{clad}$ = 2116 mm (limit value for environmental conditions without movement combination)

(eq.8) $b_{total} = \sqrt{((9{,}91\ mm)^2 + (54{,}1\ mm)^2)} = 55\ mm$ **->** OK redefinition $b_{min}$ = 55 mm

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## A.1.6. Final design

The final cladding element design under the calculated conditions is:
Cladding element with maximum dimensions <u>considering displacement combination</u>:

$H_{clad} \leq 2237$ mm
$L_{clad} \leq 1496$ mm

Adhesive beads with minimum dimensions:

$b_{min} = 33$ mm if two vertical profiles
$b_{min} = 41$ mm if three vertical profiles

Cladding element with maximum dimensions <u>WITHOUT considering displacement combination</u>:

$H_{clad} \leq 3164$ mm
$L_{clad} \leq 2116$ mm

Adhesive beads with minimum dimensions:

$b_{min} = 47$ mm if two vertical profiles
$b_{min} = 55$ mm if three vertical profiles

<u>In case of 12 mm beads</u>, the maximum distance between profiles will be:

$l_p \leq 536$ mm if two vertical profiles
$l_p \leq 230$ mm if three vertical profiles

# Annex 2 – Technical justification for equation (eq.9c) – Method 2

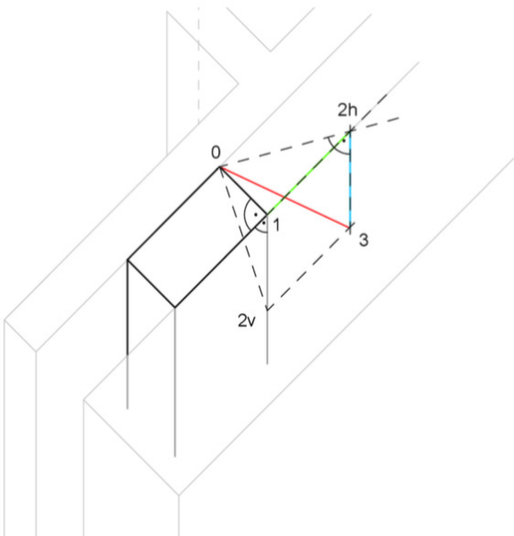
Adhesive displacement ($d_s$) for cladding elements and profiles movements due to temperature and relative humidity variations may be determined as follows, by considering that the manufacturer defines the design value $\Delta L_{t,des}$ from tensile stress tests.

$d_s^2 = (t + \Delta L_{t,des})^2 - t^2$

where:

- $d_s$ (in mm) = limit value for the absolute shear displacement of the adhesive.
- $\Delta L_{t,des}$ (in mm) = design value of the tensile deformation corresponding to the limit of the elastic field of the glued connection.
- t (in mm) = adhesive bead thickness.

As shown in figure A2.1, initial distance $t = d_{0\text{-}1}$ becomes final distance $d_{0\text{-}3}$ after the movement, therefore the equations are:




$d_{0\text{-}3}^2 = d_{2h\text{-}3}^2 + d_{0\text{-}2h}^2 \rightarrow d_{0\text{-}2h}^2 = d_{0\text{-}3}^2 - d_{2h\text{-}3}^2$
$d_{0\text{-}2h}^2 = d_{0\text{-}1}^2 + d_{1\text{-}2h}^2 \rightarrow d_{1\text{-}2h}^2 = d_{0\text{-}2h}^2 - d_{0\text{-}1}^2$
$d_{1\text{-}2h}^2 = d_{0\text{-}3}^2 - d_{2h\text{-}3}^2 - d_{0\text{-}1}^2$
$d_{1\text{-}2h}^2 + d_{2h\text{-}3}^2 = d_{0\text{-}3}^2 - d_{0\text{-}1}^2$
$d_{0\text{-}3} = d_{0\text{-}1} + \Delta L_{t,des}$
$d_{1\text{-}2h}^2 + d_{2h\text{-}3}^2 = (d_{0\text{-}1} + \Delta L_{t,des})^2 - d_{0\text{-}1}^2$
$d_{1\text{-}2h} = d_h$ ; $d^{2h\text{-}3} = d_v$
$d_s^2 = d_h^2 + d_v^2 = d_{1\text{-}2h}^2 + d_{2h\text{-}3}^2$
$d_s^2 = d_h^2 + d_v^2 = (d_{0\text{-}1} + \Delta L_{t,des})^2 - d_{0\text{-}1}^2$
$d_{0\text{-}1} = t$
$d_s^2 = d_h^2 + d_v^2 = (t + \Delta L_{t,des})^2 - t^2$

**Figure A2.1:** Trigonometry justification.

Data obtained from this Method 2 are equivalent to those data obtained from Method 1 (from shear stress tests, see clause 4.4).

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