CFD analysis for optimal wind screen positioning

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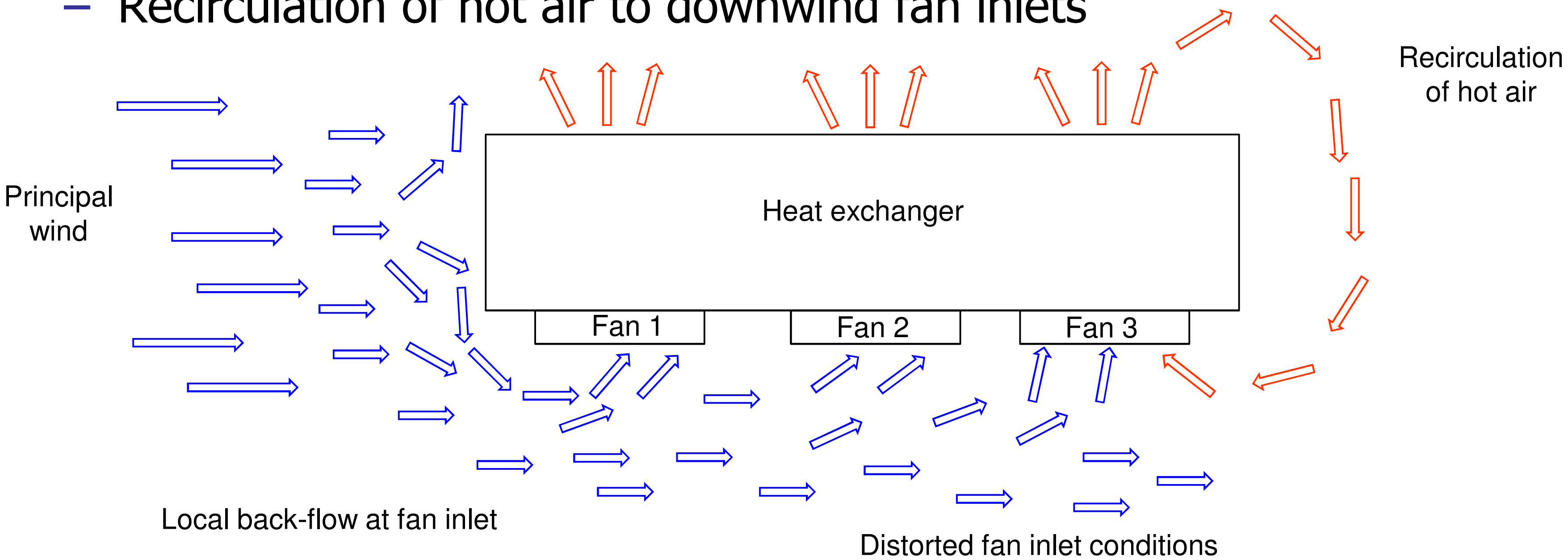
Motivation

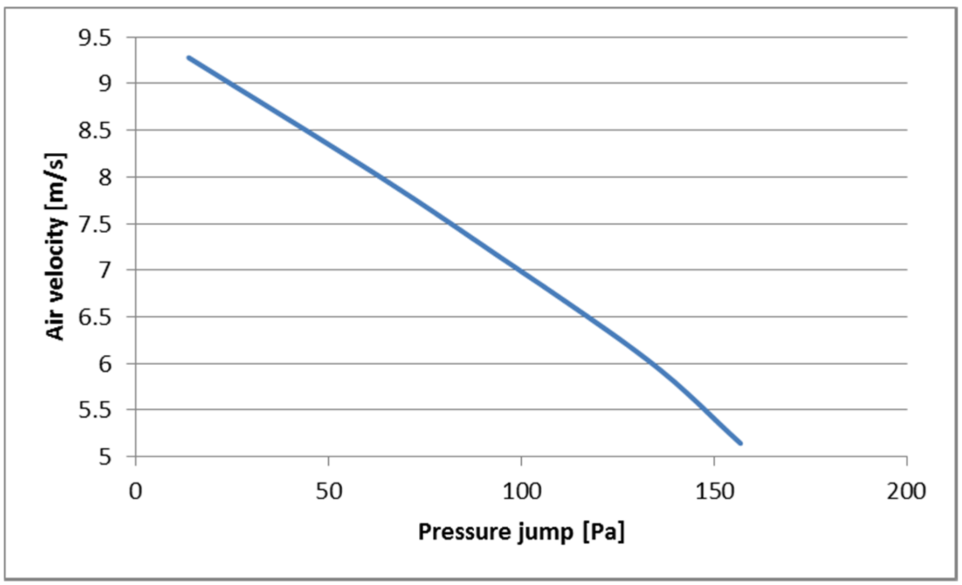
- Performance of power plants using ACC may largely be affected by wind conditions
  - Up to 10% reduction in net plant power output for 10 m/s wind[1]
- Source of losses
  - Degradation of fan performance
  - Recirculation of hot air to downwind fan inlets



[1] Field data from PP1 plant summer 2013

Motivation

- Wind screens may help maintaining high ACC fan performance
  - Protect fan inlet from cross-wind
    - →In large ACC neighbour fans generates distorted inflow conditions
    - →High wind speed below ACC fan level
  - Reduced fan flow rate due to increased pressure loss



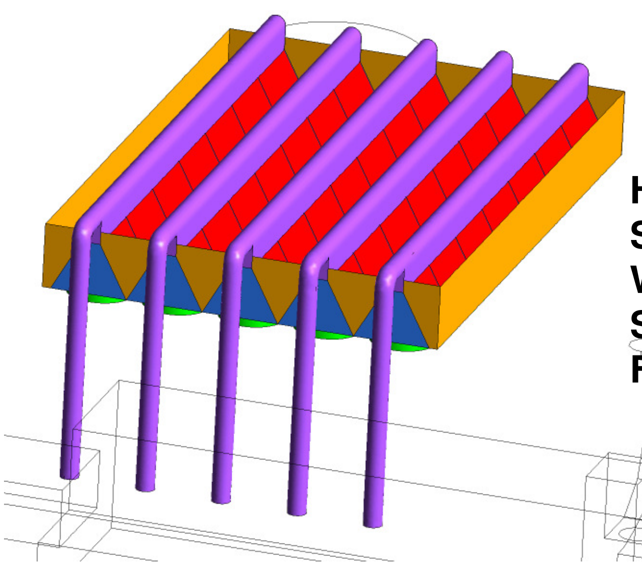
Motivation

- Design of effective wind screens protection is complex
  - Site specific
  - Wind condition specific
  - Problem specific
    - →Performance, Mechanical or Debris

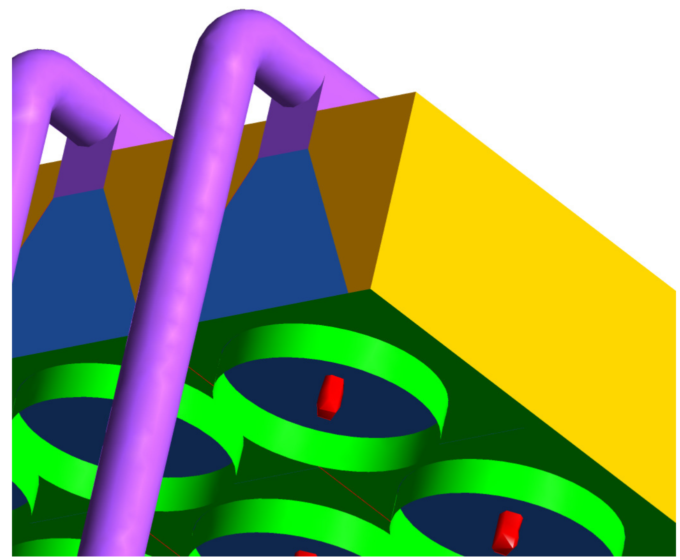
- Economic break even point is case dependent
  - Costs largely depends on installation
  - Selling price per MW is variable
  - Benefits can be quantified using site PI Data

Modelling strategy

- Reproduce the 3D local air field around ACC by means of CFD
  - To reduce computational cost: steady-state assumption
    - →Wind is assumed constant in magnitude and direction
    - →Other plant modules operate at nominal conditions
    - →ACC model includes active sub-modules for fan, heat exchanger and… Wind Screens

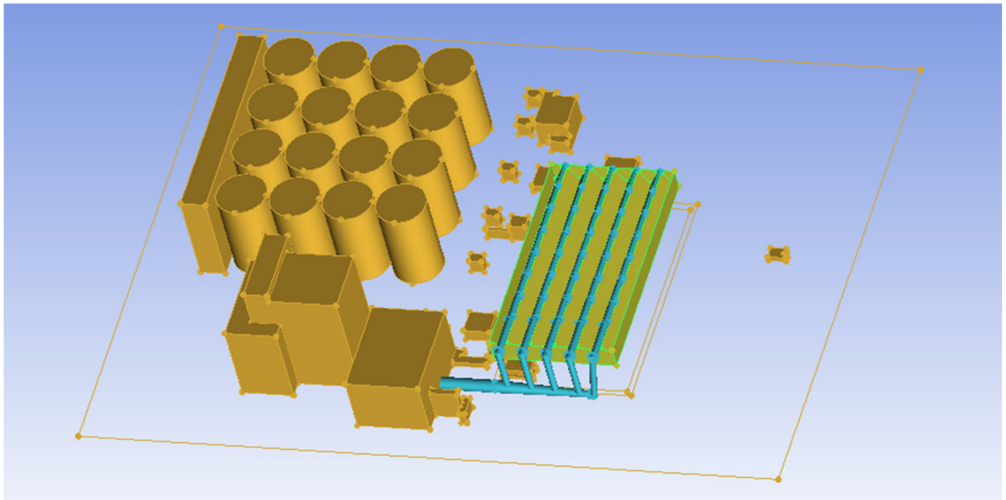


Heat-exchanger bundles: red
Steam pipes: purple
Windwalls: orange
Single unit separation: azure
Fan Inlet Bells: green



Chosen test case

- Large ACC assembly
  - 5 condenser streets x 8 fans each
  - Fan diameter is about 11.5m
  - Fan deck elevation is about 20m
  - At nominal working conditions the cross-flow is already higher than half of vertical fan velocity
- ACC is partially surrounded by tanks and buildings
- ACC is dimensioned to have 13 °C rise in cooling air through the bundles

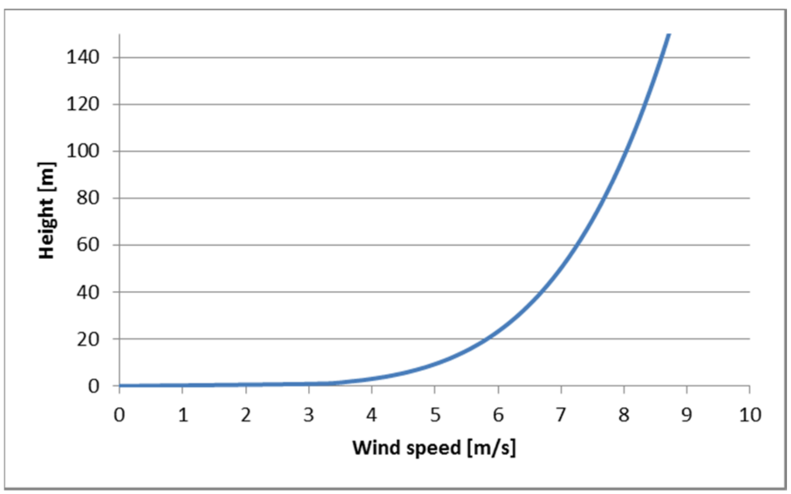


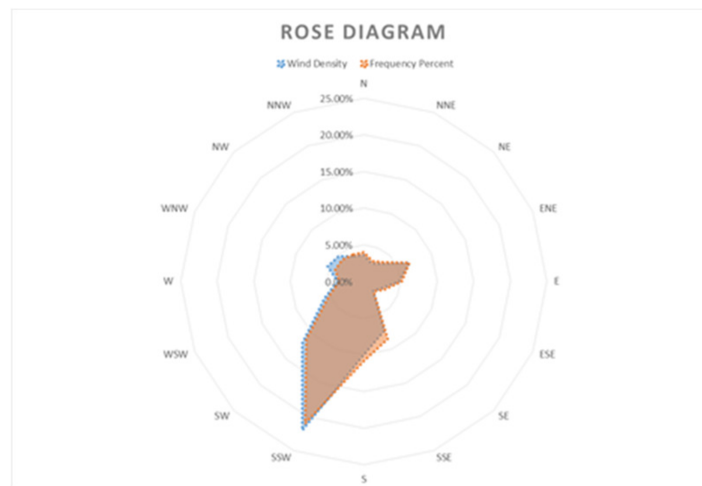
Chosen test case

- Weather conditions
  - Pressure = 1 atm, Temperature = 10 °C
  - Wind speed
    - →Power law profile
    - →n = 0.2 for open landscape, y_{ref}=34.7m

$$V(y) = V_{ref}\left(\frac{y}{y_{ref}}\right)^{n}$$

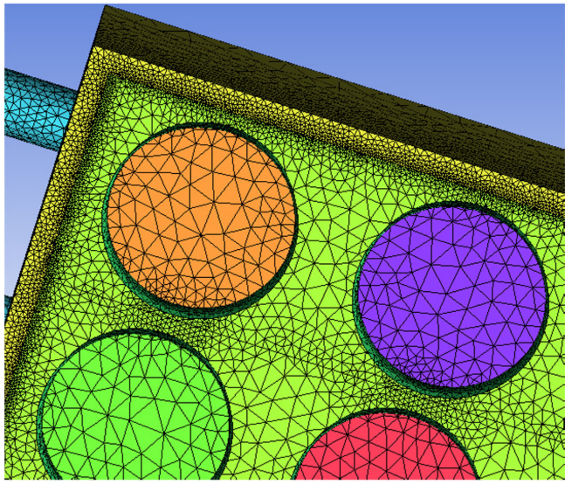
  - Wind direction
    - →Principal wind direction accounts for more than 20% of events
    - →60% of registered events are characterized by deviation larger than 45°



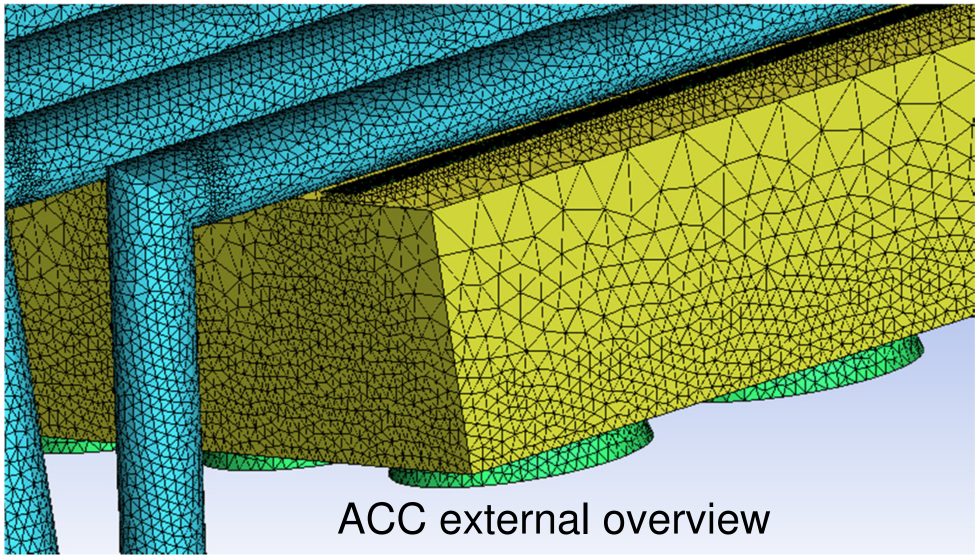


Geometrical modelling

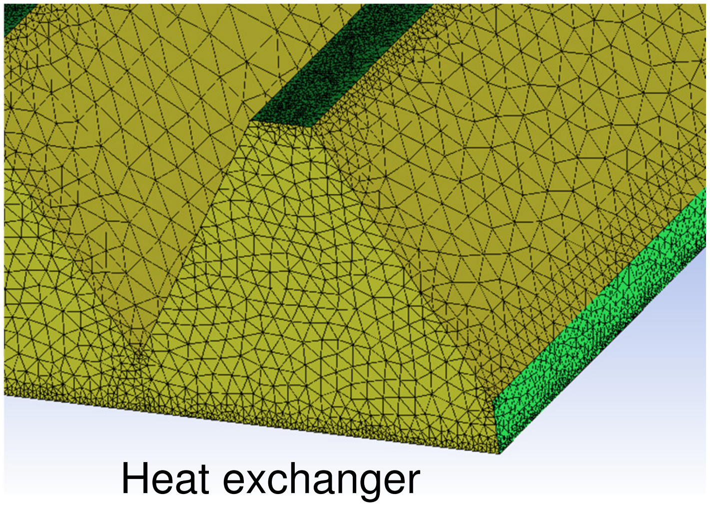
- Unstructured hybrid grid
  - Tetrahedral elements used to model the free-stream
  - Prismatic cells exploited to better discretize boundary layer
  - Many solid walls treated as thin surfaces
    - → Most of ACC solid walls
    - → Fan and bundle surfaces
    - → Wind screens and lifting devices
  - Total of 10M cells



Fan



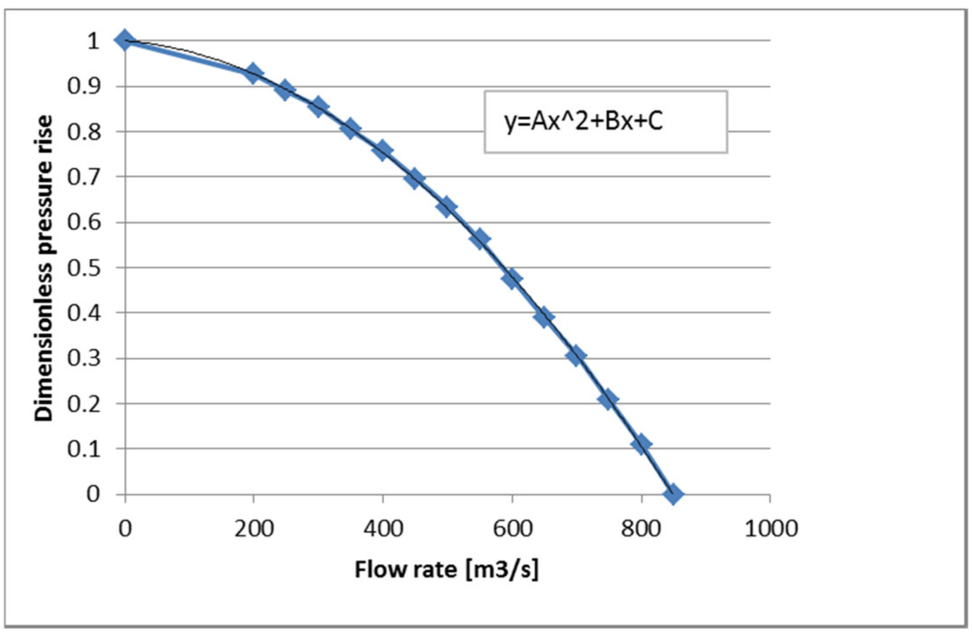
ACC external overview



Heat exchanger

Active elements modelling

- **Fan** is treated with *fan* model
  - It sustantially implements the pressure-jump model
  - Pressure jump profile is polynomial with velocity
    - →Parabolic fit with fan datasheet points
    - →Polinomium is limited for minimum and maximum fan velocity
      - Avoid unphysical curve behaviour



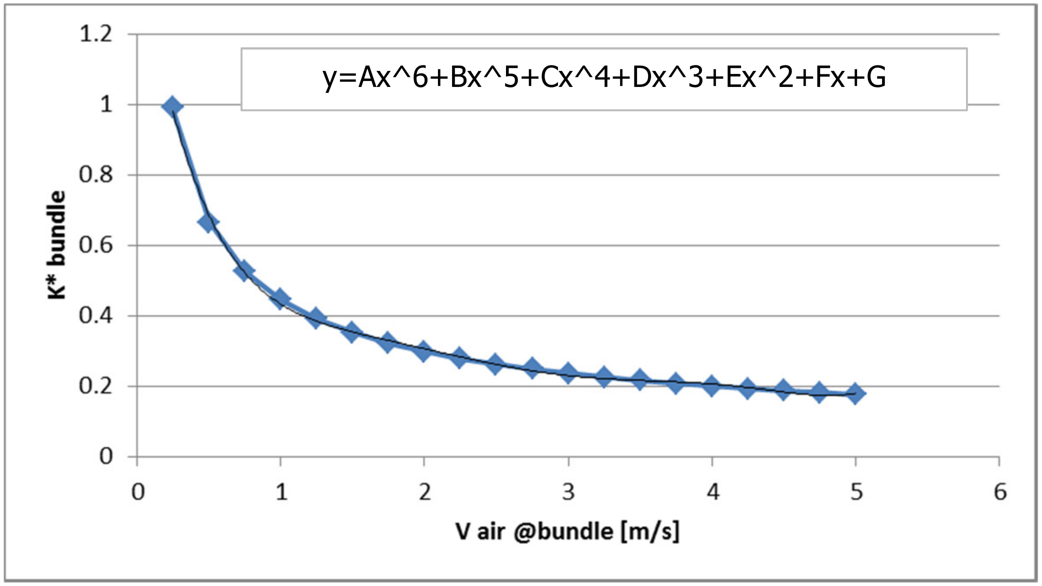
Active elements modelling

- **Condenser bundles** are treated with *radiator* model
  - Radiator is a combined thermal- and pressure-jump interface
  - Pressure-jump is proportional to bundle dynamic head

    → $dp_{bundle} = K_{bundle} \frac{1}{2} \rho V^2$

    → Any different term is adjusted through a variable K_{bundle} coefficient

    - 6° order polynomial to fit available manufacturer data



Active elements modelling

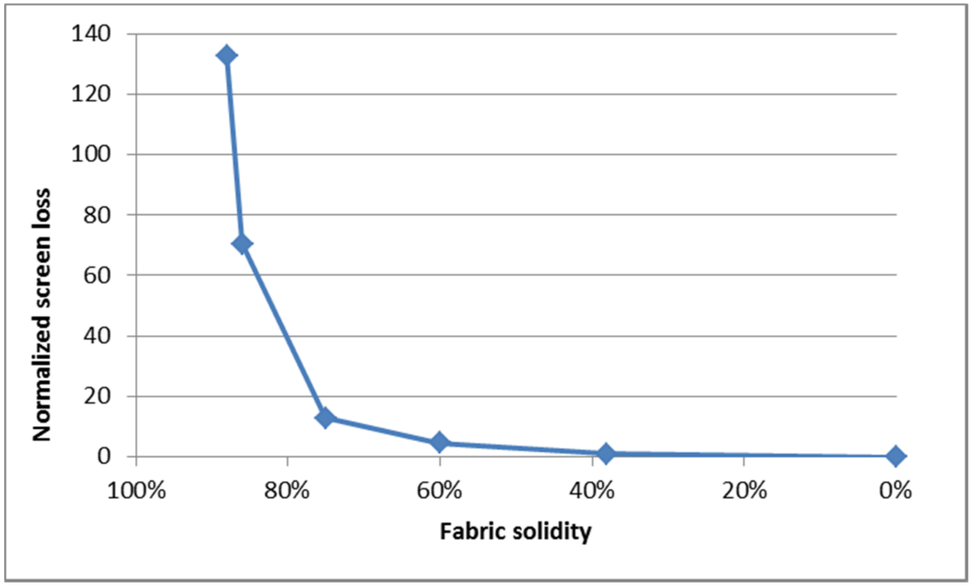
- **Condenser bundles** are treated with *radiator* model
  - Radiator is a combined thermal- and pressure-jump interface
  - Thermal-jump behaviour may be described either by:
    - →Global heat transfer coefficient and reference temperature
    - →Heat Flux
  - Fixed air bundle outlet temperature assigning a virtually infinite heat transfer coefficient and desired reference temperature

Active elements modelling

- **Wind screens** are treated with a *pressure-jump* model
  - Porous screens loss is proportional to local dynamic pressure

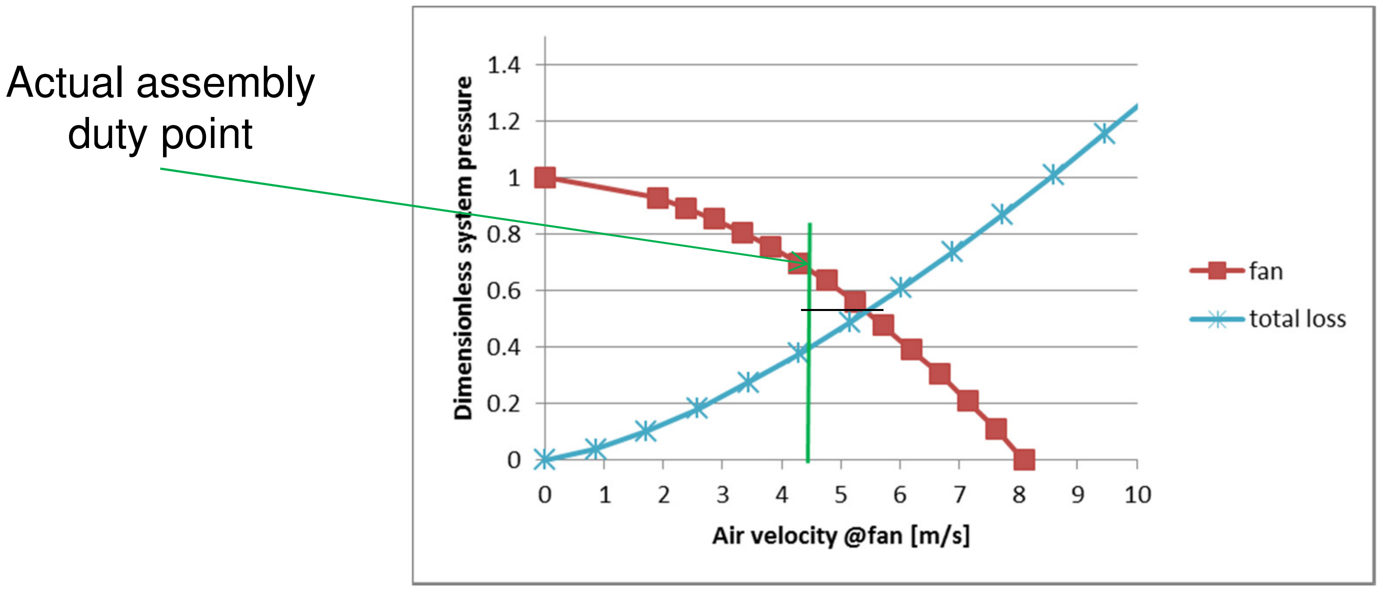
    $\rightarrow dp = K_{screen}\frac{1}{2}\rho U^2$

  - Loss coefficient is function of fabric solidity



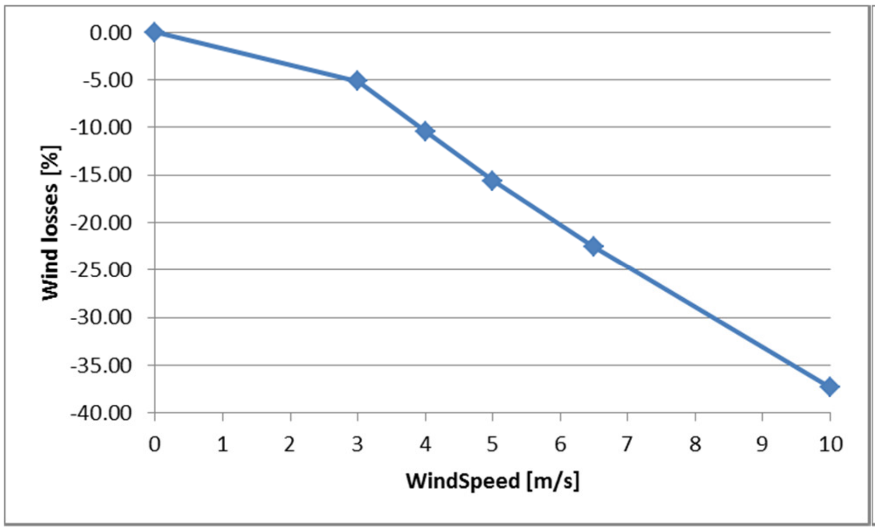
Fan bundle coupling

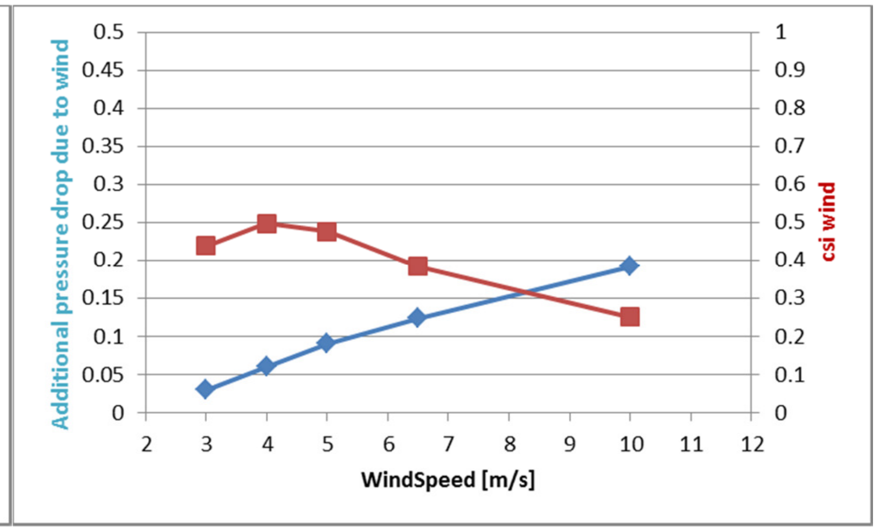
- Validation of correct sub-model implementation checked for isolated single fan configuration
  - 1.6% difference against theoretical duty point
- Global assembly has lower average performance
  - Cross-wind effects increase pressure loss by 15% of the maximum fan pressure rise



Wind speed effects

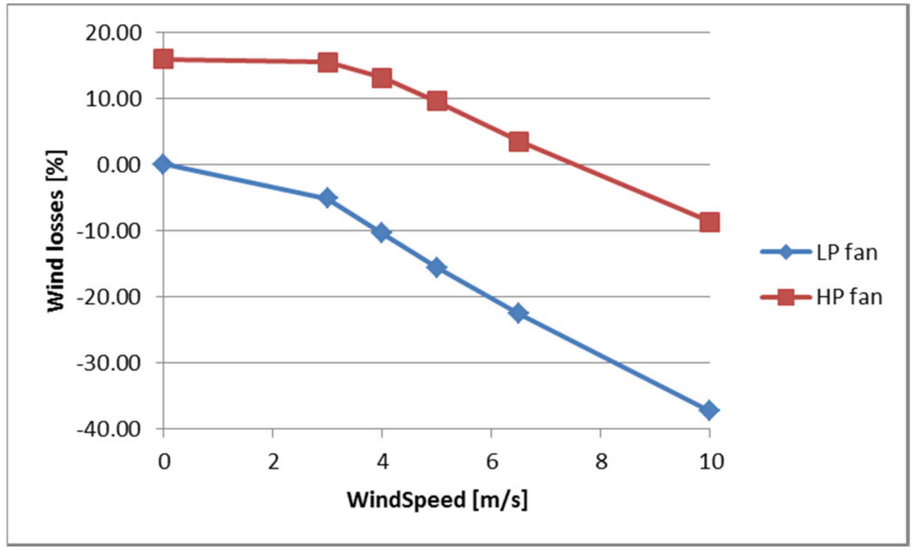
- ACC performance degradate with increasing wind speed
  - Mass flow rate losses are above 35% already at 10m/s wind speed
  - This corresponds to an additional 30% in total pressure resistance
- Wind loss coefficient
  - $\xi_{wind} = \frac{dp_{wind}}{\frac{1}{2}\rho U^2{}_{wind}}$ is comprised between 0.2 and 0.5

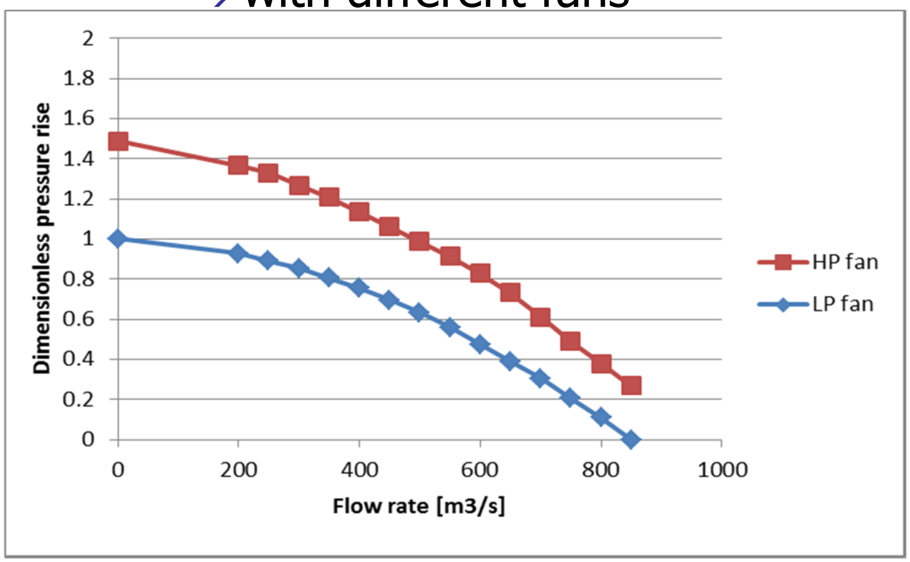


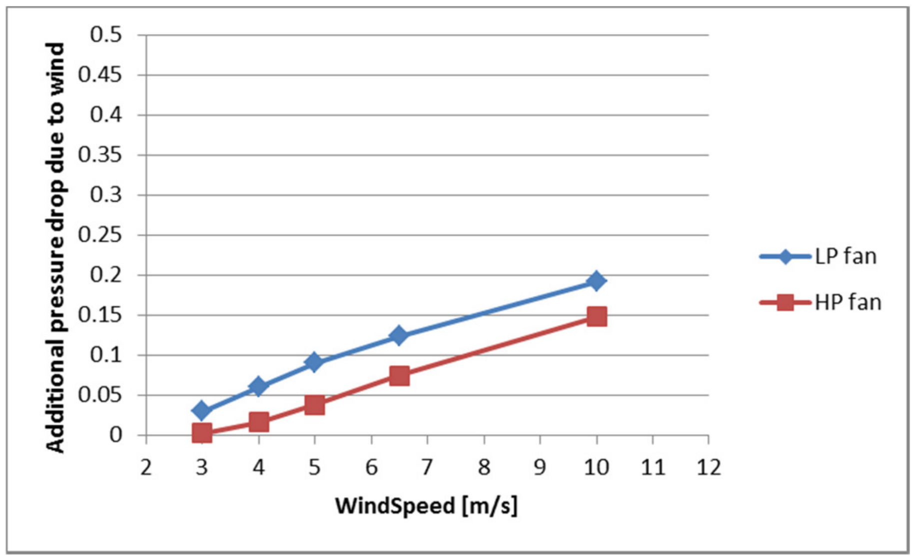


Wind speed effects

- Increasing fan head
  - Wind losses are compensated
  - Additional pressure due to wind follows the same trend
  - Reliable tool to predict potential gains
    - →at other wind speeds
    - →with different fans

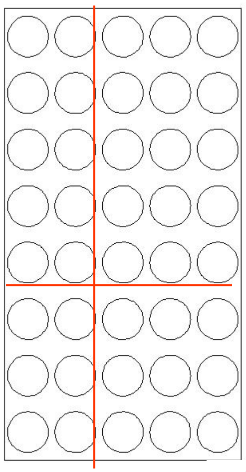






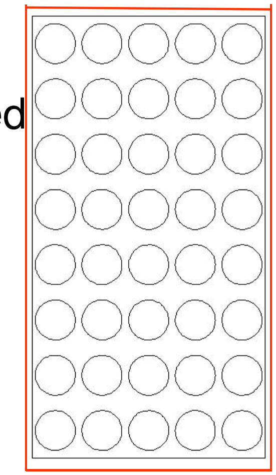
Wind screens

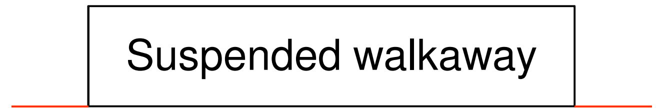
- 11 mitigating devices tested
  - Configurations obtained combining different concepts



Cruciform ground screens

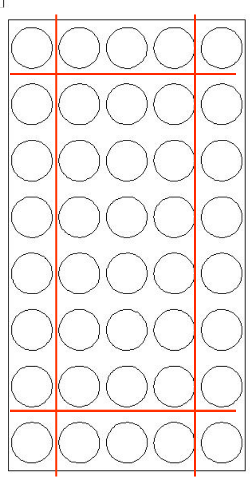
Suspended wrap



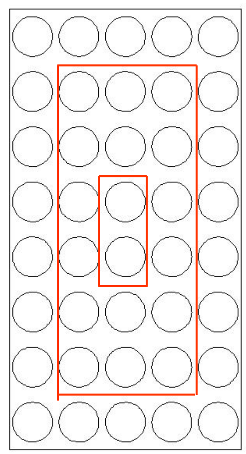


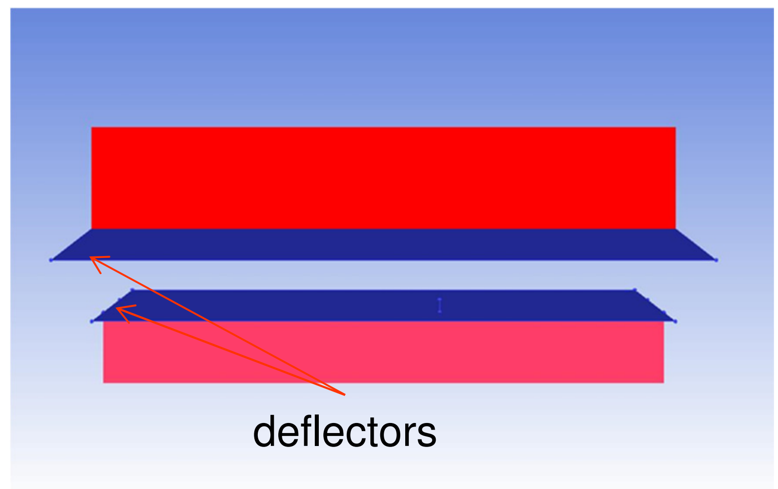
Screens attached on the risers

Double cruciform ground screens



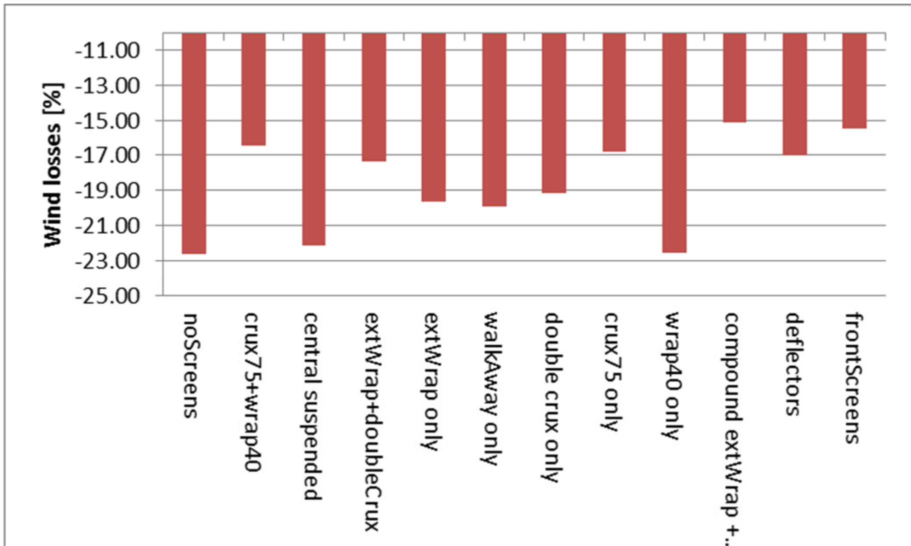
Suspended central

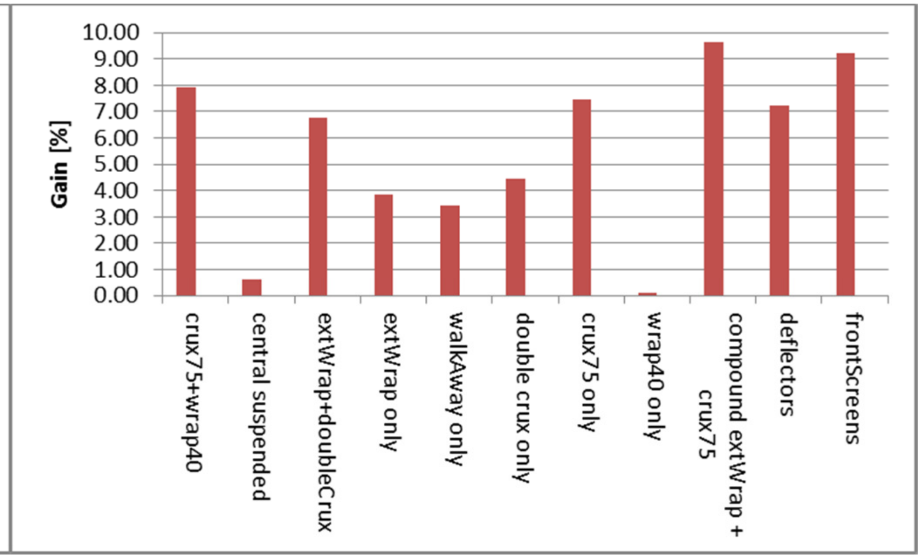




Wind screens

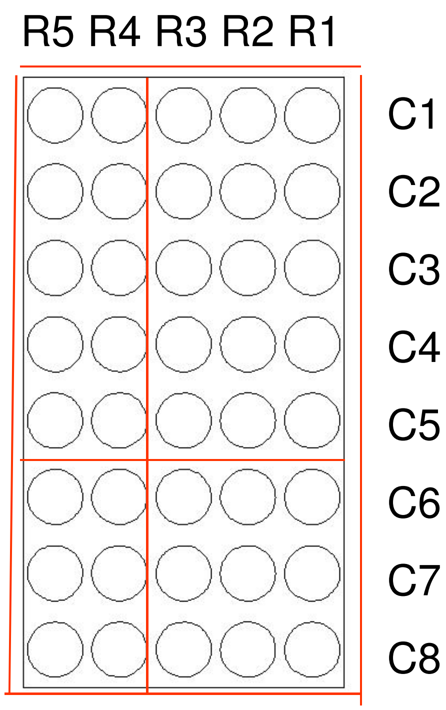
- Optimal configuration scouting
  - Intermediate wind speed of 6.5 m/s
- Wind losses can be reduced up to 15%
- Maximum gain is nearly 10%
  - Achieved with cruciform and external wrap





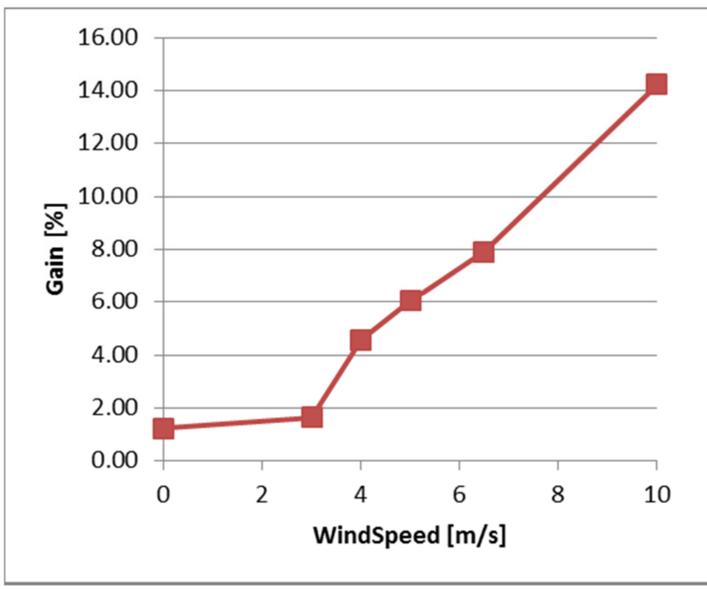
Wind screens

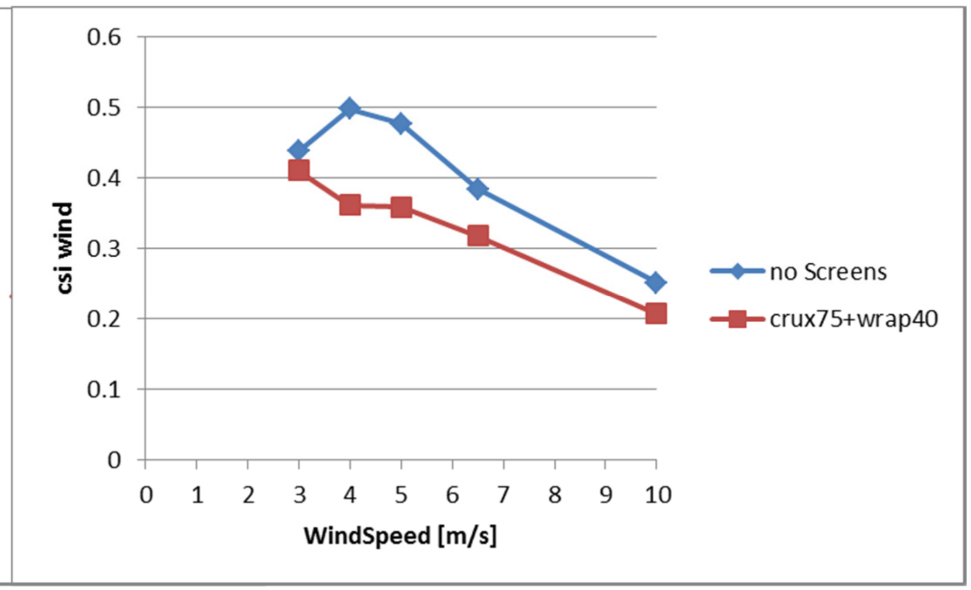
- Optimal configuration
  - Compromize between performance and simplicity (cost)
  - cruciform fabric screen with 70% solidity
  - suspended vertical wrap around ACC walls



Wind screens

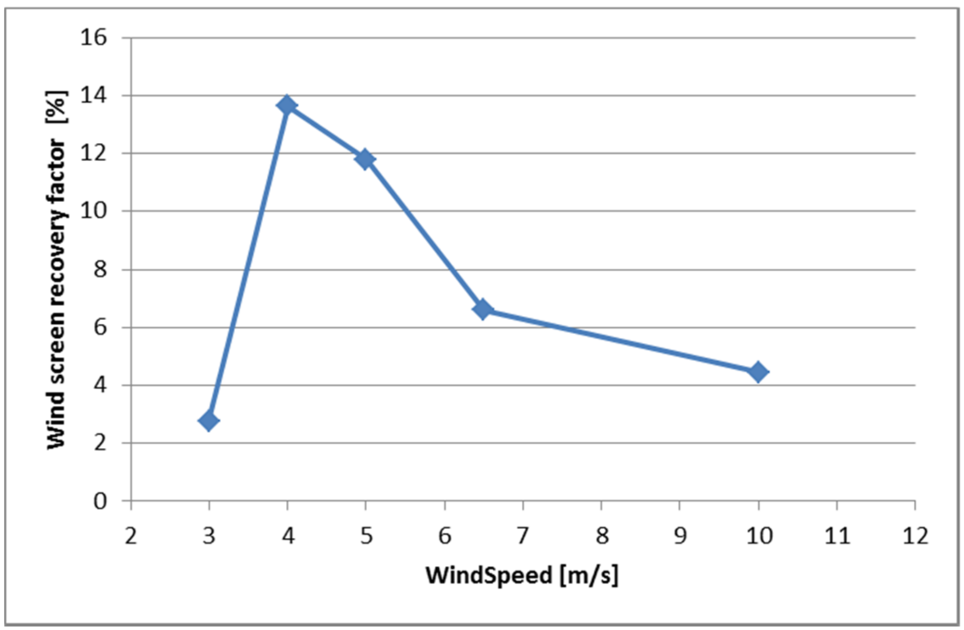
- Gain is proportional to wind speed
  - At 10 m/s it is above 14%
- Wind loss coefficient present a maximum
  - Maximum reduction in wind loss coefficient is at intermediate wind speeds





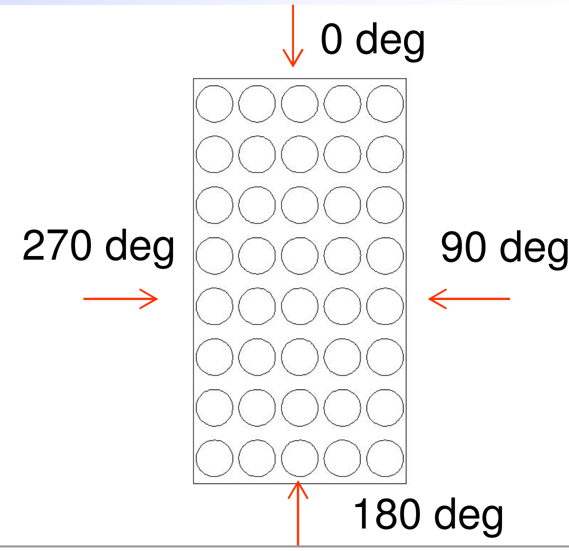
Wind screens

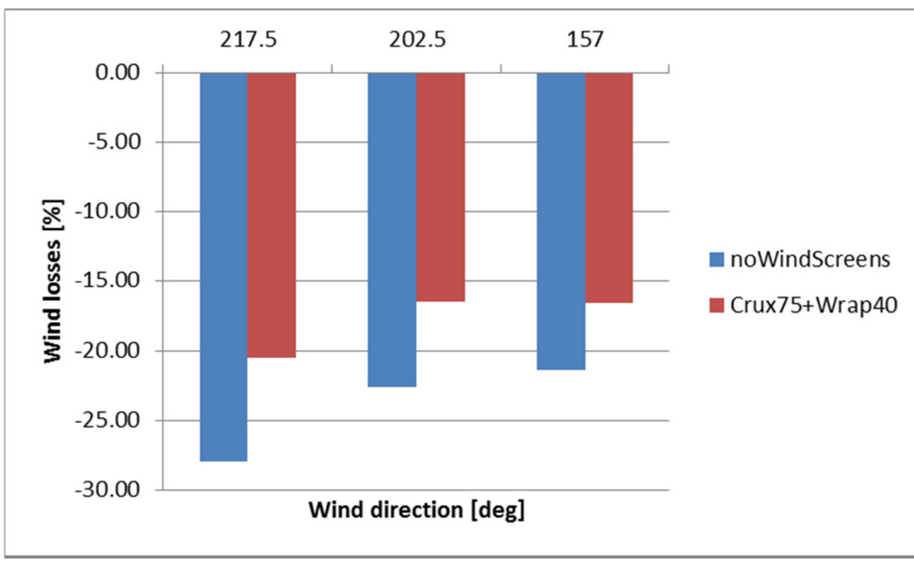
- Wind screen recovery factor
  - Express the pressure recovered by the fan respect to the non-shielded case respect to the dynamic wind pressure
  - Wind screens are mostly efficient at intermediate wind speeds…
    - →But recover more air flow at high wind speed

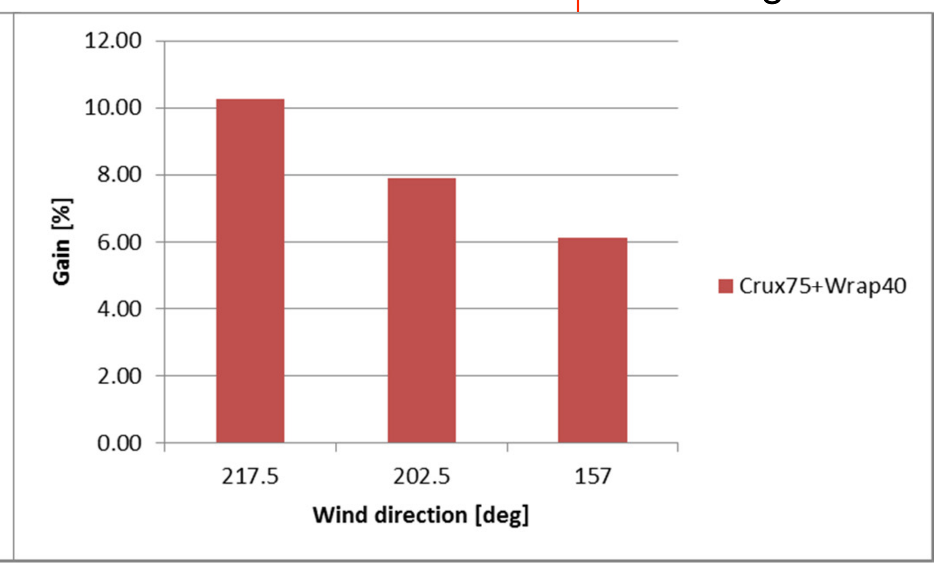


Wind angle effects

- Also the wind direction has an impact on fan flow rate
  - Minimum losses are obtained with wind normal to the condenser streets
  - The gain of the wind screens is at the opposite maximum for larger angle of the wind







Conclusions

- A CFD model was built to investigate possible benefits in reducing wind losses by means of wind screens
  - The model was validated against theoretical data
- Wind screens are capable to mitigate wind losses
  - Gain increases with wind speed (Max 14% at 10 m/s)
  - Wind screen recovery factor starts decreasing at intermediate wind speed
- Actual flow rate depends on wind screens configuration, wind speed and wind direction
  - Extrapolation of results to other conditions may be pursued by means of the wind loss coefficient