Windscreens
A-frame vs V-frame

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Motivation

- V-frame layout is believed to be more resistant to wind detrimental effects than standard A-frame
  - This belief is due to the more protected position of the fan
  - Only few studies about the aerodynamics of V-frame ACCs with significant wind
    - None provides a fair comparison between A-frame and V-frame
- Little is known about the aerodynamic mechanisms generating losses in the V-frame layout
  - Effect of wind on flow rate and recirculation
  - Effect of large assemblies on performance
- The potentiality of wind mitigation devices to further reduce the wind losses are substantially unexplored

Objectives

- Conduct a comparison of the performance of an A-frame and a V-frame layout with nominal capabilities under the same conditions
  - The comparison is performed exploiting CFD methods
- A three fans ACC is selected as a simple but relevant example
  - Verification of fan delivered flow rate and recirculation over the bundles
  - Understanding the loss mechanisms
- Identify wind mitigation devices able to improve the performance of the ACC under high wind conditions
  - Fabric screens with variable porosity were chosen as the most cost-effective mean to mitigate wind detrimental effects
  - Different wind screens layouts were tested for the A-frame and the V-frame

Modelling

- Numerical modelling based on established practice
  - Ansys Fluent v192 CFD code
    - Steady state coupled solver
  - Air as ideal gas
  - Buoyancy forces activated
  - Turbulence model: Standard k-e with buoyancy effects
  - Ad-hoc submodels for the fans and the bundles
  - Power-law wind profile

Modelling

- Ambient conditions:
  - Ambient pressure = 101300 Pa
  - Ambient temperature = 288.15 K
  - Wind direction =
    - Inclined 45° to the ACC axis
    - Conventionally associates this direction with South-West (225 deg from plant north)
  - Wind speeds =
    - 1 m/s (low wind day)
    - 8 m/s (high wind day)

Modelling

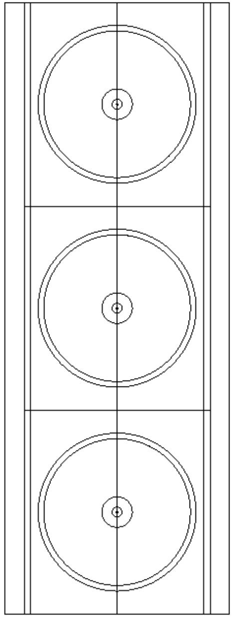
- ACCs nomenclature:
  - Wind is approaching the ACC from fan 3

A-frame

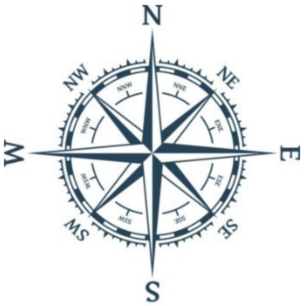
Fan 1

Fan 2

Fan 3



Upstream side **Downstream side**



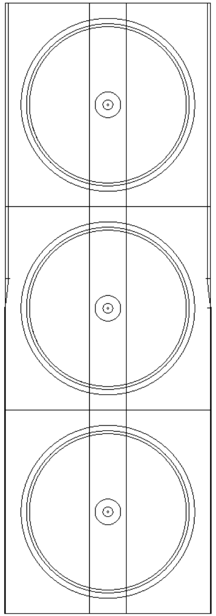
Wind direction
SW (225 deg)

V-frame

Fan 1

Fan 2

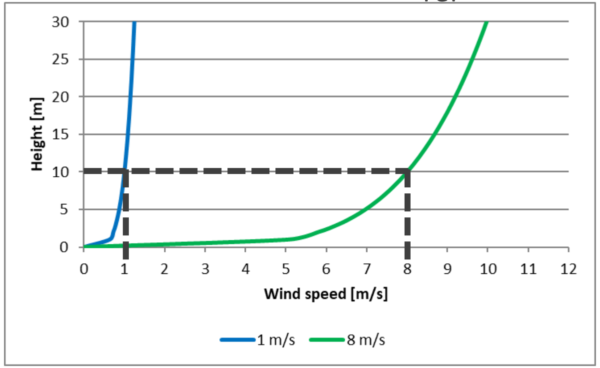
Fan 3



Upstream side **Downstream side**

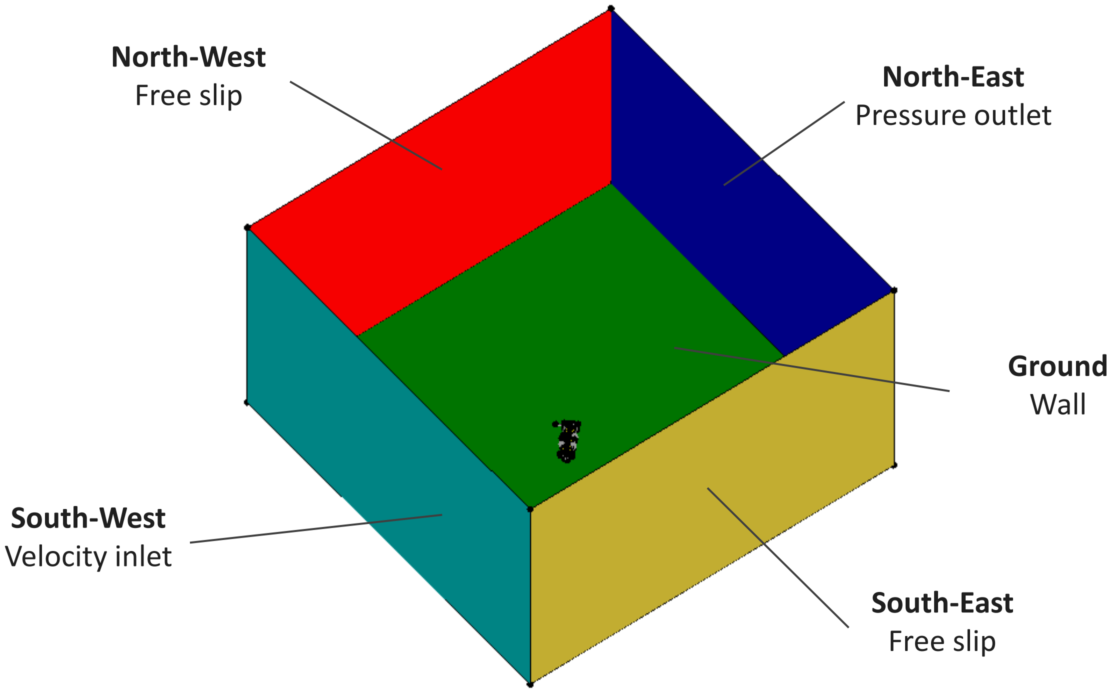
Modelling

- Wind profile:
  - Far field boundary layer: $V(y) = V_{ref} \cdot \left(\frac{y}{H_{ref}}\right)^{a}$ $\begin{cases} V_{ref} \\ H_{ref} \\ a \end{cases}$
  - Power law exponent a is a function of ground roughness and BL stability (and of H_{ref})
    - Irwin 1979 suggests a value of 0.2 for stable BL over rough surfaces (http://www.webmet.com)
  - Reference wind conditions are measured at H_{ref} = 10m (common anemometer height)



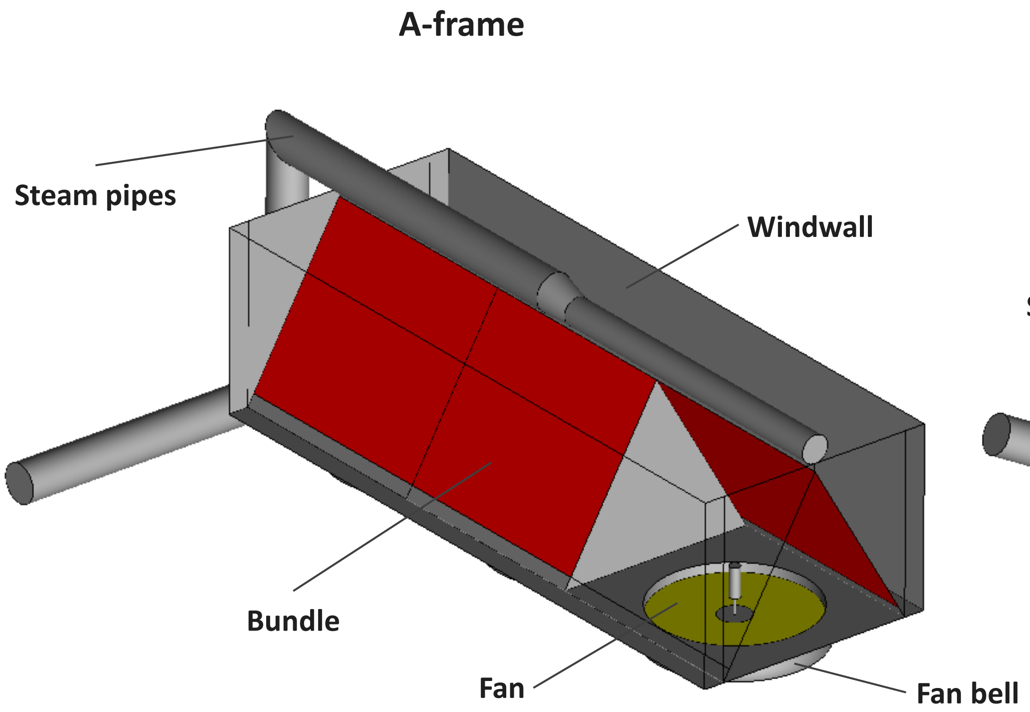
Modelling

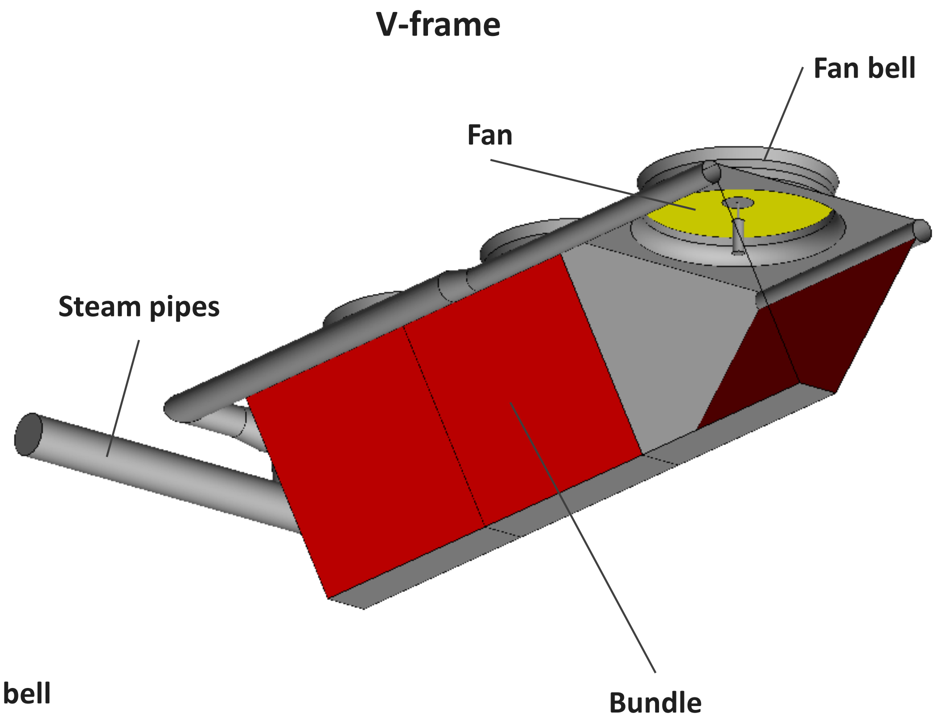
- Domain:
  - Base = 500 x 500 m
  - Height = 300 m



Modelling

- ACCs geometries:

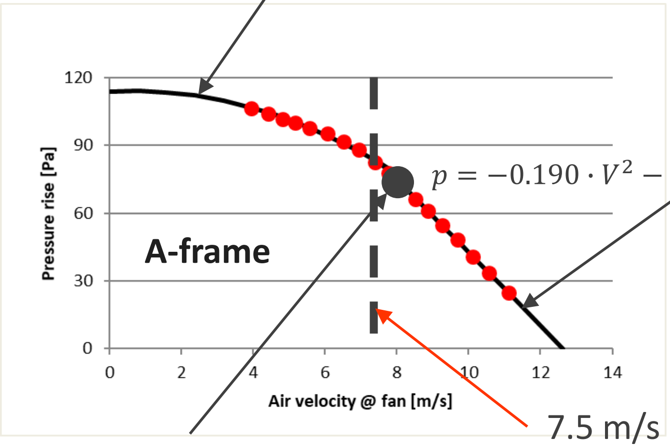




Modelling

- Fan model:
  - Fan model implements a sudden pressure rise (p) as a function of normal velocity (V)
  - Piecewise function implemented in order to extend the range towards low flow rates

$p = -0.708 \cdot V^2 + 1.083 \cdot V + 113.637$

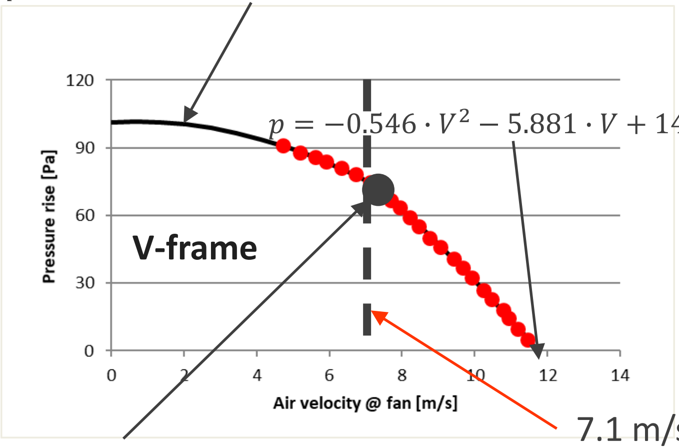


$p = -0.190 \cdot V^2 - 12.154 \cdot V + 183.542$

7.5 m/s

Duty point:
Flow rate = 501.3 m^3/s
Pressure rise = 74.3 Pa

$p = -0.653 \cdot V^2 + 0.914 \cdot V + 101.167$



$p = -0.546 \cdot V^2 - 5.881 \cdot V + 144.338$

7.1 m/s

Duty point:
Flow rate = 537.4 m^3/s
Pressure rise = 71.0 Pa

Modelling

- Bundle model:
  - Pressure drop at bundle (k) is set by a pressure drop coefficient

$$k = \frac{K_1 \cdot V^{(K_2-2)}}{\frac{1}{2}\rho}$$

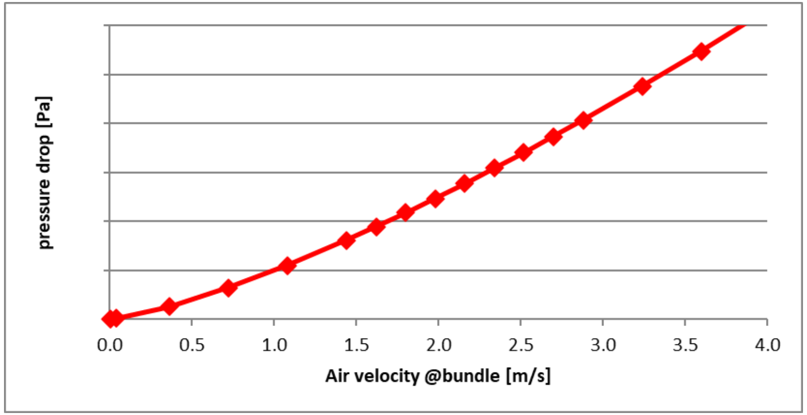
– Where:

» K_1 and K_2 = coefficients

» Δp = pressure drop

» ρ = air density

» V = air velocity @bundle

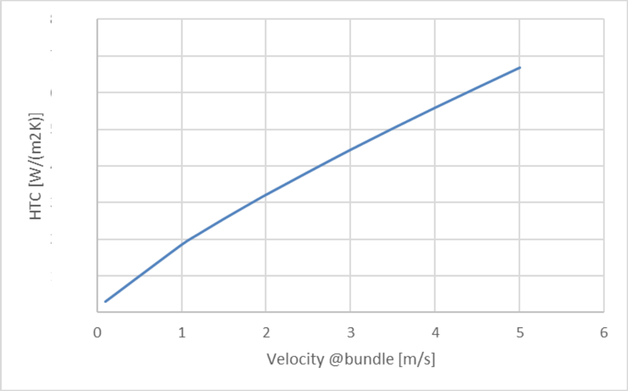


Modelling

- Bundle model:
  - Thermal behavior is modelled by setting:
    - The Heat Transfer Coefficient (HTC)

$$HTC = HTC_{des} \cdot \left(\frac{V_b}{V_{b\_des}}\right)^{0.8}$$

$$HTC_{des} = \frac{\dot{Q}}{(T_{steam} - T_{amb}) \cdot A_{bundle}}$$



» Where

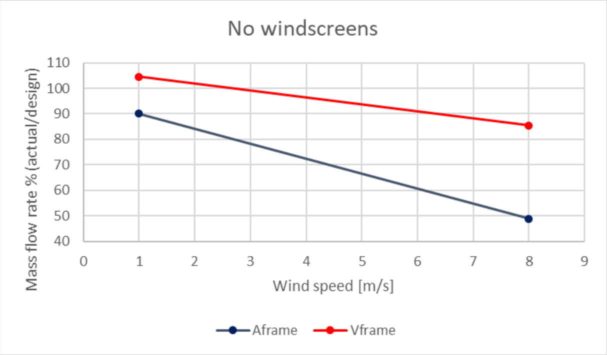
- $\dot{Q}$ = Thermal power
- T_{steam} = Steam temperature = 323.15 K
- T_{amb} = Ambient temperature = 288.15 K
- A_{bundle} = Bundle surface

    - The Reference temperature (T_{ref})

» $T_{ref} = T_{steam}$ = 323.15 K

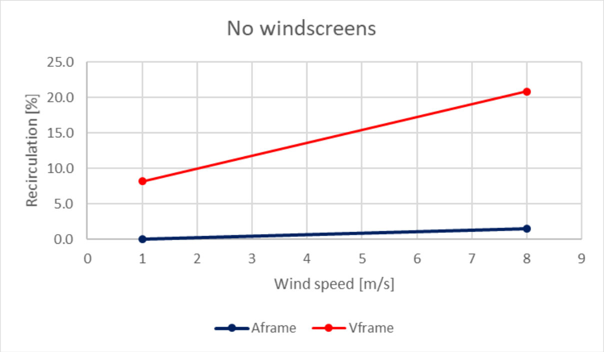
Results without windscreens

- No screen configuration:
  - V-frame flow rate is less affected by wind effects than A-frame
    - It is also characterized by higher flow rates at low wind speed
  - A-frame is practically not subjected to recirculation issues
    - V-frame is prone to recirculation already at low wind speed and achieve values above 20% at 8 m/s



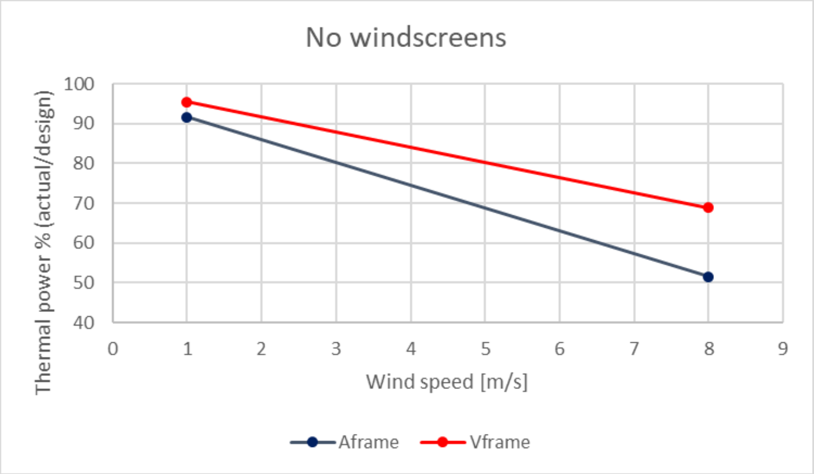
$$R_{A/forced} = \frac{(T_{fan} - T_{ambient})}{(T_{bundle\_outlet} - T_{ambient})}$$

$$R_{V/induced} = \frac{(T_{bundle\_inlet} - T_{ambient})}{(T_{fan} - T_{ambient})}$$



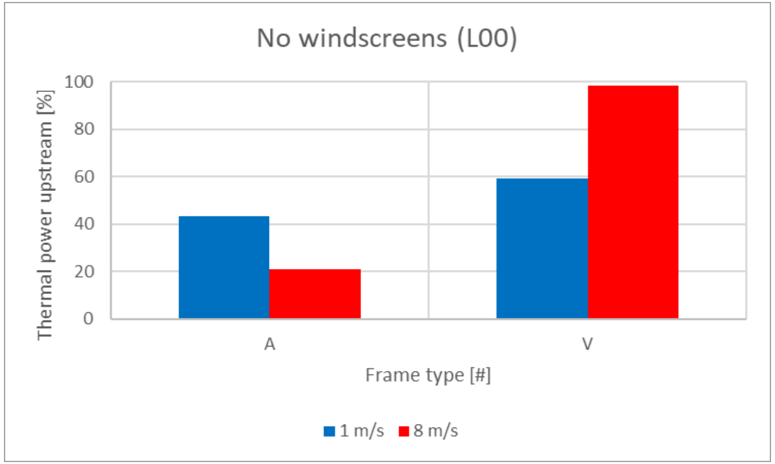
Results without windscreens

- No screen configuration:
  - In total V-frame is providing a higher level of cooling than the A-frame
    - At low wind speed the values are comparable
    - At high wind speed the improvement is nearly 20%



Results without windscreens

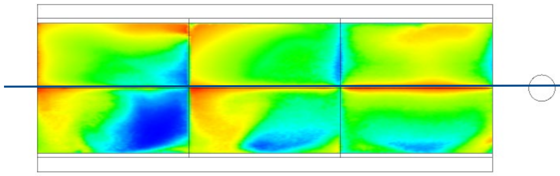
- Thermal power upstream (percentage of the total):
  - At low wind speed the thermal power is exchanged almost equally in upstream and downstream bundle
    - A frame promote exchange on the downstream bundle, V frame on the upstream one
  - At high wind speed the thermal power exchange is largely unbalanced
    - Only 20% of the total power is exchanged on upstream bundle for the A frame
      - This further reduces to 5% for the downstream bundle for the V frame



Results without windscreens

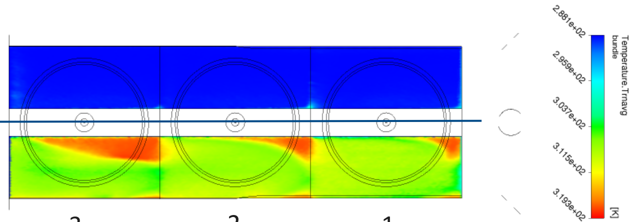
- Focus on no-screen configuration @8m/s WS:

Temperature



upstream

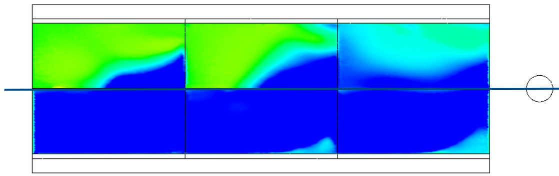
downstream



Wind direction

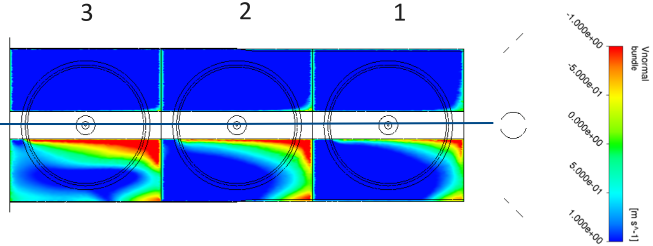
A-frame

V-frame



upstream

downstream



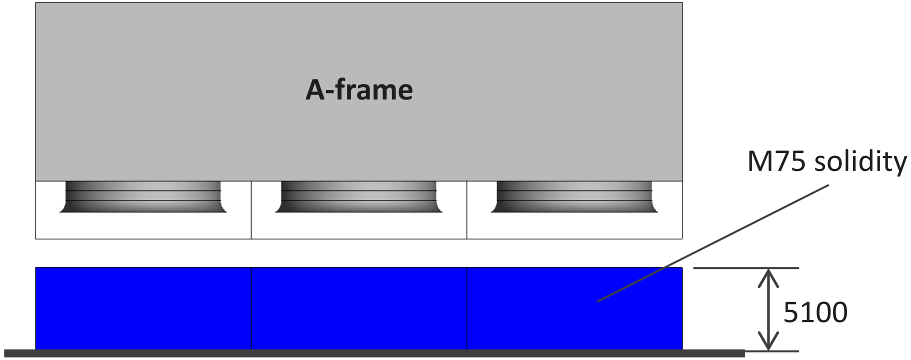
Velocity normal to the bundle negative (red) means backflow

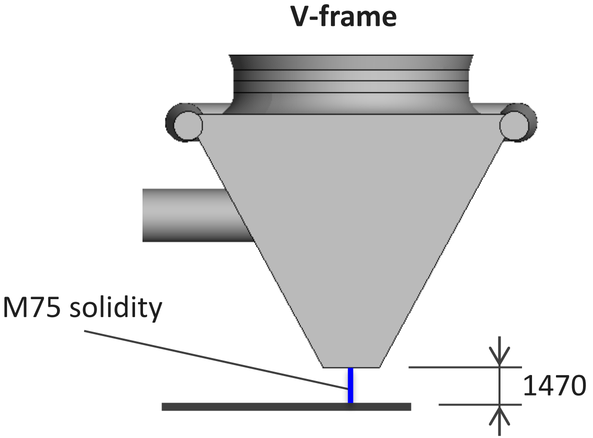
Analyzed configurations

- Windscreens layouts:

A-frame	
L00	No windscreens
L01	**Ground based**
L02	Perimeter

V-frame			
L00	No windscreens	L04	Horizontal
L01	**Ground based**	L05	Vertical
L02	Perimeter	L04+L05	
L03	Internal	L04 + L05 solid	





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A-frame	
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L02	**Perimeter**

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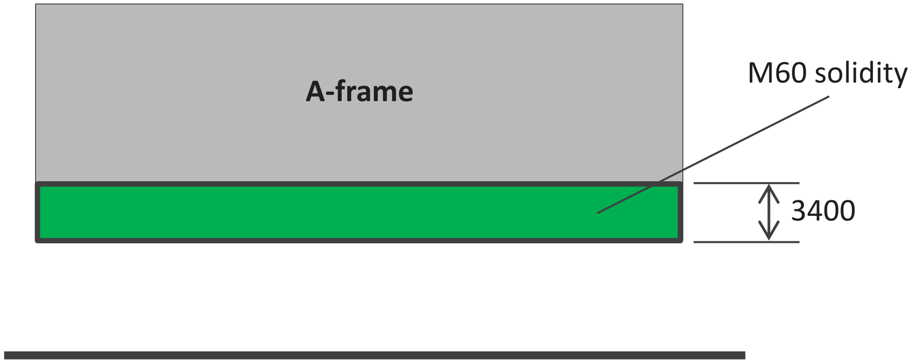
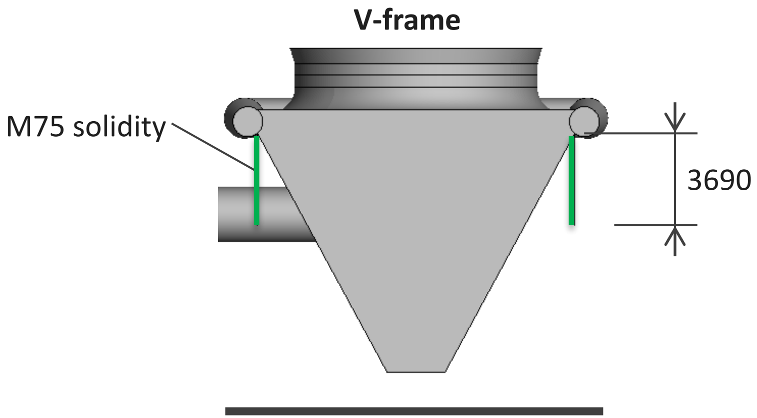
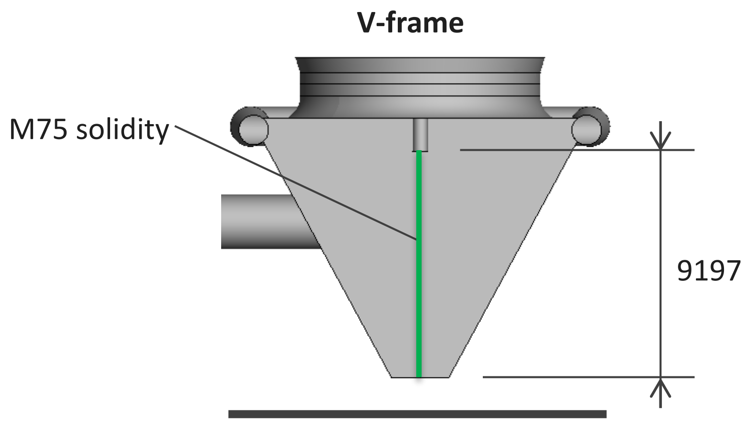


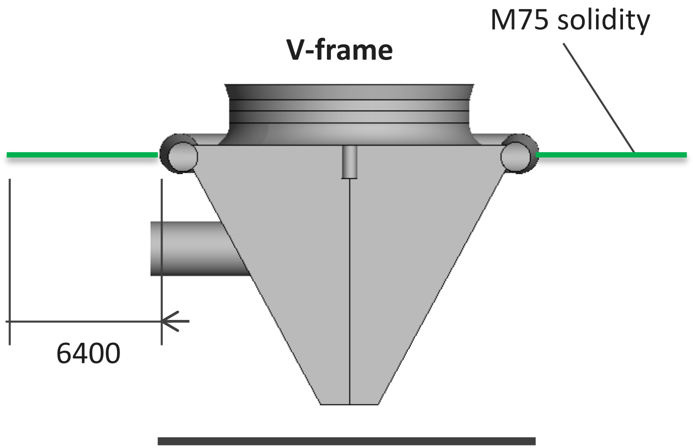


Analyzed configurations

- Windscreens layouts:

V-frame			
L00	No windscreens	**L04**	**Horizontal**
L01	Ground based	L05	Vertical
L02	Perimeter	L04+L05	
L03	**Internal**	L04 + L05 solid	





Analyzed configurations

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V-frame			
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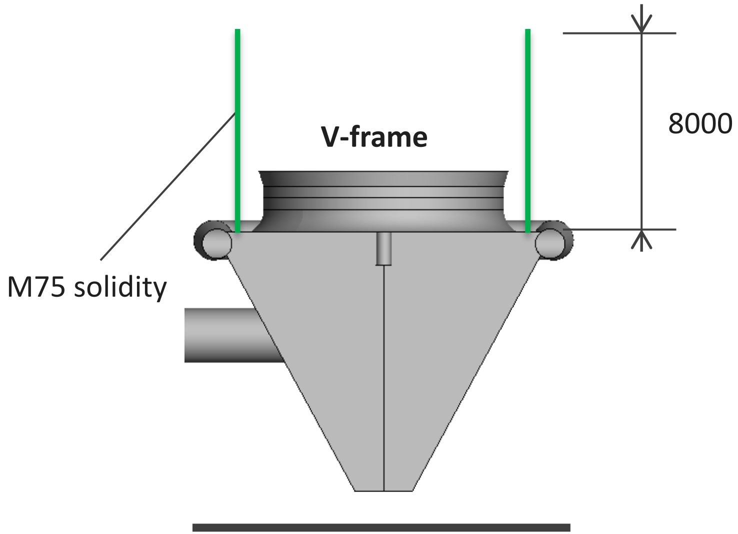
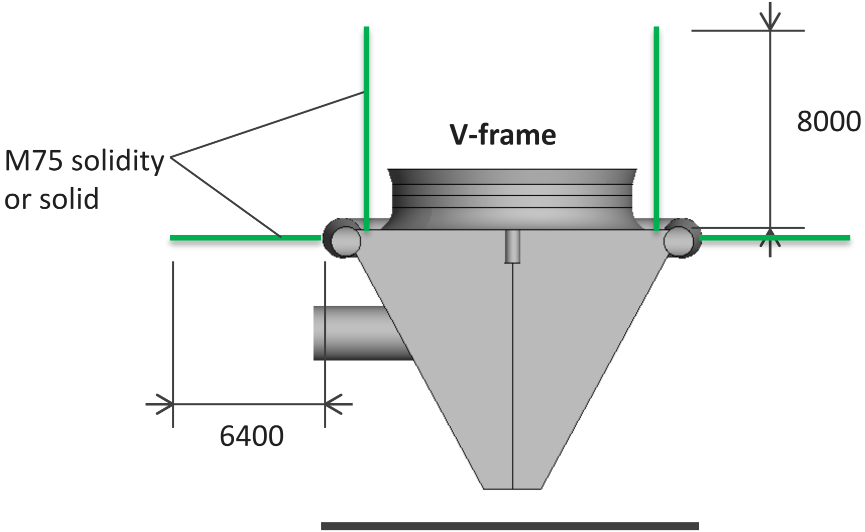
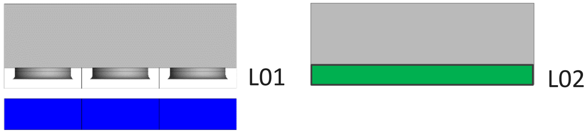
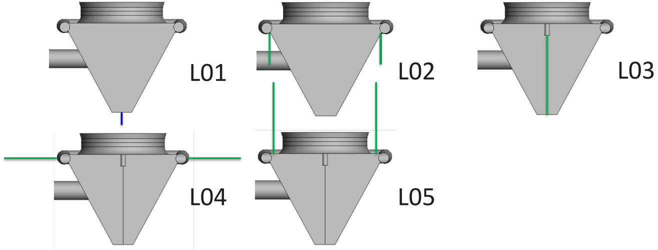
L01	Ground based	**L05**	**Vertical**
L02	Perimeter	**L04+L05**	
L03	Internal	**L04 + L05 solid**	



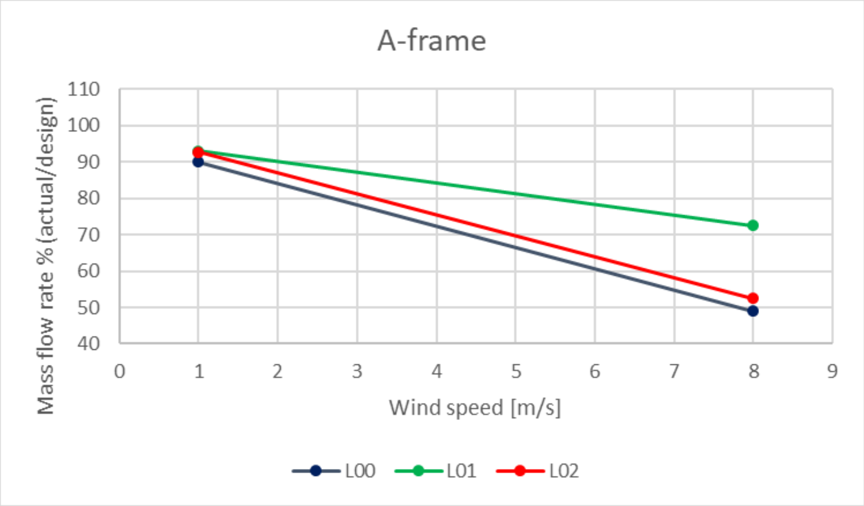


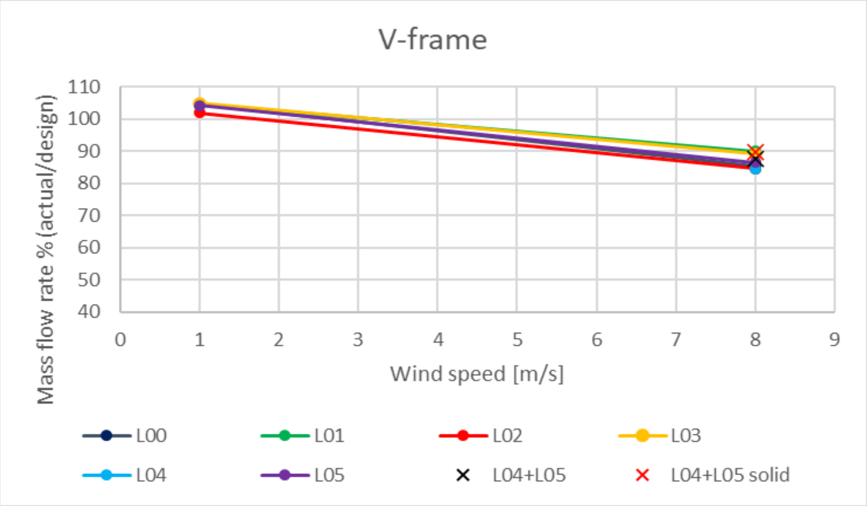


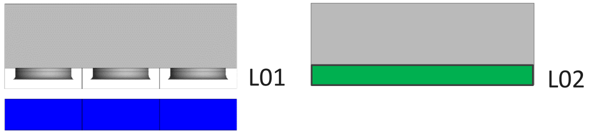
Results



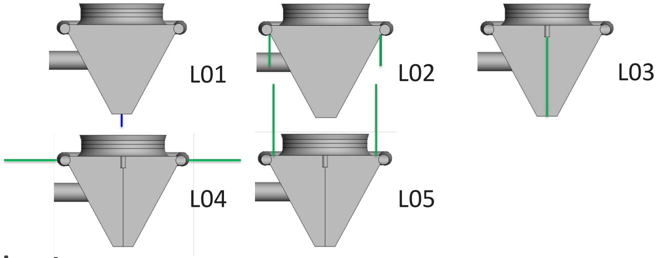
- Mass flow rate:
  - Ground based screens (L01) shows the highest flow rate for both the frame types
    - For the V-frame the improvements are minor
    - For the A-frame an effectiveness of nearly 60% is achieved



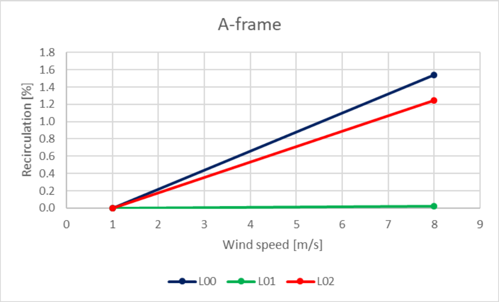




Results



- Recirculation:
  - For the A-frame, L01 substantially eliminate the recirculation
  - For the V-frame, tested layouts are not effective in reducing the recirculation



$$R_{A/forced} = \frac{(T_{fan} - T_{ambient})}{(T_{bundle\_outlet} - T_{ambient})}$$

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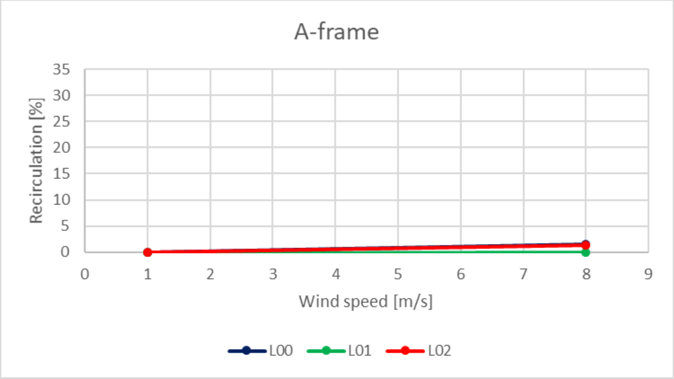
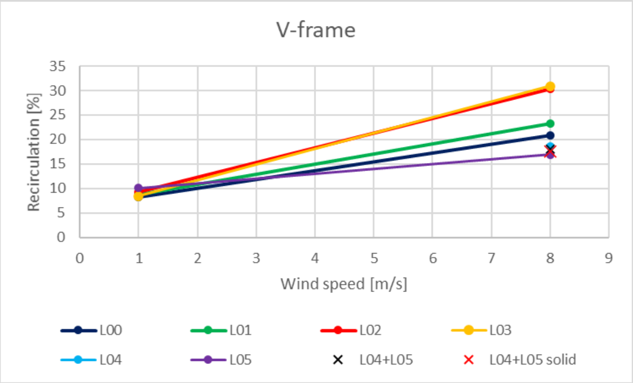
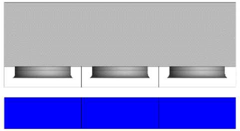


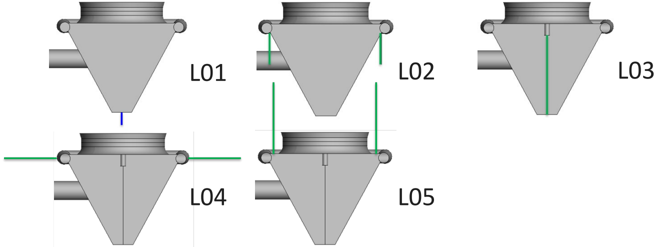




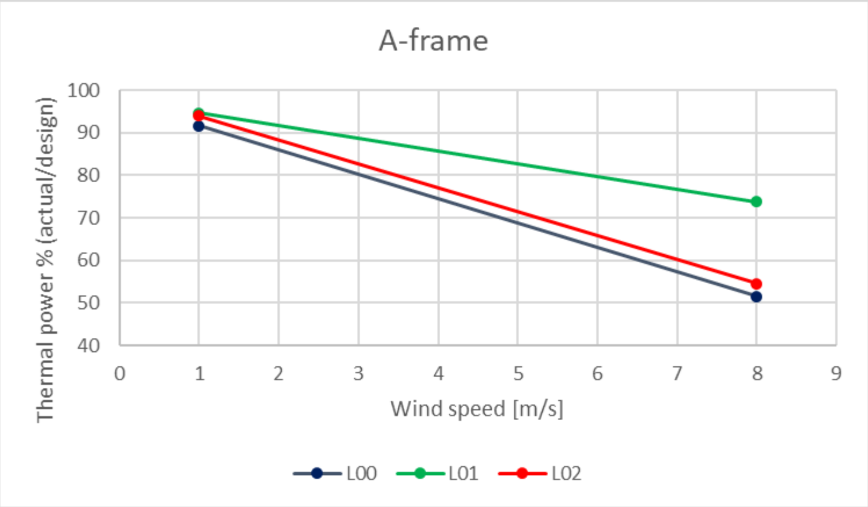
L01

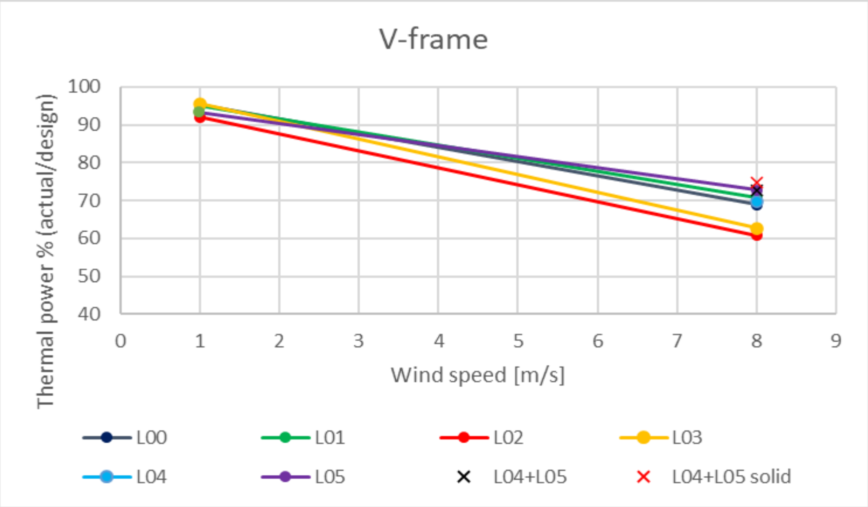
L02

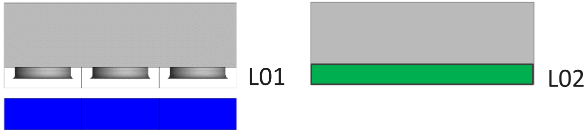
Results



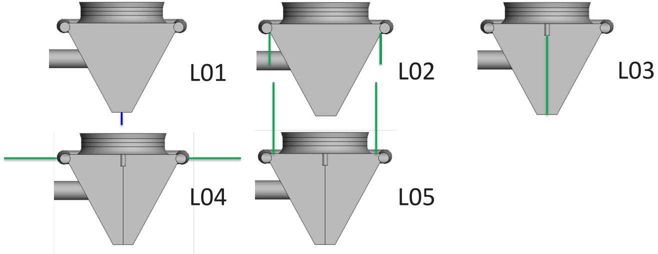
- Thermal power:
  - Best layout (highest thermal power): L01 for the A-frame, L04+L05 for the V-frame
    - A-frame: gain respect to L00 is 22% of the nominal thermal duty
    - V-frame: gain respect to L00 is 6% of the nominal thermal duty



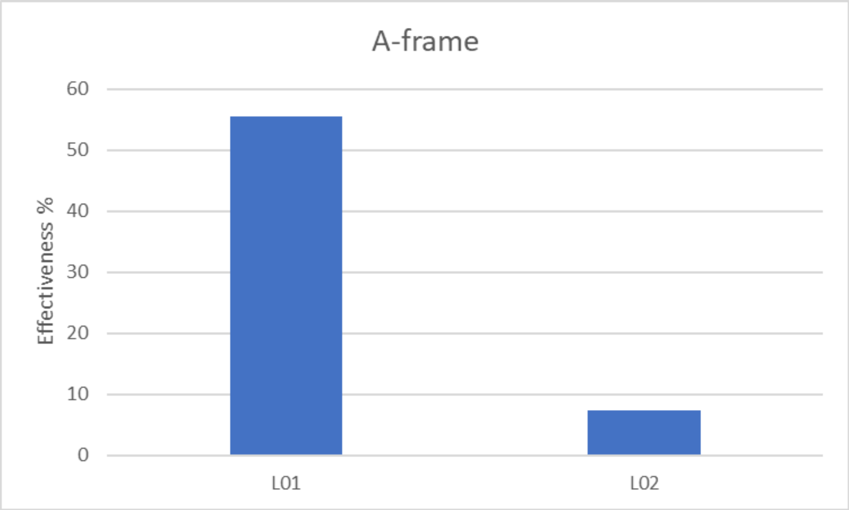


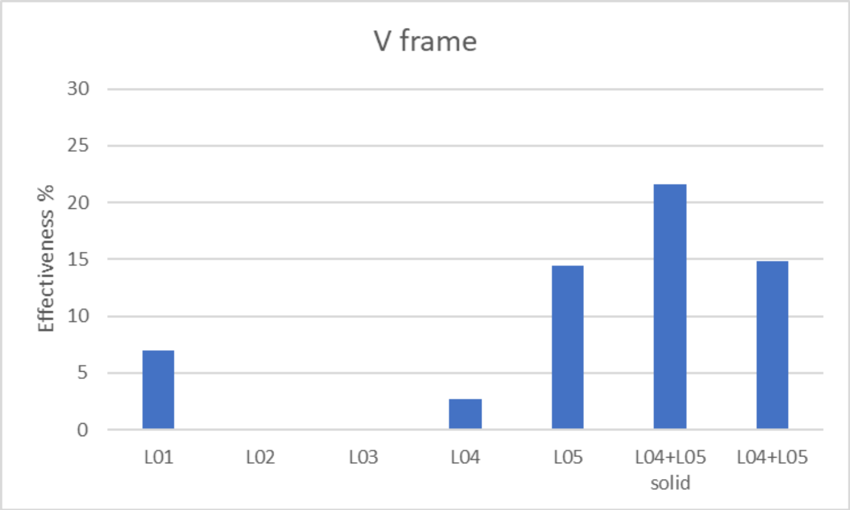


Results



- Windscreen effectiveness:
  - Percentage measure of the reduction of losses due to wind
    - For the A-frame (L01) an effectiveness of nearly 60% is achieved
    - For the V-frame (L04+L05) effectiveness is above 20%





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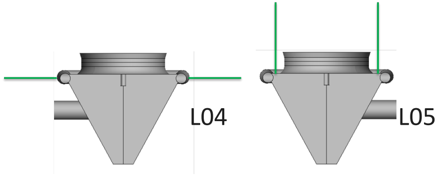
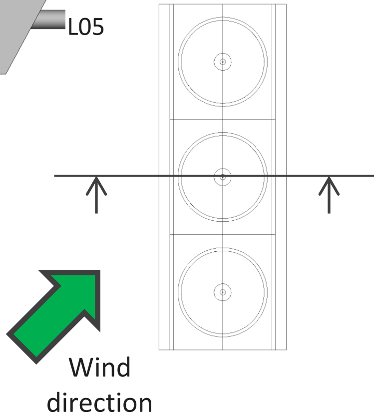
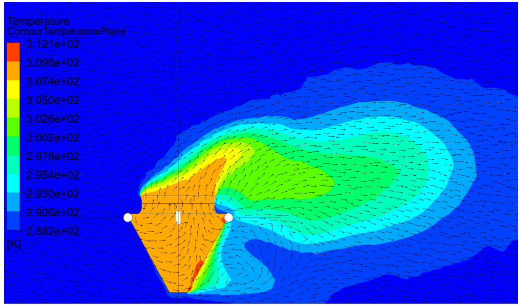




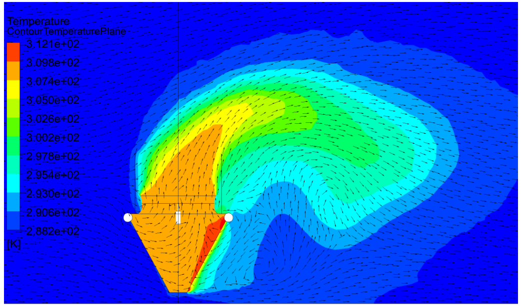
- Temperature @8 m/s:

V-frame

L04

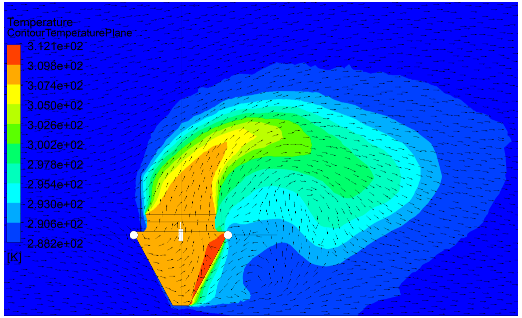


L05

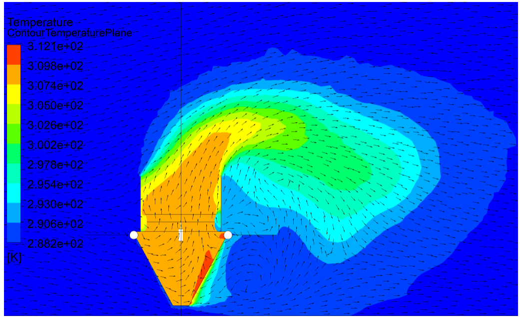


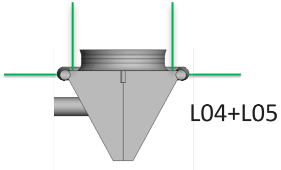
V-frame

L04 + L05



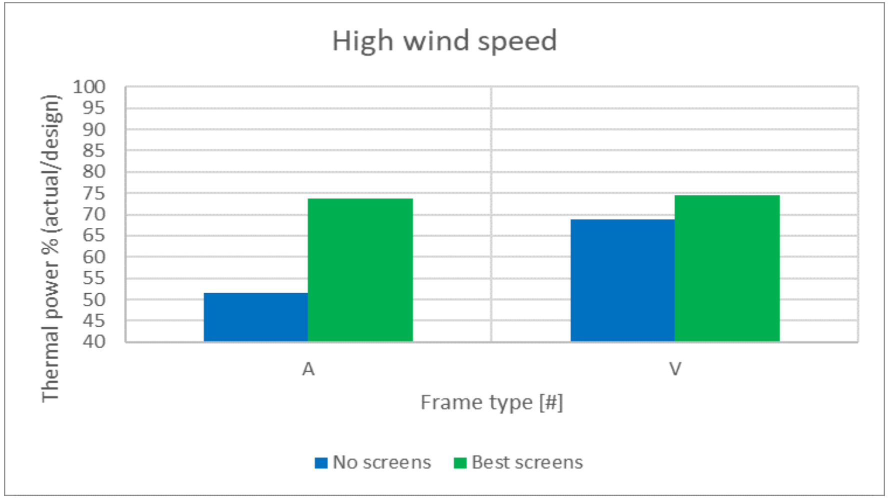
L04 + L05 solid





Results summary

- At high wind speed
  - Without screens (L00), V-frame exchange 6.4 MW (33.6%) more than A frame
  - With screens (best layout), V-frame exchange 0.3 MW (1.1%) more than A frame



Conclusions

- An analysis to compare the thermal performance of a small ACC between the A-frame and V-frame concept was completed
  - Chosen ACC is 3 cell in single street arrangement
  - The investigation was conducted by means of CFD
- The study was focused on quantifying the resistance to wind of the two layouts
  - The capability of windscreen to increment the resistance to wind was also investigated
  - Optimal wind screen layout was identified for both the two layouts

Conclusions

Comparison of A-frame vs V-frame layouts

- At low wind speed the two frameworks work similarly
  - Performance are above 90% of nominal thermal power in both cases
    - Under the given conditions, V-frame is better performing by nearly 5%
  - A-frame favors the downstream bundle while V-frame favors the upstream
    - The split is close to 60-40% in both cases
- At high wind speed (8 m/s) performance drops significantly
  - Performance reduction is higher for the A-frame (40% of losses due to wind)
  - V-frame wind losses (25%) are mostly due to recirculation
- The advantages in a multi-street layout should be confirmed by dedicated analysis

Conclusions

Windscreen design

- Windscreens are:
  - Capable of improving the performance for both frameworks
    - For the A-frame, ground-based screens recovers nearly 60% of the wind losses
    - For the V-frame, top mounted screens (horizontal + vertical) recovers 22% of the wind losses
  - Capable of recovering the same level of performance for the V-frame and A-frame