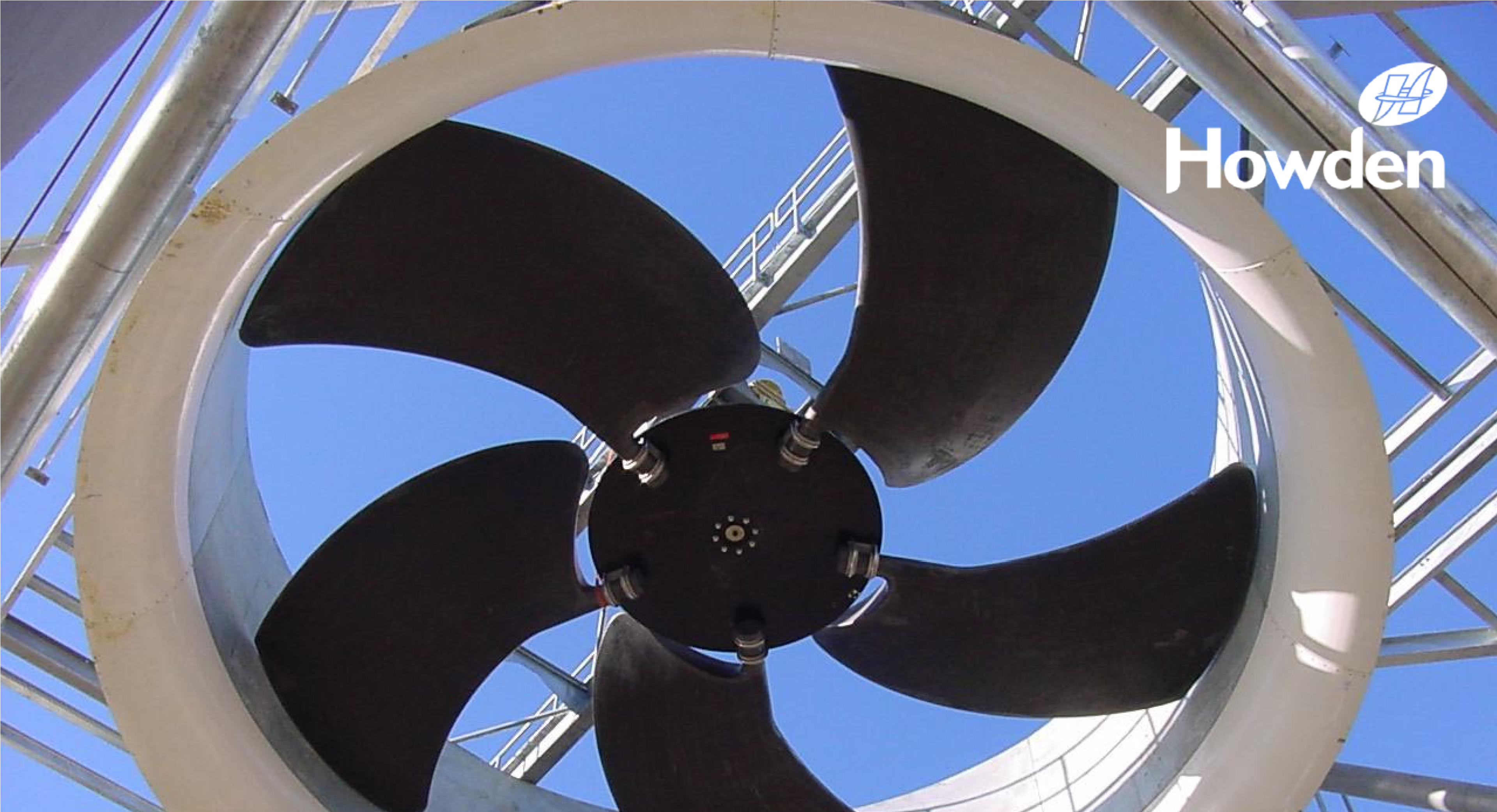


Howden Netherlands

A closer look to air side condenser performance

Martin Huis in ‘t Veld

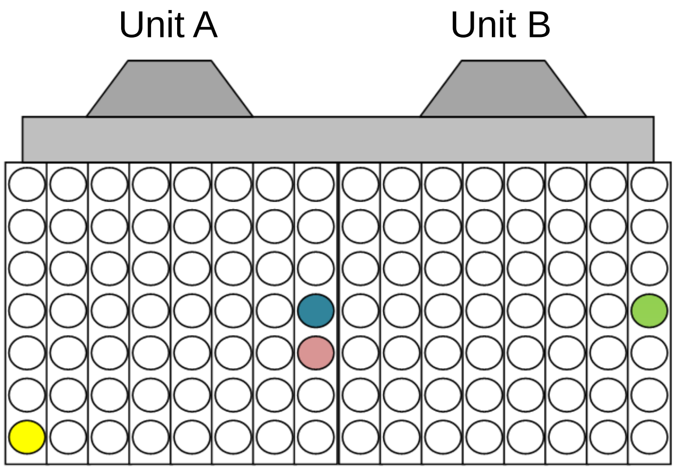
Date: 16 October 2013

Air side condenser performance

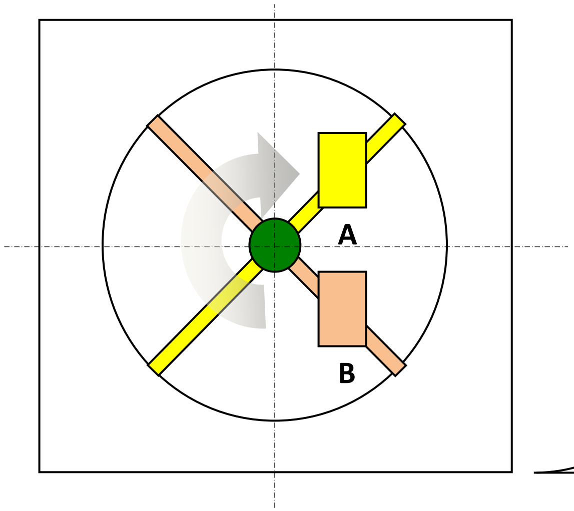
Site assessment

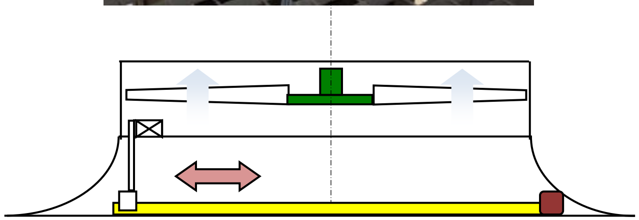
Air side condenser performance

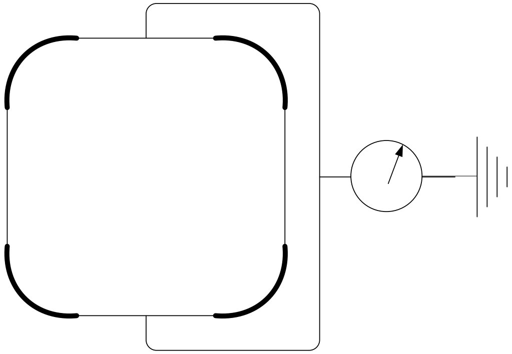
Site assessment: Volume, pressure, temperature – system resistance curve



Top view of ACC with measured fans.

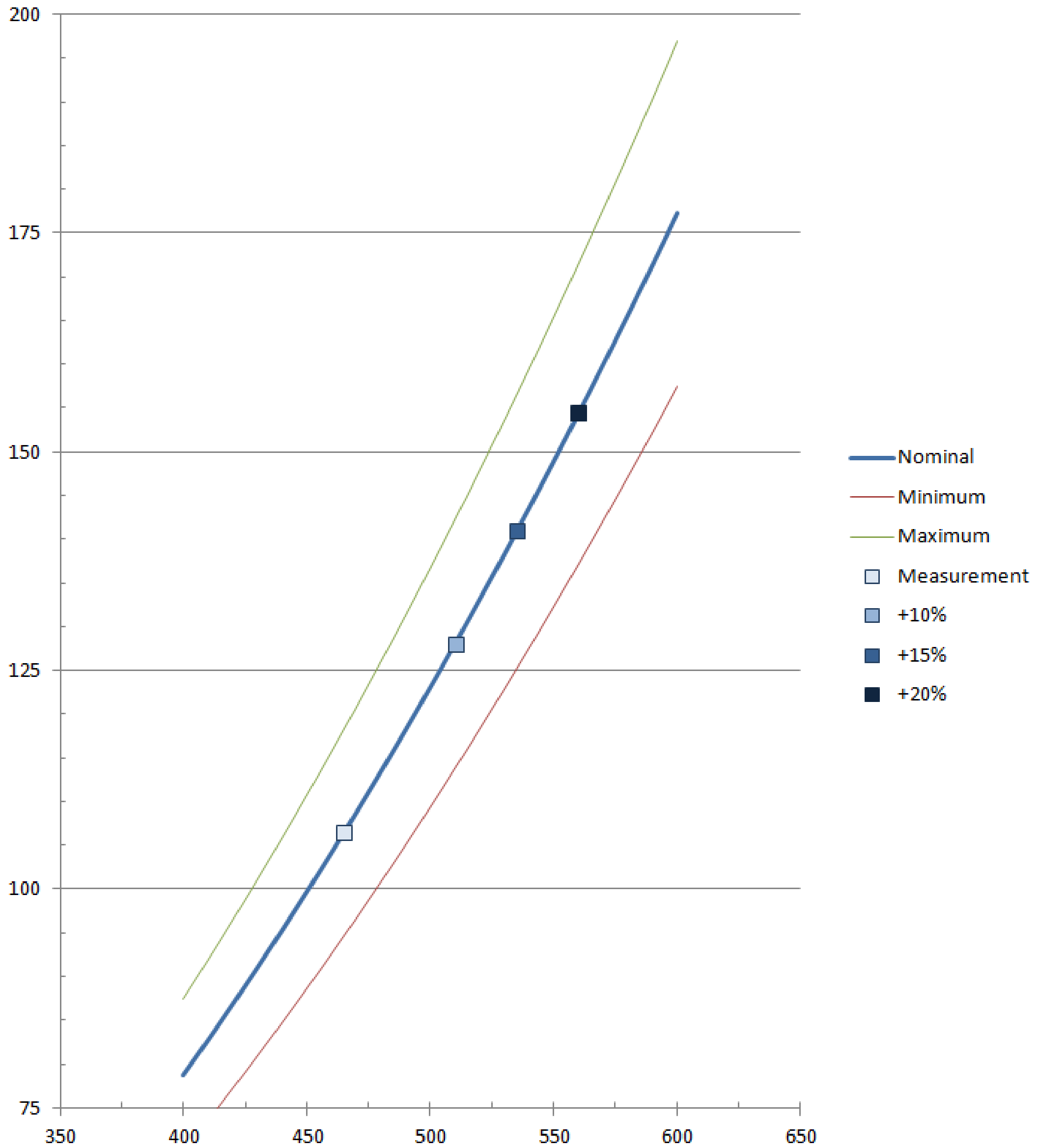






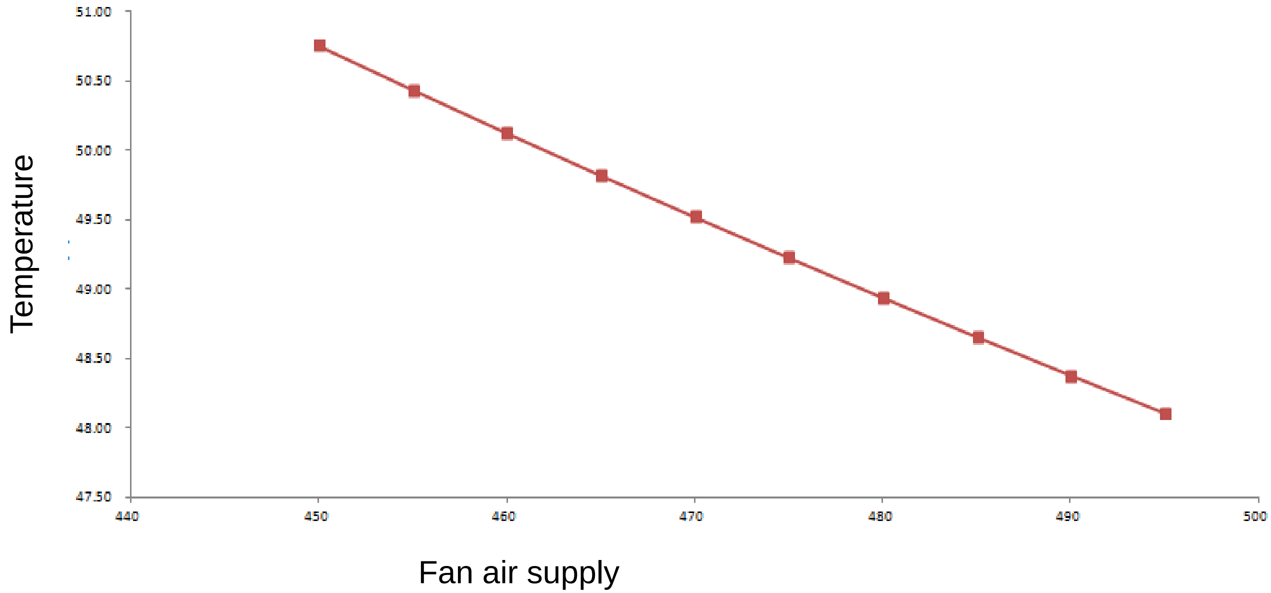
Air side condenser performance

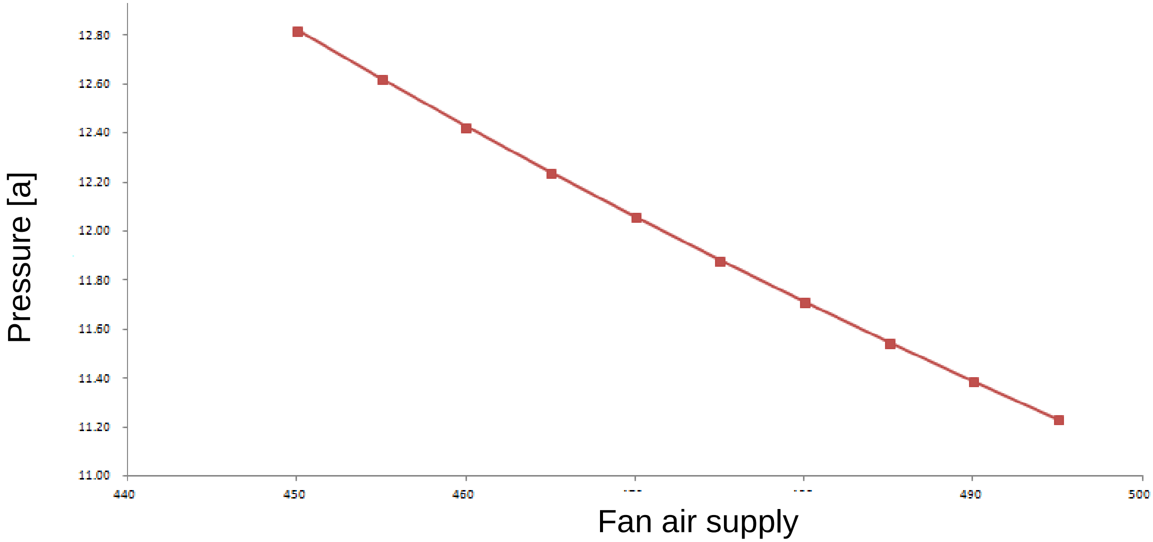
Increased air side performance



Air side condenser performance

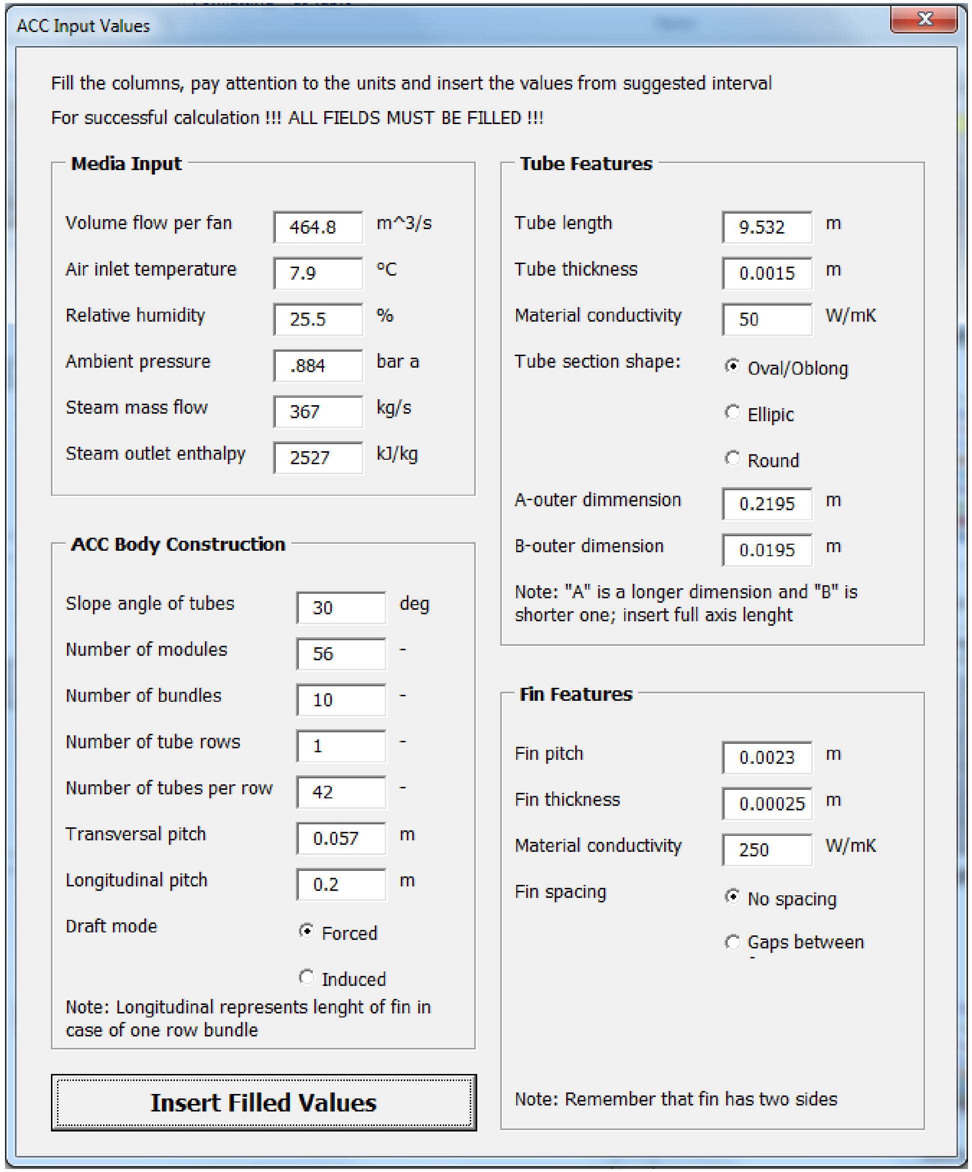
Condensing data relation to fan air supply





Air side condenser performance

Process data estimation



Air side condenser performance

Process data estimation

Stand_alone_version_V2-datong - Microsoft Excel

Start

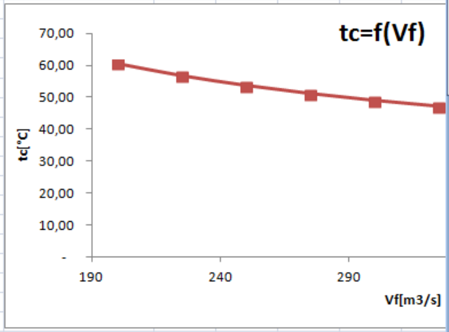
	Cells legend
	do not touch
(yellow)	change by hand
(orange)	important cells
xxx	must be equal

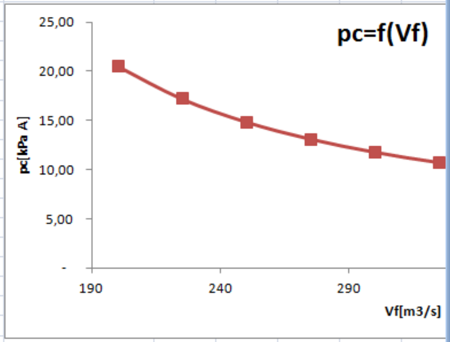
	A	B	C	D
6	**Input table overview**			
7	Media Input			
8	volume flow per fan	V f	m3/s	535,2
9	air inlet temperature	t ai	°C	7,4
10	relative humidity	φ	-	25,0
11	ambient pressure	p b	bar a	0,890
12	steam mass flow	m s	kg/s	367,000
13	steam outlet enthalpy	i s1	kJ/kg	2527,0
14	expected condensation temperature	t c	°C	40,388
15				
16	ACC Body Construction			
17	half of top point angle	θ	deg	30
18	modules	n m	-	64
19	bundles per module	n b	-	10
20	number of rows	n r	-	1
21	tubes per row in bundle	n t	-	42
22	transversal pitch	P t	m	0,057
23	longitudial pitch	P l	m	0,200
24				0,000
25	Tube Features			
26	tube length	l t	m	9,5
27	tube thickness	t t	m	0,002
28	tube thermal conductivity	k t	W/mK	50,0
29	A-outer characteristic dimension	a t	m	0,220
30	B-outer characteristic dimension	b t	m	0,020
31				
32	Fin Features			
33	Fin pitch	P f	m	0,00230
34	Fin thickness	t f	m	0,0003
35	Fin thermal conductivity	k f	W/mK	250,000
36	Fin area per fin pitch(without tf)	A fp	m2	0,015
37	Fin circumference	L fp	m	0,875
38				
39	Fan			
40	Forced/Induced Draft	D	-	1
41	Fan overall efficiency	η f	%	55
42				
43	Turbine			
44	Power output from turbine	E t	MW	290,000

Calculation

F	G	H	I
tube inner circumference	L ti	m	0,461
tube outer circumference	L to	m	0,452
tube inner section	A ti	m2	0,004
tube outer section	A to	m2	0,004
tube inner characteristic dimmension	d ri	m	0,030
tube outer characteristic dimmension	d ro	m	0,041
Fin characteristic dimension	d f	m	0,080
minimum free flow area per fin pitch	A afp	m2	7,688E-05
partial water vapor pressure	p v"	Pa	1029,8842
water in air	w	kg/kg	0,0018046
dry air density	ρ ai	kg/m3	1,1050369
wet air density	ρ awi	kg/m3	1,1038284
dry air inlet specific heat capacity	c pai	J/kgK	1006,4341
wet air specific heat capacity	c pawi	J/kgK	1007,9878
water vapor inlet specific heat capacity	c pvi	J/kgK	1868,9275
dry air dynamic viscosity	μ ai	Pa s	1,756E-05
wet air dynamic viscosity	μ awi	Pa s	1,755E-05
water vapor inlet dynamic viscosity	μ vi	Pa s	9,453E-06
dry air dynamic conductivity	k ai	W/mK	0,0247022
wet air dynamic conductivity	k awi	W/mK	0,0246844
water vapor inlet dynamic conductivity	k vi	W/mK	0,0175107
air mass flow	m a	kg/s	37812,203
wet inlet air Prandtl	Pr ai	-	0,7164969
mass velocity of air	G ai	kg/m2s	4,4153119
wet air inlet Reynolds	Re 1	-	10268,498
formula 5.5.1 Brigs+Young	h a1	W/m2K	31,651719
formula 49 Schmidt	h a2	W/m2K	28,139151
formula 50 VDI Heat atlas	h a3	W/m2K	34,858647
critical speed in the narrowest place	vc	m/s	3,9999983
vc+row effect coeficient	h nr	-	0,7982597
forced draft mode factor	h/h6	-	1,15
induced draft mode factor	h/h6	-	0,7
HTC air overall average	h ae	W/m2K	28,962711
air exposed area of condenser	A a	m2	1774187
rib area	A f	m2	1671001
tube inner area	A i	m2	118184,38
corresponding air mass flow over one hal	m at	kg/s	0,703352
condensate enthalpy	i c	kJ/kg	169,16279
condensate density	ρ c	kg/m3	992,18651
condensate thermal conductivity	k c	W/mK	0,6315699
condensate dynamic viscosity	μ c	Pa s	0,0006466
HTC on condensate side	h c	W/m2K	12331,691
ribbing efficiency	Ω	-	0,8961223

Input table	1	2	3	4	
V f [m3/s]	200	225	250	275	3
m s [kg/s]	210	210	210	210	2
t c [°C]	60,65	56,87	53,80	51,24	49,0
p c [kPa A]	20,55	17,23	14,87	13,13	11,8
Δp S [Pa]	23,79	26,96	30,19	33,45	36,7
E f [MW]	0,433	0,552	0,686	0,836	1,0





Functions | Calculation | List of signs

Air side condenser performance

Process data

			Measurement	
Nom. air flow per fan	Q_{air}	m^3/s	465	
Nom. fan static pressure	p_{Static}	Pa	106	
Fan shaft power	P_{Fan}	kW	82	
Generated output	E_{turb}	MW	293	
Steam mass flow per unit	$\dot{m}_{steam}$	kg/s	367.0	
Condensing temperature	t_C	° C	49.9	
Condensing pressure	t_p	bar a	0.123	
Condensate enthalpy	h_c	kJ/kg	207.5	
Turbine inlet enthalpy	h_{turb}	kJ/kg	3395	
Required fuel energy	E_{fuel}	MJ/s	1170.0	$E_{fuel} = (h_{turb} - h_c) \times \dot{m}_{steam}$

Air side condenser performance

Process data

			Measurement
Nominal air flow per fan	Q_{air}	ACFMx10^3	985
Nominal fan static pressure	p_{Static}	In H2O	0.426
Fan shaft power	P_{Fan}	HP	112
Generated output	E_{turb}	MW	
Steam mass flow per unit	$\dot{m}_{steam}$	lb/s	809.2
Condensing temperature	t_C	° F	121.8
Condensing pressure	t_p	PSI	1.784
Condensate enthalpy	h_c	btu/lb	89.3
Turbine inlet enthalpy	h_{turb}	btu/lb	1461
Required fuel energy	E_{fuel}	btu/s	1109645

$$E_{fuel} = (h_{turb} - h_c) \times \dot{m}_{steam}$$

Air side condenser performance

Estimated savings

			Measurement	+10%
Nom. air flow per fan	Q_{air}	m^3/s	465	510
Nom. fan static pressure	p_{Static}	Pa	106	128
Fan shaft power	P_{Fan}	kW	82	108
Generated output	E_{turb}	MW	293	293
Steam mass flow per unit	$\dot{m}_{steam}$	kg/s	367.0	364.2
Condensing temperature	t_C	° C	49.9	47
Condensing pressure	t_p	bar a	0.123	0.103
Condensate enthalpy	h_c	kJ/kg	207.5	195.6
Turbine inlet enthalpy	h_{turb}	kJ/kg	3395	3395
Required fuel energy	E_{fuel}	MJ/s	1170.0	1165.2
Saving	ΔE_{fuel}	MJ/day		407331
Heat density coal		MJ/kg	25	
Coal saving per day	$\Delta Coal_{Cons}$	ton/day		16.3
Estimated carbon content		%	70	
CO2 saving per day	ΔCO_2	ton/day		41.8

$$E_{fuel} = (h_{turb} - h_c) \times \dot{m}_{steam}$$

$$\Delta CO_2 = 3.667 \times \Delta Coal_{Cons} \times C_{coal}$$

$$3.667 = \frac{44 \text{ kg } [1\text{kgmol } CO_2]}{12 \text{ kg } [1\text{kgmol C}]}$$

Air side condenser performance

Estimated savings

			Measurement	+10%
Nominal air flow per fan	Q_{air}	ACFMx1 0^3	985	1081
Nominal fan static pressure	p_{Static}	In H2O	0.426	0.512
Fan shaft power	P_{Fan}	HP	112	147
Generated output	E_{turb}	MW		
Steam mass flow per unit	$\dot{m}_{steam}$	lb/s	809.2	802.9
Condensing temperature	t_C	° F	121.8	116.6
Condensing pressure	t_p	PSI	1.784	1.494
Condensate enthalpy	h_c	btu/lb	89.3	84.1
Turbine inlet enthalpy	h_{turb}	btu/lb	1461	1461
Required fuel energy	E_{fuel}	btu/s	1109645	1105173
Fuel saving per day	ΔE_{fuel}	btu		386333458
Heat density coal		btu/lb	10755	
Coal saving per day	$\Delta Coal_{Cons}$	lb		35921
Estimated carbon content	C_{coal}	%	70	
CO2 saving per day	ΔCO_2	lb		92198

$$E_{fuel} = (h_{turb} - h_c) \times \dot{m}_{steam}$$

$$\Delta CO_2 = 3.667 \times \Delta Coal_{Cons} \times C_{coal}$$

$$3.667 = \frac{44 \text{ kg [1kgmol } CO_2]}{12 \text{ kg [1kgmol C]}}$$

Air side condenser performance

Estimated savings

			Measurement	+10%	+15%	+20%
Nom. air flow per fan	Q_{air}	m^3/s	465	510	535	560
Nom. fan static pressure	p_{Static}	Pa	106	128	140	154
Fan shaft power	P_{Fan}	kW	82	108	125	143
Generated output	E_{turb}	MW	293	293	293	293
Steam mass flow per unit	$\dot{m}_{steam}$	kg/s	367.0	364.2	362.7	361.9
Condensing temperature	t_C	° C	49.9	47	45.7	44.8
Condensing pressure	t_p	bar a	0.123	0.103	0.100	0.0949
Condensate enthalpy	h_c	kJ/kg	207.5	195.6	189.9	186.3
Turbine inlet enthalpy	h_{turb}	kJ/kg	3395	3395	3395	3395
Required fuel energy	E_{fuel}	MJ/s	1170.0	1165.2	1162.5	1161.2
Saving	ΔE_{fuel}	MJ/day		407331	644924	753895
Heat density coal		MJ/kg	25			
Coal saving per day	$\Delta Coal_{Cons}$	ton/day		16.3	25.8	30.2
Estimated carbon content		%	70			
CO2 saving per day	ΔCO_2	ton/day		41.8	66.2	77.4

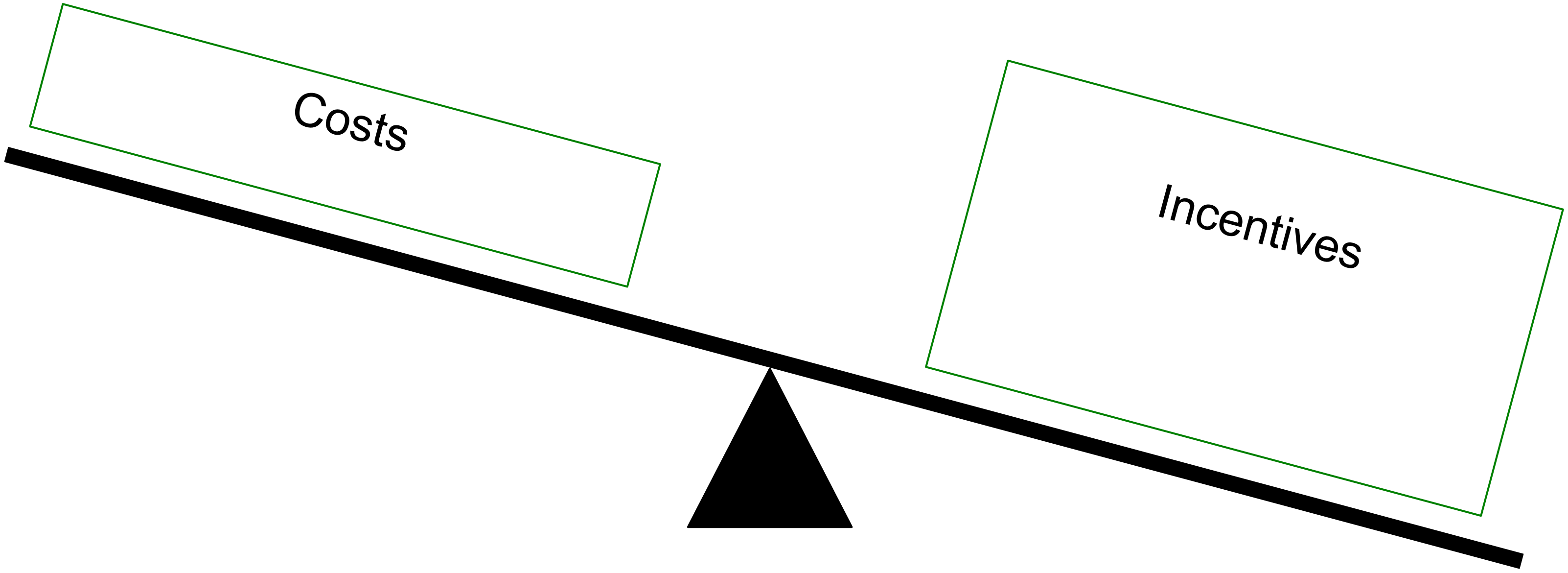
Air side condenser performance

Estimated savings

			Measurement	+10%	+15%	+20%
Nominal air flow per fan	Q_{air}	ACFMx10 3	985	1081	1134	1187
Nominal fan static pressure	p_{Static}	In H2O	0.426	0.512	0.563	0.617
Fan shaft power	P_{Fan}	HP	112	147	170	195
Generated output	E_{turb}	MW				
Steam mass flow per unit	$\dot{m}_{steam}$	lb/s	809.2	802.9	799.6	797.9
Condensing temperature	t_C	° F	121.8	116.6	114.3	112.6
Condensing pressure	t_p	PSI	1.784	1.494	1.450	1.376
Condensate enthalpy	h_c	btu/lb	89.3	84.1	81.7	80.1
Turbine inlet enthalpy	h_{turb}	btu/lb	1461	1461	1461	1461
Required fuel energy	E_{fuel}	btu/s	1109645	1105173	1102565	1101369
Fuel saving per day	ΔE_{fuel}	btu		386333458	611678959	715032787
Heat density coal		btu/lb	10755			
Coal saving per day	$\Delta Coal_{Cons}$	lb		35921	56874	66484
Estimated carbon content	C_{coal}	%	70			
CO2 saving per day	ΔCO_2	lb		92198	145976	170642

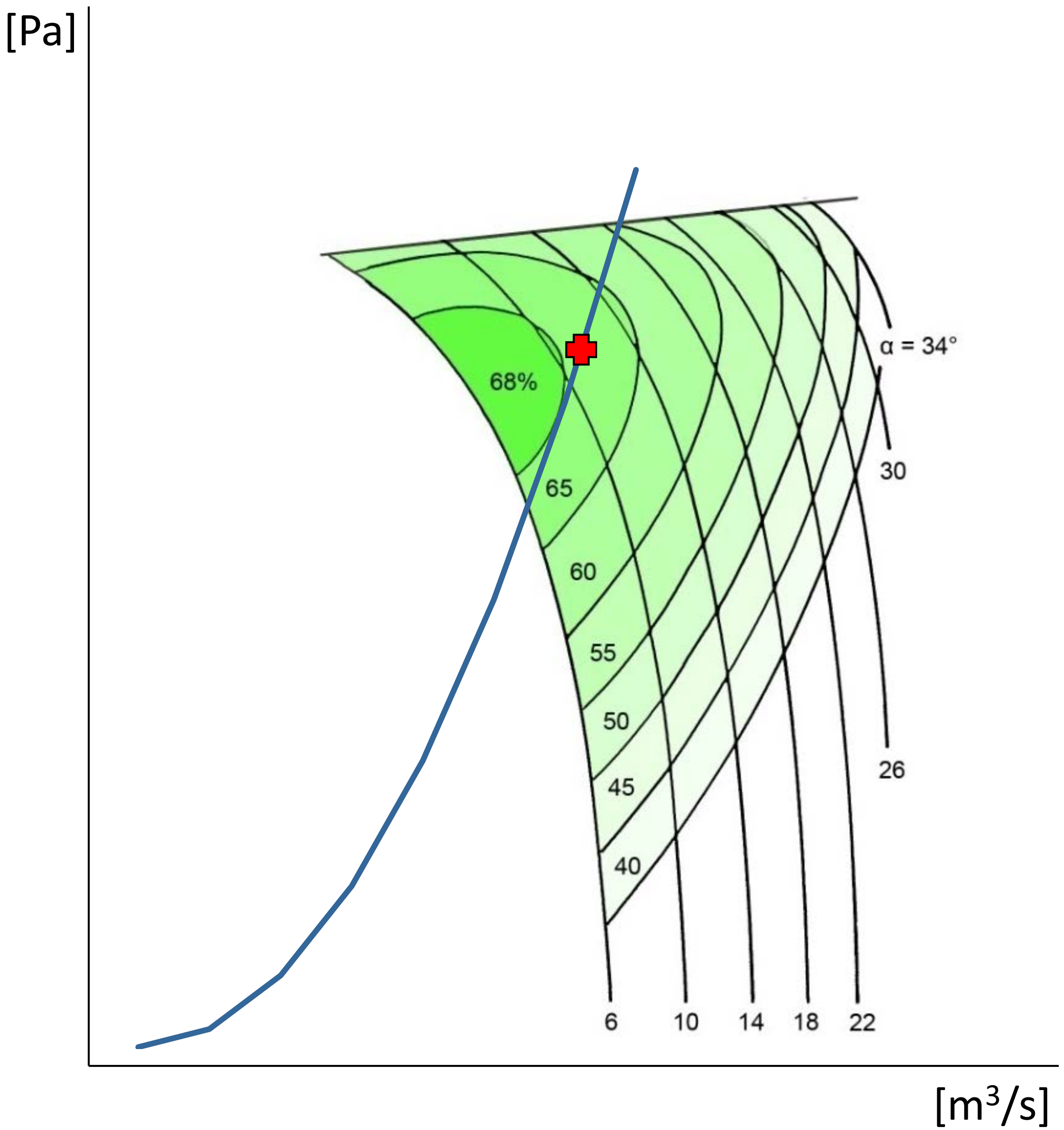
Air side condenser performance

Costs versus incentives



Air side condenser performance

Increased air supply – Blade angle

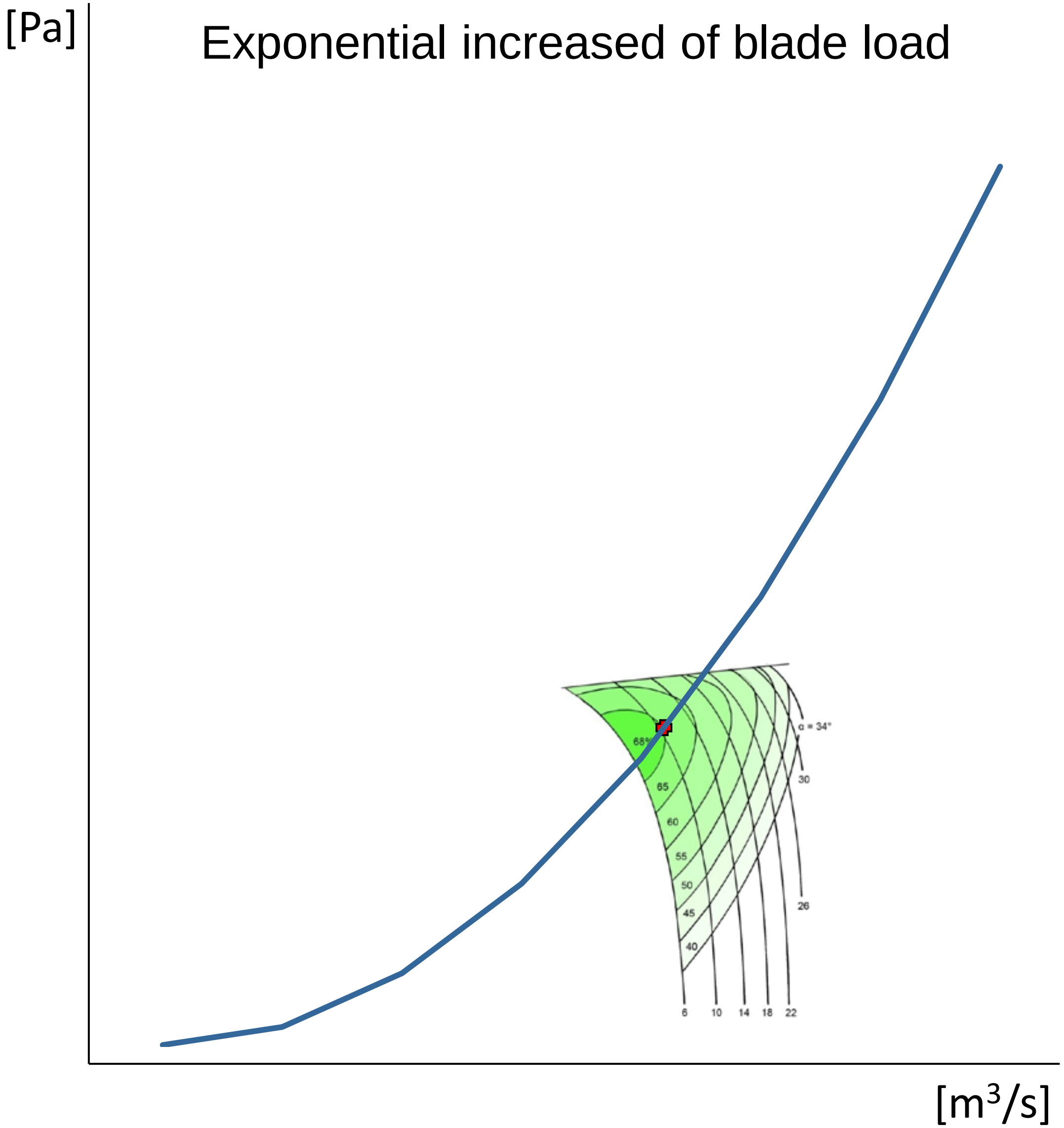


- Increased power consumption to compensate reduced efficiency.
- Increased risk of stall due to reduced pressure margin.

Air flow %	Δ PWL db(A)
120	2.4
115	1.8
110	1.2
105	0.6
100	0.0
95	-0.7
90	-1.4
85	-2.1

Air side condenser performance

Increased air supply – More speed



Volume: $$\frac{Q_2}{Q_1} = \frac{n_2}{n_1}$$

Pressure: $$\frac{p_2}{p_1} = \left(\frac{n_2}{n_1}\right)^2$$

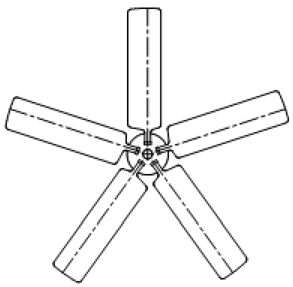
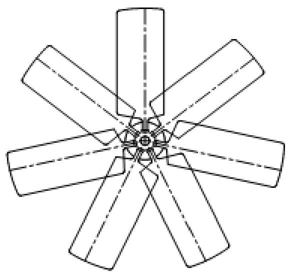
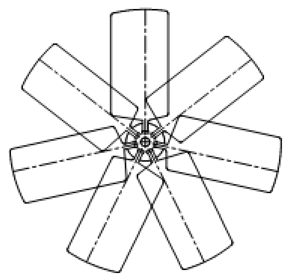
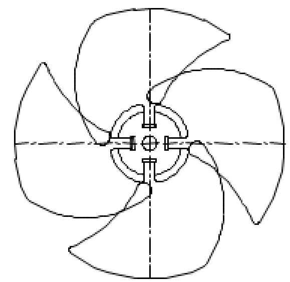
Abs. Power: $$\frac{P_{Fan2}}{P_{Fan1}} = \left(\frac{n_2}{n_1}\right)^3$$

Noise: $$\Delta PWL = 60 LOG\left(\frac{n_2}{n_1}\right)$$

Air side condenser performance

Increased air supply – More speed

Basic formula: $$PWL_{Fan} = C + 30LOG\,U_{Tip} + 10LOG\,P_{Aero} - 5LOG\,D_{Waaier} + \Delta dB$$

	ENF / DNF	ELF / DLF	ELFA / DVF	SX / FPX
Shape				
Noise Classification	Standard	Low-noise	Very low-noise	Ultra low-noise

Air flow %	Δ PWL
120	4.8
115	3.6
110	2.5
105	1.3
100	0.0
95	-1.3
90	-2.7
85	-4.2

Air side condenser performance

Retrofit – Extrapolating a new fan duty

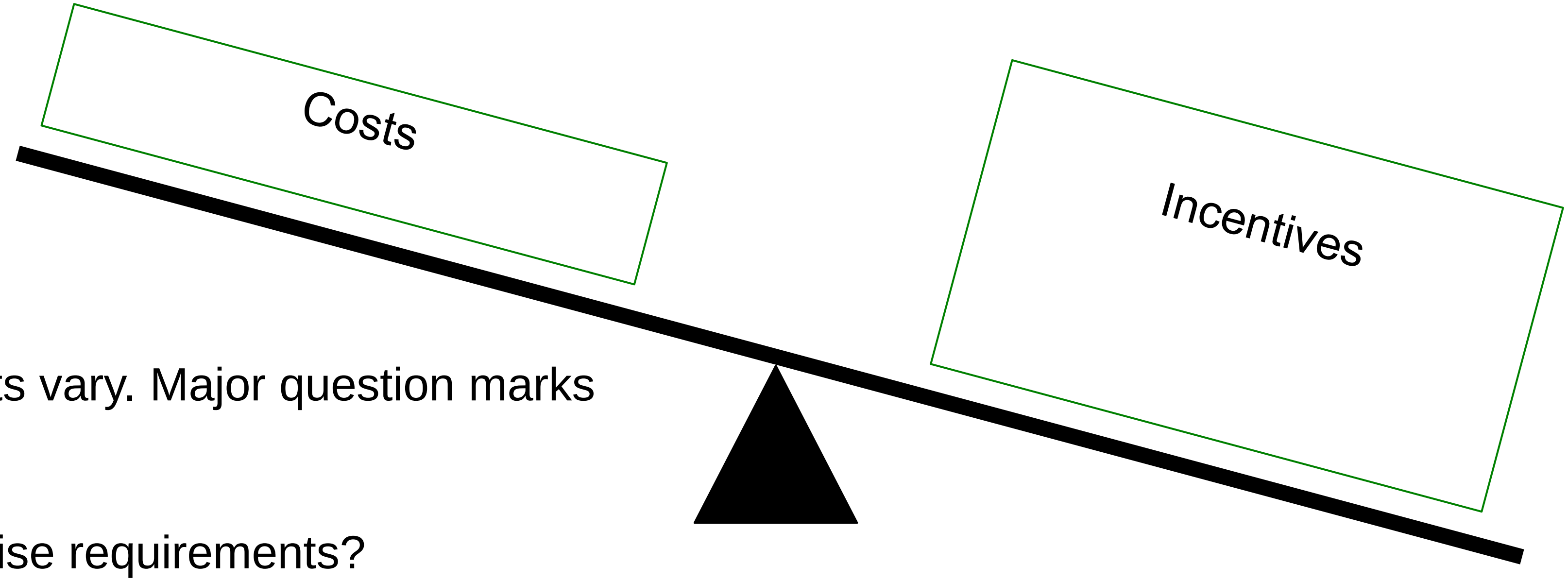
Output kW	Motor type		Product code		Speed r/min	Efficiency Full load 100%	Efficiency 3/4 load 75%	Power factor cos φ 100%
1000 r/min = 6-poles								
75	M3BP	315 SMA	3GBP	313 21				
90	M3BP	315 SMB	3GBP	313 22				
110	M3BP	315 SMC	3GBP	313 23				
132	M3BP	315 MLA	3GBP	313 41				

Output kW		Motor type		Product code					
1500 r/min = 4-poles						**400 V 50 Hz**			
110		M3BP	315 SMA	3GBP	312 210-••G	1487	95.6	95.4	0.86
132		M3BP	315 SMB	3GBP	312 220-••G	1487	95.8	95.7	0.86
160		M3BP	315 SMC	3GBP	312 230-••G	1487	96.0	95.9	0.85
200	2)	M3BP	315 MLA	3GBP	312 410-••G	1486	96.2	96.2	0.86

Air side condenser performance

Retrofit – Extrapolating a new fan duty

$$P = \frac{T \times n}{9550}$$



Costs vary. Major question marks are:

- Noise requirements?
- Power supply / Cabling capacity?

Air side condenser performance

Coal saving

			Measurement	+10%	+15%	+20%
Nominal air flow per fan	Q_{air}	m^3/s	465	510	535	560
Required fuel energy	E_{fuel}	MJ/s	1170.0	1165.2	1162.5	1161.2
Saving	ΔE_{fuel}	MJ/day		407331	644924	753895
Heat density coal		MJ/kg	25			
Coal saving	$\Delta Coal_{Cons}$	ton/day		16.3	25.8	30.2
Price black coal / ton		RMB	450			
		USD	74			
Saving in black coal/year		RMB		2,676,163	4,237,150	4,953,090
		USD		438,715	694,615	811,982

Air side condenser performance

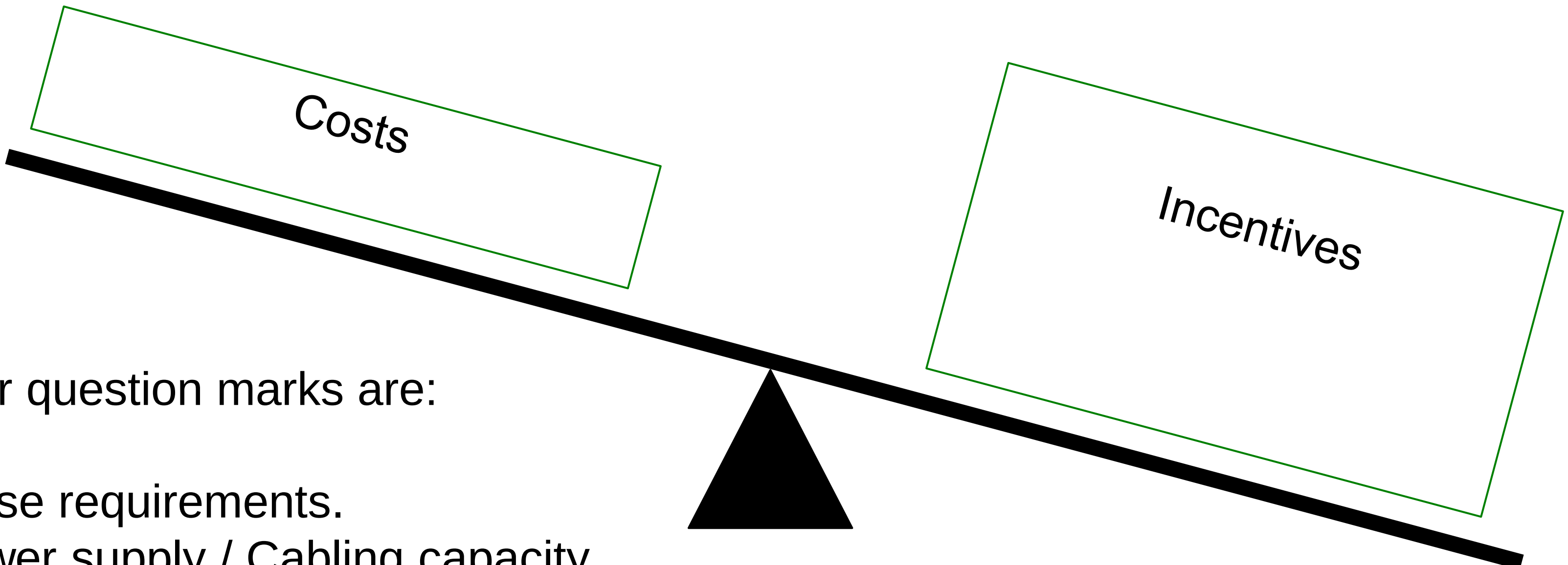
CO_2 saving

			Measurement	+10%	+15%	+20%
Nominal air flow per fan	Q_{air}	m^3/s	465	510	535	560
Coal saving per day	$\Delta Coal_{Cons}$	ton		16.3	25.8	30.2
Estimated carbon content	C_{coal}	%	70			
CO2 saving per day	ΔCO_2	ton/day		41.8	66.2	77.4
Costs CO2 emission per ton		RMB	30			
		USD	5			
Saving in CO2 emission		RMB		457,921	725,023	847,529
		USD		75,069	118,856	138,939

Air side condenser performance

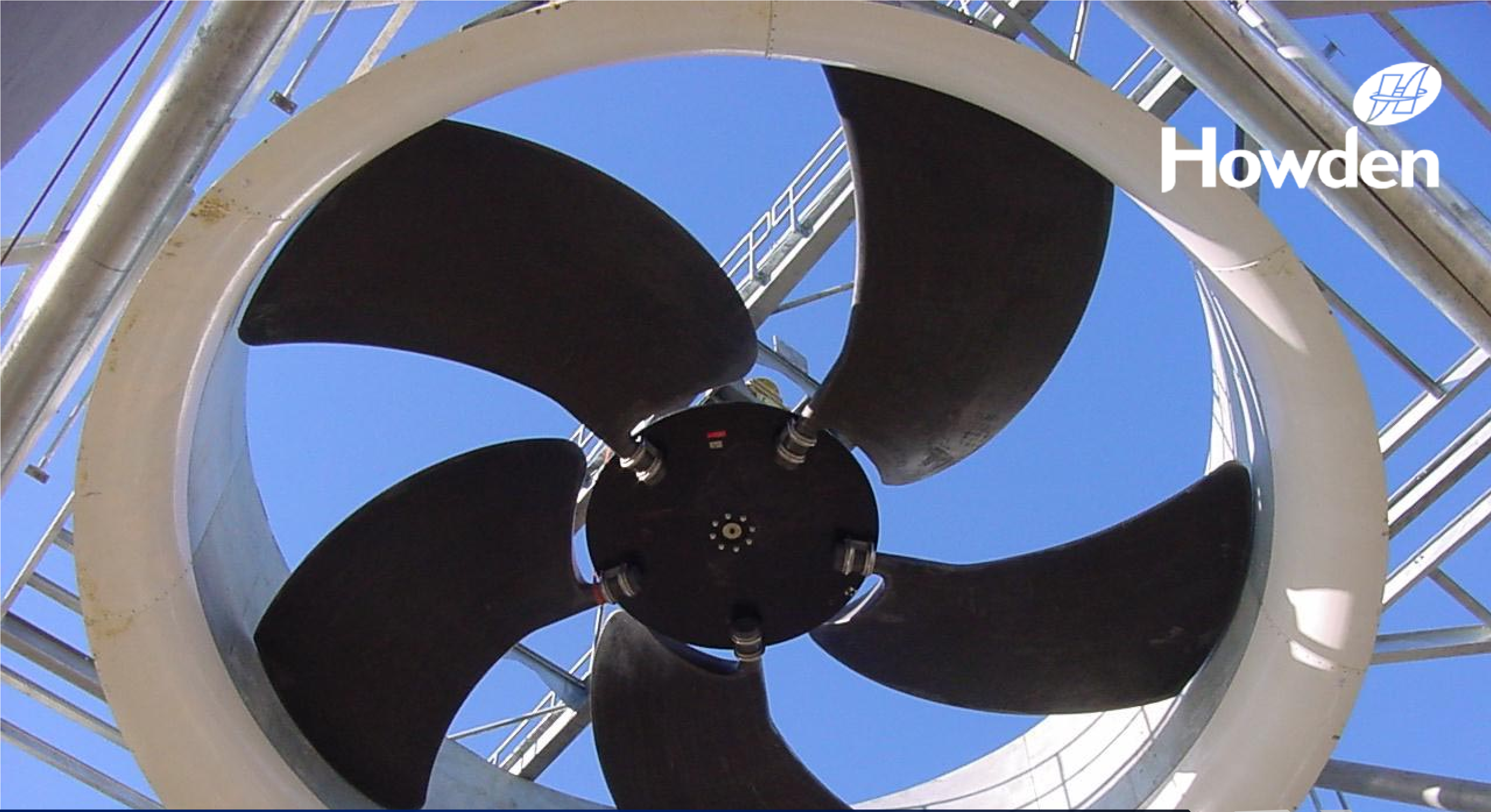
Costs versus incentives

Total savings/year		+10%	+15%	+20%
	RMB	3,134,085	4,962,173	5,800,619
	USD	513,784	813,471	950,921



Major question marks are:

- Noise requirements.
- Power supply / Cabling capacity



Howden Netherlands

Do take a closer look to air side condenser performance!

Martin Huis in 't Veld

Date: 16 October 2013