

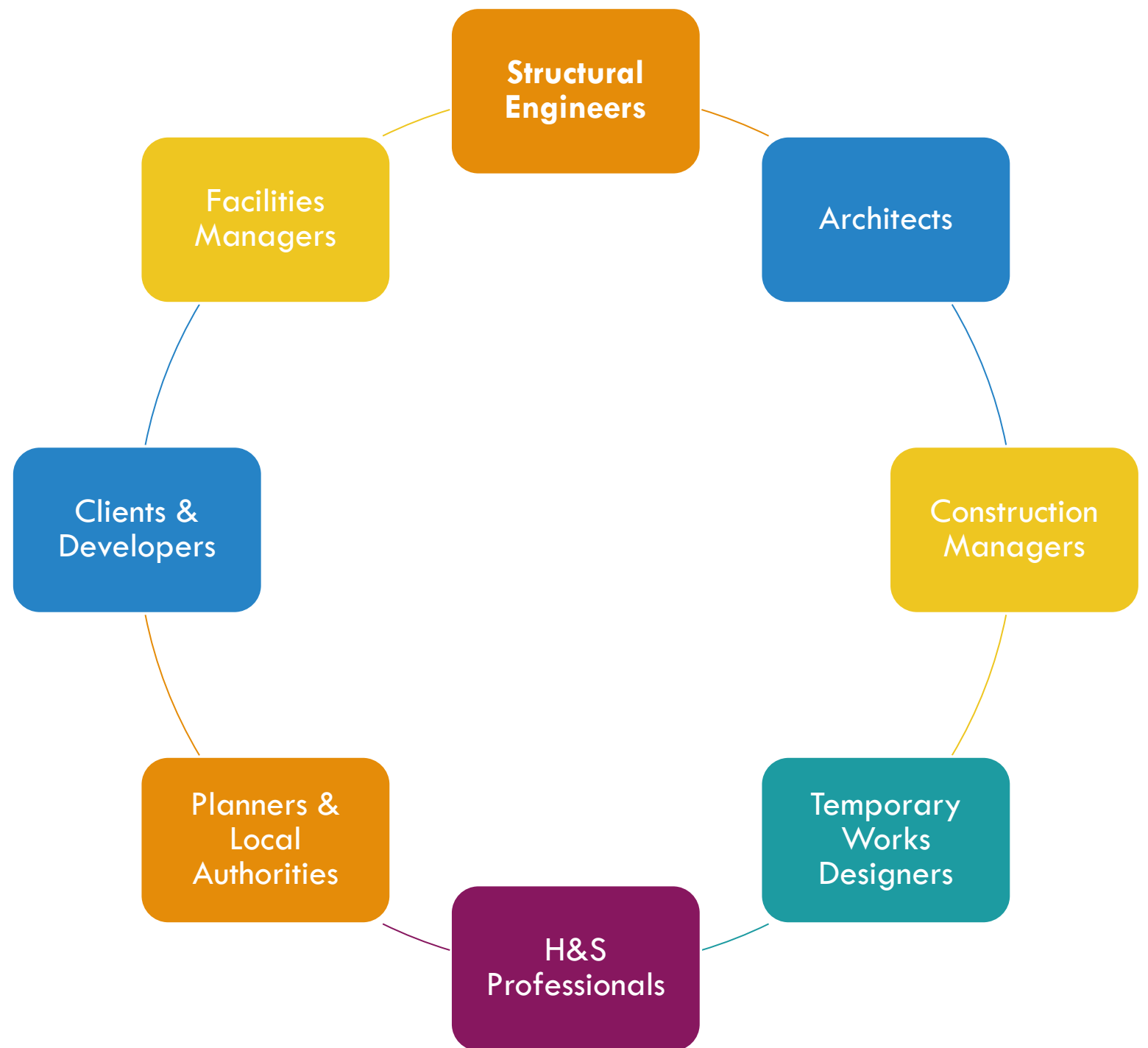


WIND

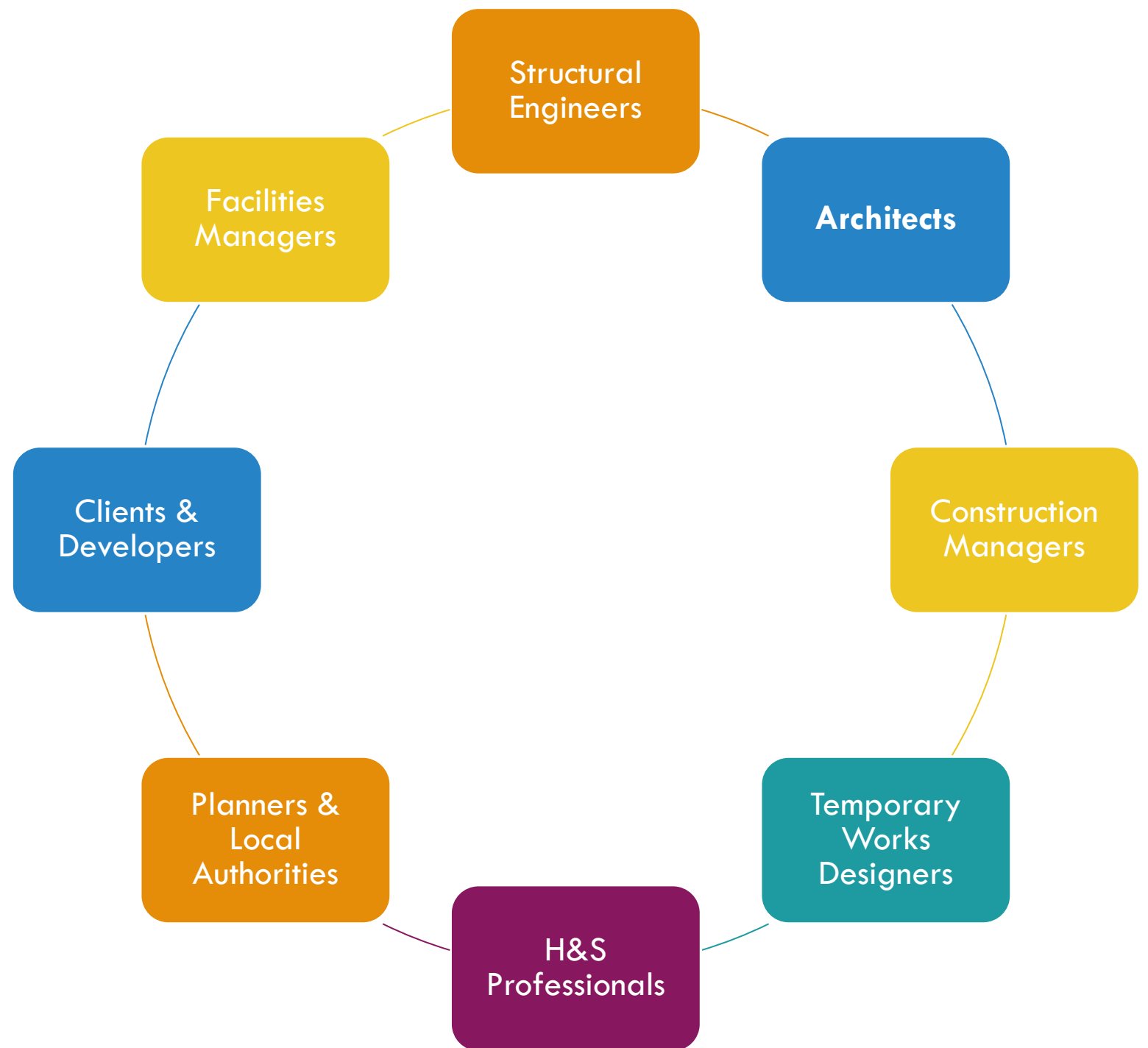
— WHO NEEDS TO UNDERSTAND WIND LOADING?



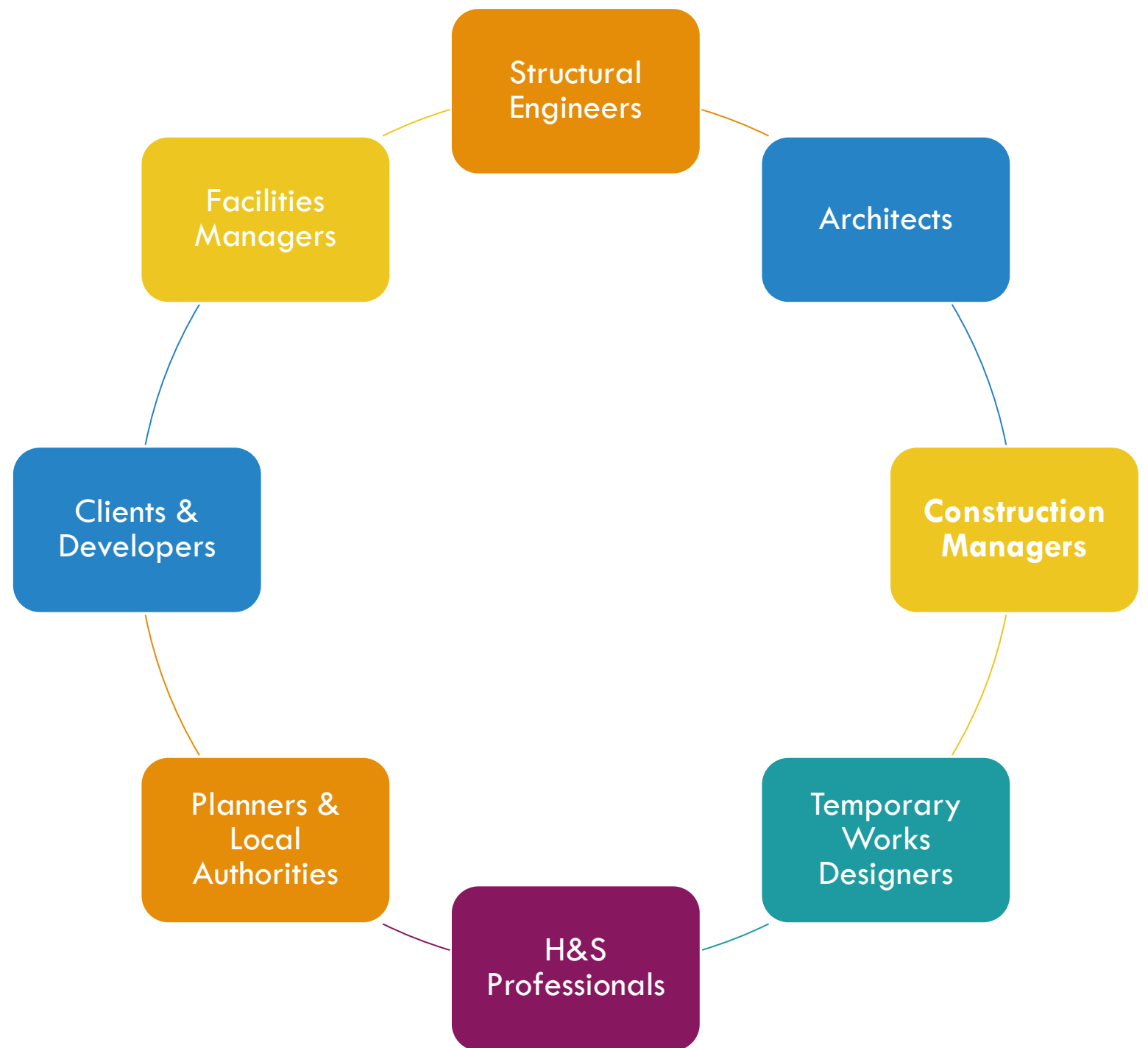
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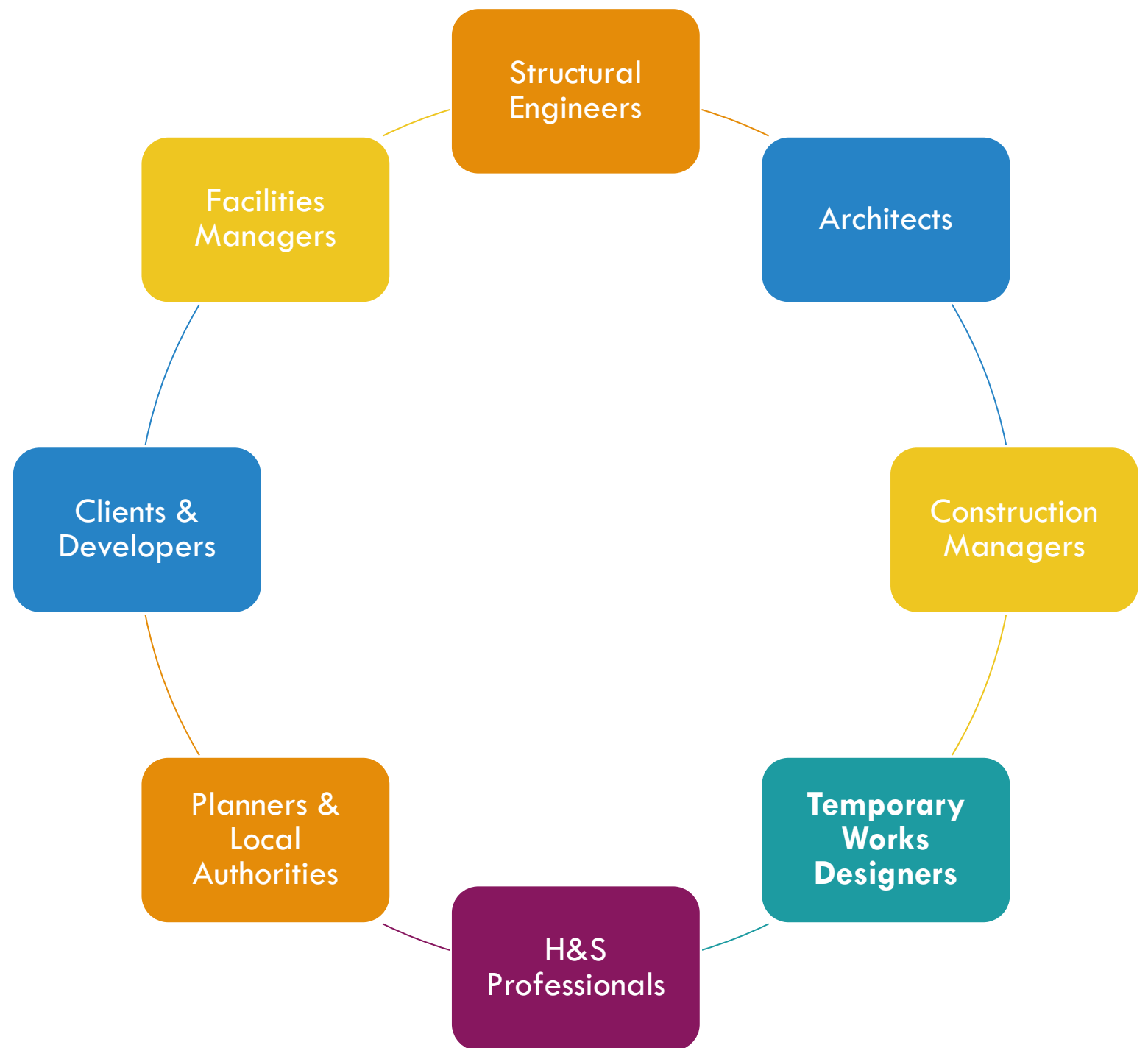
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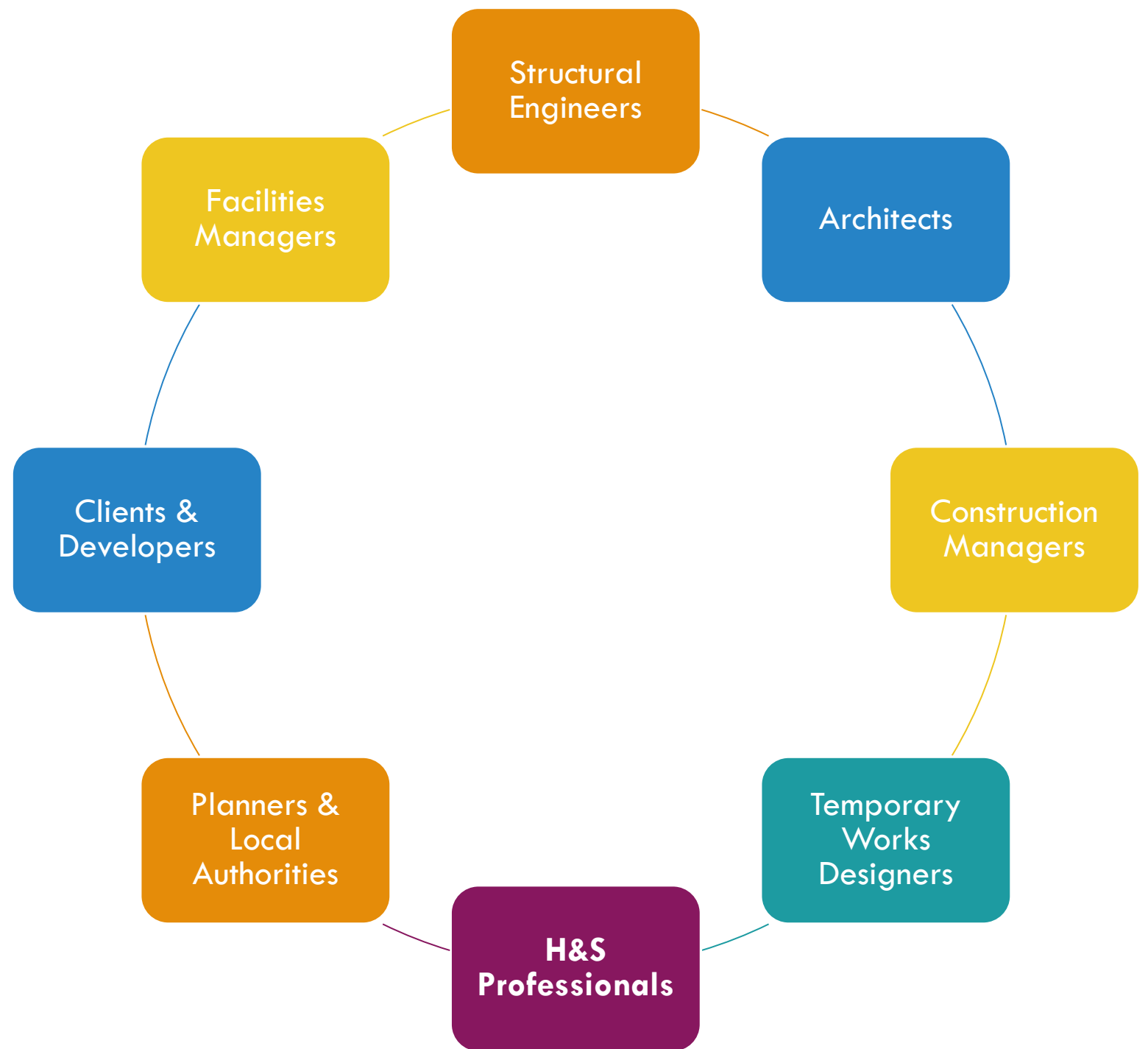
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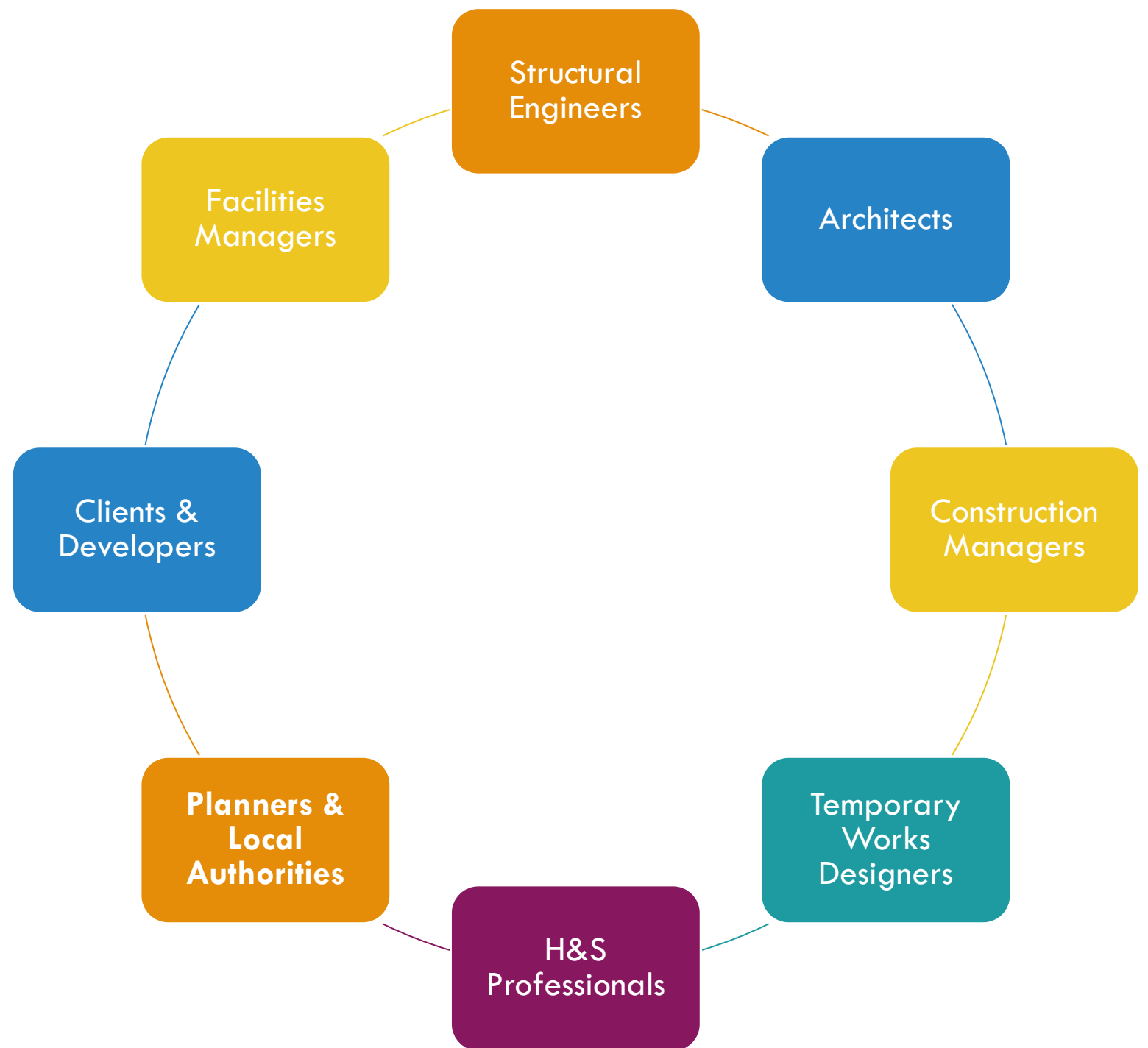
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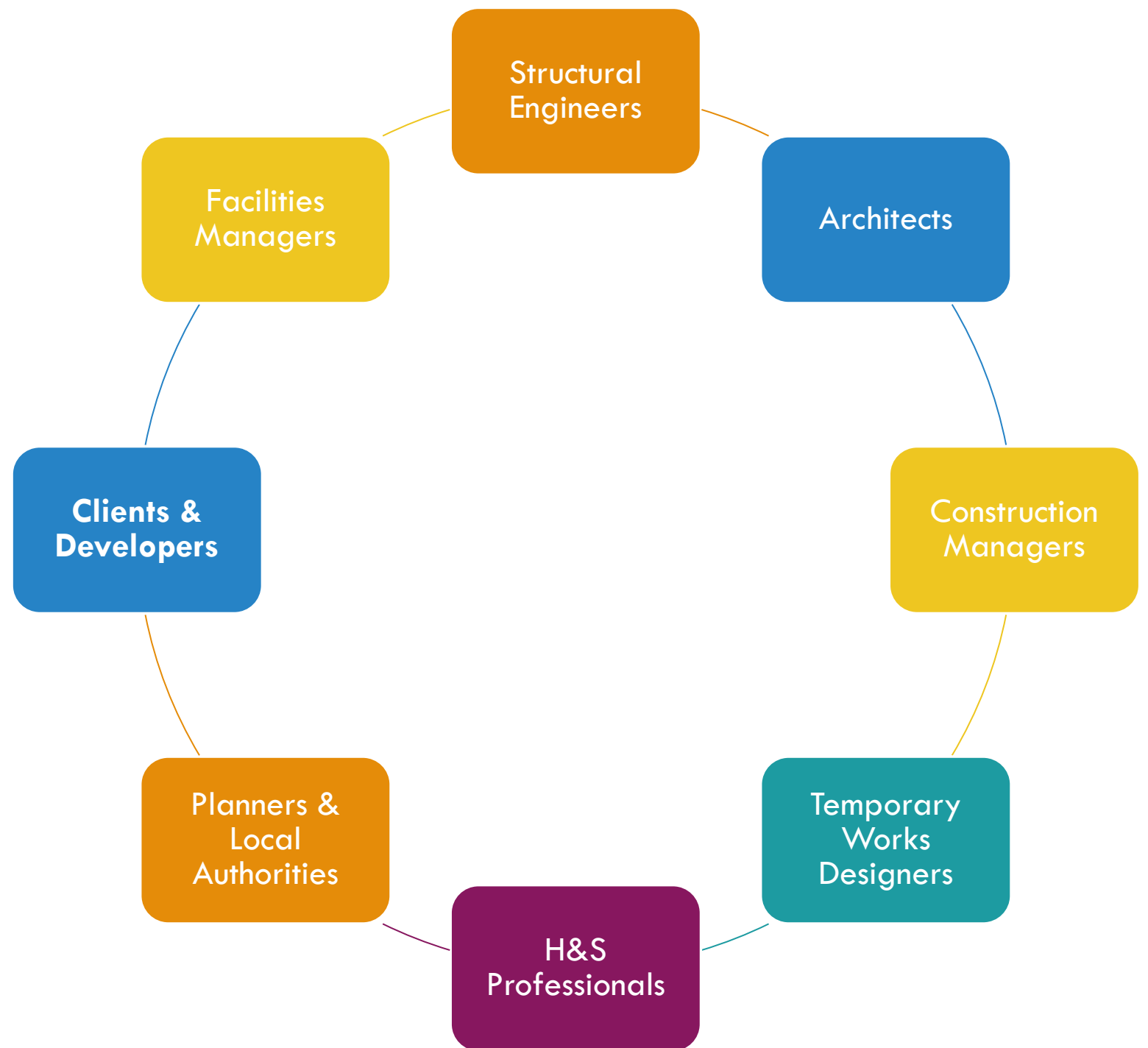
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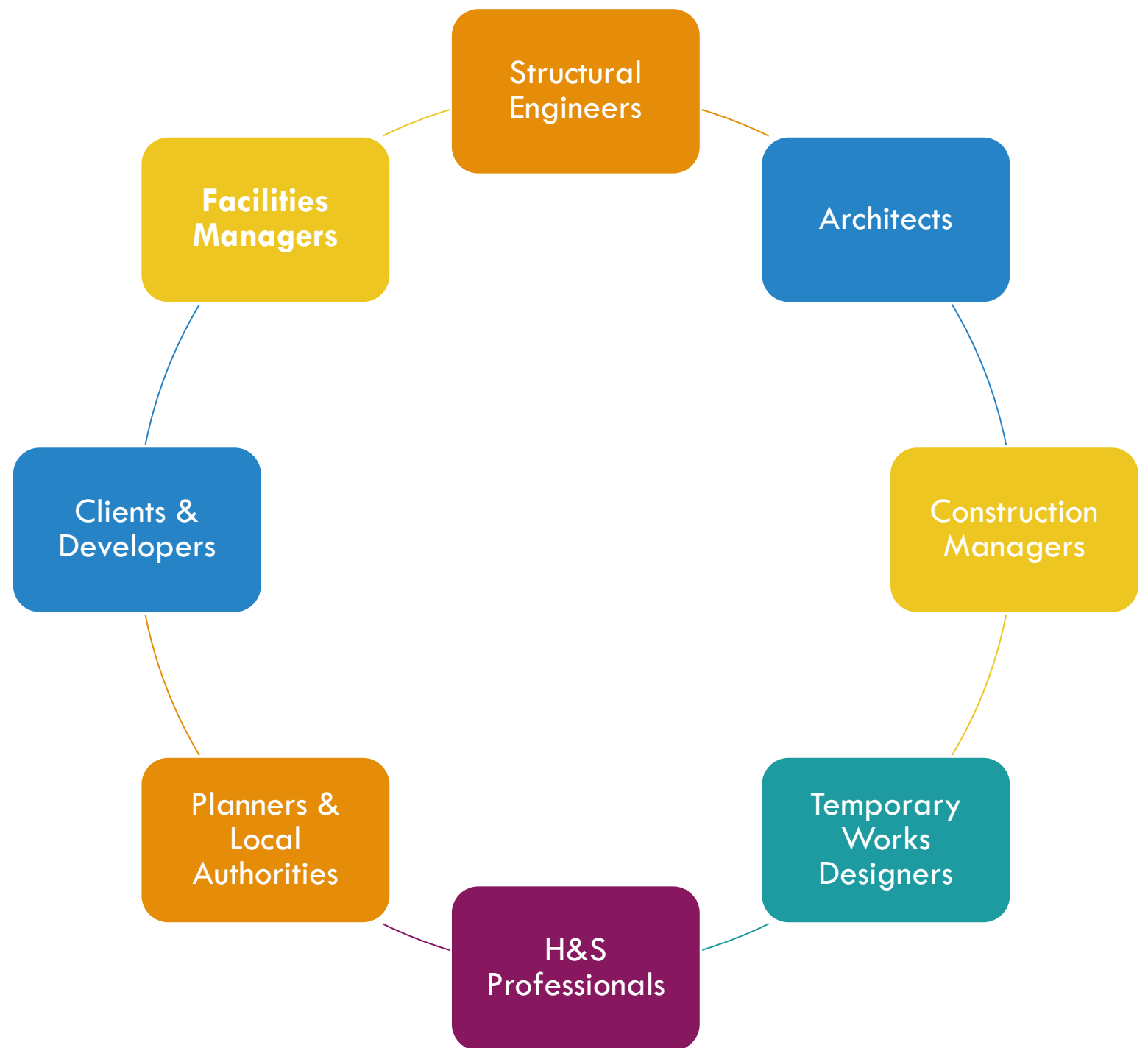
WHO NEEDS TO UNDERSTAND WIND LOADING?



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WHO NEEDS TO UNDERSTAND WIND LOADING?

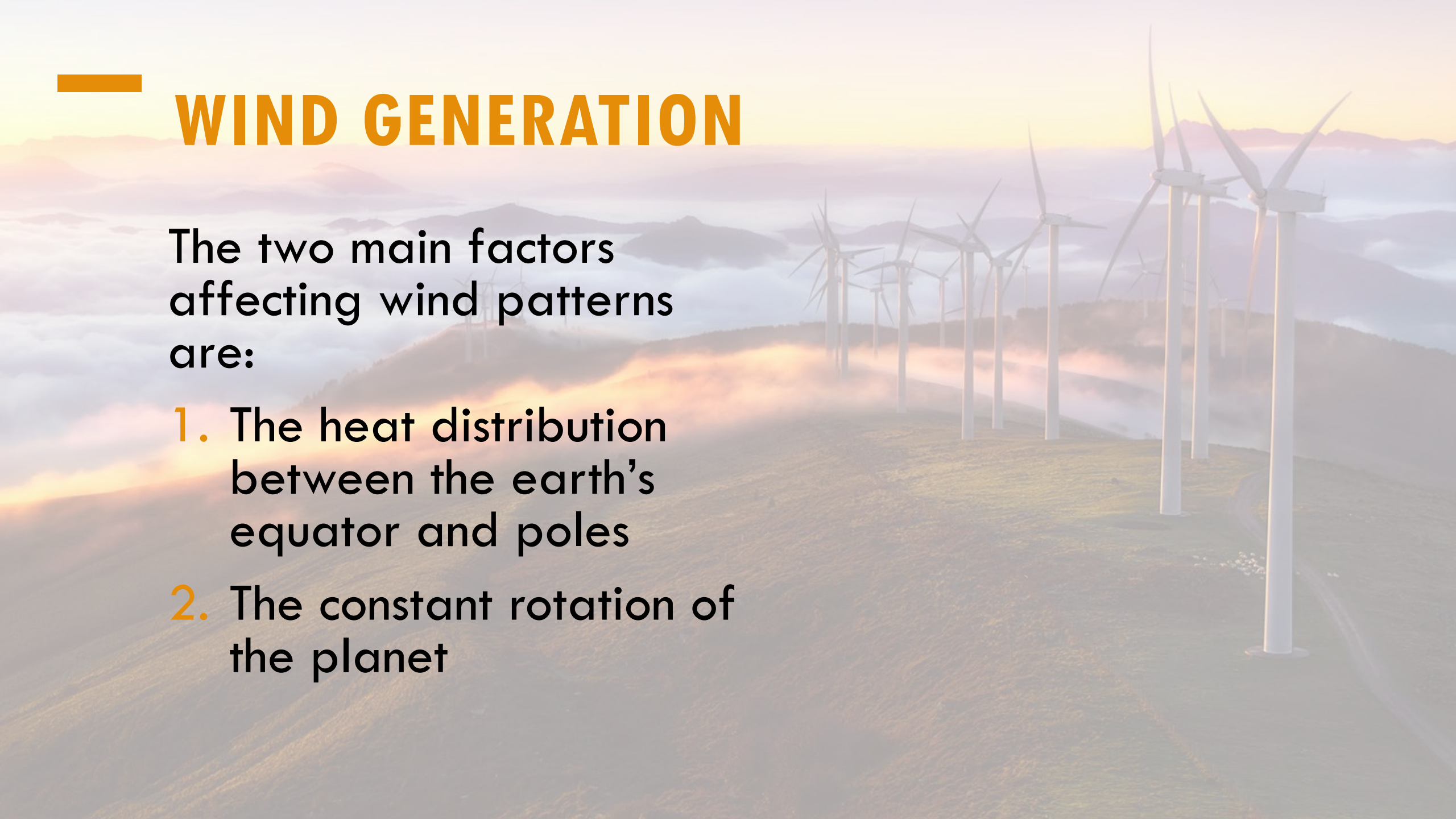




WIND GENERATION

Wind is the movement of air.





WIND GENERATION

The two main factors affecting wind patterns are:

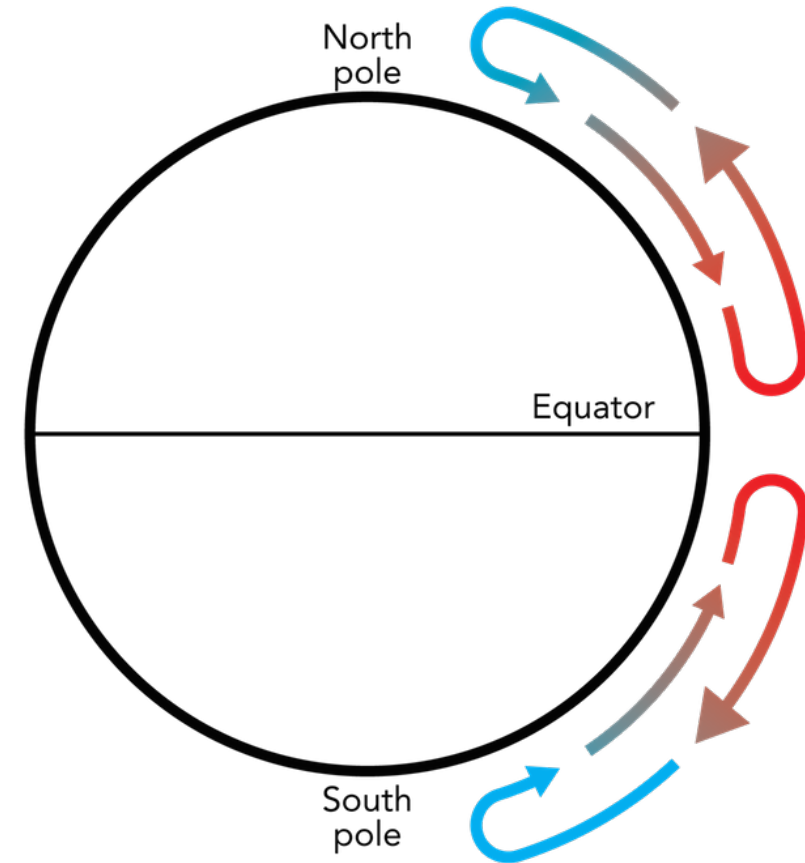
1. The heat distribution between the earth's equator and poles
2. The constant rotation of the planet

WIND GENERATION

Warm equatorial air rises higher into the atmosphere and migrates toward the poles. This is a low-pressure system.

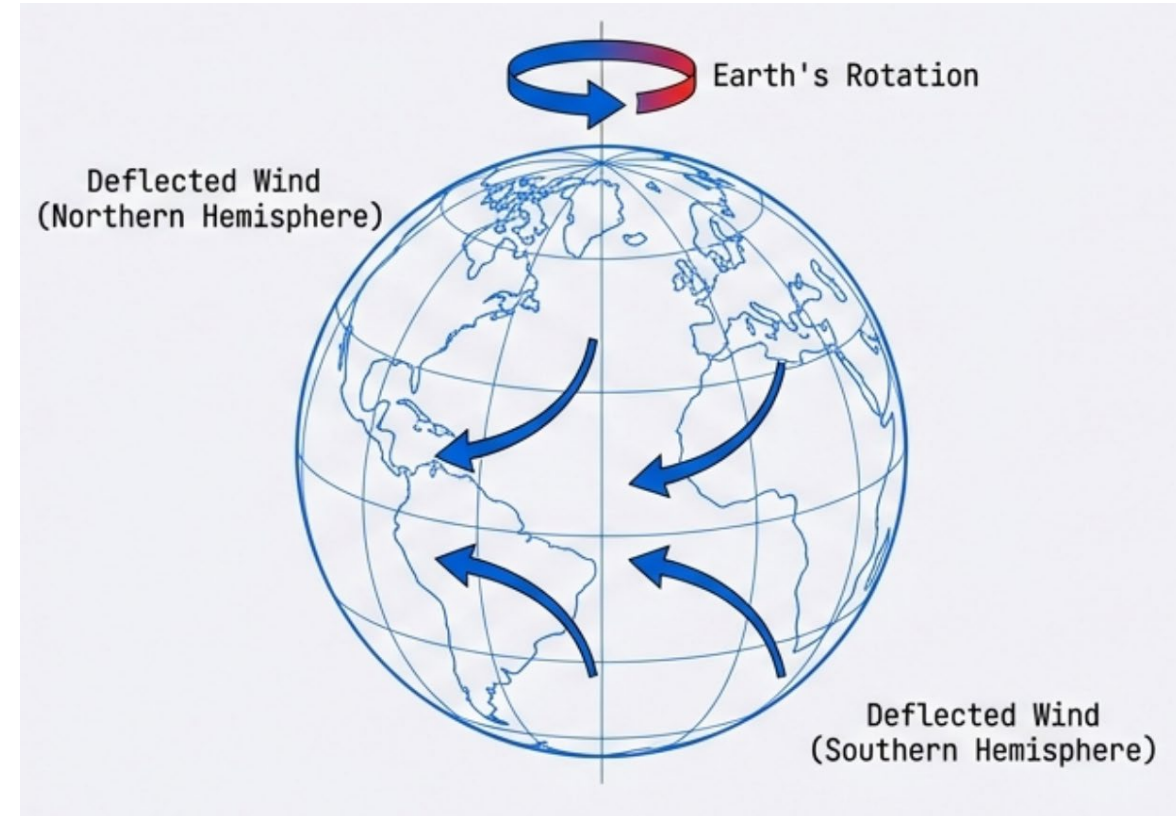
At the same time, cooler, denser air moves over Earth's surface toward the Equator to replace the heated air. This is a high-pressure system.

Winds generally blow from high-pressure areas to low-pressure areas.



WIND GENERATION

In reality, wind does not flow directly from areas of high to low pressure as there is a separate force at work - the Coriolis effect.





WIND GENERATION

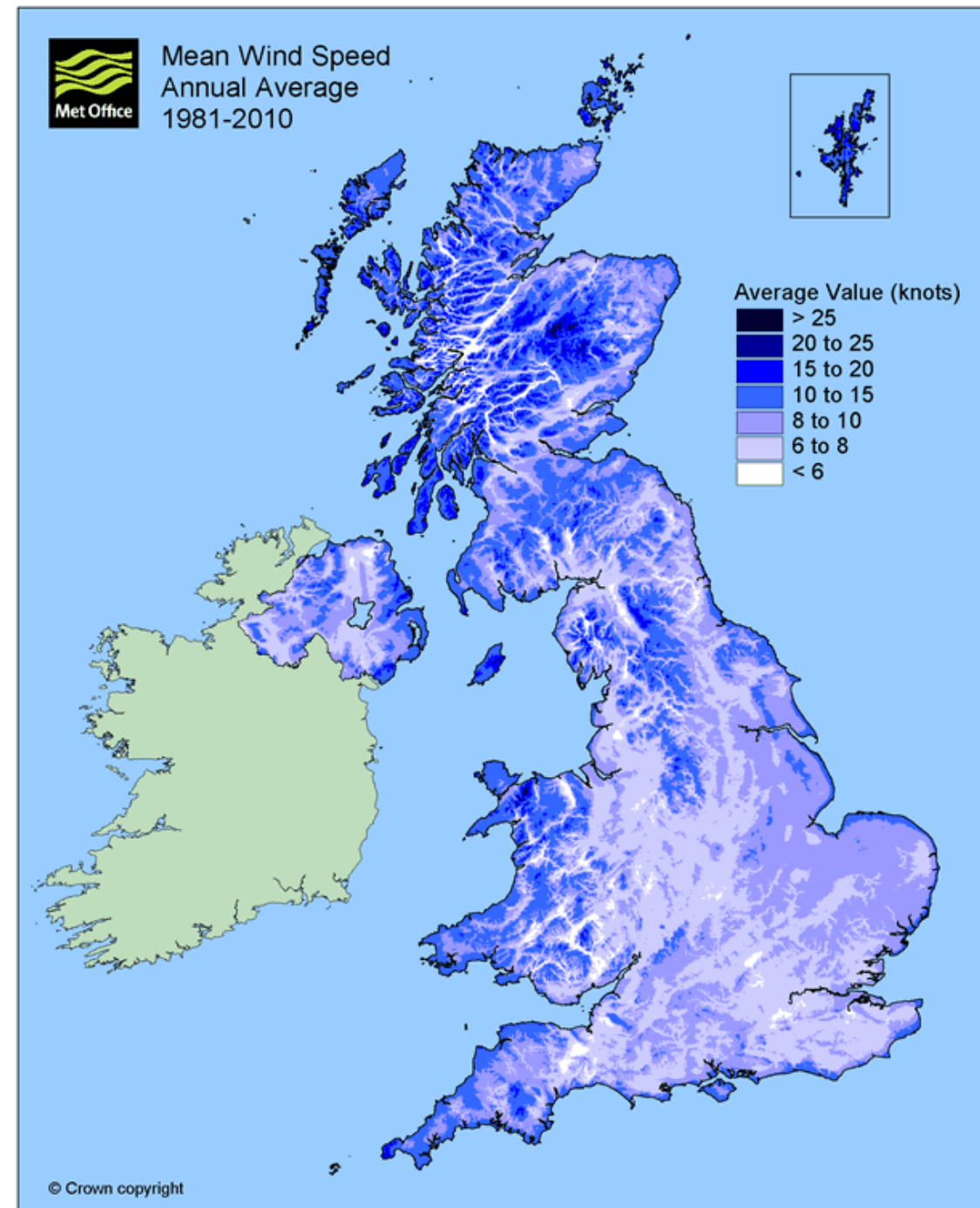


WIND SPEED

- Wind speed is typically measured in metres per second (m/s) or miles per hour (mph).
- Meteorological stations and wind turbines often measure wind speed at standard heights (e.g., 10m above ground).

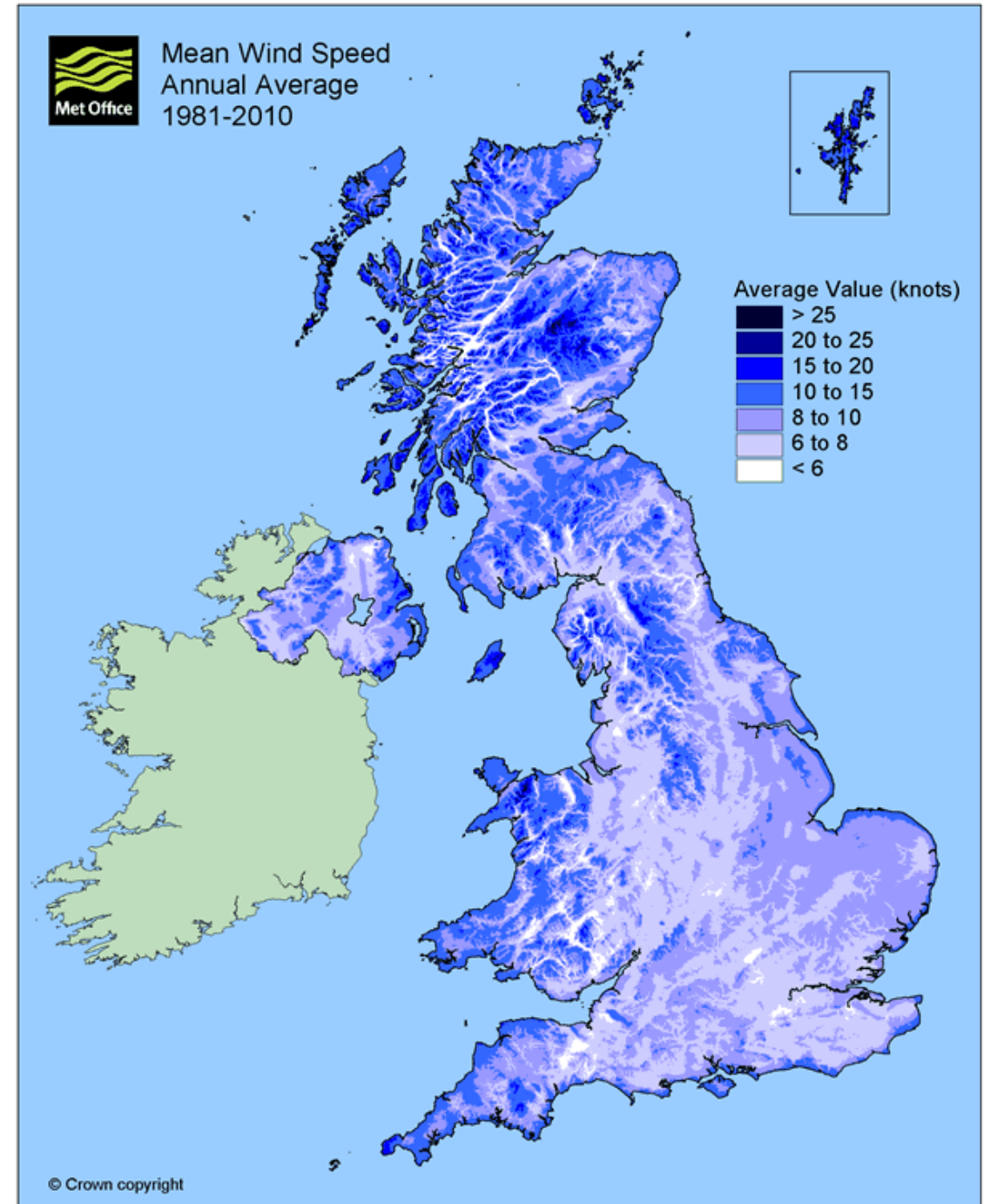
LOCATION, LOCATION, LOCATION

The location of a structure is a foundational element in determining the wind loads it will experience, as it directly influences the intensity, velocity, and turbulence of the wind it must withstand



LOCATION, LOCATION, LOCATION

Different geographic locations have different recorded, long-term wind speeds, often represented on wind maps.



LOCATION, LOCATION, LOCATION

The surrounding environment directly impacts wind speed at ground level.



LOCATION, LOCATION, LOCATION

Hills, cliffs, and valleys can significantly magnify wind speeds, particularly on windward slopes and crests.



LOCATION, LOCATION, LOCATION

Adjacent structures or terrain features can either shield a building or funnel wind into it.

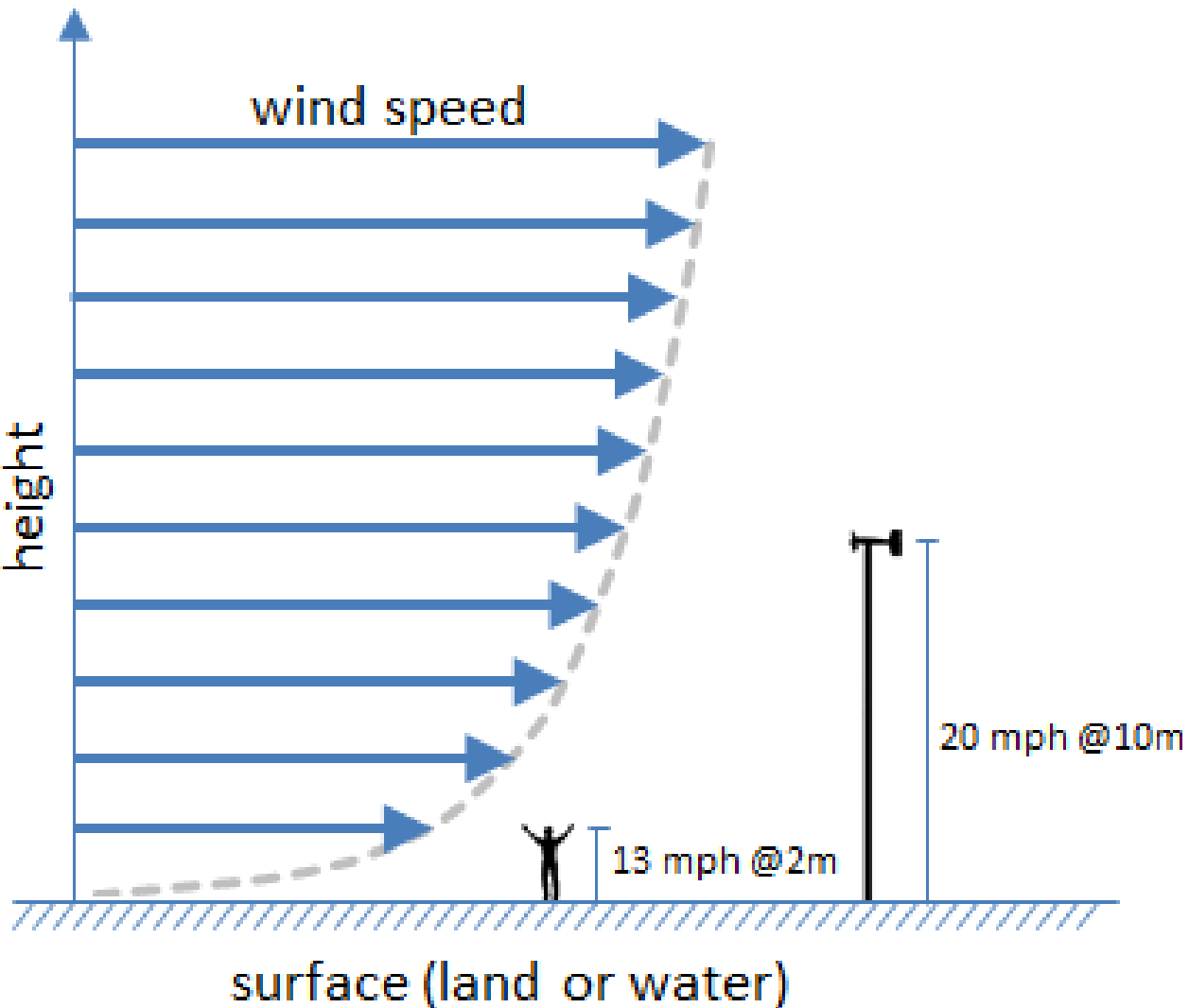


LOCATION, LOCATION, LOCATION

Wind speed generally increases with height, making top-floor and roof components susceptible to higher pressures.

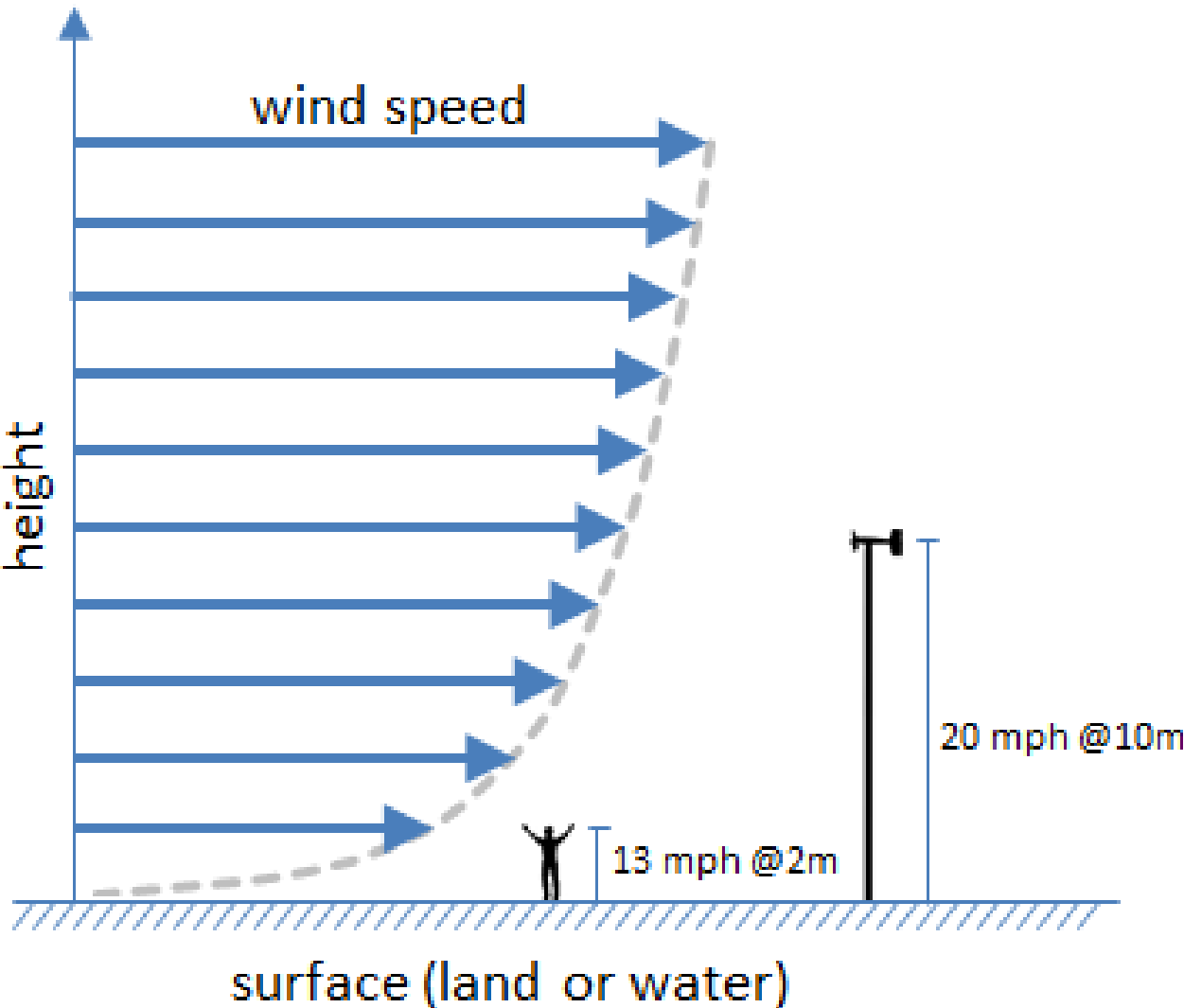


WIND GRADIENT



- Wind speed increases with height due to reduced friction with the ground.
- The atmospheric boundary layer is where wind interacts with terrain and structures.

WIND GRADIENT



- Wind speed at height (h) is given by:

$$V_h = V_r \left(\frac{h}{h_r} \right)^\alpha$$

- Where:

V_h = Wind Speed at height h

V_r = Reference Wind speed at height h_r

α = Power Law Exponent (typically 0.1-0.4)



WIND GRADIENT

A building is located in open terrain. The wind speed at 10m height is 30m/s. Estimate the wind speed at 50m height.

$$V_h = V_r \left(\frac{h}{h_r} \right)^\alpha$$

- Where:

V_h = Wind Speed at height h

V_r = Reference Wind speed at height h_r

α = Power Law Exponent (typically 0.1 - 0.4)



WIND GRADIENT

A building is located in open terrain. The wind speed at 10m height is 30m/s. Estimate the wind speed at 50m height.

$$V_{50} = V_{10} \left(\frac{h}{h_{10}} \right)^{\alpha}$$

Terrain Description	α
Smooth hard ground, lake or ocean	0.10
Open grassland	0.14
Many trees and occasional buildings	0.22-0.24
Small towns and suburbs	0.28-0.30
Urban areas with tall buildings	0.4



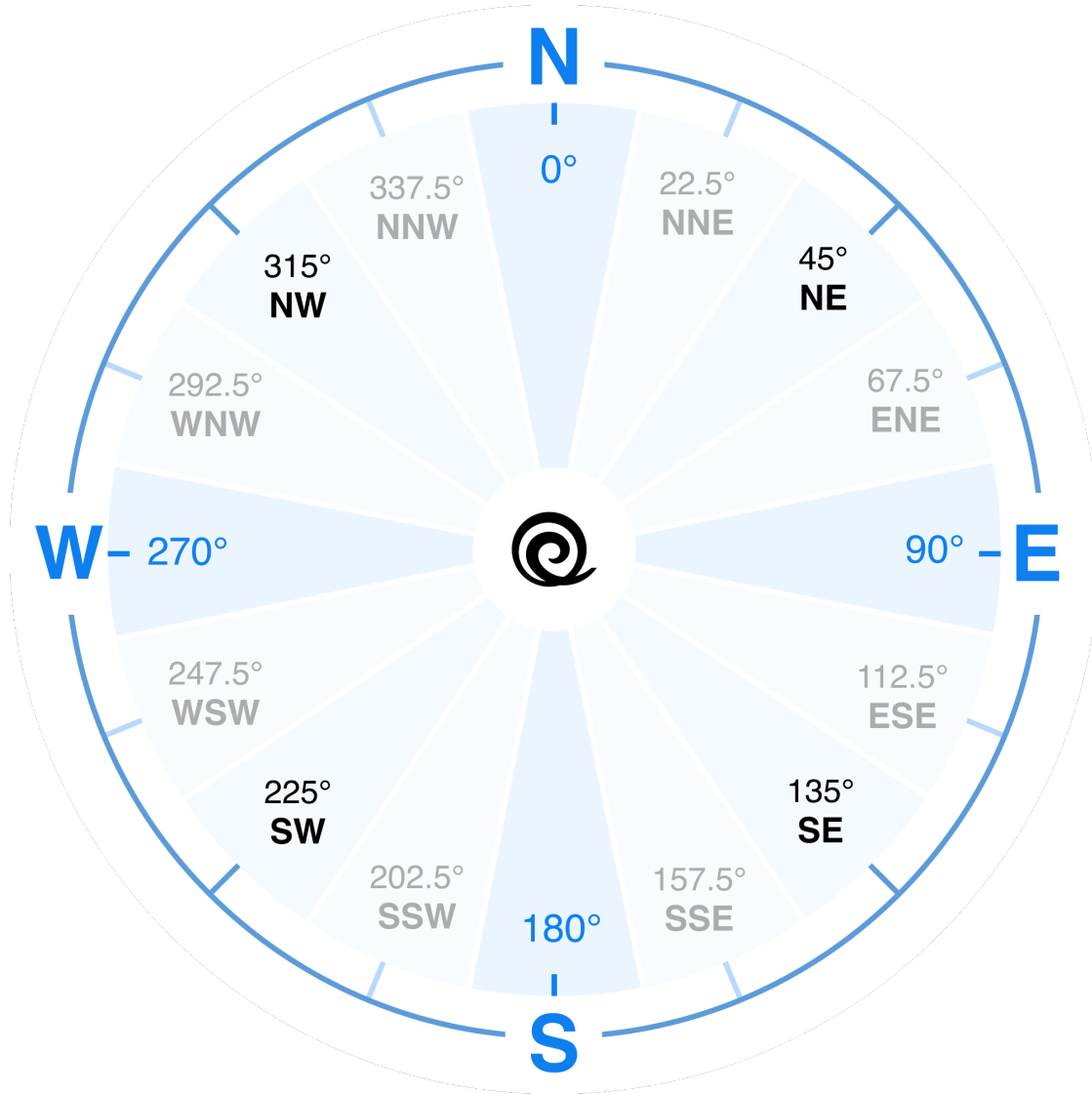
WIND GRADIENT

A building is located in open terrain. The wind speed at 10m height is 30m/s. Estimate the wind speed at 50m height.

$$V_{50} = 30 \left(\frac{50}{10} \right)^{0.14} = 37.5m/s$$

Terrain Description	α
Smooth hard ground, lake or ocean	0.10
Open grassland	0.14
Many trees and occasional buildings	0.22-0.24
Small towns and suburbs	0.28-0.30
Urban areas with tall buildings	0.4

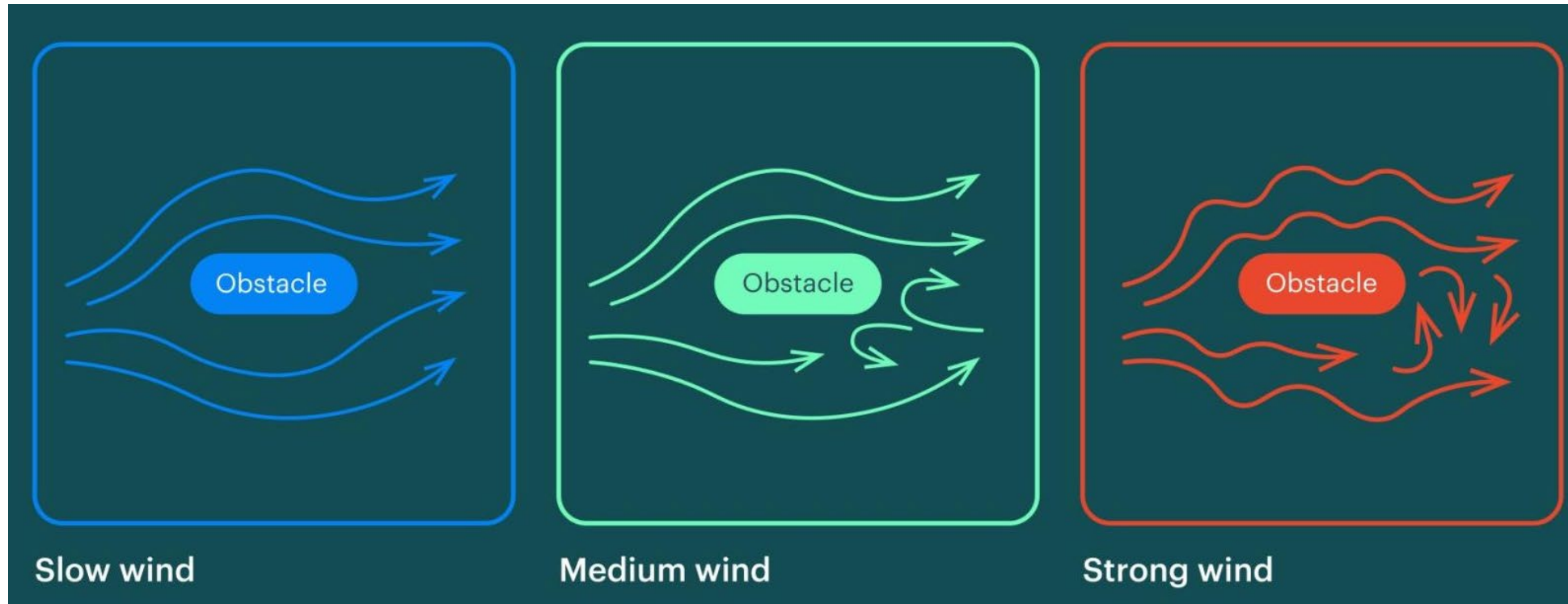
WIND DIRECTION



- The direction from which the wind originates, measured in degrees from true north

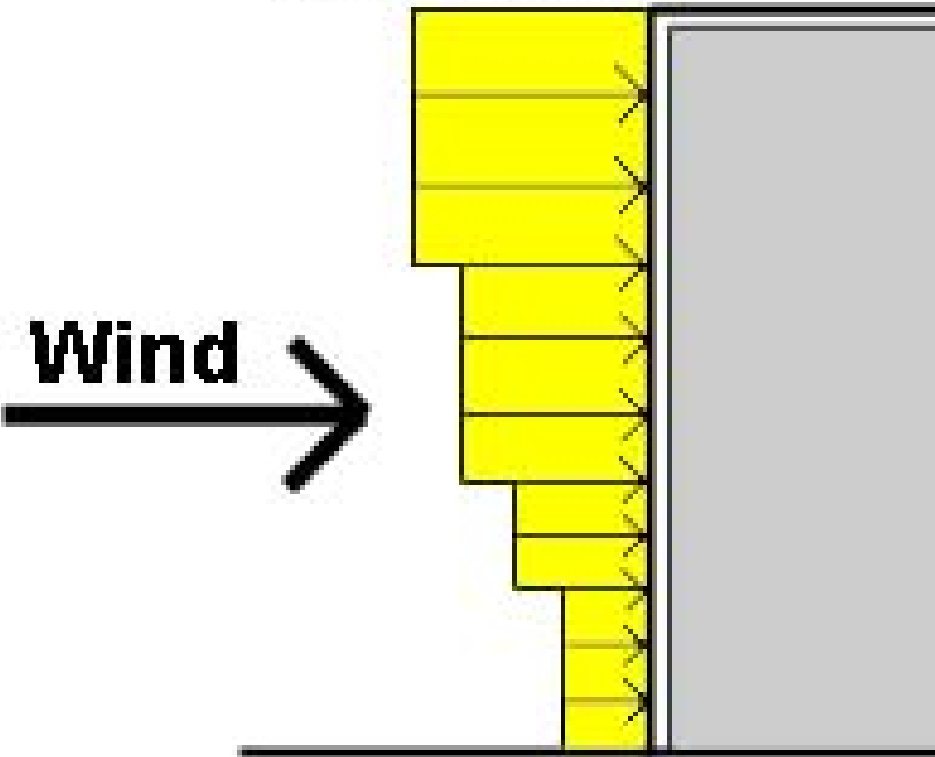
TURBULENCE

- Turbulence is irregular wind motion caused by obstacles, temperature changes and atmospheric instability.



WIND LOADS

**Windward
pressure**



- As the wind blows against a building, the resulting force acting on the elevations is called the 'wind load'.
- The building's structural design must absorb wind forces safely and efficiently and transfer them to the foundations to avoid structural collapse.



WIND LOADS

- It is an essential consideration in the design and analysis of buildings, bridges, towers, and other structures, as wind can exert significant pressures that can cause structural failures or excessive deformations.



WIND LOADS

There are basically 3 types of wind load:

- Uplift load – Wind pressures that flow upwards towards the roof, resulting in a pulling effect.



WIND LOADS

There are basically 3 types of wind load:

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- Shear load – Wind pressures that flow horizontally parallel to the ground, causing a building to tilt.

WIND LOADS

There are basically 3 types of wind load:

- Uplift load – Wind pressures that flow upwards towards the roof, resulting in a pulling effect.
- Shear load – Wind pressures that flow horizontally parallel to the ground, causing a building to tilt.
- Lateral load – Wind pressures that flow horizontally against the structure, causing a building to slide off the foundation.





ESTIMATING WIND LOADS

There are three levels of wind load estimate:

- The Five Second Guess
- The Ten-Minute Calculation
- The One Hour Calculation



ESTIMATING WIND LOADS

There are three levels of wind load estimate:

- **The Five Second Guess**
- **The Ten-Minute Calculation**
- ~~The One Hour Calculation~~



5 SECOND GUESS

This is useful when you need a really quick answer.

- It won't be correct, but it will be a good guess.
- Most laterally applied loads are in the order of 1kN/m^2 .
- To give some conservatism, you could use 1.3kN/m^2 , and if your building is on high ground or near the coast (especially if exposed to south-westerly winds), you could use 1.5kN/m^2 .



5 SECOND GUESS

Step 1: Select Design Pressure

Since the building is:

- Near the coast
- Exposed to strong prevailing winds

Adopt:

$$p = 1.5kN/m^2$$

Estimate the total wind force and overturning moment on a building of height 12m, width (windward face) 18m at an exposed coastal site.



5 SECOND GUESS

Estimate the total wind force and overturning moment on a building of height 12m, width (windward face) 18m at an exposed coastal site.

Step 2: Calculate Projected Area

Area = Height x Width

$$A = 12 \times 18 = 216m^2$$



5 SECOND GUESS

Step 3: Calculate Total Wind Force

Estimate the total wind force and overturning moment on a building of height 12m, width (windward face) 18m at an exposed coastal site.

$$F = pA = 1.5 \times 216 = 324kN$$

The building experiences a horizontal force of approximately 324kN due to wind.



5 SECOND GUESS

Estimate the total wind force and overturning moment on a building of height 12m, width (windward face) 18m at an exposed coastal site.

Step 4: Estimate Overturning Moment

Assume the resultant wind force acts at mid-height

$$z = \frac{12}{2} = 6m$$

$$M = F \times z = 324 \times 6 = 1944kNm$$



10 MINUTE CALCULATION

- If you have a little longer, it isn't very hard to get a conservative wind load.
- You need to take the following steps:



10 MINUTE CALCULATION

Step 1.

- Use Figure NA.1 from the National Annex to BS EN 1991-1-4.
- Locate your building and choose $v_{b,map}$.



10 MINUTE CALCULATION

Estimate the total wind force and overturning moment on a building of height 12m, width (windward face) 18m at an exposed coastal site in Swansea.

10 MINUTE CALCULATION

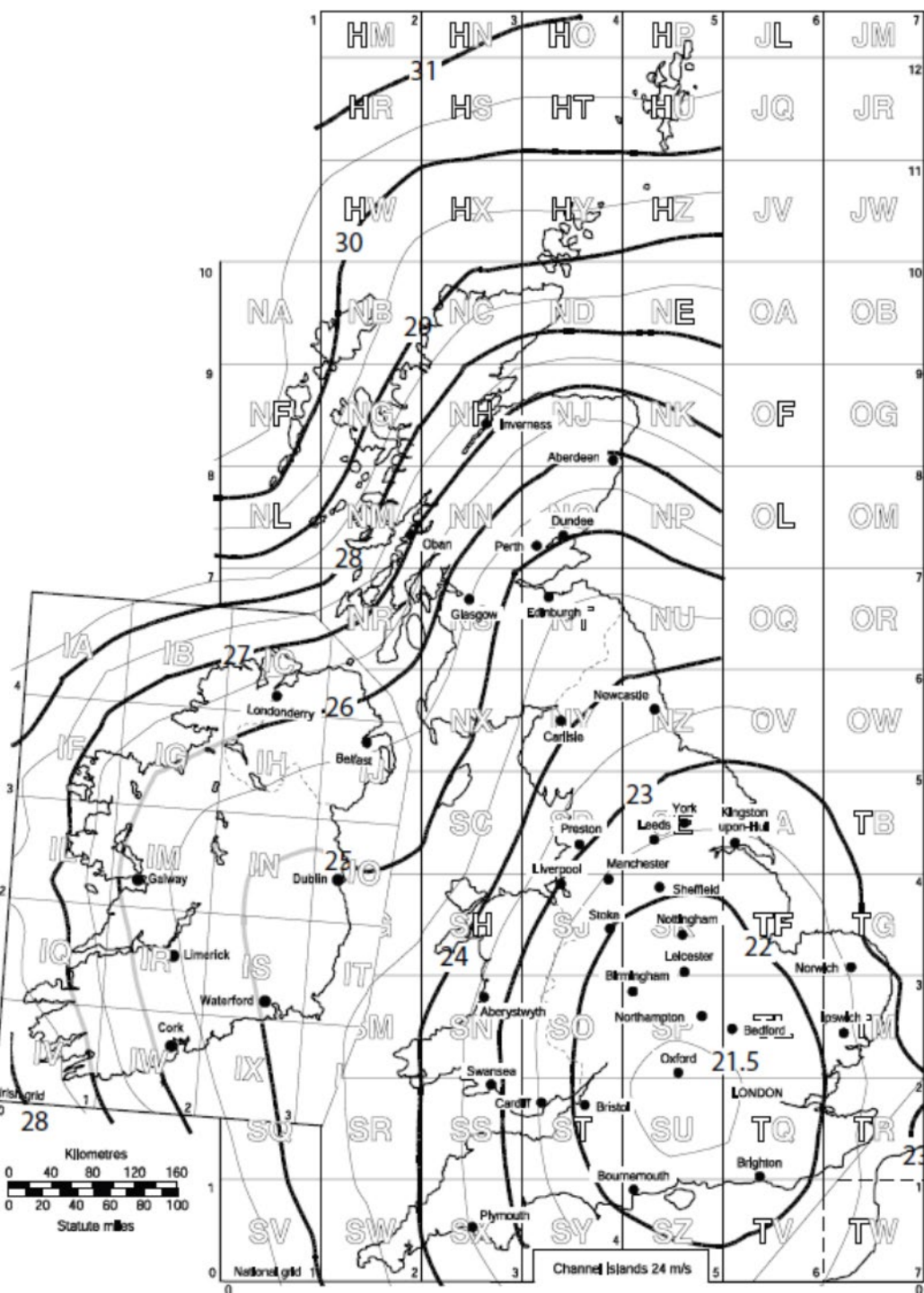


Figure NA.1

For Swansea, $v_{b, \text{map}} = 23 \text{ m/s}$

10 MINUTE CALCULATION

NA.2.5 Procedure for determining the influence of altitude [BS EN 1991-1-4:2005, 4.2 (2)P Note 1]

The altitude factor c_{alt} should be determined from Equations NA.2a) or NA.2b).

$$\text{(NA.2a))} \quad c_{\text{alt}} = 1 + 0,001 \cdot A \quad \text{for } z \leq 10 \text{ m)}$$

$$\text{(NA.2b))} \quad c_{\text{alt}} = 1 + 0,001 \cdot A \cdot (10/z)^{0.2} \quad \text{for } z > 10 \text{ m}$$

where

A is the altitude of the site in metres above mean sea level;

z is either z_s as defined in BS EN 1991-1-4:2005 Figure 6.1 or z_e the height of the part above ground as defined in BS EN 1991-1-4:2005 Figure 7.4.

NOTE Equation NA.2a) may be used conservatively for any building height.

Step 2.

- Use NA.2.5 to calculate C_{alt} using equation NA.2a (for buildings taller than 10m the other equation gives a less conservative value).
- We can now multiply $v_{b,\text{map}}$ by c_{alt} to get our final, conservative wind speed

10 MINUTE CALCULATION

NA.2.5 Procedure for determining the influence of altitude [BS EN 1991-1-4:2005, 4.2 (2)P Note 1]

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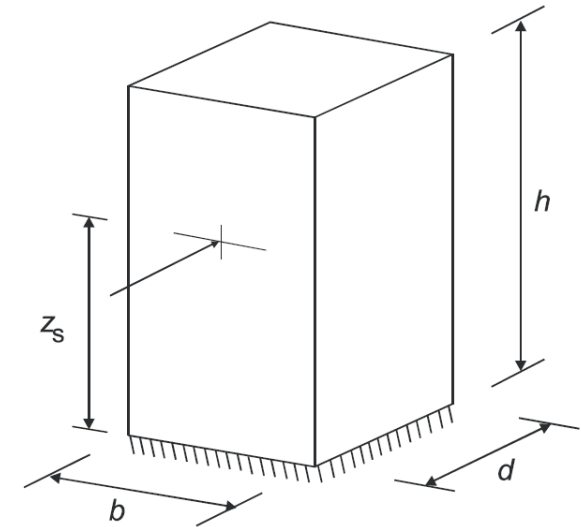
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NOTE Equation NA.2a) may be used conservatively for any building height.

a) vertical structures such as buildings etc.



is are also giver

$$Z_s = 0.6 \times h = 0.6 \times 12 = 7.2$$

$$z_s = 0,6 \cdot h \geq z_{\text{min}}$$

10 MINUTE CALCULATION



$$C_{alt} = 1 + 0.001 \times A$$

$$C_{alt} = 1 + 0.001 \times 10.4$$

$$C_{alt} = 1.0104$$



10 MINUTE CALCULATION

Step 3.

Calculate the pressure using Equation 4.10 of BS EN 1991-1-4.

10 MINUTE CALCULATION

$$q_b = \frac{1}{2} \cdot \rho \cdot v_b^2 \quad (4.10)$$

NOTE 2 The values for ρ may be given in the National Annex. The recommended value is 1,25 kg/m³.

$$q_b = \frac{1}{2} \rho v_b^2$$

$$q_b = \frac{1}{2} \times 1.25 \times 23^2$$

$$q_b = \frac{1}{2} \times 1.25 \times 529$$

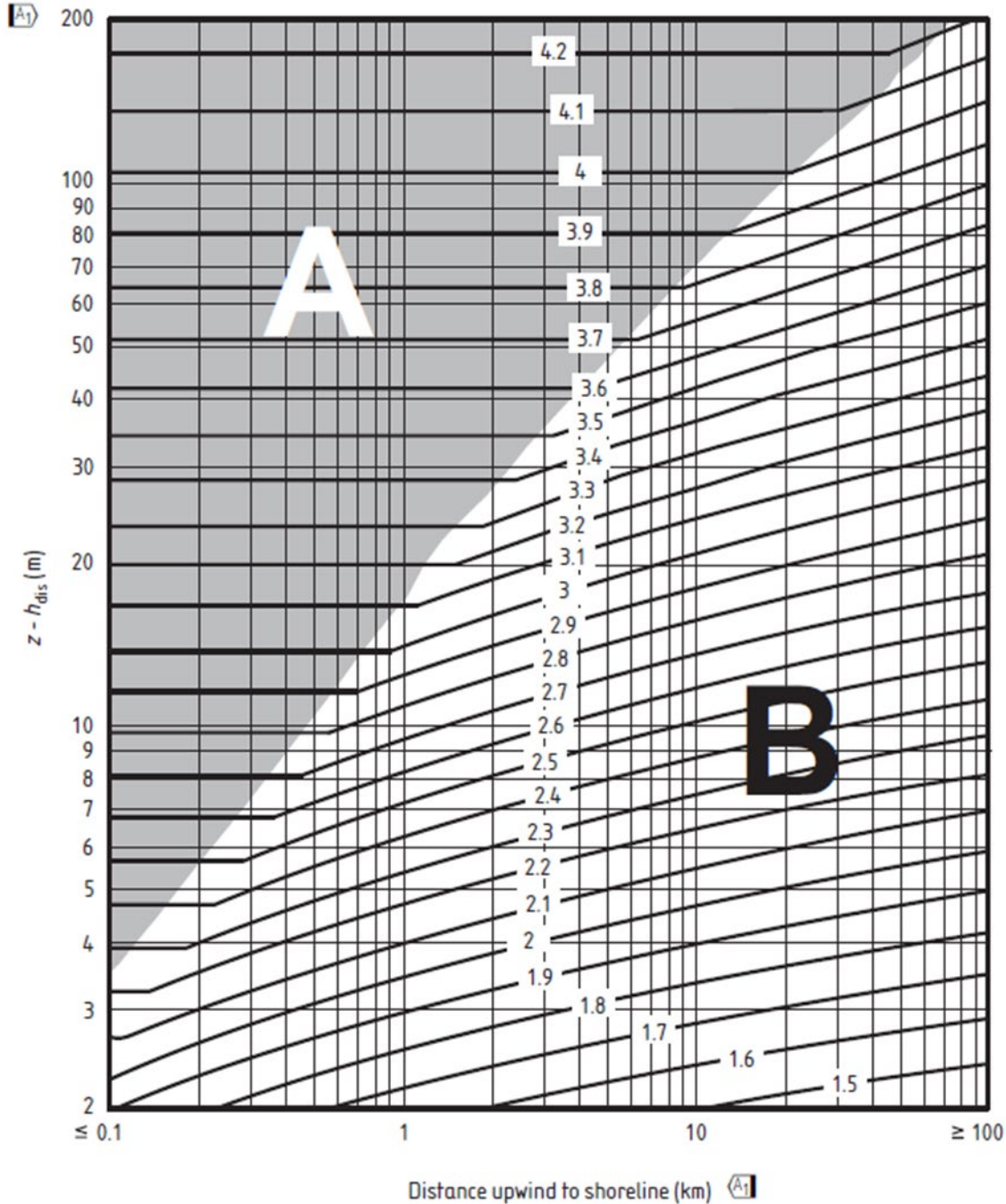
$$q_b = 330.6$$



10 MINUTE CALCULATION

Step 4.

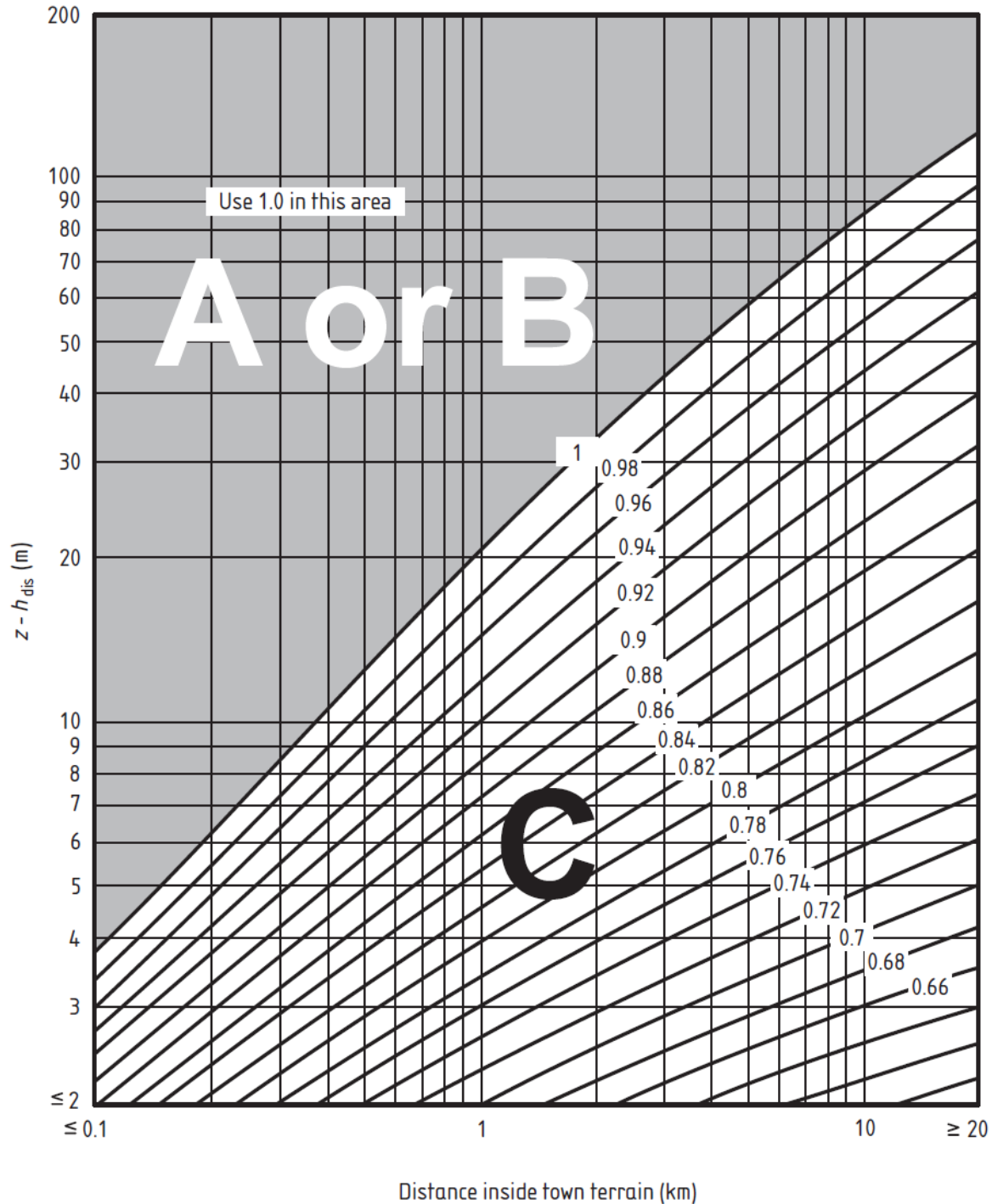
Choose the worst distance to town and sea and use these values to look up the $c_e(z)$ and $c_{e,T}$ from Figure NA.7 and NA.8 in the National Annex



10 MINUTE CALCULATION

NOTE 1 The height z is the height at which q_p is sought using Equations NA.3a) or NA.3b).

NOTE 2 Zones A and B are indicated for use in Table NA.3.



10 MINUTE CALCULATION



10 MINUTE CALCULATION

Step 5

Multiply these values and the basic wind pressure to get the site wind pressure



10 MINUTE CALCULATION

$$q_s = q_b \times c_{alt} \times C_e(z) \times C_{e,T}$$

$$q_s = 330.6 \times 1.0104 \times 2.9 \times 1$$

$$q_s = 968.7 \text{ N/m}^2 = \mathbf{0.97 \text{ kN/m}^2}$$



10 MINUTE CALCULATION

Step 6

- Using Table NA.4, calculate the building c_p . If you don't have time to calculate h/d or it is not clear use 1.3. This gives the lateral load on a roughly rectangular building in kN/m^2

10 MINUTE CALCULATION

$$= h/d$$

$$= 12/18$$

$$= 0.67$$

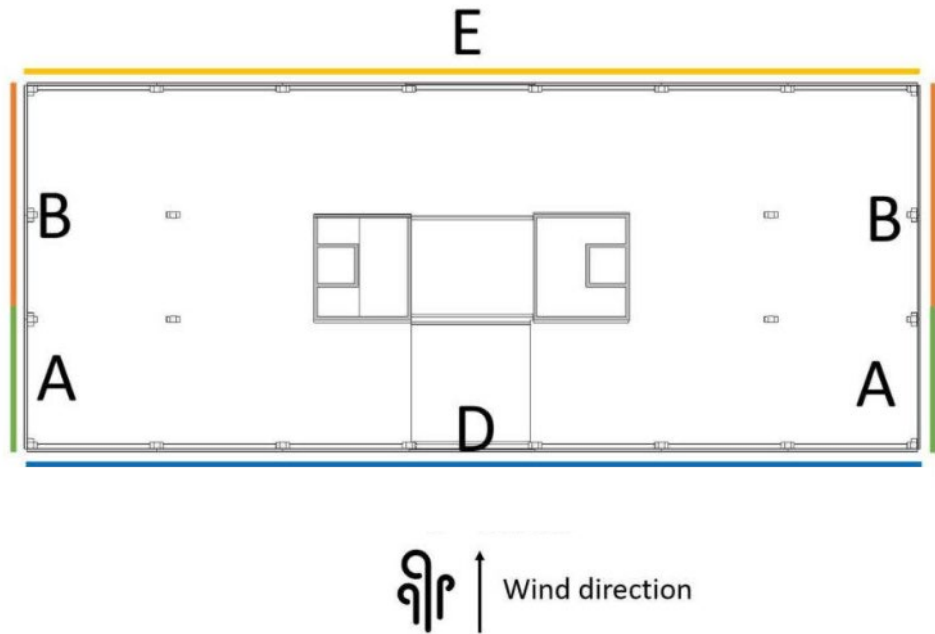


Table NA.4 Values of external pressure coefficients for vertical walls of rectangular-plan buildings ($C_{pe,10}$ and $C_{pe,1}$)

h/d	Zone				
	A	B	C	D	E
5	-1,2	-0,8	-0,5	+0,8	-0,7
1,0	-1,2	-0,8	-0,5	+0,8	-0,5
$\leq 0,25$	-1,2	-0,8	-0,5	+0,7	-0,3



10 MINUTE CALCULATION

$$\textit{Total Wind Load} = q_s \times c_p$$

$$= 0.97 \times 0.8$$

$$= \mathbf{0.77\text{kN/m}^2}$$

10 MINUTE CALCULATION

$$\textit{Total Wind Load} = q_s \times c_p$$

$$= 0.97 \times 0.8$$

$$= \mathbf{0.77kN/m^2}$$

Calculate Total Wind Force

$$F = pA = 0.77 \times 216 = 166kN$$

The building experiences a horizontal force of approximately 166kN due to wind.

CONSTRUCTION STAGE

COMMON FAILURE POINTS



**FRAME
COLLAPSES**



**SCAFFOLDING
FAILURE**



**CRANE
OVERTURNING**



OPERATIONAL HAZARDS

Wind creates unsafe conditions at height and increases the risk of falling debris.

CONSTRUCTION STAGE

CDM SAFETY CONTROLS



DESIGN & SEQUENCE PLANNING

Verify temporary works and sequence construction to avoid unstable stages.



CLEAR OPERATIONAL LIMITS

Establish specific wind speed limits and mandatory stop-work criteria.



THE CONSTRUCTION PHASE PLAN

All wind safety protocols must be formally communicated through the Phase Plan.

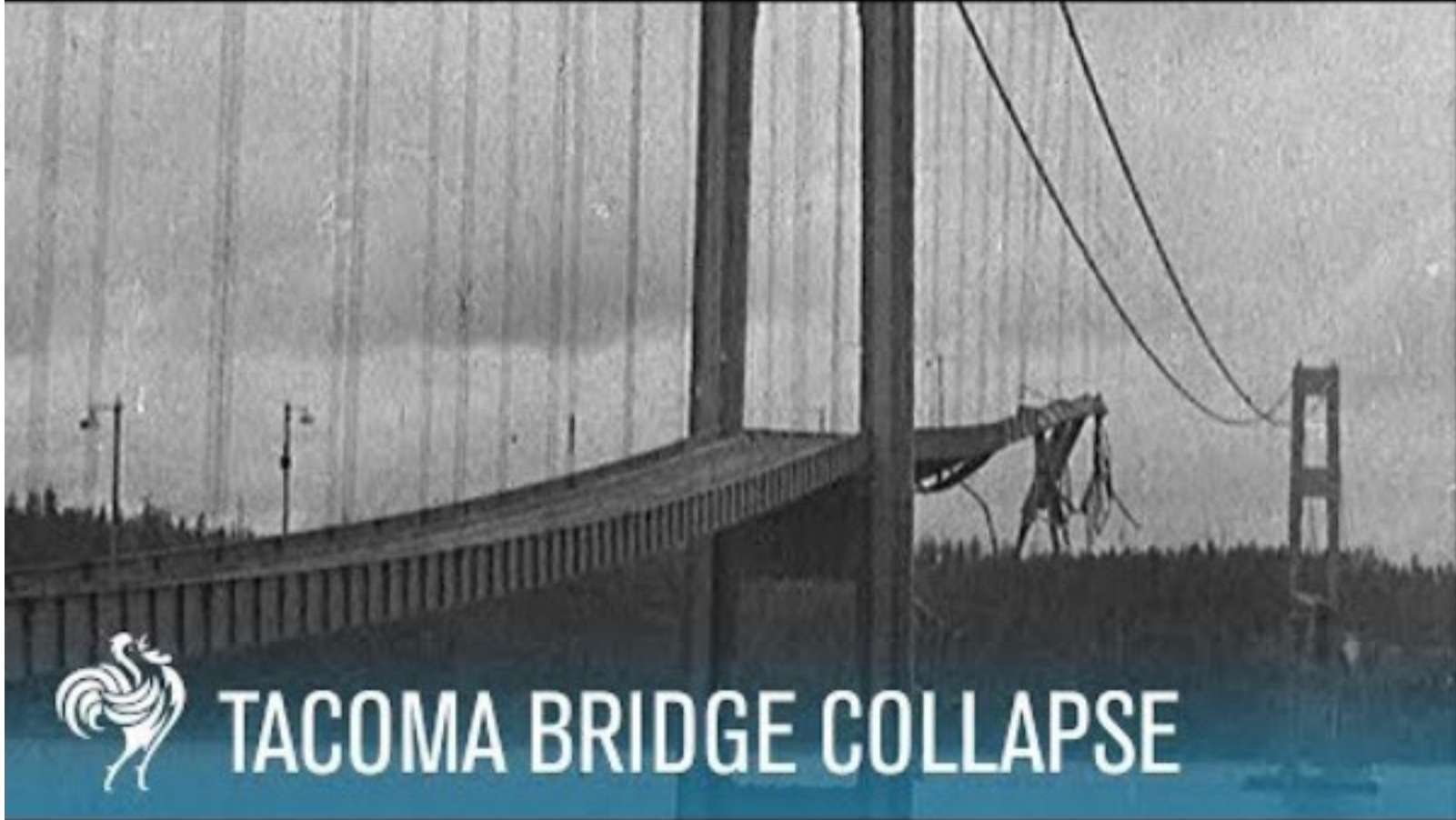


RESONANCE

Occurs when wind-induced vibrations match a structure's natural frequency, causing amplified oscillations.



TACOMA BRIDGE COLLAPSE



TUNED MASS DAMPERS

- A large suspended mass (pendulum-like) moves opposite to building sway, dissipating energy.
- Reduces structural vibrations and prevents resonance.

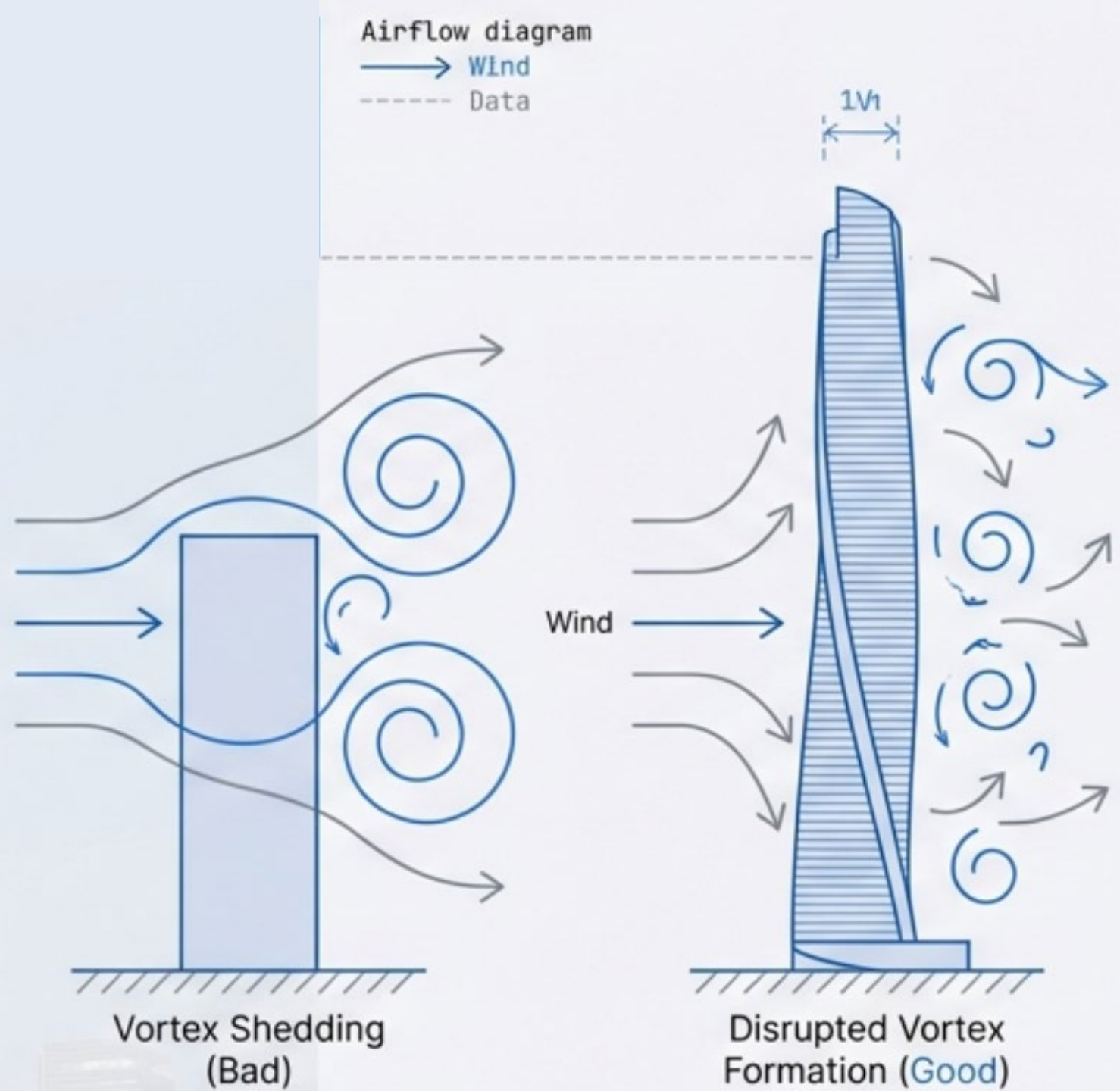


AERODYNAMIC MODIFICATIONS

- Reducing wind impact by altering building shape.
- Tapering, twisting, or adding openings to disrupt airflow and reduce vortex shedding.



AERODYNAMIC MODIFICATIONS

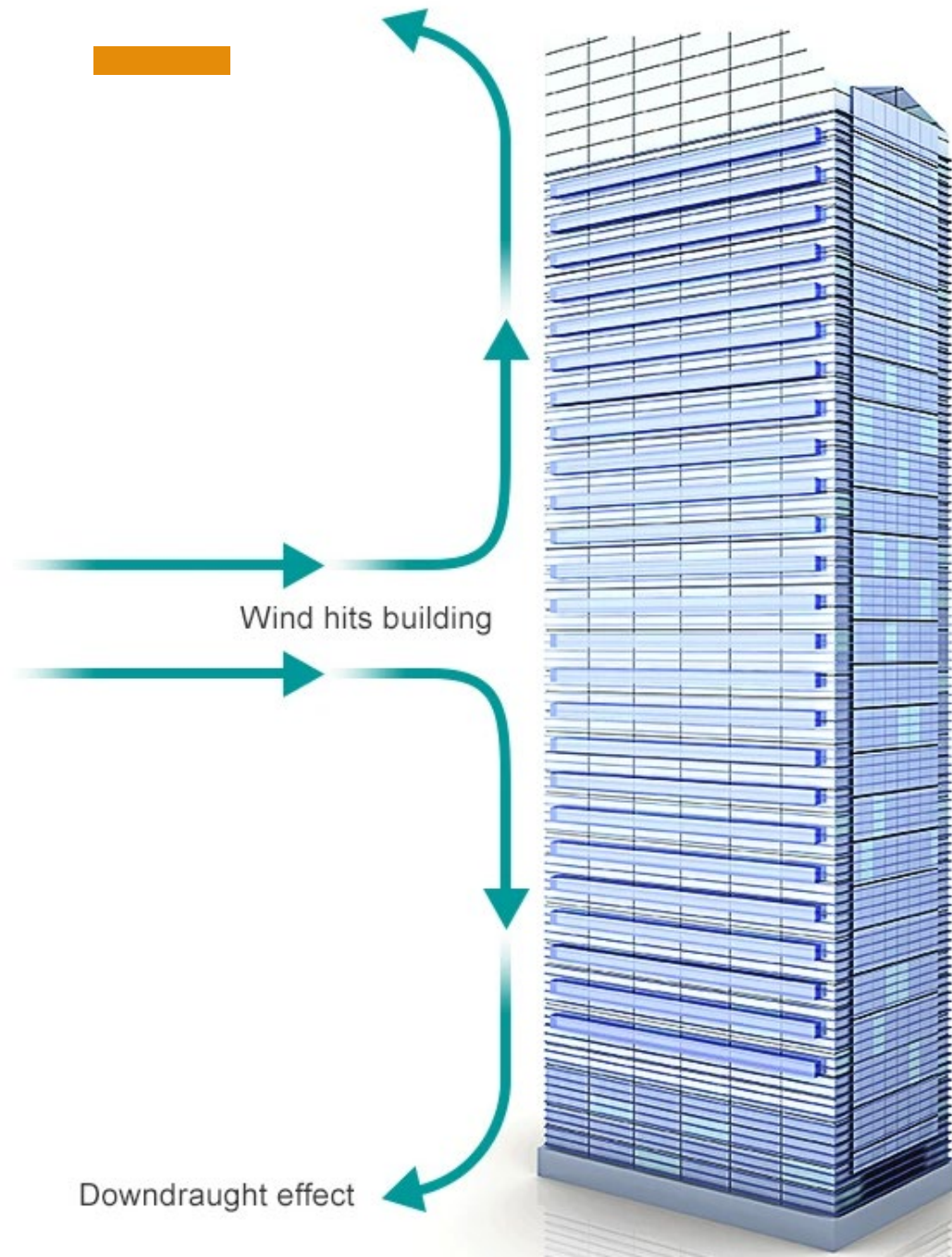




MICROCLIMATES

- The wind flow around buildings can have a major impact on pedestrian comfort and safety.
- A pleasant (and safe) pedestrian-level wind environment is a crucial requirement of good building design.

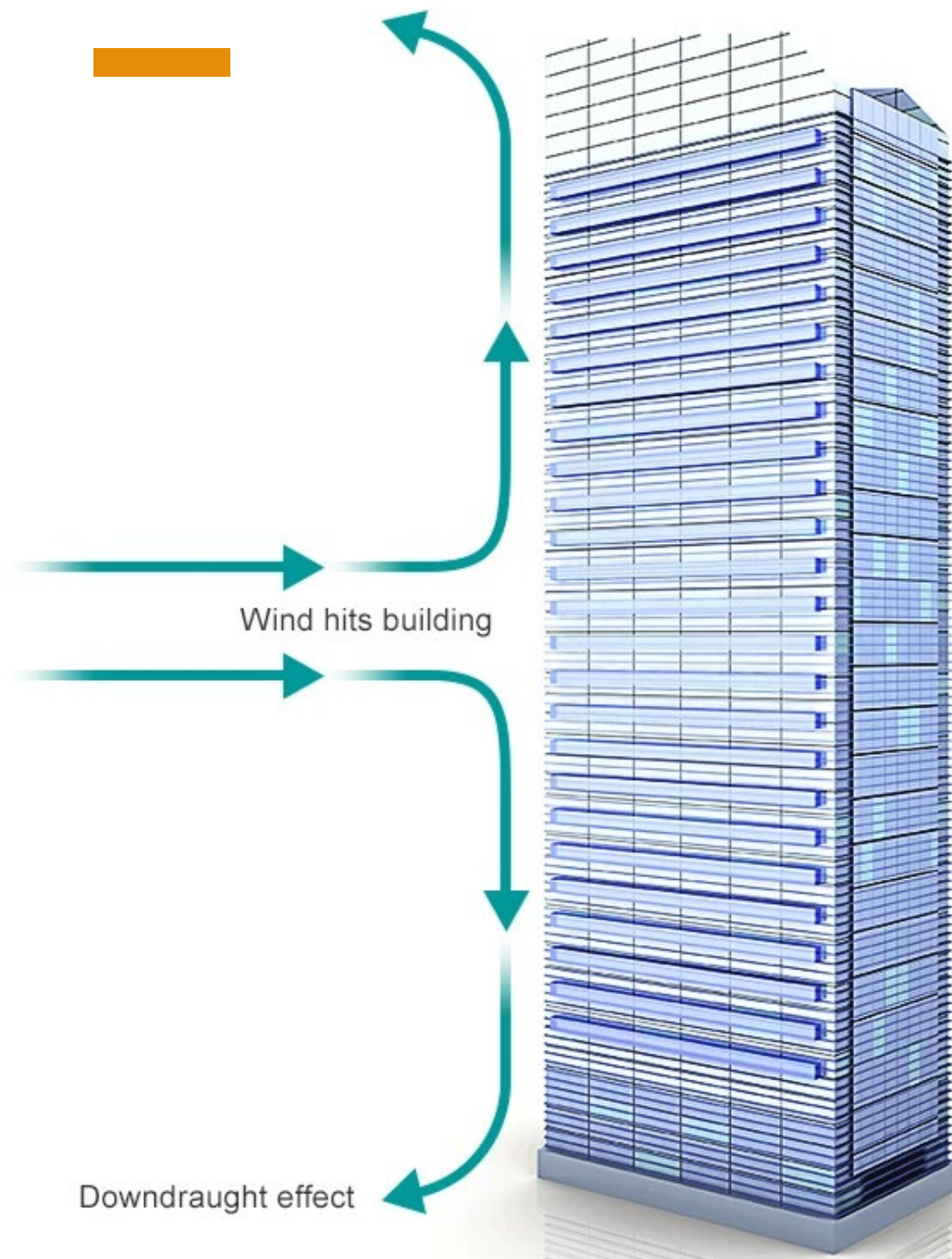
The downdraught effect



MICROCLIMATES

- The pedestrian-level wind environment is governed by the layout and massing of buildings.
- Tall buildings can cause strong downward currents of air and are a major cause of wind problems at pedestrian level.

The downdraught effect

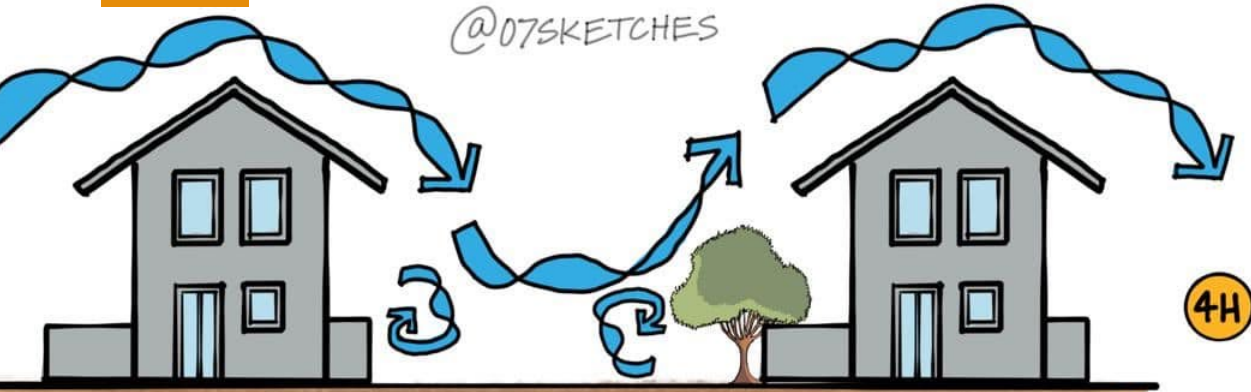


MICROCLIMATES

- When the wind strikes a building, it will generate positive pressures on the windward face and suctions on the side, roof and leeward faces.
- The wind will flow in the direction of decreasing pressure gradient, i.e. from areas of high pressure to areas of lower pressure.
- This causes wind flow down the front face, which brings high-speed wind from higher levels down to ground level.

BUILDING SPACING - WIND EFFECT

@07SKETCHES



E-BOOKS ➡

MICROCLIMATES



PEDESTRIAN COMFORT

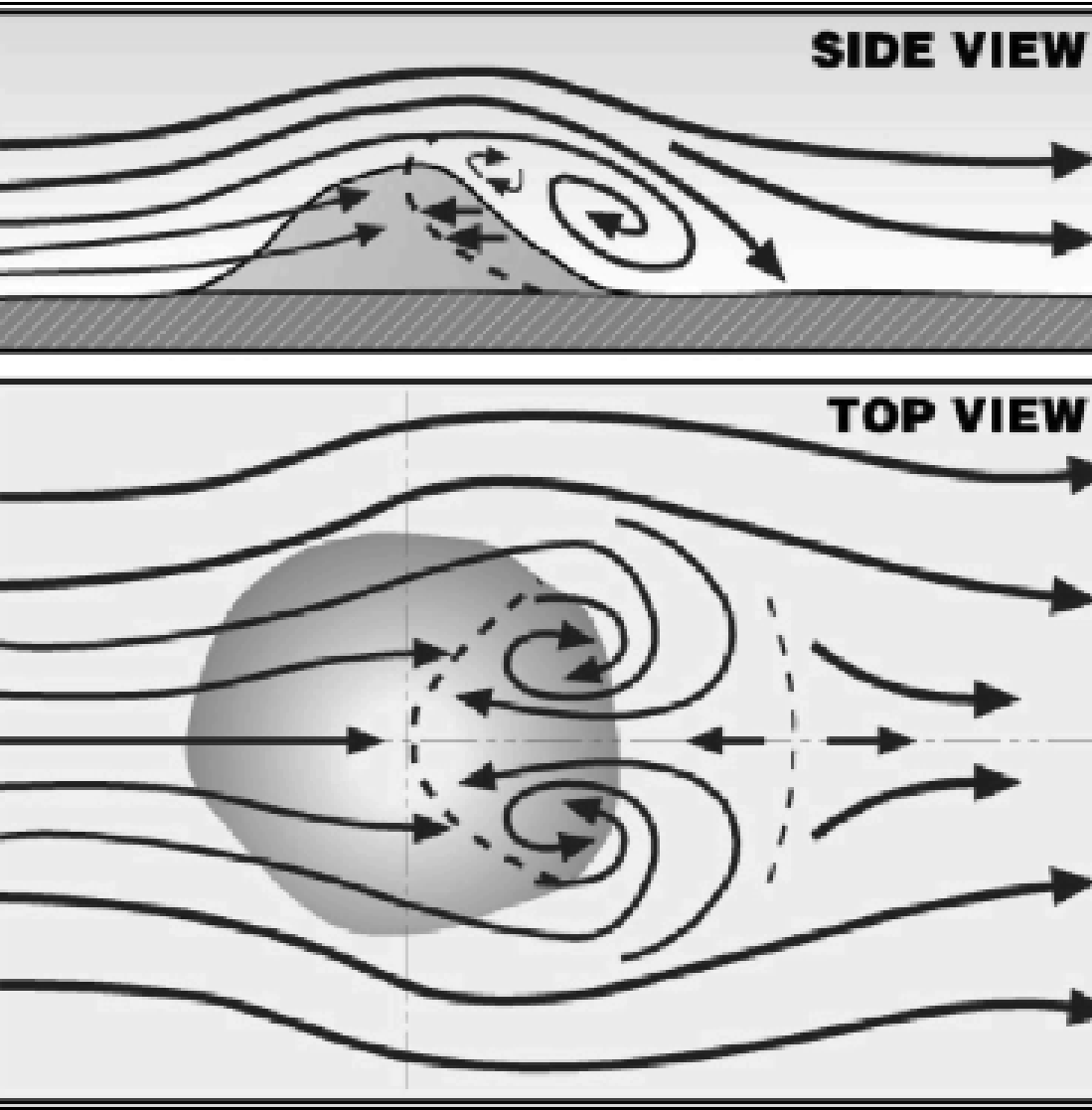
- There are no statutory requirements in the UK governing pedestrian-level wind microclimate around buildings, nor are there any national planning policies directly relating to wind microclimate.
- However, most regional or local planning policies include some requirements for wind microclimate.



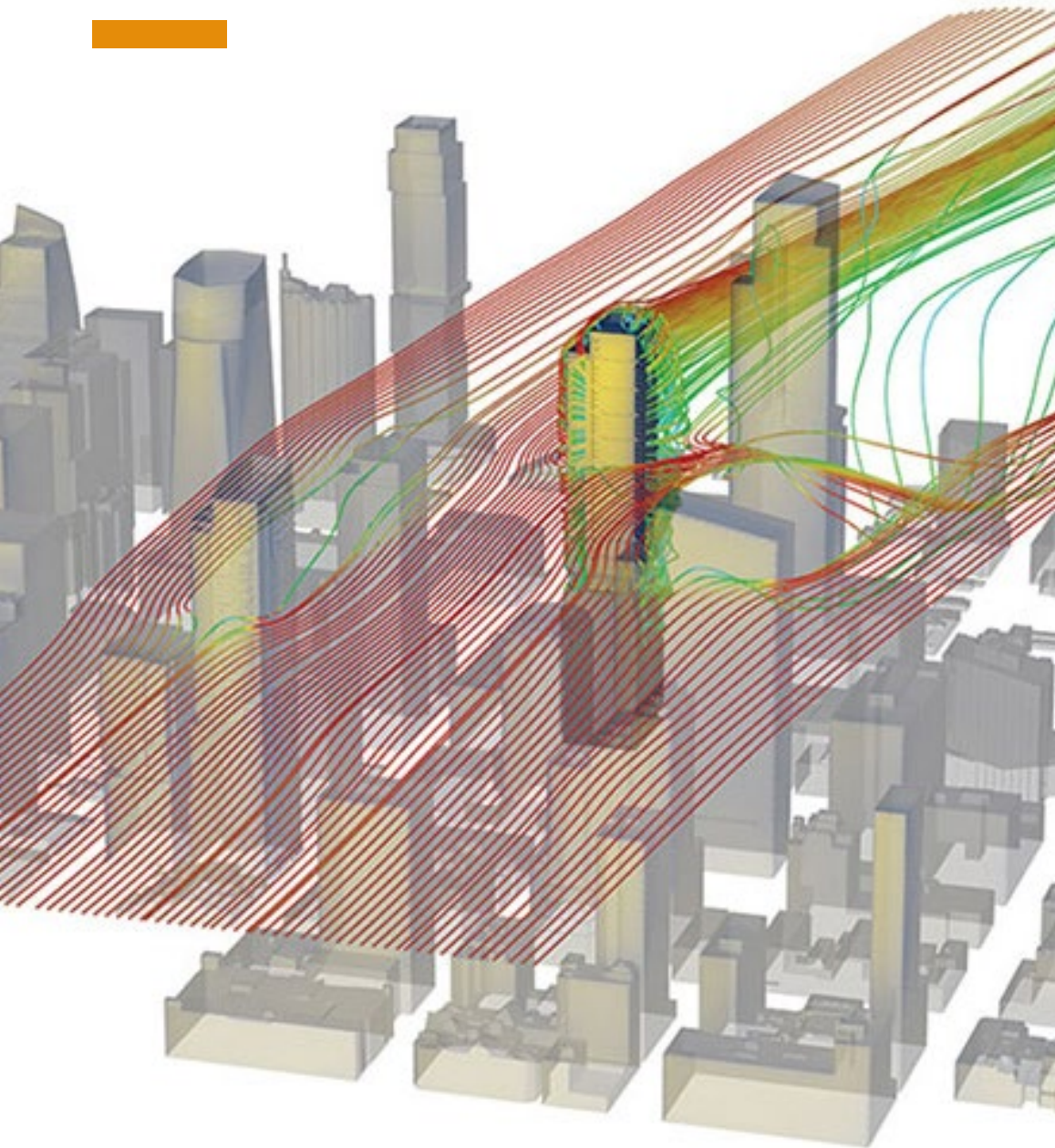
FLOW AROUND BUILDINGS

- Buildings obstruct wind flow, causing deflection and acceleration, resulting in complex flow patterns.
- When wind hits a building, it creates positive pressures on the front face and downwash towards the ground, increasing wind speeds at ground level.
- Wind is also deflected upwards and around the sides, creating areas of high wind speed and turbulence, which can affect roof gardens and terraces.
- The wake, a region of negative pressure, forms downwind and persists for six to ten times the building height

TERRAIN



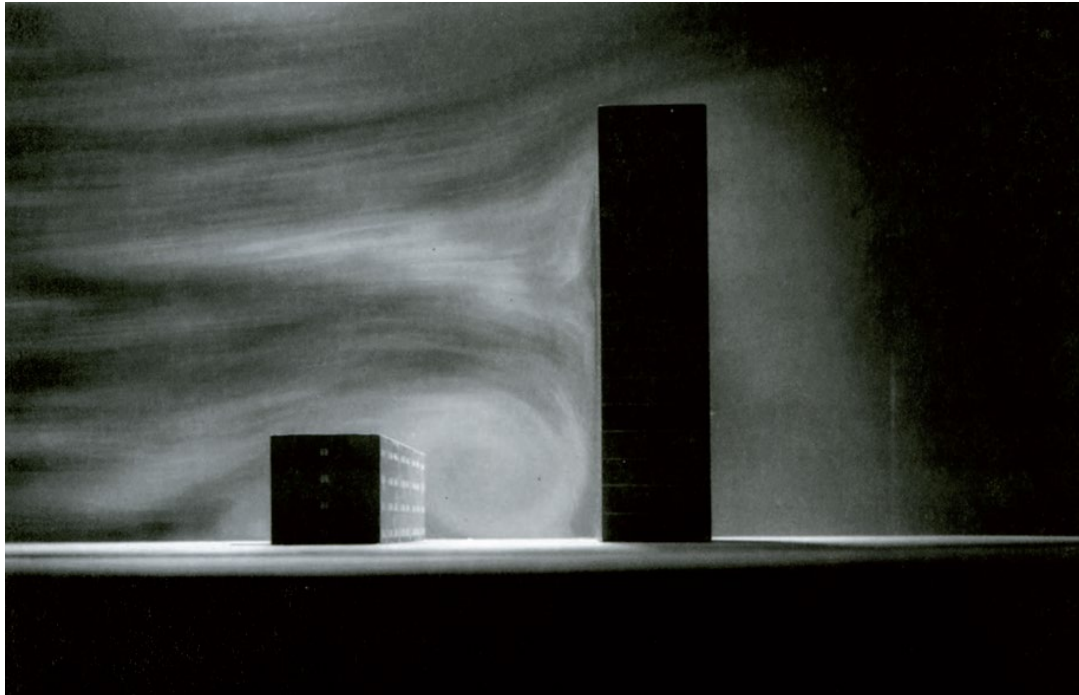
- The terrain has a significant influence on local wind speed.
- Wind blowing over smooth terrain, such as short grass or water, will have a high mean speed at pedestrian level with relatively little turbulence. As the wind blows over rougher terrain, such as towns and cities, the mean wind speed is reduced due to frictional drag at the surface, but the turbulence in the wind increases.



BUILDING HEIGHT

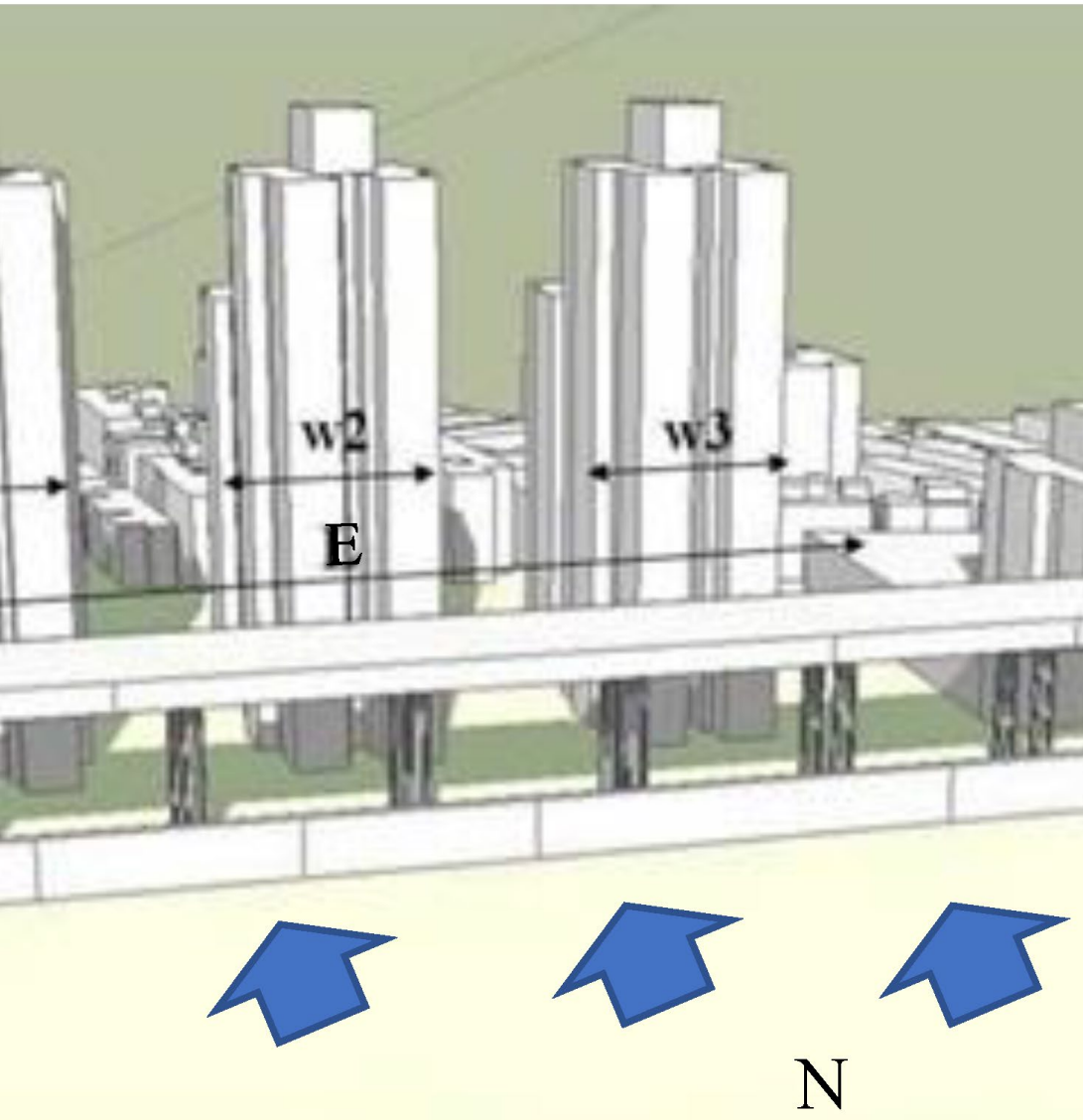
- Wind speed increases with height, affecting tall buildings more.
- The relative height of a building compared to its surroundings is crucial in determining wind impact.
- Tall buildings in clusters may not cause issues, while mid-rise buildings near open areas can create hazardous conditions.
- Wind pressure on buildings generates positive pressures on the windward face and suctions on other faces, causing downwash and increased ground-level wind speeds.
- This can be mitigated with canopies, podiums, or building orientation.

INTERACTION

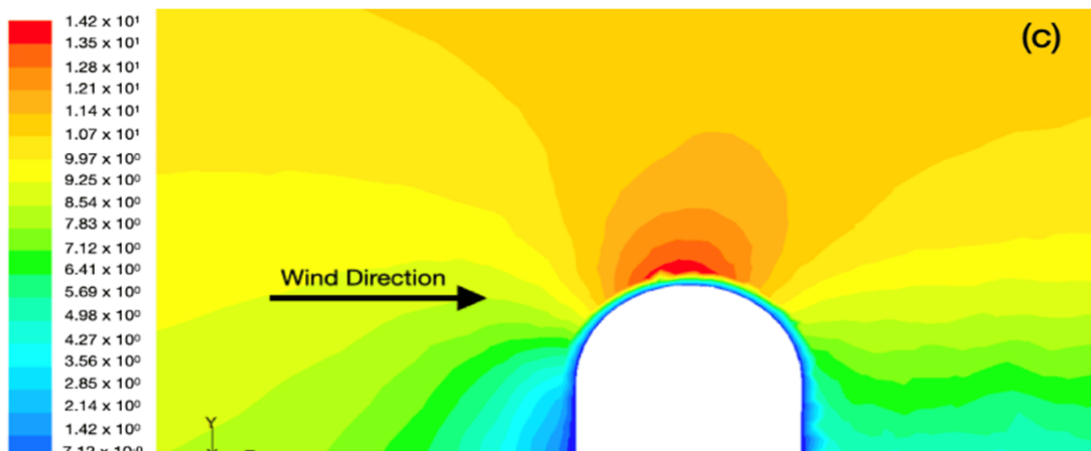
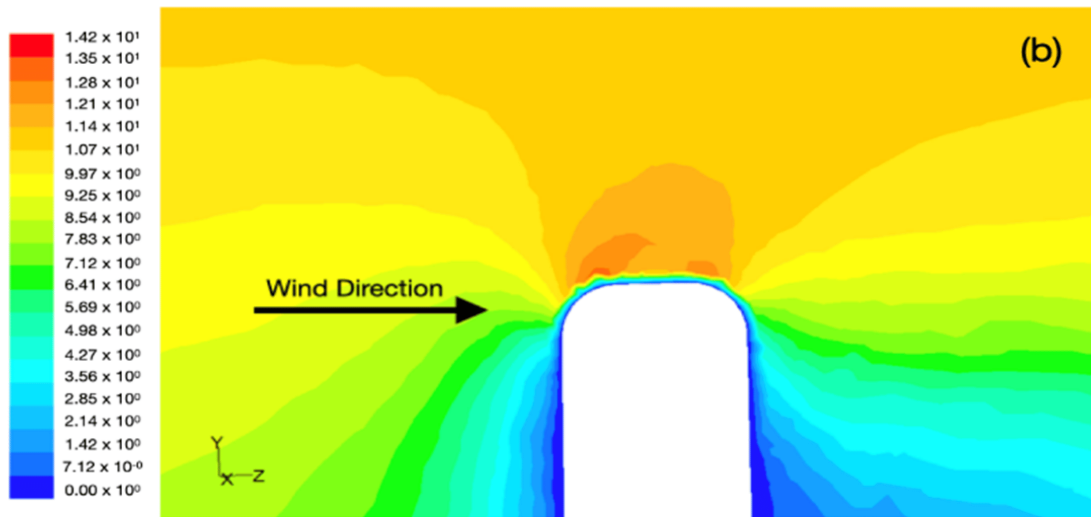
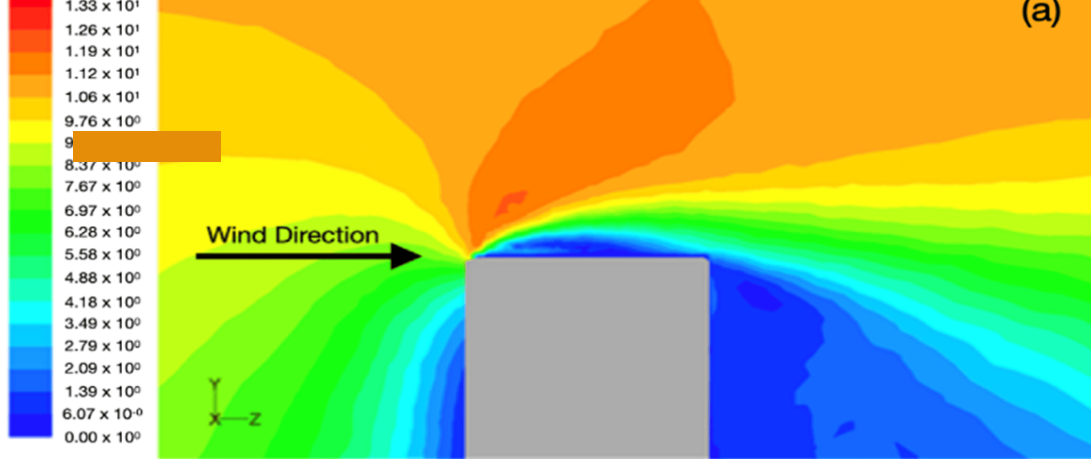


- When a tall rectangular building is positioned upwind of a low-rise building, the ground-level wind speeds in front of the tall building can be significantly magnified.
- This is due to the flow down the face of the tall building combining with the wake from the low building, creating a stable vortex in the gap between them.

PASSAGEWAYS

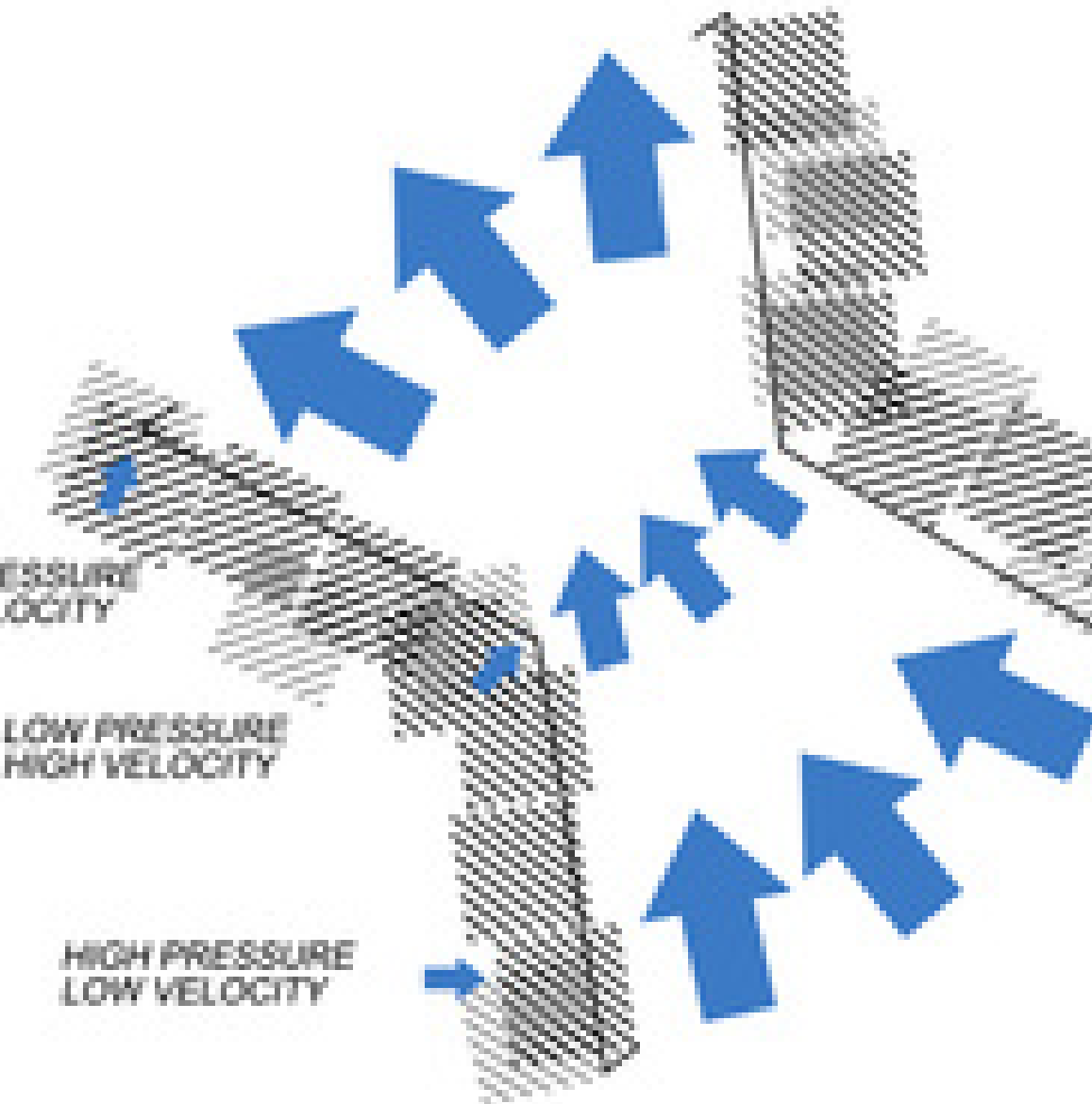


- Where passageways or tunnels pass beneath a building at ground level, or where the building is raised on columns, this will frequently be a source of wind problems because there is a direct path from the positive pressure on the windward face to the low-pressure region in the wake.
- Such features are often best avoided unless they are intended for vehicular access only.



BUILDING SHAPE

- Tall, rectangular, sharp-edged buildings generate the highest local ground-level wind speeds and the largest footprint area of unpleasant wind speeds.
- To minimize their impact, these buildings should be oriented with their long axis aligned with the prevailing wind direction.
- Circular or multi-faceted buildings provide a more aerodynamic profile, causing less downwash and smaller footprint areas of unpleasant

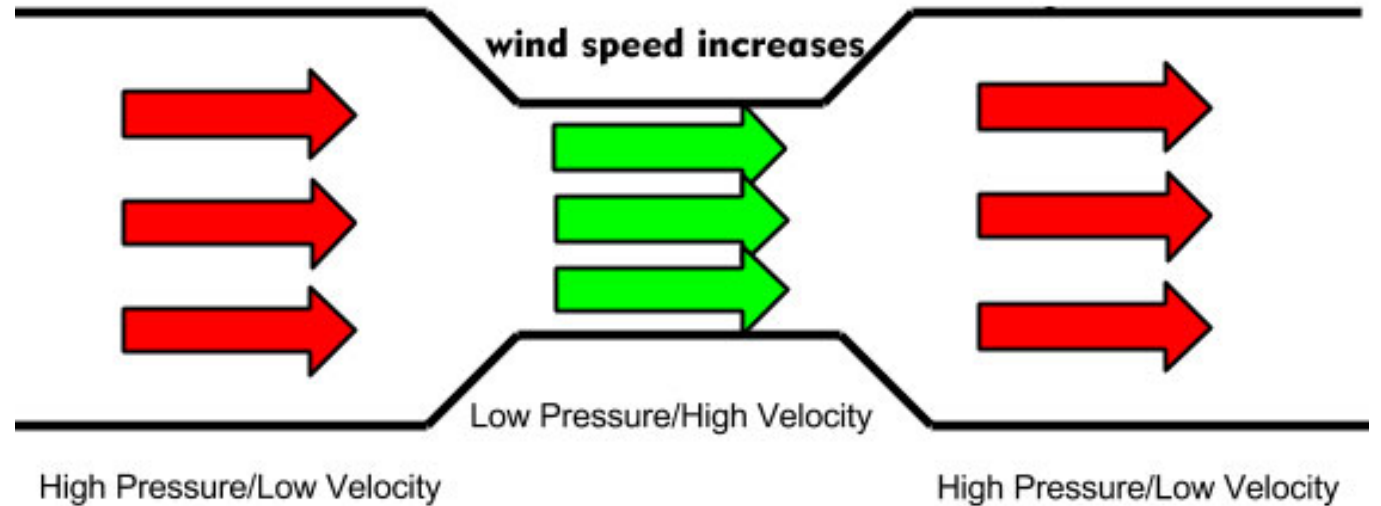


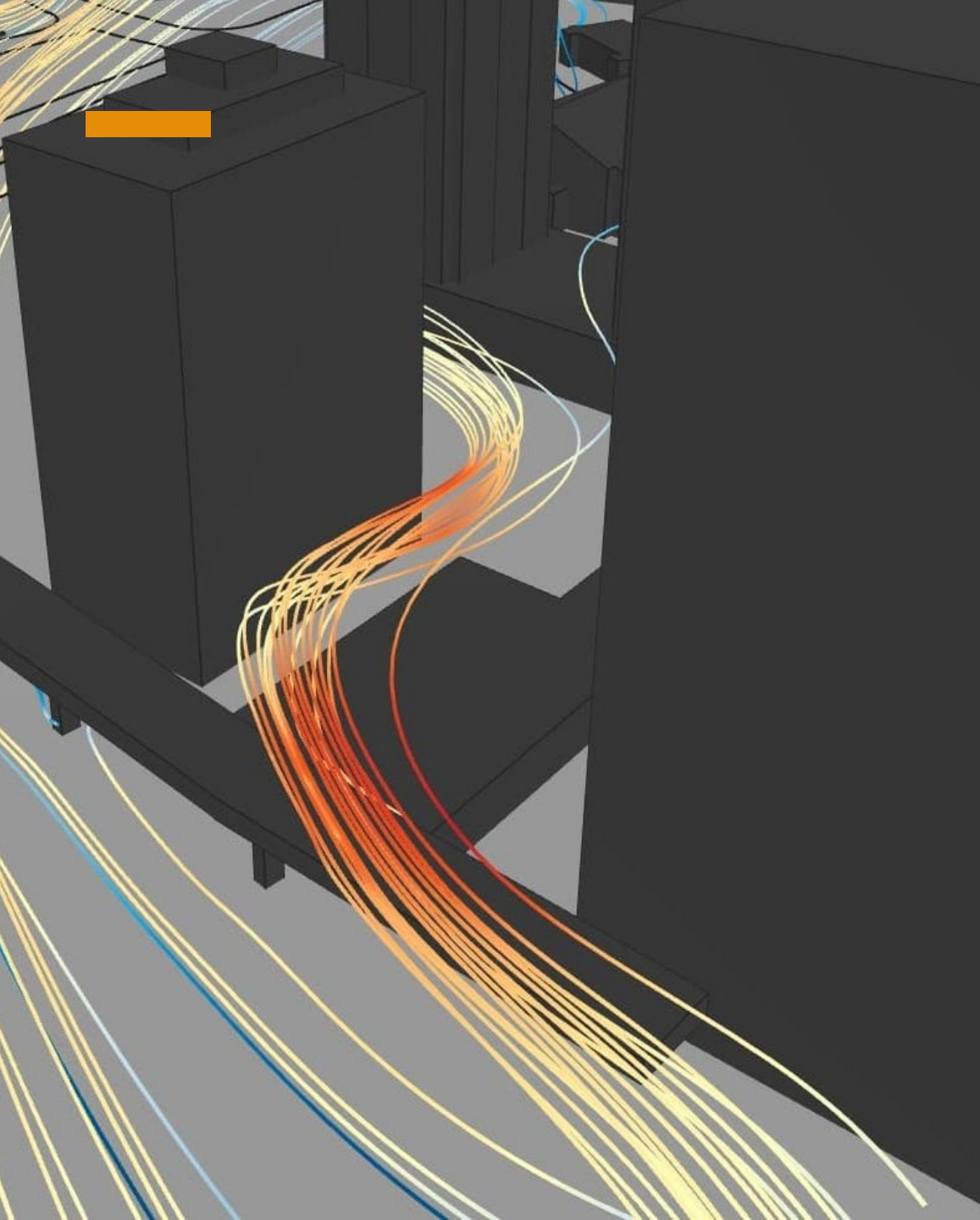
FUNNELLING

- Wind funnelling and flow acceleration can occur where there are gaps between buildings.
- The effect is stronger where the axes of the buildings make an angle of 90° or less.

VENTURI EFFECT

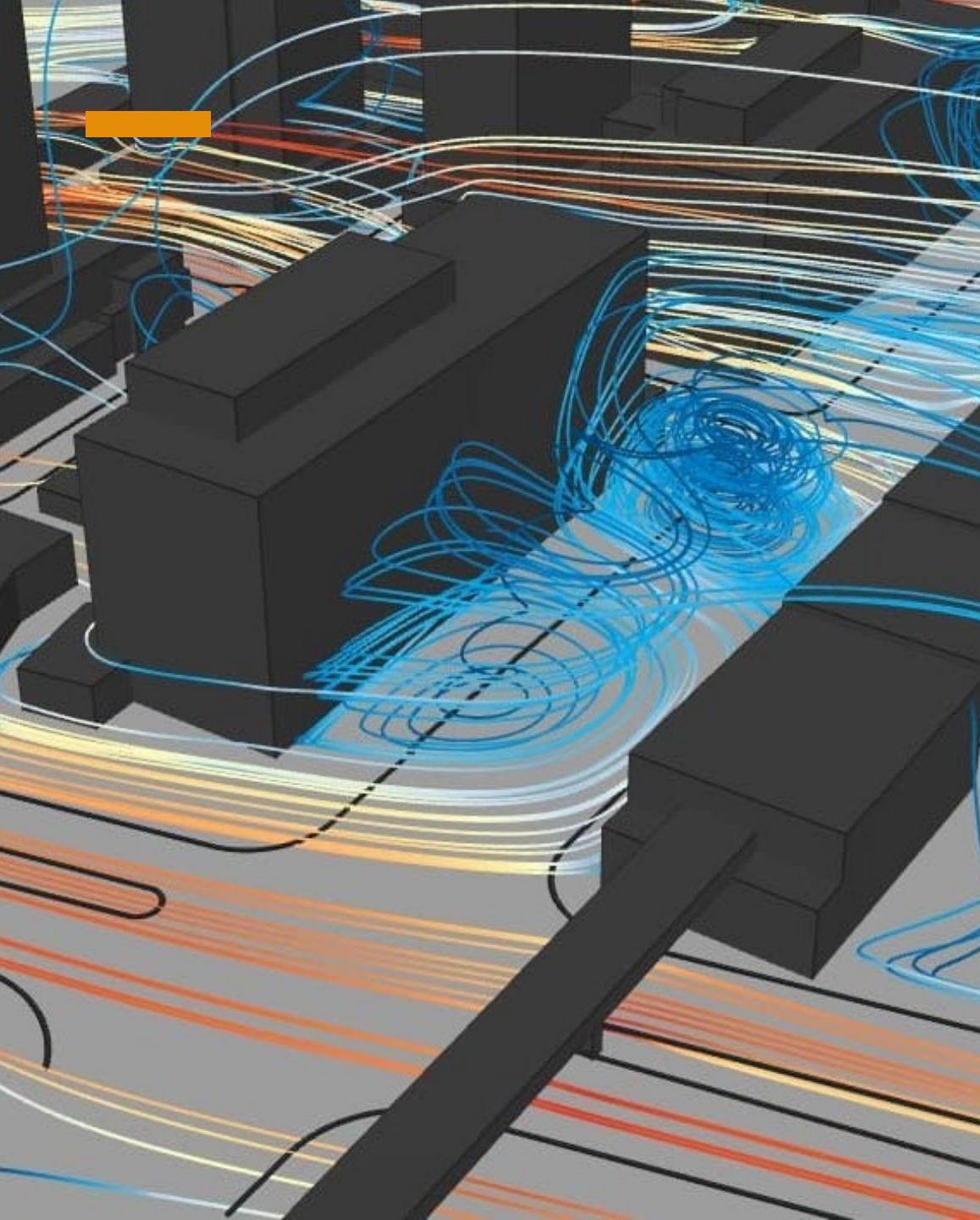
- When gaps between buildings are narrow relative to building heights, wind speed can increase substantially due to the Venturi effect.
- In simple terms, for the same mass of air (mass continuity) to pass through a narrower space, the velocity must increase.





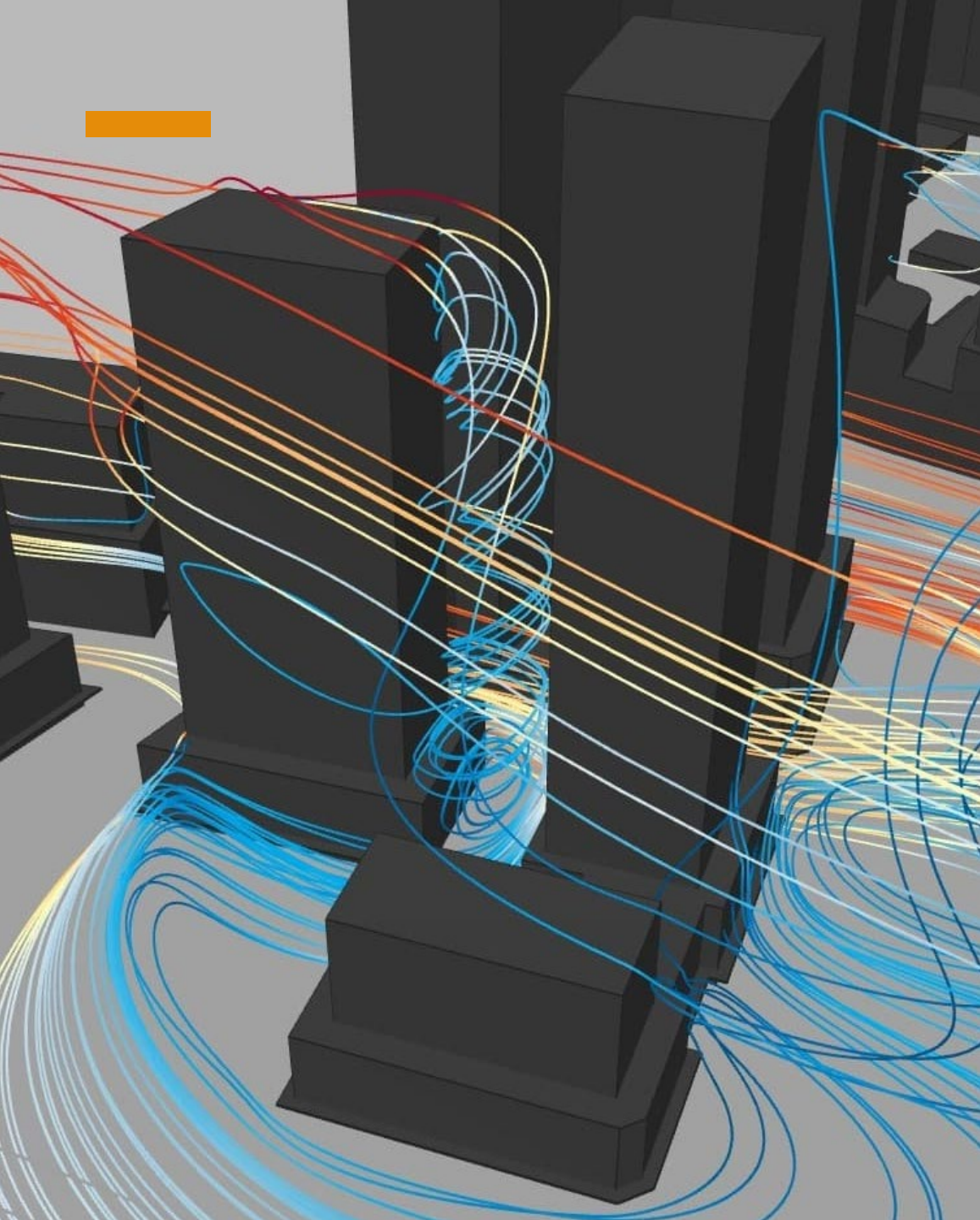
CORNER ACCELERATION

- Corner acceleration describes the scenario in which a wind flow ‘attaches’ to a building, and then separates at the edges — creating high wind activity at the corners.



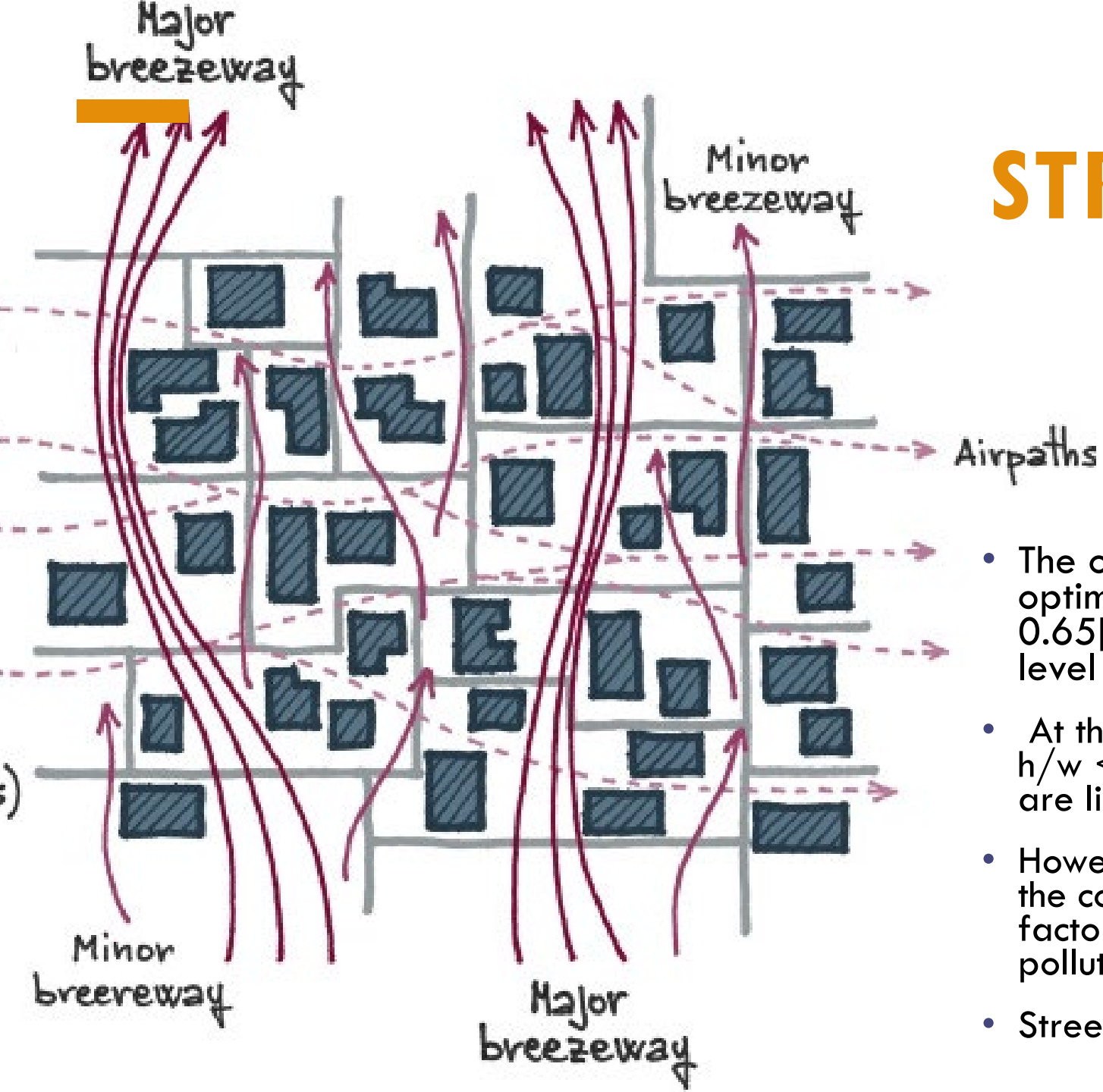
VORTICES

- Corners can also create vortices, which are swirling patterns of fast-moving air.
- Beyond impacting pedestrian safety and comfort, these vortices can cause harmonic oscillations within the building structure itself.
- This is a potentially serious safety issue caused by a phenomenon called vortex shedding.



VORTICES

- Of course, in a typical urban setting, wind interacts with multiple buildings and the many factors at play work in combination.
- This leads to extraordinarily complex flows that often vary widely due to different wind directions and speeds.



STREET GEOMETRY

- The optimum height-to-width (h/w) ratio for optimum wind comfort is approximately 0.65[5]. As h/w increases, the pedestrian-level wind speeds are likely to reduce
- At the other extreme, very wide streets with $h/w < 0.3$ will not benefit from wind shelter and are likely to be quite exposed.
- However, street design cannot be based just on the consideration of wind microclimate; other factors such as sunlight, convective cooling and pollution dispersal all have to be considered.
- Street layout will therefore be a compromise.

STREET GEOMETRY

Table 1: Summary of factors to be considered for urban street design^[5]

Aspect of design	Street canyon height-to-width (h/w) ratio		
	Optimum	Good	Undesirable
Wind comfort	> 0.65	> 0.4	< 0.3
Pollution dispersal	< 0.3	< 0.65	> 1.0
Solar radiation	< 0.3–0.4	< 0.5	> 0.5
Sense of enclosure	0.4–0.5	0.33–0.67	< 0.3 or > 1.0
Convective cooling	0.4–0.6	< 0.65	> 0.65
Best compromise	0.4–0.5	0.3–0.65	< 0.3 or > 1.0

ENTRANCES

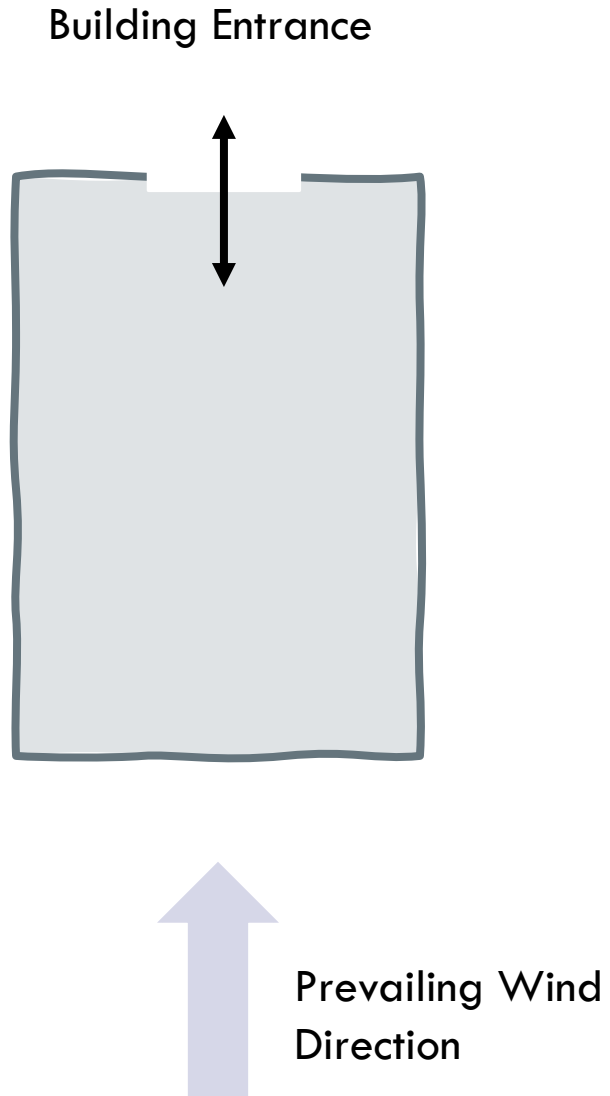
- Entrances can be particularly wind-sensitive areas.
- Even light breezes far exceed air speeds within buildings, so as people move from warm conditioned internal environments to the external environment the wind conditions can be perceived to be much worse than they actually are.
- If windy conditions at entrances are anticipated at the design stage, then the entrances should ideally be positioned at less windy locations around the building and away from corners.



Beaufort scale	Description	Mean wind speed range		Effects
		(m/s)	(mph)	
B0	Calm	0–0.2	0–0.5	No noticeable wind, smoke rises vertically
B1	Light air	0.3–1.5	0.7–3.4	Direction of wind shown by smoke drift but not wind vanes
B2	Light breeze	1.6–3.3	3.6–7.4	Wind felt on face, leaves rustle
B3	Gentle breeze	3.4–5.4	7.6–12.1	Wind extends light flag, leaves in constant motion
B4	Moderate breeze	5.5–7.9	12.3–17.7	Raises dust and loose paper; hair disarranged, clothing flaps
B5	Fresh breeze	8.0–10.7	17.9–24.0	Small trees in leaf begin to sway; limit of agreeable wind on land
B6	Strong breeze	10.8–13.8	24.2–30.9	Umbrellas used with difficulty; force of the wind felt on the body; wind noisy, frequent blinking
B7	Near gale	13.9–17.1	31.1–38.3	Inconvenience felt when walking; difficult to walk steadily; hair blown straight
B8	Gale	17.2–20.7	38.5–46.4	Generally impedes progress; walking difficult to control; great difficulty with balance in gusts
B9	Strong gale	20.8–24.4	46.6–54.7	People blown over by gusts; slight structural damage
B10	Storm	24.5–28.4	54.9–63.6	Seldom experienced inland; trees uprooted, significant structural damage
B11	Violent storm	28.5–32.2	63.8–72.1	Very rarely experienced; accompanied by widespread structural damage
B12	Hurricane	> 32.3	> 72.4	Countryside devastated; winds of this force only occur in hurricanes and tornadoes

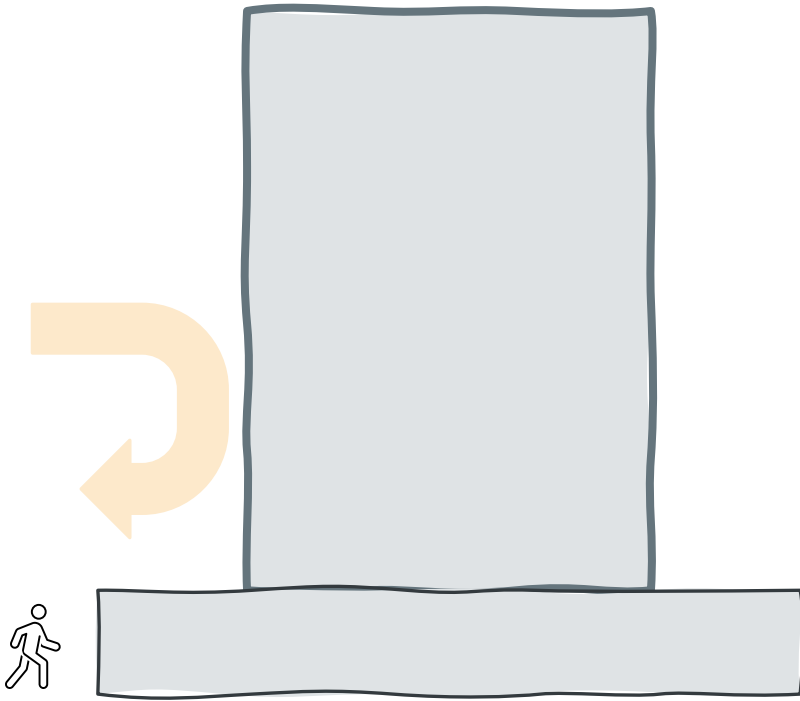
Activity	Lawson comfort criteria	
	Unacceptable	Tolerable
Roads and car parks, business walking, fast walking from A to B	10.7 m/s (B5) > 6%	10.7 m/s (B5) > 2%
People at work, workers around buildings	10.7 m/s (B5) > 2%	7.9 m/s (B4) > 2%
Pedestrian strolling, slow walking with occasional stops, shopping, short-term standing eg at bus stops	7.9 m/s (B4) > 4%	5.4 m/s (B3) > 6%
Long-term sitting – in open-air cafes, parks, etc. for periods of more than about 10 min	5.4 m/s (B3) > 6%	3.3 m/s (B2) > 6%
Entrances and exits of buildings or areas where there is a risk of sudden exposure to wind	5.4 m/s (B3) > 6%	3.3 m/s (B2) > 4%
Covered areas – pedestrian seating areas under cover, places of high cultural significance	5.4 m/s (B3) > 1%	3.3 m/s (B2) > 4%

GENERAL DESIGN GUIDANCE



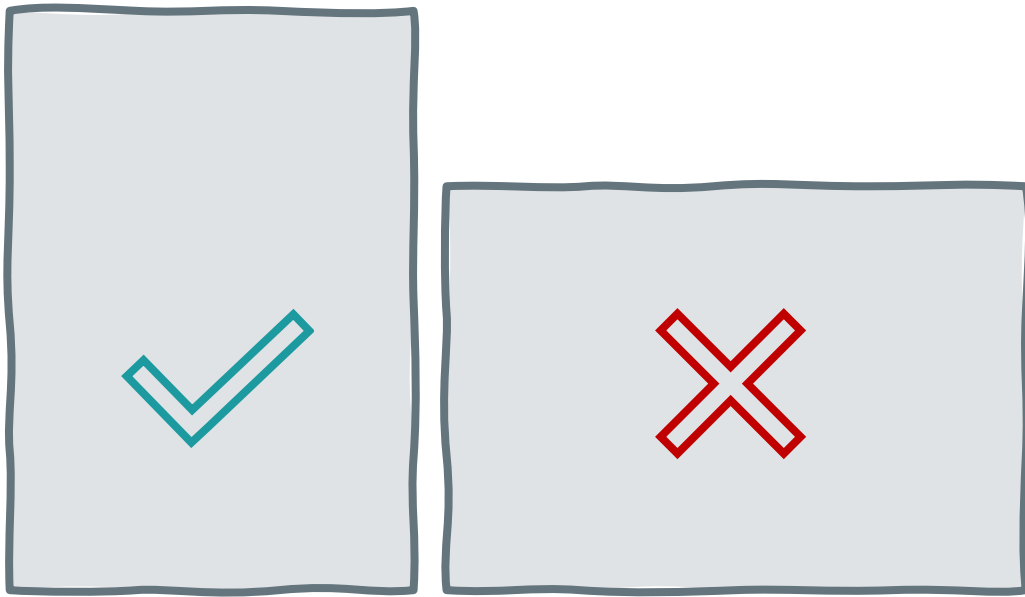
- Locate building entrances on the lee side of the building and well away from corners.

GENERAL DESIGN GUIDANCE



- Include extensive ground-level horizontal projections around tall buildings to form a podium to deflect downwash away from pedestrian areas.

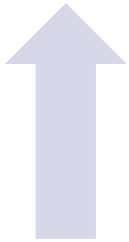
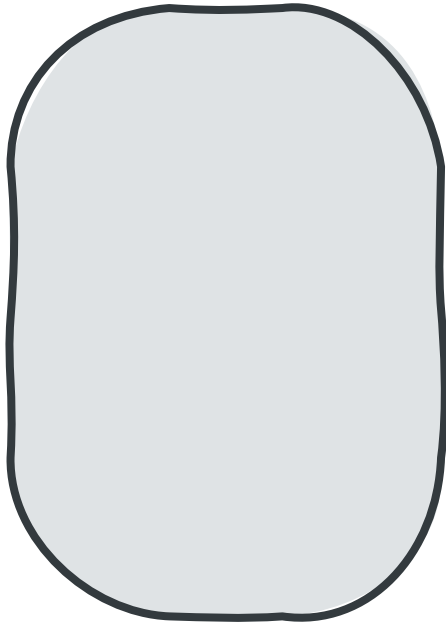
GENERAL DESIGN GUIDANCE



Prevailing Wind
Direction

- Position tall buildings so that their narrow facades face the prevailing wind.

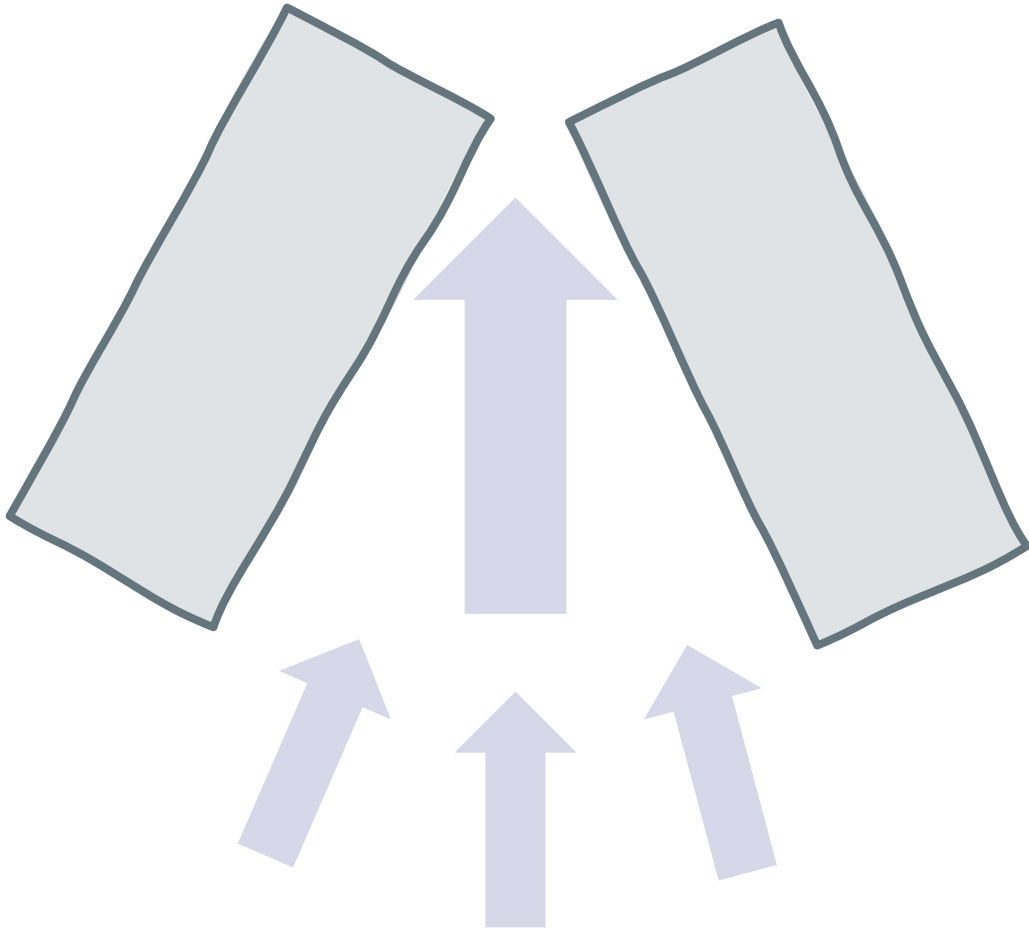
GENERAL DESIGN GUIDANCE



Prevailing Wind
Direction

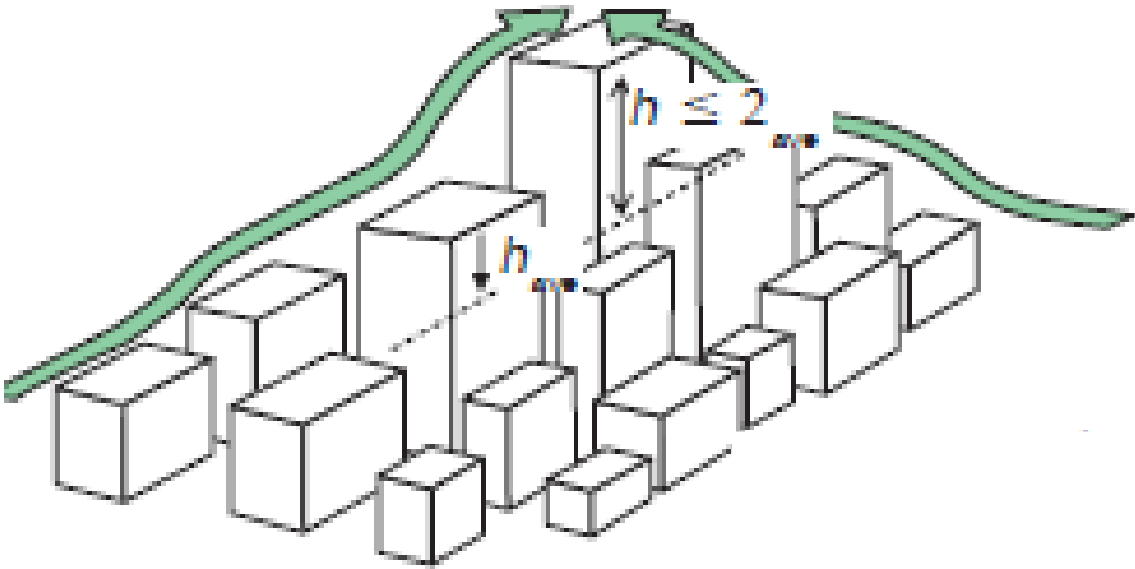
- Chamfer or round the corners of tall buildings. This will reduce the extent of the high wind speed area but will not significantly reduce the maximum ground-level wind speeds.

GENERAL DESIGN GUIDANCE



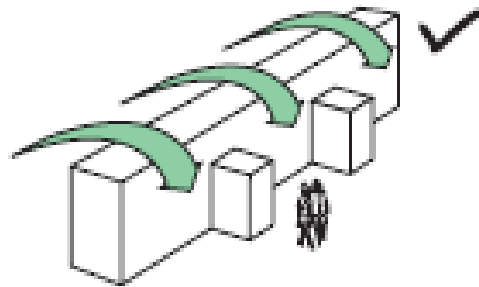
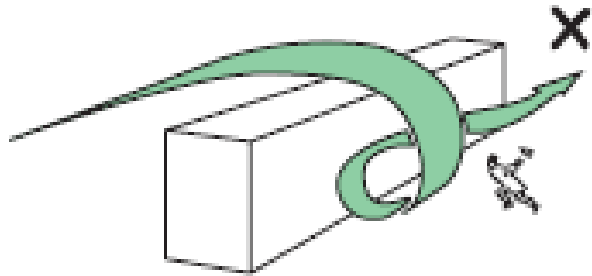
- Avoid funnel-like gaps between buildings

GENERAL DESIGN GUIDANCE



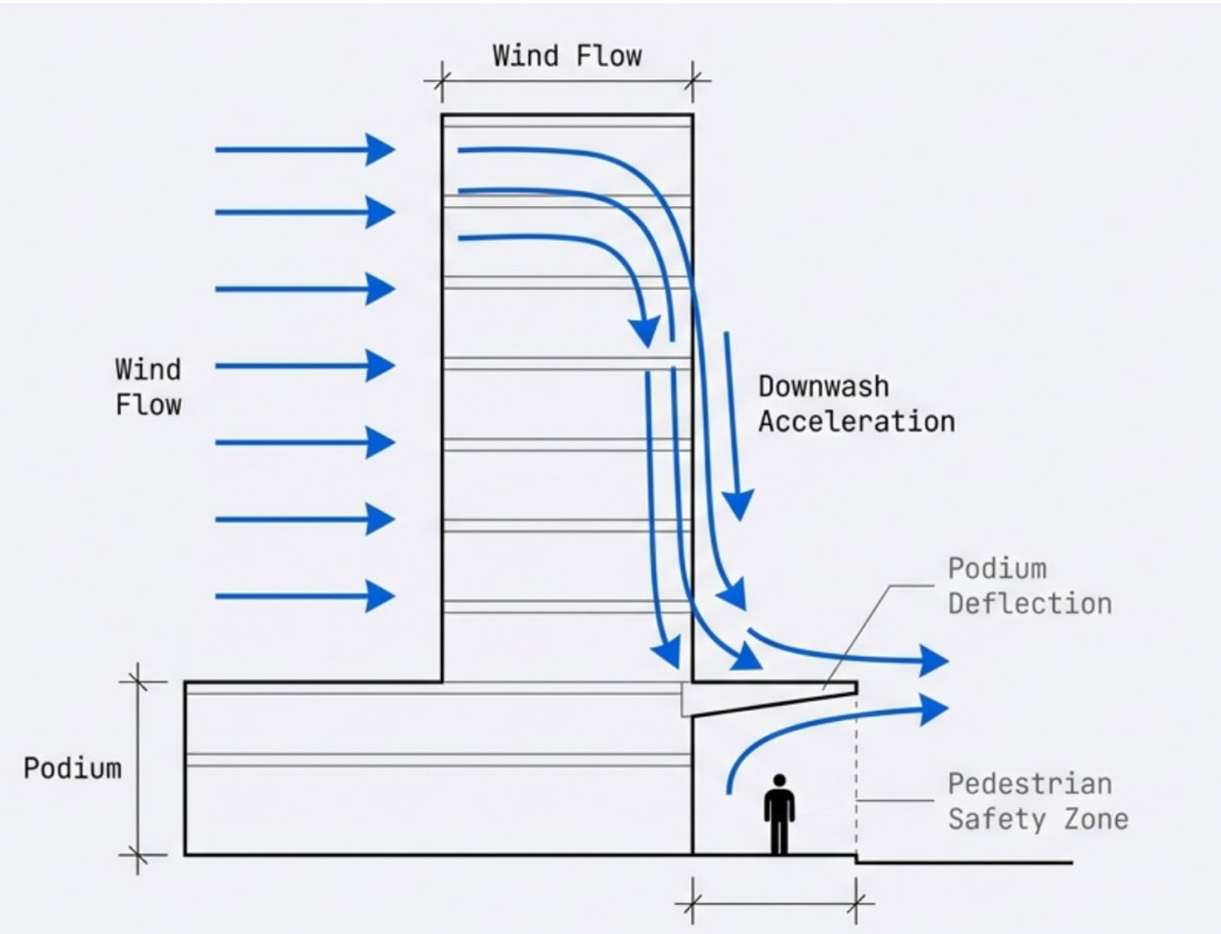
- Group buildings so that the height differential is minimised; ideally, the protruding building height should be less than twice the average height

GENERAL DESIGN GUIDANCE



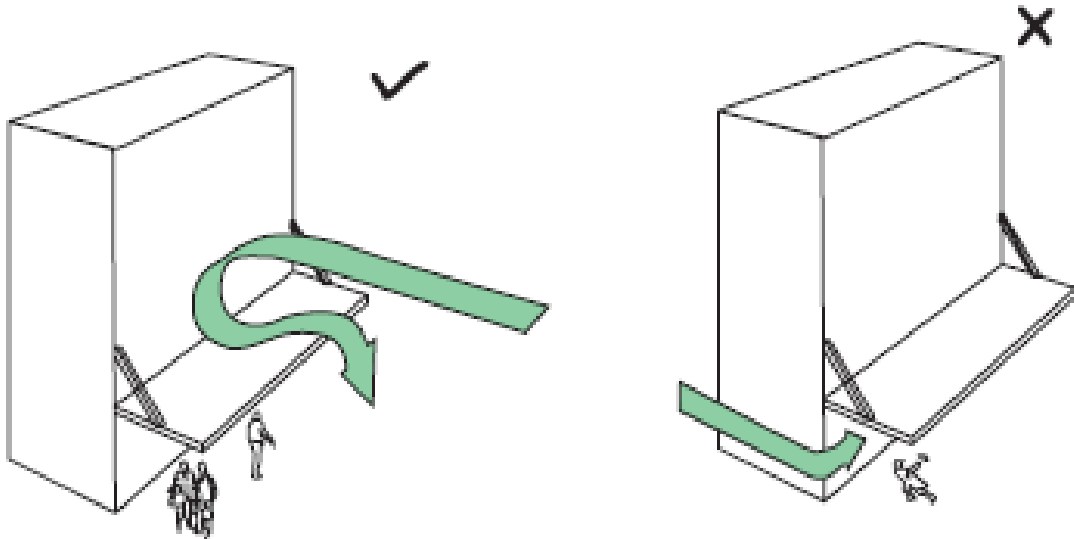
- Avoid potential issues with transverse wake flow by using finger blocks on the rear face

GENERAL DESIGN GUIDANCE



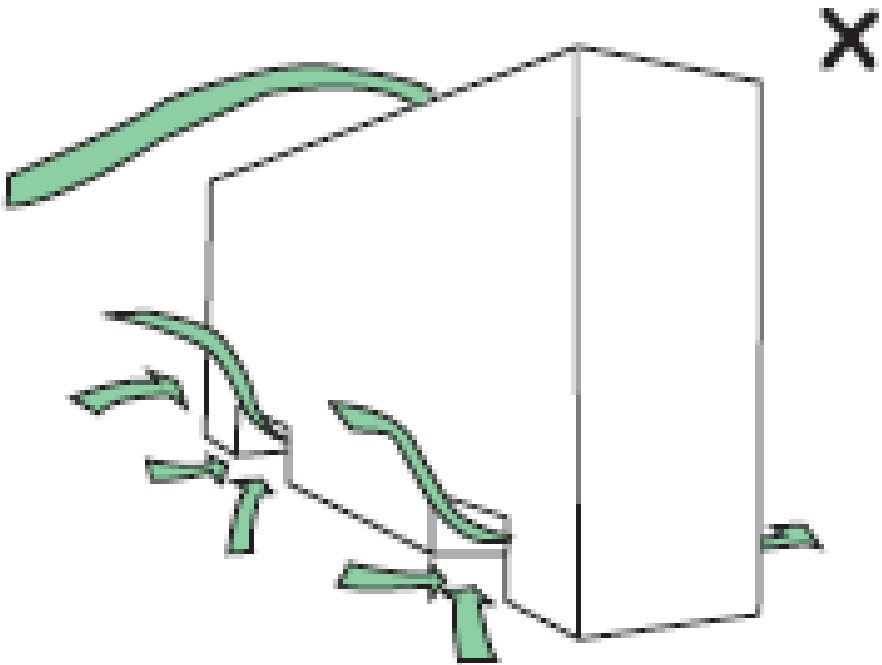
- Use large canopies to mitigate downwash – but be aware that this can trap and accelerate horizontal flows

GENERAL DESIGN GUIDANCE



- Use large canopies to mitigate downwash – but be aware that this can trap and accelerate horizontal flows

GENERAL DESIGN GUIDANCE



- Avoid passageways beneath buildings at ground level



