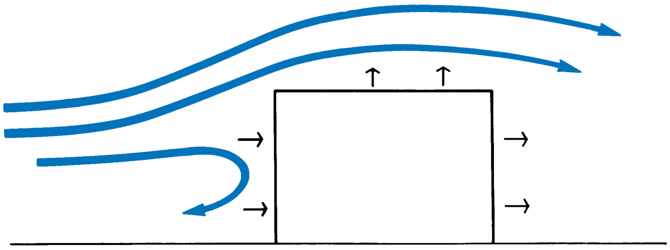
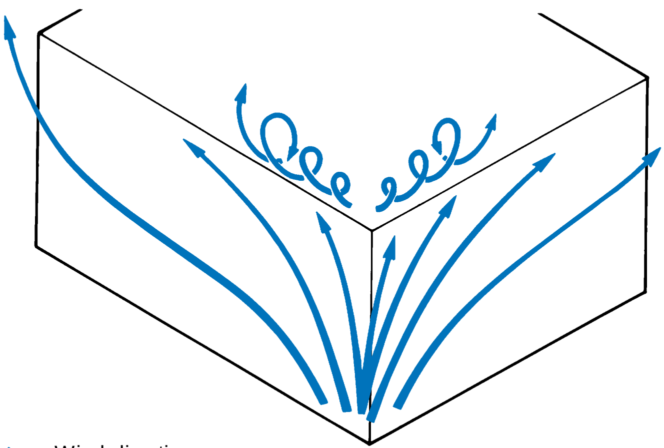
1.6 WIND

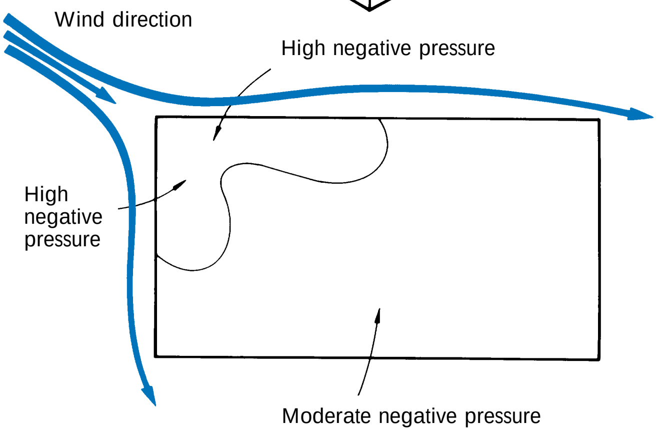
INTRODUCTION

Protection against wind forces should be one of the fundamental principles behind good roofing design. When wind strikes a building, it is deflected to generate a positive pressure on the windward face, and it accelerates round the side of the building and over the roof, leading to a reduced, or negative pressure over the roof and in the lee of the building.



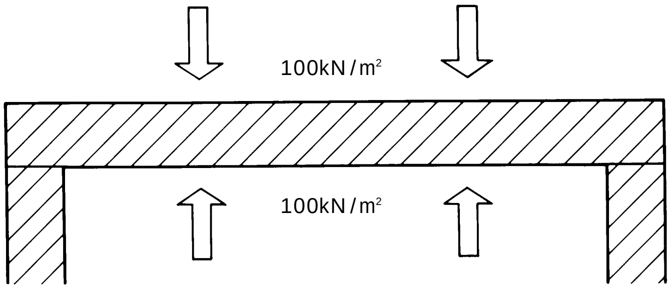
Distribution of pressure over the roof is far from uniform, even for the simple box type structure illustrated. The wind does not normally strike square to the face of a building. When, as is more usual, it strikes at an oblique angle, the air deflected up and over the roof is at the same time moving along the face of the building, creating vortices along the roof edges. The greatest wind pressures are experienced at the windward corners and edges of the roof, where the negative pressure can be several times that experienced in the central areas.





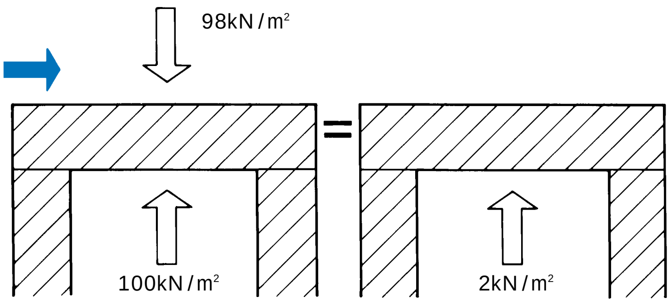
THE CRITICAL LAYER

When there is no wind the air pressure on the upper surface of a roofing system is the same as that on the underside. This will be normal atmospheric pressure, which is in the order of 100kN / m^2. The upward pressure is balanced by the downward pressure and there are no forces acting on the roof covering.



Wind changes this equilibrium by reducing the atmospheric pressure on top of the roofing system. The atmospheric pressure on the underside of the roof will remain the same or may be increased if windows or doors are open on the windward side of the building. The result is a net upward pressure, or push, acting on the underside of the roofing system, not in any sense the wind pulling at the roofing system from above.

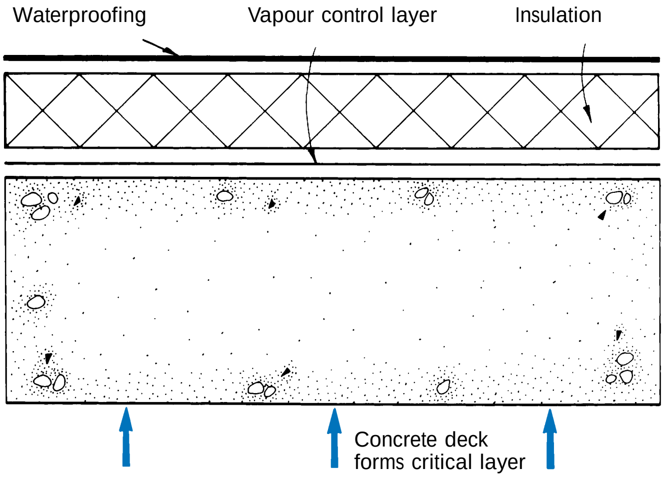
For example, if the wind reduces the atmospheric pressure on the top of the roof to say 98kN / m^2 whilst the atmospheric pressure on the underside remains at 100kN / m^2 then the result is an upward thrust of 2kN / m^2 acting on the underside of the roofing system.



The importance of understanding this basic concept lies in the need to provide secure attachment at the correct position to withstand this upward thrust wherever it occurs. The thrust will be exerted on the lowest air impermeable layer in the roof which will stop air from flowing further into the system. In most roof constructions there is one layer which provides the dominant barrier against the upward thrusting flow of air, and this is referred to as the critical layer. The attachment of this layer is referred to as the critical attachment.

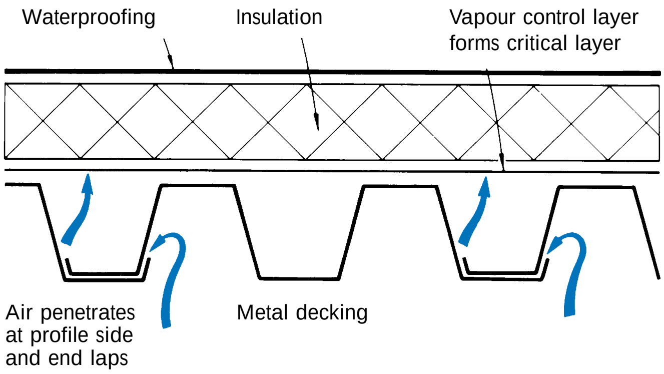
A flat roof is composed of many layers of material and it is essential to decide which of these is the first air impermeable barrier to form the critical layer and require the critical attachment. The critical layer will sometimes be the roof deck itself, sometimes a vapour control layer or thermal insulation and sometimes the waterproof covering. This is best illustrated by considering a few typical roof constructions.

Concrete deck with insulation and waterproofing with or without a vapour control layer



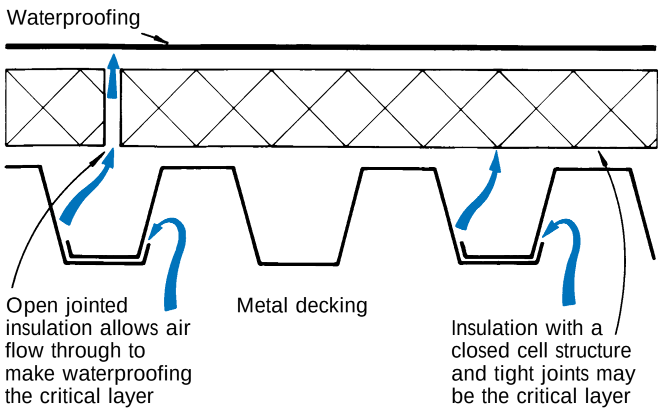
The first air impermeable layer is clearly the concrete deck itself. This will take the resultant wind thrust direct, and as there is no critical layer of attachment above the deck, the roofing specification is at minimum risk.

Metal decking with a vapour control layer, insulation and waterproof covering



The metal deck itself can be taken as permeable to air through the profile side and end laps. The first impermeable layer in this case is the vapour control layer and it is the attachment of this layer to the top flats of the deck which is the critical attachment.

Metal decking with insulation and waterproof covering but no vapour control layer



In the absence of a vapour control layer there are two contenders for the critical layer. The first air impermeable layer will be the insulation if the joints are reasonably tight and the insulation is of a closed cell structure. If the insulation is open jointed and allows air through the joints to the underside of the membrane, the waterproof covering will then be the first impermeable layer. If in addition the waterproofing is partially bonded, a flow of air beneath the membrane will be allowed and will exert a high pressure on the underside of the entire membrane.

In practice the insulation will probably restrict the flow of air to the extent that it will take most of the air pressure. Enough air may, however, pass through the joints to make the membrane an equally critical layer and unless there is some over-riding factor it would be wise to treat the attachment of both insulation and waterproofing as critical.

INTERMEDIATE LAYERS OF ATTACHMENT

Having identified the critical layer it must be firmly attached so that wind loads are transferred back to the roof deck where necessary. Consideration then needs to be given to the attachment of layers of the roof construction above the critical layer. Waterproofing specifications will either be loose laid such as mastic asphalt or partially or fully bonded as for built-up roofing and most insulation layers. There is only a high risk of wind damage at intermediate layers if air can flow to the underside of that layer. This flow of air must be prevented by closing off the edges of the roof by the suitable formation of edge details and edge bonding.

Under some circumstances, certain specifications allow for only minimal forms of attachment or for completely unattached waterproofing. The prime example is mastic asphalt which is applied over a loose-laid sheathing felt, leaving no form of attachment to the deck. The self-weight of asphalt waterproofing is approximately 50kg/m^2 and yet it does not blow off even when wind forces considerably exceed the self-weight. This is due to a suction effect below the asphalt which depends on the provision of a wind impermeable deck to hold the suction.

To explain the mechanism, it must be appreciated that there is a thin layer of air between the mastic asphalt and the deck. When wind reduces the atmospheric pressure above the roof, this thin layer of air will expand until its pressure is reduced to equal the pressure of the air above the membrane. At this stage an effective suction is formed between the asphalt and the deck, and lift-off is prevented.

LIGHTWEIGHT FLEXIBLE MEMBRANES

The negative pressures which develop over the roof will often be quite small in area and may traverse the roof or parts of the roof in the form of eddies. With lightweight flexible waterproofing, it only requires a small flow of air to the underside of the waterproofing to allow air to collect locally under an eddy formation and form a wave which will follow the eddy as it passes over the roof surface.

If the waterproofing is fully bonded to a good stable surface, the wind forces involved will not be sufficient to break down the bond, and will not allow a wave to form. Extreme wind forces can, however, be sufficient to break down a partially bonded waterproofing specification or even a fully bonded specification to an insulation board with a loose or friable surface. If a wave form develops, the amount of air under the waterproof covering can sometimes increase rapidly, and failure can occur by simple lift-off. Alternatively, splitting of the waterproofing can occur from stressing as the wave hits up against an edge or at the junction between full bonded and part bonded areas. It is also possible for the waterproofing to be lifted up and down or dragged out of position until air can find an entry at an edge condition and cause further damage.

The stiffness of the waterproof covering and the application of loading coats will do much to reduce the possibility of this form of wind damage, and the stronger the membrane, the less likely it is to tear in the wind. It should be appreciated that once wind damage has started, the stronger membranes are more likely to develop into a sail by catching the wind and this can lead to large scale blow-offs. High performance felts and membranes are more likely to form sails than traditional BS 747 glass base roofing felts which tear more easily, and extra care needs to be taken with the design and formation of details.

LOADING COATS

In the design and testing of a membrane, it is normal to assume that the wind exerts a continuous static force but the reality is that wind forces are of extremely short duration. In practice, a layer of 10mm chippings provides sufficient weight and inertia to prevent damage to most bonded and partially bonded specifications, provided the roof edges are closed off to prevent entry of air.

A mineral surfaced roofing is lighter and more vulnerable to the wind. If it is installed on an insulation which has a low laminar strength, the risk of delamination will be increased. Under these circumstances, a first layer of high performance roofing mechanically fixed through the insulant and into the deck may be necessary to present a stable base for the rest of the waterproofing.

INVERTED ROOF SPECIFICATION

With an inverted roof specification the insulation is laid loose, and the security of the entire system depends on the loading coat which may be 50mm of gravel ballast or 50mm concrete paving.

The weight of these loading coats should prove adequate to resist wind damage, and also guard against floatation of the insulation if significant ponding occurs. When using gravel ballast, precautions should be taken against wind scour if necessary. A design procedure to predict conditions which are free of scour is given in BRE Digest 311 "Wind scour of gravel ballast on roofs".

LIGHTWEIGHT CEMENTITIOUS SURFACED PANELS

Some manufacturers supply interlocking extruded polystyrene with a cementitious facing to form an integral loading coat or promenade surface panel. These panels normally have interlocking edges and can be loose-laid as an inverted roof system with no additional loading coats unless in a position which is exposed to severe wind.

BRE Digest 295 "Stability under wind load of loose-laid external roof insulation boards" gives a calculation method for the design of the panels against wind up-lift, and guidance for the use of additional loading where necessary. In essence the wind load on the panels is taken as one third of the design wind load using the internal coefficient for the roof area in question. This load must not be exceeded by the self weight of the panel, or double the self weight of the panel if it is fully interlocked into an area of panel surfacing. Open edges are best avoided, but can be accepted if a continuous edge restraint and trim is incorporated.

EDGE DETAILING

Surveys after widespread gales indicate that the majority of damage caused to flat roofs has started at the exposed windward corners and edges of the roof. Oversails, fascias, cappings, trims and drips take the brunt of the wind forces and these details or their grounds are usually the first components to fail.

A calculation of the actual forces on these roof edge details is usually difficult, but the cost of fixing is cheap, and there is no reason why these details should not be amply fixed. As a rough guide, all metal cappings and trims should be fixed at 300mm centres, with extra fixings added under conditions of extreme exposure. Cappings which have both edges exposed will need at least two lines of fixing at 300mm centres. The grounds to which the details are secured must themselves be firmly attached to the structure. Wall plates which support a roof oversail must be firmly anchored to the supporting walls with straps and fixings specially designed to withstand the calculated wind forces.

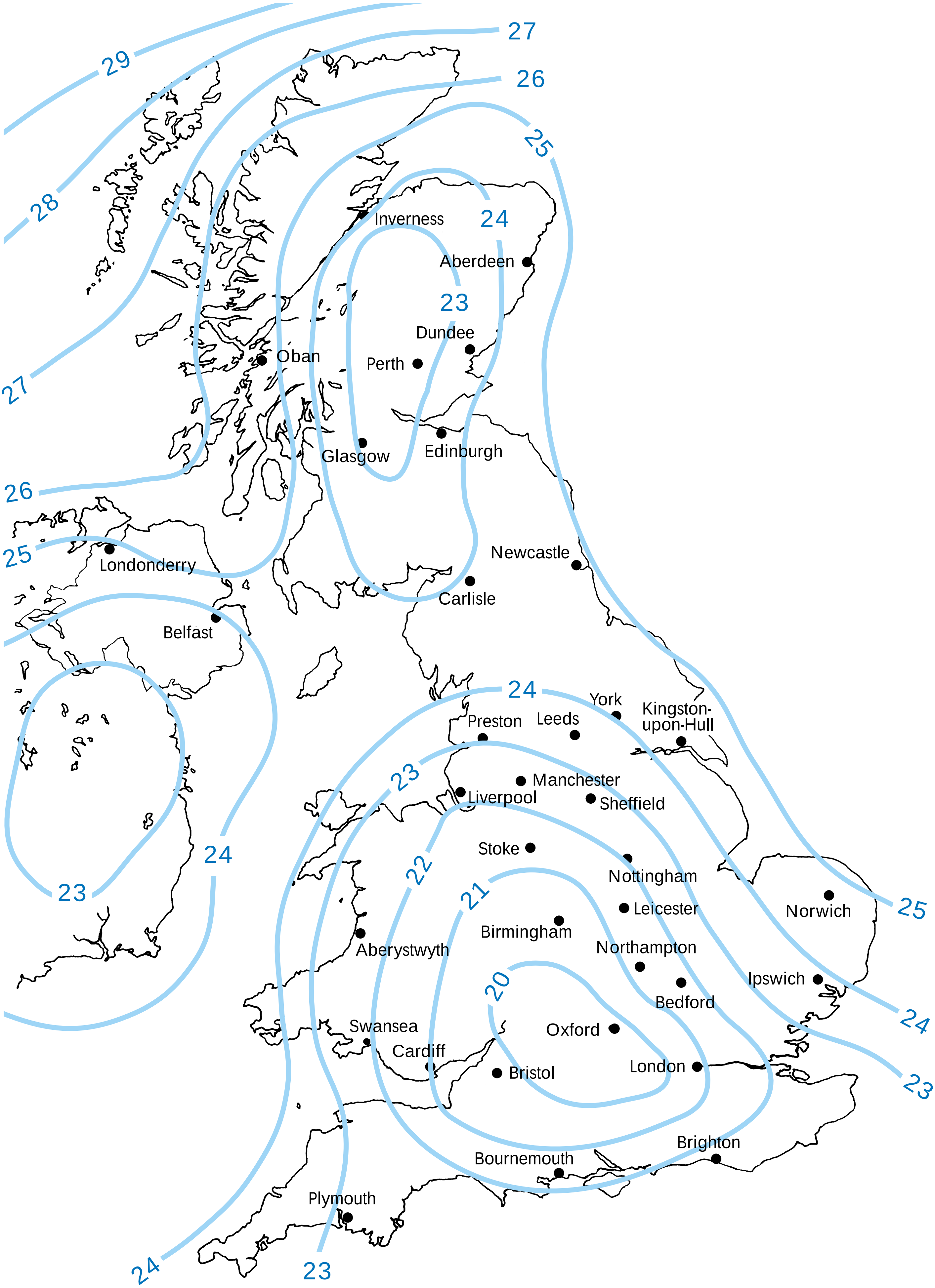
All details should be designed to reduce the free entry of air beneath the membrane. In particular, profiled sidewall cladding and overhangs can be permeable to air and may allow additional wind pressure into the system and additional bonding or fixing may be required.

WIND SPEEDS

The roof designer should always estimate the likely wind loads over the roof and make sure that the specification for the insulation and waterproofing takes these into account. The wind loads will be determined from the basic wind speed taken from the wind map overleaf, and will be calculated in accordance with BS 6399:1993:Part 2 Code of practice for wind loads.

As an aid to designers, a conservative assessment of wind loads for typical conditions is given in tables 1.16 to 1.22. Practical advice is given in the Wind Attachment Design Guide Section 1.7.

Wind map : Basic wind speed Vb in m/s



This map has been reproduced from draft British Standard BS 6399:Part 2 with permission.

DESIGN WIND LOADS

BS 6399:1995:Part 2 Code of practice for wind loads gives methods for calculating gust peak wind loads for the design of buildings. The dynamic pressure is calculated for any given roof, and roof zones are established with appropriate external and internal coefficients to give design wind loads for each zone.

The full assessment of wind loads on a roof is somewhat complex and best carried out by computer analysis using special programmes which incorporate all the requirements of the standard.

Two alternative methods are given; a standard method, and a directional method which gives a more detailed analysis where appropriate.

For flat roofing membranes the standard method will suffice for the majority of buildings and always gives a safe assessment.

Factors taken into account in the tabulated wind loads tables 1.16 to 1.22, using the standard method, are as follows:

Basic wind speed V_b
From BRE map reproduced on the preceding page. The wind speeds are expressed as hourly mean values, unlike the previous wind code which gave them as 3-second gust values.

Altitude factor S_a
Depending on altitude of site above sea level. Information should be taken from local detail maps or from Ordnance Survey bench marks.

Directional factor S_d
For most roofs it will be best to keep to a symmetrical and equal pattern of attachment and assume the orientation of the building is unknown or ignored, and the basic wind speed applies from all directions, i.e. $S_d = 1$

Seasonal factor S_s
For permanent roofs $S_s = 1$

Probability factor S_p
For mean recurrence interval of fifty years $S_p = 1$

Effective height H_e
The effective height for roofs in the country can be taken as the height of the roof above ground level. This may be reduced for a town terrain by taking account of the shielding effect of other buildings. See BS 6399:Part 2.

Terrain and building factor S_b
The standard method considers three ground roughness categories, sea, country and town. S_b is tabulated according to effective building height, for sites in the country at 0, 2, 10 and 100 km or more from the sea, and sites in town at 1, 10 and 100 km or more from the sea. Town sites need to be 2 km from the upwind edge of town.

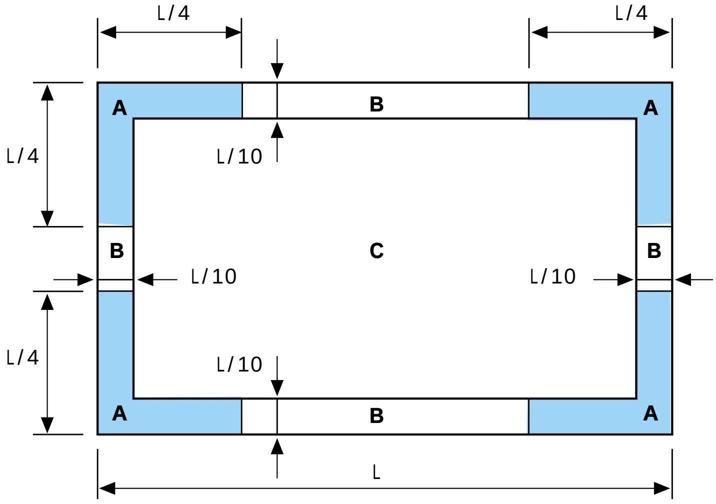
Size effect factor C_a
Can be taken as $C_a = 1$ for flat roofing

Topographic location factors

Topographic locations include hills, ridges, cliffs and escarpments. The factor comes into effect when a building is more than half way up a significant ground slope or hill, and always applies at a ridge, cliff or escarpment.

Roof zones

To make allowance for areas of high wind load at the corners and edges of a flat roof, roof zones are introduced. If the direction of the wind is not taken into account there are effectively three zones for a rectangular flat roof A, B & C, located as below.



It is recommended that this simplified pattern is adopted for most flat roofs to avoid complicated layouts and the possibility of mistakes on site. Major roofing projects with full time site management can accept complicated layouts with more certainty of correct application and a full analysis may help to reduce attachment costs for these buildings.

External pressure coefficients, C_{pe}
For flat rectangular roofs with sharp eaves.

Zone A; C_{pe} = - 2.0

Zone B; C_{pe} = - 1.4

Zone C; C_{pe} = - 0.7

C_{pe} can be slightly reduced for a roof with parapets.

Internal pressure coefficients, C_{pi}
For flat roofs of buildings with normal doors and windows C_{pi} = + 0.2

For buildings with dominant openings or open sided buildings refer to BS 6399:Part 2.

At the time of printing the wind load map and the information given above have been reproduced from the draft BS 6399:Part 2, with permission. Draft standards are subject to review and amendment and should only be used with caution. Readers should always ensure they have the latest information on the current status of documents.

The revision of BS 6399:Part 2 is expected to be published during the second half of 1995. Copies will be available from BSI Customer Services, 389 Chiswick High Road, London W4 4AL. Telephone 0181 996 7000.

DESIGN WIND LOAD EASY REFERENCE TABLES

Tables 1.16 to 1.22 give conservative design wind loads for flat roofs based on BS 6399:Part 2 with simplifying assumptions.

TO USE THE TABLES:

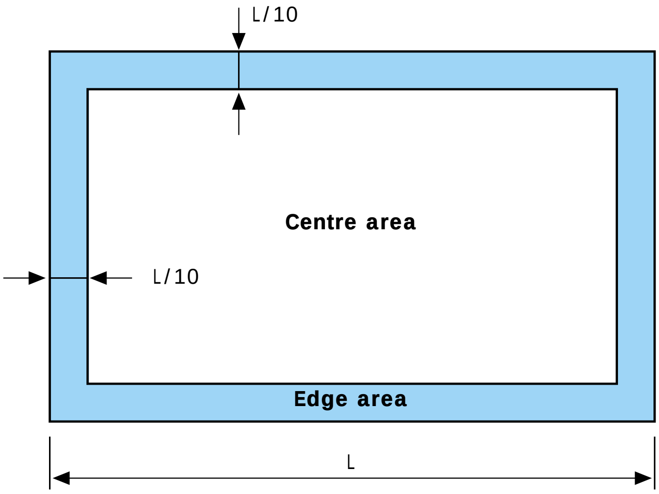
1 Select the basic wind speed from the wind map.

2 Select the table for the appropriate wind speed.

3 Determine the altitude of the site above sea level (local maps or bench mark levels obtainable from Ordnance Survey agents).

4 Decide town or country, and distance from sea (West coast if in doubt).

5 Read off design wind loads for the centre area of the roof, and edge area, for the height of roof and altitude in question.



Zone B is small and for simplicity has been ignored

NOTE:

1 The calculation of design wind loads given in the table has been simplified by taking worst case assumptions. It refers only to rectangular flat roofs and is for design of membrane attachment, not for design of structure.

2 Less onerous design loads may be determined by using a full calculation, with an input of precise data for the roof in question, in accordance with BS 6399:Part 2.

3 No allowance is made for increased wind load due to the topography being significant which arises when the site is located on a hill, ridge, cliff or escarpment. Refer to BS 6399:Part 2 if these conditions apply. As a generalisation all buildings more than half-way up a hill, or on a ridge, cliff or escarpment will attract increased wind loading.

4 Allowance has been made for external coefficients at the edge area of the roof (effectively zone A and B) of --2.0 and at the centre areas of the roof (effectively zone C) of --0.7. The internal coefficient is taken as +0.2. With open sided buildings or buildings with dominant openings the internal coefficient will increase to 75% or 90% of the external coefficient depending on the size of the opening. See BS 6399:Part 2.

Design wind loads (kN / m²)

Table 1.16 Basic wind speed 20 m / s

Altitude m	Building height m	Distance from Sea (km) COUNTRY 0		2		10		⩾100		TOWN 2		10		⩾100	
		edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre
0	⩽2	1.18	0.48	1.06	0.43	0.98	0.40	0.86	0.35	0.75	0.31	0.71	0.29	0.62	0.25
	5	1.47	0.60	1.42	0.58	1.33	0.54	1.13	0.46	1.21	0.50	1.13	0.46	1.00	0.41
	10	1.71	0.70	1.71	0.70	1.61	0.66	1.42	0.58	1.61	0.66	1.54	0.63	1.35	0.55
	15	1.85	0.76	1.85	0.76	1.79	0.73	1.58	0.65	1.85	0.76	1.79	0.73	1.58	0.65
	20	1.95	0.80	1.95	0.80	1.93	0.79	1.69	0.69	1.95	0.80	1.93	0.79	1.69	0.69
50	⩽2	1.30	0.53	1.17	0.48	1.08	0.44	0.94	0.39	0.83	0.34	0.79	0.32	0.68	0.28
	5	1.62	0.66	1.56	0.64	1.47	0.60	1.25	0.51	1.34	0.55	1.25	0.51	1.10	0.45
	10	1.88	0.77	1.88	0.77	1.78	0.73	1.56	0.64	1.78	0.73	1.70	0.69	1.48	0.61
	15	2.04	0.83	2.04	0.83	1.97	0.81	1.74	0.71	2.04	0.83	1.97	0.81	1.74	0.71
	20	2.15	0.88	2.15	0.88	2.12	0.87	1.86	0.76	2.15	0.88	2.12	0.87	1.86	0.76
100	⩽2	1.43	0.58	1.28	0.52	1.19	0.49	1.04	0.42	0.91	0.37	0.86	0.35	0.75	0.31
	5	1.78	0.73	1.71	0.70	1.61	0.66	1.37	0.56	1.47	0.60	1.37	0.56	1.21	0.49
	10	2.07	0.85	2.07	0.85	1.95	0.80	1.71	0.70	1.95	0.80	1.86	0.76	1.63	0.67
	15	2.23	0.91	2.23	0.91	2.16	0.88	1.91	0.78	2.23	0.91	2.16	0.88	1.91	0.78
	20	2.36	0.96	2.36	0.96	2.33	0.95	2.04	0.84	2.36	0.96	2.33	0.95	2.04	0.84
150	⩽2	1.56	0.64	1.40	0.57	1.30	0.53	1.13	0.46	0.99	0.41	0.94	0.39	0.82	0.33
	5	1.94	0.79	1.87	0.77	1.76	0.72	1.50	0.61	1.61	0.66	1.50	0.61	1.32	0.54
	10	2.26	0.92	2.26	0.92	2.14	0.87	1.87	0.77	2.14	0.87	2.04	0.83	1.78	0.73
	15	2.44	1.00	2.44	1.00	2.36	0.97	2.09	0.85	2.44	1.00	2.36	0.97	2.09	0.85
	20	2.58	1.05	2.58	1.05	2.55	1.04	2.24	0.91	2.58	1.05	2.55	1.04	2.24	0.91
200	⩽2	1.70	0.70	1.52	0.62	1.42	0.58	1.23	0.50	1.08	0.44	1.03	0.42	0.89	0.36
	5	2.11	0.87	2.04	0.83	1.91	0.78	1.63	0.67	1.75	0.72	1.63	0.67	1.44	0.59
	10	2.46	1.01	2.46	1.01	2.32	0.95	2.04	0.83	2.32	0.95	2.22	0.91	1.94	0.79
	15	2.66	1.09	2.66	1.09	2.57	1.05	2.27	0.93	2.66	1.09	2.57	1.05	2.27	0.93
	20	2.80	1.15	2.80	1.15	2.77	1.14	2.43	1.00	2.80	1.15	2.77	1.14	2.43	1.00
250	⩽2	1.85	0.76	1.65	0.68	1.54	0.63	1.34	0.55	1.17	0.48	1.11	0.46	0.97	0.39
	5	2.29	0.94	2.21	0.90	2.08	0.85	1.77	0.72	1.90	0.78	1.77	0.72	1.56	0.64
	10	2.67	1.09	2.67	1.09	2.52	1.03	2.21	0.90	2.52	1.03	2.41	0.98	2.10	0.86
	15	2.88	1.18	2.88	1.18	2.79	1.14	2.46	1.01	2.88	1.18	2.79	1.14	2.46	1.01
	20	3.04	1.24	3.04	1.24	3.01	1.23	2.64	1.08	3.04	1.24	3.01	1.23	2.64	1.08

Design wind loads (kN/m²)

Table 1.17 Basic wind speed 21 m/s

Altitude	Building height	Distance from Sea (km)													
		COUNTRY								TOWN					
m	m	0		2		10		≥100		2		10		≥100	
		edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre
0	≤2	1.30	0.53	1.17	0.48	1.08	0.44	0.94	0.39	0.83	0.34	0.79	0.32	0.68	0.28
	5	1.62	0.66	1.56	0.64	1.47	0.60	1.25	0.51	1.34	0.55	1.25	0.51	1.10	0.45
	10	1.88	0.77	1.88	0.77	1.78	0.73	1.56	0.64	1.78	0.73	1.70	0.69	1.48	0.61
	15	2.04	0.83	2.04	0.83	1.97	0.81	1.74	0.71	2.04	0.83	1.97	0.81	1.74	0.71
	20	2.15	0.88	2.15	0.88	2.12	0.87	1.86	0.76	2.15	0.88	2.12	0.87	1.86	0.76
50	≤2	1.44	0.59	1.29	0.53	1.19	0.49	1.04	0.43	0.91	0.37	0.87	0.35	0.75	0.31
	5	1.79	0.73	1.72	0.70	1.62	0.66	1.38	0.56	1.48	0.60	1.38	0.56	1.21	0.50
	10	2.08	0.85	2.08	0.85	1.96	0.80	1.72	0.70	1.96	0.80	1.87	0.77	1.64	0.67
	15	2.24	0.92	2.24	0.92	2.17	0.89	1.92	0.78	2.24	0.92	2.17	0.89	1.92	0.78
	20	2.37	0.97	2.37	0.97	2.34	0.96	2.05	0.84	2.37	0.97	2.34	0.96	2.05	0.84
100	≤2	1.58	0.64	1.41	0.58	1.31	0.54	1.14	0.47	1.00	0.41	0.95	0.39	0.82	0.34
	5	1.96	0.80	1.89	0.77	1.77	0.73	1.51	0.62	1.62	0.66	1.51	0.62	1.33	0.54
	10	2.28	0.93	2.28	0.93	2.15	0.88	1.89	0.77	2.15	0.88	2.06	0.84	1.80	0.73
	15	2.46	1.01	2.46	1.01	2.38	0.98	2.10	0.86	2.46	1.01	2.38	0.98	2.10	0.86
	20	2.60	1.06	2.60	1.06	2.57	1.05	2.25	0.92	2.60	1.06	2.57	1.05	2.25	0.92
150	≤2	1.72	0.70	1.54	0.63	1.43	0.59	1.25	0.51	1.10	0.45	1.04	0.43	0.90	0.37
	5	2.14	0.88	2.06	0.84	1.94	0.79	1.65	0.68	1.77	0.72	1.65	0.68	1.45	0.60
	10	2.49	1.02	2.49	1.02	2.35	0.96	2.06	0.84	2.35	0.96	2.25	0.92	1.96	0.80
	15	2.69	1.10	2.69	1.10	2.61	1.07	2.30	0.94	2.69	1.10	2.61	1.07	2.30	0.94
	20	2.84	1.16	2.84	1.16	2.81	1.15	2.46	1.01	2.84	1.16	2.81	1.15	2.46	1.01
200	≤2	1.88	0.77	1.68	0.69	1.56	0.64	1.36	0.56	1.19	0.49	1.13	0.46	0.98	0.40
	5	2.33	0.95	2.25	0.92	2.11	0.86	1.80	0.74	1.93	0.79	1.80	0.74	1.58	0.65
	10	2.71	1.11	2.71	1.11	2.56	1.05	2.25	0.92	2.56	1.05	2.45	1.00	2.14	0.87
	15	2.93	1.20	2.93	1.20	2.84	1.16	2.50	1.02	2.93	1.20	2.84	1.16	2.50	1.02
	20	3.09	1.26	3.09	1.26	3.06	1.25	2.68	1.10	3.09	1.26	3.06	1.25	2.68	1.10
250	≤2	2.04	0.83	1.82	0.75	1.69	0.69	1.48	0.60	1.29	0.53	1.23	0.50	1.06	0.44
	5	2.53	1.03	2.44	1.00	2.29	0.94	1.95	0.80	2.09	0.86	1.95	0.80	1.72	0.70
	10	2.94	1.20	2.94	1.20	2.78	1.14	2.44	1.00	2.78	1.14	2.65	1.09	2.32	0.95
	15	3.18	1.30	3.18	1.30	3.08	1.26	2.72	1.11	3.18	1.30	3.08	1.26	2.72	1.11
	20	3.35	1.37	3.35	1.37	3.32	1.36	2.91	1.19	3.35	1.37	3.32	1.36	2.91	1.19

Design wind loads (kN/m²)

Table 1.18 Basic Wind Speed 22 m/s

Altitude m	Building height m	Distance from Sea (km) COUNTRY 0 edge	0 centre	2 edge	2 centre	10 edge	10 centre	⩾100 edge	⩾100 centre	TOWN 2 edge	2 centre	10 edge	10 centre	⩾100 edge	⩾100 centre
0	⩽2	1.43	0.58	1.28	0.52	1.19	0.49	1.04	0.42	0.91	0.37	0.86	0.35	0.75	0.31
	5	1.78	0.73	1.71	0.70	1.61	0.66	1.37	0.56	1.47	0.60	1.37	0.56	1.21	0.49
	10	2.07	0.85	2.07	0.85	1.95	0.80	1.71	0.70	1.95	0.80	1.86	0.76	1.63	0.67
	15	2.23	0.91	2.23	0.91	2.16	0.88	1.91	0.78	2.23	0.91	2.16	0.88	1.91	0.78
	20	2.36	0.96	2.36	0.96	2.33	0.95	2.04	0.84	2.36	0.96	2.33	0.95	2.04	0.84
50	⩽2	1.58	0.64	1.41	0.58	1.31	0.54	1.14	0.47	1.00	0.41	0.95	0.39	0.82	0.34
	5	1.96	0.80	1.89	0.77	1.77	0.73	1.51	0.62	1.62	0.66	1.51	0.62	1.33	0.54
	10	2.28	0.93	2.28	0.93	2.15	0.88	1.89	0.77	2.15	0.88	2.06	0.84	1.80	0.73
	15	2.46	1.01	2.46	1.01	2.38	0.98	2.10	0.86	2.46	1.01	2.38	0.98	2.10	0.86
	20	2.60	1.06	2.60	1.06	2.57	1.05	2.25	0.92	2.60	1.06	2.57	1.05	2.25	0.92
100	⩽2	1.73	0.71	1.55	0.63	1.44	0.59	1.25	0.51	1.10	0.45	1.04	0.43	0.90	0.37
	5	2.15	0.88	2.07	0.85	1.95	0.80	1.66	0.68	1.78	0.73	1.66	0.68	1.46	0.60
	10	2.50	1.02	2.50	1.02	2.36	0.97	2.07	0.85	2.36	0.97	2.26	0.92	1.97	0.81
	15	2.70	1.11	2.70	1.11	2.62	1.07	2.31	0.94	2.70	1.11	2.62	1.07	2.31	0.94
	20	2.85	1.17	2.85	1.17	2.82	1.15	2.47	1.01	2.85	1.17	2.82	1.15	2.47	1.01
150	⩽2	1.89	0.77	1.69	0.69	1.57	0.64	1.37	0.56	1.20	0.49	1.14	0.47	0.99	0.40
	5	2.35	0.96	2.27	0.93	2.13	0.87	1.81	0.74	1.94	0.79	1.81	0.74	1.60	0.65
	10	2.74	1.12	2.74	1.12	2.58	1.06	2.27	0.93	2.58	1.06	2.47	1.01	2.15	0.88
	15	2.95	1.21	2.95	1.21	2.86	1.17	2.52	1.03	2.95	1.21	2.86	1.17	2.52	1.03
	20	3.12	1.27	3.12	1.27	3.08	1.26	2.70	1.11	3.12	1.27	3.08	1.26	2.70	1.11
200	⩽2	2.06	0.84	1.84	0.75	1.71	0.70	1.49	0.61	1.31	0.54	1.24	0.51	1.08	0.44
	5	2.56	1.05	2.47	1.01	2.32	0.95	1.98	0.81	2.11	0.87	1.98	0.81	1.74	0.71
	10	2.98	1.22	2.98	1.22	2.81	1.15	2.47	1.01	2.81	1.15	2.68	1.10	2.35	0.96
	15	3.22	1.32	3.22	1.32	3.11	1.27	2.75	1.12	3.22	1.32	3.11	1.27	2.75	1.12
	20	3.39	1.39	3.39	1.39	3.36	1.37	2.94	1.20	3.39	1.39	3.36	1.37	2.94	1.20
250	⩽2	2.23	0.91	2.00	0.82	1.86	0.76	1.62	0.66	1.42	0.58	1.35	0.55	1.17	0.48
	5	2.78	1.14	2.68	1.09	2.51	1.03	2.14	0.88	2.29	0.94	2.14	0.88	1.89	0.77
	10	3.23	1.32	3.23	1.32	3.05	1.25	2.68	1.09	3.05	1.25	2.91	1.19	2.55	1.04
	15	3.49	1.43	3.49	1.43	3.38	1.38	2.98	1.22	3.49	1.43	3.38	1.38	2.98	1.22
	20	3.68	1.51	3.68	1.51	3.64	1.49	3.20	1.31	3.68	1.51	3.64	1.49	3.20	1.31

Design wind loads (kN / m²)

Table 1.19 Basic Wind Speed 23 m/s

Altitude m	Building height m	COUNTRY 0 edge	COUNTRY 0 centre	COUNTRY 2 edge	COUNTRY 2 centre	COUNTRY 10 edge	COUNTRY 10 centre	COUNTRY ⩾100 edge	COUNTRY ⩾100 centre	TOWN 2 edge	TOWN 2 centre	TOWN 10 edge	TOWN 10 centre	TOWN ⩾100 edge	TOWN ⩾100 centre
0	⩽2	1.56	0.64	1.40	0.57	1.30	0.53	1.13	0.46	0.99	0.41	0.94	0.39	0.82	0.33
	5	1.94	0.79	1.87	0.77	1.76	0.72	1.50	0.61	1.61	0.66	1.50	0.61	1.32	0.54
	10	2.26	0.92	2.26	0.92	2.14	0.87	1.87	0.77	2.14	0.87	2.04	0.83	1.78	0.73
	15	2.44	1.00	2.44	1.00	2.36	0.97	2.09	0.85	2.44	1.00	2.36	0.97	2.09	0.85
	20	2.58	1.05	2.58	1.05	2.55	1.04	2.24	0.91	2.58	1.05	2.55	1.04	2.24	0.91
50	⩽2	1.72	0.70	1.54	0.63	1.43	0.59	1.25	0.51	1.10	0.45	1.04	0.43	0.90	0.37
	5	2.14	0.88	2.06	0.84	1.94	0.79	1.65	0.68	1.77	0.72	1.65	0.68	1.45	0.60
	10	2.49	1.02	2.49	1.02	2.35	0.96	2.06	0.84	2.35	0.96	2.25	0.92	1.96	0.80
	15	2.69	1.10	2.69	1.10	2.61	1.07	2.30	0.94	2.69	1.10	2.61	1.07	2.30	0.94
	20	2.84	1.16	2.84	1.16	2.81	1.15	2.46	1.01	2.84	1.16	2.81	1.15	2.46	1.01
100	⩽2	1.89	0.77	1.69	0.69	1.57	0.64	1.37	0.56	1.20	0.49	1.14	0.47	0.99	0.40
	5	2.35	0.96	2.27	0.93	2.13	0.87	1.81	0.74	1.94	0.79	1.81	0.74	1.60	0.65
	10	2.74	1.12	2.74	1.12	2.58	1.06	2.27	0.93	2.58	1.06	2.47	1.01	2.15	0.88
	15	2.95	1.21	2.95	1.21	2.86	1.17	2.52	1.03	2.95	1.21	2.86	1.17	2.52	1.03
	20	3.12	1.27	3.12	1.27	3.08	1.26	2.70	1.11	3.12	1.27	3.08	1.26	2.70	1.11
150	⩽2	2.07	0.85	1.85	0.76	1.72	0.70	1.50	0.61	1.31	0.54	1.25	0.51	1.08	0.44
	5	2.57	1.05	2.48	1.01	2.33	0.95	1.98	0.81	2.12	0.87	1.98	0.81	1.75	0.71
	10	2.99	1.22	2.99	1.22	2.82	1.16	2.48	1.01	2.82	1.16	2.69	1.10	2.36	0.96
	15	3.23	1.32	3.23	1.32	3.13	1.28	2.76	1.13	3.23	1.32	3.13	1.28	2.76	1.13
	20	3.41	1.39	3.41	1.39	3.37	1.38	2.96	1.21	3.41	1.39	3.37	1.38	2.96	1.21
200	⩽2	2.25	0.92	2.01	0.82	1.87	0.77	1.63	0.67	1.43	0.59	1.36	0.56	1.18	0.48
	5	2.80	1.14	2.70	1.10	2.53	1.04	2.16	0.88	2.31	0.95	2.16	0.88	1.90	0.78
	10	3.25	1.33	3.25	1.33	3.07	1.26	2.70	1.10	3.07	1.26	2.93	1.20	2.56	1.05
	15	3.52	1.44	3.52	1.44	3.40	1.39	3.00	1.23	3.52	1.44	3.40	1.39	3.00	1.23
	20	3.71	1.52	3.71	1.52	3.67	1.50	3.22	1.32	3.71	1.52	3.67	1.50	3.22	1.32
250	⩽2	2.44	1.00	2.18	0.89	2.03	0.83	1.77	0.72	1.55	0.63	1.47	0.60	1.28	0.52
	5	3.03	1.24	2.93	1.20	2.75	1.12	2.34	0.96	2.51	1.03	2.34	0.96	2.06	0.84
	10	3.53	1.44	3.53	1.44	3.34	1.36	2.93	1.20	3.34	1.36	3.18	1.30	2.78	1.14
	15	3.82	1.56	3.82	1.56	3.69	1.51	3.26	1.33	3.82	1.56	3.69	1.51	3.26	1.33
	20	4.02	1.65	4.02	1.65	3.98	1.63	3.49	1.43	4.02	1.65	3.98	1.63	3.49	1.43

Design wind loads (kN / m²)

Table 1.20 Basic Wind Speed 24 m/s

Altitude m	Building height m	Distance from Sea (km) COUNTRY 0		2		10		⩾100		TOWN 2		10		⩾100	
		edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre
0	⩽2	1.70	0.70	1.52	0.62	1.42	0.58	1.23	0.50	1.08	0.44	1.03	0.42	0.89	0.36
	5	2.11	0.87	2.04	0.83	1.91	0.78	1.63	0.67	1.75	0.72	1.63	0.67	1.44	0.59
	10	2.46	1.01	2.46	1.01	2.32	0.95	2.04	0.83	2.32	0.95	2.22	0.91	1.94	0.79
	15	2.66	1.09	2.66	1.09	2.57	1.05	2.27	0.93	2.66	1.09	2.57	1.05	2.27	0.93
	20	2.80	1.15	2.80	1.15	2.77	1.14	2.43	1.00	2.80	1.15	2.77	1.14	2.43	1.00
50	⩽2	1.88	0.77	1.68	0.69	1.56	0.64	1.36	0.56	1.19	0.49	1.13	0.46	0.98	0.40
	5	2.33	0.95	2.25	0.92	2.11	0.86	1.80	0.74	1.93	0.79	1.80	0.74	1.58	0.65
	10	2.71	1.11	2.71	1.11	2.56	1.05	2.25	0.92	2.56	1.05	2.45	1.00	2.14	0.87
	15	2.93	1.20	2.93	1.20	2.84	1.16	2.50	1.02	2.93	1.20	2.84	1.16	2.50	1.02
	20	3.09	1.26	3.09	1.26	3.06	1.25	2.68	1.10	3.09	1.26	3.06	1.25	2.68	1.10
100	⩽2	2.06	0.84	1.84	0.75	1.71	0.70	1.49	0.61	1.31	0.54	1.24	0.51	1.08	0.44
	5	2.56	1.05	2.47	1.01	2.32	0.95	1.98	0.81	2.11	0.87	1.98	0.81	1.74	0.71
	10	2.98	1.22	2.98	1.22	2.81	1.15	2.47	1.01	2.81	1.15	2.68	1.10	2.35	0.96
	15	3.22	1.32	3.22	1.32	3.11	1.27	2.75	1.12	3.22	1.32	3.11	1.27	2.75	1.12
	20	3.39	1.39	3.39	1.39	3.36	1.37	2.94	1.20	3.39	1.39	3.36	1.37	2.94	1.20
150	⩽2	2.25	0.92	2.01	0.82	1.87	0.77	1.63	0.67	1.43	0.59	1.36	0.56	1.18	0.48
	5	2.80	1.14	2.70	1.10	2.53	1.04	2.16	0.88	2.31	0.95	2.16	0.88	1.90	0.78
	10	3.25	1.33	3.25	1.33	3.07	1.26	2.70	1.10	3.07	1.26	2.93	1.20	2.56	1.05
	15	3.52	1.44	3.52	1.44	3.40	1.39	3.00	1.23	3.52	1.44	3.40	1.39	3.00	1.23
	20	3.71	1.52	3.71	1.52	3.67	1.50	3.22	1.32	3.71	1.52	3.67	1.50	3.22	1.32
200	⩽2	2.45	1.00	2.19	0.90	2.04	0.83	1.78	0.73	1.56	0.64	1.48	0.61	1.28	0.52
	5	3.05	1.25	2.94	1.20	2.76	1.13	2.35	0.96	2.52	1.03	2.35	0.96	2.07	0.85
	10	3.54	1.45	3.54	1.45	3.35	1.37	2.94	1.20	3.35	1.37	3.19	1.31	2.79	1.14
	15	3.83	1.57	3.83	1.57	3.71	1.52	3.27	1.34	3.83	1.57	3.71	1.52	3.27	1.34
	20	4.04	1.65	4.04	1.65	4.00	1.63	3.50	1.43	4.04	1.65	4.00	1.63	3.50	1.43
250	⩽2	2.66	1.09	2.38	0.97	2.21	0.90	1.93	0.79	1.69	0.69	1.61	0.66	1.39	0.57
	5	3.30	1.35	3.19	1.30	2.99	1.22	2.55	1.04	2.73	1.12	2.55	1.04	2.24	0.92
	10	3.85	1.57	3.85	1.57	3.63	1.49	3.19	1.30	3.63	1.49	3.47	1.42	3.03	1.24
	15	4.15	1.70	4.15	1.70	4.02	1.64	3.55	1.45	4.15	1.70	4.02	1.64	3.55	1.45
	20	4.38	1.79	4.38	1.79	4.34	1.77	3.80	1.56	4.38	1.79	4.34	1.77	3.80	1.56

Design wind load (kN / m²)

Table 1.21 Basic Wind Speed 25 m/s

Altitude m	Building height m	COUNTRY 0 edge	0 centre	2 edge	2 centre	10 edge	10 centre	⩾100 edge	⩾100 centre	TOWN 2 edge	2 centre	10 edge	10 centre	⩾100 edge	⩾100 centre
0	⩽2	1.85	0.76	1.65	0.68	1.54	0.63	1.34	0.55	1.17	0.48	1.11	0.46	0.97	0.39
	5	2.29	0.94	2.21	0.90	2.08	0.85	1.77	0.72	1.90	0.78	1.77	0.72	1.56	0.64
	10	2.67	1.09	2.67	1.09	2.52	1.03	2.21	0.90	2.52	1.03	2.41	0.98	2.10	0.86
	15	2.88	1.18	2.88	1.18	2.79	1.14	2.46	1.01	2.88	1.18	2.79	1.14	2.46	1.01
	20	3.04	1.24	3.04	1.24	3.01	1.23	2.64	1.08	3.04	1.24	3.01	1.23	2.64	1.08
50	⩽2	2.04	0.83	1.82	0.75	1.69	0.69	1.48	0.60	1.29	0.53	1.23	0.50	1.06	0.44
	5	2.53	1.03	2.44	1.00	2.29	0.94	1.95	0.80	2.09	0.86	1.95	0.80	1.72	0.70
	10	2.94	1.20	2.94	1.20	2.78	1.14	2.44	1.00	2.78	1.14	2.65	1.09	2.32	0.95
	15	3.18	1.30	3.18	1.30	3.08	1.26	2.72	1.11	3.18	1.30	3.08	1.26	2.72	1.11
	20	3.35	1.37	3.35	1.37	3.32	1.36	2.91	1.19	3.35	1.37	3.32	1.36	2.91	1.19
100	⩽2	2.23	0.91	2.00	0.82	1.86	0.76	1.62	0.66	1.42	0.58	1.35	0.55	1.17	0.48
	5	2.78	1.14	2.68	1.09	2.51	1.03	2.14	0.88	2.29	0.94	2.14	0.88	1.89	0.77
	10	3.23	1.32	3.23	1.32	3.05	1.25	2.68	1.09	3.05	1.25	2.91	1.19	2.55	1.04
	15	3.49	1.43	3.49	1.43	3.38	1.38	2.98	1.22	3.49	1.43	3.38	1.38	2.98	1.22
	20	3.68	1.51	3.68	1.51	3.64	1.49	3.20	1.31	3.68	1.51	3.64	1.49	3.20	1.31
150	⩽2	2.44	1.00	2.18	0.89	2.03	0.83	1.77	0.72	1.55	0.63	1.47	0.60	1.28	0.52
	5	3.03	1.24	2.93	1.20	2.75	1.12	2.34	0.96	2.51	1.03	2.34	0.96	2.06	0.84
	10	3.53	1.44	3.53	1.44	3.34	1.36	2.93	1.20	3.34	1.36	3.18	1.30	2.78	1.14
	15	3.82	1.56	3.82	1.56	3.69	1.51	3.26	1.33	3.82	1.56	3.69	1.51	3.26	1.33
	20	4.02	1.65	4.02	1.65	3.98	1.63	3.49	1.43	4.02	1.65	3.98	1.63	3.49	1.43
200	⩽2	2.66	1.09	2.38	0.97	2.21	0.90	1.93	0.79	1.69	0.69	1.61	0.66	1.39	0.57
	5	3.30	1.35	3.19	1.30	2.99	1.22	2.55	1.04	2.73	1.12	2.55	1.04	2.24	0.92
	10	3.85	1.57	3.85	1.57	3.63	1.49	3.19	1.30	3.63	1.49	3.47	1.42	3.03	1.24
	15	4.15	1.70	4.15	1.70	4.02	1.64	3.55	1.45	4.15	1.70	4.02	1.64	3.55	1.45
	20	4.38	1.79	4.38	1.79	4.34	1.77	3.80	1.56	4.38	1.79	4.34	1.77	3.80	1.56
250	⩽2	2.88	1.18	2.58	1.06	2.40	0.98	2.09	0.86	1.83	0.75	1.74	0.71	1.51	0.62
	5	3.59	1.47	3.46	1.41	3.25	1.33	2.77	1.13	2.96	1.21	2.77	1.13	2.44	1.00
	10	4.17	1.71	4.17	1.71	3.94	1.61	3.46	1.41	3.94	1.61	3.76	1.54	3.29	1.34
	15	4.51	1.84	4.51	1.84	4.36	1.78	3.85	1.58	4.51	1.84	4.36	1.78	3.85	1.58
	20	4.75	1.94	4.75	1.94	4.70	1.92	4.13	1.69	4.75	1.94	4.70	1.92	4.13	1.69

Design wind load (kN / m²)

Table 1.22 Basic Wind Speed 26 m/s

Altitude	Building height	Distance from Sea (km) COUNTRY								TOWN					
m	m	0		2		10		⩾100		2		10		⩾100	
		edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre	edge	centre
0	⩽2	2.00	0.82	1.79	0.73	1.66	0.68	1.45	0.59	1.27	0.52	1.21	0.49	1.04	0.43
	5	2.48	1.02	2.39	0.98	2.25	0.92	1.92	0.78	2.05	0.84	1.92	0.78	1.69	0.69
	10	2.89	1.18	2.89	1.18	2.73	1.12	2.39	0.98	2.73	1.12	2.60	1.07	2.28	0.93
	15	3.12	1.28	3.12	1.28	3.02	1.24	2.67	1.09	3.12	1.28	3.02	1.24	2.67	1.09
	20	3.29	1.35	3.29	1.35	3.26	1.33	2.86	1.17	3.29	1.35	3.26	1.33	2.86	1.17
50	⩽2	2.20	0.90	1.97	0.81	1.83	0.75	1.60	0.65	1.40	0.57	1.33	0.54	1.15	0.47
	5	2.74	1.12	2.64	1.08	2.48	1.01	2.11	0.86	2.26	0.93	2.11	0.86	1.86	0.76
	10	3.18	1.30	3.18	1.30	3.01	1.23	2.64	1.08	3.01	1.23	2.87	1.17	2.51	1.03
	15	3.44	1.41	3.44	1.41	3.33	1.36	2.94	1.20	3.44	1.41	3.33	1.36	2.94	1.20
	20	3.63	1.48	3.63	1.48	3.59	1.47	3.15	1.29	3.63	1.48	3.59	1.47	3.15	1.29
100	⩽2	2.42	0.99	2.16	0.88	2.01	0.82	1.75	0.72	1.54	0.63	1.46	0.60	1.26	0.52
	5	3.00	1.23	2.89	1.18	2.72	1.11	2.32	0.95	2.48	1.02	2.32	0.95	2.04	0.83
	10	3.50	1.43	3.50	1.43	3.30	1.35	2.89	1.18	3.30	1.35	3.15	1.29	2.75	1.13
	15	3.78	1.54	3.78	1.54	3.65	1.49	3.23	1.32	3.78	1.54	3.65	1.49	3.23	1.32
	20	3.98	1.63	3.98	1.63	3.94	1.61	3.46	1.41	3.98	1.63	3.94	1.61	3.46	1.41
150	⩽2	2.64	1.08	2.36	0.97	2.20	0.90	1.91	0.78	1.68	0.69	1.59	0.65	1.38	0.56
	5	3.28	1.34	3.16	1.29	2.97	1.22	2.53	1.04	2.71	1.11	2.53	1.04	2.23	0.91
	10	3.82	1.56	3.82	1.56	3.61	1.48	3.16	1.29	3.61	1.48	3.44	1.41	3.01	1.23
	15	4.13	1.69	4.13	1.69	3.99	1.63	3.53	1.44	4.13	1.69	3.99	1.63	3.53	1.44
	20	4.35	1.78	4.35	1.78	4.31	1.76	3.78	1.55	4.35	1.78	4.31	1.76	3.78	1.55
200	⩽2	2.88	1.18	2.57	1.05	2.39	0.98	2.08	0.85	1.83	0.75	1.74	0.71	1.50	0.61
	5	3.57	1.46	3.45	1.41	3.24	1.32	2.76	1.13	2.95	1.21	2.76	1.13	2.43	0.99
	10	4.16	1.70	4.16	1.70	3.93	1.61	3.45	1.41	3.93	1.61	3.75	1.53	3.28	1.34
	15	4.49	1.84	4.49	1.84	4.35	1.78	3.84	1.57	4.49	1.84	4.35	1.78	3.84	1.57
	20	4.74	1.94	4.74	1.94	4.69	1.92	4.11	1.68	4.74	1.94	4.69	1.92	4.11	1.68
250	⩽2	3.12	1.28	2.79	1.14	2.60	1.06	2.26	0.93	1.98	0.81	1.88	0.77	1.63	0.67
	5	3.88	1.59	3.74	1.53	3.51	1.44	2.99	1.23	3.21	1.31	2.99	1.23	2.63	1.08
	10	4.51	1.85	4.51	1.85	4.26	1.74	3.74	1.53	4.26	1.74	4.07	1.66	3.56	1.45
	15	4.88	1.99	4.88	1.99	4.72	1.93	4.17	1.70	4.88	1.99	4.72	1.93	4.17	1.70
	20	5.14	2.10	5.14	2.10	5.09	2.08	4.46	1.83	5.14	2.10	5.09	2.08	4.46	1.83