September 24, 2019

# **CIBSE HCNE**: Wind Design for Building Enclosures

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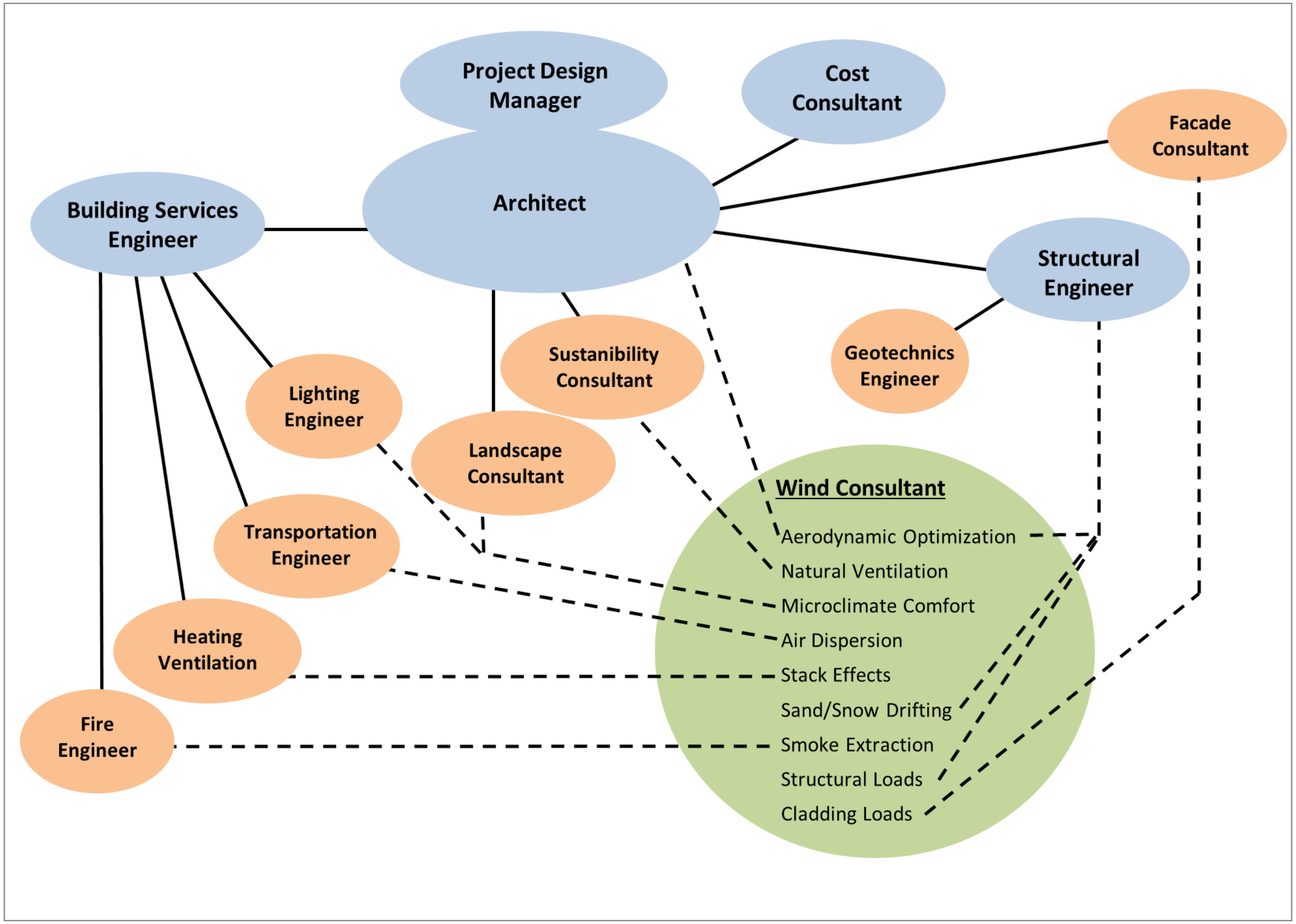
*Technical Director*

# Wind engineering

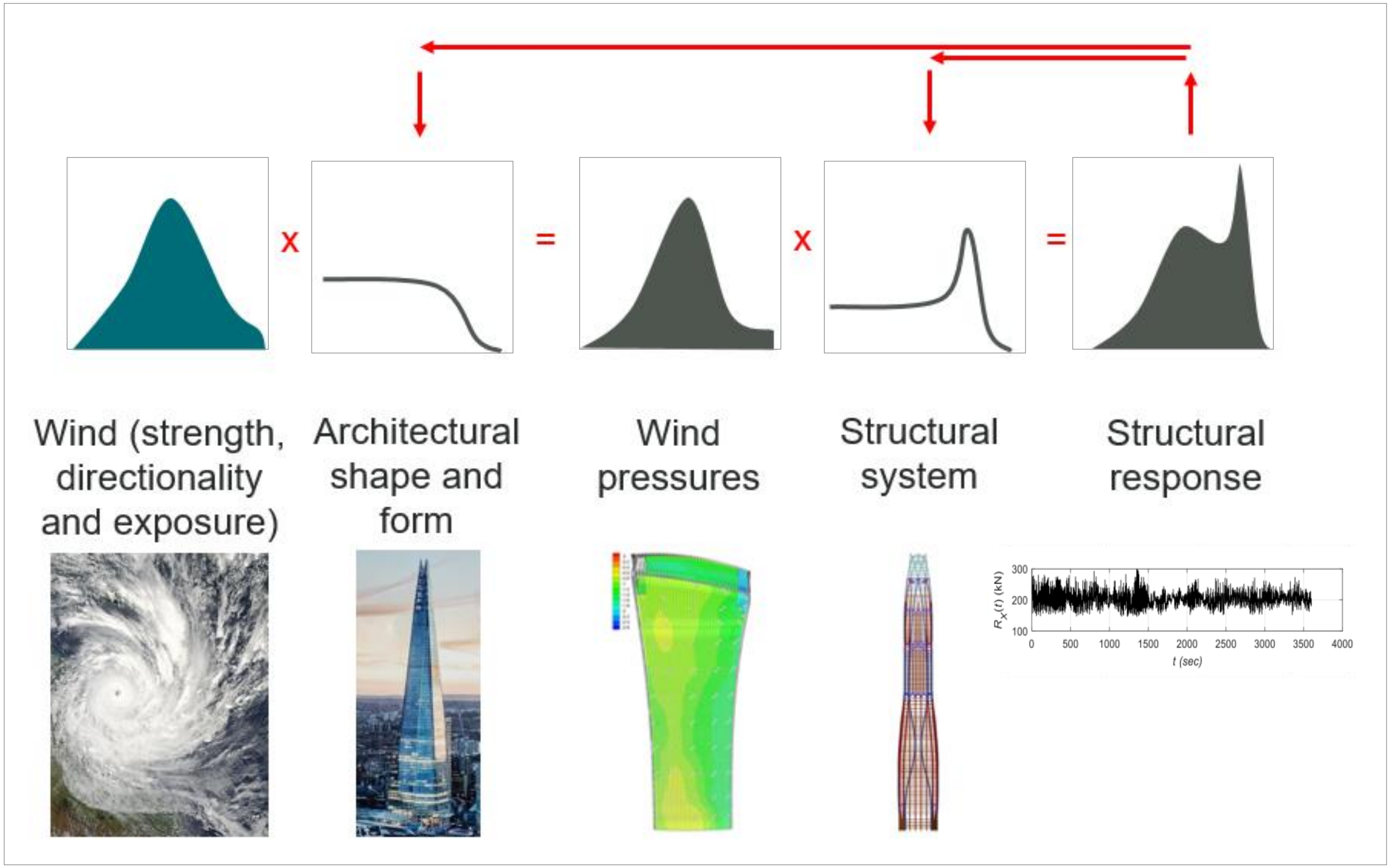
“*Wind engineering* is best defined as the rational treatment of interactions between *wind* in the *atmospheric boundary layer* and man and his works on the surface of Earth”

*Jack Cermak*, 1975

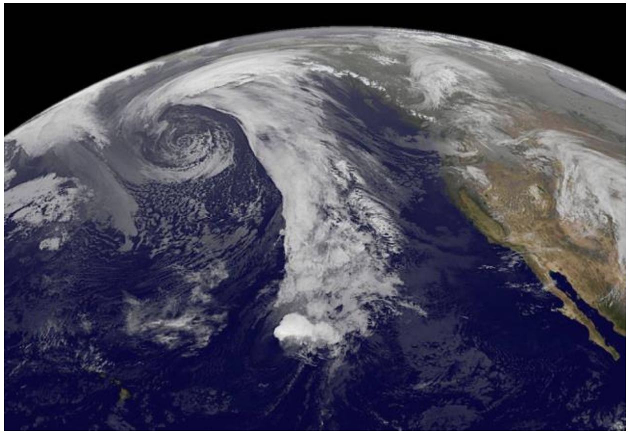
# Wind engineering as an integrated part of the design

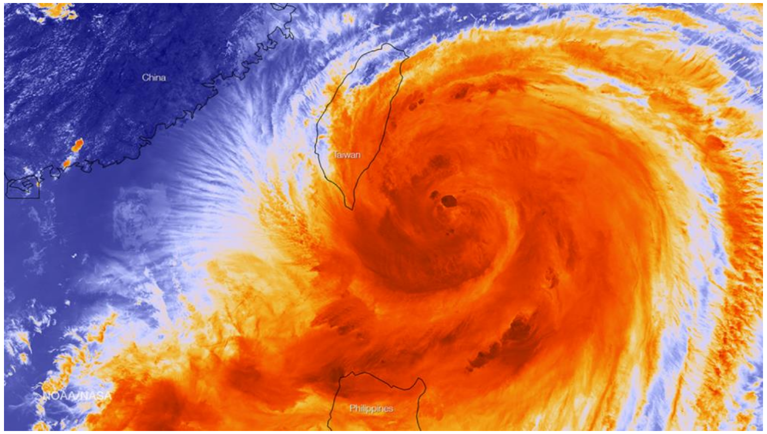


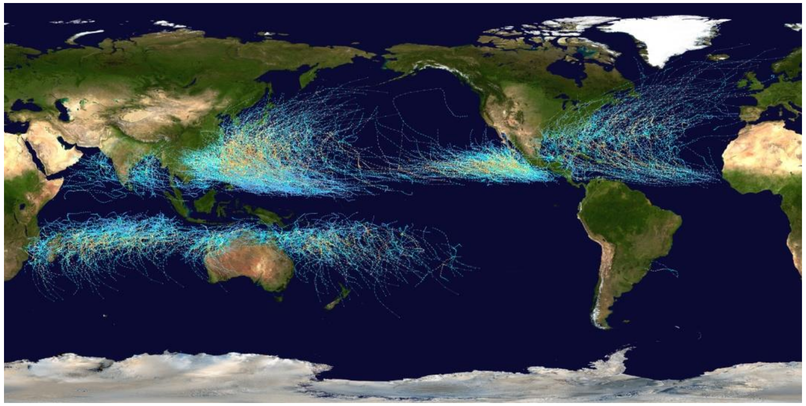
# Davenport's wind loading chain



# Wind climate (what we know well)

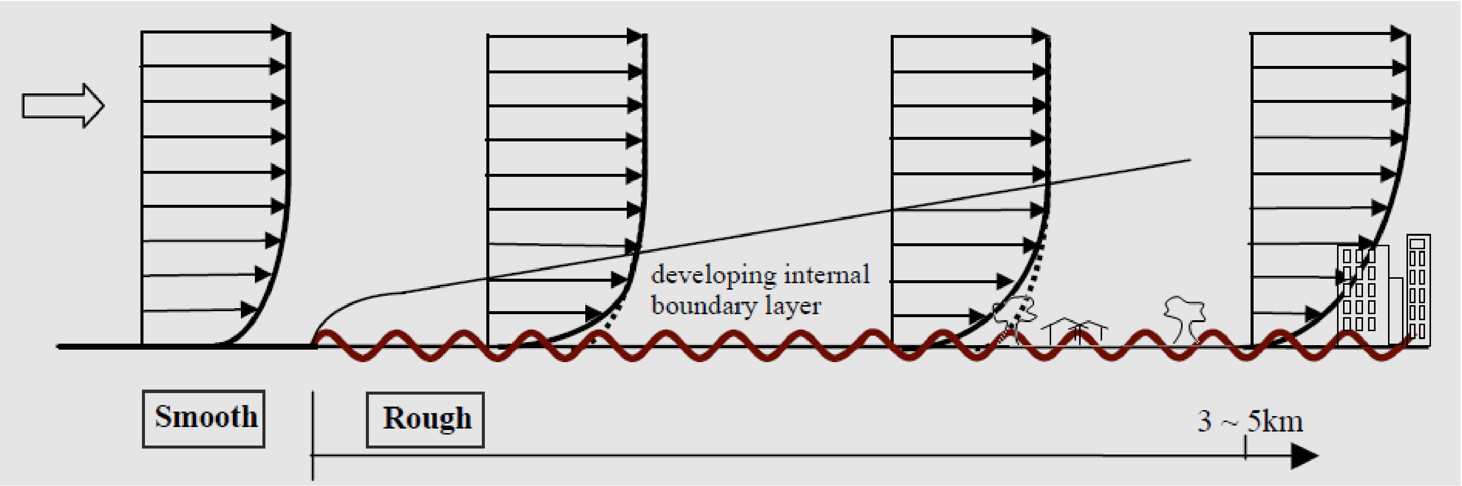






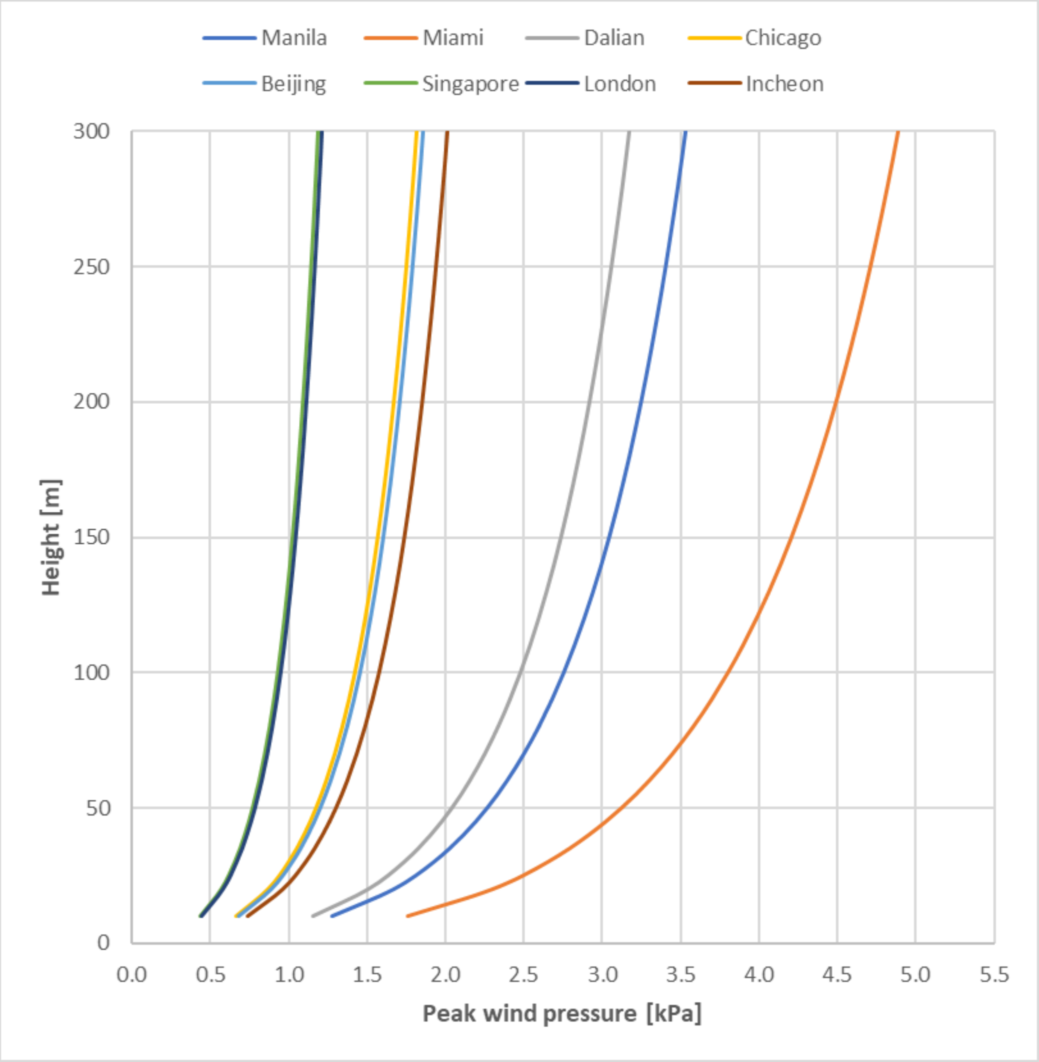
- Extra-tropical depressions (e.g. monsoons, gales) [frequent]
- Tropical storms (e.g. hurricanes, typhoons, cyclones) [less frequent]
- Follow reasonably well the ‘atmospheric boundary layer’ profile

# Atmospheric boundary layer



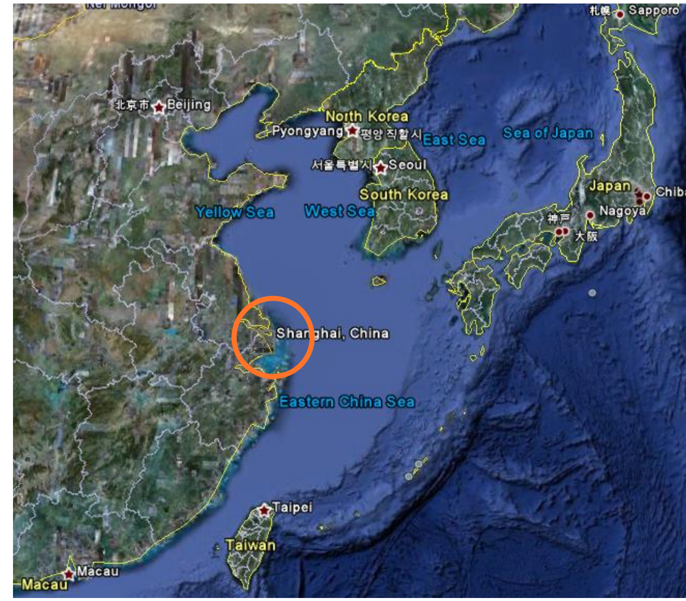

- Low turbulence (e.g. sea exposure) → winds with higher strength
- Higher turbulence (e.g. urban exposure) → winds with lower strength

# Wind climate



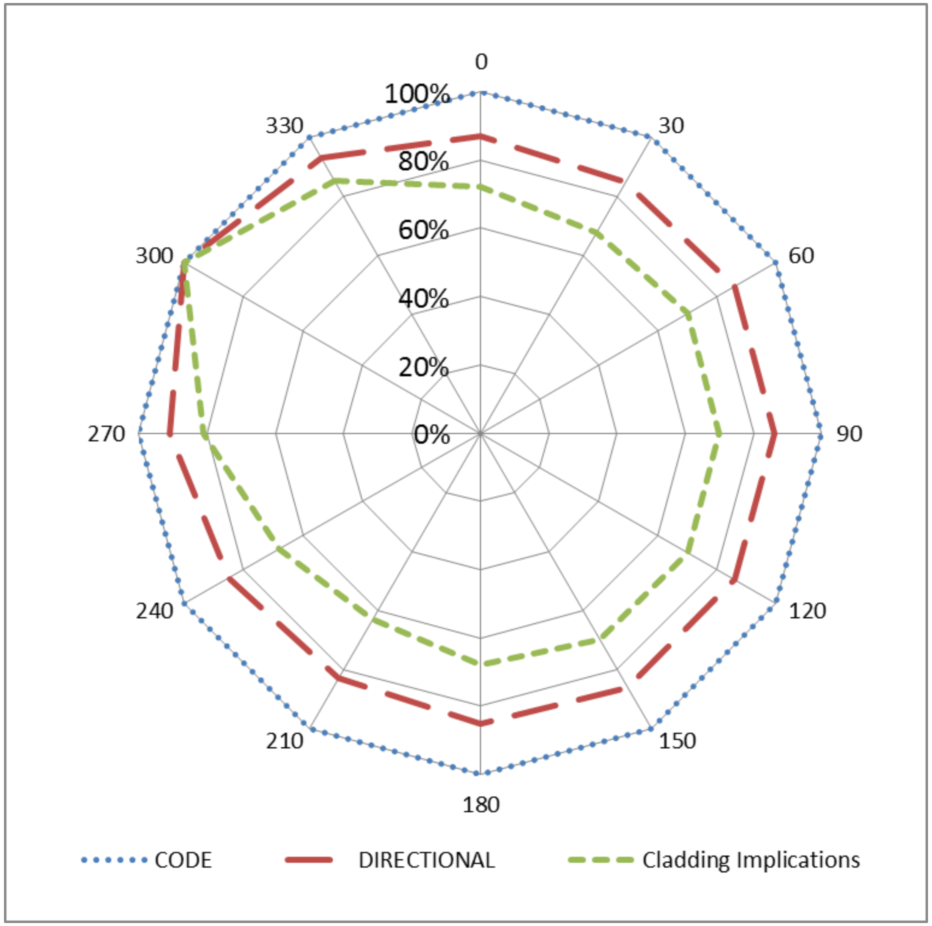

– Codified design wind pressures

# Wind climate


– Design wind pressures: Shanghai ~ 1.6 x Jeddah

# Wind climate

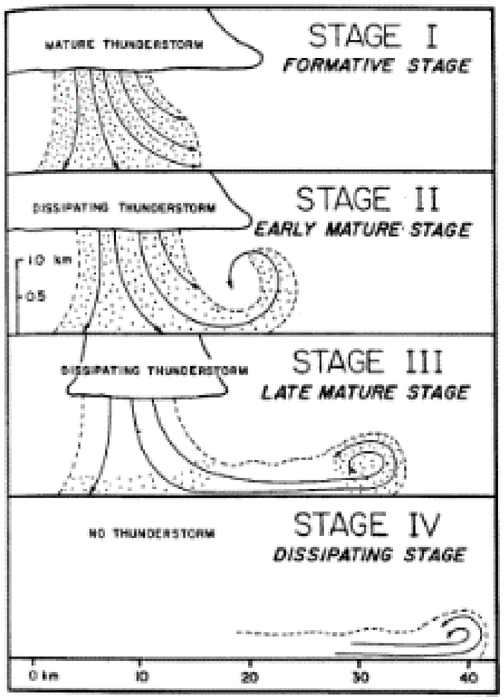


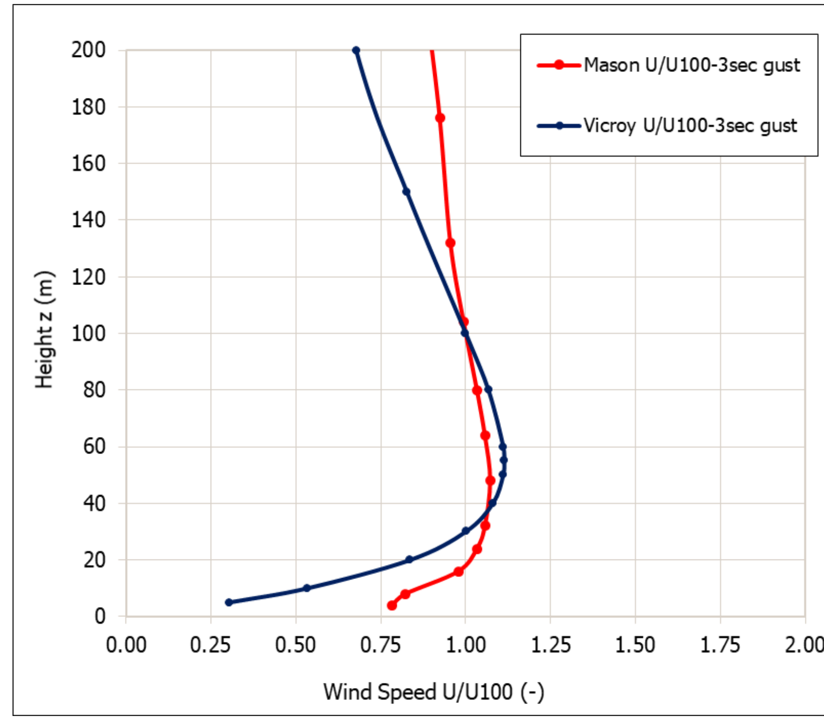

– Implications of directionality effects of extreme winds on façade wind pressures

# Wind climate (what we know *less* well)

- Dust storms (e.g. Shamal winds, very common in the Middle East)
- Thunderstorms, downbursts and tornados: meso-scale events driven by local convection

# Transient wind events

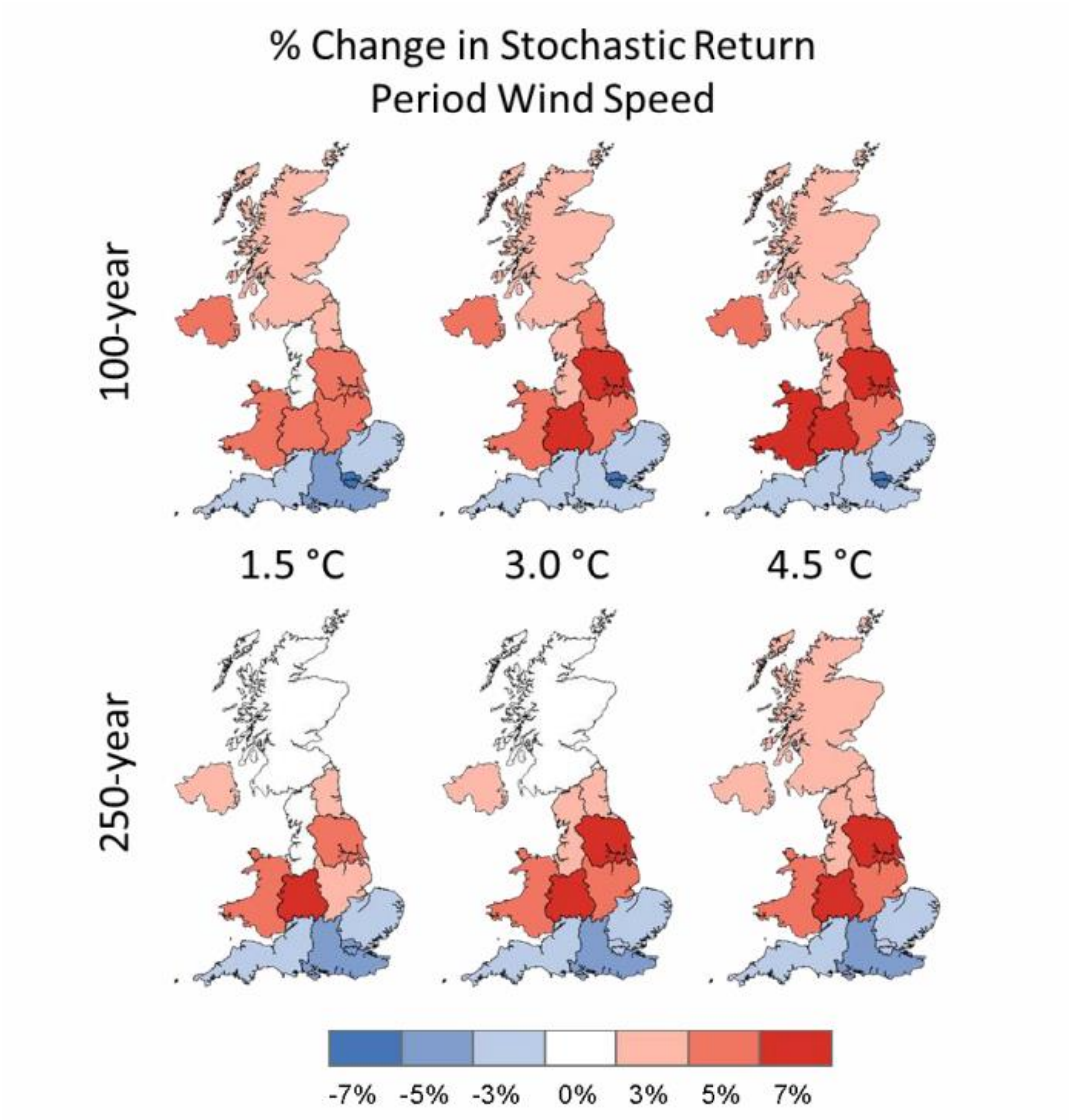


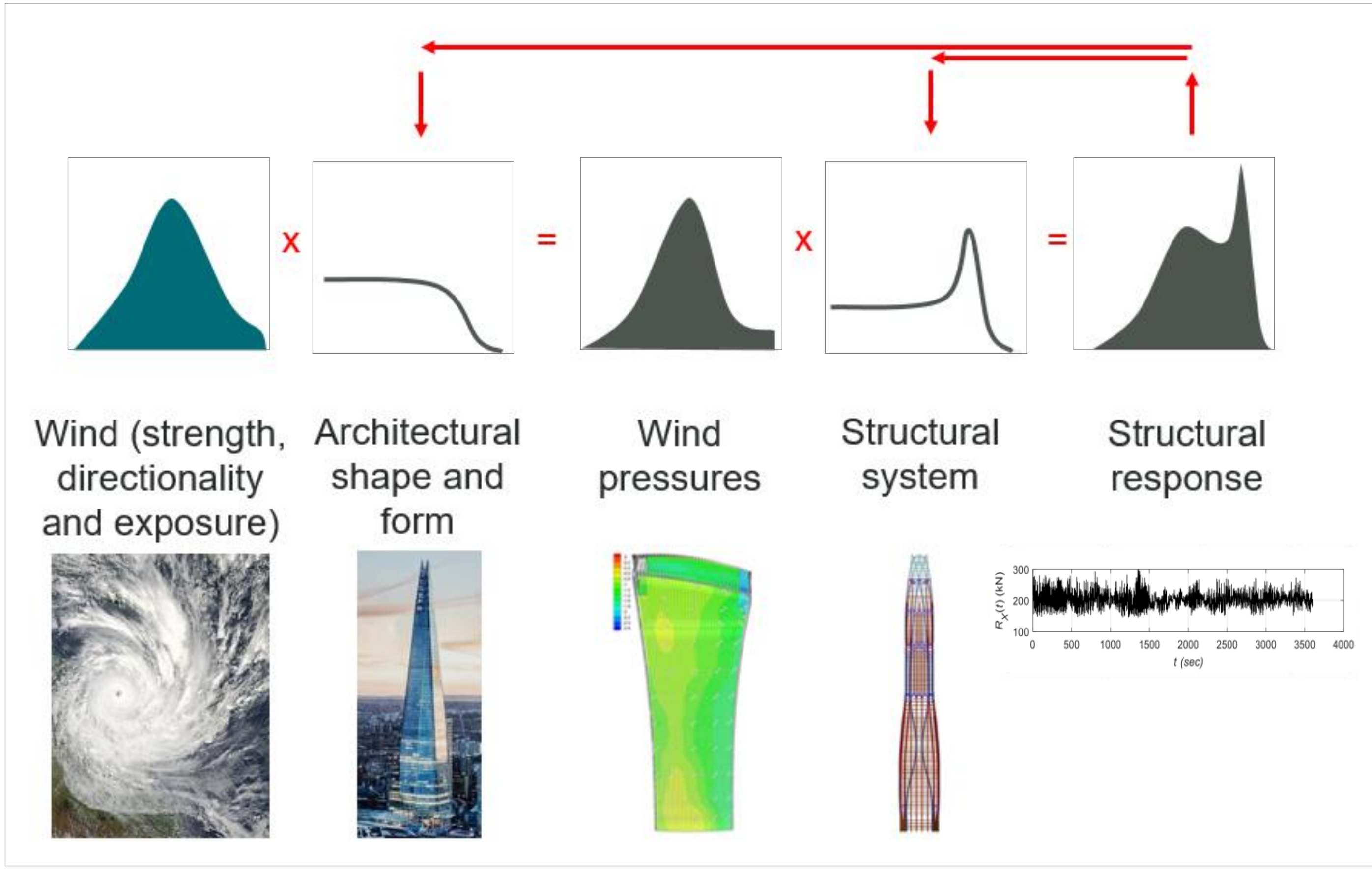

- Very short duration, strong outflows close to ground level
- The ‘nose’ of the jet typically sits at 100m (or less) above the local ground

# Temporary structures and thunderstorms

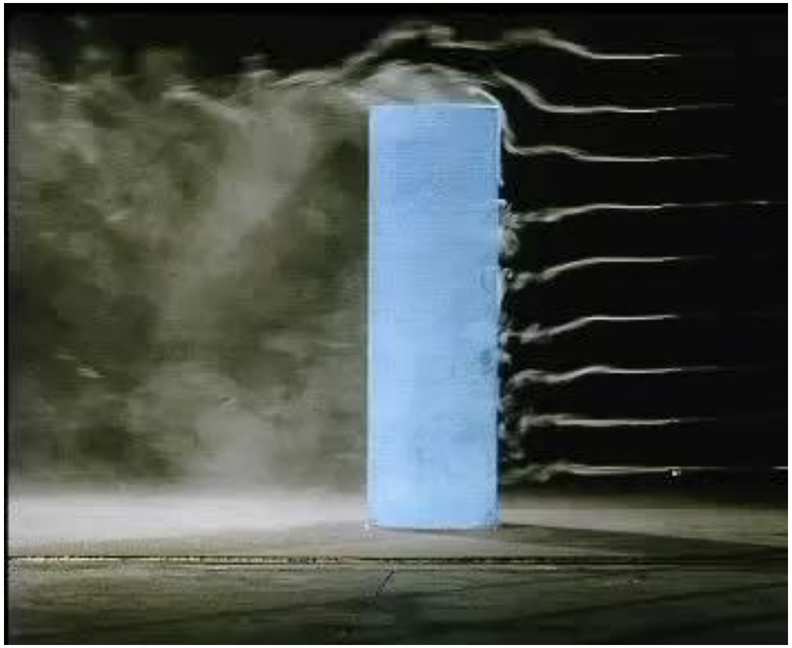
# Impact of climate change

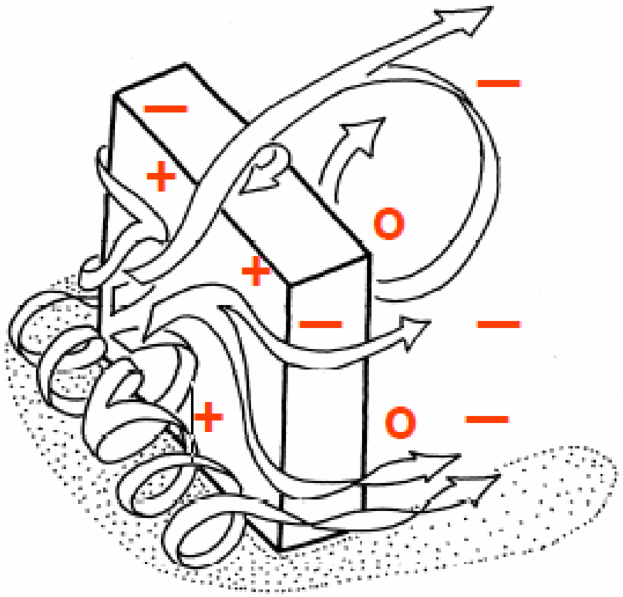


# Davenport’s wind loading chain



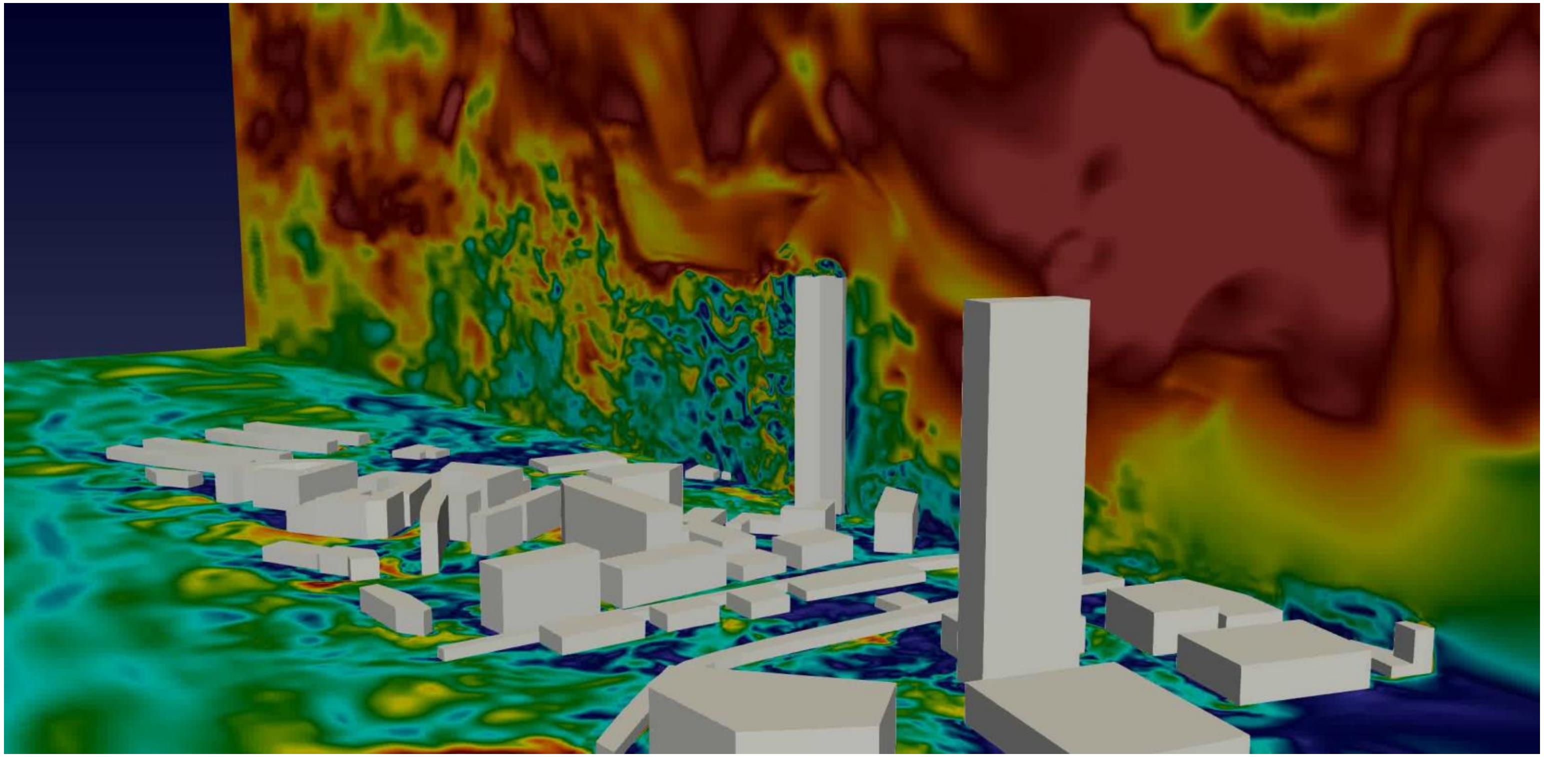
# Complex wind flow patterns





- Centre of pressure typically sits at 2/3 of the building height
- Flow over the top 1/3 of the building is highly three-dimensional
- Down drafts from tall towers can create windy areas at street level (hotspots of suctions close to the base of tall buildings are not that uncommon)
- Geometries featuring sharp edges are more prone to generate higher localised suctions (stronger flow separation)

# Façade wind pressures

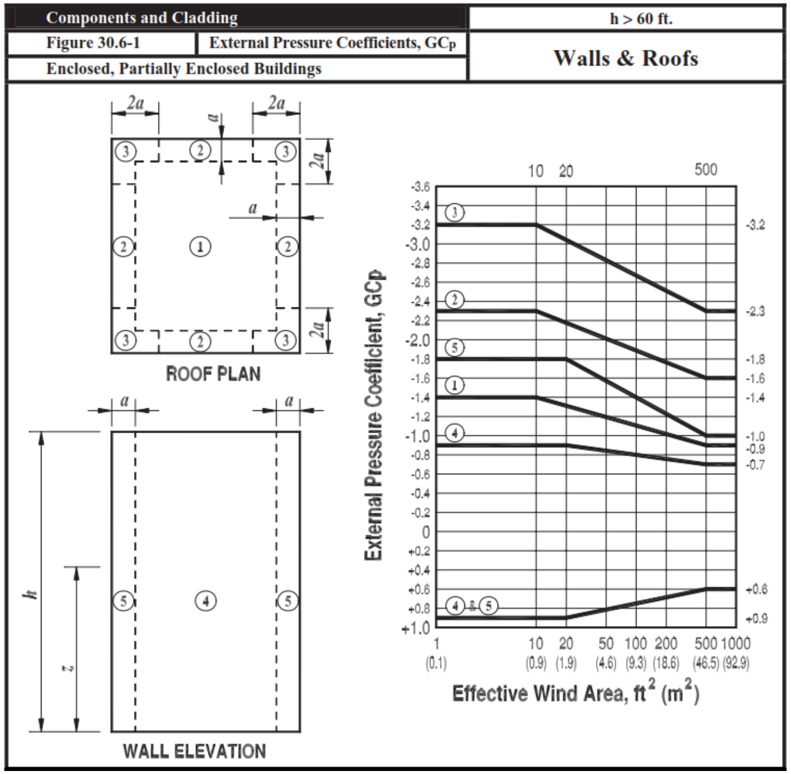


# Façade wind pressures

- Wind-driven kinetic façade consisting of 612 freely-rotating blades
- As gusts of wind hit the wall, the blades spin independently, demonstrating the localised flow of the wind and the way it interacts with the building

# Façade wind pressures

- The highest local wind pressures (suctions) are often the result of flow separation around the edges of the façade
- Pressure fluctuations are spatially and temporally correlated, what this means is that larger façade panels require a longer duration gust to get excited



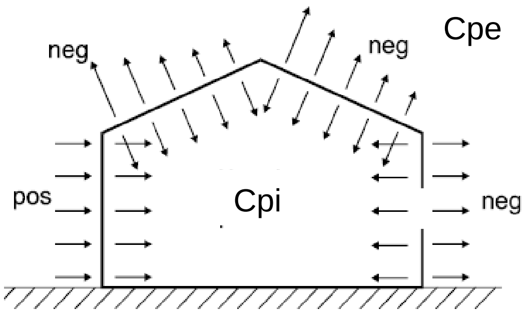
# Code approach

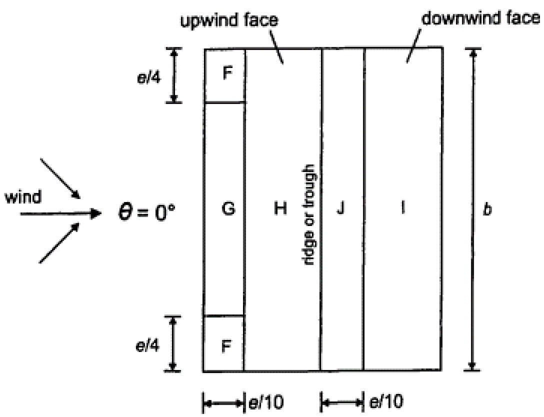
− Pressure coefficients for various shapes of structures are commonly given in codes. There are three pressure coefficients to consider:

i. $Cp_e$: external pressure coefficient

ii. $Cp_i$: internal pressure coefficient

iii. $Cp_{net}$: net pressure coefficient




(b) wind direction θ = 0°

e = b or 2h
whichever is smaller

b : crosswind dimension

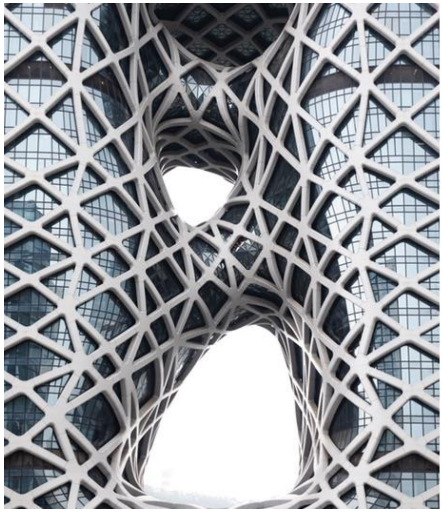
# Code approach

- Often a limit of applicability of the code-based pressure coefficients is:

i. Complex geometry

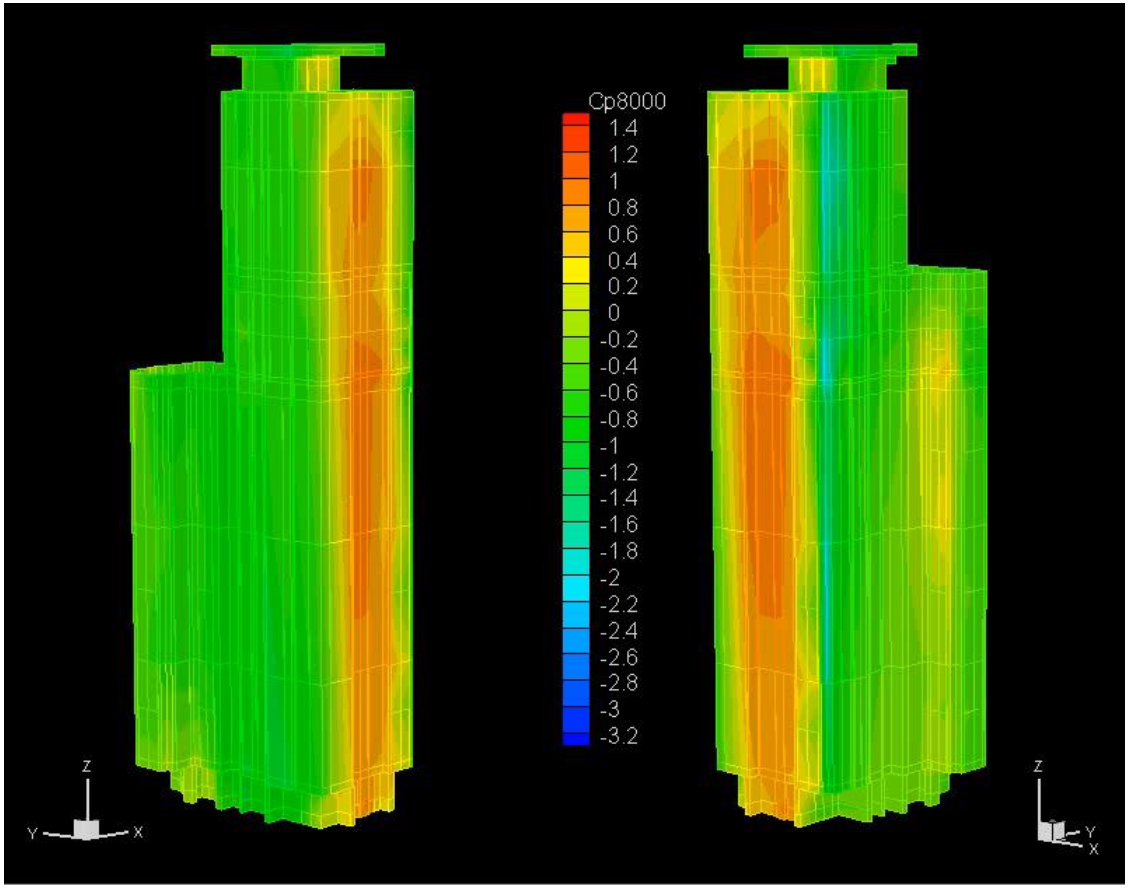
ii. Effect of surroundings buildings

iii. Complex topography



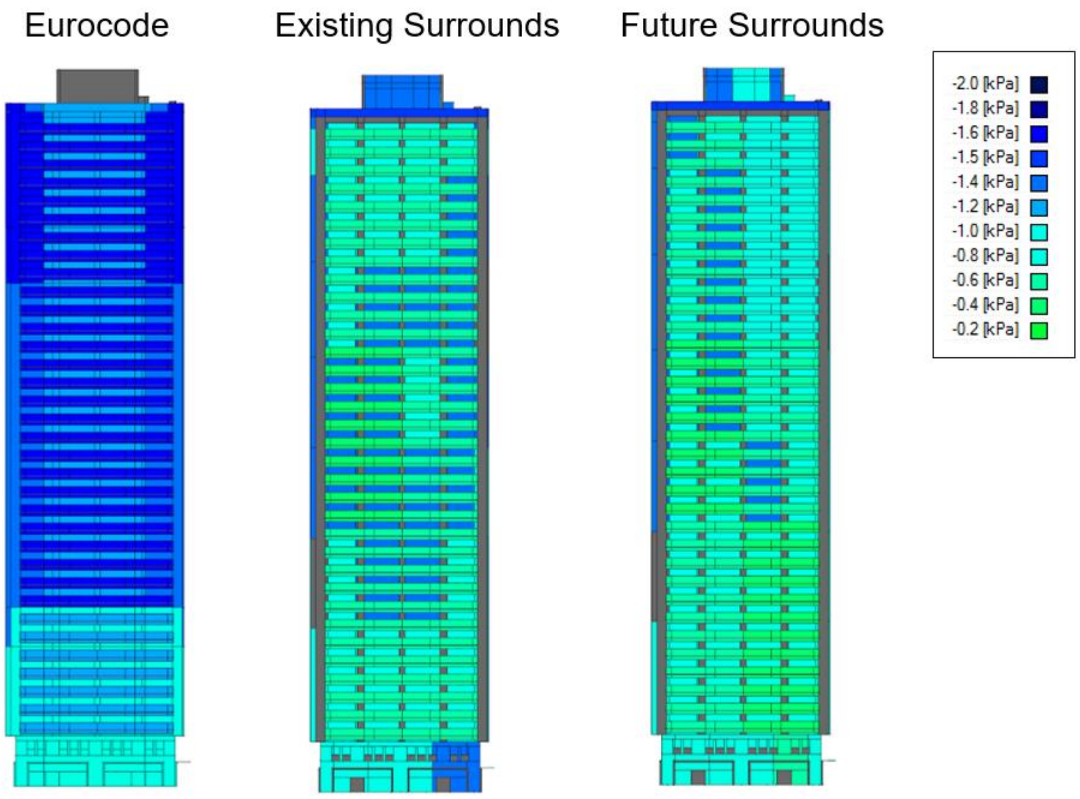
# Code approach vs. wind tunnel tests

- In reality, wind pressures vary smoothly over the building surface and rapidly over time



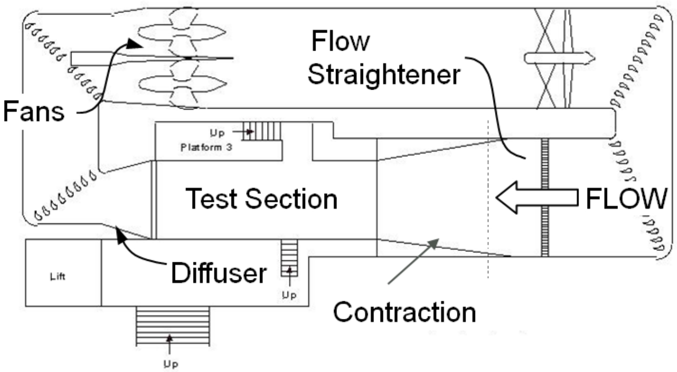
# Code approach vs. wind tunnel tests

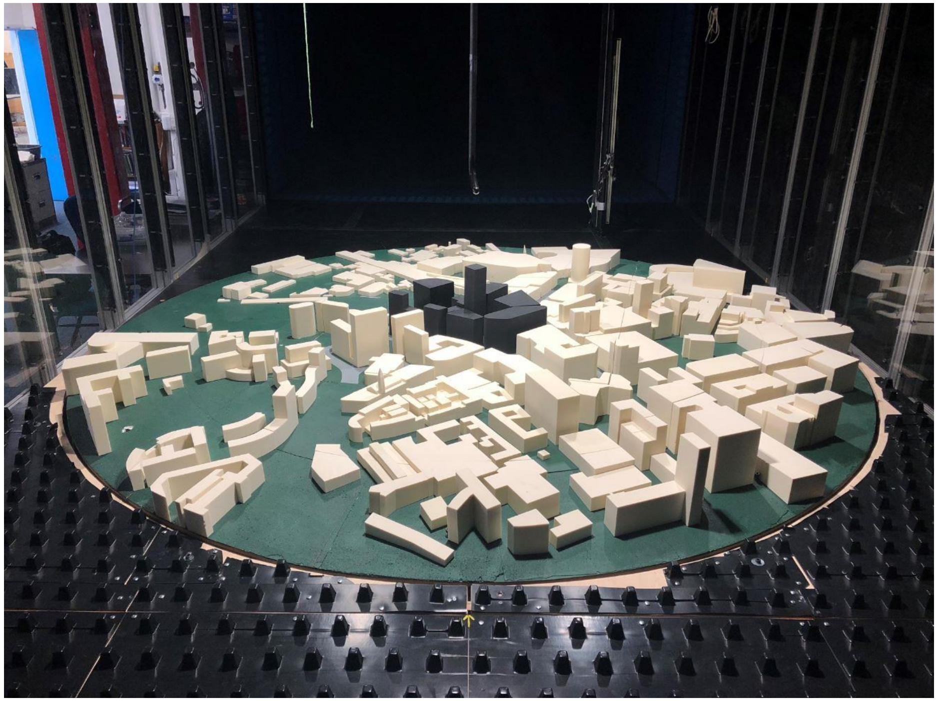
- Typically carrying out a wind tunnel test for cladding is where most of the value is found
- Often, in fact, cladding pressures measured in the wind tunnel are about 25% - 30% less than code values (this is especially true in built-up city environments)



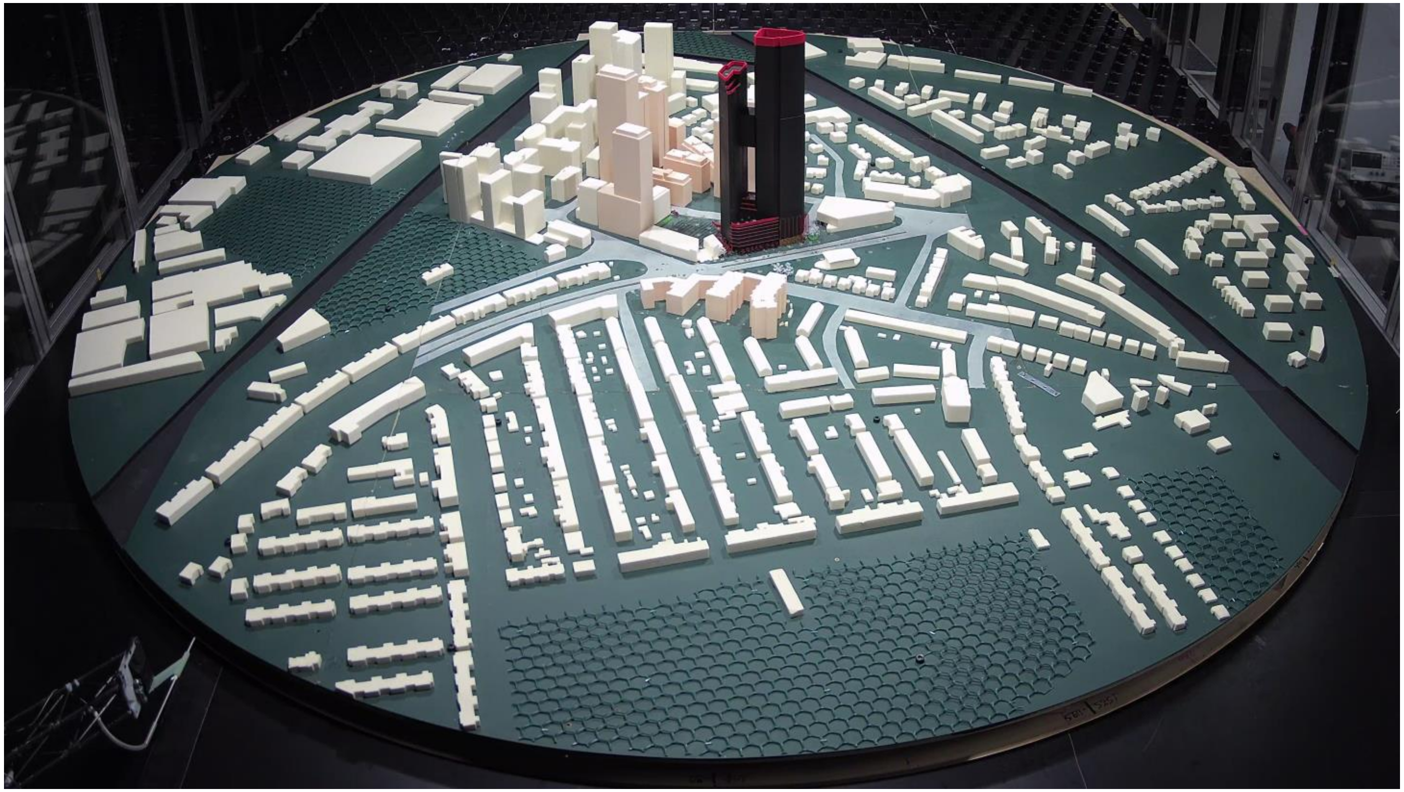
# Wind tunnel testing

- Typical model scales: 1:200 to 1:500
- Full range of wind directions: 10deg increments

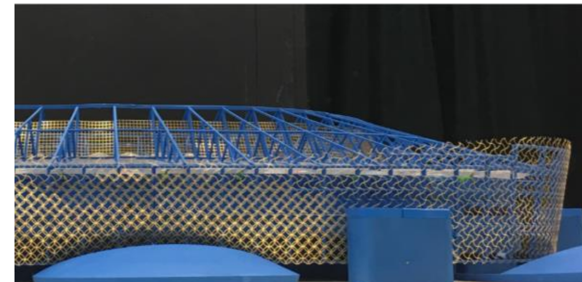


# Wind tunnel models



# Wind tunnel pressure models

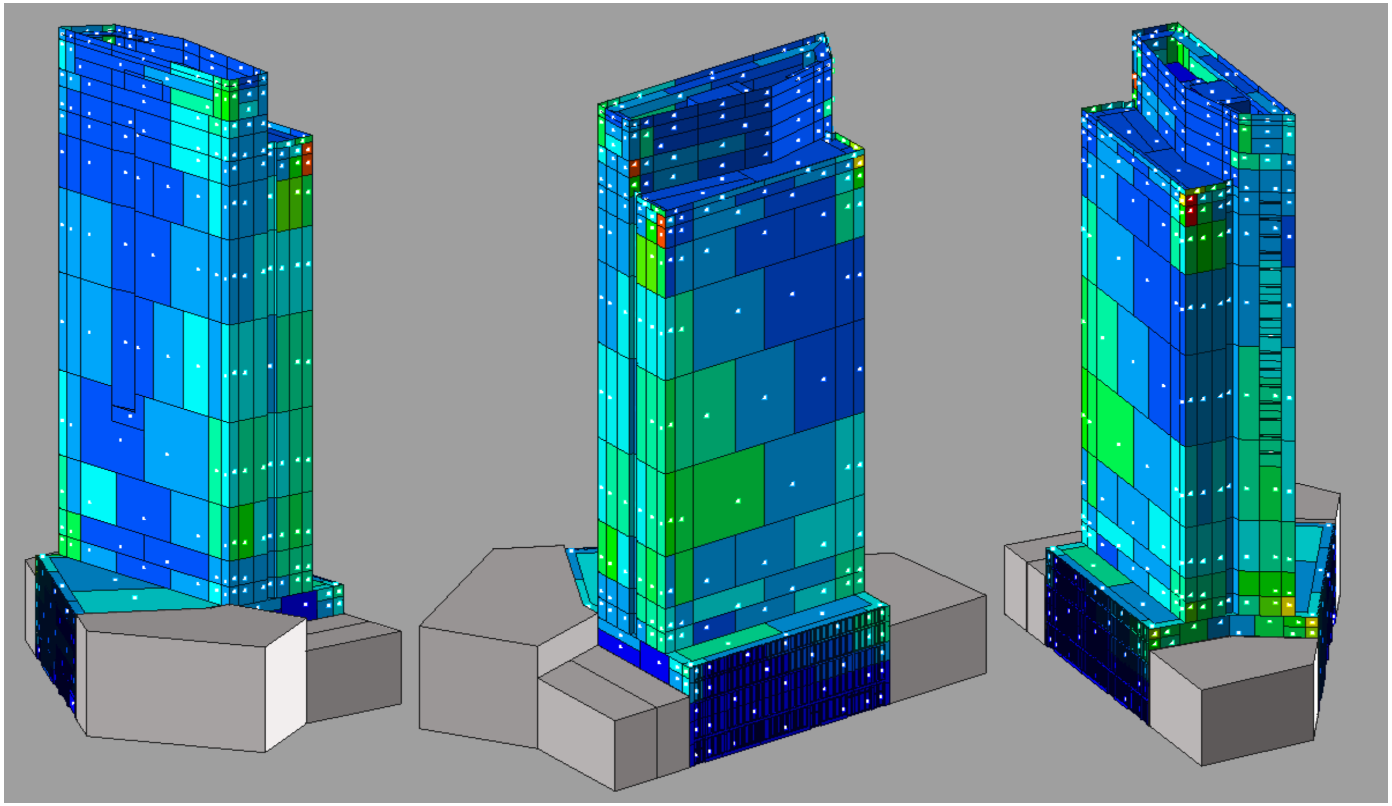


- 3D printed wind tunnel pressure models
- Number of pressure sensors in the hundreds

# Wind tunnel tests

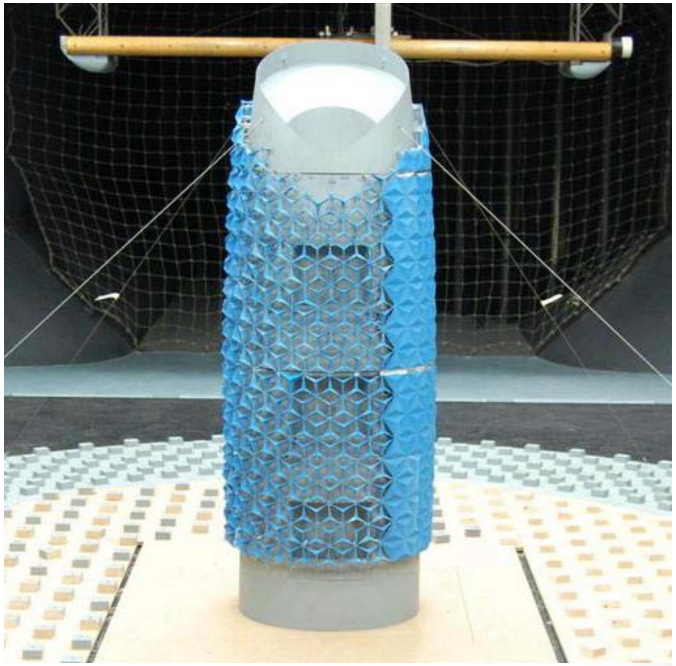
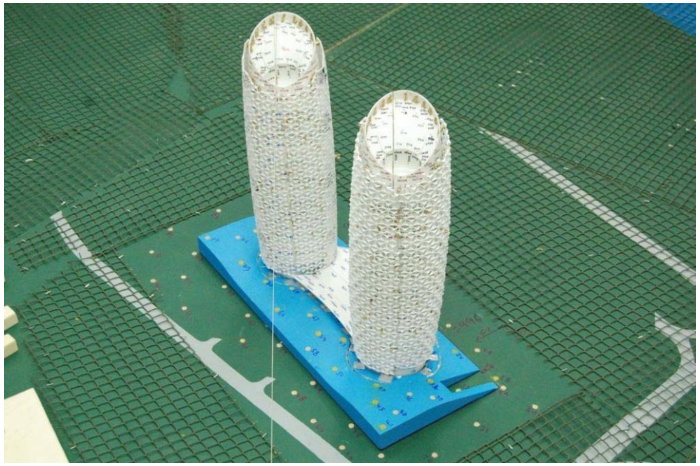
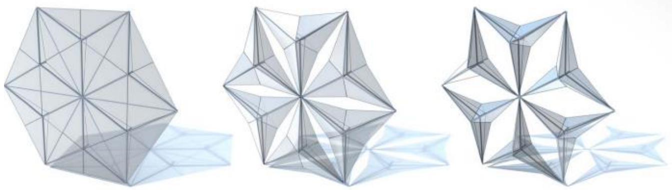
- Typical duration: 3 hours
- Pressure data typically sampled at 5Hz full-scale
- For each pressure sensor and each wind direction about **50,000** data points are acquired
- For each pressure sensor and for a full set of wind directions about **2,000,000** data points are acquired
- For 500 pressure sensors and for a full set of wind directions about **1,000,000,000** data points are acquired

# Wind tunnel testing results

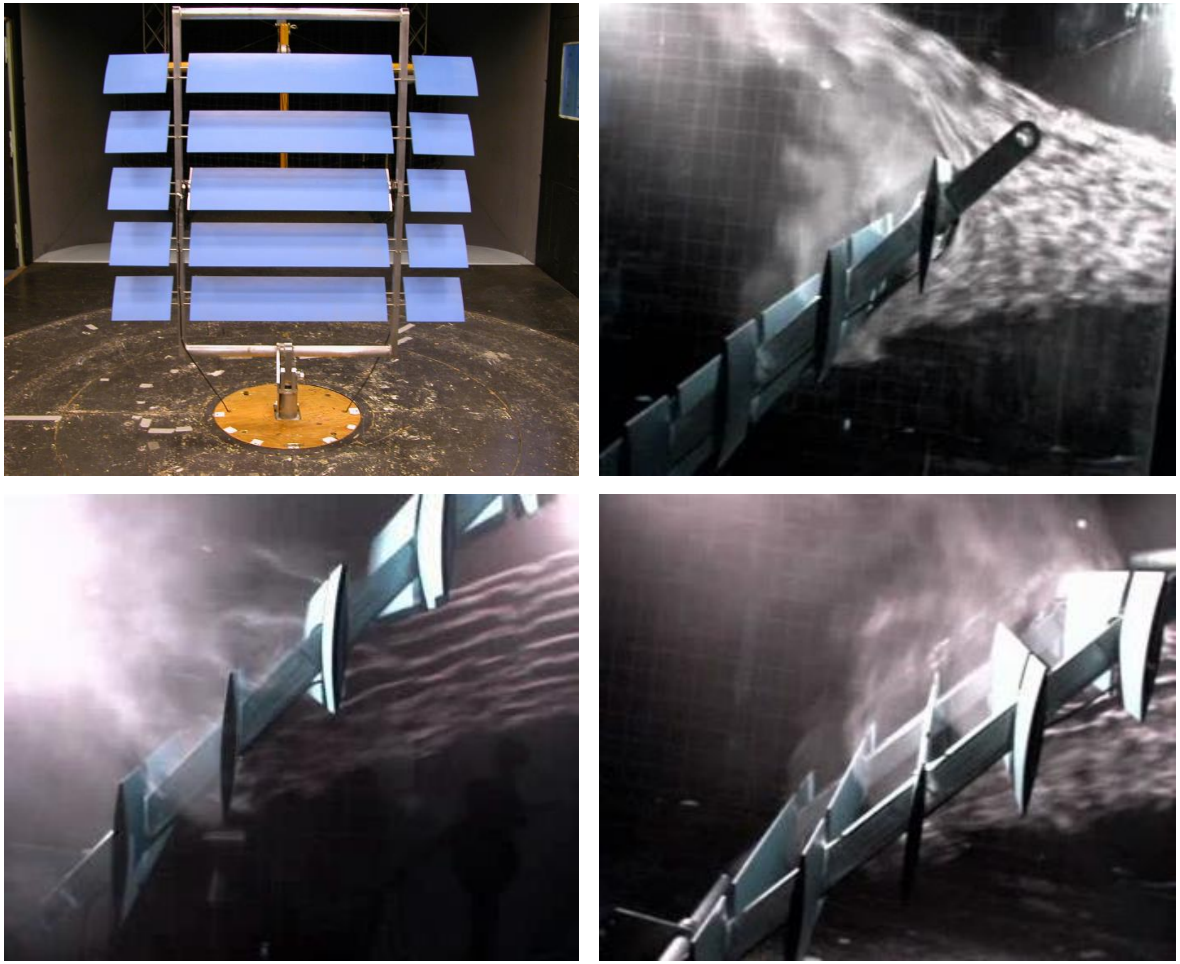


# Large scale models: kinetic façades

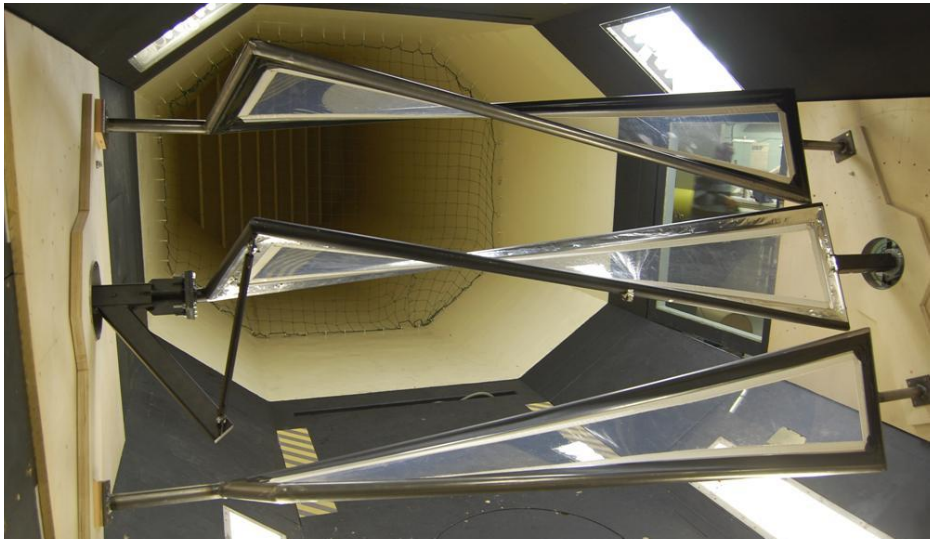
- 1:300 scale global wind tunnel models (pressure test)
- 1:75 scale partial and more detailed wind tunnel model (pressure test)

# Large scale models: louvers



# Large scale models: permeable façade



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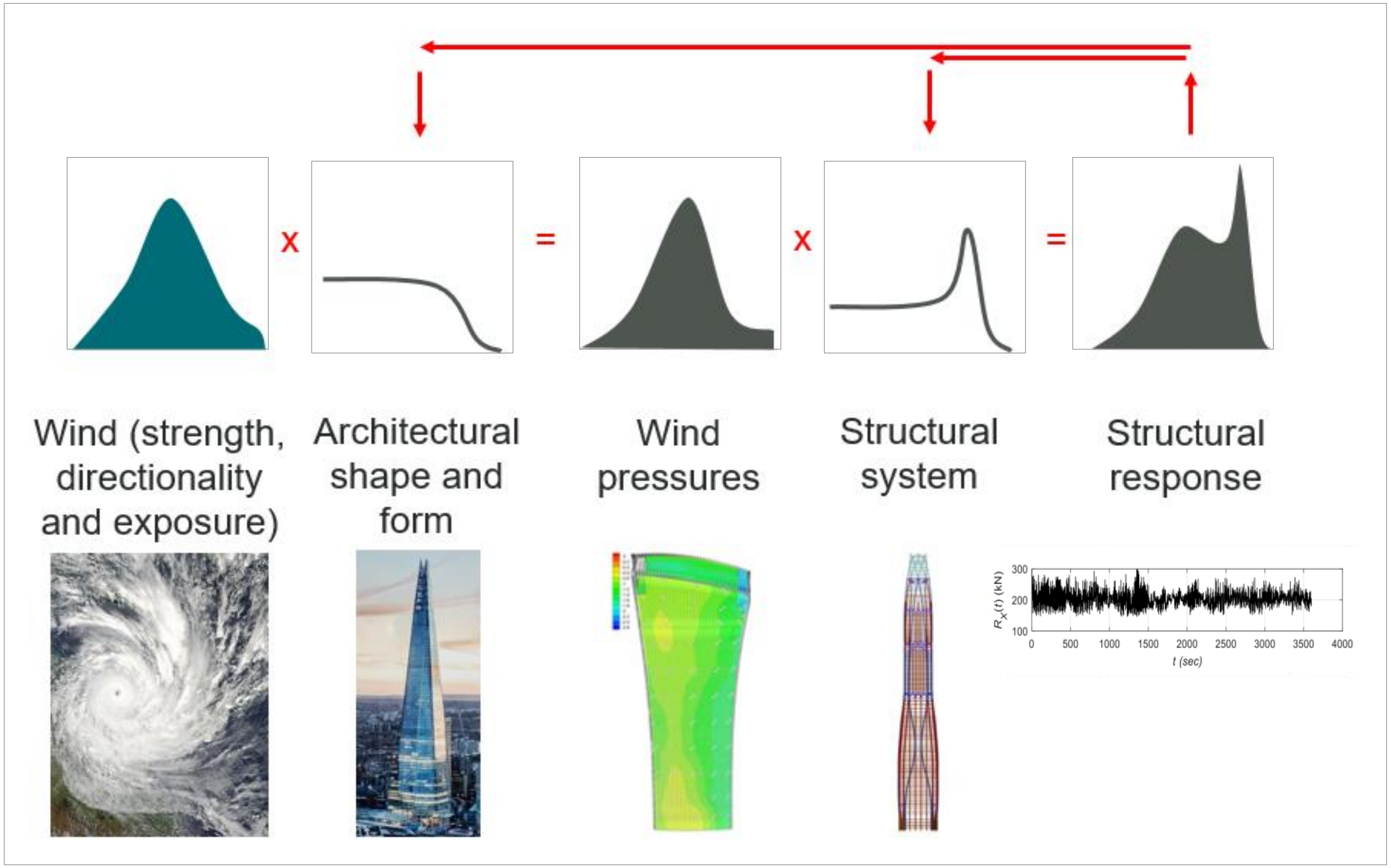

# Fins and sunshades

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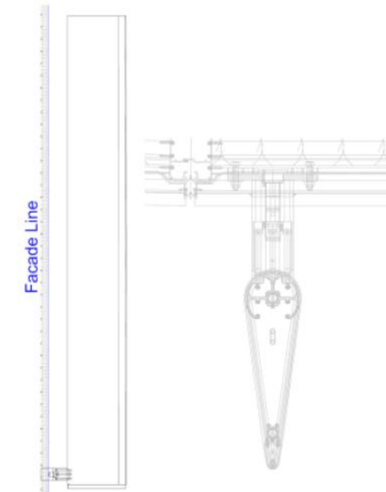


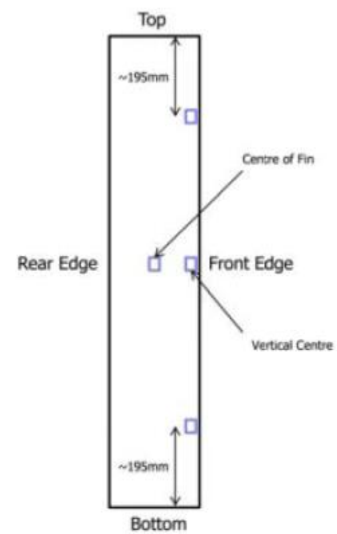

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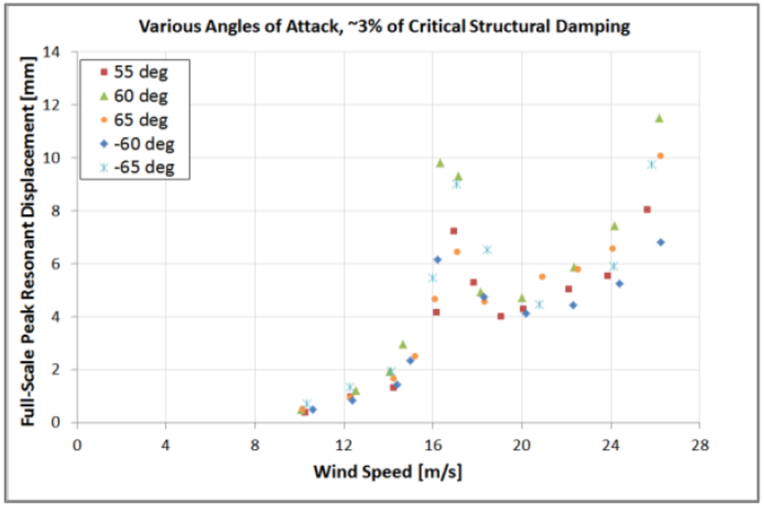
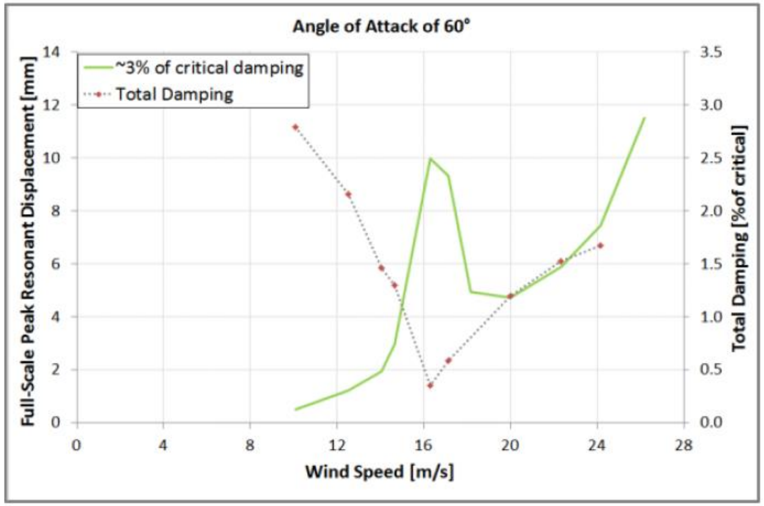


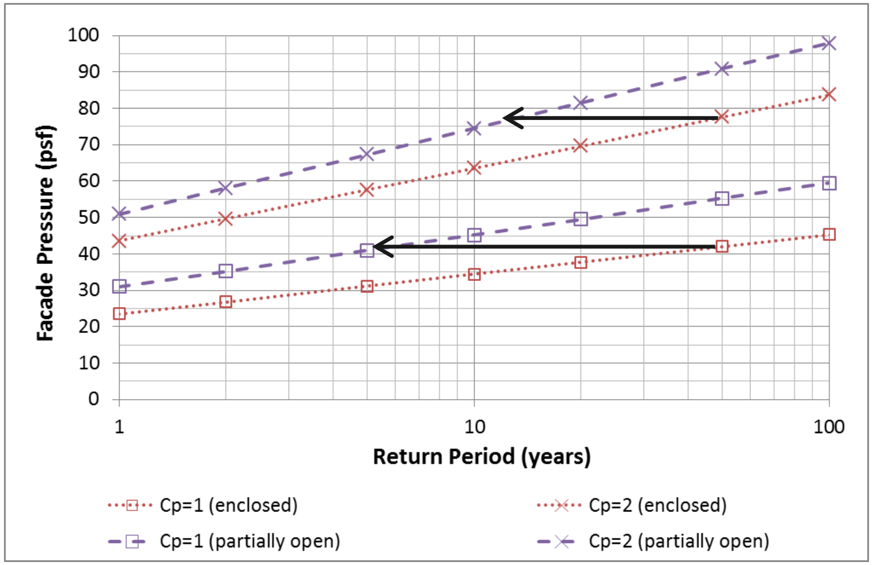

– Wind-induced dynamic response




– Aerodynamic damping

# Operable windows

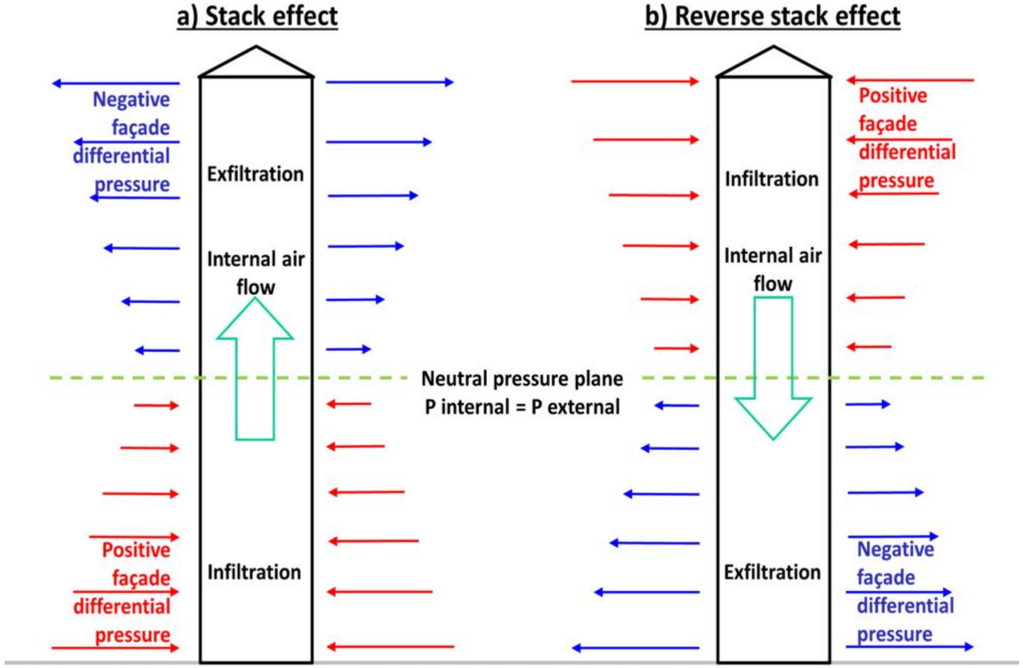
- When operable windows in buildings are left open during a storm this can result in significant cladding damage




# Façade: wind-induced damage

# Stack effect

- The stack effect is a **buoyancy-driven phenomenon** that commonly occurs in high-rise buildings. This physical phenomenon typically arises in regions experiencing extreme climatic conditions. The main driver behind the stack effect phenomenon is the temperature difference between the interior of the building and the external environment.



# Stack effect: design challenges

- *Elevator doors operation*: elevator doors, due to excessive pressure difference across them, could malfunction and not operate correctly
- *Swing doors operation*: users, due to the excessive pressure difference across swing doors, could experience difficulties in opening / closing them
- *Uncomfortable and / or excessive air flow movement*: this has the potential to occur within key occupied spaces such as lobbies, corridors and atria
- Propagation / spreading of smoke, odours and other unwanted contaminants throughout the building
- *Inefficient heating / cooling strategy*: because of the excessive infiltration of cold (hot) ambient air into the lower (upper) levels of the tall buildings, extra energy supply is likely to be required to heat up (cool down) such spaces
- *Flow-borne noise*: air flow at high speed through narrow gaps (e.g., door gaps, louvers of the shafts or natural ventilation openings) could be the cause of narrow-band high pitch whistling which in turn can create discomfort to the occupants of the tall building
- *Fire strategy*: an excessive air flow movement within the tall building could increase the propagation rate of smoke and fire

# Stack effect: how it sounds

# Stack effect: preventive measures

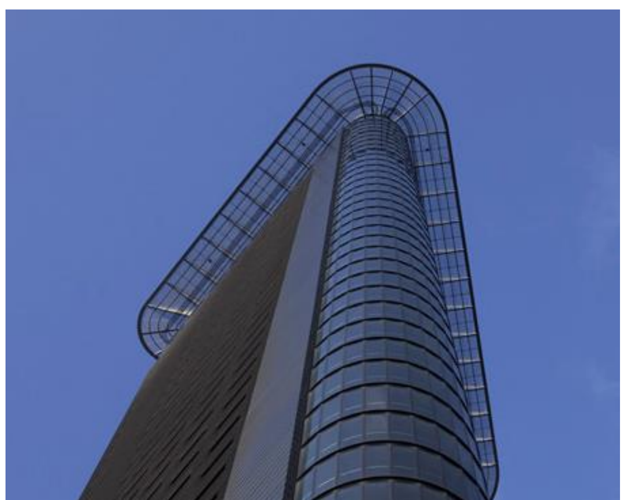
- **Improvement of the quality and air tightness of the building envelope**
- Installation of revolving doors at key access points to the building
- Implementation of vestibules between building entrances and elevator banks
- Introduction of vertical separations within elevators and stairwell shafts
- Introduction of horizontal separations (e.g. additional internal partitioning)
- Implementation of mild pressurization within elevators and stairwell shafts

| Façade specification | Air leakage [$m^3/(m^2\cdot hr)$] |
|---|---|
| Chinese Grade 1 (GB/T 21086-2007) | 2.0 – 4.0 @ 10Pa |
| Chinese Grade 2 | 1.2 – 2.0 @ 10Pa |
| Chinese Grade 3 | 0.5 – 1.2 @ 10Pa |
| Chinese Grade 4 | <0.5 @ 10Pa |
| ASTM / AAMA | ~0.2 @ 10Pa |

# Wind-induced noise


CitySpire Center [NYC]


De Hoftoren [The Hague]


Het Strijkijzer [The Hague]


Beetham Tower [Manchester]

# Wind-induced noise

Wind-borne noise occurs as a result of high frequency fluctuations either in the pressure or the velocity field. The main mechanisms behind wind noise problems subjected to urban flow are:

- **Aeolian tones**, typically generated by high frequency vortex-shedding in the wake of strong flow separation off a sharp edged object
- **Wind-induced vibrations**, often causing architectural appendices to move and potentially creating noise as a consequence of mechanical friction between moving parts
- **Shear layers**, high frequency broadband pressure fluctuations often generated by flow through narrow gaps

# Wind-induced noise studies

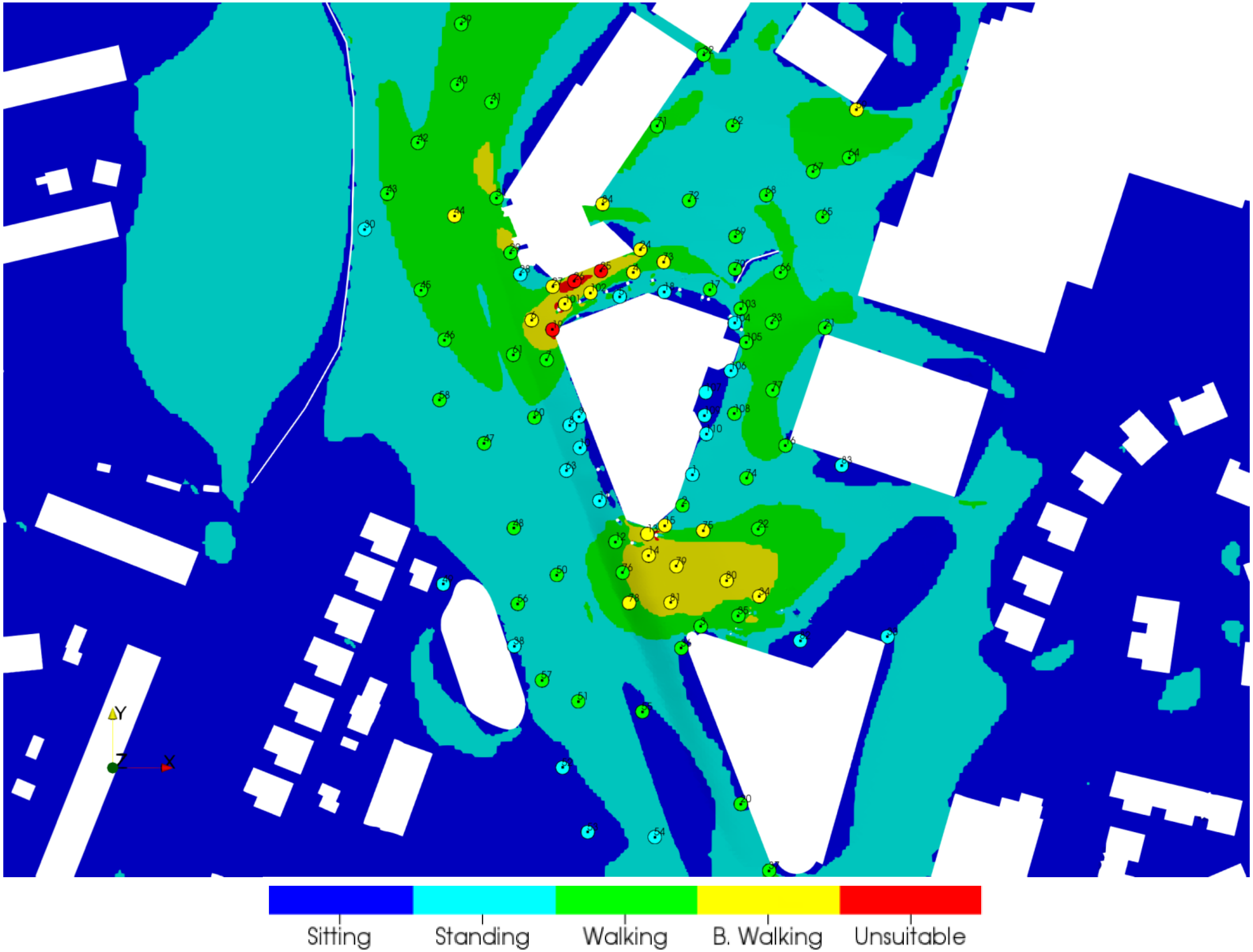
- Façade features analysis (sun-shades, external frames, cables, mesh, etc)
- Window / door opening assessment
- Apertures and edge size / shape optimisation

# Will *CFD* ever replace *wind tunnels* for building wind simulations?

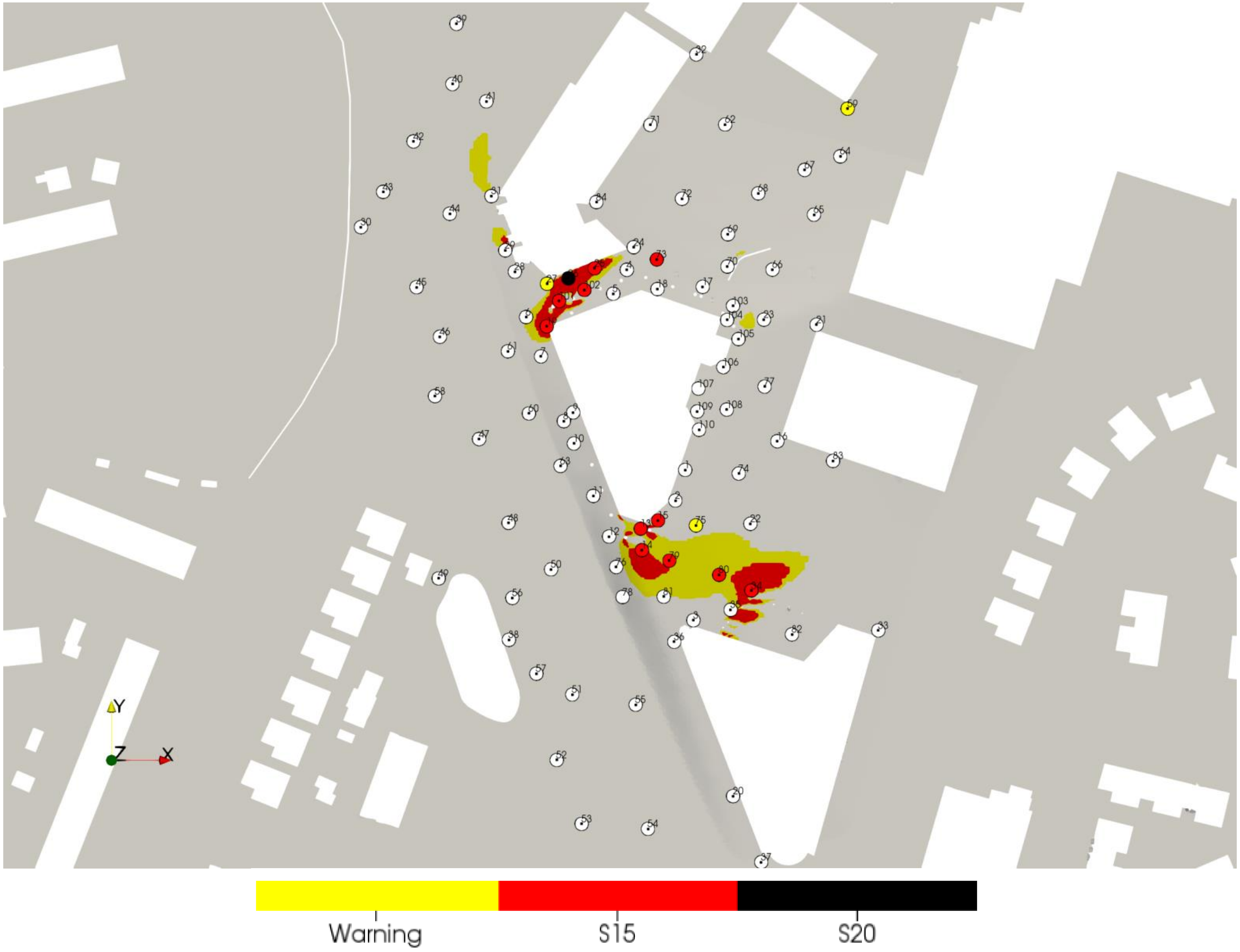
# TOTAL Wind Engineering

- Experimental (wind tunnel testing) and computational (CFD) wind engineering working ‘hand in hand’ from start to finish, sharing the same wind statistics, the same boundary conditions and complementing each other with one single goal: develop, test and rapidly validate effective and viable architectural aerodynamic solutions

# TOTAL Wind Engineering



# TOTAL Wind Engineering



# Takeaways

- **Wind design** incorporates aspects of many disciplines, including meteorology, statistics, fluid dynamics, engineering and architecture
- **Wind climatology** can affect, influence and shape the built environment
- **Analytical** methods, **numerical** tools and **wind tunnel testing** can help assess wind effects for both typical and less conventional building enclosures
- The use of these available design tools **early in the design** process can help in the assessment of the impacts of complex wind flows that are typically formed in the urban environment
- High quality numerical CFD simulations coupled with detailed experimental wind tunnel testing is these days seen as **the way forward in the industry**

# Thank you