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GUIDANCE PAPER
VELUX MODULAR SKYLIGHTS
SELF-SUPPORTING RIDGELIGHT

Determination of structural design values

1. Introduction

The aim of this document – together with ETA-17/0467– is to facilitate the determination of design values.

By means of structural calculations and design values, it can be demonstrated whether the requirements of the load bearing capacity of a specific kit, installed in a given building on a given location, are met.

ETA-17/0467 contains information on the kit, e.g. the structural system, hardware, cross section of the profiles, as well as the characteristic values. For convenience, a number of the relevant characteristic values are repeated in this document.

The load bearing capacity of the glazing is not subject to this document.

2. Principle

The design load bearing capacities (1) R_d and C_d shall be calculated using the following equations (see ETAG 010, 6.3.1.1 and 6.3.1.2):

$$\mathbf{R_d = R_k/(\gamma_{MR}*K_t*K_u*K_\theta)}$$

and

$$\mathbf{C_d = C_k/(\gamma_{MC}*C_t*C_u*C_\theta)}$$

where:

R_k = load bearing capacity (ULS) calculated in accordance with ETA-17/0467
C_k = load bearing capacity (SLS) calculated in accordance with ETA-17/0467
γ_{MR} = partial safety factor for ULS
γ_{MC} = partial safety factor for SLS
K_t = effect of duration for ULS (2)
C_t = effect of duration for SLS (2)
K_u = effect of ageing/environment for ULS (2)
C_u = effect of ageing/environment for SLS (2)
K_θ = effect of temperature for ULS (2)
C_θ = effect of temperature for SLS (2)

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(1) The self-weight, including partial safety factors, shall be calculated in accordance with Clause 6.
(2) Relevant only for profiles and their hardware connections.

3. Partial safety factors, magnification and reduction factors

Whenever possible internationally and/or nationally determined parameters and factors shall be taken into account. By default, the parameters and factors shown in Table 1 and Table 2 and Table 5 are recommended.

The recommended parameters are based on
“BÜV-Empfehlung Tragende Kunststoffbauteile im Bauwesen [TKB] - Entwurf, Bemessung und Konstruktion - Stand 08 / 2010” (BÜV) and some European standards and VELUX test reports.

Table 1: Partial safety factors

Partial safety factor	γ_{MR}	γ_{MC}
Frame profiles at connections	1,5 (1)	Not relevant
Bolt/Rivet/Bracket/Rotating shoe/Mounting clamp	1,25 (2)	Not relevant
Frame profiles	1,2 (1)	1,1 (3)

(1) See BÜV Tablelle E-1
(2) See EN 1993-1-8:2005, section 2.2
(3) See BÜV Abschnitt 5.5

Table 2: Magnification and reduction factors (8)

ULS			SLS		
K_t (1) (2)	10 minutes	1,10	**C_t** (1) (4)	10 minutes	1,02
	1 week	1,48		1 week	1,08
	3 months	1,66		3 months	1,11
	6 months	1,71		6 months	1,11
	25 years	2,02		25 years	1,15
K_u (1) (3)		1,2	C_u (1) (5)		1,2
K_θ (1)	0°C (6)	0,95	C_θ (1)	0°C (6)	1,00
	20°C (6)	1,00		20°C (6)	1,00
	40°C (7)	1,35		40°C (7)	1,05
	60°C (6)	1,50		60°C (6)	1,05
	80°C (6)	2,05		80°C (6)	1,10

(1) $K_t = A^f_1$, $C_t = A^E_1$ (see ETAG 010: 2002, section 6.3 and Annex H, BÜV Abschnitt 5.2)
$K_u = A^f_2$, $C_u = A^E_2$ (see ETAG 010: 2002, section 6.3 and Annex H, BÜV Abschnitt 5.2)
$K_\theta = A^f_3$, $C_\theta = A^E_3$ (see ETAG 010: 2002, section 6.3 and Annex H, BÜV Abschnitt 5.2)
(2) See BÜV Tabelle B-1a and Gleichung 8.2.
(3) See BÜV Tabelle B-2.
(4) See BÜV Tabelle B-1b and Gleichung 8.2.
(5) See BÜV Tabelle B-2.
(6) See VELUX test reports no. 147775 and 145611 and DTI report no. 743795-2.
(7) Conservative approximation based on measurements from VELUX test reports nos. 147775 and 145611.
(8) Relevant only for profiles and their hardware connections.

4. Design values of small scale tests

The design values of the small-scale tests can be calculated as shown in Table 3.

Table 3: Characteristic and design values

Property	Characteristic values see ETA-17/0467 Annex D.1	Design values see Table 1 and Table 2 above
Tensile strength	832,9 MPa	ULS= Characteristic value / (γ_{MR} *K_t*K_u*K_θ) SLS= Characteristic value / (γ_{MC}*C_t*C_u*C_θ)
Compression strength	465 MPa	
Bending strength	1257 MPa	
E-modulus	39,5 GPa	
	41,6 GPa (1)(3)	
G-modulus	3,1 GPa	
	3,4 GPa (2)	
Shear strength	53,8 MPa	

(1) Mean value, confidence level 75%, unknown standard deviation (See ISO 16269-6:2014).
(2) Mean value, confidence level 75%, unknown standard deviation (See ISO 16269-6:2014).
(3) For openable windows subjected to a downward action force, the E-modulus shall be multiplied with a factor of 0,83, see “VELUX report 1100005818_06_1 VMS Full scale test Ridgelight – Stiffness of module 2016-11-29”

5. Determination of values for hardware connections

Figure 1: Applied forces to the hardware

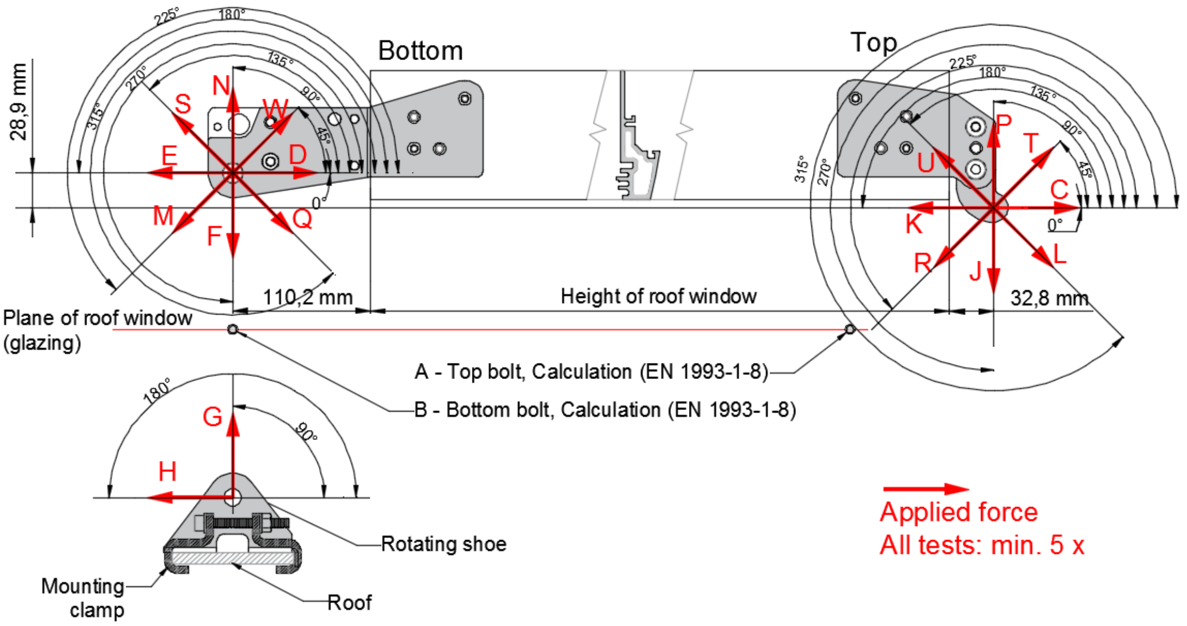


Table 4: Characteristic and design values for hardware connections

	Element/Connection	**Characteristic value (kN)**	**Design value (kN) see Table 1**
A	Top bolt connection (calculated minimum)	13,5 (1)	ULS= Characteristic value / γ_{MR} SLS: Not relevant
B	Bottom bolt connection (calculated minimum)	17,6 (1)	
G	Rotating shoe/mounting clamp/roof connection in 90°	20,3	
H	Rotating shoe/mounting clamp/roof connection in 180°	28,2	

Note:

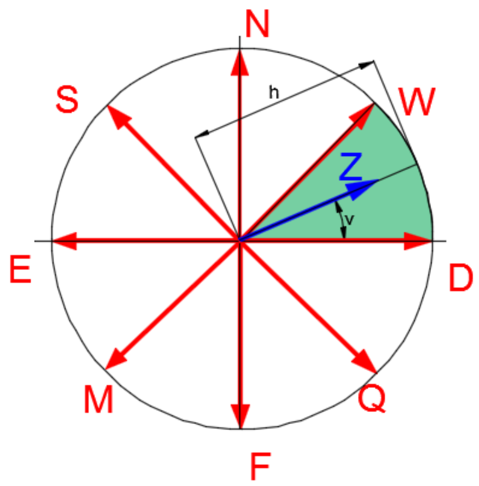
(1) Strength of the bottom and top bolt themselves: 17,6 kN

	Element/Connection	**Characteristic value (kN)** (1)				**Design value (kN) see Table 1 and Table 2 above**
		Product variant				
		HFC 100240 00**10**	HVC 100240 00**10**	HFC 100240 00**16T**	HVC 100240 00**16T**	
C	Top corner bracket/frame connection in 0°	9,9	10,6	8,8	10,6	ULS= Characteristic value / (γ_{MR} *K_t*K_u*K_θ) SLS: Not relevant
D	Bottom corner bracket/frame connection in 0°	9,5	7,5	10,9	7,5	
E	Bottom corner bracket/frame connection in 180°	22,7	12,8	15,2	12,8	
F	Bottom corner bracket/frame connection in 270°	3,9	2,0	4,3	2,1	
J	Top corner bracket/frame connection in 270°	3,9	2,0	4,3	2,1	
K	Top corner bracket/frame connection in 180°	9,5	9,7	8,4	9,7	
L	Top corner bracket/frame connection in 315°	6,2	3,4	6,0	3,5	
M	Bottom corner bracket/frame connection in 225°	6,2	3,4	6,0	3,5	
N	Bottom corner bracket/frame connection in 90°	6,0	6,0	6,3	5,7	
P	Top corner bracket/frame connection in 90°	6,0	6,0	6,3	5,7	
Q	Bottom corner bracket/frame connection in 315°	5,4	3,0	5,0	3,6	
R	Top corner bracket/frame connection in 225°	5,4	3,0	5,0	3,6	
S	Bottom corner bracket/frame connection in 135°	7,8	8,2	8,1	7,5	
T	Top corner bracket/frame connection in 45°	7,8	8,2	8,1	7,5	
U	Top corner bracket/frame connection in 135°	8,7	9,3	8,6	9,0	
W	Bottom corner bracket/frame connection in 45°	8,7	9,3	8,6	9,0	

Note:

(1) Without influence caused by nationally determined magnification and reduction factors (duration, aging/environment, temperature, i.e. $C_t = C_u = C_\Theta = 1$ and $K_t = K_u = K_\Theta = 1$, see ETAG 010, 6.3.1.2)

Figure 2: Determination of values for hardware connections in other directions than tested (principle)



Z: Result of a structural calculations [kN]

v : Result of a structural calculations [angle to the roof window]

h: Result of a linear interpolation [kN]

$$h = (D * (45^\circ - v^\circ) + W * v^\circ) / 45^\circ$$

Requirement: $h \geq Z$

6. Self-weight

The self-weight (including hardware, lining, cladding and flashing) of the fixed roof window (G_f and g_f) and the openable roof window (G_v and g_v) shall be calculated as follows:

$$\mathbf{G_f = (W\text{-}12) * (L\text{-}96) * t{*}25{*}10^{-9}{+}2(W{+}L) {*}57{*}10^{-6}} \qquad [kN]$$
$$\mathbf{g_f = G_f /(W{*}L){*}\, 10^{6}} \qquad [kN/m^2]$$

and

$$\mathbf{G_v = (W\text{-}12) * (L\text{-}96) * t{*}25 * 10^{-9}{+}2(W{+}L) * 96 * 10^{-6}} \qquad [kN]$$
$$\mathbf{g_v = G_v /(W{*}L){*}\, 10^{6}} \qquad [kN/m^2]$$

where:

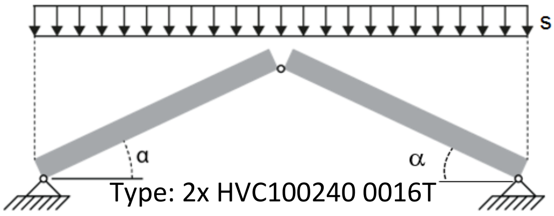
W = Width of the roof window in mm
L = Height of the roof window in mm
t = Sum of glass thicknesses in mm

Table 5: Partial safety factors for permanent action (self-weight):

	Unfavourable $\gamma_{G,sup}$	Favourable $\gamma_{G,inf}$	Unfavourable $\xi_{G,sup}$	Reference
ULS	1,35	1,0	0,85	EN 1990:2007, Table A1.2(B), Eq. 6.10b
SLS	1,0	1,0	N/A	EN 1990:2007, Table A1.4

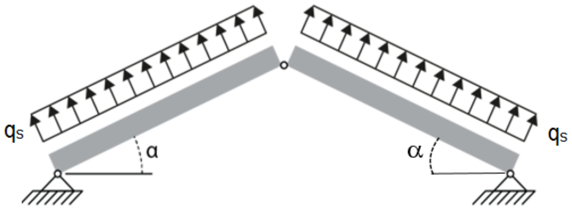
7. Examples of design values for the load bearing capacity

Table 6a: Characteristic and design load bearing capacities for snow-load (kN/m^2)

		Characteristic values for s see ETA-17/0467 Annex E.1			Design calculation Self-weight partial safety factors (see Table 5): $\gamma_{G,sup,ULS}$=1,35 $\xi_{G,sup,ULS}$=0,85 $\gamma_{G,sup,SLS}$=1,00 Material partial safety factors (see Table 1): $\gamma_{MR,ULS}$=1,50 $\gamma_{MC,SLS}$=1,10 Magnification and reduction factors (see Table 2): (s) Leading snow load (1): 3 months duration, 20°C. K_t=1,66; K_u=1,2; K_θ=1,00 C_t=1,11; C_u=1,2; C_θ=1,00 (g) Leading self-weight (2): 25 years duration, 20°C. K_t=2,02; K_u=1,2; K_θ=1,00 C_t=1,15; C_u=1,2; C_θ=1,00 Load factor snow, from EN 1990:2007: $\gamma_{Q,1}$ = 1,5 $\Psi_{0,snow}$ = 0,5 E= 0,83 x 41,6 GPa See NOTE 3 to Table 3.		
Application examples – Snow-load	α°	ULS	SLS		ULS (3)	SLS (4)	
			1/300	1/150		1/300	1/150
 Type: 2x HVC100240 0016T (1000mm x 2400mm) Glazing: 22 mm glass in total	25°	3,8	1,5	3,8	0,36(g)	0,53(s)	1,81(s)
	30°	4,6	1,6	4,0	0,68(g)	0,59(s)	1,93(s)
	35°	5,3	1,7	4,2	0,99(g)	0,67(s)	2,08(s)
	40°	6,1	1,9	4,6	1,23(s)	0,76(s)	2,27(s)

(1) Load combination ULS: $\gamma_{G,sup} \cdot \xi_{G,sup} \cdot G_k + \gamma_{Q,1} \cdot s_k$ SLS: $G_k + s_k$
(2) Load combination ULS: $\gamma_{G,sup} \cdot G_k + \gamma_{Q,1} \cdot \Psi_{0,snow} \cdot s_k$ SLS: $G_k + \Psi_{0,snow} \cdot s_k$
(3) Values in Table are design snow load for ULS: $\gamma_{Q,1} \cdot s_k$
(4) Values in Table are design snow load for SLS: s_k

Table 6b: Characteristic and design load bearing capacities for wind suction (kN/m^2)

		Characteristic values for q_s see ETA-17/0467 Annex E.1			Design values Self-weight partial safety factors (see Table 5): $\gamma_{G,inf,ULS}$=1,00 $\gamma_{G,sup,SLS}$=1,00 Material partial safety factors (see Table 1): $\gamma_{MR,ULS}$=1,50 $\gamma_{MC,SLS}$=1,10 Magnification and reduction factors (see Table 2): (q_s) Leading wind load (2): 10 minutes, 60°C (1). ULS: K_t=1,10; K_u=1,2; K_θ=1,50 SLS: C_t=1,02; C_u=1,2; C_θ=1,05 Load factor wind, from EN 1990:2007: $\gamma_{Q,1}$ = 1,5 $\Psi_{0,wind}$ = 0,6		
Application examples – Wind suction	α°	ULS	SLS		ULS (3)	SLS (4)	
			1/300	1/150		1/300	1/150
 (1000mm x 2400mm) Glazing: 14 mm glass in total	25°	4,8	1,9	3,4	1,95(q_s)	1,53(q_s)	2,53(q_s)
	30°	5,0	1,9	3,3	1,98(q_s)	1,51(q_s)	2,51(q_s)
	35°	4,9	1,9	3,3	1,77(q_s)	1,48(q_s)	2,48(q_s)
	40°	4,5	1,9	3,3	1,78(q_s)	1,45(q_s)	2,45(q_s)

(1) See VELUX test report 149292.
(2) Load combination ULS: $\gamma_{G,inf} \cdot G_k + \gamma_{Q,1} \cdot q_{s,k}$ SLS: $G_k + q_{s,k}$
(3) Values in Table are design snow load for ULS: $\gamma_{Q,1} \cdot q_{s,k}$
(4) Values in Table are design snow load for SLS: $q_{s,k}$

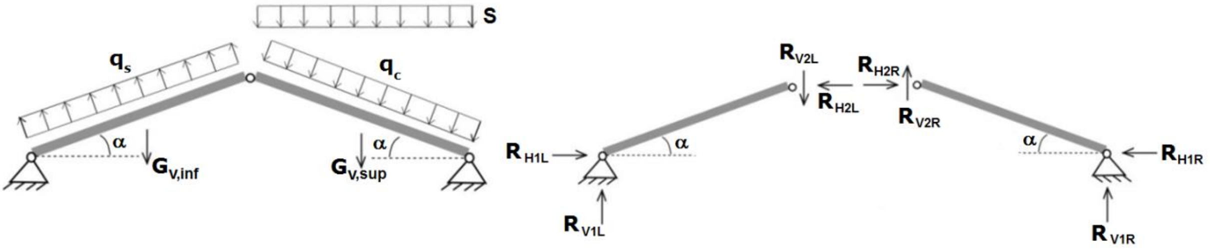
8. Calculation example, asymmetric load (design values)

For the calculations example “Asymmetric load” the same example as Annex E.2 in ETA-17/0467 is used.

NOTE: National Standards and Annexes may specify different loads and combinations hereof, that are not mentioned in this document.

To demonstrate the calculation procedure, a VELUX modular skylight self-supporting ridgelight application under asymmetric wind and snow load is examined.
Geometry and roof window variant is the same as in the wind load example in Table 6b:
2 x HVC1002400 0010 (1000mm x 2400mm). Glazing: 14mm glass in total.
The pitch is $\alpha = 25^\circ$.

Figure 3: Load model for calculation example



Partial safety factors and the magnification and reduction factors used in the calculation are presented in Tables 7a and 7b.

Table 7a: Partial safety factors

	ULS	SLS
Frame profiles at connections:	γ_{MR} = 1,5	N/A
Frame profiles:	γ_{MR} = 1,2	γ_{MC} = 1,1
Variable Load, leading:	$\gamma_{Q,1}$ = 1,5 (1)	$\gamma_{Q,1}$ = 1,0 (1)
Variable Load, non-leading:	$\gamma_{Q,i}$ = 1,5 (1)	$\gamma_{Q,i}$ = 1,0 (1)
Permanent action, unfavourable:	$\gamma_{G,sup}$ = 1,35	$\gamma_{G,sup}$ = 1,0
Permanent action, favourable:	$\gamma_{G,inf}$ = 1,0	$\gamma_{G,inf}$ = 1,0
Factor for combination, wind	$\Psi_{0,wind}$ = 0,6 (1)	$\Psi_{0,wind}$ = 0,6 (1)
Factor for combination, snow	$\Psi_{0,snow}$ = 0,5 (1)	$\Psi_{0,snow}$ = 0,5 (1)
Reduction factor for G_{sup}	$\xi_{G,sup}$ = 0,85	N/A

(1) See EN 1990:2007

Table 7b: Magnification and reduction factors

Duration dependency, self-weight leading:	$K_{t,25\ years}$ = 2,02	$C_{t,25\ years}$ = 1,15
Duration dependency, wind leading:	$K_{t,10\ min}$ = 1,1	$C_{t,10\ min}$ = 1,02
Duration dependency, snow leading:	$K_{t,3\ month}$ = 1,66	$C_{t,3\ month}$ = 1,11
Ageing/environment dependency:	K_u = 1,2	C_u = 1,2
Temperature dependency, 20°:	$K_{\theta,20^o}$ = 1,0	$C_{\theta,20^o}$ = 1,00
Temperature dependency, 60°:	$K_{\theta,60^o}$ = 1,5	$C_{\theta,60^o}$ = 1,05

Table 8: Brackets characteristic resistance

Element/Connection	**Characteristic values [kN]**
A: Top bolt connection (calculated minimum)	13,5 (1)
B: Bottom rivet connection (calculated minimum)	17,6
C: Top corner bracket/frame connection in 0°	10,6
D: Bottom corner bracket/frame connection in 0°	7,5
E: Bottom corner bracket/frame connection in 180°	12,8
F: Bottom corner bracket/frame connection in 270°	2,0
G: Rotating shoe/mounting clamp/roof connection in 90°	20,3
H: Rotating shoe/mounting clamp/roof connection in 180°	28,2
J: Top corner bracket/frame connection in 270°	2,0
K: Top corner bracket/frame connection in 180°	9,7
L: Top corner bracket/frame connection in 315°	3,4
M: Bottom corner bracket/frame connection in 225°	3,4
N: Bottom corner bracket/frame connection in 90°	6,0
P: Top corner bracket/frame connection in 90°	6,0
Q: Bottom corner bracket/frame connection in 315°	3,0
R: Top corner bracket/frame connection in 225°	3,0
S: Bottom corner bracket/frame connection in 135°	8,2
T: Top corner bracket/frame connection in 45°	8,2
U: Top corner bracket/frame connection in 135°	9,3
W: Bottom corner bracket/frame connection in 45°	9,3

(1) Strength of the bolt itself: 17,6 kN

Corrections in height and angle

Because of the brackets, it is necessary to correct the calculation angle and the profile height. In Figure 1 $\Delta L_1 = 110{,}2$ mm and $\Delta L_2 = 43{,}7$ mm for the brackets can be found. ΔL_2 can be transformed into a parallel part $\Delta L_{2ll} = 32{,}8$ mm and a perpendicular part $\Delta L_{2\perp} = 28{,}9$ mm.
ΔL_1 and ΔL_2 are constants no matter the height L or angle α of the glazing.

The corrected height can thereby be found:

$$L_{cor} = \sqrt{(L + \Delta L_1 + \Delta L_{2ll})^2 + (L_{2\perp})^2} = \sqrt{(2400mm + 110{,}2mm + 32{,}8mm)^2 + (28{,}9mm)^2} = 2543mm$$

The corrected angle is found:

$$\Delta\alpha = \sin^{-1}\left(\frac{\Delta L_{2\perp}}{L + \Delta L_1 + \Delta L_{2ll}}\right) = \sin^{-1}\left(\frac{28{,}9mm}{2400mm + 110{,}2mm + 32{,}8mm}\right) = 0{,}65^o$$

$$\alpha_{cor} = \alpha - \Delta\alpha = 25^o - 0{,}7^o = 24{,}3^o$$

For deflection calculations of an upwards load for an openable window, only the casement will deflect. Therefore only the height of the casement profile and correct angle hereof should be used for the deflections calculations. From Figure 4 $\Delta L_{1,up,dfl}$ = -9,7 mm, $\Delta L_{2ll,up,dfl}$ = 23,5 mm and $\Delta L_{2\perp,up,dfl}$ = 24 mm are found.

The corrected height $L_{cor,up,dfl}$ can thereby by found:

$$L_{cor,up,dfl} = \sqrt{\left(L + \Delta L_{1,up,dfl} + \Delta L_{2ll,up,dfl}\right)^2 + \left(L_{2\,,up,dfl}\right)^2}$$

$$= \sqrt{(2400mm - 9{,}7mm + 23{,}5mm)^2 + (24mm)^2} = 2414mm$$

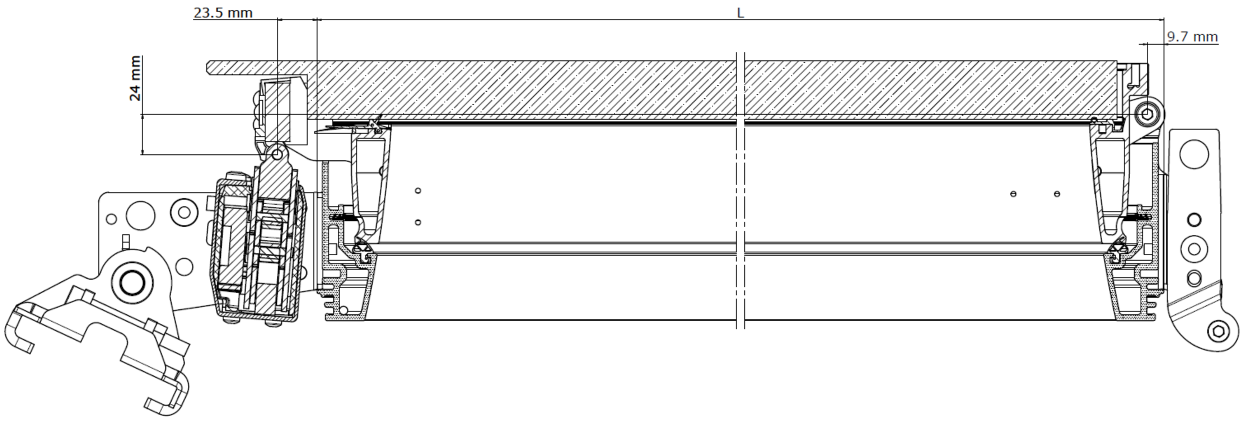
The corrected angle is found:

$$\Delta\alpha_{up,dfl} = \sin^{-1}\left(\frac{\Delta L_{2\,,up,dfl}}{L + \Delta L_{1,up,dfl} + \Delta L_{2ll,up,dfl}}\right)$$

$$= \sin^{-1}\left(\frac{24mm}{2400mm - 9{,}7mm + 23{,}5mm}\right) = 0{,}57^o$$

$$\alpha_{cor,up,dfl} = \alpha + \Delta\alpha = 25^o + 0{,}6^o = 25{,}6^o$$

Figure 4: Corrections vectors for an openable window subjected to an upwards acting force, deflections only



$\Delta L_{1,up,dfl}$ = -9,7 mm, $\Delta L_{2ll,up,dfl}$ = 23,5 mm and $\Delta L_{2\perp,up,dfl}$ = 24 mm are found. These measurements are constants.

Characteristic loads

Self-weight on each side frame/casement:

$$G_{V,k} = \frac{1}{2}\cdot\left((W-12)\cdot(L-96)\cdot t\cdot 25\cdot 10^{-9} + 2\cdot(W+L)\cdot 96\cdot 10^{-6}\right)$$

$$= \frac{1}{2}\cdot\left((1000-12)\cdot(2400-96)\cdot 14\cdot 25\cdot 10^{-9} + 2\cdot(1000+2400)\cdot 96\cdot 10^{-6}\right) = 0.72kN$$

To be able to divide the self-weight up in sup and inf, the self-weight is given for the left and the right frame/casement.

$$G_{VL,k} = G_{VR,k} = 0{,}72kN$$

In this example, the wind peak velocity pressure is set to 0,8kN/m^2 and the shape factor is set to 0,5 for wind pressure and -0,5 for wind suction. Hence, the load is

$q_{c,k} = q_{s,k} = 0{,}8kN/m^2 \cdot 0{,}5 \cdot 0{,}5m = 0{,}2kN/m\,,\ \ on\ each\ side\ frame/casement$

The wind load is split into a vertical and a horizontal component, using the original angle α. Using the corrected height, L_{cor} to find the equivalent concentrated load.

$Q_{sH,k} = Q_{cH,k} = q_{c,k} \cdot L_{cor} \cdot \sin(\alpha) = 0{,}2kN/m \cdot 2{,}543m \cdot \sin(25^o) = 0{,}21kN\ on\ each\ side\ frame/casement$

$Q_{sV,k} = Q_{cV,k} = q_{c,k} \cdot L_{cor} \cdot \cos(\alpha) = 0{,}2kN/m \cdot 2{,}543m \cdot \cos(25^o) = 0{,}46kN\ \ on\ each\ side\ frame/casement$

For the snow load in this example the two C factors (according to EN 1991-1-3) are set to 1,0, the shape factor μ_2 set to 0,8 and the characteristic value of snow load on the ground S_k=1,0kN/m², given the characteristic snow load s_k:

$s_k = \mu_2 \cdot C_e \cdot C_t \cdot S_k = 0{,}8 \cdot 1{,}0 \cdot 1{,}0 \cdot 1{,}0kN/m^2 = 0{,}8kN/m^2\ \ \rightarrow 0{,}4kN/m\,, on\ each\ side\ frame/casement$

The snow load is only vertical, and the corrected height L_{cor} is used to find the equivalent concentrated load.

$S_{V,k} = s \cdot \cos(\alpha) \cdot L_{cor} = 0{,}4kN/m \cdot \cos(25^o) \cdot 2{,}543m = 0{,}92kN$

Reactions in brackets

The corrected height L_{cor} and angle α_{cor} are used in the static system to determine the reactions.
These calculations are not presented here.
Reactions are calculated separately for each load type and are found in Table 9.
From the characteristic reactions, different load combinations are made from the partial safety factors found in Table 7A:

a) Characteristic load combination:
$1{,}0 \cdot G_{VL.k} + 1{,}0 \cdot G_{VR,k} + 1{,}0 \cdot Q_k + 1{,}0 \cdot S_{V,k}$

b) Leading self-weight combination:
$\gamma_{G,inf} \cdot G_{VL,k} + \gamma_{G,sup} \cdot G_{VR,k} + \gamma_{Q,1} \cdot \Psi_{0,wind} \cdot Q_k + \gamma_{Q,i} \cdot \Psi_{0,snow} \cdot S_{V,k} =>$
$1{,}0 \cdot G_{VL,k} + 1{,}35 \cdot G_{VR,k} + 1{,}5 \cdot 0{,}6 \cdot Q_k + 1{,}5 \cdot 0{,}5 \cdot S_{V,k}$

c) Leading self-weight, no snow load combination:
$\gamma_{G,inf} \cdot G_{VL,k} + \gamma_{G,sup} \cdot G_{VR,k} + \gamma_{Q,1} \cdot \Psi_{0,wind} \cdot Q_k =>$
$1{,}0 \cdot G_{VL,k} + 1{,}35 \cdot G_{VR,k} + 1{,}5 \cdot 0{,}6 \cdot Q_k$

d) Leading wind combination:
$\gamma_{G,inf} \cdot G_{VL,k} + \gamma_{G,sup} \cdot \xi_{G,sup} \cdot G_{VR,k} + \gamma_{Q,1} \cdot Q_k + \gamma_{Q,i} \cdot \Psi_{0,snow} \cdot S_{V,k} =>$
$1{,}0 \cdot G_{VL,k} + 1{,}35 \cdot 0{,}85 \cdot G_{VR,k} + 1{,}5 \cdot Q_k + 1{,}5 \cdot 0{,}5 \cdot S_{V,k}$

e) Leading wind combination, no snow load:
$\gamma_{G,inf} \cdot G_{VL,k} + \gamma_{G,sup} \cdot \xi_{G,sup} \cdot G_{VR,k} + \gamma_{Q,1} \cdot Q_k =>$
$1{,}0 \cdot G_{VL,k} + 1{,}35 \cdot 0{,}85 \cdot G_{VR,k} + 1{,}5 \cdot Q_k$

f) Leading snow combination:
$\gamma_{G,inf} \cdot G_{VL,k} + \gamma_{G,sup} \cdot \xi_{G,sup} \cdot G_{VR,k} + \gamma_{Q,i} \cdot \Psi_{0,wind} \cdot Q_k + \gamma_{Q,1} \cdot S_{V,k} =>$
$1{,}0 \cdot G_{VL,k} + 1{,}35 \cdot 0{,}85 \cdot G_{VR,k} + 1{,}5 \cdot 0{,}6 \cdot Q_k + 1{,}5 \cdot S_{V,k}$

Table 9, Horizontal and vertical reactions of the brackets

Load type	R_{H1L} [kN]	R_{V1L} [kN]	R_{H2L} [kN]	R_{V2L} [kN]	R_{H2R} [kN]	R_{V2R} [kN]	R_{H1R} [kN]	R_{V1R} [kN]
$G_{VL,k}$	0,40	0,18	0,40	-0,54	0,40	-0,54	0,40	0,54
$G_{VR,k}$	0,40	0,54	0,40	0,54	0,40	0,54	0,40	0,18
Q_k ($Q_{s,k}$ and $Q_{c,k}$)	0,21	-0,18	0,00	0,28	0,00	0,28	-0,21	0,18
$S_{V,k}$	0,51	0,23	0,51	0,23	0,51	0,23	0,51	0,69
a) Characteristic combi.	1,52	0,77	1,31	0,51	1,31	0,51	1,10	1,59
b) Leading self-weight	1,51	0,92	1,32	0,61	1,32	0,61	1,13	1,46
c) Leading self-weight - snow	1,13	0,75	0,94	0,44	0,94	0,44	0,75	0,95
d) Leading wind	1,56	0,70	1,24	0,67	1,24	0,67	0,93	1,53
e) Leading wind, -snow	1,17	0,53	0,86	0,50	0,86	0,50	0,54	1,02
f) Leading snow	1,81	0,98	1,62	0,68	1,62	0,68	1,44	1,94

The factors to find the design value of the bearing resistance of the bracket are found from the formula given in chapter 2 and Table 7b. Duration is taken for the leading load, and temperature is taken for the highest it can be, 20^{o} when snow and 60^{o} when no snow.

Leading self-weight combination, duration: 25 years, temperature: 20^{o}:
$b)\ factor = \gamma_{MR} \cdot K_{t,25years} \cdot K_u \cdot K_{\theta,20^o} = 1{,}5 \cdot 2{,}02 \cdot 1{,}2 \cdot 1{,}0 = 3{,}64$

Leading self-weight, no snow combination, duration: 25 years, temperature: 60^{o}:
$c)\ factor = \gamma_{MR} \cdot K_{t,25years} \cdot K_u \cdot K_{\theta,60^o} = 1{,}5 \cdot 2{,}02 \cdot 1{,}2 \cdot 1{,}5 = 5{,}45$

Leading wind combination, duration: 10 minutes, temperature: 20^{o}:
$d)\ factor = \gamma_{MR} \cdot K_{t,10\,min} \cdot K_u \cdot K_{\theta,20} = 1{,}5 \cdot 1{,}1 \cdot 1{,}2 \cdot 1{,}0 = 1{,}98$

Leading wind combination, no snow load, duration: 10 minutes, temperature: 60^{o}:
$e)\ factor = \gamma_{MR} \cdot K_{t,10\,min} \cdot K_u \cdot K_{\theta,60} = 1{,}5 \cdot 1{,}1 \cdot 1{,}2 \cdot 1{,}5 = 2{,}97$

Leading snow combination, duration: 3 month, temperature: 20^{o}:
$f)\ factor = \gamma_{MR} \cdot K_{t,3\,month} \cdot K_u \cdot K_{\theta,20} = 1{,}5 \cdot 1{,}66 \cdot 1{,}2 \cdot 1{,}0 = 2{,}99$

The resulting bracket forces and utilization hereof are found in Table 10a to 10f for the load combinations. The bearing resistances of the brackets in the resulting angle are found by linear interpolation between the two neighboring bearing resistances, see Figure 2 and Table 8.

Table 10a, Brackets forces (resultants) and utilization for the characteristic load combination

a) Characteristic combi.	R_{1L}	R_{2L}	R_{2R}	R_{1R}
Characteristic bracket reaction [kN]	1,69	1,40	1,40	1,93
Angle according to Figure 1 [°]	2,0	176,4	133,6	30,6
Characteristic bearing resistance [kN]	7,58	9,67	9,20	8,72
Utilization [%]	22	14	15	22

Table 10b, Brackets forces (resultants) and utilization for the leading self-weight load combination

b) Leading self-weight	**R_{1L}**	**R_{2L}**	**R_{2R}**	**R_{1R}**
Design bracket reaction force [kN]	1,77	1,46	1,46	1,85
Angle according to Figure 1 [º]	6,3	179,9	130,1	27,2
Characteristic bearing resistance [kN]	7,75	9,70	8,94	8,59
Design bearing resistance [kN]	2,13	2,66	2,46	2,36
Utilization [%]	83	55	59	78

Table 10c, Brackets forces (resultants) and utilization for the leading self-weight, without snow load combination

c) Leading self-weight, no snow	**R_{1L}**	**R_{2L}**	**R_{2R}**	**R_{1R}**
Design bracket reaction force[kN]	1,35	1,04	1,04	1,21
Angle according to Figure 1 [º]	8,5	180,1	129,9	26,5
Characteristic bearing resistance [kN]	7,84	9,68	8,92	8,56
Design bearing resistance [kN]	1,44	1,78	1,64	1,57
Utilization [%]	94	58	63	77

Table 10d, Brackets forces (resultants) and utilization for the leading wind load combination

d) Leading wind	**R_{1L}**	**R_{2L}**	**R_{2R}**	**R_{1R}**
Design bracket reaction force [kN]	1,71	1,41	1,41	1,79
Angle according to Figure 1 [º]	359,3	183,4	126,6	33,9
Characteristic bearing resistance [kN]	7,43	9,19	8,68	8,85
Design bearing resistance [kN]	3,75	4,64	4,38	4,47
Utilization [%]	46	30	32	40

Table 10e, Brackets forces (resultants) and utilization for the leading wind, without snow load combination

e) Leading wind, no snow	R_{1L}	R_{2L}	R_{2R}	R_{1R}
Design bracket reaction force [kN]	1,29	0,99	0,99	1,15
Angle according to Figure 1 [º]	359,3	185,2	124,8	36,8
Characteristic bearing resistance [kN]	7,43	8,93	8,55	8,97
Design bearing resistance [kN]	2,50	3,01	2,88	3,02
Utilization [%]	51	33	35	38

Table 10f, Brackets forces (resultants) and utilization for the leading snow load combination

f) Leading snow	R_{1L}	R_{2L}	R_{2R}	R_{1R}
Design bracket reaction force [kN]	2,06	1,76	1,76	2,42
Angle according to Figure 1 [º]	3,5	177,6	132,4	28,6
Characteristic bearing resistance [kN]	7,64	9,68	9,11	8,64
Design bearing resistance [kN]	2,55	3,24	3,05	2,89
Utilization [%]	81	54	58	84

Bending in frame and casement profile

The bending in frame and casement profile is in this example only calculated for the leading snow combination, hereby showing the calculations procedure. Normally all load combination should be investigated.

Design capacity of frame and casement, duration: 3 month, temperature: 20º:

$$\sigma_{R,d} = \frac{\sigma_{R,k}}{\gamma_{MR} \cdot K_{t,3\,month} \cdot K_u \cdot K_{\theta,20^o}} = \frac{1257N/mm^2}{1{,}2 \cdot 1{,}66 \cdot 1{,}2 \cdot 1{,}0} = 526N/mm^2$$

(For characteristic bending strength see Table 3, for partial safety factors see Table 7a/ULS and for magnification and reduction factors see Table 7b/ULS.)

The characteristic line load from self-weight perpendicular to the roof window is denoted $g_{p,k}$ and perpendicular line load from the characteristic snow pressure is denoted $s_{p,k}$. The corrected height is applied but the original angle is used:

$$g_{p,k} = \frac{G_{VR,k} \cdot cos(\alpha)}{L_{cor}} = \frac{0{,}72 \ \cdot cos(25)}{2{,}543} = 0{,}26kN/m\,, \quad on\ each\ side\ frame/casement$$

$$q_{c,k} = 0{,}20kN/m\ on\ each\ Helo\ beam$$

$$s_{p,k} = 0{,}40kN/m \cdot \cos(\alpha) = 0{,}40kN/m \cdot \cos(25) = 0{,}36kN/m\,, \quad on\ each\ side\ frame/casement$$

$$M_d = \frac{1}{8} \cdot \left(\gamma_{G,sub} \cdot \xi_{G,sub} \cdot g_p + \gamma_{Q,i} \cdot \Psi_{0,wind} \cdot q_c + \gamma_{Q,1} \cdot s_p\right) \cdot L_{cor}^2$$

$$= \frac{1}{8} \cdot (1{,}35 \cdot 0{,}85 \cdot 0{,}26 + 1{,}5 \cdot 0{,}6 \cdot 0{,}20 + 1{,}5 \cdot 0{,}36) kN/m \cdot (2{,}543m)^2 = 0{,}82kNm$$

$$M_{frame,d} = M_d \cdot \frac{I_{frame}}{I_{frame}+I_{casement}} = 0{,}82kNm \cdot \frac{0{,}669}{0{,}669+0{,}930} = 0{,}34kNm$$

$$\sigma_{frame,d} \approx \frac{M_{frame,d}}{W_{y,frame}} = \frac{0{,}34 \cdot 10^6 Nmm}{9{,}93 \cdot 10^3 mm^3} = 34{,}2N/mm^2 \quad \ll \quad 526N/mm^2$$

$$M_{casement,d} = M_d \cdot \frac{I_{casement}}{I_{frame}+I_{casement}} = 0{,}82kNm \cdot \frac{0{,}930}{0{,}669+0{,}930} = 0{,}48kNm$$

$$\sigma_{frame,d} \approx \frac{M_{frame,d,}}{W_{y,frame}} = \frac{0{,}48 \cdot 10^6 Nmm}{16{,}4 \cdot 10^3 mm^3} = 29{,}3N/mm^2 \quad \ll \quad 526N/mm^2$$

Here, the characteristic bending strength is taken from Annex D.1 in ETA-17/0467. Second moment of area and section modulus are taken from Annex C.1 and C.4 in ETA-17/0467. The rotation of the main axis is ignored, as it has little influence on the result, and the resulting stress is much lower than the bending strength.

Shear force in frame profile

The shear force in frame profile is in this example only calculated for the leading snow combination, hereby showing the calculations procedure. Normally all load combination shall be investigated.

Design capacity shear stress of frame, duration: 3 month, temperature: 20^o:

$$\tau_{frame,R,d} = \frac{\tau_{frame,R,k}}{\gamma_{MR} \cdot K_{t,3\ month} \cdot K_u \cdot K_{\theta,20^o}} = \frac{53{,}8N/mm^2}{1{,}2 \cdot 1{,}66 \cdot 1{,}2 \cdot 1{,}0} = 22{,}5N/mm^2$$

(For characteristic shear strength see Table 3, for partial safety factors see Table 7a/ULS and for magnification and reduction factors see Table 7b/ULS.)

The shear force is generally taken in combination by the frame and casement profile, but near the ends of the roof window, the entire shear force is taken by the frame profile. The original angle is used. Largest shear force is in the right roof window in this example:

$$V_{frame} = R_{V1R} \cdot cos(\alpha) - R_{H1R} \cdot sin(\alpha)$$

$$= 1{,}94kN \cdot cos(25) - 1{,}44kN \cdot sin(25)$$

$$= 1{,}15kN$$

$$\tau_{frame} = \frac{V_{frame}}{A_{web}} \approx \frac{1{,}15 \cdot 10^3 N}{550mm^2} = 2{,}09N/mm^2 \quad \ll \quad 22{,}5N/mm^2$$

Here, the characteristic shear strength is taken from Annex D.1 and A_{web} from Annex C1 in ETA-17/0467.

Deflection

Deflections are checked for each side separately and perpendicular to the corrected roof window angle. 6 SLS load combinations can therefore be made:

g) Leading self-weight, with wind and snow
$G_{VR,k} + \Psi_{0,wind} \cdot Q_{c,k} + \Psi_{0,snow} \cdot S_{V,k}$ =>
$G_{VR,k} + 0{,}5 \cdot Q_{c,k} + 0{,}5 \cdot S_{V,k}$

h) Leading self-weight, with wind and without snow
$G_{VR,k} + \Psi_{0,wind} \cdot Q_{c,k}$ =>
$G_{VR,k} + 0{,}5 \cdot Q_{c,k}$

i) Leading wind pressure with snow
$G_{VR,k} + Q_{c,k} + \Psi_{0,snow} \cdot S_{V,k}$ =>
$G_{VR,k} + Q_{c,k} + 0{,}5 \cdot S_{V,k}$

j) Leading wind pressure without snow
$G_{VR,k} + Q_{c,k}$

k) Leading snow load
$G_{VR,k} + \Psi_{0,wind} \cdot Q_{c,k} + S_{V,k}$ =>
$G_{VR,k} + 0{,}6 \cdot Q_{c,k} + S_{V,k}$

l) Leading wind suction
$G_{VL,k} + Q_{s,k}$

The factors to find the design value of the deflection of the frame/casement are found from the formula given in chapter 2 and Table 7b. Duration is taken for the leading load, and temperature is taken for the highest it can be, 20° when snow and 60° when no snow.

Leading self-weight, with wind and snow, duration 25 years, temperature: 20°:
$g)\ factor = \gamma_{MC} \cdot C_{t,25\ years} \cdot C_u \cdot C_{\theta,20^o} = 1{,}1 \cdot 1{,}15 \cdot 1{,}2 \cdot 1{,}0 = 1{,}52$

Leading self-weight, with wind and without snow, duration 25 years, temperature: 60°:
$h)\ factor = \gamma_{MC} \cdot C_{t,10min} \cdot C_u \cdot C_{\theta,20^o} = 1{,}1 \cdot 1{,}15 \cdot 1{,}2 \cdot 1{,}05 = 1{,}59$

Leading wind pressure with snow, duration: 10 minutes, temperature: 20°:
$i)\ factor = \gamma_{MC} \cdot C_{t,10min} \cdot C_u \cdot C_{\theta,20^o} = 1{,}1 \cdot 1{,}02 \cdot 1{,}2 \cdot 1{,}0 = 1{,}35$

Leading wind pressure without snow, duration: 10 minutes, temperature: 60°:
$j)\ factor = \gamma_{MC} \cdot C_{t,10min} \cdot C_u \cdot C_{\theta,60^o} = 1{,}1 \cdot 1{,}02 \cdot 1{,}2 \cdot 1{,}05 = 1{,}41$

Leading snow load, duration: 3 month, temperature: 20°:
$k)\ factor = \gamma_{MC} \cdot C_{t,3\ month} \cdot C_u \cdot C_{\theta,20^o} = 1{,}1 \cdot 1{,}11 \cdot 1{,}2 \cdot 1{,}0 = 1{,}47$

Leading wind suction, duration: 10 minutes, temperature: 60°:
$l)\ factor = \gamma_{MC} \cdot C_{t,10min} \cdot C_u \cdot C_{\theta,60^o} = 1{,}1 \cdot 1{,}02 \cdot 1{,}2 \cdot 1{,}05 = 1{,}41$

(For partial safety factors see Table 7a/SLS and for magnification and reduction factors see Table 7b/SLS).

Characteristic Self-weight perpendicular to the corrected roof window angle:

$$g_{p,cor,k} = \frac{G_V \cdot cos(\alpha_{cor})}{L_{cor}} = \frac{0{,}72\ \cdot cos(24{,}3)}{2{,}543} = 0{,}26kN/m\ ,\ \ on\ each\ side\ frame/casement$$

Characteristic wind pressure and suction perpendicular to the corrected roof window angle:

$$q_{c,cor,k} = 0{,}20kN/m \cdot \cos(-\Delta\alpha) = 0{,}2kN/m \cdot \cos(0{,}7) = 0{,}20kN/m\ ,\ \ on\ each\ side\ frame/casement$$

Characteristic snow load perpendicular to the corrected roof window angle:

$$s_{p,cor,k} = 0{,}40kN/m \cdot \cos(\alpha_{cor})^2 = 0{,}40kN/m \cdot \cos(24{,}3) = 0{,}33kN/m\ ,\ \ on\ each\ side\ frame/casement$$

In the deflection calculations the *second moment of area are found in* ETA-17/0467 *Annex C and for E-modulus see Table 3 including note 3*

g) Deflection for leading self-weight, with wind and snow

$$u = \frac{5}{384} \cdot \frac{(g_{p,cor,k} + \Psi_{0,wind} \cdot q_{c,cor,k} + \Psi_{0,snow} \cdot s_{p,cor,k}) \cdot L_{cor}^4}{E \cdot (I_{frame} + I_{casement})} \cdot 1{,}52$$

$$= \frac{5}{384} \cdot \frac{(0{,}26 + 0{,}6 \cdot 0{,}20 + 0{,}5 \cdot 0{,}33) N/mm \cdot (2543 mm)^4}{41600 N/mm^2 \cdot 0{,}83 \cdot (0{,}669 \cdot 10^6 mm^4 + 0{,}930 \cdot 10^6 mm^4)} \cdot 1{,}52 = 8{,}2 mm < \frac{L_{cor}}{150} = 17\, mm$$

h) Deflection for leading self-weight, with wind and without snow

$$u = \frac{5}{384} \cdot \frac{(g_{p,cor,k} + \Psi_{0,wind} \cdot q_{c,cor,k}) \cdot L_{cor}^4}{E \cdot (I_{frame} + I_{casement})} \cdot 1{,}59$$

$$= \frac{5}{384} \cdot \frac{(0{,}26 + 0{,}6 \cdot 0{,}20) N/mm \cdot (2543 mm)^4}{41600 N/mm^2 \cdot 0{,}83 \cdot (0{,}669 \cdot 10^6 mm^4 + 0{,}930 \cdot 10^6 mm^4)} \cdot 1{,}59 = 6{,}0 mm < \frac{L_{cor}}{150} = 17\, mm$$

i) Deflection for leading wind pressure with snow:

$$u = \frac{5}{384} \cdot \frac{(g_{p,cor,k} + q_{c,cor,k} + \Psi_{0,snow} \cdot s_{p,cor,k}) \cdot L_{cor}^4}{E \cdot (I_{frame} + I_{casement})} \cdot 1{,}35$$

$$= \frac{5}{384} \cdot \frac{(0{,}26 + 0{,}20 + 0{,}5 \cdot 0{,}33) N/mm \cdot (2543 mm)^4}{41600 N/mm^2 \cdot 0{,}83 \cdot (0{,}669 \cdot 10^6 mm^4 + 0{,}930 \cdot 10^6 mm^4)} \cdot 1{,}35 = 8{,}3 mm < \frac{L_{cor}}{150} = 17\, mm$$

j) Deflection for leading wind pressure without snow:

$$u = \frac{5}{384} \cdot \frac{(g_{p,cor,k} + q_{c,cor,k}) \cdot L_{cor}^4}{E \cdot (I_{frame} + I_{casement})} \cdot 1{,}41$$

$$= \frac{5}{384} \cdot \frac{(0{,}26 + 0{,}20) N/mm \cdot (2543 mm)^4}{41600 N/mm^2 \cdot 0{,}83 \cdot (0{,}669 \cdot 10^6 mm^4 + 0{,}930 \cdot 10^6 mm^4)} \cdot 1{,}41 = 6{,}4 mm < \frac{L_{cor}}{150} = 17\, mm$$

k) Deflection for leading snow load:

$$u = \frac{5}{384} \cdot \frac{(g_{p,cor,k} + \Psi_{0,wind} \cdot q_{c,cor,k} + s_{p,cor,k}) \cdot L_{cor}^4}{E \cdot (I_{frame} + I_{casement})} \cdot 1{,}47$$

$$= \frac{5}{384} \cdot \frac{(0{,}26 + 0{,}6 \cdot 0{,}20 + 0{,}33) N/mm \cdot (2543 mm)^4}{41600 N/mm^2 \cdot 0{,}83 \cdot (0{,}669 \cdot 10^6 mm^4 + 0{,}930 \cdot 10^6 mm^4)} \cdot 1{,}47 = 10{,}3 mm < \frac{L_{cor}}{150} = 17\, mm$$

l) Since the self-weight is larger than the wind suction, the combination with wind suction as is not investigated.
Note: For a suction load, only the second moment of area of the casement is used when calculating the deflection for an openable window.