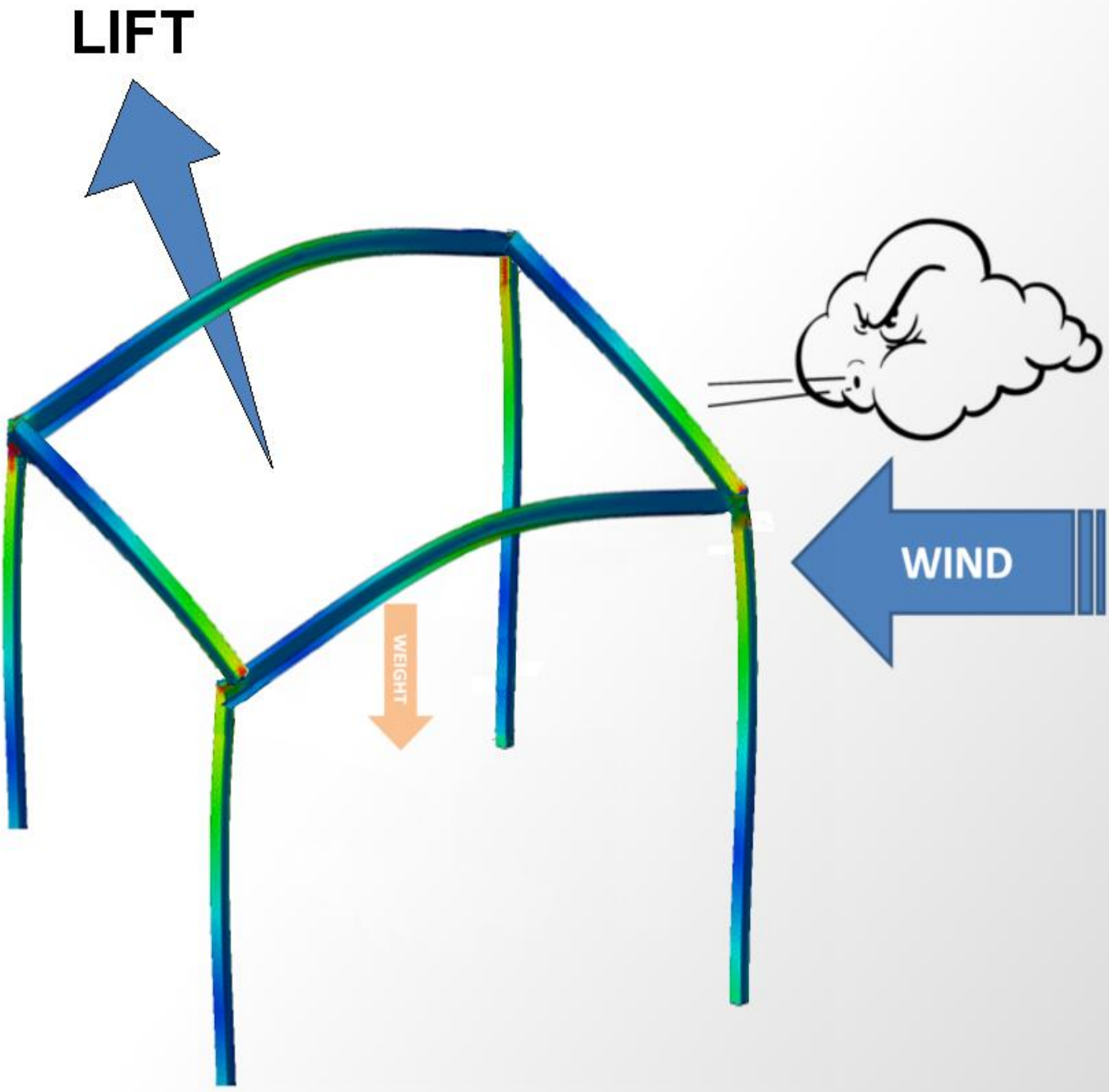


Wind strength

Wind strength assessment for retractable pergolas

One area of concern for pergola installations is their capacity to overcome wind forces. Especially in Japan, a place where very strong winds are common, the wind strength of the pergolas is of paramount importance.

1. DESIGN BASIS

For the assessment the wind strength, the following standards are used:

- Ministry of Construction Notification 1454 – 1458
- Ministry of Land, Infrastructure and Transport Notification No. 408, 409, 410 and 607.

Aluminium calculations are done based on the Building Standard Code
The pergolas are self standing without surrounding walls

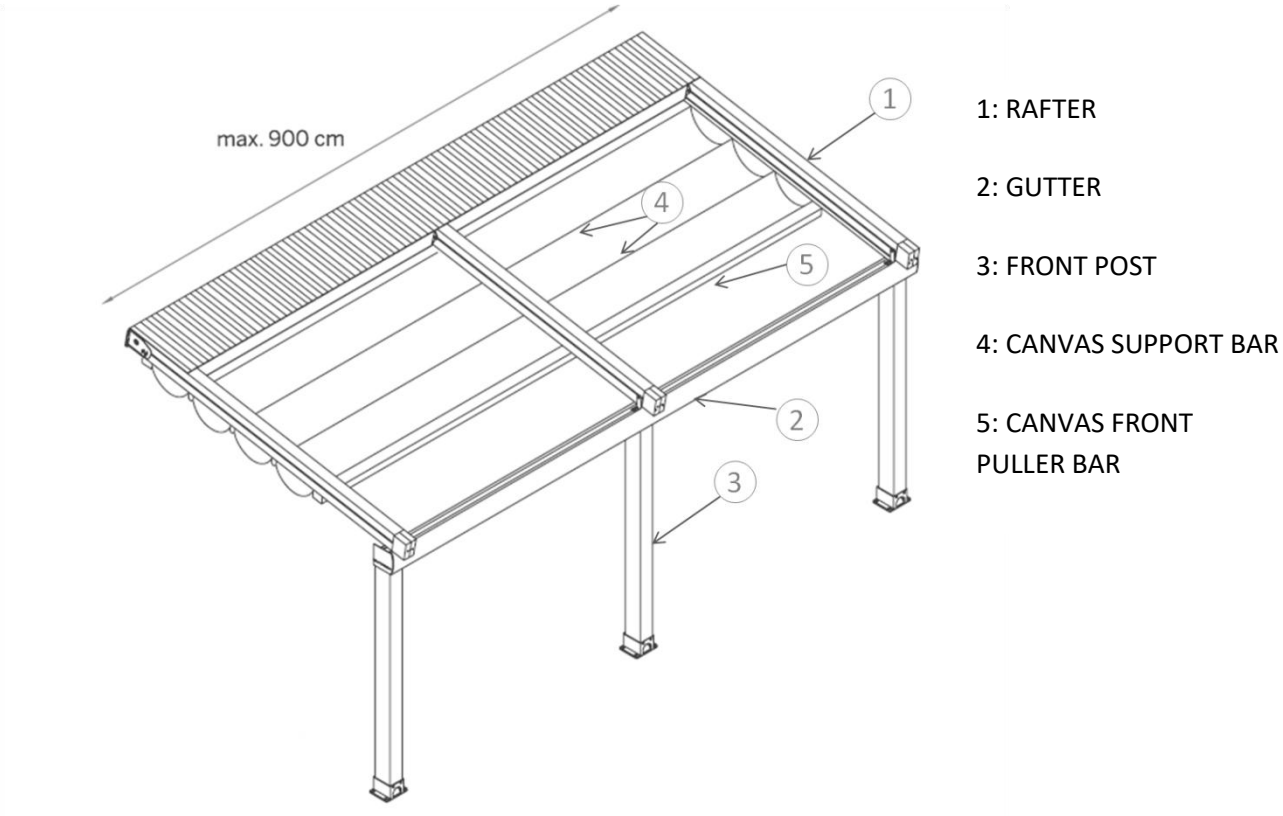
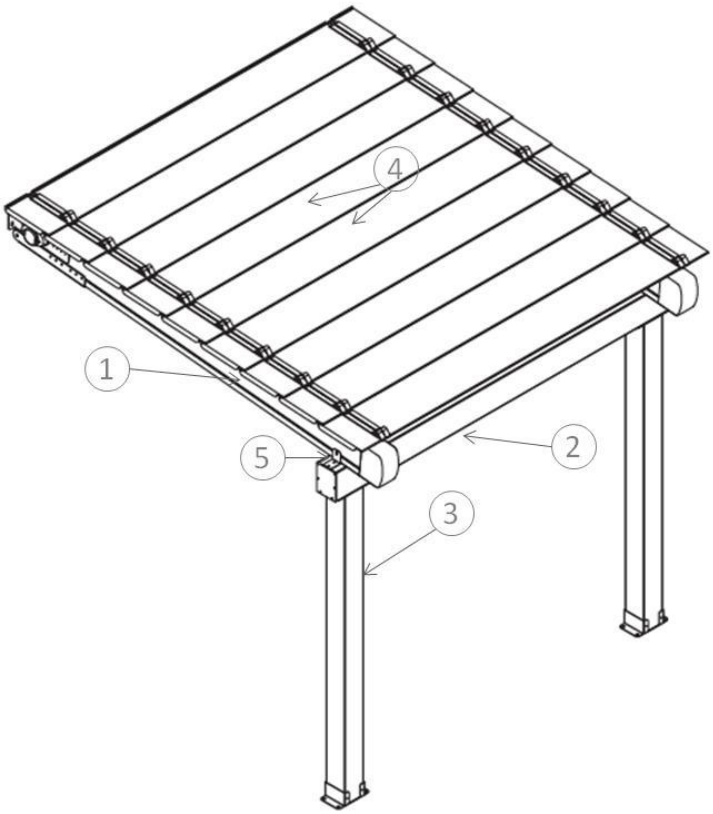


Fig.1 Skycover straight pergola: PVC canvas retractable pergola , back support not shown Systems 1,2,3



1: RAFTER

2: FRONT BEAM

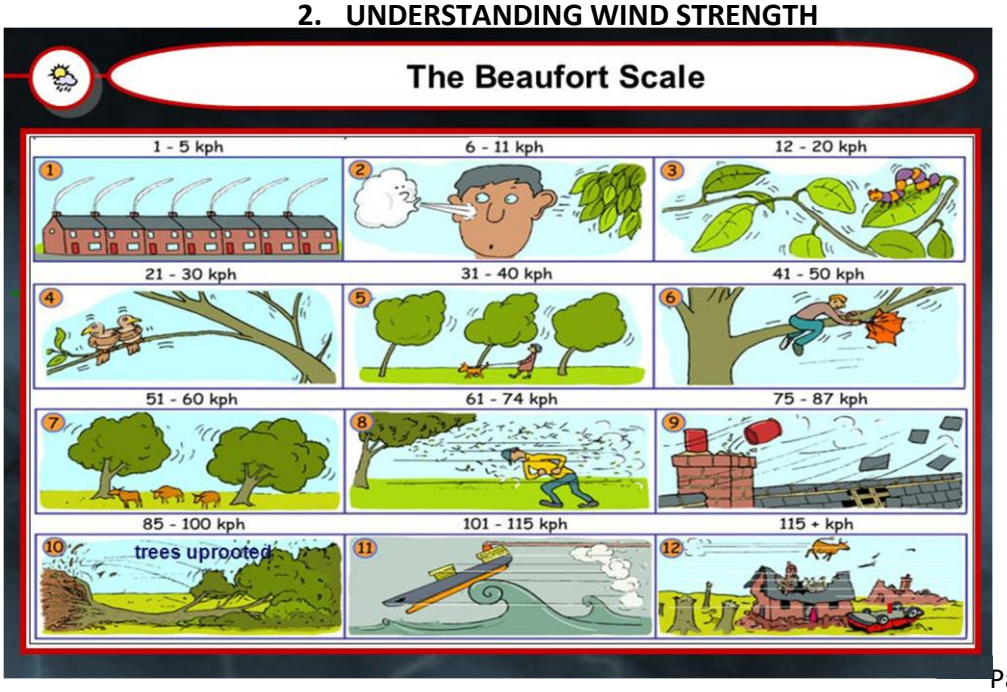
3: FRONT POST

4: ALUMINIUM LOUVERS

5: RAFTER/POST BRACKET

Fig.2: Skycover premium model Persa: aluminum louver rertractable pergola, back support not shown. System 4

2. UNDERSTANDING WIND STRENGTH



Beaufort number	Description	Wind speed	Land conditions
0	Calm	< 1 km/h < 0.3 m/s	Smoke rises vertically.
1	Light air	1–5 km/h 0.3–1.5 m/s	Direction shown by smoke drift but not by wind vanes.
2	Light breeze	6–11 km/h 1.6–3.3 m/s	Wind felt on face; leaves rustle; wind vane moved by wind.
3	Gentle breeze	12–19 km/h 3.4–5.5 m/s	Leaves and small twigs in constant motion; light flags extended.
4	Moderate breeze	20–28 km/h 5.5–7.9 m/s	Raises dust and loose paper; small branches moved.
5	Fresh breeze	29–38 km/h 8–10.7 m/s	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	Strong breeze	39–49 km/h 10.8–13.8 m/s	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	High wind, near gale	50–61 km/h 13.9–17.1 m/s	Whole trees in motion; inconvenience felt when walking against the wind.
8	Gale, fresh gale	62–74 km/h 17.2–20.7 m/s	Twigs break off trees; generally impedes progress.
9	Strong/severe gale	75–88 km/h 20.8–24.4 m/s	Slight structural damage (chimney pots and slates removed).
10	Storm whole gale	89–102 km/h 24.5–28.4 m/s	Seldom experienced inland; trees uprooted; considerable structural damage.
11	Violent storm	103–117 km/h 28.5–32.6 m/s	Very rarely experienced; accompanied by widespread damage.
12	Hurricane force	≥ 118 km/h	Devastation.

Fig.3a,b: The Beaufort scale

3. CALCULATING WIND PRESSURE

The wind pressure increases with the square of wind velocity, proximity to the coast (terrain) and elevation.

For more detailed reading, the APPENDIX shows the detailed calculations. Further details can be provided for orders

4. WIND STRENGTH PERFORMANCE OF SYSTEMS

4.1 Gerneral

The strength of aluminium frame components, (rafter, gutter, posts, support and puller bars and alumnium louvers for persa) and of the steel brackets/base plates of the retractable pergolas are verified against bending or buckling, lateral and local, Figs 3,4. The weakest performance is accounted for.

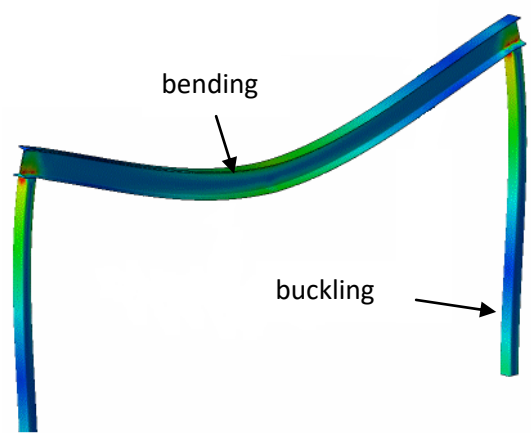


Fig.4 Deformation of aluminum frame

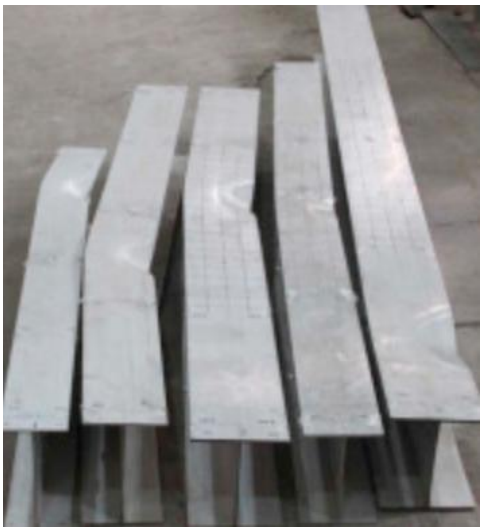


Fig.5 Buckling of 6063 aluminum

4.2 Wind strength results

The results for the four systems are presented below.

The width is examined from 3m to 13m and the projection from 3m to 10m (6.5m for PERSA). All systems are self standing and no side is closed.

A 2nd floor installtion, (H=10m) inland and at the coast and a 9th floor (H=35m) floor installation inland are presented

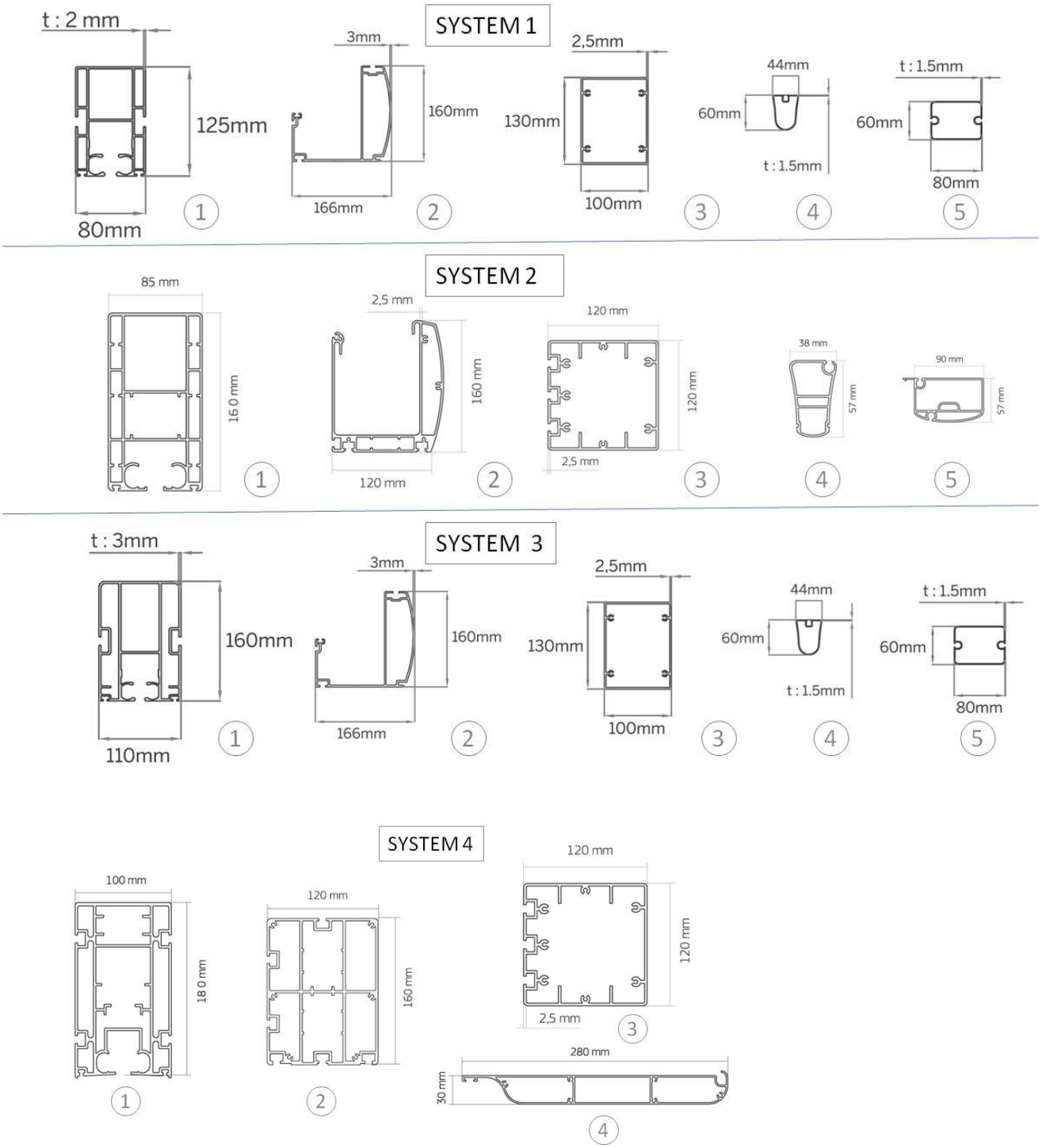


Fig.5 The four pergola configurations. Systems 1,2,3 shown Fig.1, System 4 shown Fig.2

CASE 1:

Height, H=10m, inland

System 1:
STRAIGHT with 125mm X 80mm rafter

		最高風速 maximum wind speed, m/sec										
		出幅 projection,m										
		3	4	5	6	7	8	9	10	11	12	13
幅 width, m	3	34	34	34	34	34	34	34	34	34	34	34
	4	34	34	34	32.6	32.6	30	28.5	32.6	30	30	28.5
	5	34	33	30	28.5	24.5	24.5	22	26	26	24.5	22
	6	30	26	26	22	22	20.8	18	22	22	20.8	18
	7	26	24.5	22	20.8	18	18	17.2	18	18	18	18
	8	22	20.8	18	18	17.2	13.9	13.9	18	17.2	13.9	13.9
	9	20.8	18	17.2	13.9	13.9	13.9	13.9	12	13.9	13.9	13.9
	10	18	17.2	13.9	13.9	13.9	13.9	12	13.9	13.9	13.9	10.8

System 2:
STRAIGHT with 160mm X 85mm rafter

		最高風速 maximum wind speed, m/sec										
		出幅 projection,m										
		3	4	5	6	7	8	9	10	11	12	13
幅 width, m	3	34	34	34	34	34	34	32	34	34	34	34
	4	34	34	34	34	34	30	30	34	34	30	30
	5	34	34	32.6	30	26	26	24.5	26	26	26	24.5
	6	34	28.5	24.5	22	20.8	18	18	22	22	18	18
	7	30	26	22	22	18	18	18	20.8	18	18	18
	8	26	22	20.8	18	18	17.2	13.9	18	17.2	17.2	13.9
	9	22	20.8	18	17.2	13.9	13.9	13.9	13.9	13.9	13.9	13.9
	10	18	17.2	17.2	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9

System 3:
STRAIGHT with 160mm X 110mm rafter

		最高風速 maximum wind speed, m/sec										
		?? projection,m										
		3	4	5	6	7	8	9	10	11	12	13
? width, m	3	34	34	34	34	34	34	34	34	34	34	34
	4	34	34	34	34	34	34	34	34	34	34	34
	5	34	34	34	34	32.6	30	28.5	32.6	30	30	28.5
	6	34	34	32.6	28.5	26	26	24.5	26	26	26	24.5
	7	34	30	26	24.5	22	22	20.8	24.5	22	22	20.8
	8	30	26	24.5	22	20.8	18	18	18	18	18	18
	9	26	24.5	22	18	18	18	17.2	18	18	18	17.2
	10	22	22	18	18	17.2	13.9	13.9	17.2	18	13.9	13.9

System 4:
PERSA with 180mmX100mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	34	34	34	34	34
4	34	34	34	34	34	34	34	34	34	34	34
5	34	34	34	34	34	34	34	34	34	34	34
6	34	34	34	34	34	34	34	34	34	34	34
7	34	34	32.7	30	34	30	30	30	30	30	30

Remarks:

Livingbetter does not furnish 125mm x 80mm rafter beyond 6m projection, better use the stronger rafter, results are displayed for comparison purposes

PERSA is the choice for “very windy” or elevated installations. PERSA can also withstand snow.

Livingbetter will evaluate the strength of the system according to the site condistions and will propose the most suitable solutions

CASE 2:

Height, H=10m, coastal

System 1:
STRAIGHT with 125mm X 80mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	34	34	34	34	34
4	34	34	30	30	26	24.5	24.5	28.5	26	26	24.5
5	32.6	26	26	22	22	20.8	22	22	22	20.8	17.2
6	26	20.8	20.8	18	17.2	13.9	13.9	17.2	13.9	13.9	13.9
7	22	18	18	17.2	13.9	13.9	13.9	13.9	13.9	13.9	13.9
8	18	17.2	17.2	13.9	13.9	13.9	12	13.9	13.9	13.9	12
9	17.2	13.9	13.9	13.9	12	12	12	13.9	12	12	12
10	13.9	13.9	13.9	12	12	10.8	10.8	12	12	10.8	10.8

System 2:
STRAIGHT with 160mm X 85mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	34	34	34	34	34
4	34	34	33	30	28.5	26	26	28.5	26	26	24.5
5	34	30	26	24.5	22	20.8	18	22	22	20.8	20.8
6	28.5	24.5	22	20.8	18	18	17.2	18	18	18	18
7	24.5	22	18	18	17.2	13.9	13.9	17.2	13.9	13.9	13.9
8	22	18	18	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9
9	18	17.2	13.9	13.9	13.9	12	12	13.9	13.9	12	12
10	18	13.9	13.9	13.9	12	12	10.8	12	12	12	12

System 3:
STRAIGHT with 160mm X 110mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	32	34	34	34	34
4	34	34	34	34	34	30	30	34	32.6	30	30
5	34	34	32.6	30	26	24.5	24.5	30	26	26	24.5
6	34	30	26	24.5	22	20.8	20.8	26	22	22	20.8
7	30	26	22	20.8	18	17.2	18	22	18	18	18
8	26	22	20.8	18	18	13.9	13.9	18	17.2	13.9	13.9
9	22	20.8	18	17.2	13.9	13.9	13.9	18	13.9	13.9	13.9
10	20.8	18	17.2	13.9	13.9	12	12	13.9	13.9	13.9	12

System 4:
PERSA with 180mmX100mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	34	34	34	34	34
4	34	34	34	34	34	34	34	34	34	34	34
5	34	34	34	34	34	34	34	34	34	34	34
6	34	34	34	34	32.7	30	34	34	28.5	32.7	30
6.5	26	32.7	28.5	26	28.5	28.5	26	28.5	28.5	26	28.5

<u>Remarks:</u>

Livingbetter does not furnish 125mm x 80mm rafter beyond 6m projection, better use the stronger rafter, results are displayed for comparison purposes

PERSA is the choice for “very windy” or elevated installations. PERSA can also withstand snow.

Livingbetter will evaluate the strength of the system according to the site condistions and will propose the most suitable solutions

CASE3:

Height=35m, inland

System 1:
STRAIGHT with 125mm X 80mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	32.6	30	34	34	32.6	30
4	34	34	30	28.5	26	24.5	22	24.5	24.5	24.5	24.5
5	32.6	28.5	24.5	22	22	20.8	18	20.8	20.8	18	18
6	26	20.8	18	18	13.9	13.9	13.9	13.9	13.9	13.9	13.9
7	22	20.8	17.2	17.2	13.9	13.9	13.9	13.9	13.9	13.9	13.9
8	18	17.2	13.9	13.9	13.9	13.9	12	13.9	13.9	13.9	12
9	17.2	13.9	13.9	13.9	12	12	12	12	12	12	12
10	13.9	13.9	13.9	12	12	10.8	10.8	12	12	10.8	10.8

System 2:
STRAIGHT with 160mm X 85mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	33	34	34	34	32.6
4	34	34	33	30	28.5	26	22	28.5	26	26	24.5
5	34	28.5	26	22	22	20.8	20.8	22	22	22	20.8
6	28.5	24.5	22	18	18	18	17.2	18	18	18	18
7	24.5	22	18	18	13.9	13.9	17.2	18	18	18	18
8	22	18	17.2	13.9	13.9	13.9	12	13.9	13.9	13.9	13.9
9	18	17.2	13.9	12	12	12	12	12	12	12	12
10	17.2	13.9	13.9	10.8	12	12	10.8	12	12	12	10.8

System 3:
STRAIGHT with 160mm X 110mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	32	34	34	34	34
4	34	34	34	34	34	32.6	30	34	34	32.6	30
5	34	34	32.6	30	26	26	24.5	28.5	26	26	24.5
6	34	30	26	24.5	22	22	20.8	22	22	22	22
7	30	26	22	22	18	18	18	20.8	18	18	18
8	26	22	20.8	18	18	17.2	13.9	18	17.2	17.2	13.9
9	22	20.8	18	17.2	13.9	13.9	13.9	13.9	13.9	13.9	13.9
10	22	18	17.2	13.9	13.9	12	12	13.9	13.9	13.9	12

System 4:
PERSA with 180mmX100mm rafter

幅 width, m	最高風速 maximum wind speed, m/sec 出幅 projection,m										
	3	4	5	6	7	8	9	10	11	12	13
3	34	34	34	34	34	34	34	34	34	34	34
4	34	34	34	34	34	34	34	34	34	34	34
5	34	34	34	34	34	34	34	34	34	34	34
6	34	34	34	28.5	28.5	30	34	34	28.5	28.5	30
6.5	26	30	28.5	26	28.5	28.5	26	28.5	26	26	28.5

Remarks:

Livingbetter does not furnish 125mm x 80mm rafter beyond 6m projection, better use the stronger rafter, results are displayed for comparison purposes

PERSA is the choice for “very windy” or elevated installations. PERSA can also withstand snow.

Livingbetter will evaluate the strength of the system according to the site condistions and will propose the most suitable solutions

APPENDIX

Detailed calculations

Wind loads for no damage design are given by the following formulas. The formula for structural frames is

$$W_f = 0.6 E_r G_f V_o^2 C_f \quad (1)$$

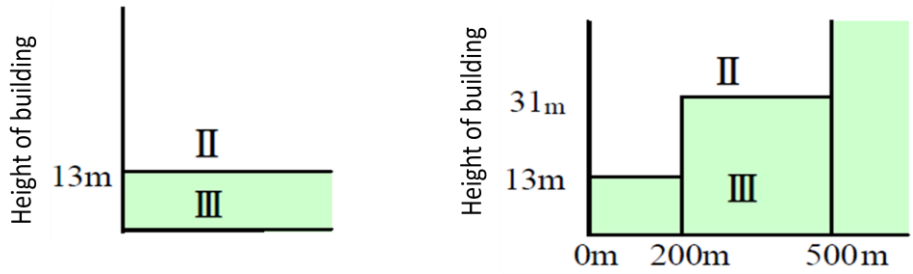
where, W_f = wind load (N/m^2),
E_r =vertical distribution coefficient for mean wind speed,
G_f =gust effect factor,
V_0 = datum wind speed (m/s) and C_f =wind force coefficient.

While the formula for external building components is

$$W_c = q\, C_f \quad (2)$$

where, W_c = wind load (N/m_2),
q =mean velocity pressure $0.6 E_r V_o^2$= and C_f =peak wind force coefficient.

The terrain categories in Japan are:



Outside of city planning Inside city planning

Fig.a: Categories of exposure factor

The area of Category I is designated in the area of Category II and the area of Category IV is designated in III by regional governments

The vertical distribution coefficient E_r for mean wind speed is determined by

$E_r = 1.7\,(Z_b/Z_G)^a$ H<= Z_b and

$E_r = 1.7\,(H/Z_G)^a$ H> Z_b (3)

where, H = mean height of roof, and the other parameters are shown in table 1.

Terrain category	Z_b (m)	$Z_G(m)$	α
I	5	250	0.10
II	5	350	0.15
III	5	450	0.20
IV	10	550	0.27

Table 1: Parameters of E_r

The Gust effect factor is G_f given by

Terrain category	Mean height of roof		
	H≤10m	10<H<40m	40m≤H
I	2.0	due to linear interpolation	1.8
II	2.2		2.0
III	2.5		2.1
IV	3.1		2.3

Table 2: Parameters of G_f

	windward		leeward	
*計算用	positive	negative	positive	negative
cf(10)	0.6	-1	0.2	-0.8
cf(30)	0.9	-0.5	0	-1.5

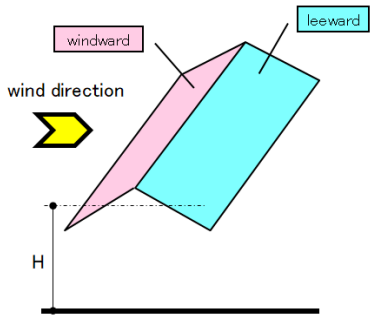


Figure b: Wind coefficent with roof slope

Therefore for a straight pergola, with slope less than 10° installed on the second floor of a building (H=10m) we have:

H=10m, Width W=9m, Projection L=5m

$E_r = 1.7\ (H/Z_G)^a$ H> Z_b , $E_r = 0.794$

$G_f = 2.5$

C_f=-1 (uplift)

We will use V_o =34m/sec which is the datum wind speed for roofs in the Kanto region. The design wind speed varies in Japan according to the region

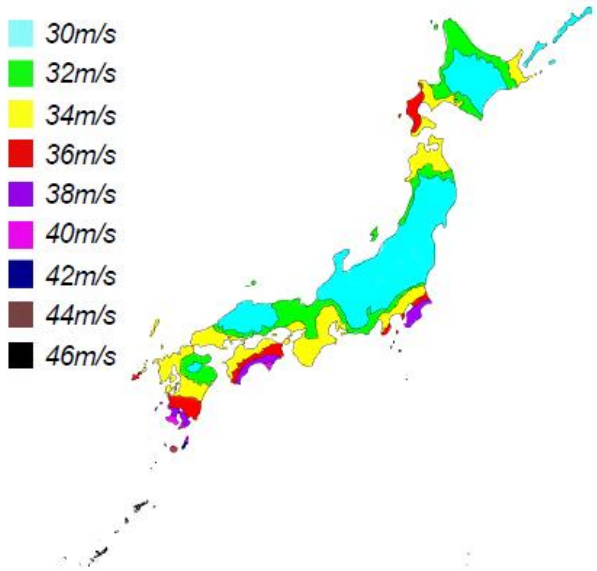


Fig.c: Datum wind speed in Japan

Then

$W_f = 0.6 E_r G_f V_o^2 C_f$, $W_f = 1093 N/m^2$

For component design,

0.1a'= 0.5m

For region 1: $W_f = 1749 N/m^2$ applicable for example to gutter, back beam and front puller bar

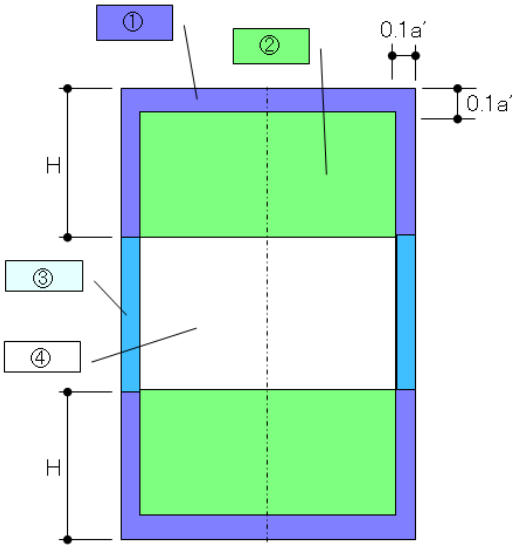


Fig.d: Area designation for component design

1. PVC canvas models

1.1 Design Basis

1.1.1 System properties:

System: STRAIGHT

System width = 9m
Tributary width= 4.5m (largest width supported by rafter upon which wind load is acting)
Projection=5m (rafter length)
Height (average system height) = 10m
Slope for calculations = 7^{o}

Component under review: RAFTER 125mm x 80mm (aluminum T6063 T5):
Aluminum Tensile strength= 165Mpa

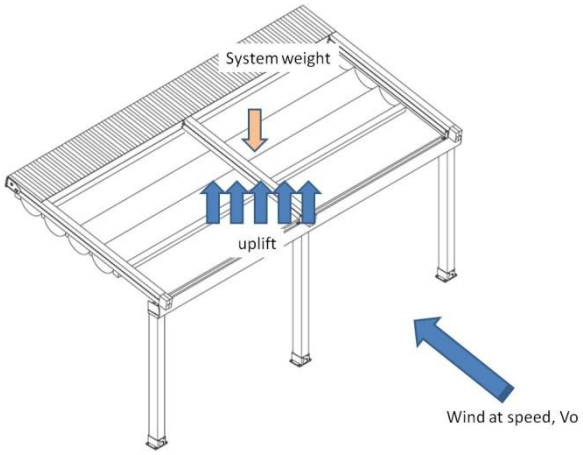
For these conditions, among bending, lateral and local buckling, the lowest value of maximum allowable stress is found for lateral buckling:

Maximum allowable stress : σ_{MAX}=106MPa

1.2 **Calculations**

The wind loading per unit length w (in kN/m) is calculated using the tributary width s =4.5m
P= W_f x s = 1.093 Kn/m^2 x 4.5m = 4.92Kn/m

Rafter dead load: 0.054KN/m
Fabric and support bars dead load: 0.20KN/m



Net uplift -4.67Kn/m
Maximum moment is M=14.59Knm
Maximum stress : σ=-M/Zx = 229.0Mpa
Check 233.1Mpa/106Mpa= 2.16 KO

The safe wind speed for the above configuration,
see 4.1 Case 1, System 1 is 22m/sec
P = 0.458 Kn/m^2 x 4.5m = 2.06Kn/m
Net uplift -1.81Kn/m
Maximum moment is M=5.66Knm
Maximum stress : σ= M/Zx = 88.8Mpa
Check 88.8Mpa/106Mpa= 0.84 OK

The rest of the components are simiarly evaluated one by one.

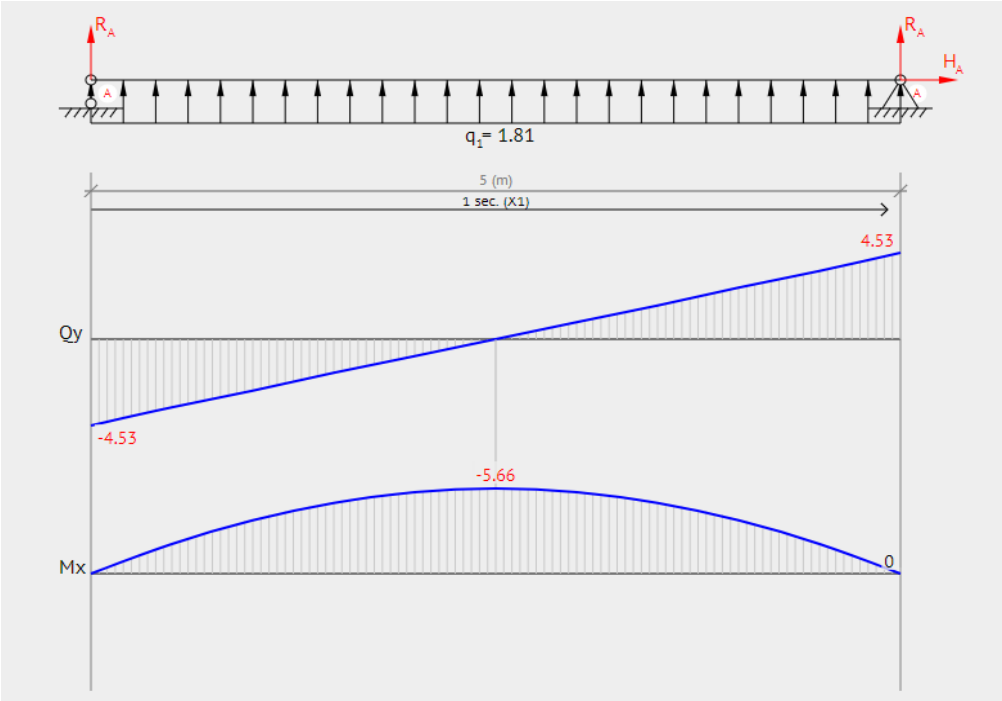


Fig.f: 5m long and wind speed 22m/sec rafter laoding