Deficiency reduction after installation of optimized wind screen configuration

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Ergon Research
Via Campani 50 Firenze

Outline

- Introduction
  - Plant description
  - Motivations
  - Objectives
- CFD modelling
- Preliminary sensitivities
- Results of optimization
- Validation against field data

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Introduction

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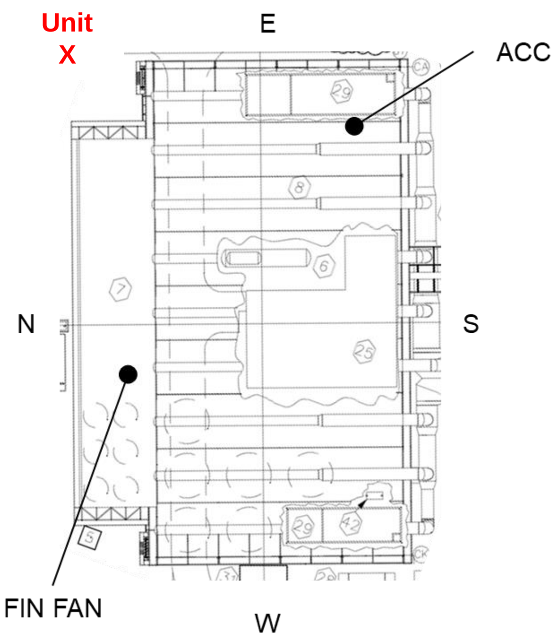
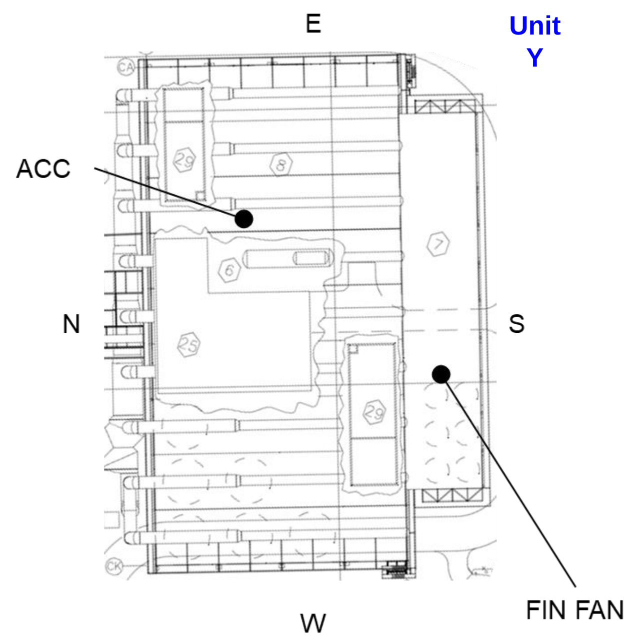
Plant description

- Two identical 800 MW CC units (Unit X & Y)
  - MHI 501G GT's (2 per unit)
  - MHI ST
    - → 300 MW nominal rating
  - Deltak HRSGs
  - Hamon ACC

ACC description

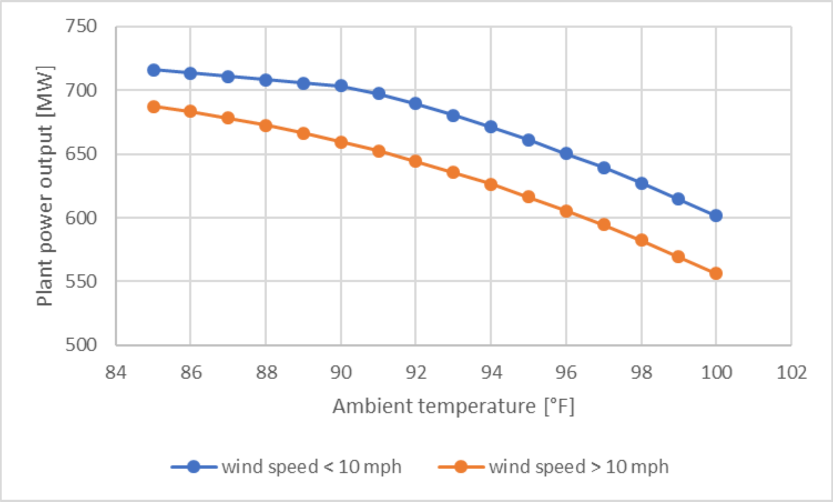
- ACC configuration is:
  - 9 streets x 4 cells per street
  - Streets 2-6 are all VSD fans.
  - Streets 1,7,8,9 are each equipped with one VSD and 3 fixed speed fans
  - Fin fan cooler attached on the external side
  - On the opposite side the turbine building is positioned quite close to the ACC

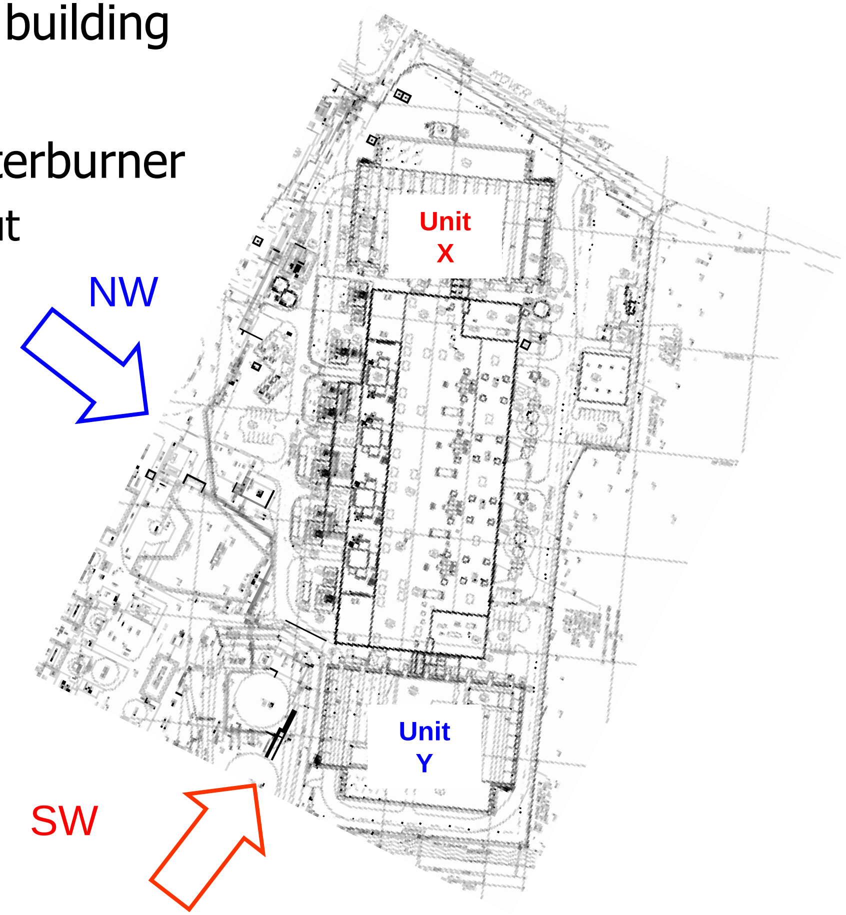




Motivations

- Both unit X and Y ACC's are affected by winds during summer operation
  - Unit X is affected by SW winds, which is the prevalent wind direction in the summer
  - Unit Y is affected by NW winds, which occur much less frequently on hot summer days
- Driving effect is the blockage of the turbine building
- Deficiencies in ACC require not using the afterburner
  - Sensible reduction (≈-50MW) in power output





Motivations

- In 2014 wind screens were installed to mitigate such effect
  - Screens were installed on Unit X only
  - Suspended windscreens:
    - → On the turbine buildings side
    - → On the west side

  - Unit performance from summer 2013 was compared to summer 2015
  - Comparisons based on similar ambient temperature, RH, wind speed and direction, and back pressure showed that:
    - → The units produce additional 15-20 MW with the wind screens in place (30% loss recovery)
    - → The screens appear most effective for wind speeds up to 20 mph
    - → The screens are less effective for winds exceeding 20 mph, but these don’t occur often

Objectives

- Analize alternative wind screen layouts to choose an optimum
  - Depending on the specific objective different optimal solutions may be identified

- The real objective was agreed to be:
  - Minimize the derating on the downstream unit
    - →Limit the afterburner shutdown
  - Main focus is on Unit X with SW winds
    - →Most frequent scenario in summer

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CFD Modelling

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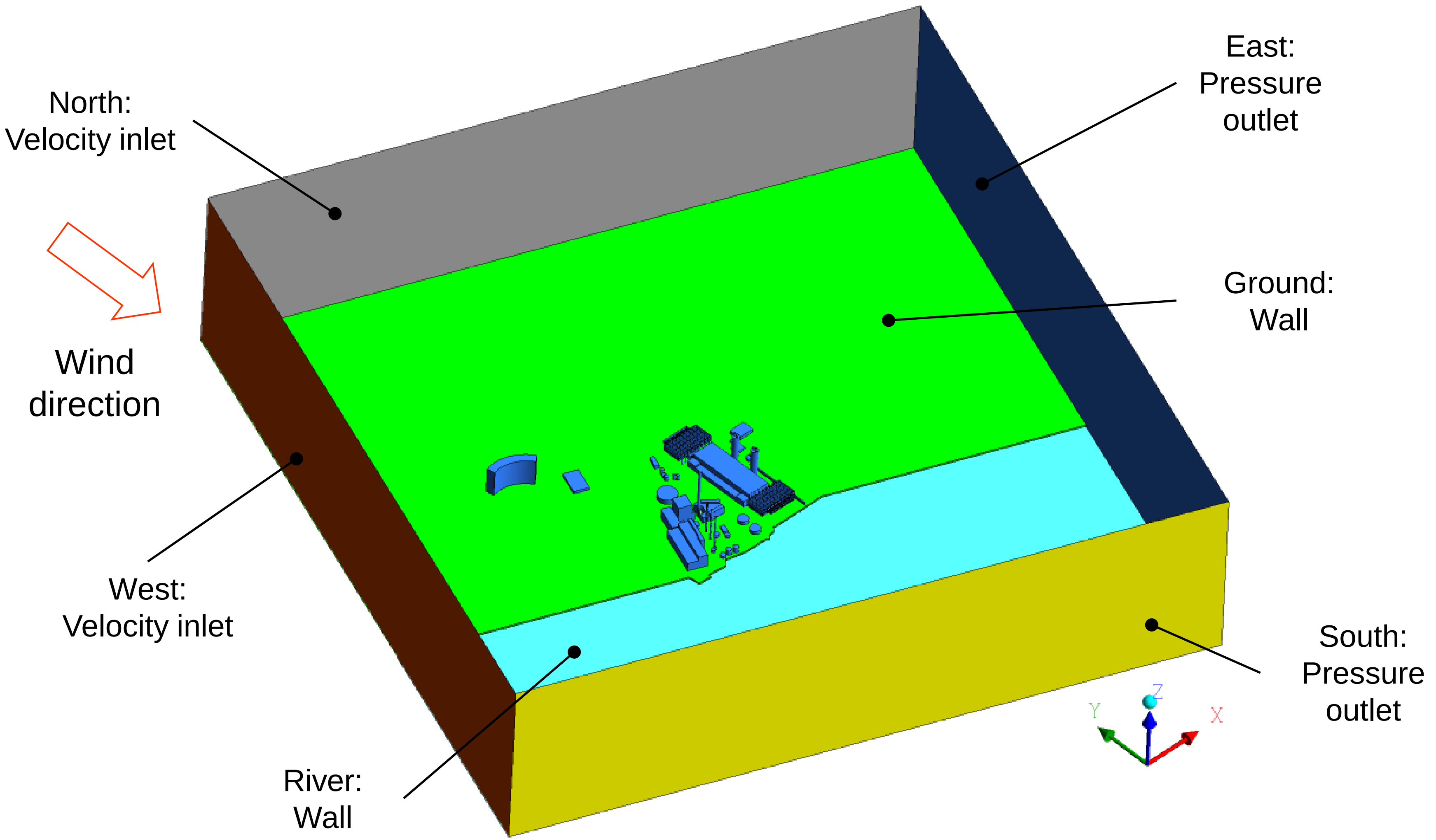
CFD modelling

- Steady-state analysis
- Ideal gas modelling
- Buoyancy effects
- Turbulence modelling is a modified k-epsilon to account for buoyancy effects
- Pressure-jump sub-models to treat fans and bundles
- Plant layout directly reconstructed in the model
- Large domain to avoid interaction with prescribed boundary conditions

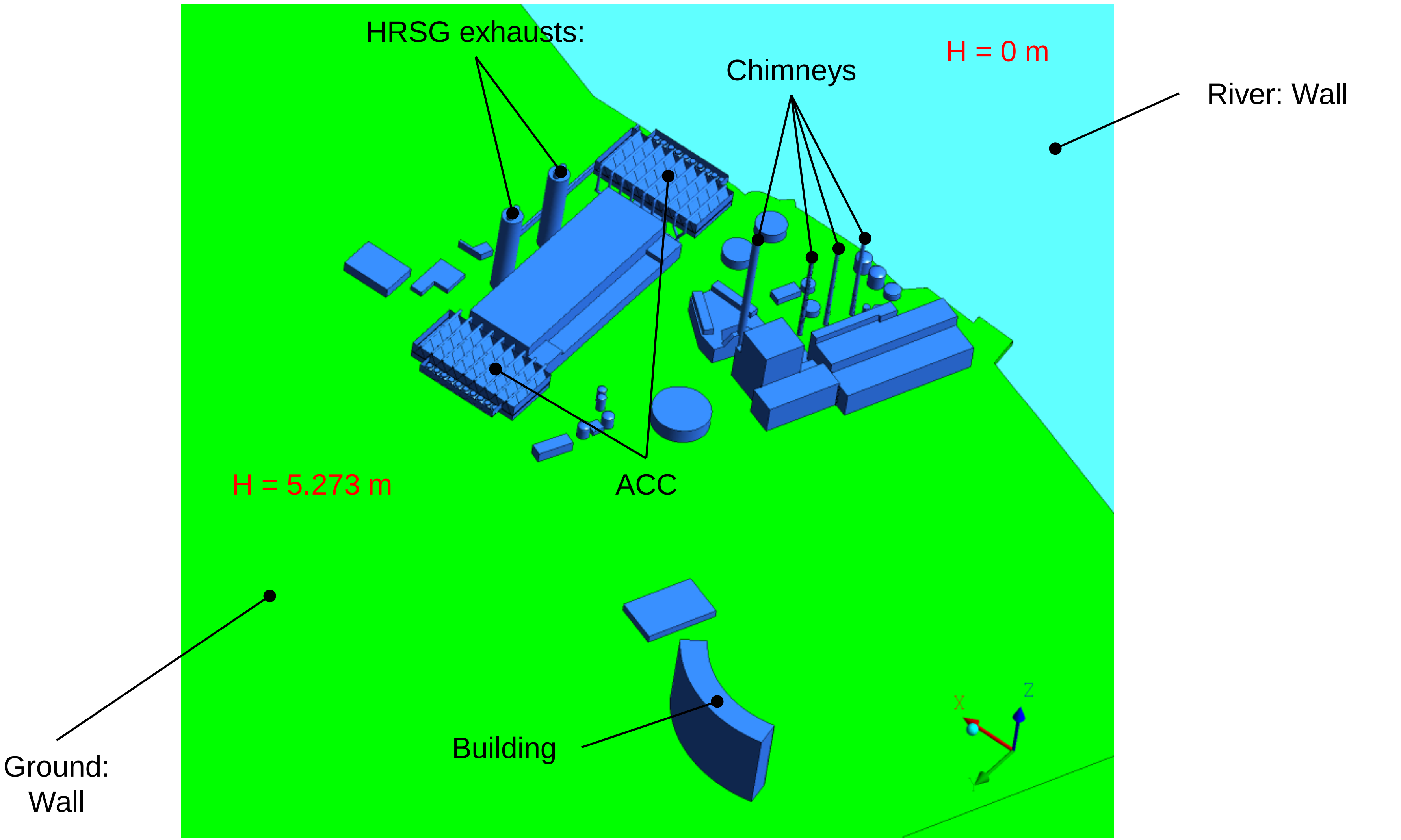
Domain geometry

- View from above (South-West) of the domain



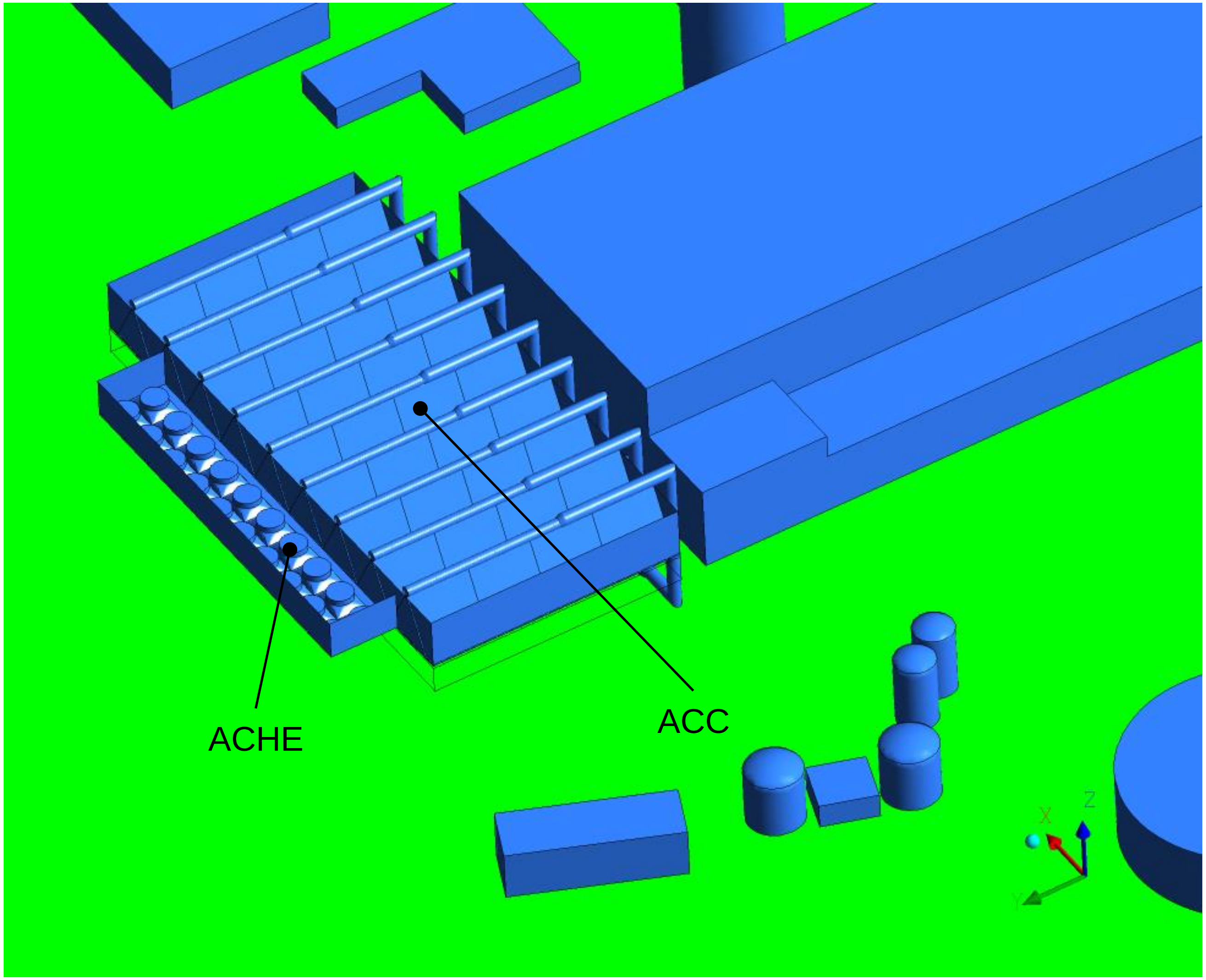
Domain geometry

- View from above (North-West) of the domain with ground elevations (H)



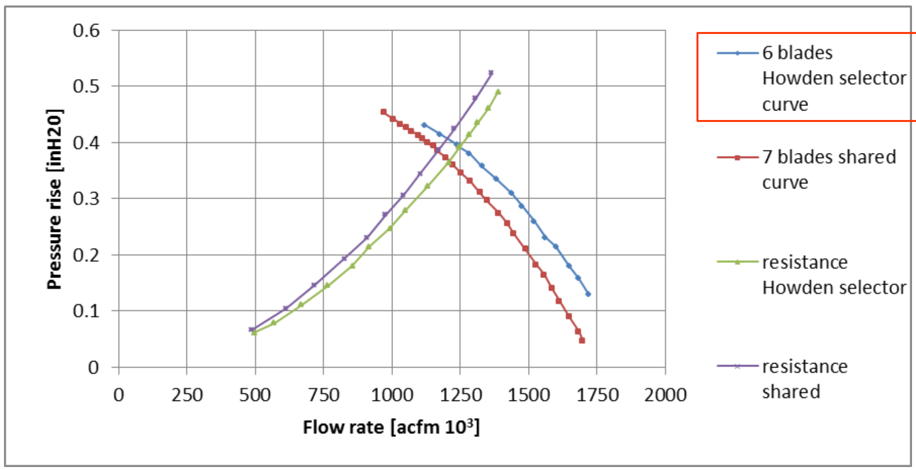
Domain geometry

- View from above (North-West) of the ACC (Unit X)



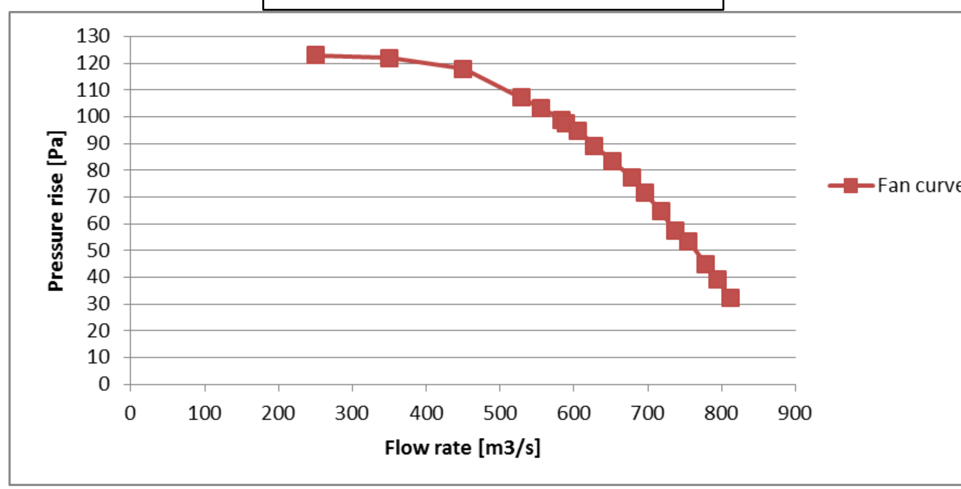
Modelling details

- Fan model
  - Fan model implement a sudden pressure rise as a function of normal air velocity
  - Quadratic function implemented in the code
  - Extended range towards low flow rates



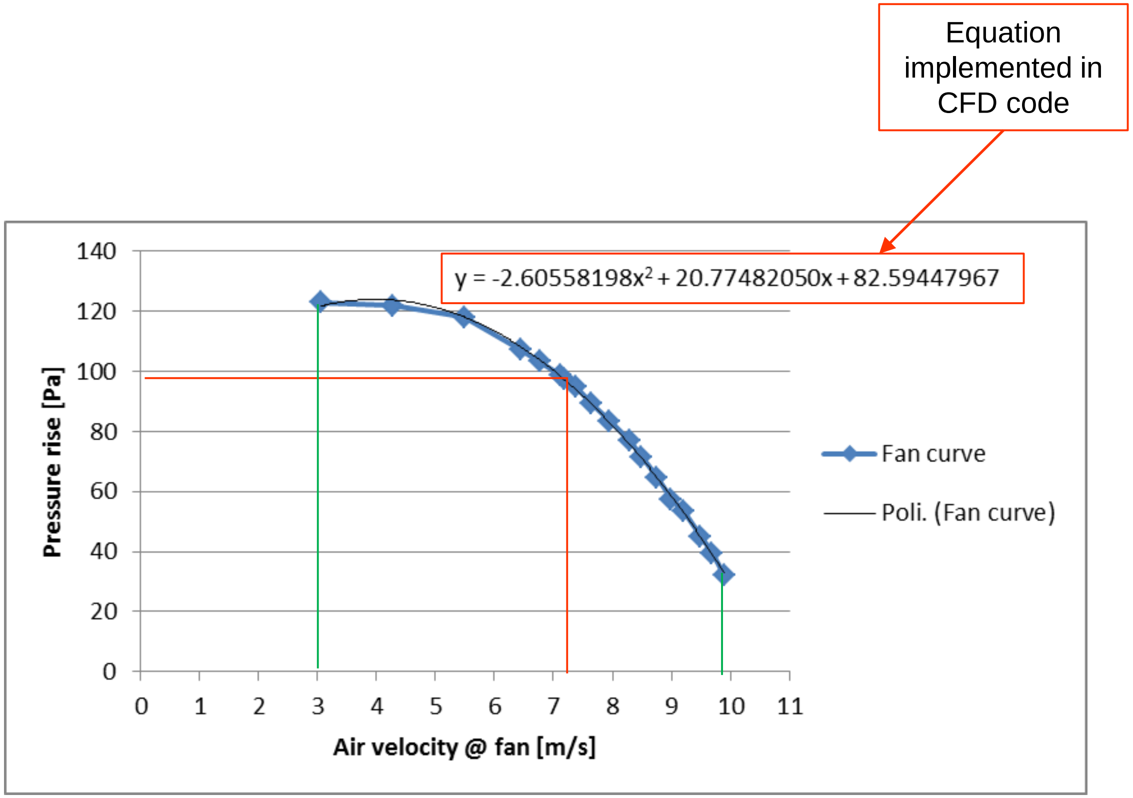
Chosen model

Duty point:
- Flow rate = 589.93 m³/s
- Pressure rise = 97.55 Pa



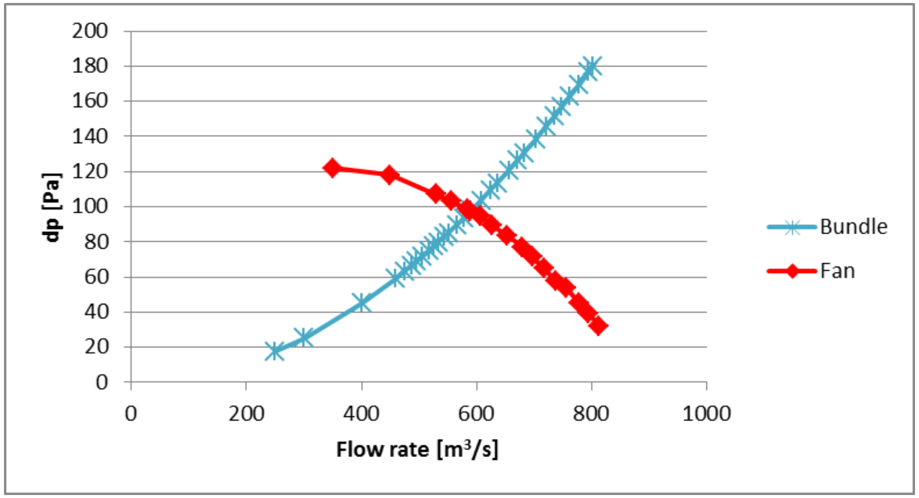
Modelling details

- ACHE fan model
  - Pressure rise is a quadratic function of air bulk velocity at the fan
  - Actual profile is clipped between 3 and 10 m/s



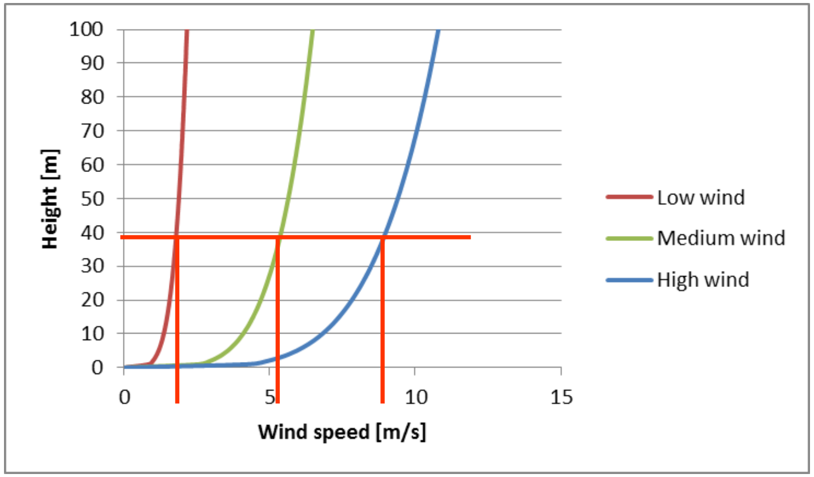
Modelling details

- Bundle model
  - Pressure drop in bundle is set by the pressure drop coefficient $K = \frac{dp}{0.5\rho U^2}$
  - Pressure drop coefficient is calculated at duty point:
    - → K_{ACC} = 59.22
  - This procedure does not consider any type of additional losses
    - → Lateral wind
    - → Neighbour fans
    - → Recirculation losses
  - Bundle thermal submodel maintain a fixed outlet temperature
    - → Other treatments are available (imposed duty, fixed HTC and ref temperature)



Modelling details

- Wind:
  - Far field boundary layer: $V(y) = V_{ref} \times \left(\frac{y}{H_{ref}}\right)^a$ $\begin{cases} V_{ref} \\ H_{ref} \\ a \end{cases}$
  - Power law exponent a is a function of ground roughness and BL stability (and of H_{ref})
    - → Irwin 1979 suggested a value of 0.2 for stable BL over rough surfaces (http://www.webmet.com)
  - Selected wind conditions:
    - → Low wind day: V_{ref} = 4 mph = 1.79 m/s
    - → Medium wind day: V_{ref} = 12 mph = 5.36 m/s
    - → High wind day: V_{ref} = 20 mph = 8.94 m/s
  - Reference wind conditions are measured at H_{ref} = 39 m



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Preliminary sensitivity

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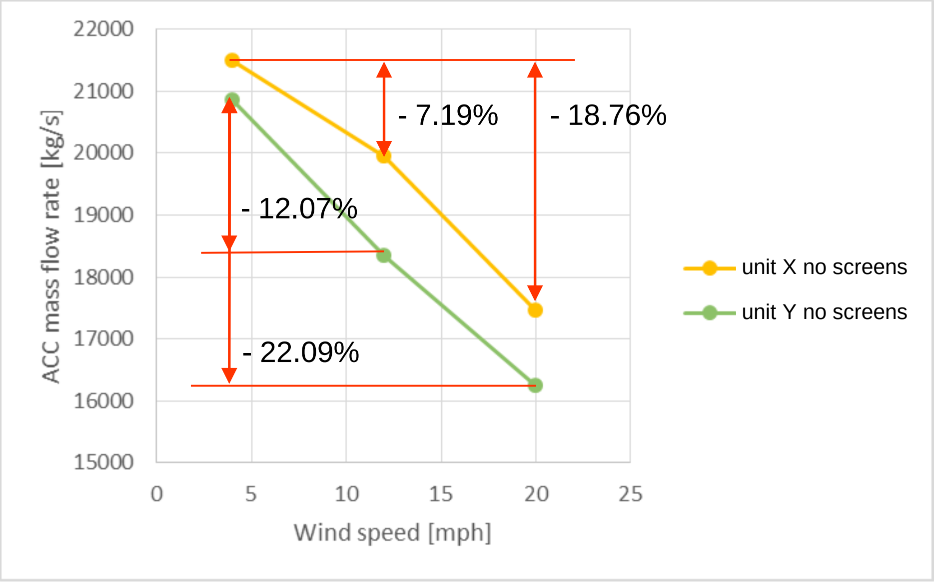
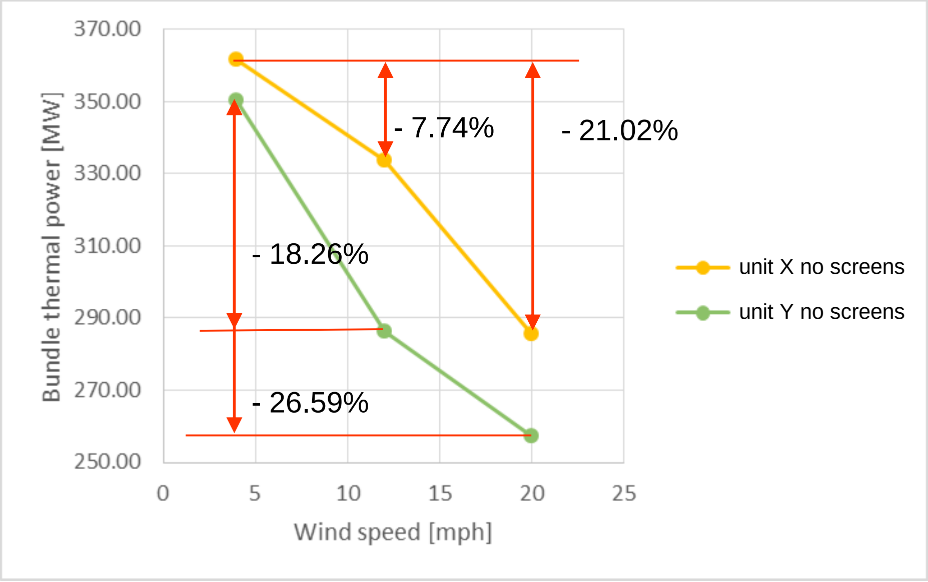
Results - Wind speed sensitivity

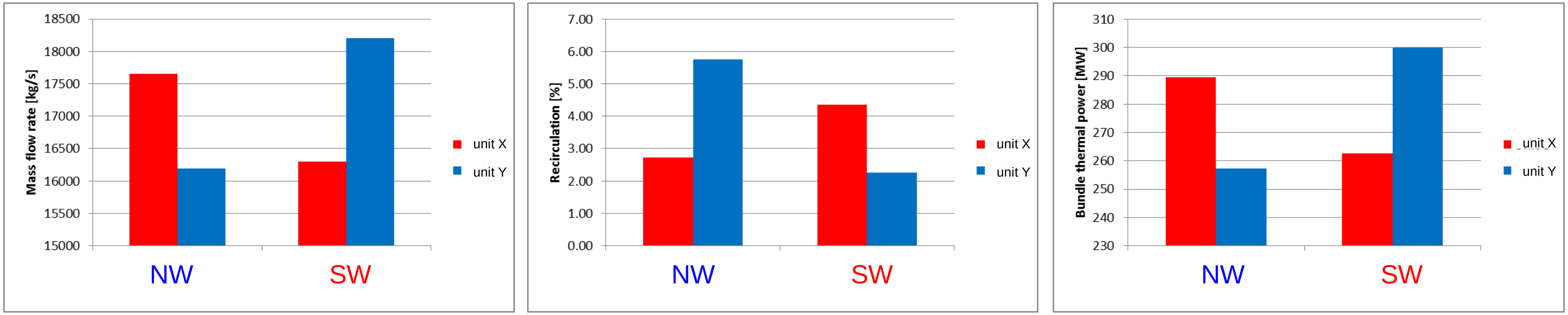
- Analysis conducted with NW wind without windscreens
  - Wind speed impacts both upstream and downstream units
    - Losses increases up to 20-25% at 20 mph
  - Downstream unit always shows a reduced capacity
    - The gap is variable with wind speed and is maximum (>40MW) for intermediate wind speeds





Results – Wind direction sensitivity

- Analysis conducted at 20 mph without windscreens
  - The mass flow on downstream unit is substantially symmetric
    - →The upstream units change by 3%
  - Recirculation is almost constant in the upstream unit
  - In terms of power the problem can be considered symmetric with a maximum 3.64% error
    - →South-West wind maximize the differences between the two units but is less critical in terms of absolute values
      - Higher thermal power extracted at ACC than with NorthWest wind

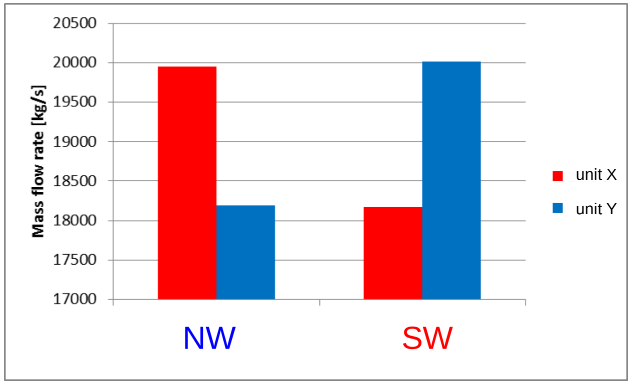


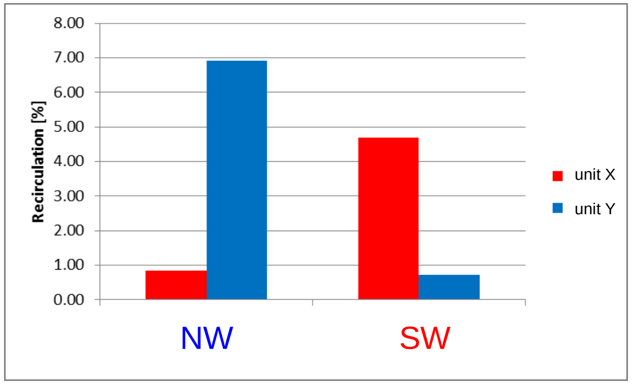
Results – Wind direction sensitivity

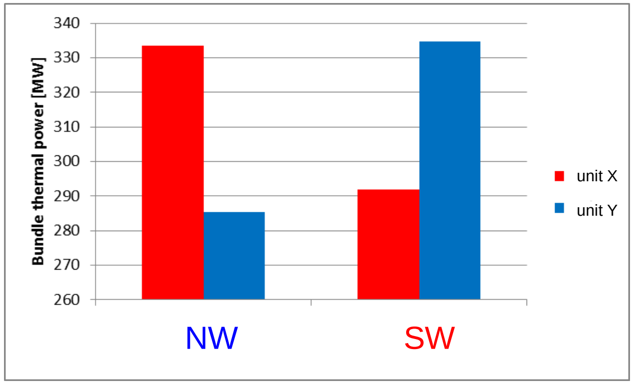
- Analysis conducted at 20 mph with windscreens
  - The mass flow is substantially symmetric
  - In terms of power the problem can be considered symmetric with a maximum 2.24% error

→North-West wind maximize the differences between the two units and is more critical in terms of absolute values

- Lower thermal power extracted at ACC with NorthWest wind

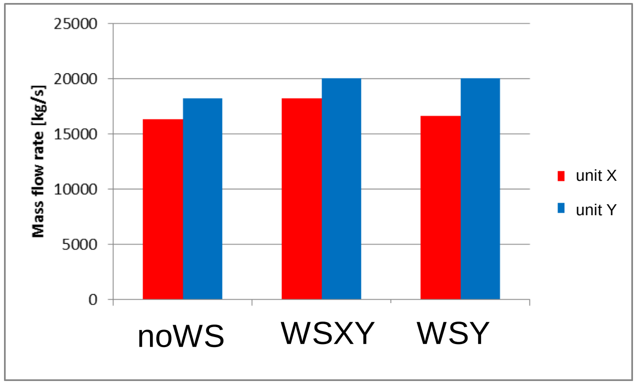


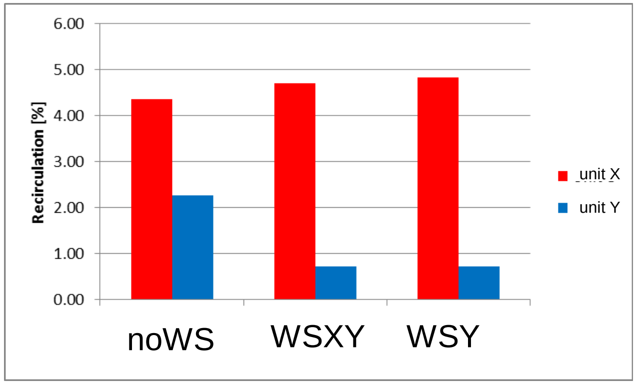


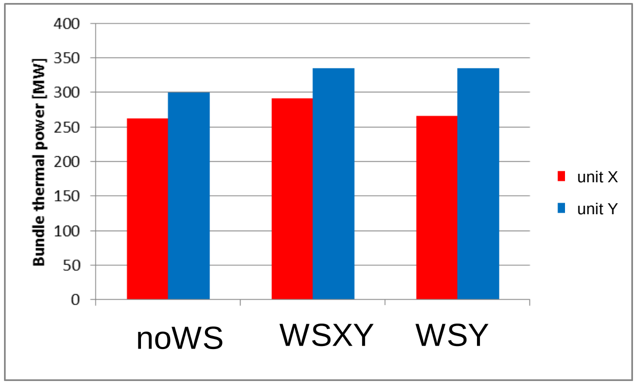


Results – Units coupling sensitivity

- Are the wind screens on one unit influencing the flow on the other unit?
  - The answer is: NO
- Analysis conducted at 20 mph with a South-West wind
  - Two units works independently
    - → Maximum effect of opposite unit wind screens is below 1.4% in terms of thermal power







Preliminary conclusions

- CFD model is robust and uncertainty of the computational model results is within 1%
- Solution with SW wind is symmetric to that with NW wind with a 3% maximum deviation
  - The deviation is further reduced with wind screens
- The two units work uncoupled so that wind screens layout can be studied independently for the upstream and downstream unit

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Obtained results

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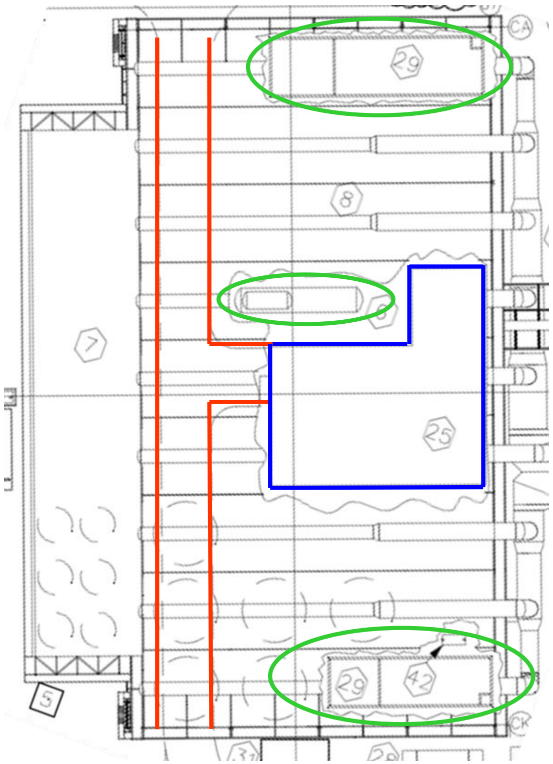
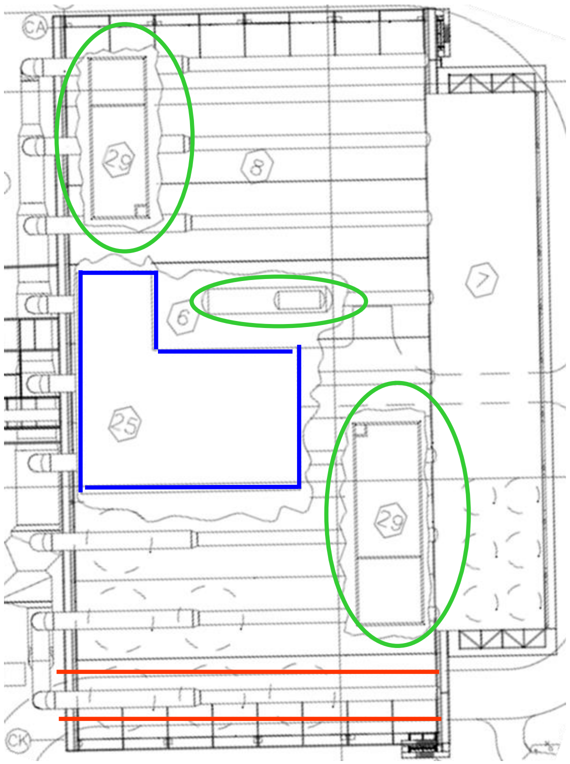
Design constraints

- Road
- Buildings
- Equipment

UNIT X

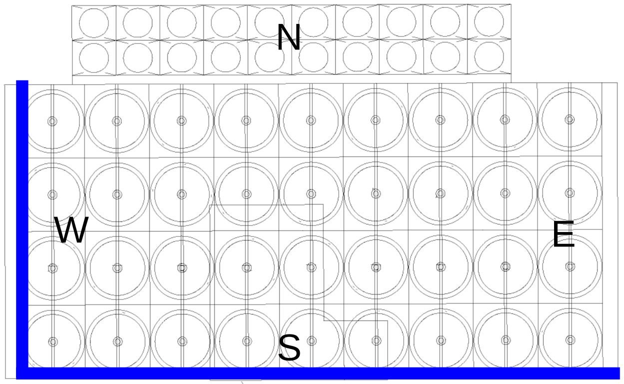




UNIT Y

Tested configurations

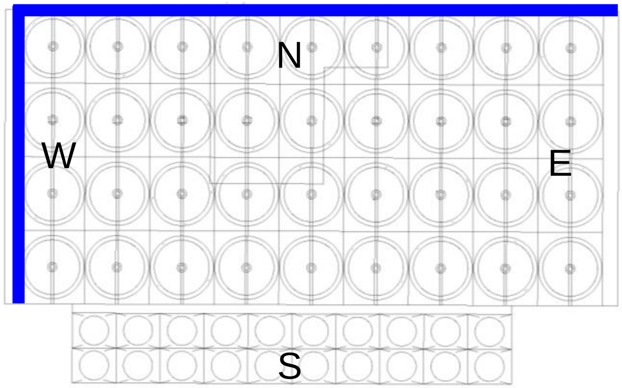
- Unit X – Unit Y implement symmetric layout

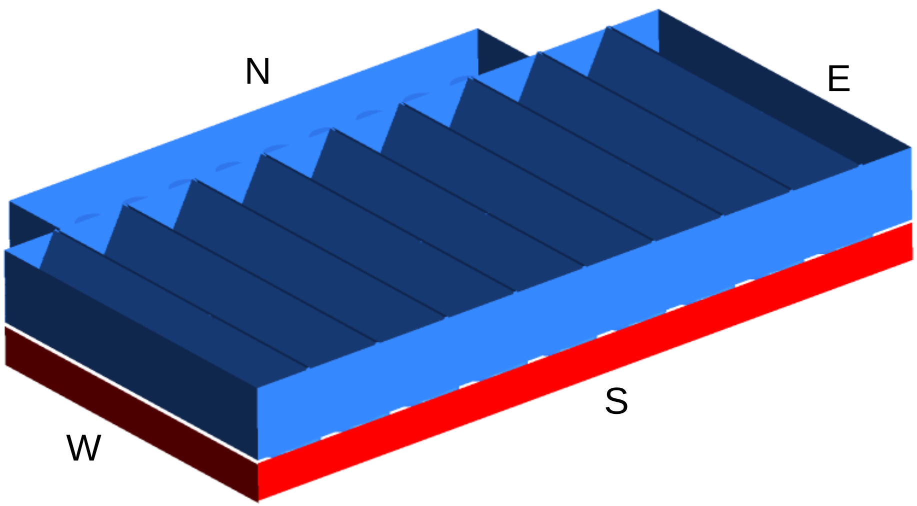


1

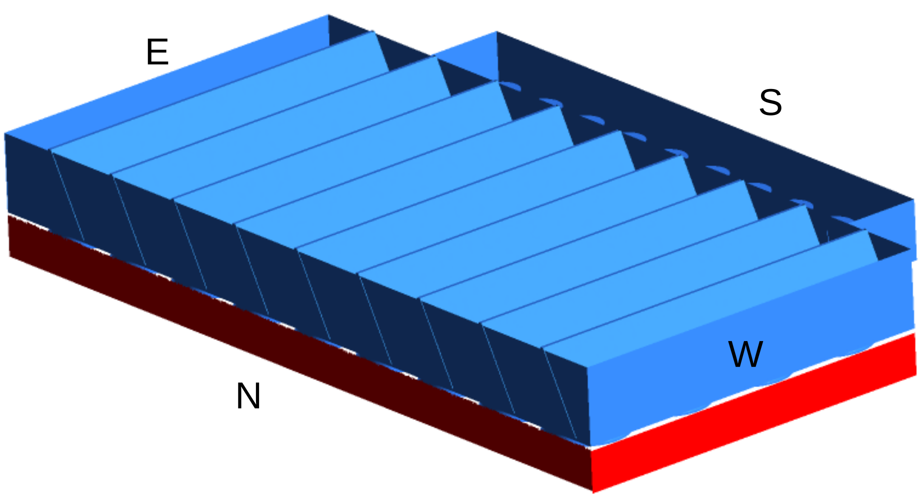
SW perimeter screens on Unit X
NW perimeter screens on Unit Y

Screen height = 5.92 m





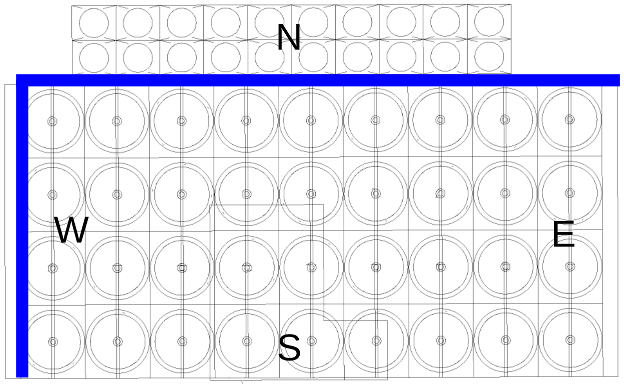
Unit X



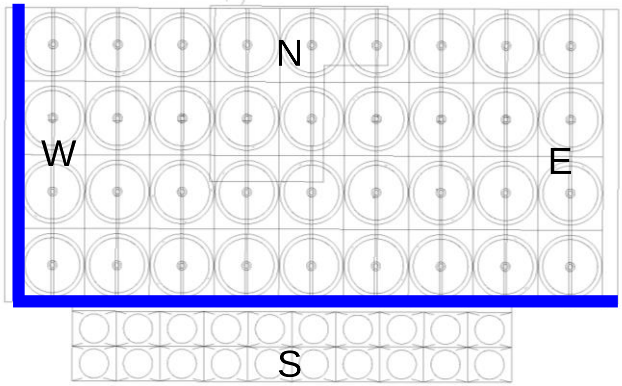
Unit Y

Tested configurations

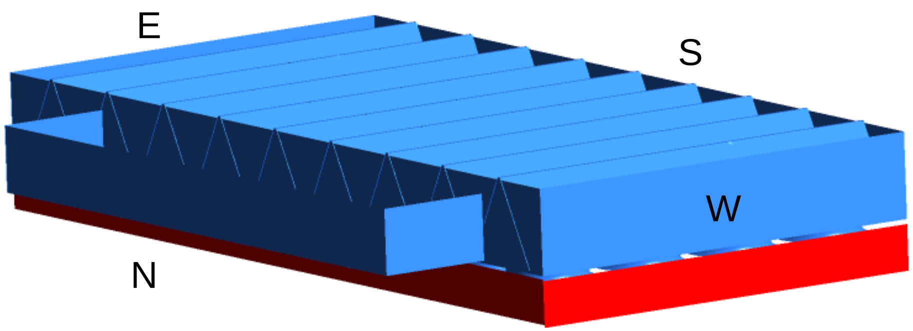
- Unit X – Unit Y implement symmetric layout



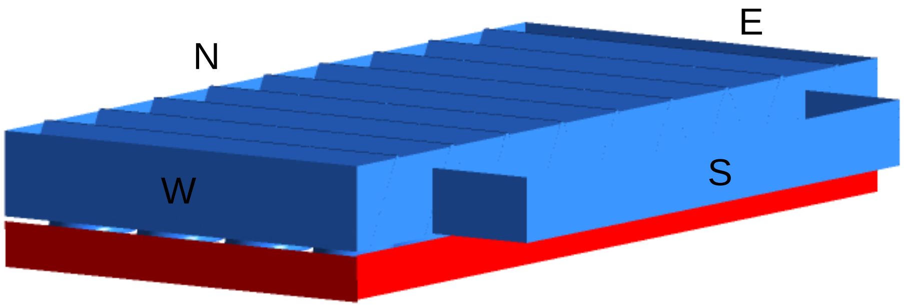
2&3
NW perimeter screens on Unit X
SW perimeter screens on Unit Y



Screen height = 5.92 m



Unit X



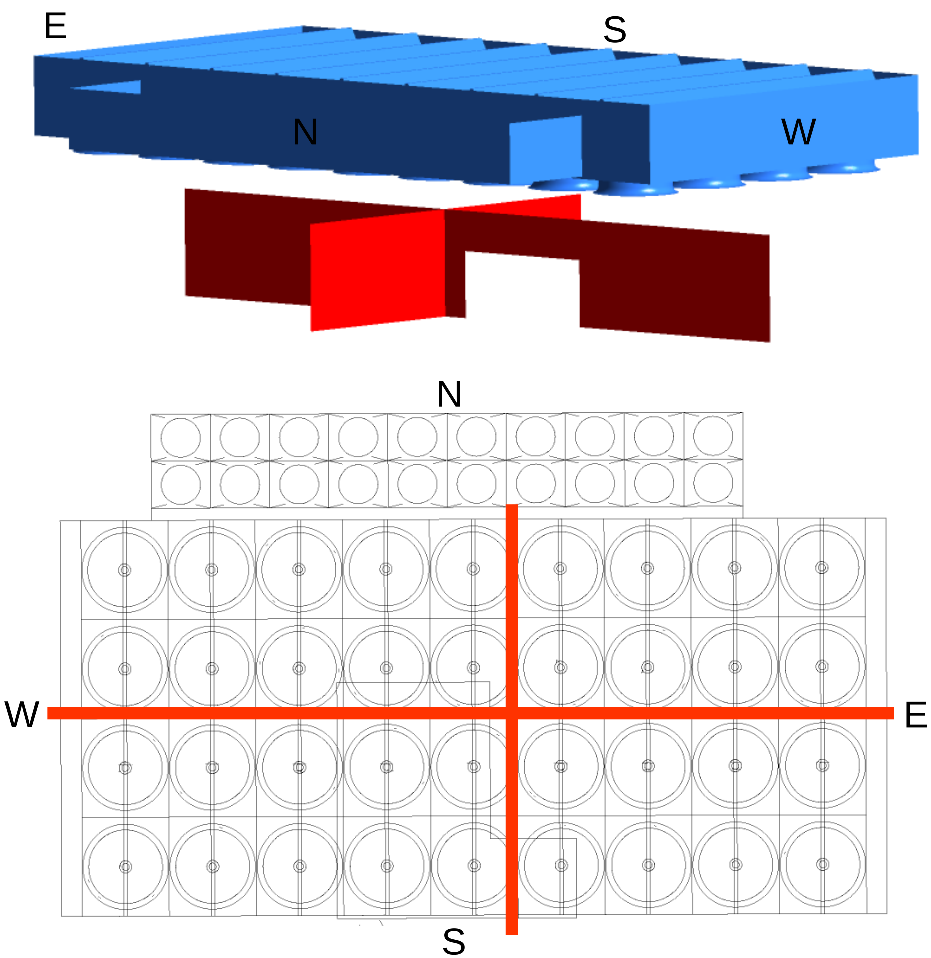
Unit Y

Tested configurations

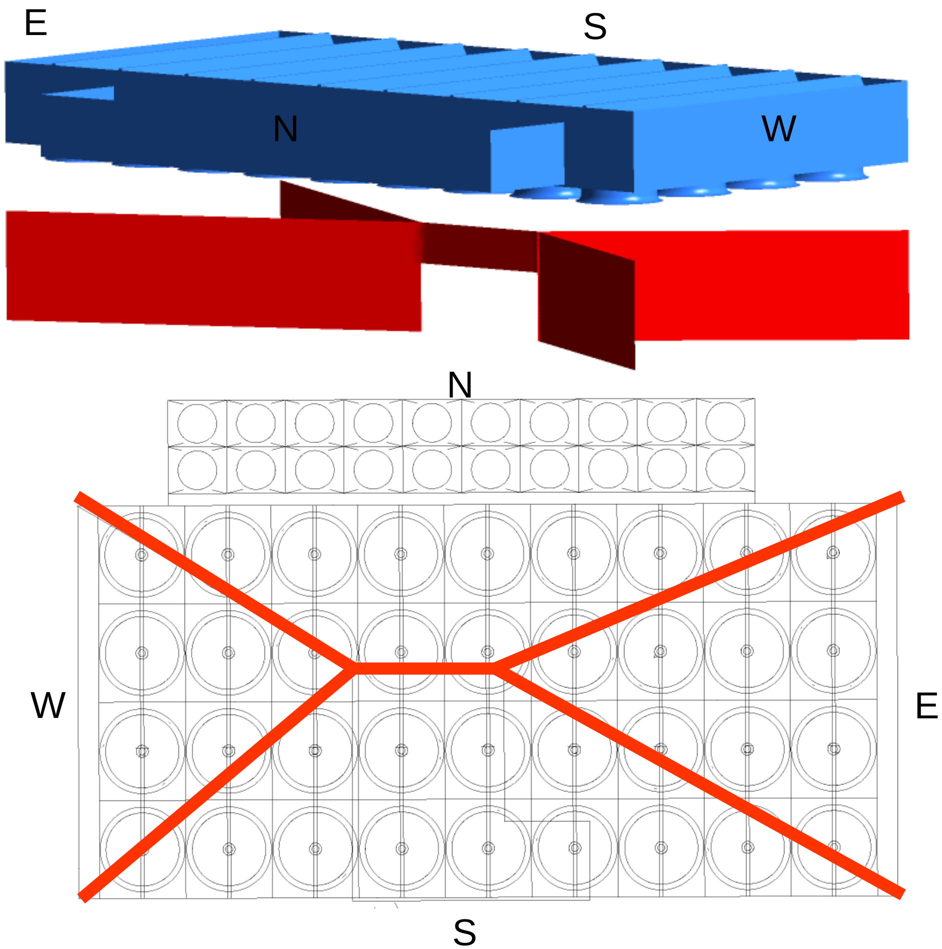
- Unit X – Unit Y implement symmetric layout

Screen height = 15 m

4
Cruciform screens

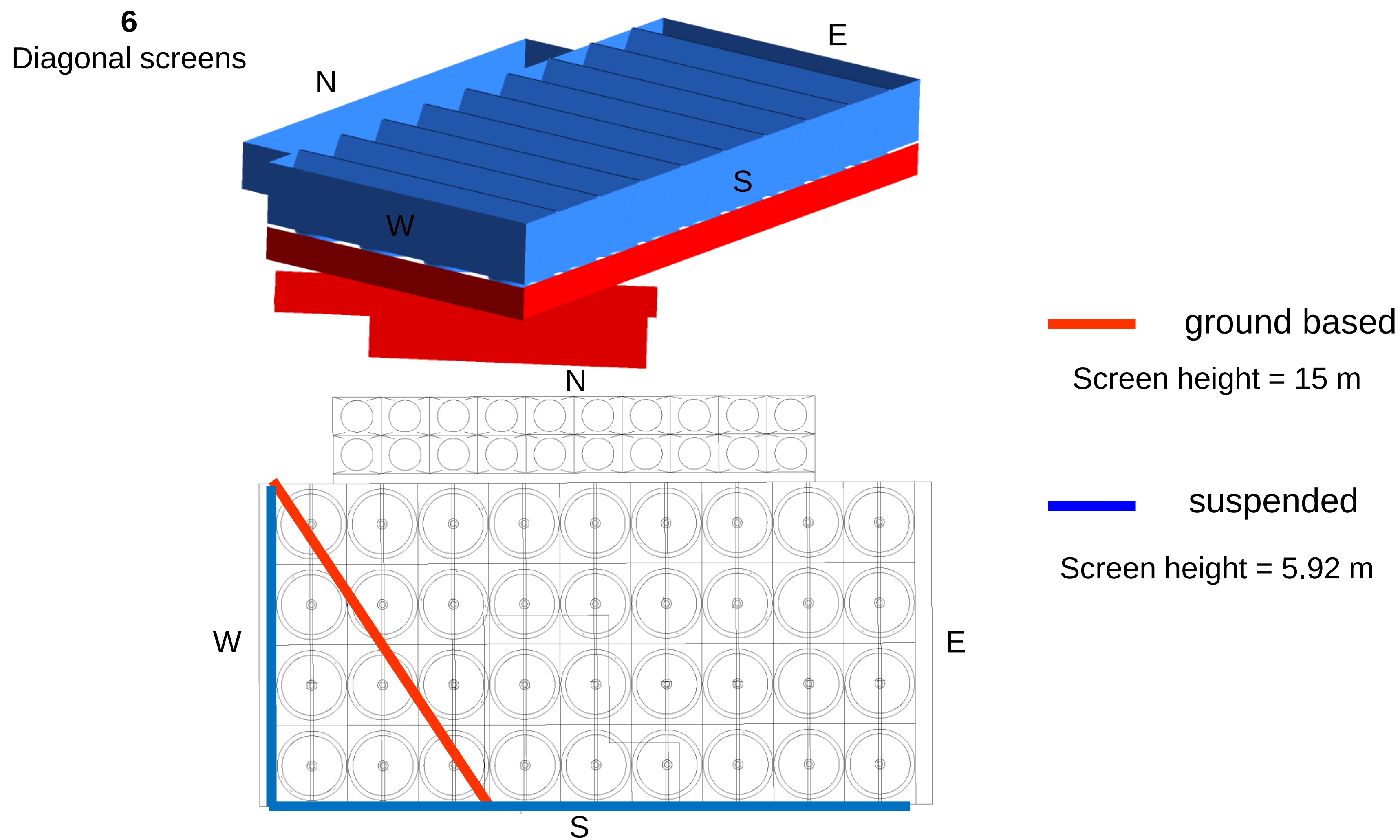


5
Wing cruciform screens



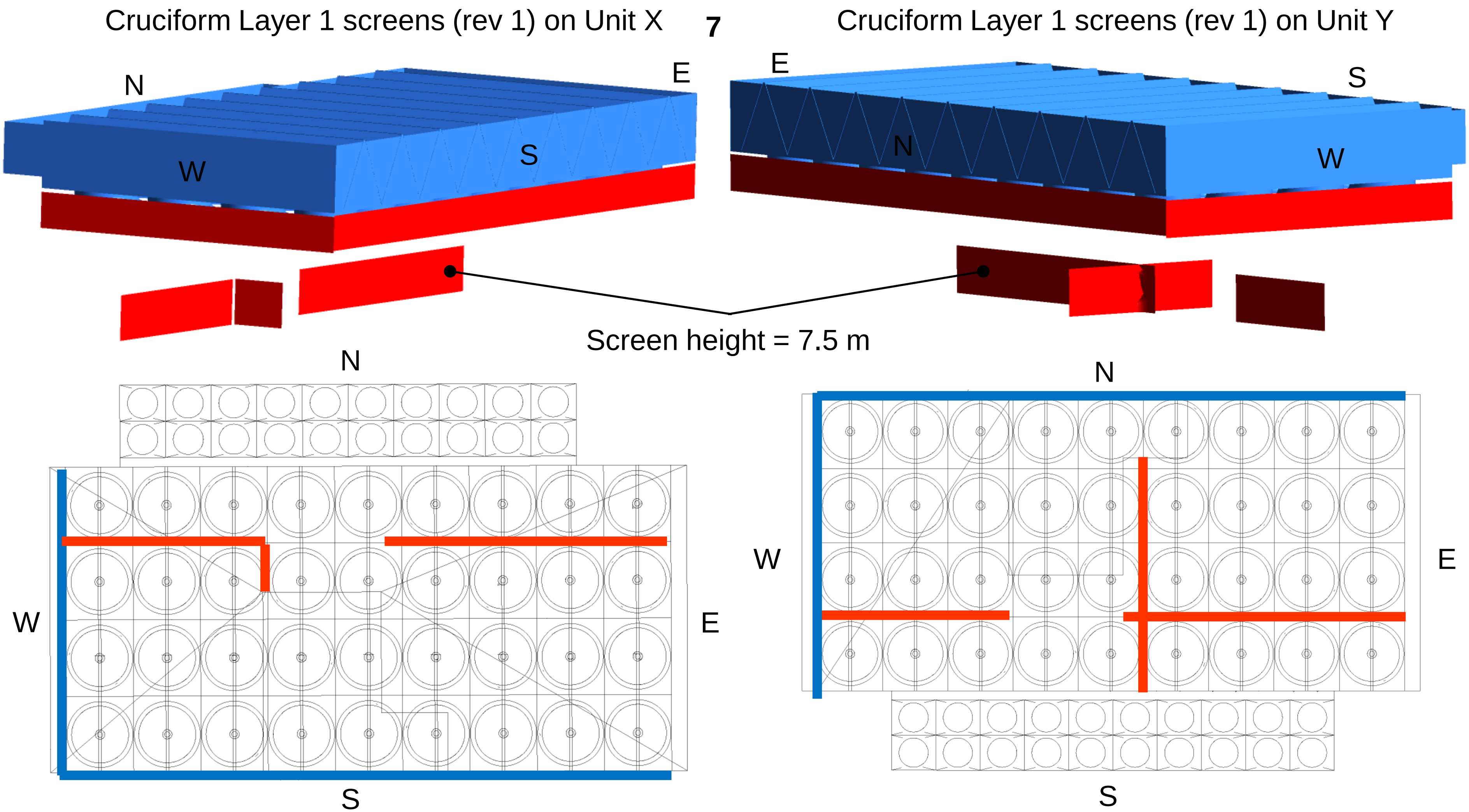
Tested configurations

- Unit X – Unit Y implement symmetric layout



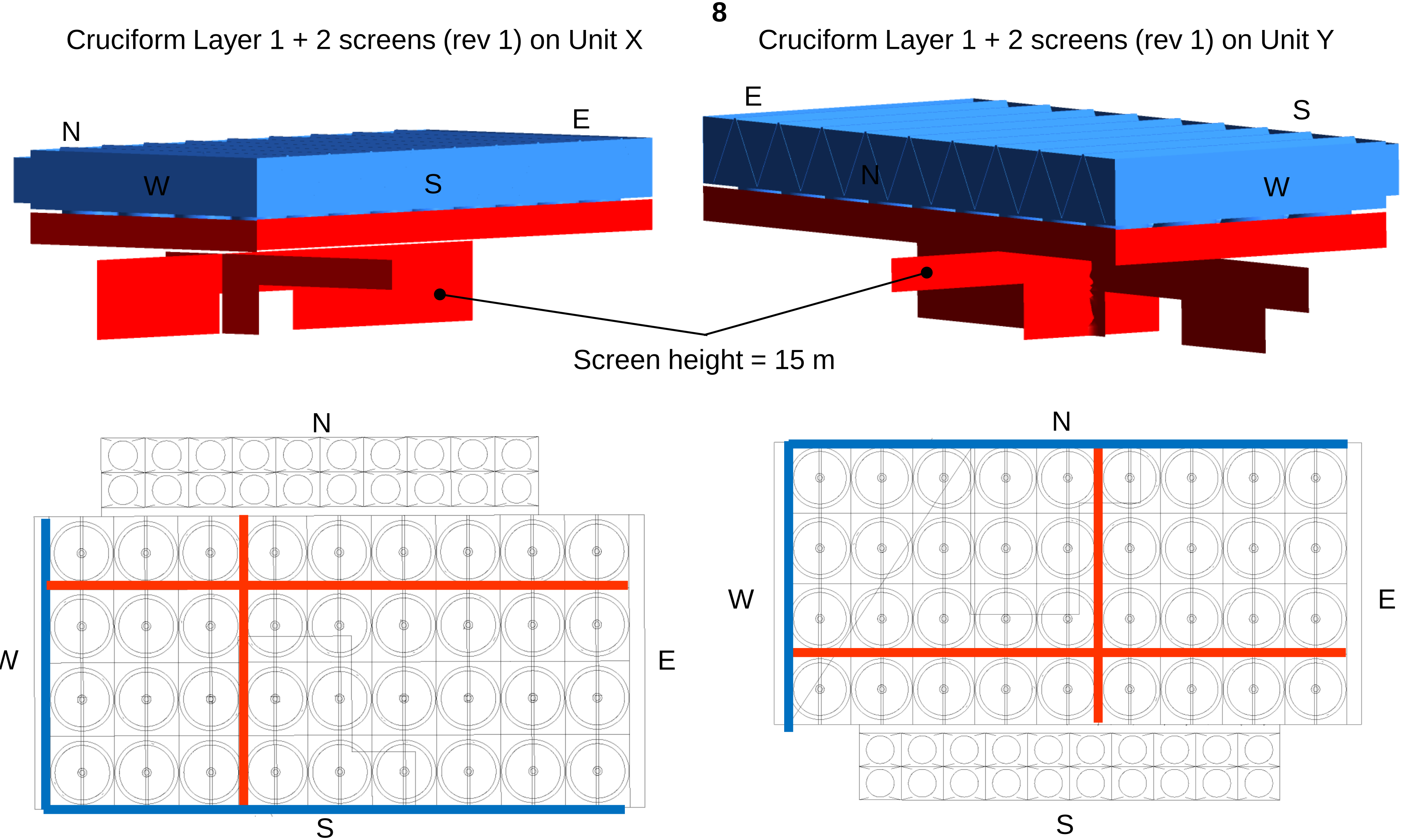
Tested configurations

- Unit X – Unit Y implement symmetric layout



Tested configurations

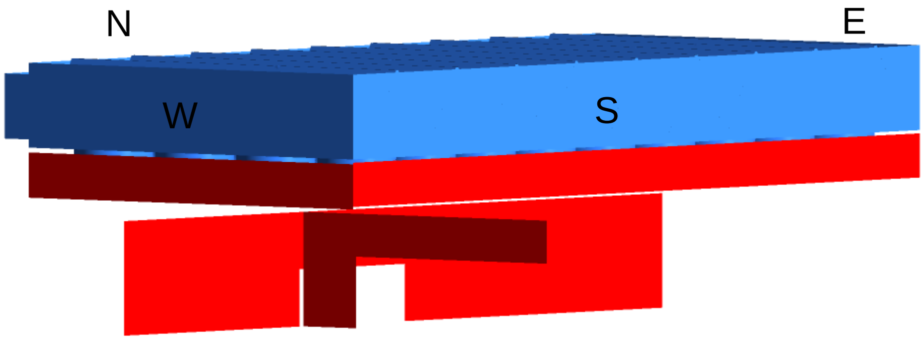
8

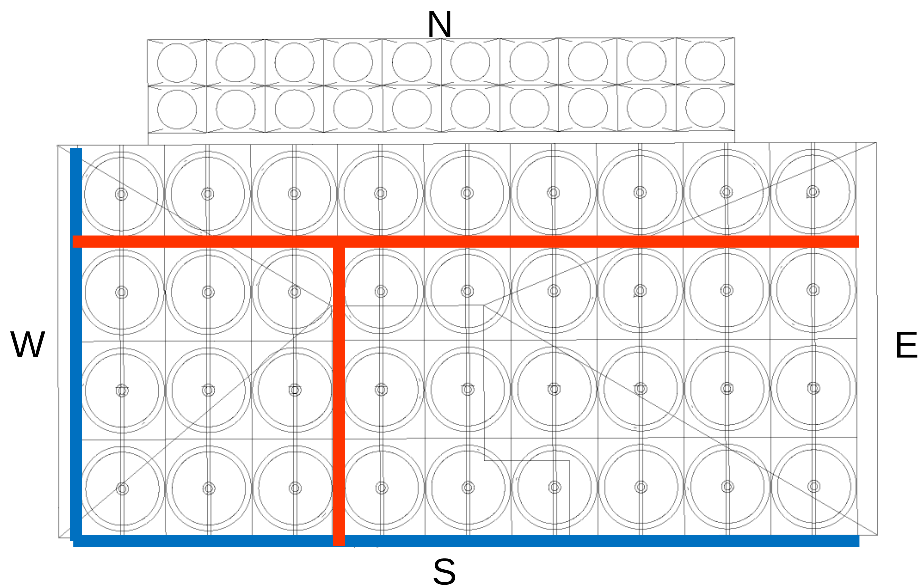


Tested configurations

- Unit X – Unit Y implement the same windscreens as "Cruciform Layer 1 + 2 screens (rev 1)"

9
Short cruciform

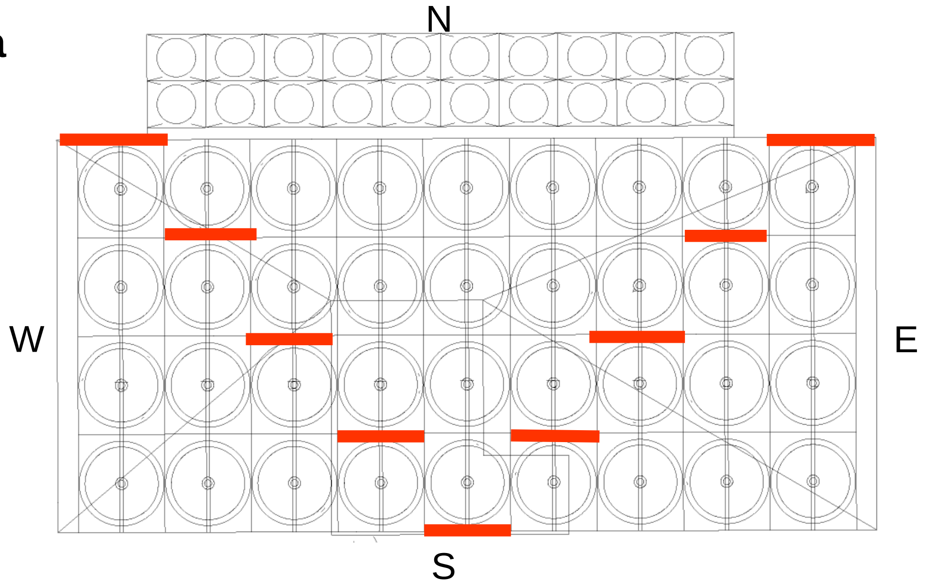




Tested configurations

- Unit X (V designs) – Unit Y implements symmetric layout

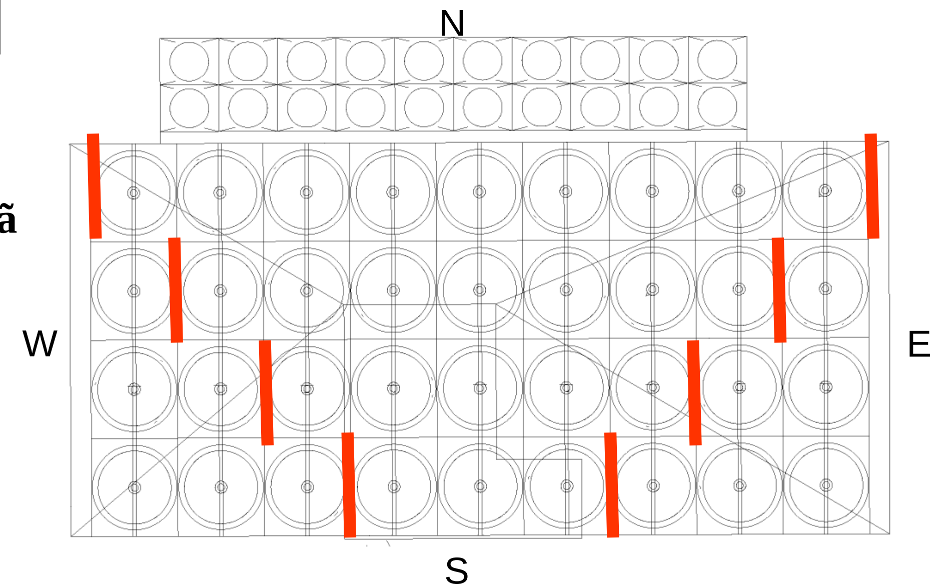
a



ground based

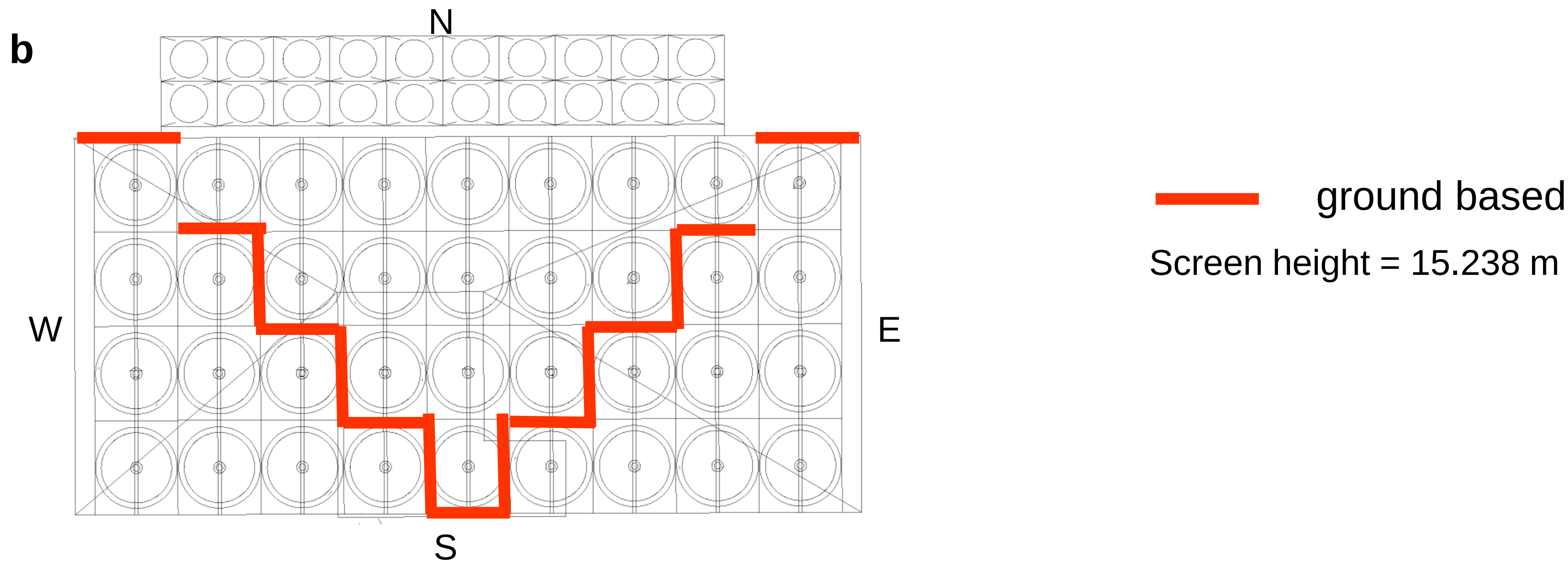
Screen height = 15.238 m

ã



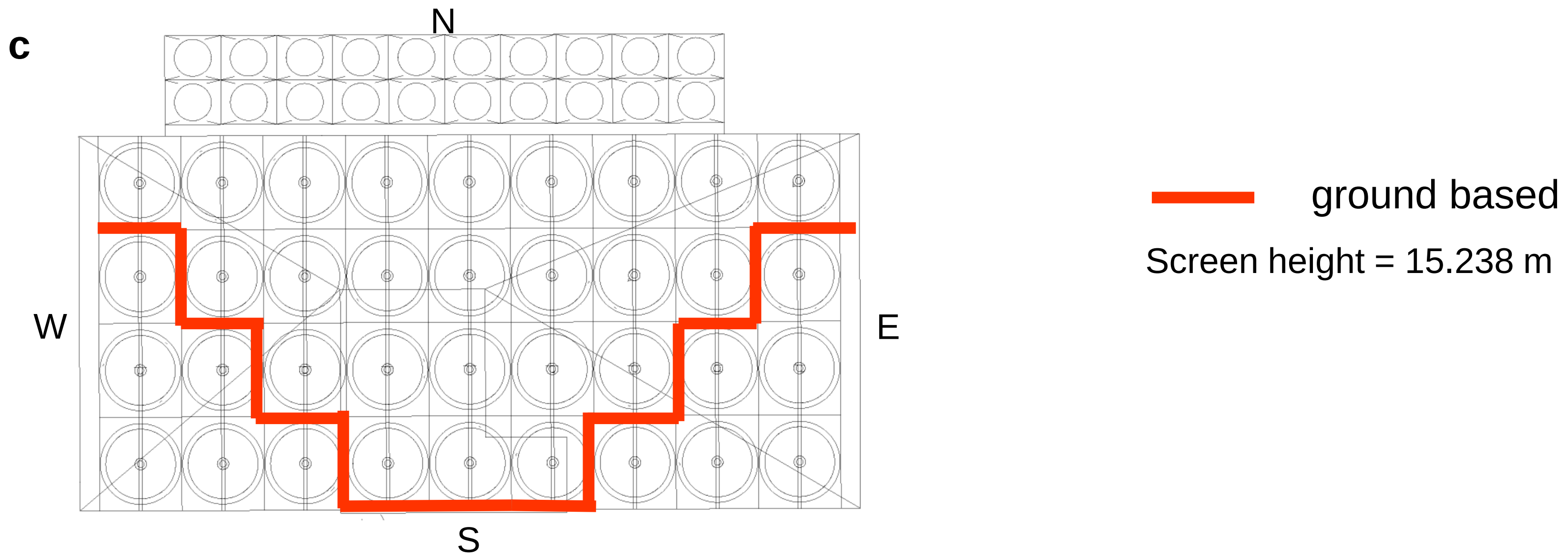
Tested configurations

- Unit X (V designs) – Unit Y implements symmetric layout



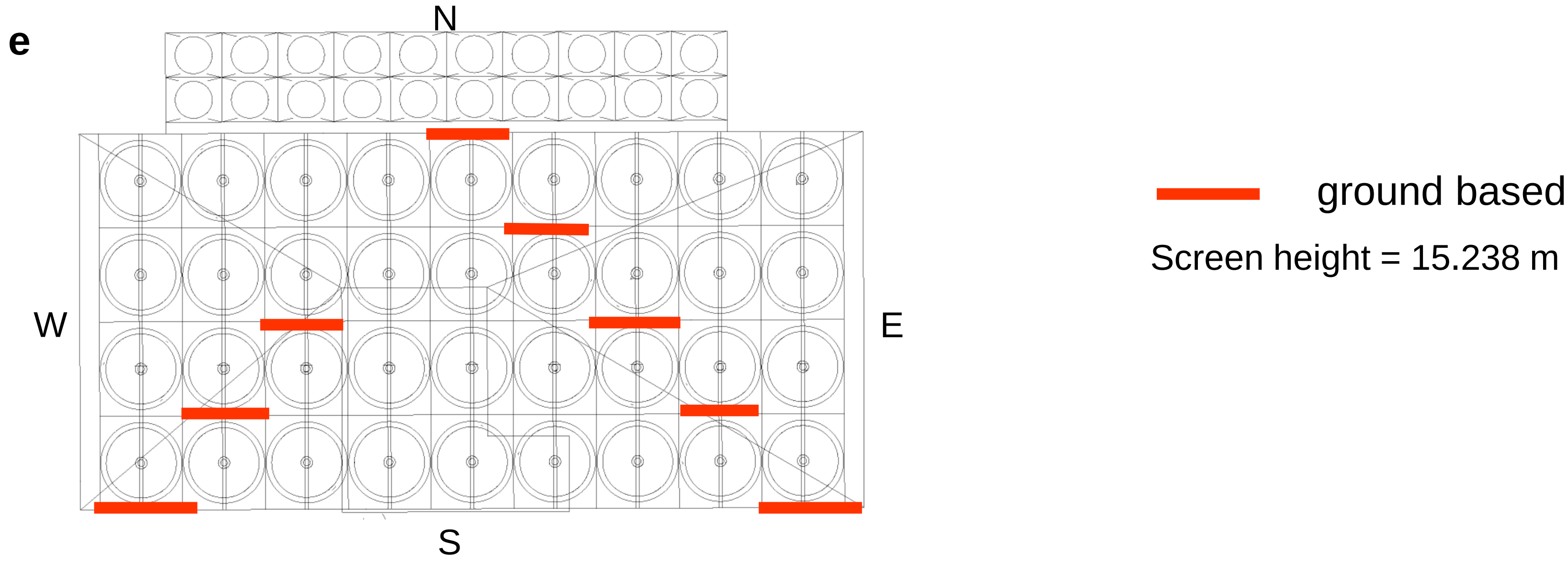
Tested configurations

- Unit X (V designs) – Unit Y implements symmetric layout



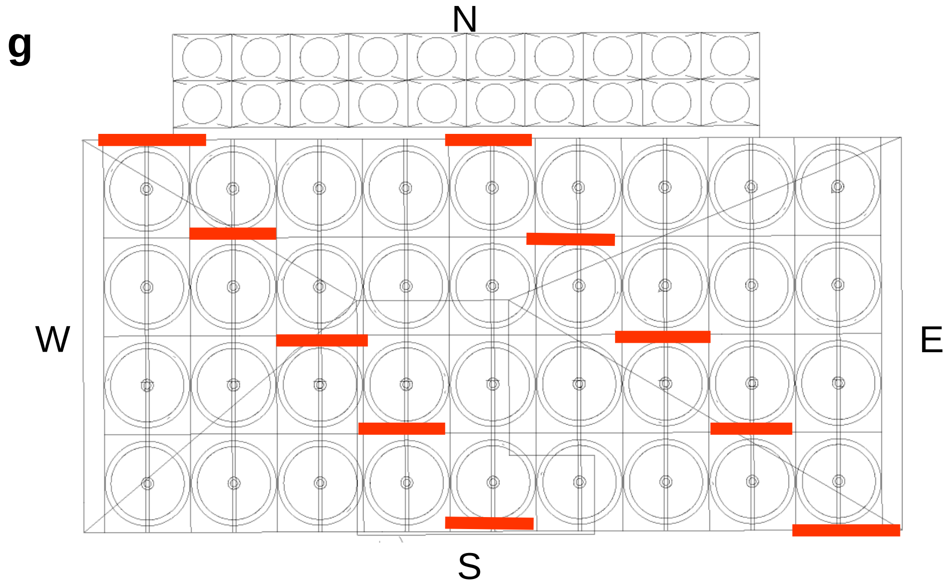
Tested configurations

- Unit X (Λ designs) – Unit Y implements symmetric layout



Tested configurations

- Unit X (parallel designs) – Unit Y implements symmetric layout



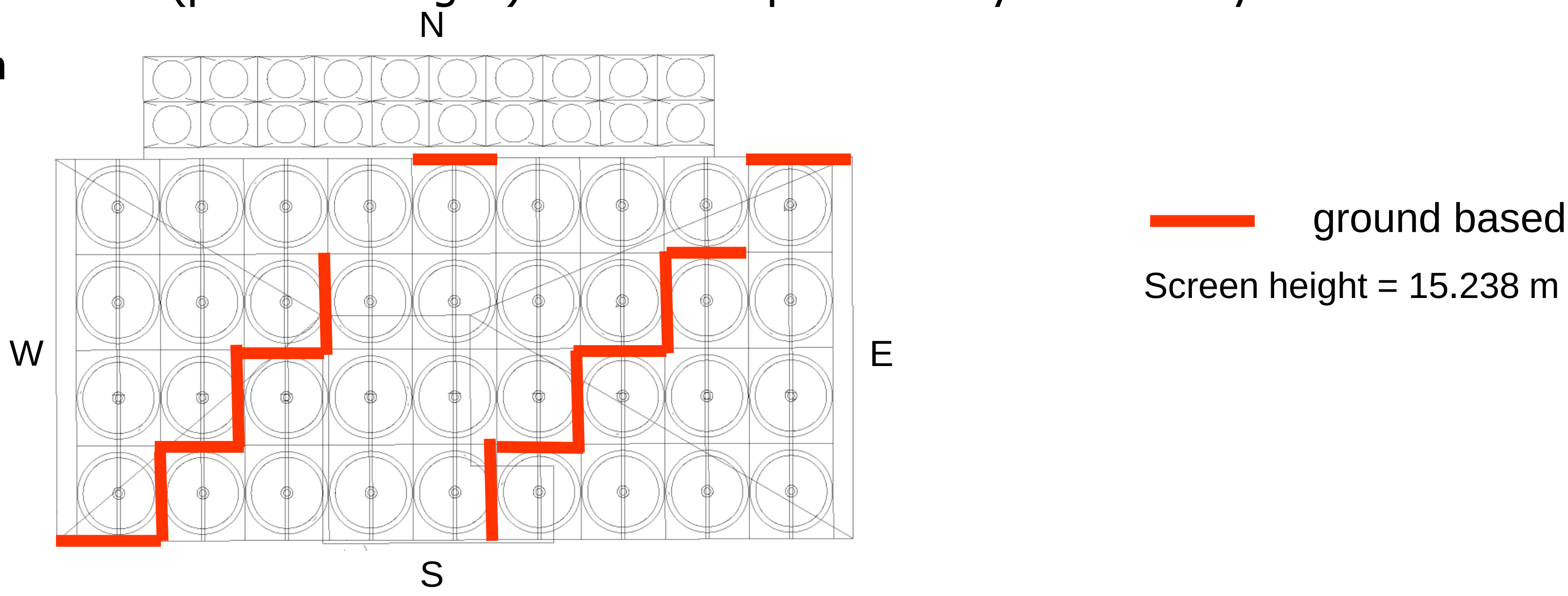
ground based

Screen height = 15.238 m

Tested configurations

- Unit X (parallel designs) – Unit Y implements symmetric layout

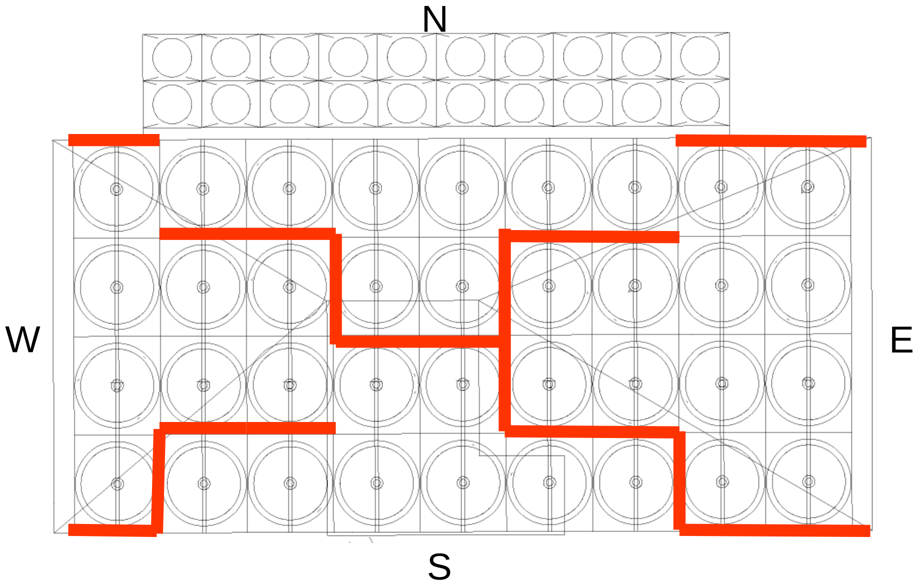
h



Tested configurations

- Unit X (X designs) – Unit Y implements symmetric layout

i

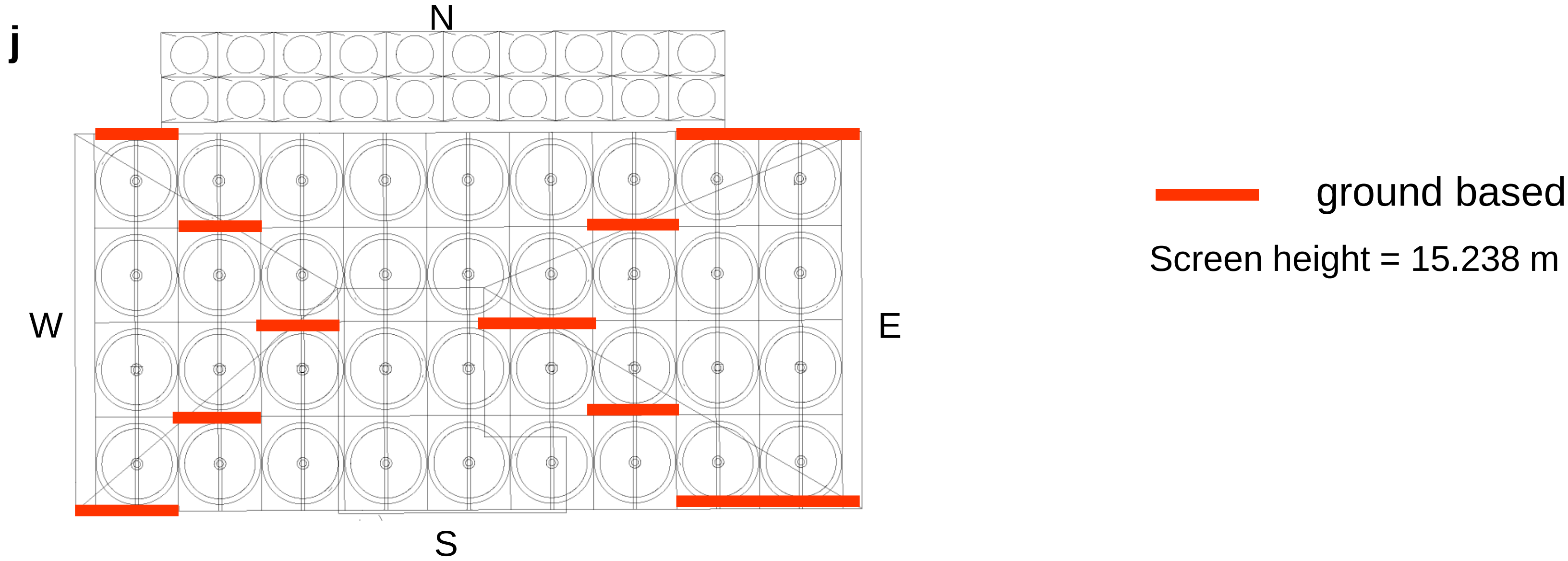


ground based

Screen height = 15.238 m

Tested configurations

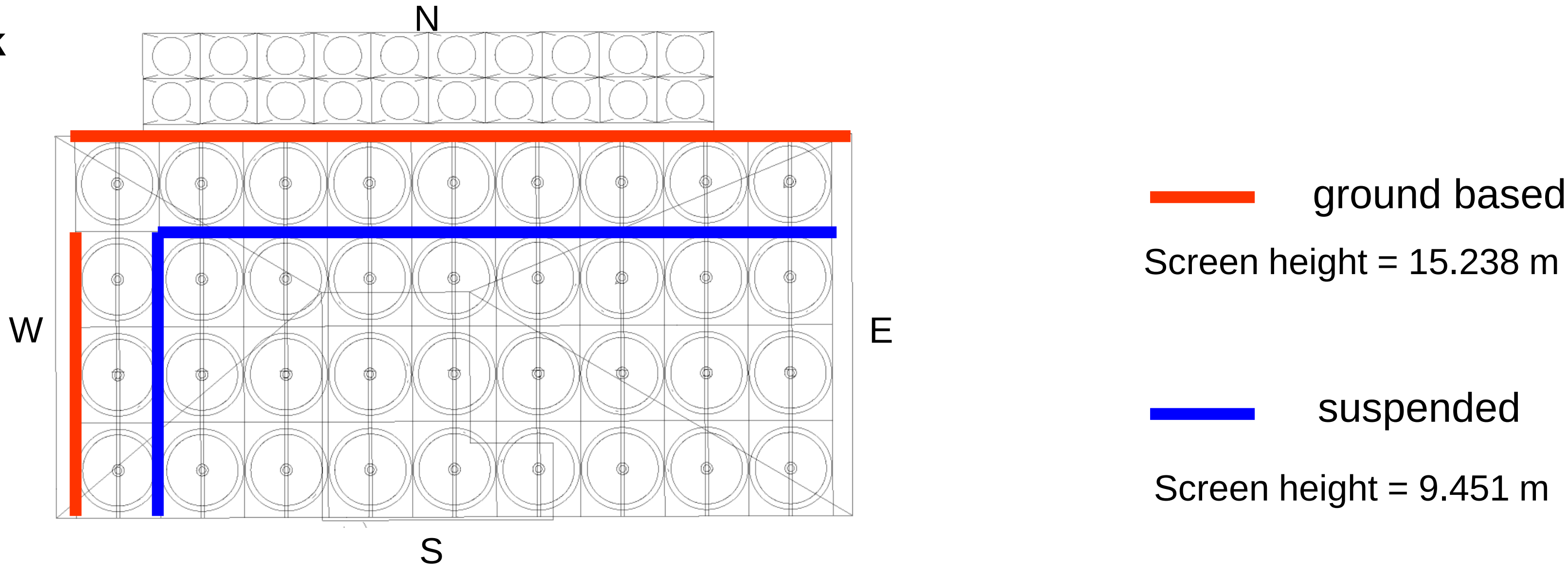
- Unit X (X designs) – Unit Y implements symmetric layout



Tested configurations

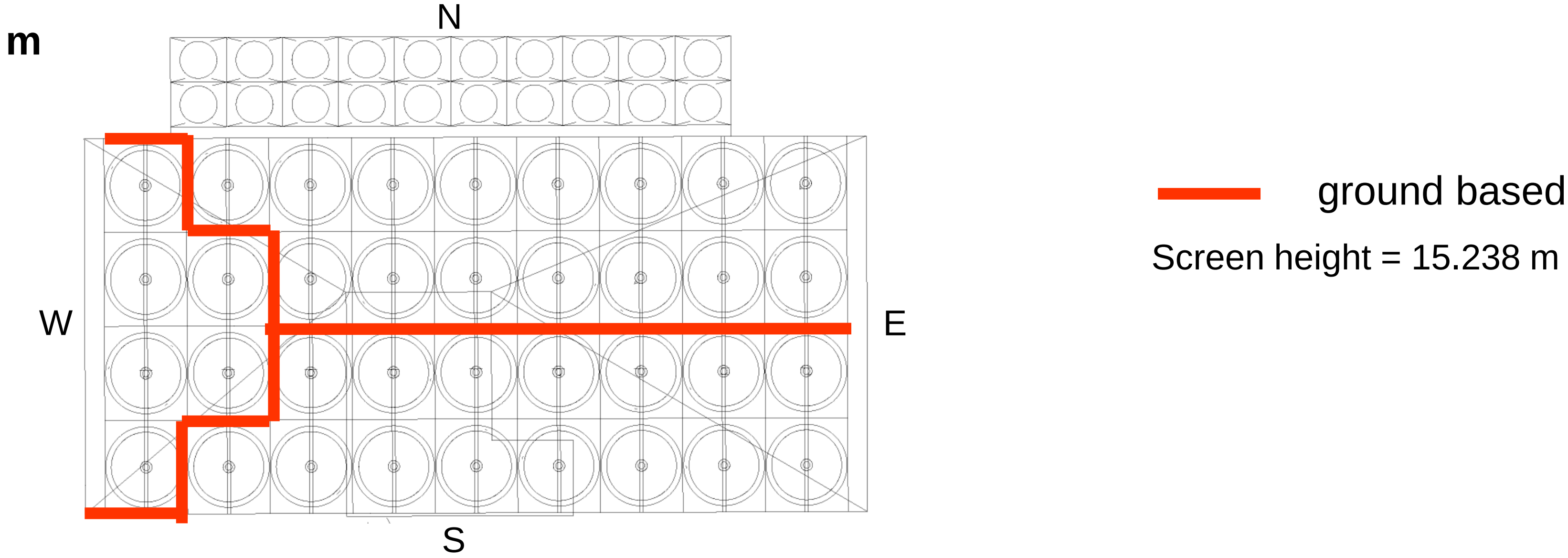
- Unit X (one-bay back designs) – Unit Y implements symmetric layout

k



Tested configurations

- Unit X (Y designs) – Unit Y implements symmetric layout



Tested configurations

- Unit X (cruciform designs) – Unit Y implements symmetric layout

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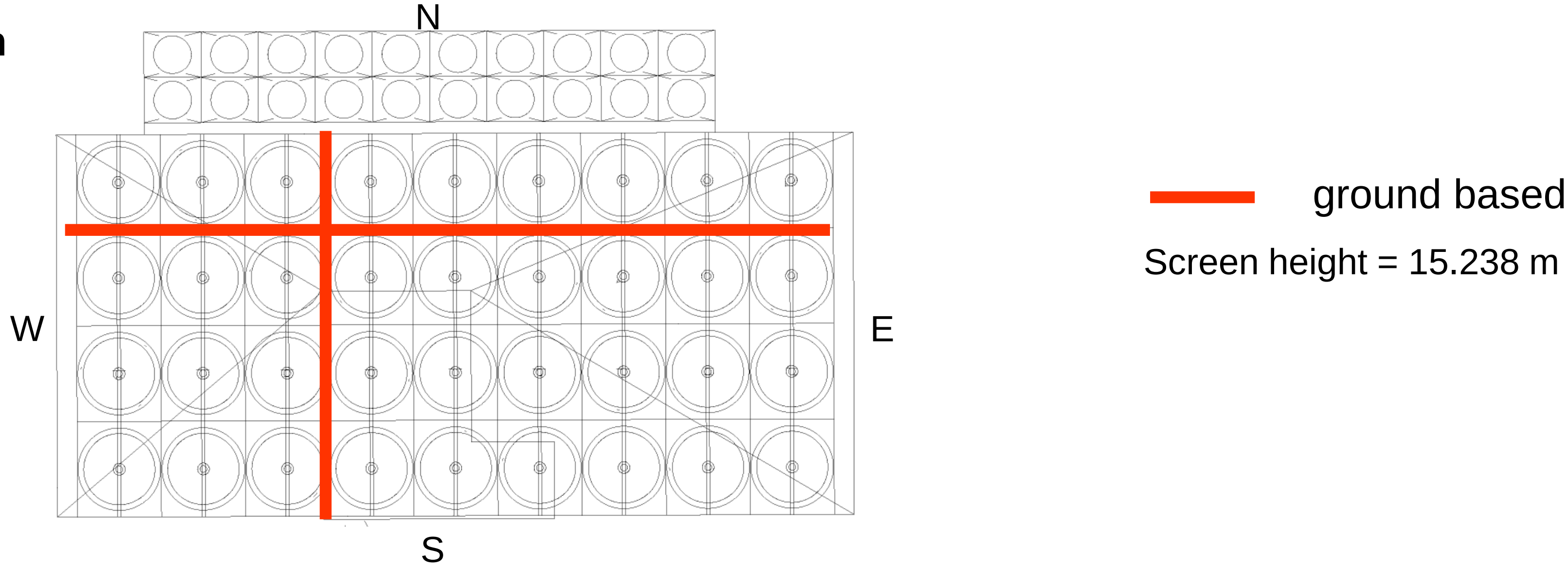
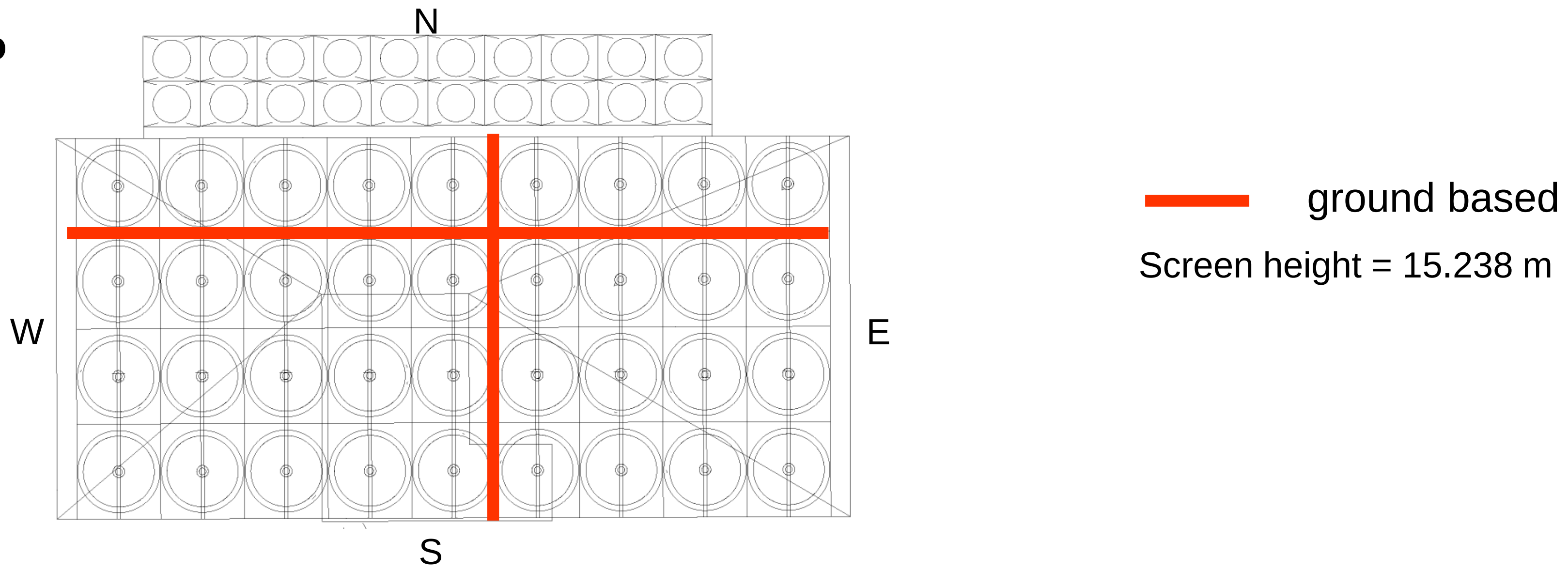


Tested configurations

- Unit X (cruciform designs) – Unit Y implements symmetric layout

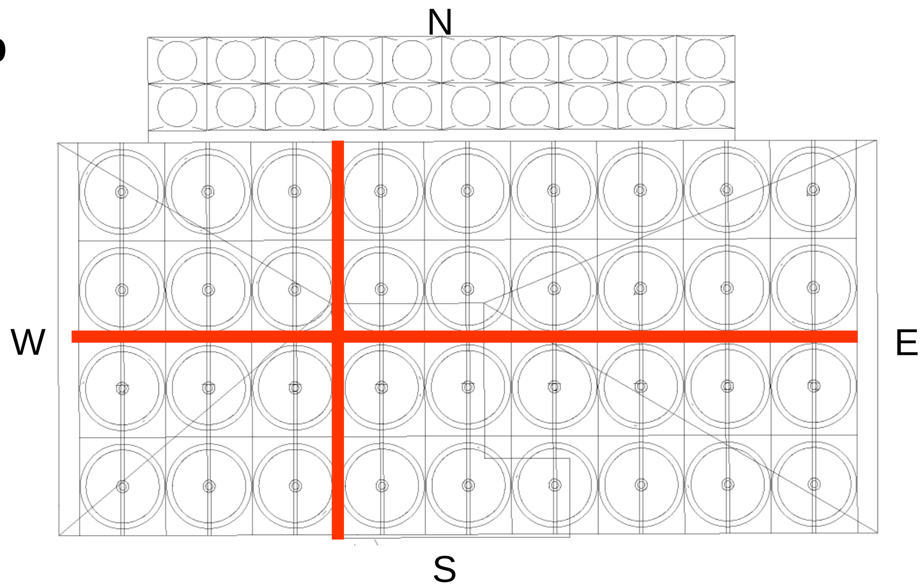
o



Tested configurations

- Unit X (cruciform designs) – Unit Y implements symmetric layout

p

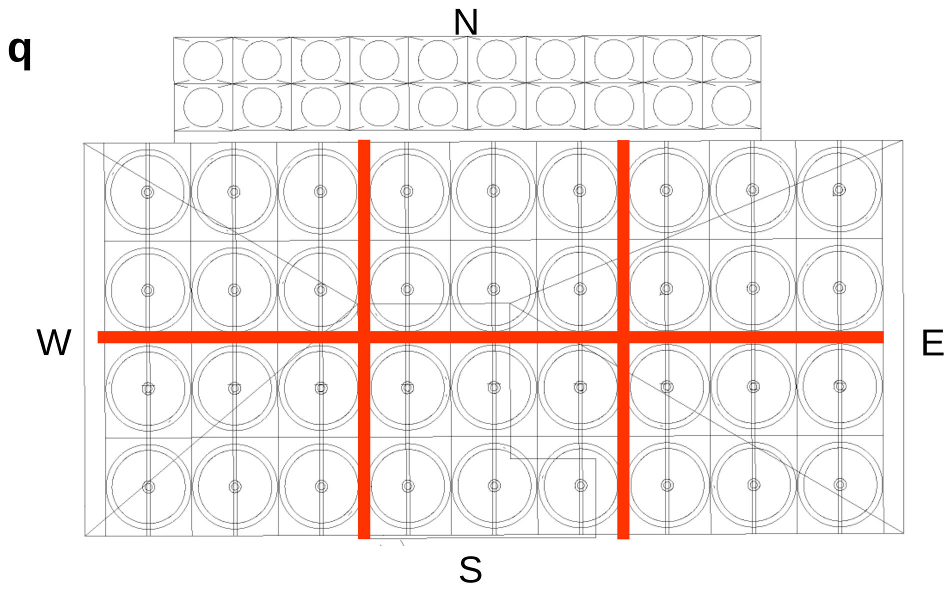


ground based

Screen height = 15.238 m

Tested configurations

- Unit X (cruciform designs) – Unit Y implements symmetric layout



ground based

Screen height = 15.238 m

Tested configurations

- Unit X (cruciform designs) – Unit Y implements symmetric layout

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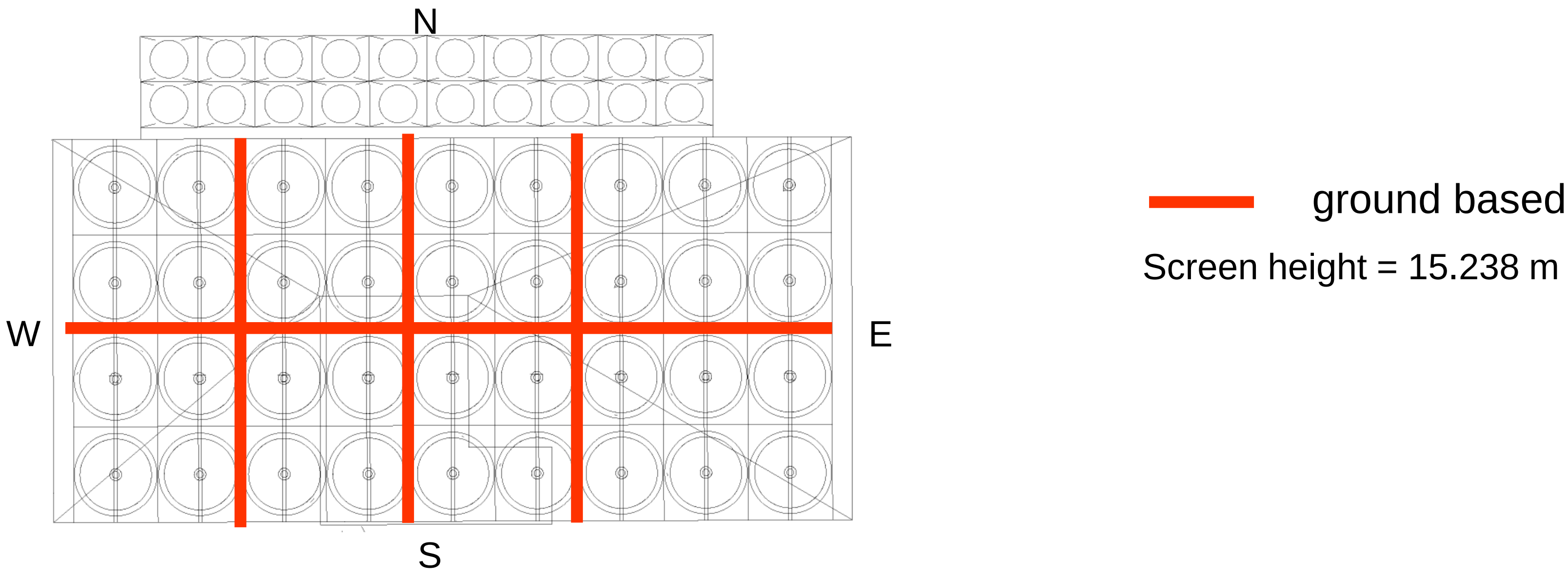
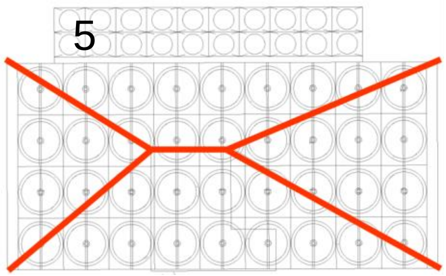
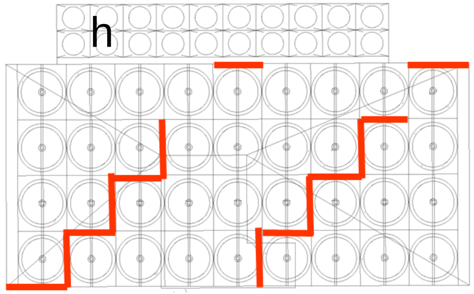
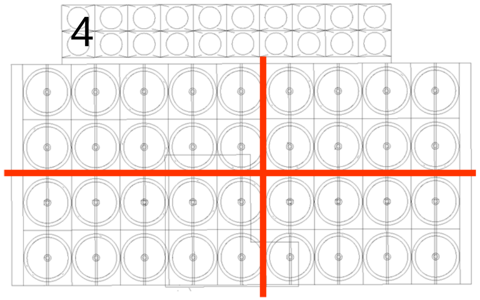


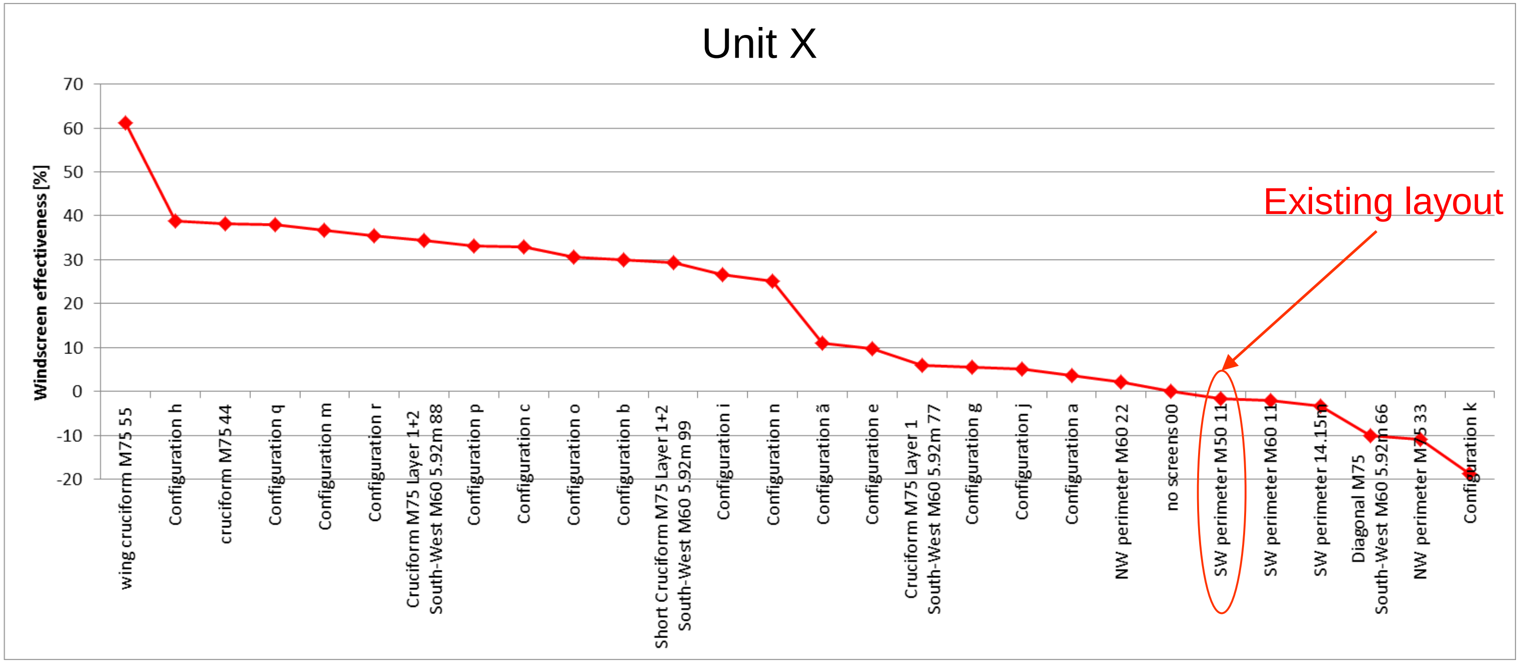
Results for NW wind at 20 mph

- Unit X is the upstream unit
- Best ranked layouts



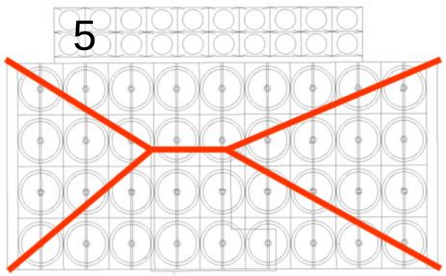


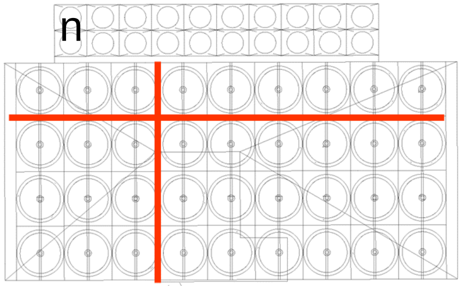


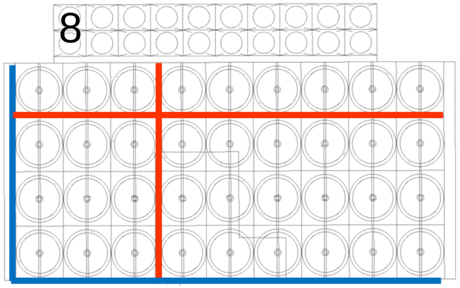


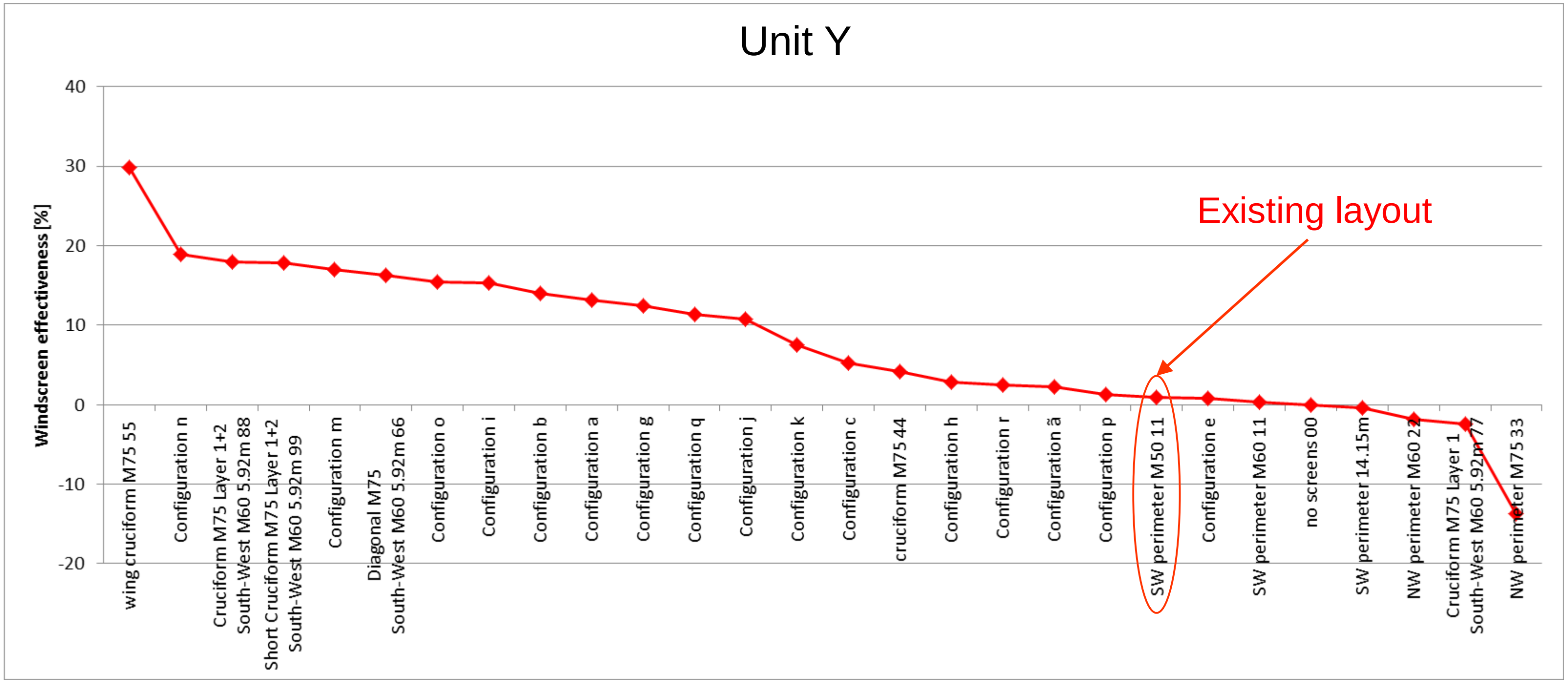
Results for NW wind at 20 mph

- Unit Y is the downstream unit
- Best ranked layouts



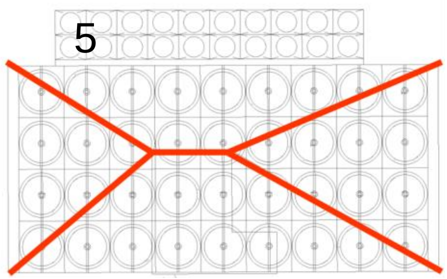


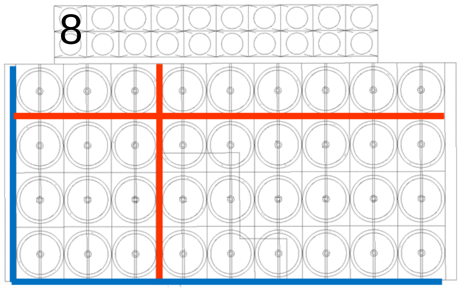


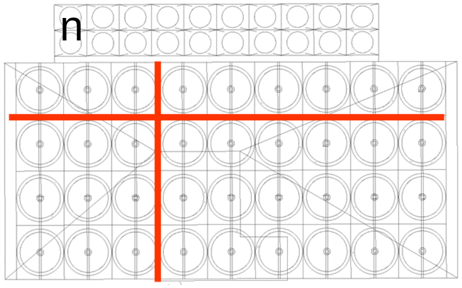


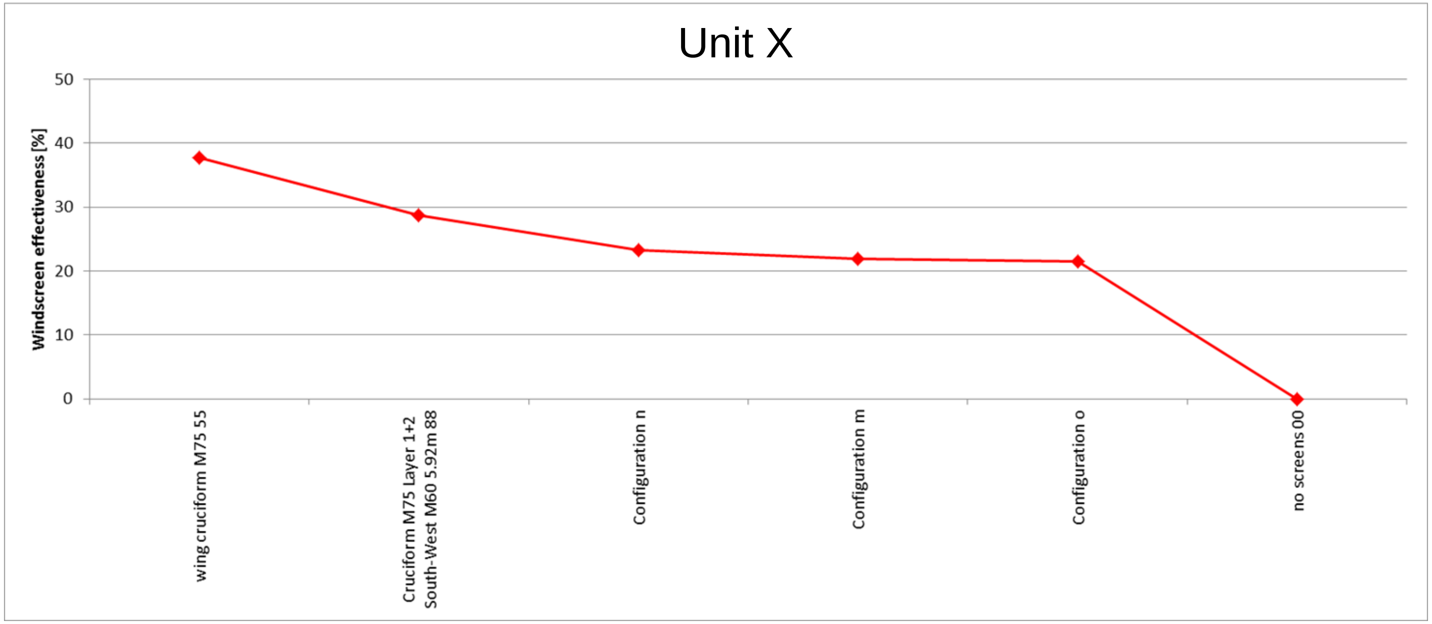
Results for SW wind at 20 mph

- Most promising layouts for the downstream unit were selected to test with SW
  - Now the downstream unit is X
- Ranking is substantially confirmed



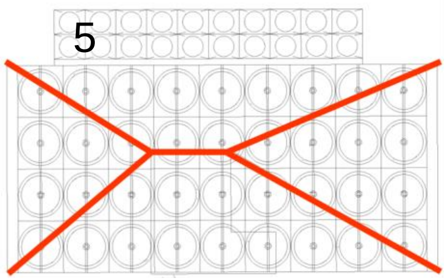


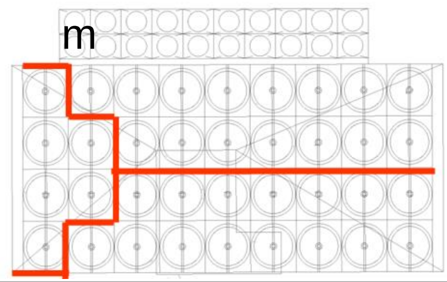


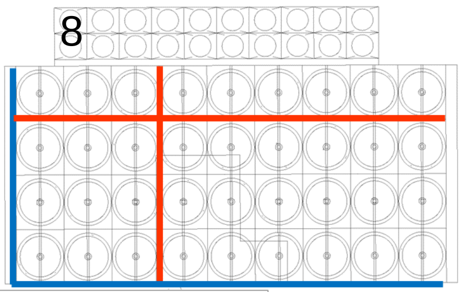


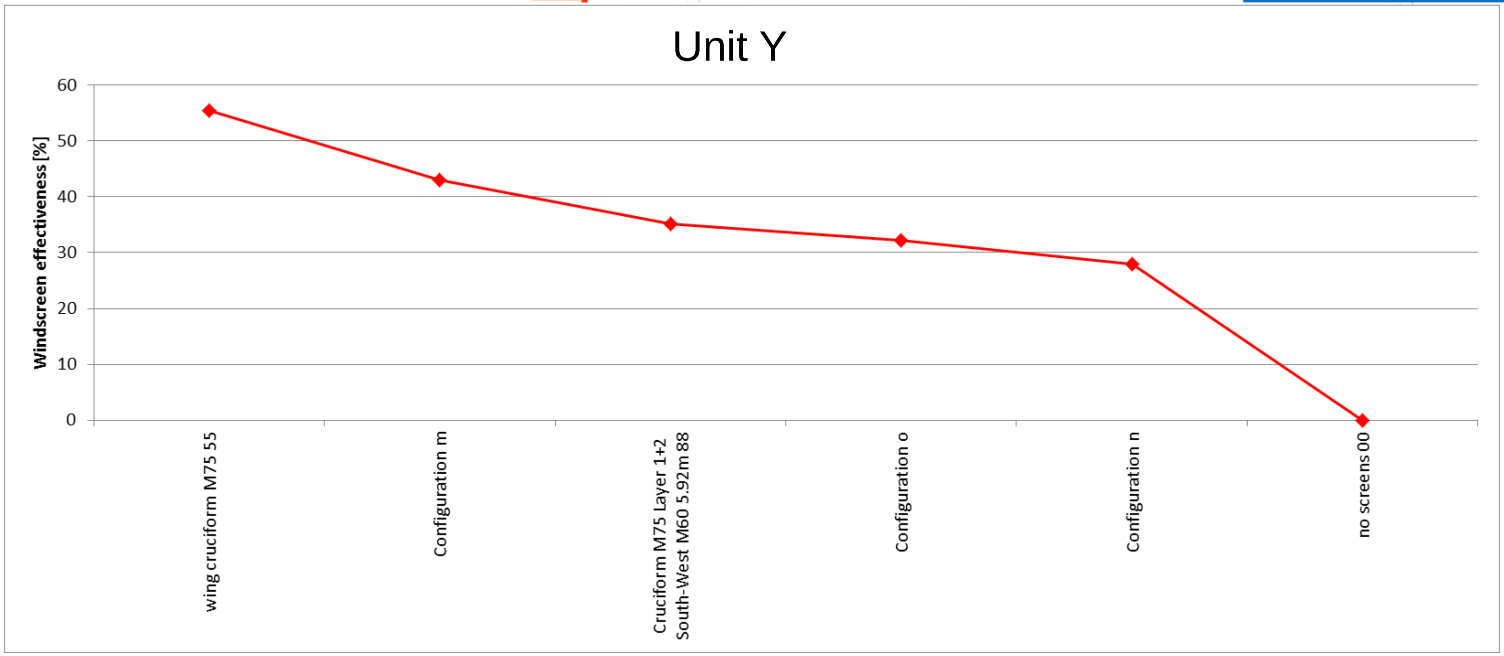
Results for SW wind at 20 mph

- Significant improvements are registered for the upstream unit as well
- Losses due to wind can be reduced up to 55%



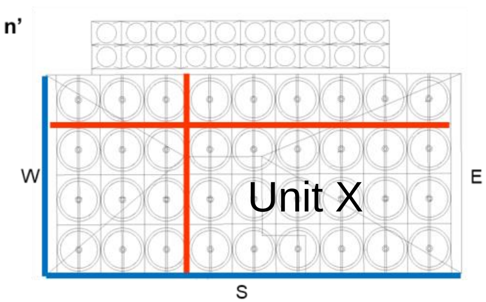


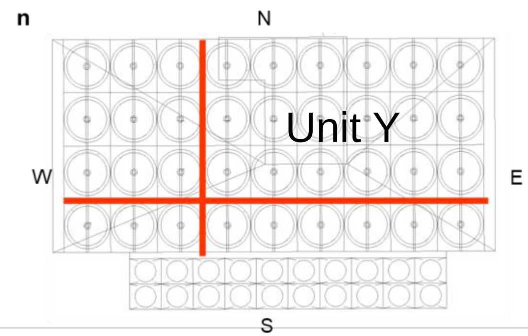


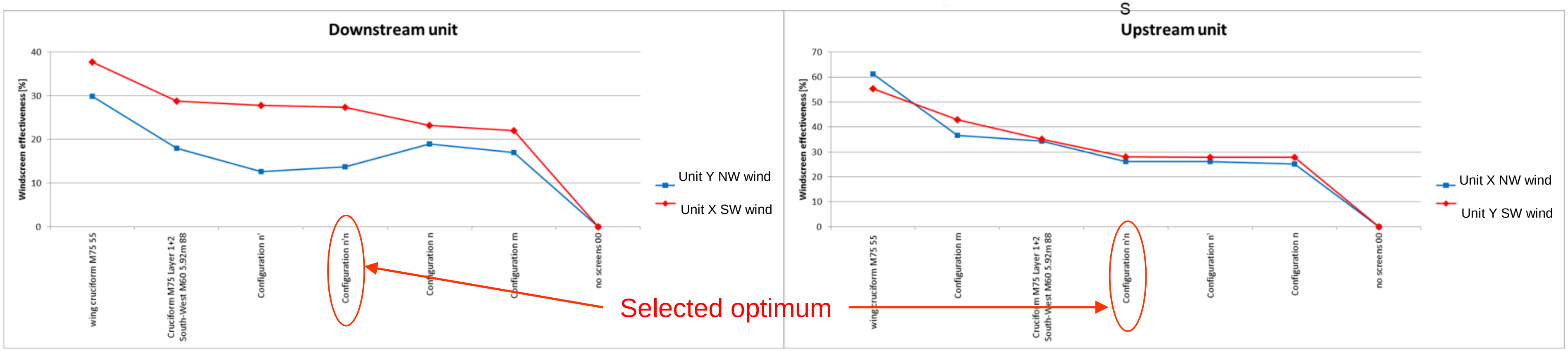


Results

- Wing cruciform layout is the most performing however it was discarded
  - More difficult installation, generate higher stresses on the structure
- Focusing on downstream unit with SW wind there are three layouts with equivalent performance (effectiveness close to 30%)
  - Layout 88 was discarded to leave space for road passing
  - Configuration n'n was selected as it better perform with NW winds

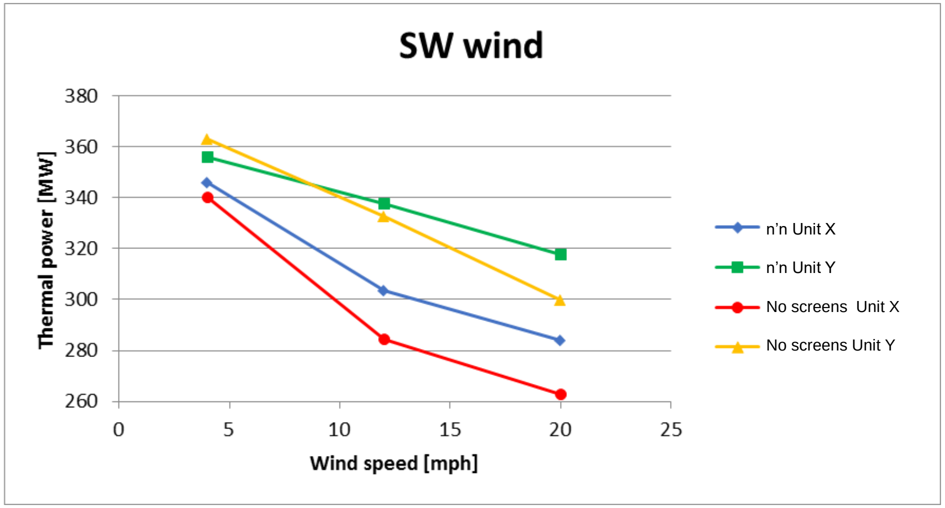


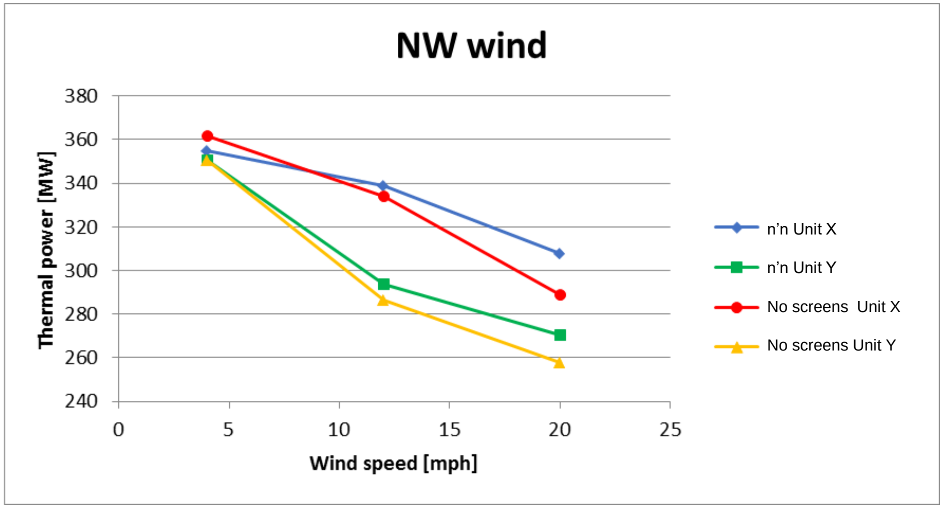




Results

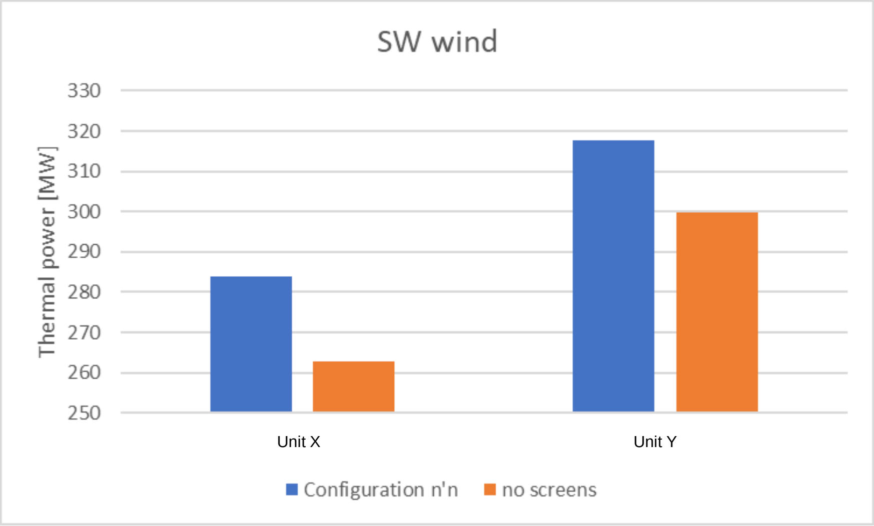
- Wind speed sensitivity
- Optimum solution performance where tested also at lower wind speeds
  - At 5 mph the benefits are negligible
  - At 12 mph the benefits are significant only on the downstream unit
  - At 20 mph significant benefits for both upstream and dowstrean unit
    - → Benefits confirmed with NW wind

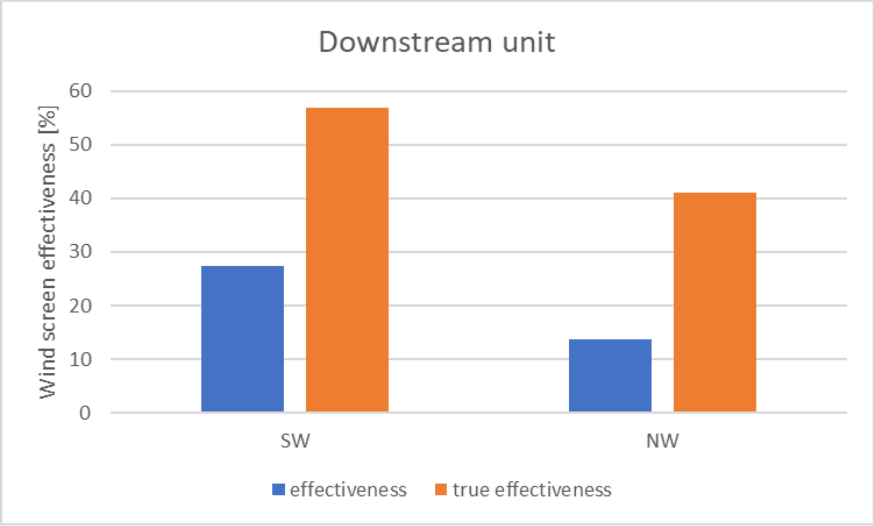




Results

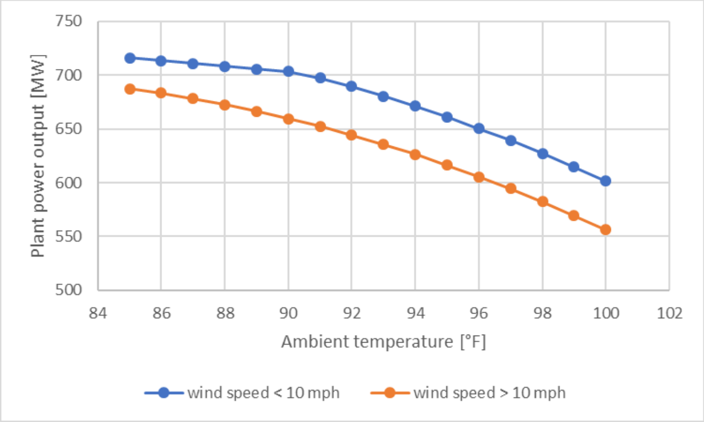
- Are the benefits enough for not derating the downstream unit?
  - Difficult to estimate directly
  - Standard wind screen effectiveness may be too conservative in this case
    - → CFD is predicting a derating of the ACC on the upstream unit
    - → Field experience: the upstream unit does not require afterburner shutdown
    - → Any ACC derating within the limit of the upstream unit derating is managable without the afterburner shutdown
  - True wind screen effectiveness is defined against the upstream unit performance
    - → Wind screens are able to recover more than 55% of the derating on the downstream unit





Results

- Pay-back period
  - The derating due to high wind is about 50MW
    - → For ambient temperature above 90 °F it is substantially independent on ambient conditions
  - True effectiveness showed the capability of recovering more than 55% of the cooling capacity of the ACC
    - → On average the derating is reduced to 21MW
  - With a low electricity price (30$MWh) the payback period for the investement is 570 h
    - → Cumulative hours with wind above 10 mph
  - Most of such derating occurs in hot summer days when the price is higher
    - → The pay-back period can be as short as 168 h (of high wind) for 100$ MWh
  - Summer 2019: 217h with wind above 10mph and temperature above 26 °C
  - Summer 2018: 368h with wind above 10mph and temperature above 26 °C



Conclusions

- The optimization of the wind screen layout by means of CFD was able to identify candidates with much higher performance than the one currently installed
  - Some canditates were discarded due to installation complexity and higher loads on the structure
- The selected optimum showed the capability of recovering 58% of the losses of the downstream ACC cooling capacity with respect to the upstream unit
  - The upstream unit do not suffer frequent net output deratings due to high wind
    - → The afterburner is rarely shutdown
  - The upstream unit also benefits the installation of wind screens
- Considering obtained improvements a simplified economical analysis shows that the pay-back period is pretty short
  - Obviously it depends on how windy the location is

Deficiency reduction after installation of optimized wind screen configuration

Validation

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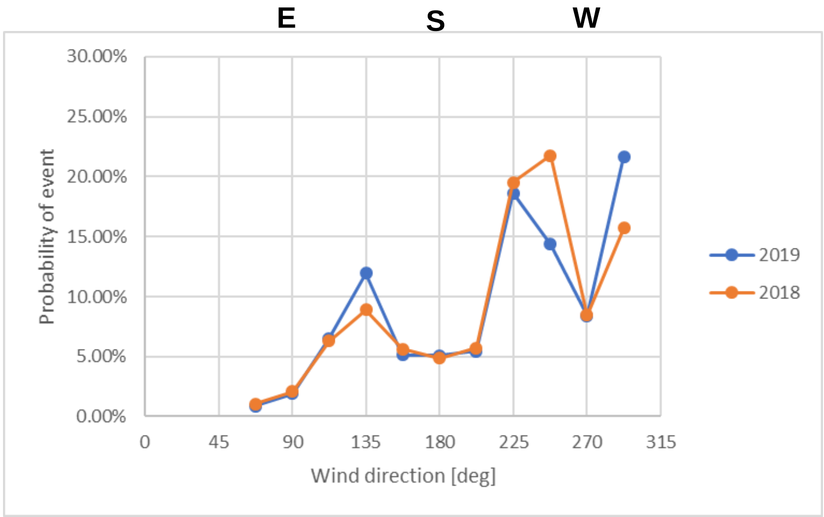
Via Campani 50 Firenze

Validation against PI Data

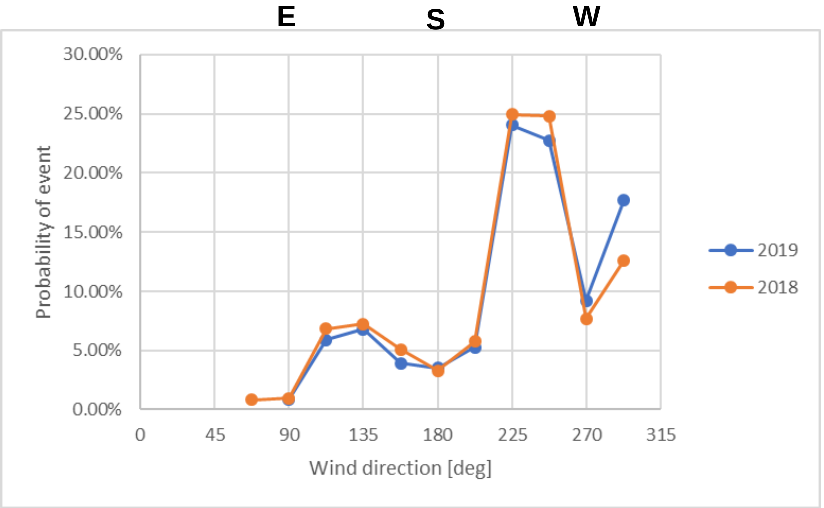
- Installation was completed during spring 2019
- Preliminary validation of new layout against PI DATA from summer 2018 against summer 2019

Weather data analysis

- Summer Data (from June to September)
  - All events

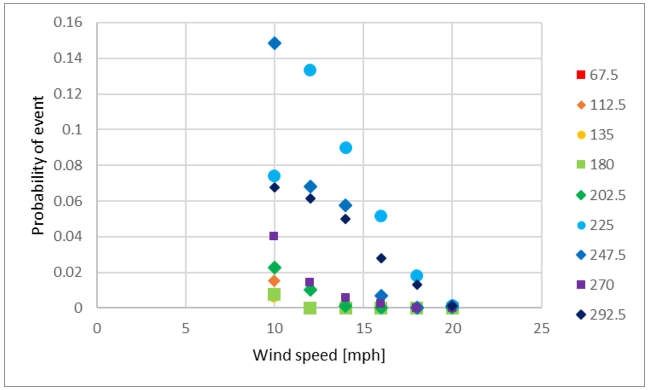


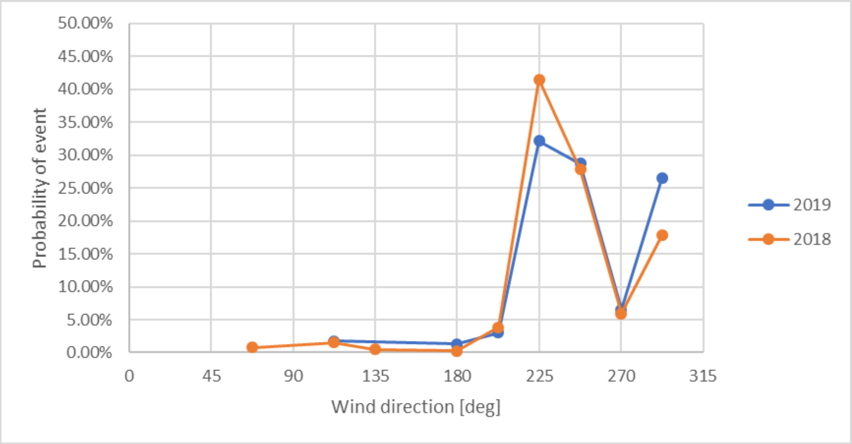
  - Hot days
    →Ambient temperature >28 °C



Weather data analysis

- Summer Data (from June to September)
  - Hot days with high wind
    - →Ambient temperature >28 °C
    - →Wind speed >10 mph





- If the sample of data is representative of all critical events
  - NW wind is not frequent
  - Optimization should focus on SW wind only

PI data analysis

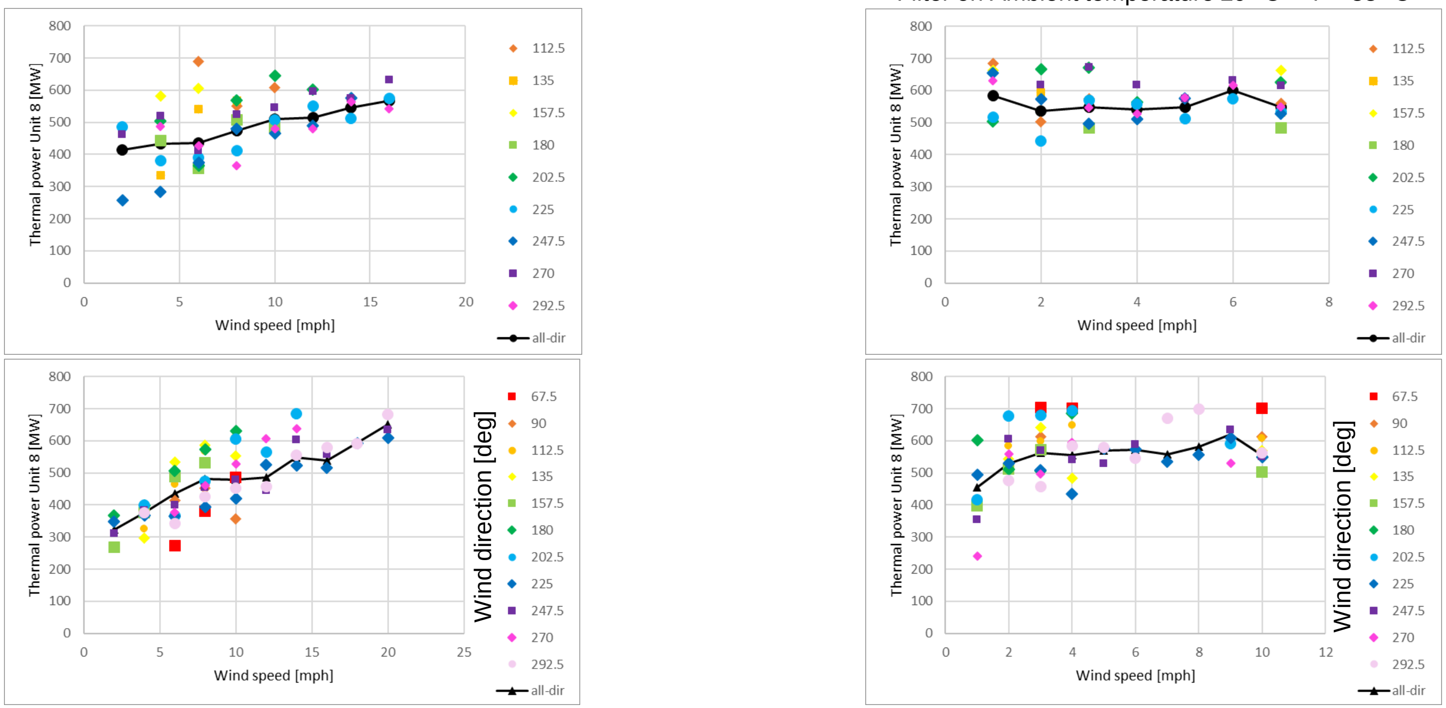
- Summer Data (from June to September)
  - Total power (Unit X) is computed as the sum of GT1 + GT2 + ST
  - Mean total power is showing a growing trend with wind speed
    → The wind direction does not have a significant impact

All events

Hot days
Filter on Ambient temperature 29 °C < T < 33 °C

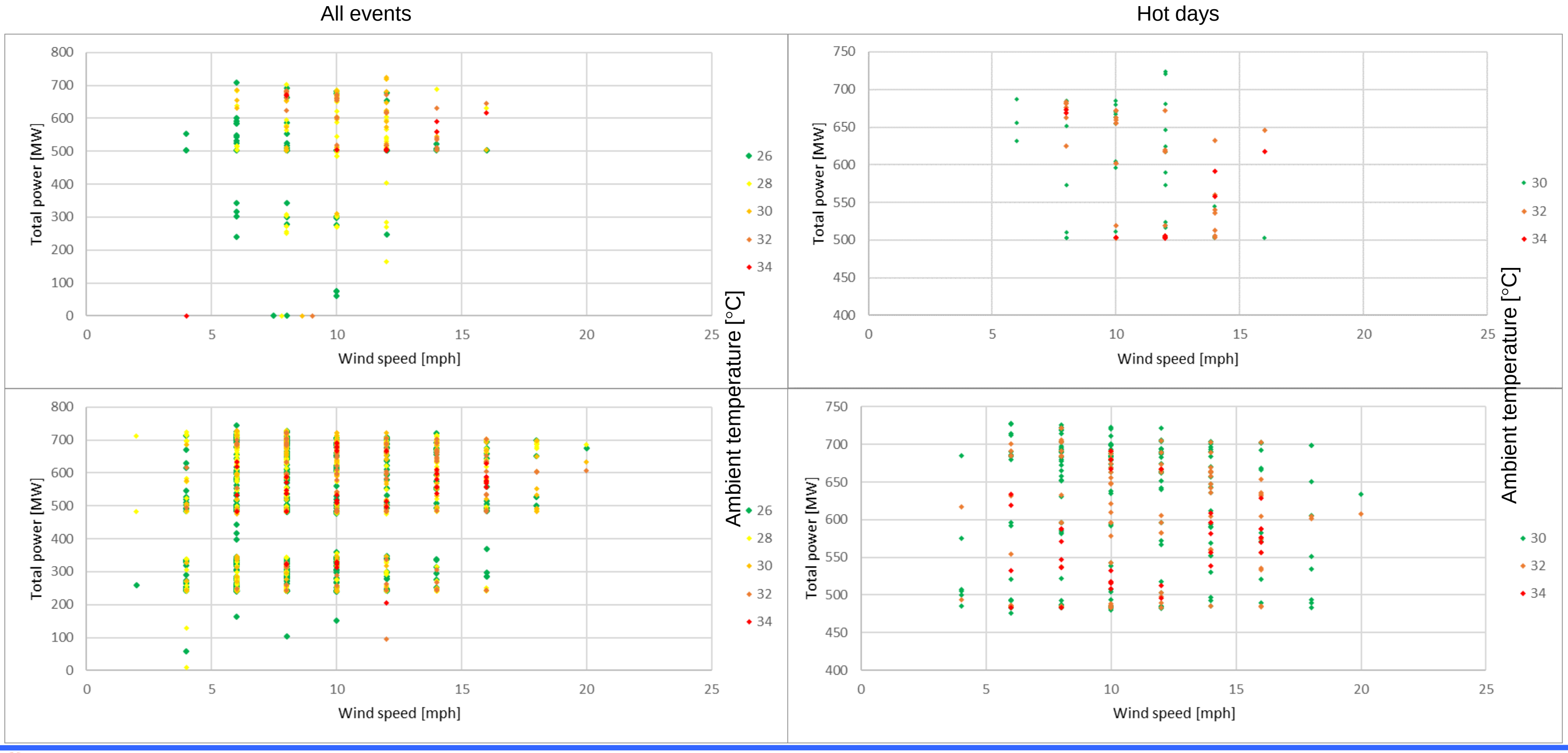
2019

2018



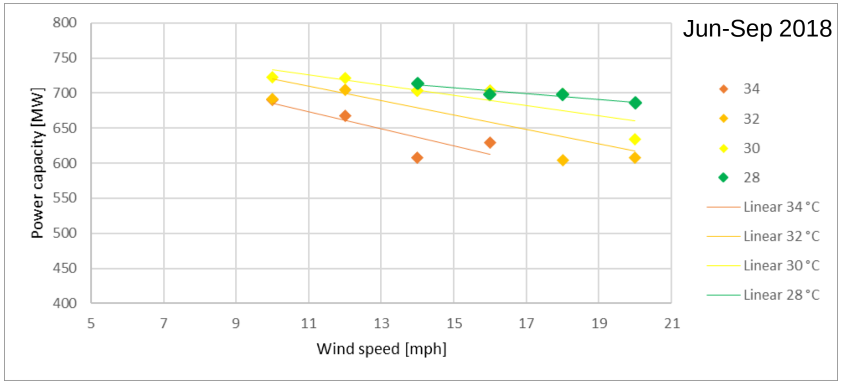
PI data analysis

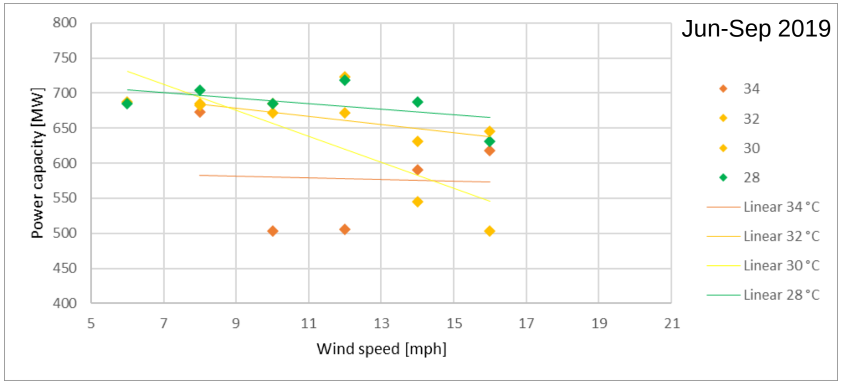
- Summer Data (from June to September)
  - The average value depends on power plant controls
    - → Most of values seem to represent off-design conditions
      - The plant is not always running at max power
    - → It does not represent the expected power capacity



PI data analysis

- Summer Data (from June to September)
  - For each wind speed and temperature level the maximum power value is taken as representative for the expected power capacity
    - → This assumption will be better justified with a larger set of data
    - → Only the wind and temperature conditions showing derating were selected
  - Power capacity for Unit X is showing:
    - → A decreasing trend with wind speed and ambient temperature
    - → The slope decreases at higher temperature
  - With wind screens the trend has a lower slope at high temperature
    - → Derating at 32 °C ambient temperature:
      - No windscreens = -10.27 MW/(mph)
      - With wind screens = -5.75 MW/(mph)





Deficiency reduction after installation of optimized wind screen configuration

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