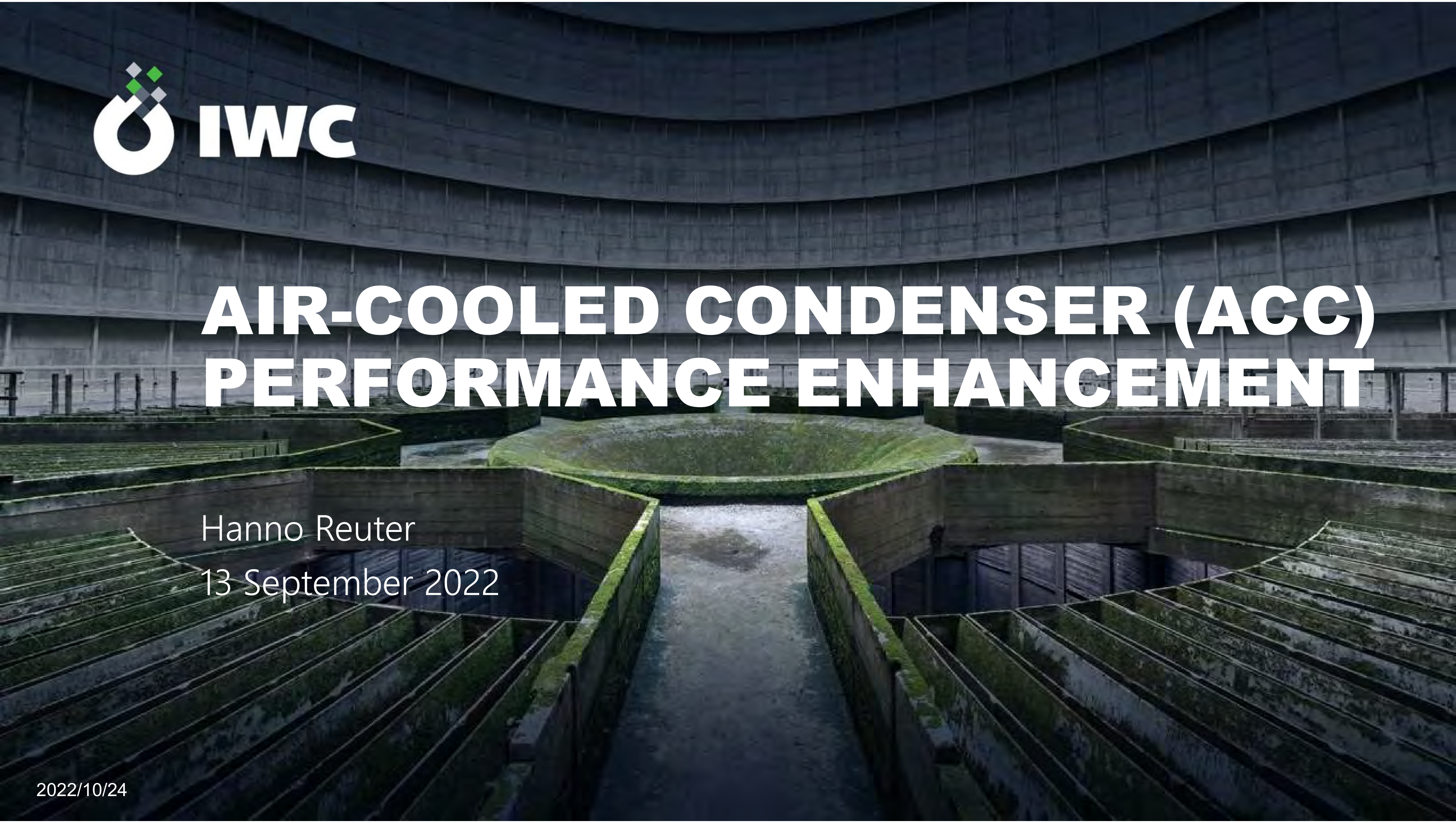

AIR-COOLED CONDENSER (ACC) PERFORMANCE ENHANCEMENT

Hanno Reuter

13 September 2022

OUR TIME TODAY

1. A short intro to IWC
2. Introduction
3. ACC performance enhancement options
4. Methodology
5. Performance and economic impact

IWC is a specialist EPC contractor, providing engineered thermal solutions to all industries

Wide range of projects

Unique, tailored solutions

Solutions that are built to last

Geographic Regions

IWC has delivered projects located in the following regions:

100+

years of collective engineering experience

30+

years of pioneering cooling technology

14,500+

successful cooling towerinstallations across Africa and the globe

Offices and representatives in and throughout

Africa, Australia, India

Industries we serve


Range of industries
Mining & minerals
Petrochemical
Agro-chemical
Power
Manufacturing
Food & Beverage

Our product range

- Cooling towers
- Heat exchangers
- Water treatment
- Chillers
- Refurbishment & spares

Some of our notable clients

Roxgold	ANGLO PLATINUM	Chevron	Nampak packaging excellence	ArcelorMittal	HARMONY
SibanyeGOLD	IMPLATS Distinctly Platinum	sasol reaching new frontiers	HATCH	FOSKOR	sappi
RCL FOODS	sappi SAICCOR	Howden	TRANSNET	TongaatHulett	SRCC sundays river citrus company
BOSCH PROJECTS	Eskom	VEOLIA	TIGER BRANDS	HELDEN	COLDFACT

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Introduction

Air-cooled condensers (ACCs) are dry-cooling systems used in power plants to condense steam turbine exhaust steam by transferring heat from the steam to the atmosphere.

By enhancing ACC performance, savings can be achieved and negative environmental impact reduced.

A methodology and desktop study are presented to evaluate the performance impact, cost saving and payback period of the following performance enhancement options on a 25 cell ACC, using plant DCS data measured over a period of 1 year:

- Addition of hybrid (dry/wet) dephlegmator modules
- Retrofitting of wind mitigating devices
- Replacement of fans with more efficient ones
- Adiabatic pre-cooling of inlet air

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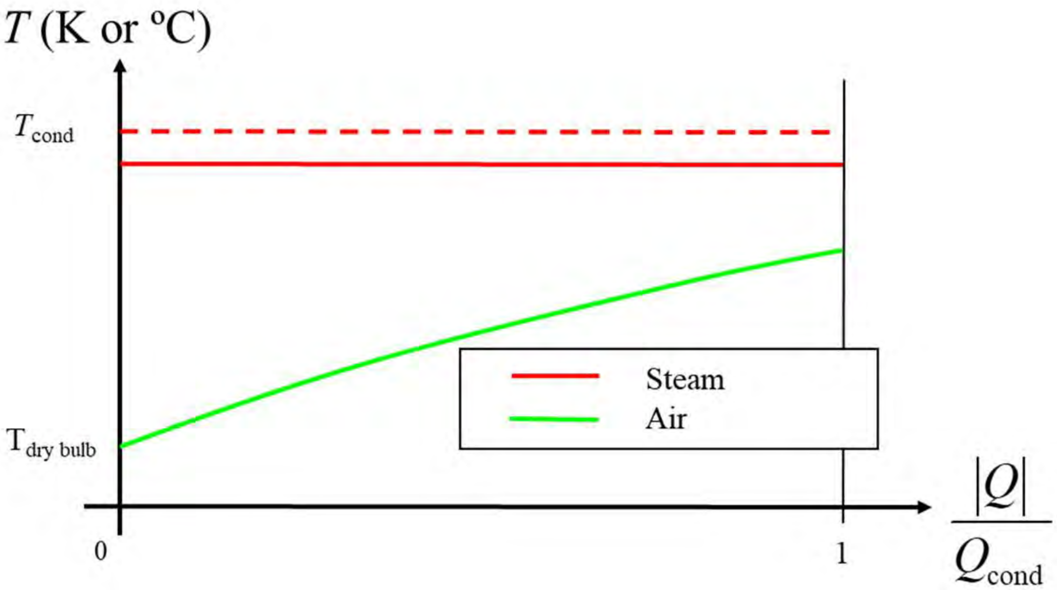
Effect of ACC performance on power plant efficiency

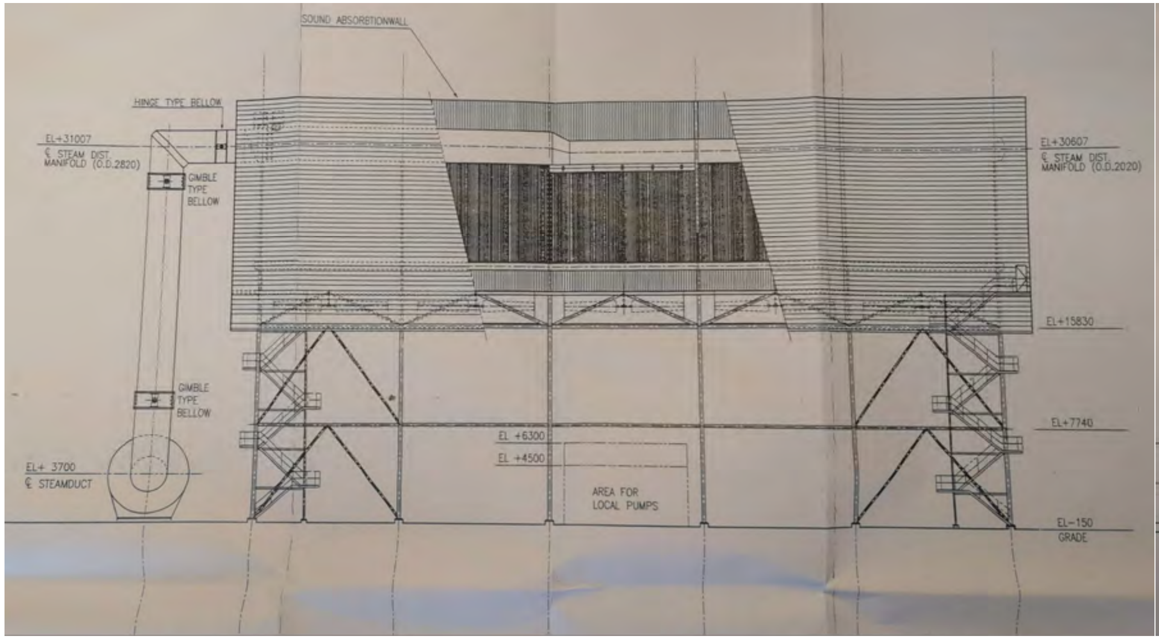


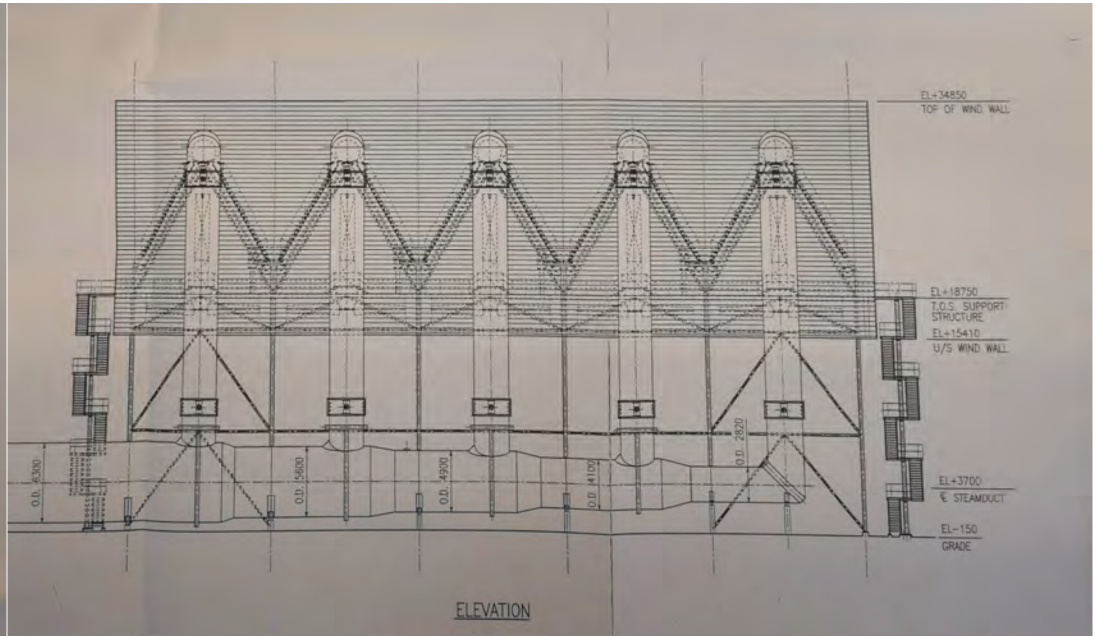
ΔT_{cond} = 1 to 3 ºC (high to low ambient temperatures)

$\Rightarrow \Delta\eta_{gross}$ = 1 %

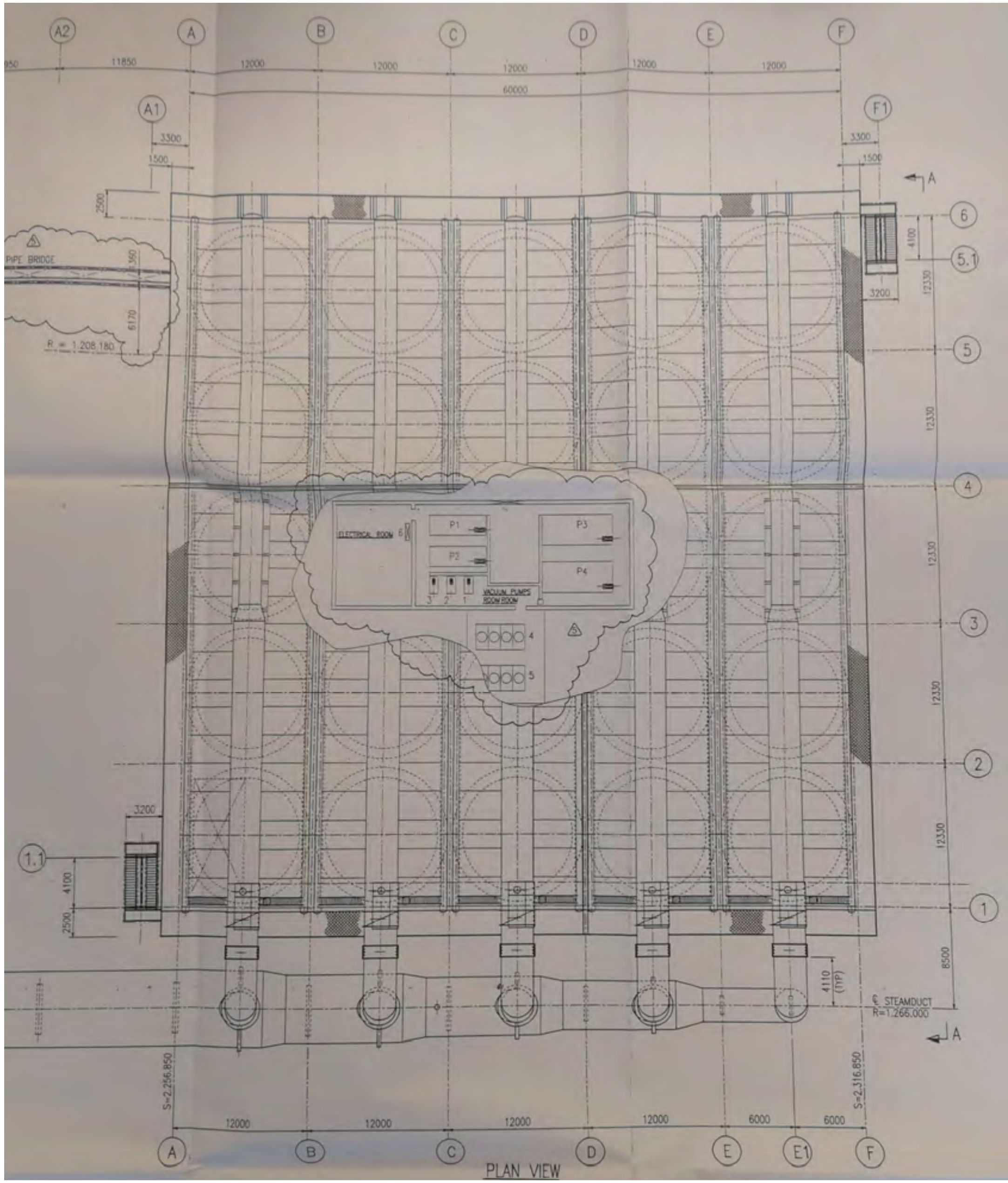
$\Rightarrow \Delta Q_{cond} / Q_{cond}$ x 100 % = 0.8 %

ACC – SIDE VIEWS

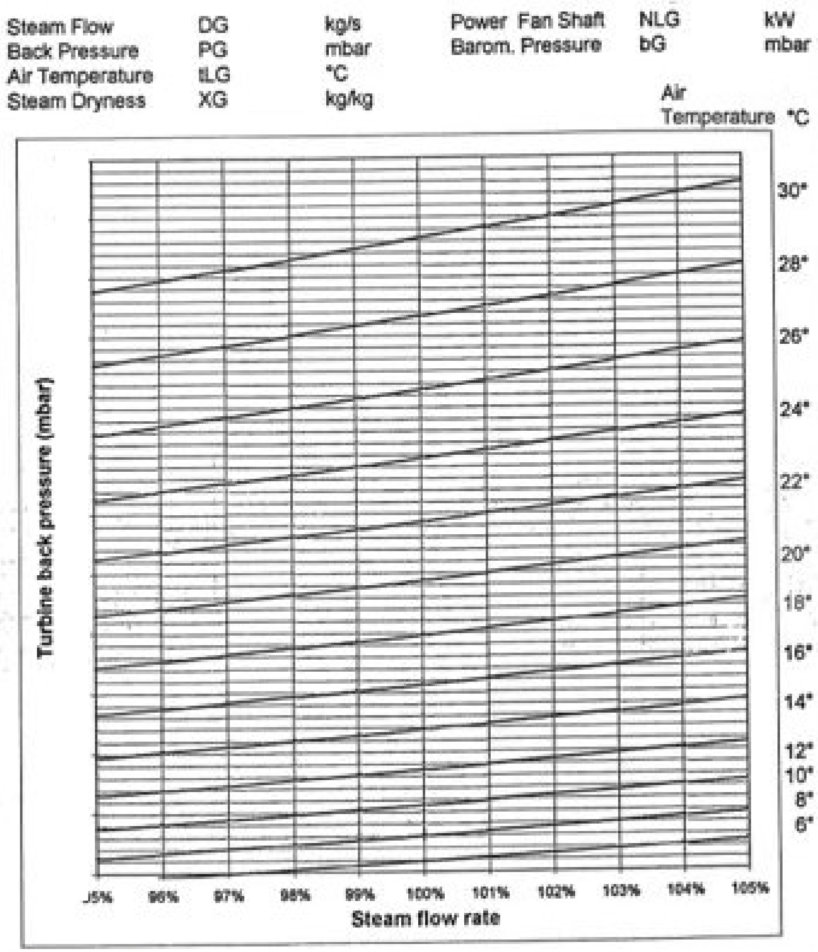




ACC – PLAN VIEW



ACC performance curves (original)



$$ITD = T_{s,ST} - T_{ai} \approx f_1\left(\frac{m_c}{m_{c,des}}, T_{ai}, \frac{N_{fan,des}}{N_{fan}}\right) \quad [\,^oC]$$

$$\Delta p_{SDuct} = f_2(\rho_s, m_s) \quad [bar]$$

used when ACC is in combination with HDWD

$$P_{fan} \approx f_3\left(\frac{\rho_{ai}}{\rho_{ai,des}}, \frac{N_{fan}}{N_{fan,des}}\right) \quad [kW]$$

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Datasheets

Datasheets were obtained for:

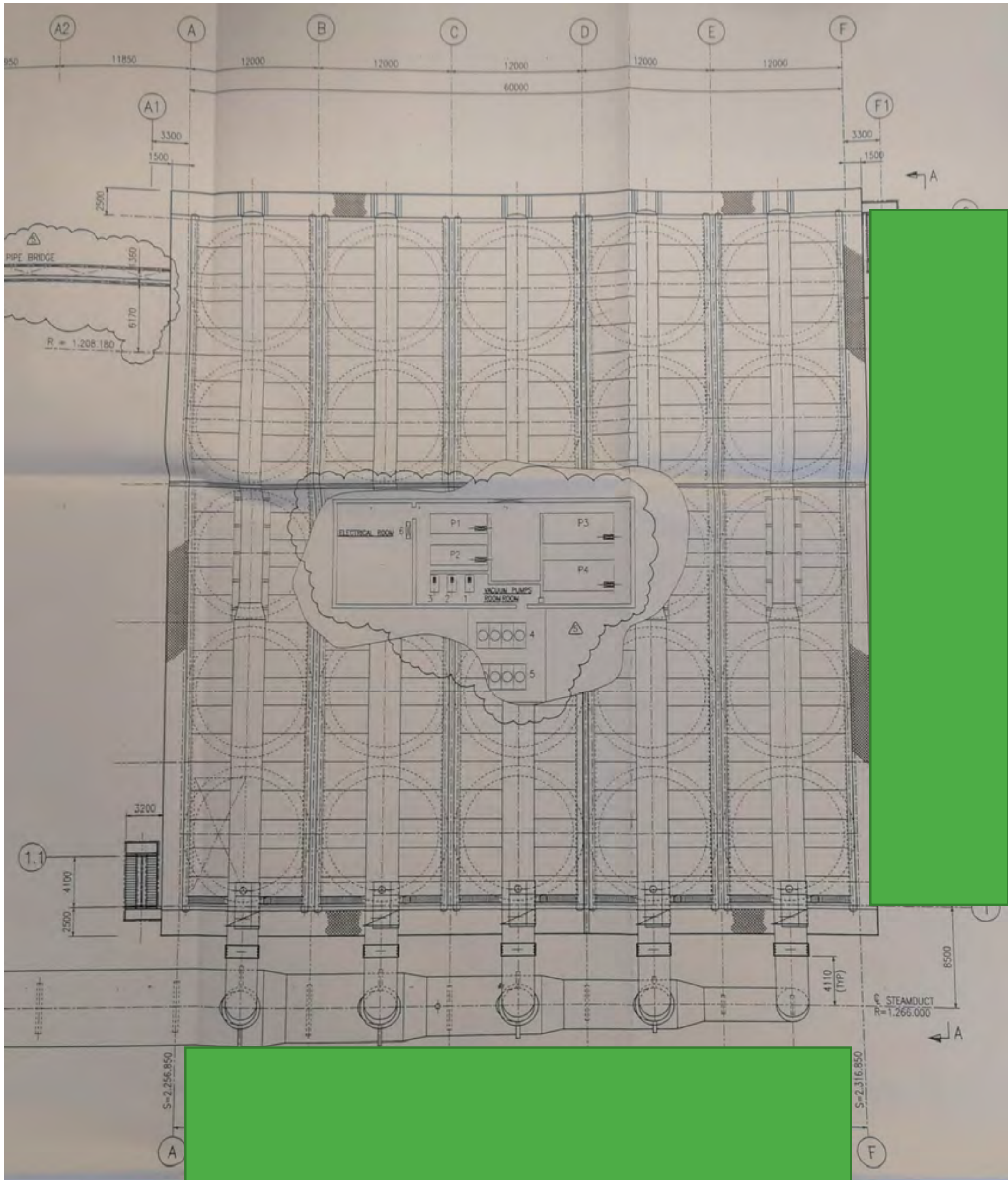
- Fans
- Gearbox
- Electric motor
- Vacuum system

Additional ACC units

$$ITD_2 \approx \frac{N_{fans,1}}{N_{fans,2}} \times ITD_1$$

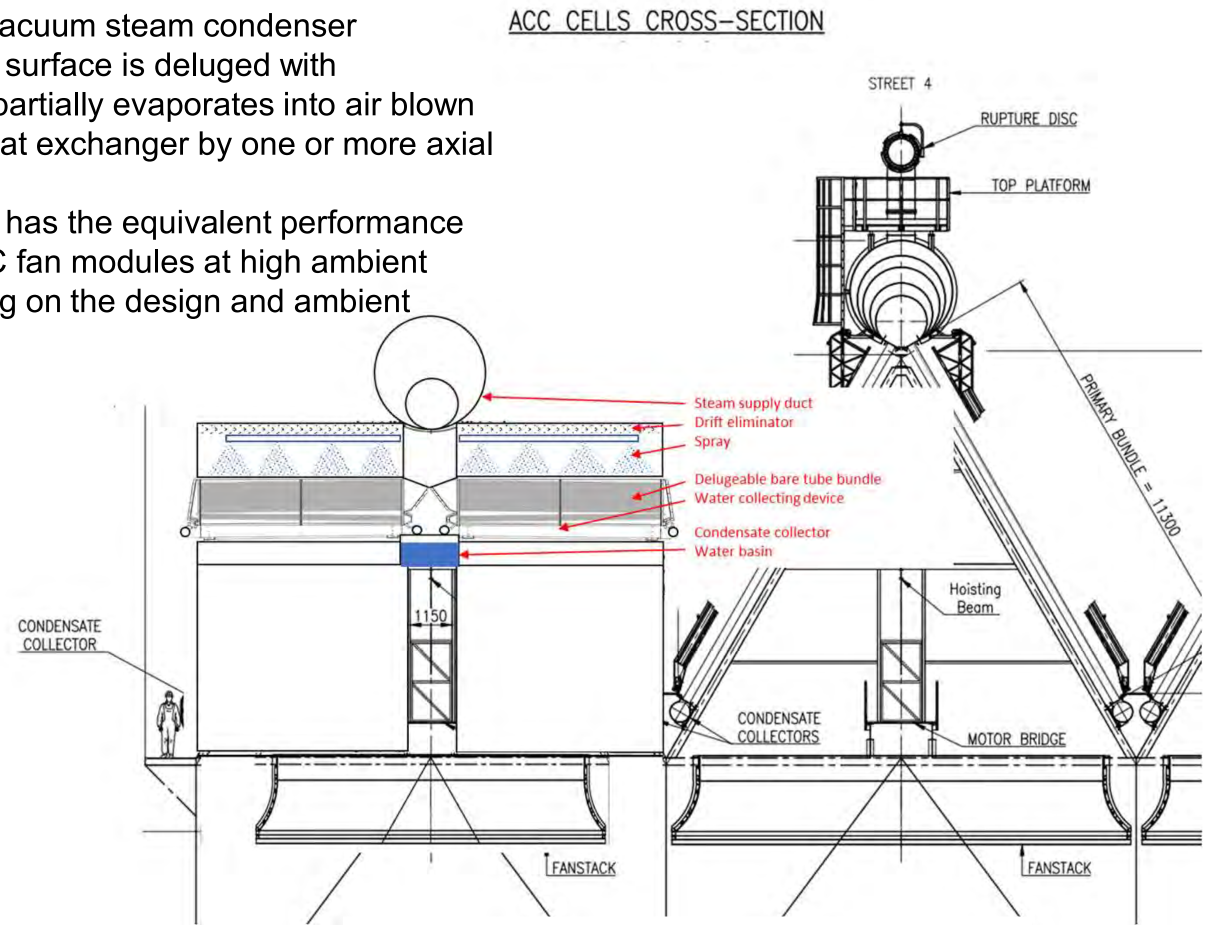
$$ITD = T_{s\,(ST\ exhaust)} - T_{amb}$$

Depending on the ambient temperature (T_{amb}), a 1 to 2 ^{o}C reduction in ITD can result in a 1 % increase in steam turbine power output (P_{ST})



HDWD fan module description

- ❑ Bare tube evaporative vacuum steam condenser
- ❑ External heat exchange surface is deluged with recirculating water that partially evaporates into air blown or drawn through the heat exchanger by one or more axial flow fans.
- ❑ One HDWD fan module has the equivalent performance to between 4 and 6 ACC fan modules at high ambient temperatures, depending on the design and ambient conditions.



HDWD ACC

One HDWD fan module:

Heat exchanger:
- Typically 12-16 bare tube bundles
- 25 tube rows
- ¾" carbon steel tubes hot-dipped galvanised
- 1 % tube inclination
- 3 tube passes.

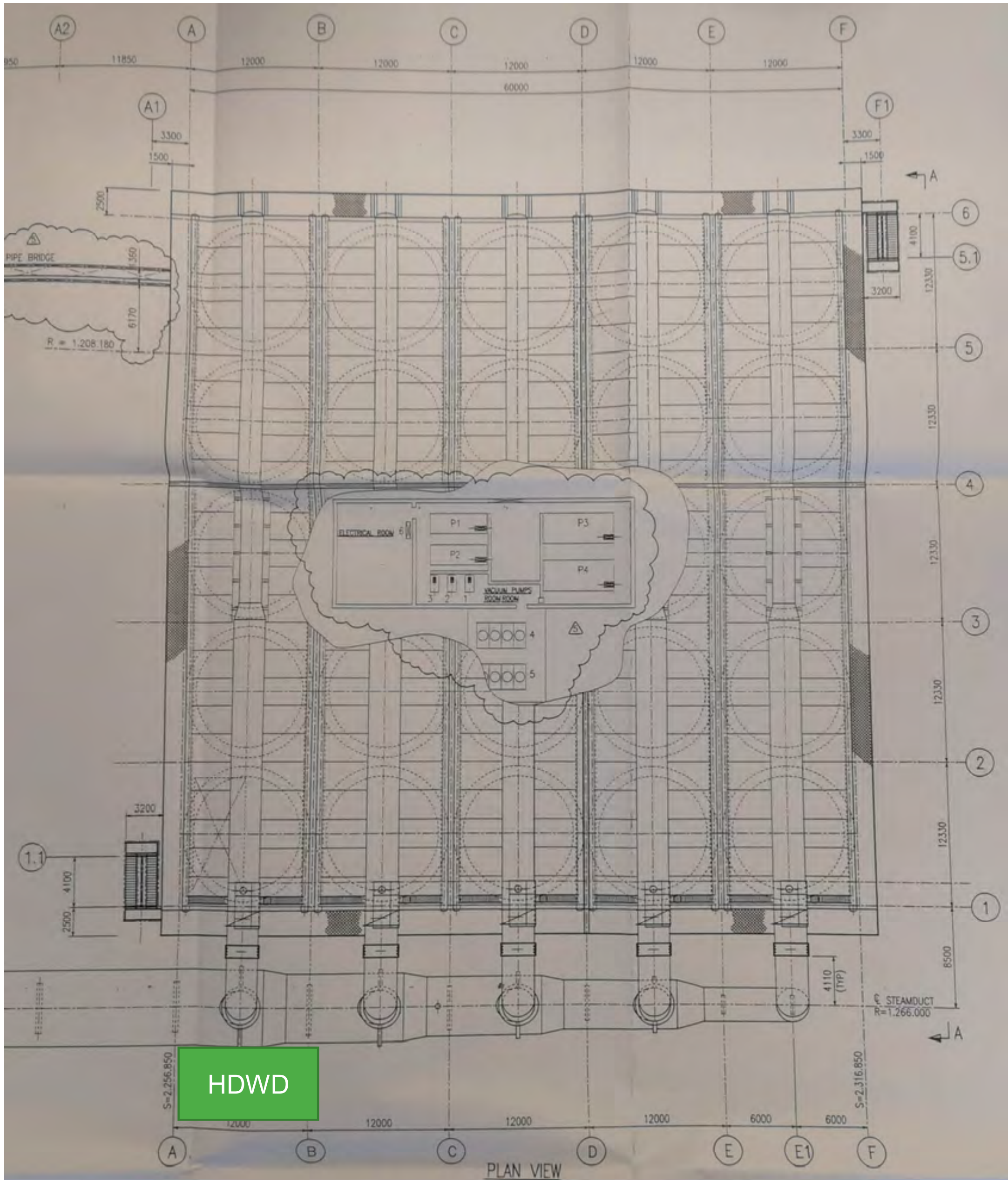
Steam:
- Enters the bundles via inlet header box
- Condensation inside the tubes
- Condensate removed at the outlet of each tube pass.
- Non-condensibles extracted at the outlet of the 3rd tube pass.

Deluge water:
- Sprayed onto the tubes by means of sprayers.
- Flow rate of at least 4 times the maximum evaporation rate.
- Collected in water collecting troughs below the bundle
- Heat transfer from steam to deluge water by condensation, conduction and convection.

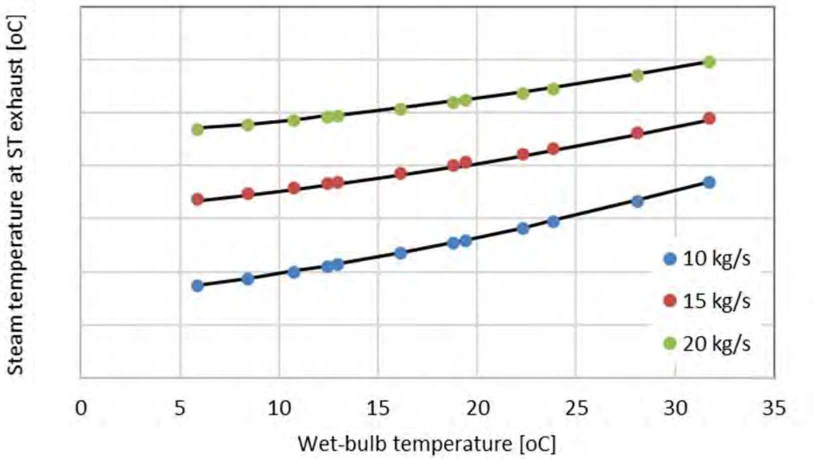
Cooling air:
- Blown through the bundles by forced or induced draft axial fans.
- Heat transfer from deluge water to air by convection and mass transfer.
- Drift eliminator removes entrained droplets.

Additional HDWD unit

- Plot area for a 50 % fan module



HDWD thermal performance curves (current)



$$T_{s,ST} \approx f_4\left(\frac{m_{s,sat}}{X_{fan}}, T_{wbi}\right) \qquad [°C]$$

$$P_{fan} \approx f_5\left(\frac{\rho_{ai}}{\rho_{ai,des}}, \frac{N_{fan}}{N_{fan,des}}\right) \qquad [kW]$$

$$V_{evap} \approx f_6\left(T_{ai}, T_{wbi}, m_{s,sat}, X_{fan}\right) \qquad \left[\frac{m^3}{h}\right]$$

where

$$X_{fan} = \frac{A_{HDWD}}{A_{HDWD,des}}$$

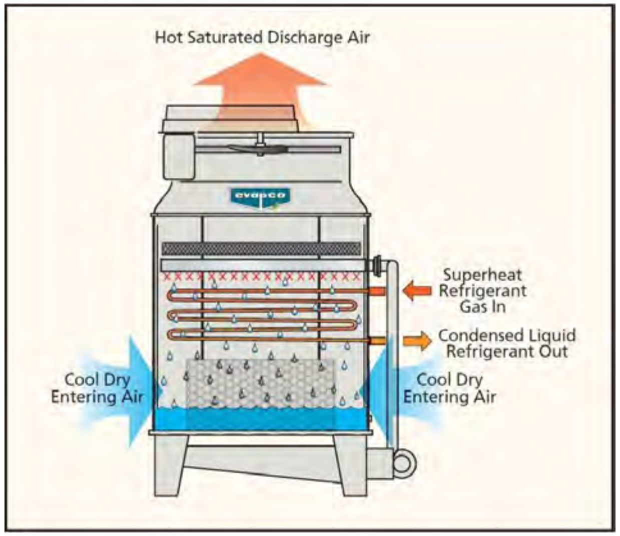
Special design features

- Invented for peak cooling and water saving.
- Can be incorporated in a new or existing ACC.
- Can be operated in dry and wet mode.
- No visible plume if installed in an ACC street.
- Does not require demineralized water quality.
- No corrosion or fouling issues as encountered with fogging/ misting type adiabatic cooling.
- Stand-alone forced draft or induced draft can be installed anywhere close to the ACC steam supply duct.
- Boosting capacity depends on the ambient conditions and number of fan modules installed - to be optimized for every plant.

Bare tube Evaporative condensers for industrial HVAC have been in use for decades

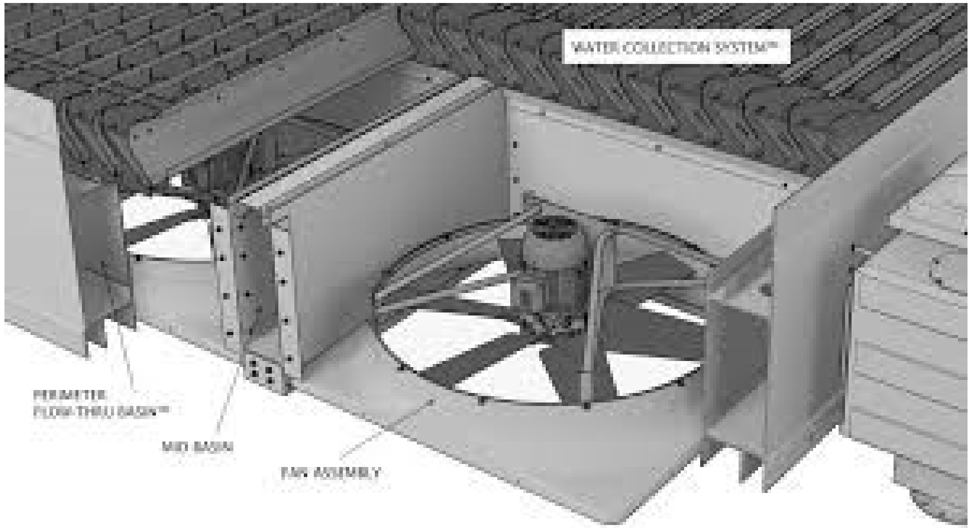
Evapco

BAC



Forced draft wet-cooling towers require water collecting devices above the fans

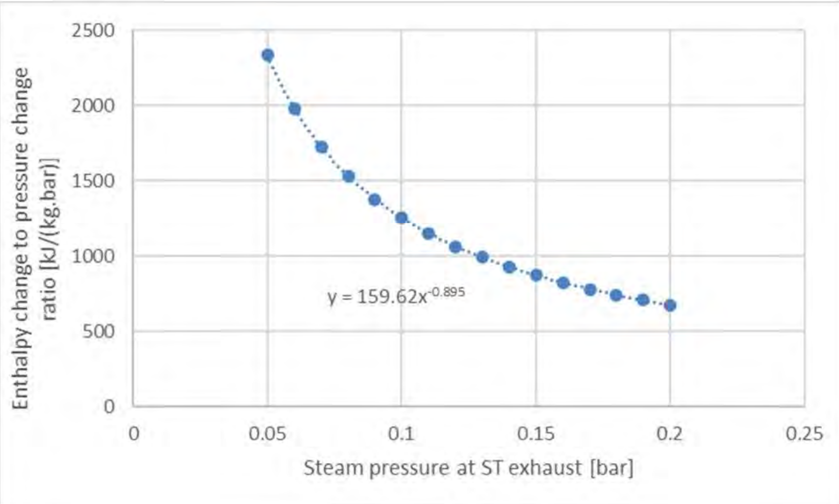
Tower Tech



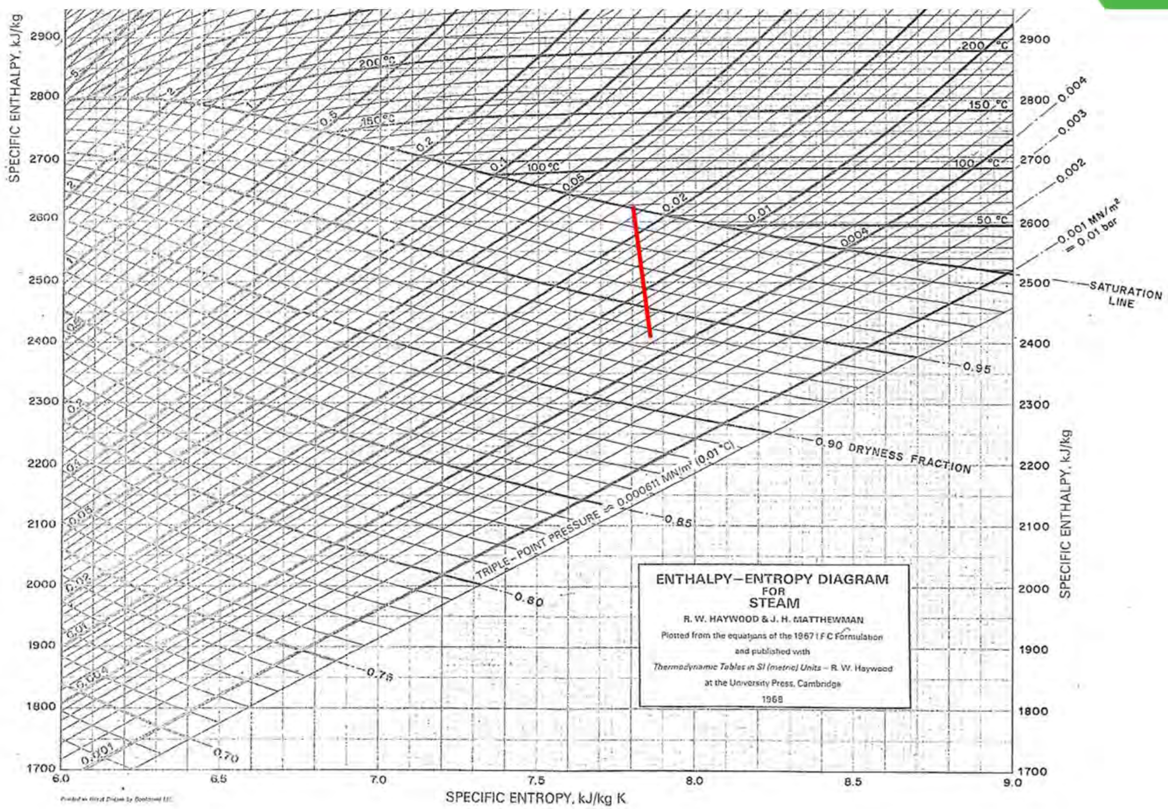
Required water quality (Evapco)

Property	G-235 Galvanized Steel	Type 304 Stainless Steel	Type 316 Stainless Steel
pH	7.0 – 8.8	6.0 – 9.5	6.0 – 9.5
pH During Passivation	7.0 – 8.0	N/A	N/A
Total Suspended Solids (ppm)*	< 25	< 25	< 25
Conductivity (Micro-mhos/cm) **	< 2,400	< 4,000	< 5,000
Alkalinity as CaCO3 (ppm)	75 - 400	< 600	< 600
Calcium Hardness CaCO3 (ppm)	50 - 500	< 600	< 600
Chlorides as Cl (ppm) ***	< 300	< 500	< 2,000
Silica (ppm)	< 150	< 150	< 150
Total Bacteria (cfu/ml)	< 10.000	< 10.000	< 10.000

ST performance change due to enhancement



$$\Delta P_{ST} \approx f_7(p_c, \Delta p_c, m_c) \quad [MW]$$



TYPICAL EXAMPLE:
Impact of Adding one HDWD fan module to six ACC fan modules

Description	Symbol	Unit	Case			
			1.1	1.2	2.1	2.2
ACC fan modules	N_{ACC}	Units	6	6	6	6
HDWD fan modules	N_{HDWD}	Units	0	1	0	1
Initial temperature difference	ITD	°C	29.6	23.7	31.2	16.5
ST exhaust temperature	T_s	°C	44.5	38.3	66.2	51.5
ST exhaust pressure	p_s	mbar	93.2	67.4	271	133
ST exhaust enthalpy	h_s	kJ/kg	2244.8	2209.1	2364	2264.3
Ambient temperature	T_a	°C	15	15	35	35
Relative humidity	Φ_a	%	60	60	60	60
Increase in net power output	$\frac{(\Delta P_{ST} - \Delta P_{Fan})}{P_{ST(ACC\ only)}} \times 100$	%	0	4.0	0	7.8
Increase in fan power output	$\frac{\Delta P_{Fan}}{P_{Fan(ACC\ only)}} \times 100$	%	0	12	0	12
Water consumption (evaporation loss)	$m_{w(evap)}$	m³/h	0	20	0	44
Estimated capital cost	*Capex*	%	100	135	100	135

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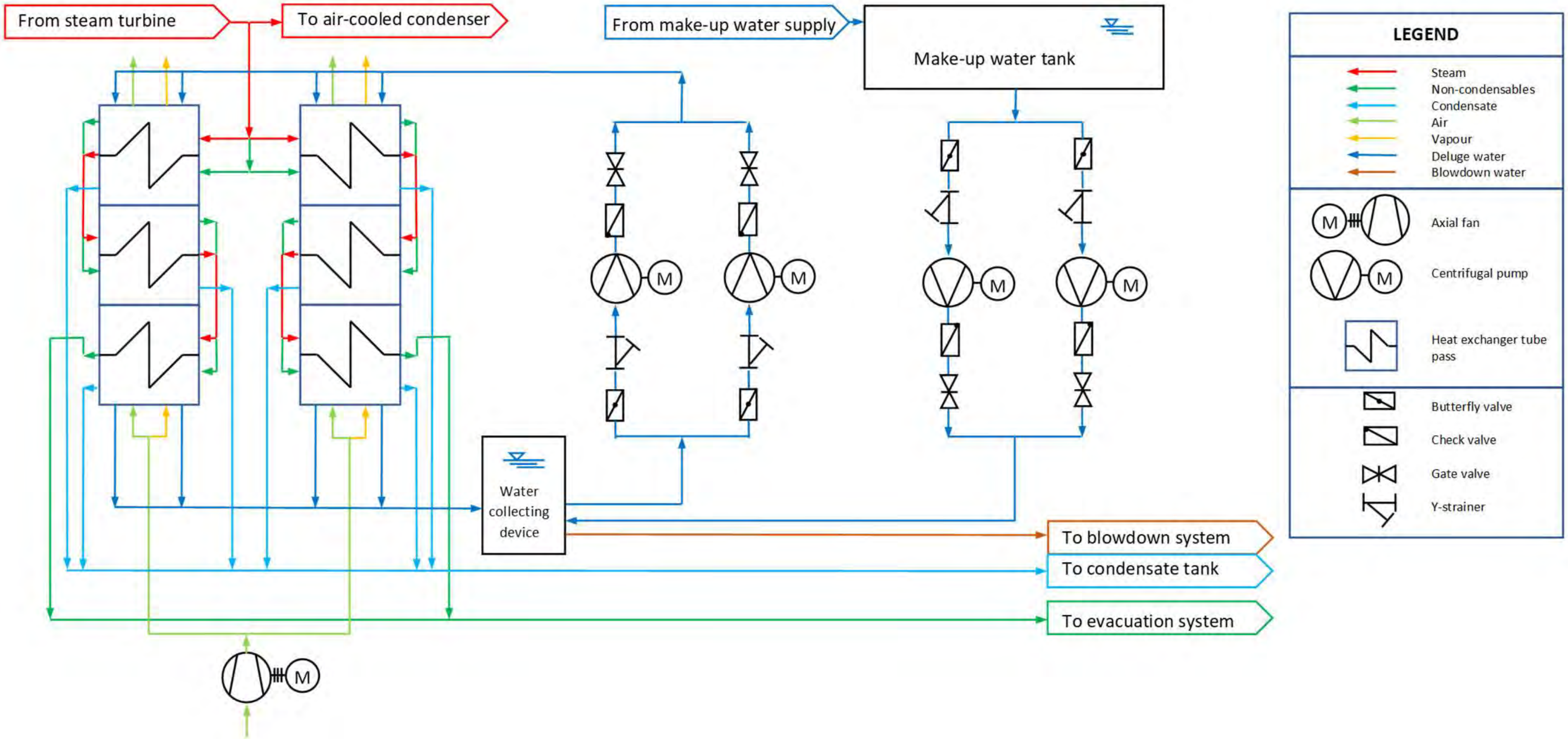
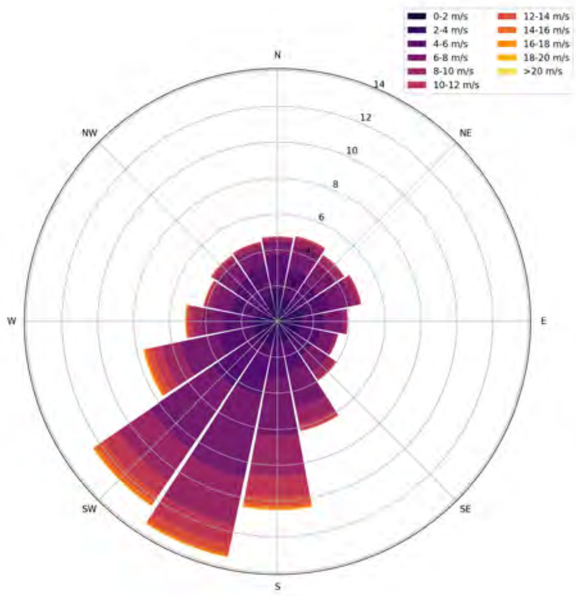
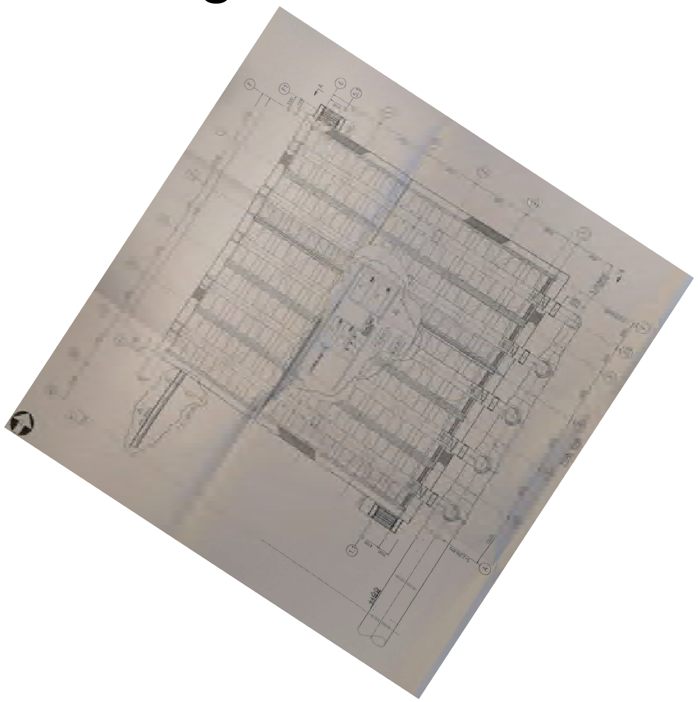
Simple line diagram



Wind mitigating devices

- 2.5 m protruding solid platform/ walkway around the outer periphery outside of the wind wall installed at fan deck level.
- 5.3 m high solid wall wind-cross at ground level below the ACC.





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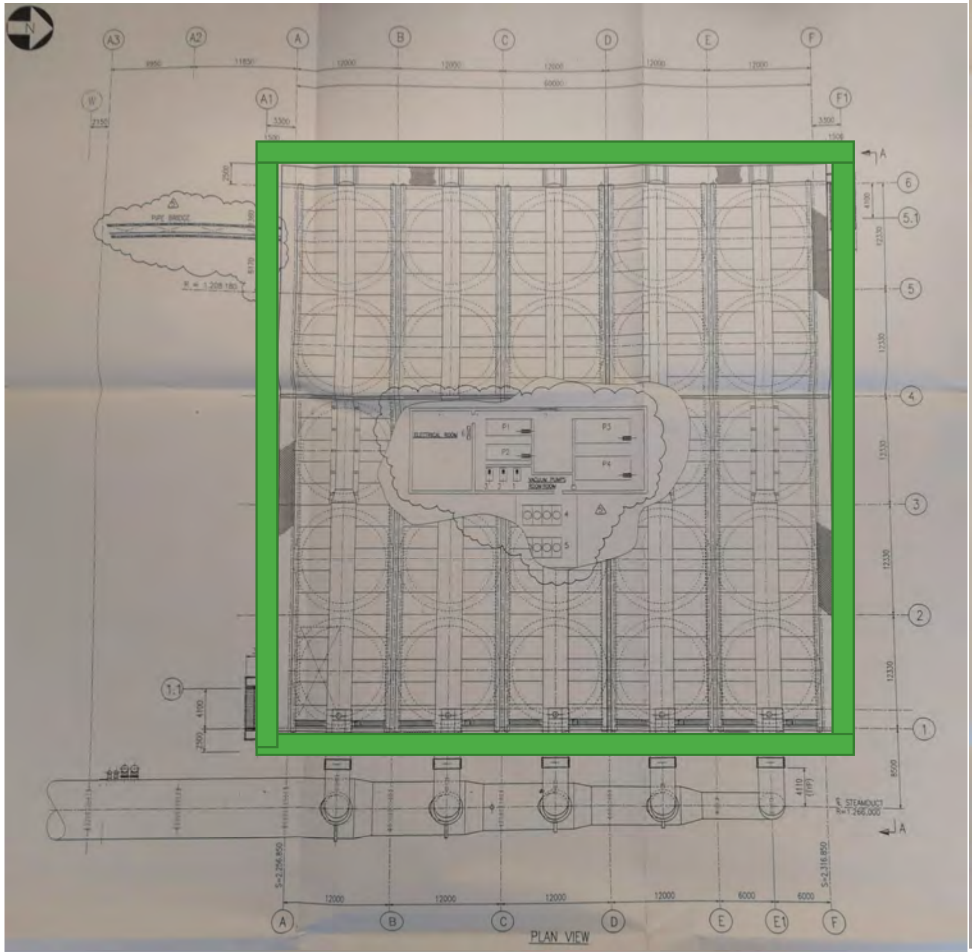
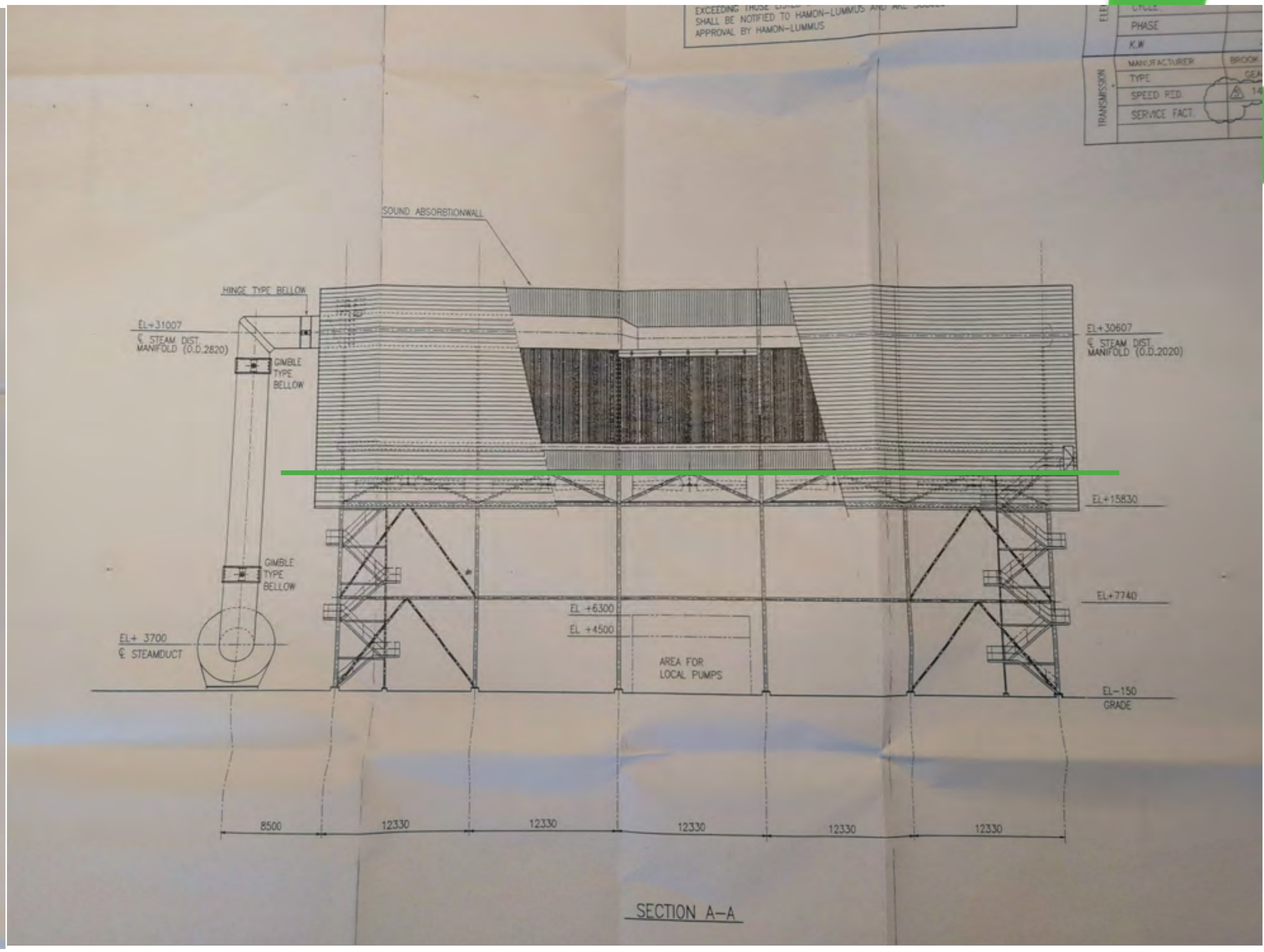
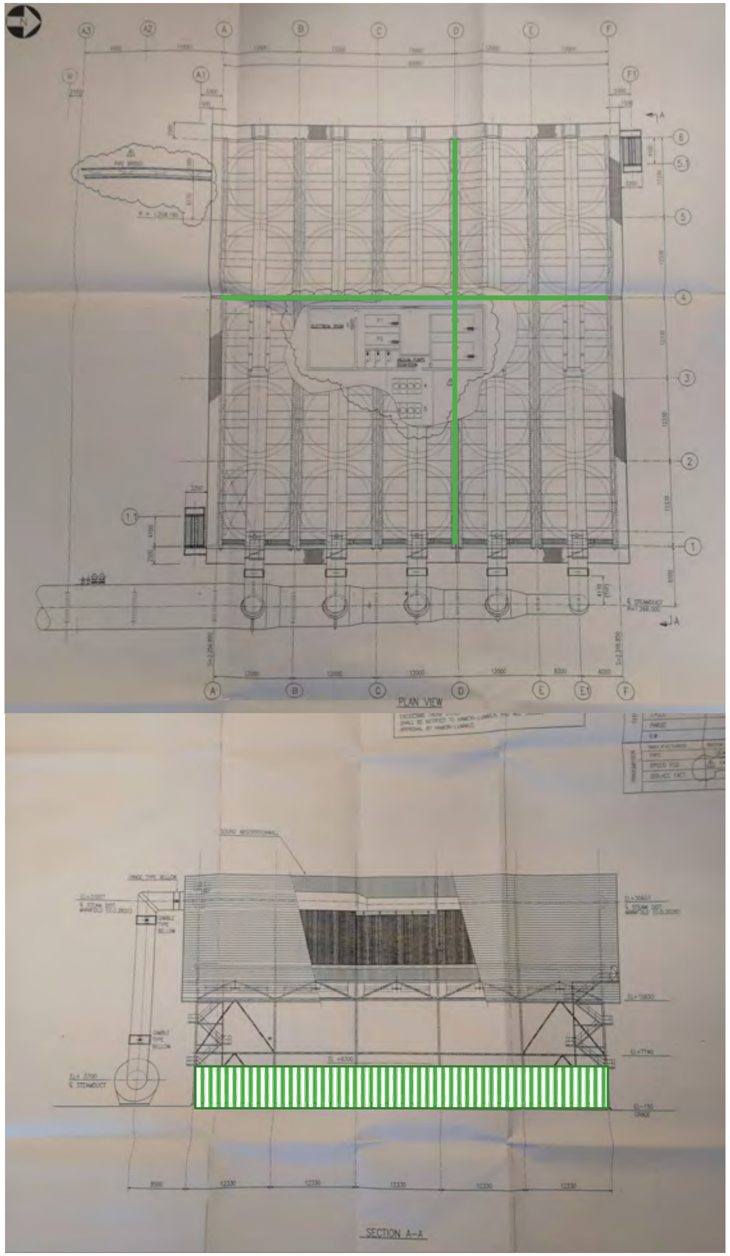
Solid protruding platform at periphery

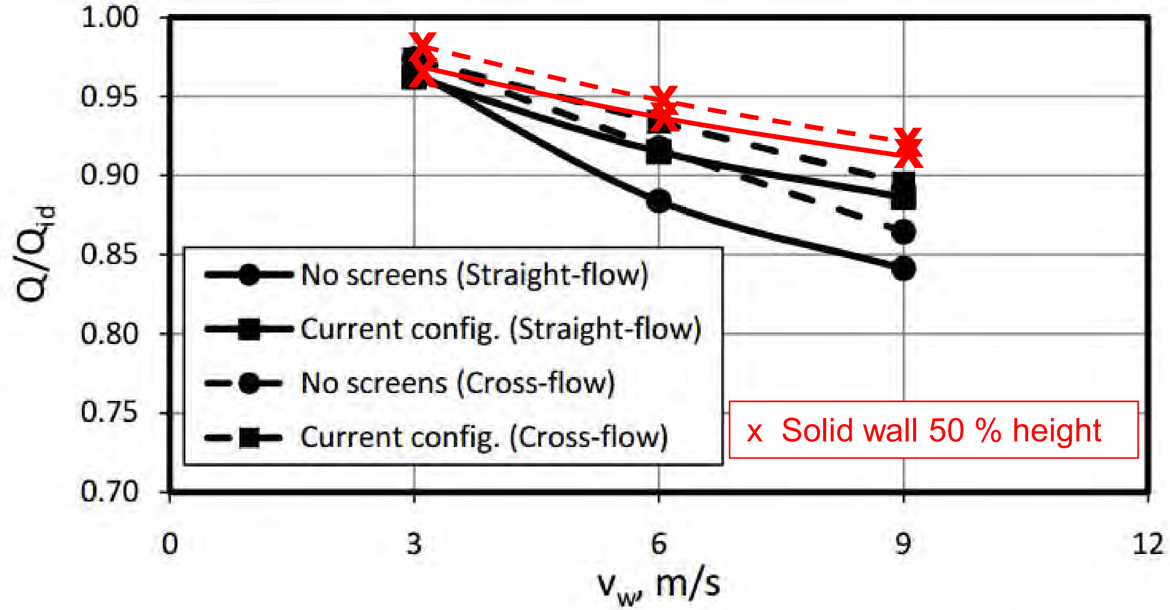




Solid wall wind-cross



Solid wall wind-cross



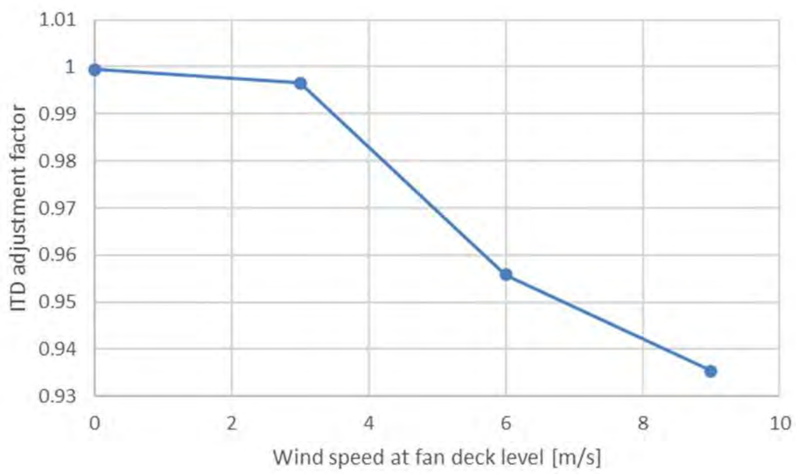


Figure 6.2: Effect of current wind screen configuration on ACSC performance at El Dorado

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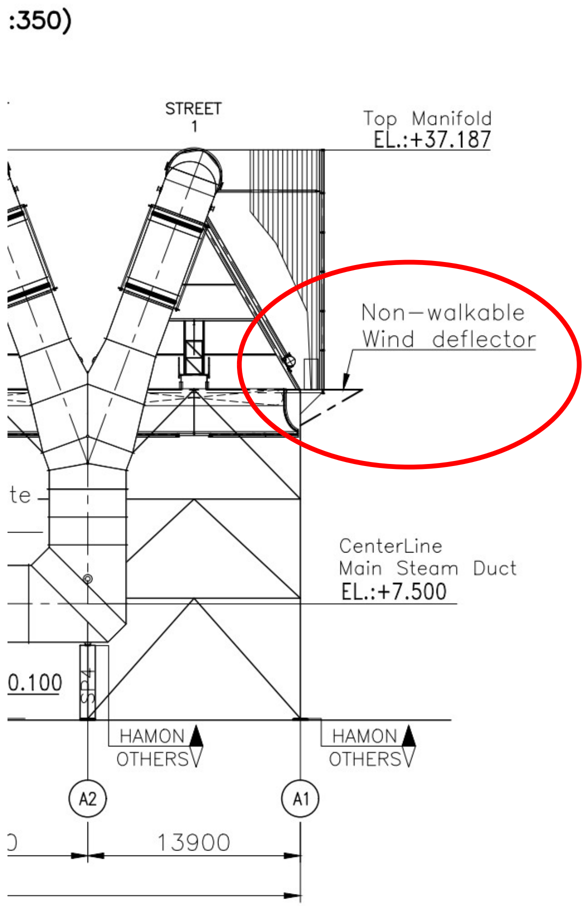
Solid protruding walkway at periphery



Solid protruding walkway at periphery

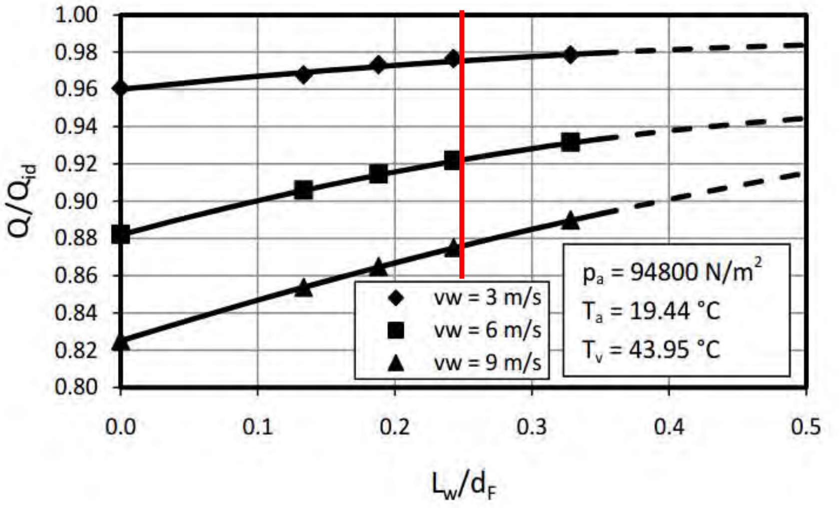
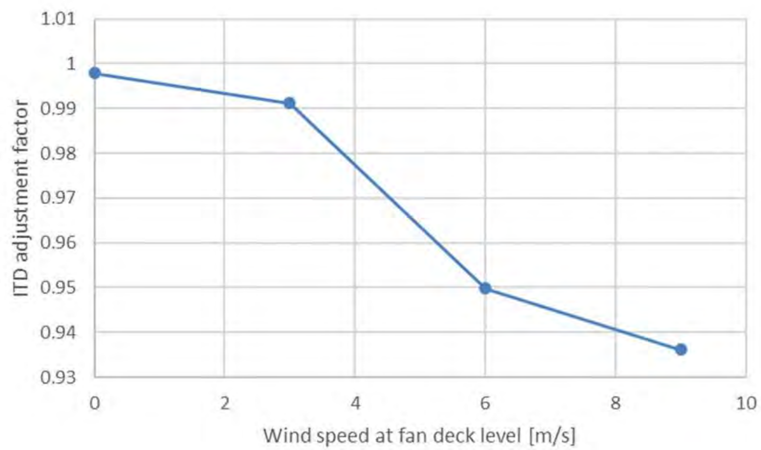


Figure 6.9: Effect of walkway width on ACSC performance under windy conditions for the generic ACSC



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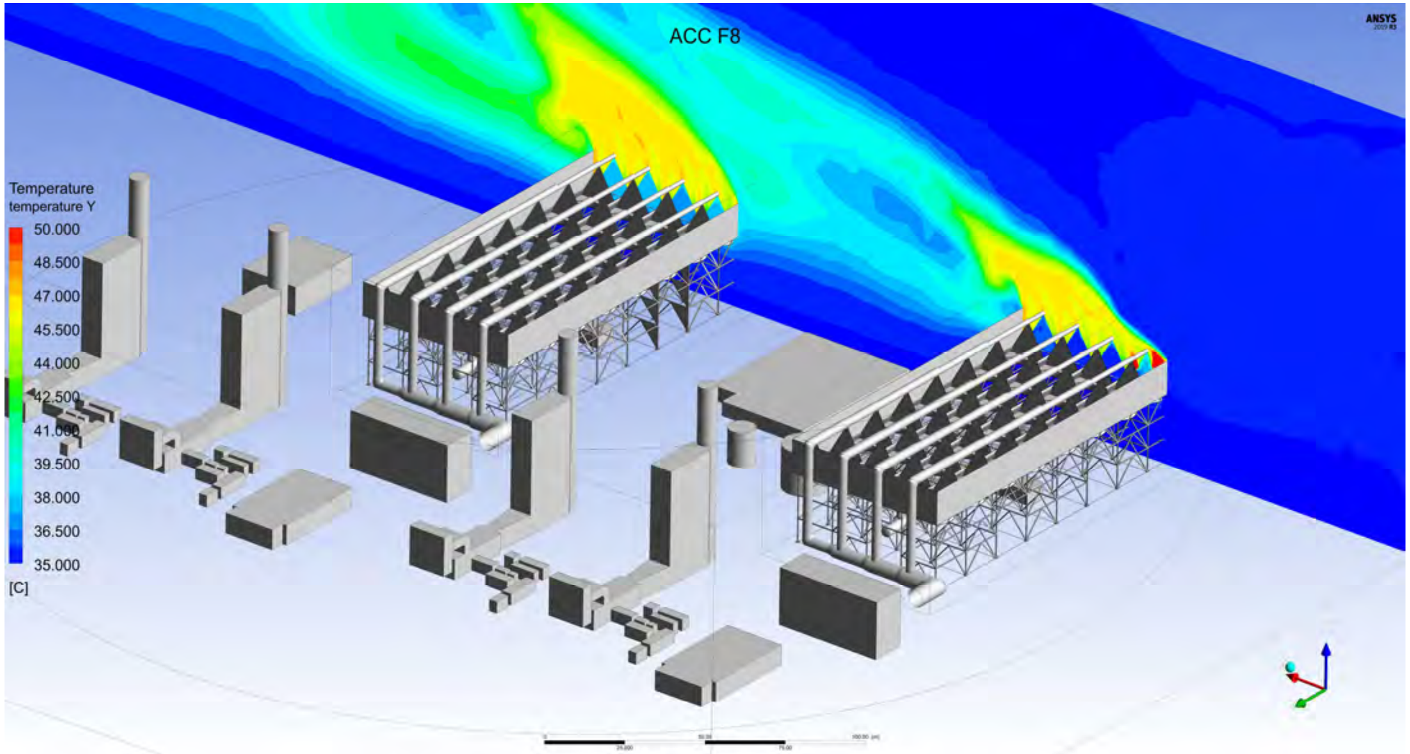
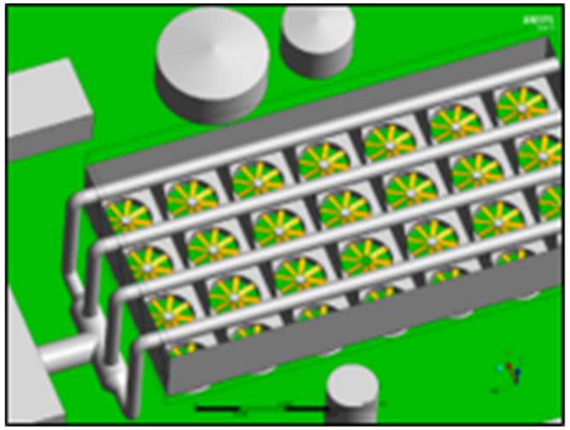
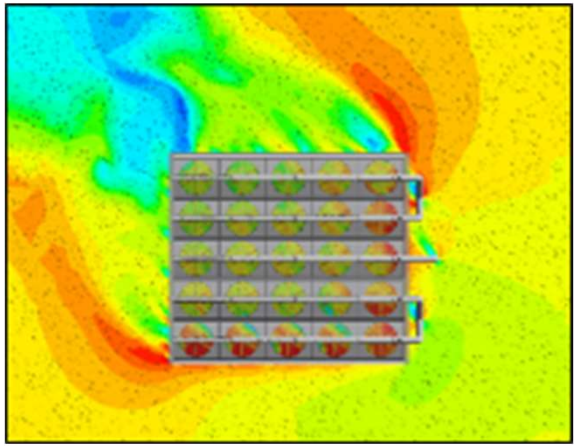
3-D CFD analysis of ACC







Replacement of fans with more efficient ones

- 10 % increase in fan efficiency gives approximately 3 % increase in air flow rate for the same fan power consumption.
- 1 % increase in air volume flow rate gives approximately 1 % reduction in ITD or increase in heat transfer rate.
- Optimised fans by Notus, a company IWC is in collaboration with, have shown to increase ACC performance measurably, see https://notus.co.za/case-studies/

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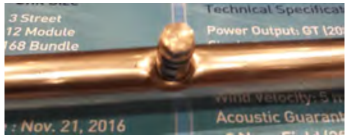
Fogging system for adiabatic cooling of inlet air

- At high ambient air temperatures, it has been found that power output/ efficiency of dry-cooled power plants can be reduced by as much as 1 % per ^{o}C change in ambient air temperature resulting in:
  - Revenue loss
  - Negative environmental impact
- ACC fogging systems can be used to reduce such power plant load losses by adiabatic cooling of the inlet air to a minimum of wet-bulb temperature by spraying water directly into the air.



Description of a fogging system

- Spray nozzles
- Spray frame
- Water piping
- High pressure piston pump skids
- Demin or softened water supply system

Photos were taken during an ACCUG visit to the Midlothian plant in Texas

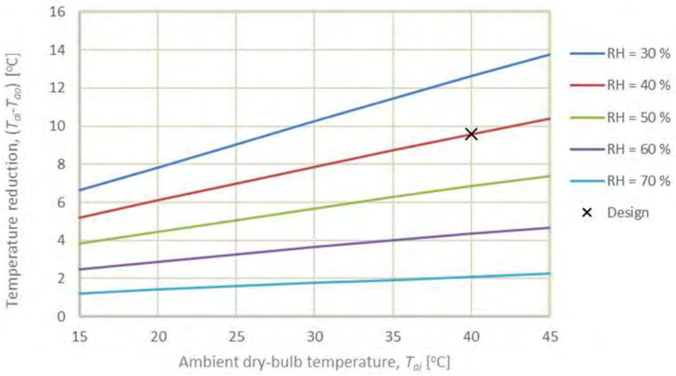
Required input data for fogging system design

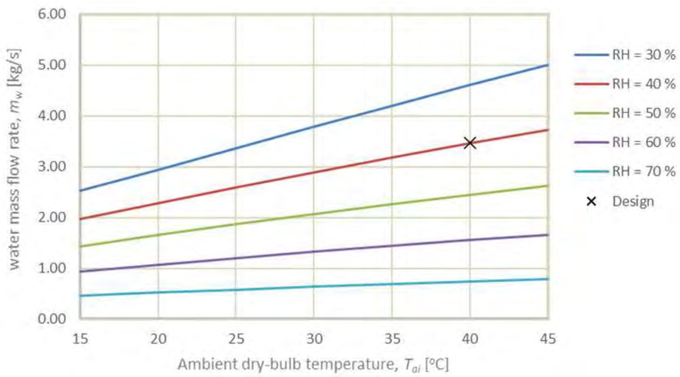
- Atmospheric pressure
- Ambient dry-bulb temperature
- Ambient relative humidity or wet-bulb temperature
- Air volume flow rate per fan
- Number of fan units
- (Max water consumption or required air temperature reduction)
- [ACC initial temperature difference (ITD)]

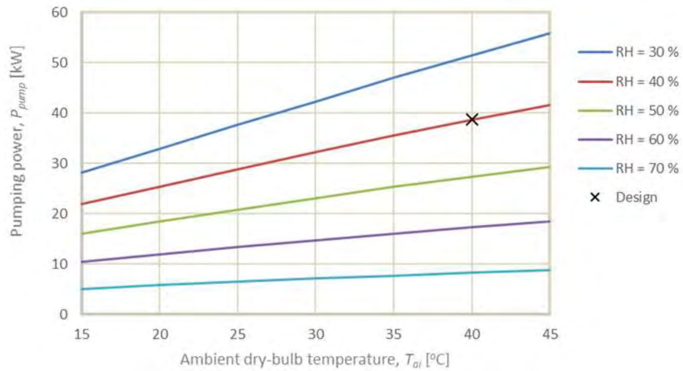
Main Parameters that impact the fogging system performance

- Flow rate of unevaporated spray water (humidification efficiency), which can be affected by:
  - Spray droplet size or pump pressure
  - Water collecting on and dripping down from structural parts
  - Relative humidity after fogging to maximimize evaporation potential
  - Water leaving the ACC air outlet as drift
- Actual air flow rate through the fan
  - Depends on the air flow resistance curve which can over time change due to finned tube fouling/ clogging
  - Accuracy of the fan manufacturer performance curves
- Air flow and spray water repartition inside the plenum

Typical example:
Graphs – fogging system design for one fan unit



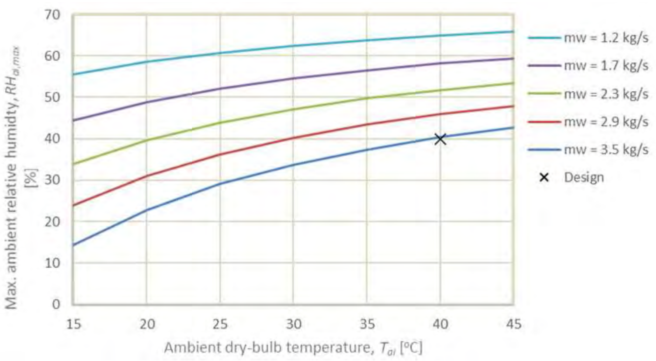


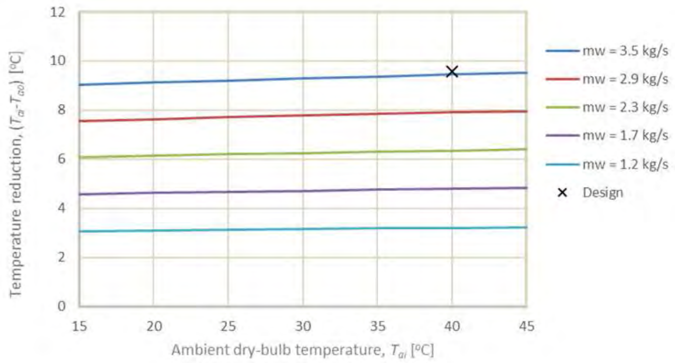


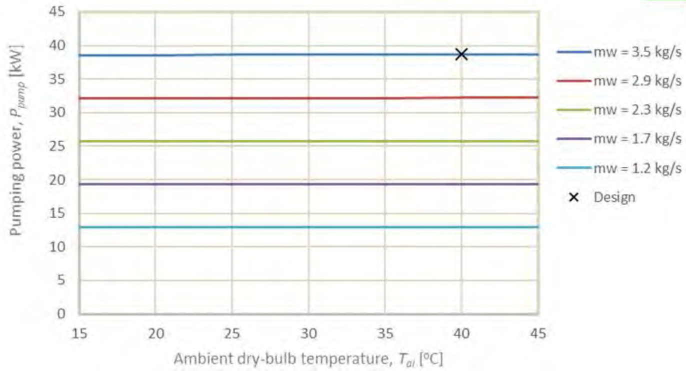
Basis for graphs:

- Atmospheric pressure: p_{ai}= 101325 N/m^2
- Air flow rate through fan unit: V_{fan} = 740 m^3/s
- Relative humidity after fogging: RH_{ao} = 80 %
- Humidification efficiency (m_{evap}/ m_{tot}): η = 85 %

Typical example:
Graphs - fogging system operation per fan unit for selected design point – constant pumping pressure







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Measurement data used for annual actual performance

- Ambient air:
  - Atmospheric pressure
  - Dry-bulb temperature
  - Relative humidity
  - Wind speed
  - Wind direction
- ST exhaust steam:
  - Pressure or temperature
  - Condensate flow rate
- Power plant
  - GT and ST output
  - Number of fans in operation
  - Back pressure and generator constraints

Input data required for yearly savings

- Electricity grid tariff
- Specific total cost of make-up water
- Specific cost of blowdown water treatment/disposal

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Output data for yearly savings

Difference in:

- Capex
- Net revenue due to additional power generation
- Net water costs
- Annual savings
- Payback period

Impact of different enhancement options on 25 ACC fan modules based on 2020 data

Option	Operating hours	Additional net power output	Additional water consumption	Capex	Annual power revenue	Annual water cost	Annual saving	Payback period
	[h/ year]	[MWh/ year]	[m³/ year]	[k€]	[k€]	[k€]	[k€]	[Years]
50 % HDWD fan module	2773.5 (31%)	2095	46900	750	168	47	121	6.2
Fogging (20 m³/h]	2773.5 (31%)	1707	55470	500	137	55	81	6.2
50 % height wind-cross wall	5891.5 (66%)	697	0	150	56	0	56	2.7
2.5 m peripheral platform	5891.5 (66%)	930	0	100	74	0	74	1.3
10% improvement in fan efficiency	5891.5 (66%)	2542	0	1000	203	0	203	4.9

Capital parity:
Electricity: € 80/ MWh
Water: € 1/ m³

	Change in ITD		Change in condensing pressure		Change in net power output		Water consumption	
Option	**ΔITDnet,avg**	**ΔITDnet,max**	**Δpcond,avg**	**Δpcond,max**	**ΔPnet,avg**	**ΔPnet,max**	**Vw,avg**	**Vw,max**
	[°C]	[°C]	[mbar]	[mbar]	[MW]	[MW]	[m³/ h]	[m³/ h]
50 % HDWD fan module	-1.50	-2.27	-7.4	-18.2	0.77	1.34	16.9	30.2
Fogging (20 m³/h]	-1.12	-1.18	-5.6	-9.7	0.62	0.74	20.0	20.0
50 % height wind-cross wall	-0.23		-1.0		0.12		0.0	
2.5 m peripheral platform	-0.31		-1.4		0.16		0.0	
10% improvement in fan efficiency	-0.84		-4.0		0.43		0.0	

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Electricity Rates in leading economies

Electricity rates varies between different countries and can even vary within a single region or distribution network of a country.

Rates typically vary between the residential, commercial, and industrial sectors, time-of-day usage, capacity usage or by the type of supply (single phase or three phase).

Average Price US$ Cents/kWh

16.81

The world bank 2019 electricity indicator (https://govdata360.worldbank.org/indicators/h6779690b?country=BRA&indicator=42573&viz=line_chart&years=2014,2019)

Conclusion

Five different performance enhancement options were evaluated for an ACC with 25 fan units based on measured DCS data over a period of 1 year.

- The savings are based on the electrical revenue and water costs and do not include any savings due to carbon emissions reduction and other operational savings.
- All the options have reasonable payback periods of maximum 6 years, which was the requirement for the plant.
- With current increases in electricity tariffs to, in some countries a 10-fold increase in fuel prices over the past year, this payback period can be reduced significantly to as little as 1 year.

Always thinking, always creating, always delivering.

Always IWC.