ATMO sphere AUSTRALIA

Trading Energy Consumption for Cooling Water Consumption in CO_2 Refrigerating Systems

Why, Where, When and by How Much if at All?

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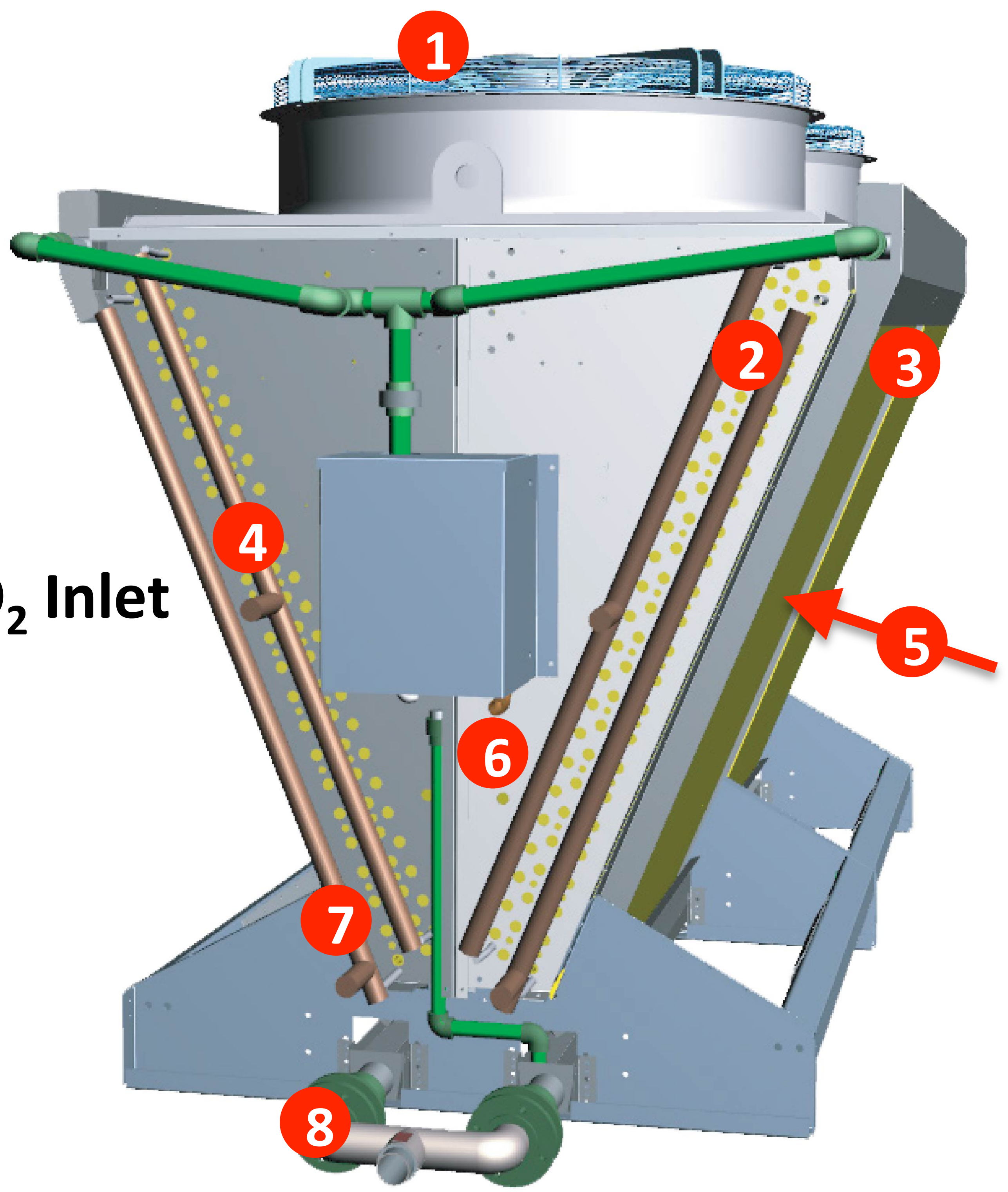
Figure 1: World's First Hybrid CO_2 Gas Cooler/Evaporative Condensers Installed at a Job Site in Sydney

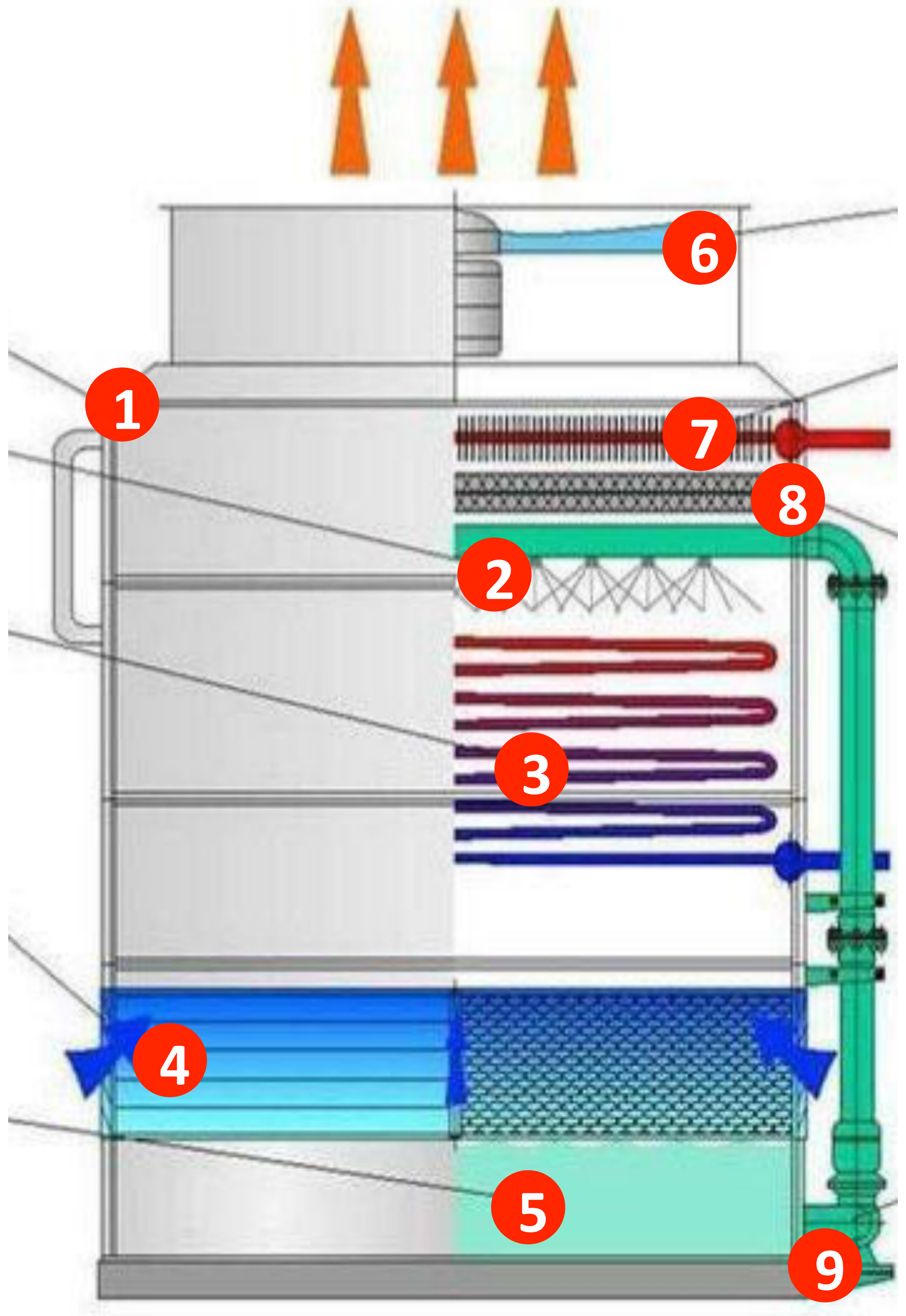
Figure 2: What are We Talking About?



4. CO_2 Inlet

1. Fan Unit
2. Dry, Finned Heat Exchanger
3. Pre-Cooling Pad
5. Air Flow
6. Water Distribution Inlet
7. CO_2 Outlet
8. Water Outlet (Drain)

Adiabatically Assisted Air Cooled CO_2 Gas Cooler
Source: Güntner



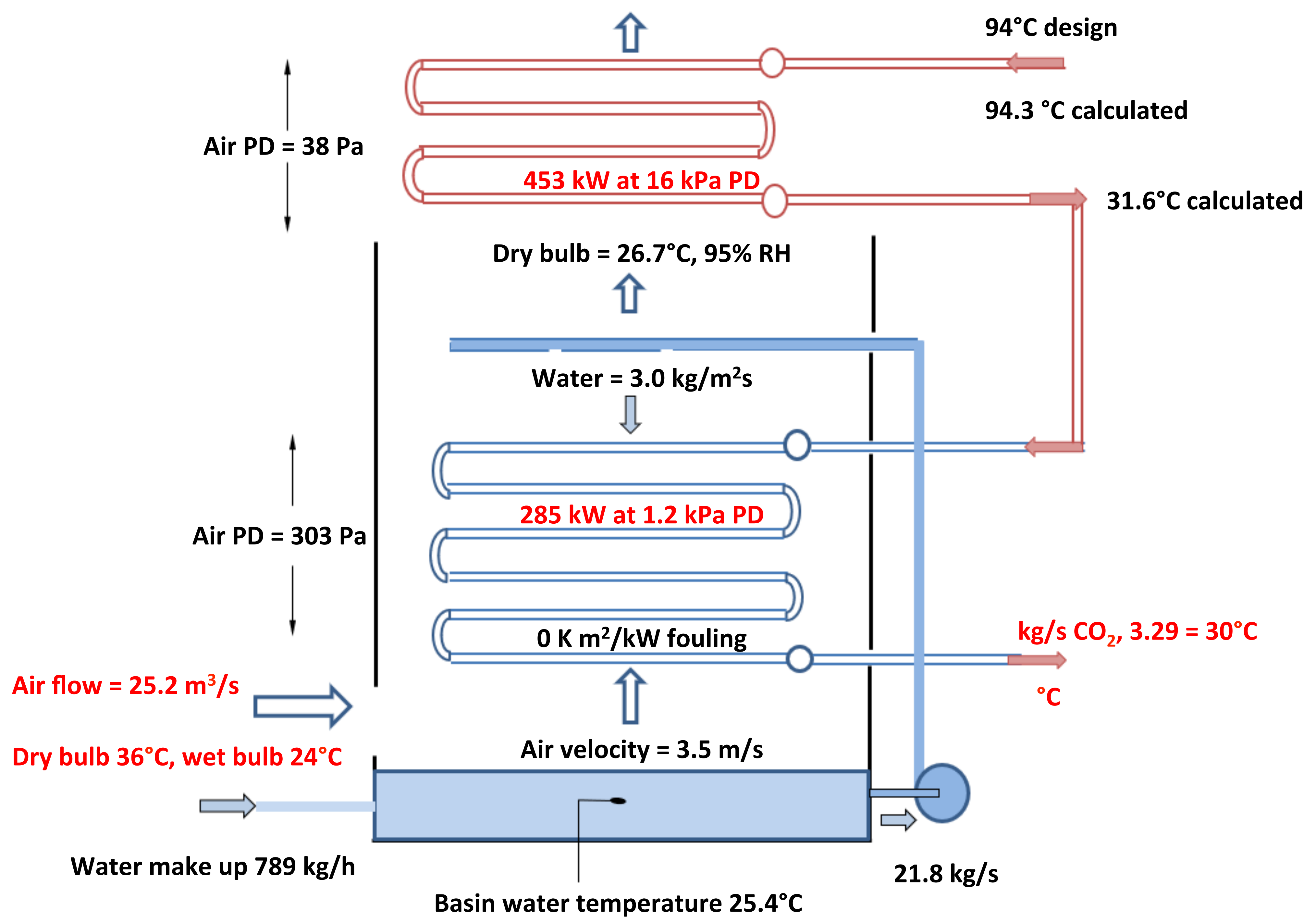
1. Plenum
2. Water Sprays
3. Tubular Evaporative Condensing Coil
4. Air Intake
5. Water Tank
6. Fan
7. Air Cooled Condenser
8. Drift Eliminators
9. Water Circulating Pump

Hybrid = Evaporative Condenser + Dry Cooler

Figure 3: Results of Calculation of Water Consumption and Fan Power at 30°C Condensing

Condensing Capacity 738 kW
Water Consumption 789 kg/h = 1.07 kg/kW.
Fan Power 14 kW

Dry bulb = 41.4°C, 42% RH, 25.6m³/s



Condensing Capacity 730 kW
Water Consumption 0 H_20 Air Cooled.
Fan Power 22 kW

Dry bulb = 33.9°C, 17% RH, 30.7m³/s

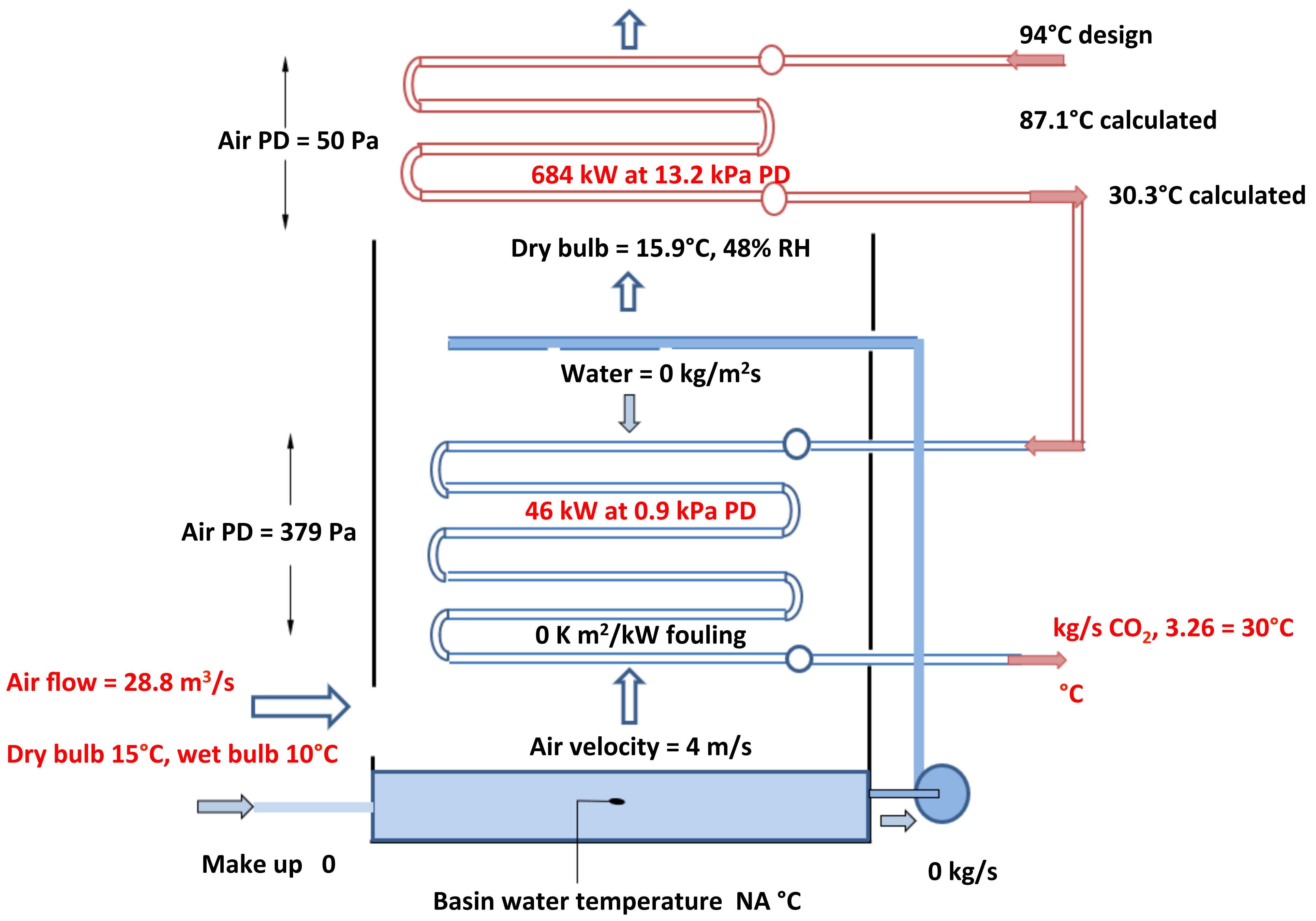


Table 1: Summary of Specific Water Consumption & Cooling Capacity with Performance Details

Dry Bulb Temp., °C	Evap. Condenser		Hybrid Evap. Cond. 6 wet + 2 dry passes		Hybrid Evap. Cond. 2 wet + 6 dry passes		Adiabatic Air Cooled, 12 K air temp. rise		Adiabatic Air Cooled, 17.7 K air temp. rise		Hybrid Evap. Cond., transcritical, 6 wet + 2 dry	
	l/h per kW	Q, kWR	l/h per kW	Q, kWR	l/h per kW	Q, kWR	l/h per kW	Q, kWR	l/h per kW	Q, kWR	l/h per kW	Q, kWR
28	1.57	763	1.08	841	0.8	705	0.3	804	0.21	536		
29											-	
30	1.69	762	1.20	834	0.95	700	0.6	802	0.42	535		
31											-	
32	1.81	761	1.32	826	1.10	694	0.86	801	0.60	534		
33											1.03	717
34	1.94	758	1.45	819	1.25	689	1.16	800	0.81	533		
35											1.26	712
36	2.06	755	1.58	812	1.42	684	1.42	798	0.99	532		
37											1.49	707
38	2.18	754	1.71	805	1.54	678	1.69	797	1.18	537		
39												
40	2.29	752	1.84	797	1.68	672	1.97	795	1.38	531	1.83	700
Wet Bulb Temp., °C	24		24		24		24		24		28	
Disch. Pressure., bar	72.14		72.14		72.14		75		80		80	
Condensing Temp., °C	30		30		30		-		-		-	
Evap. Temp., °C	-5		-5		-5		-5		-5		-5	
Suction Super Heat, K	20		20		20		20		20		20	
Liquid Sub Cool, K	3		3		3		-		-		-	
Gas Cooler Exit, °C	27		27		27		31		32		31	
COP	3.27		3.27		3.27		2.69		2.59		2.69	

Figure 4: Specific Cooling Water Consumption per kW Heat Rejection at 24°C Ambient Wet Bulb

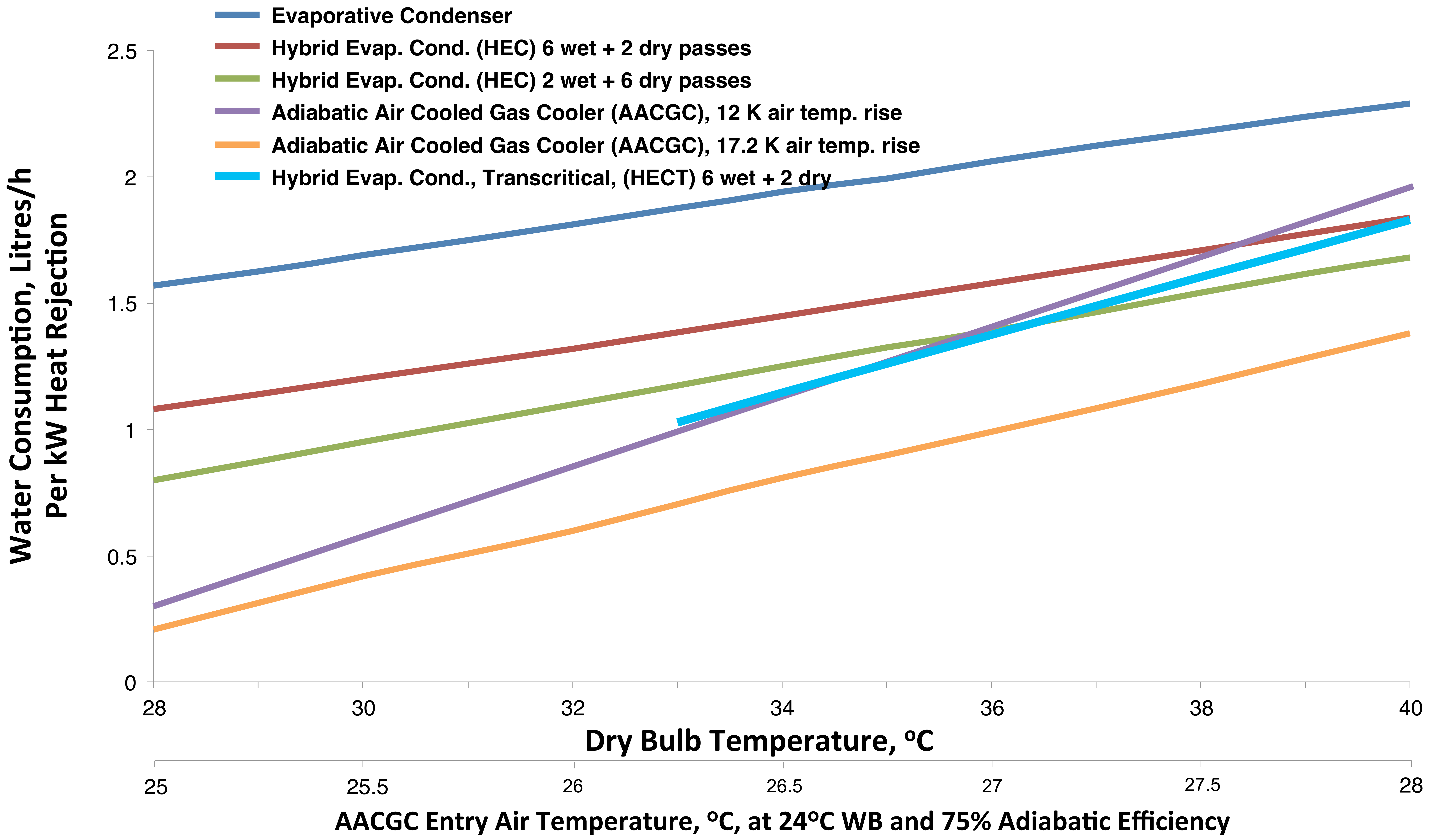


Figure 5: Shows the COP of High Stage CO_2 Compressors

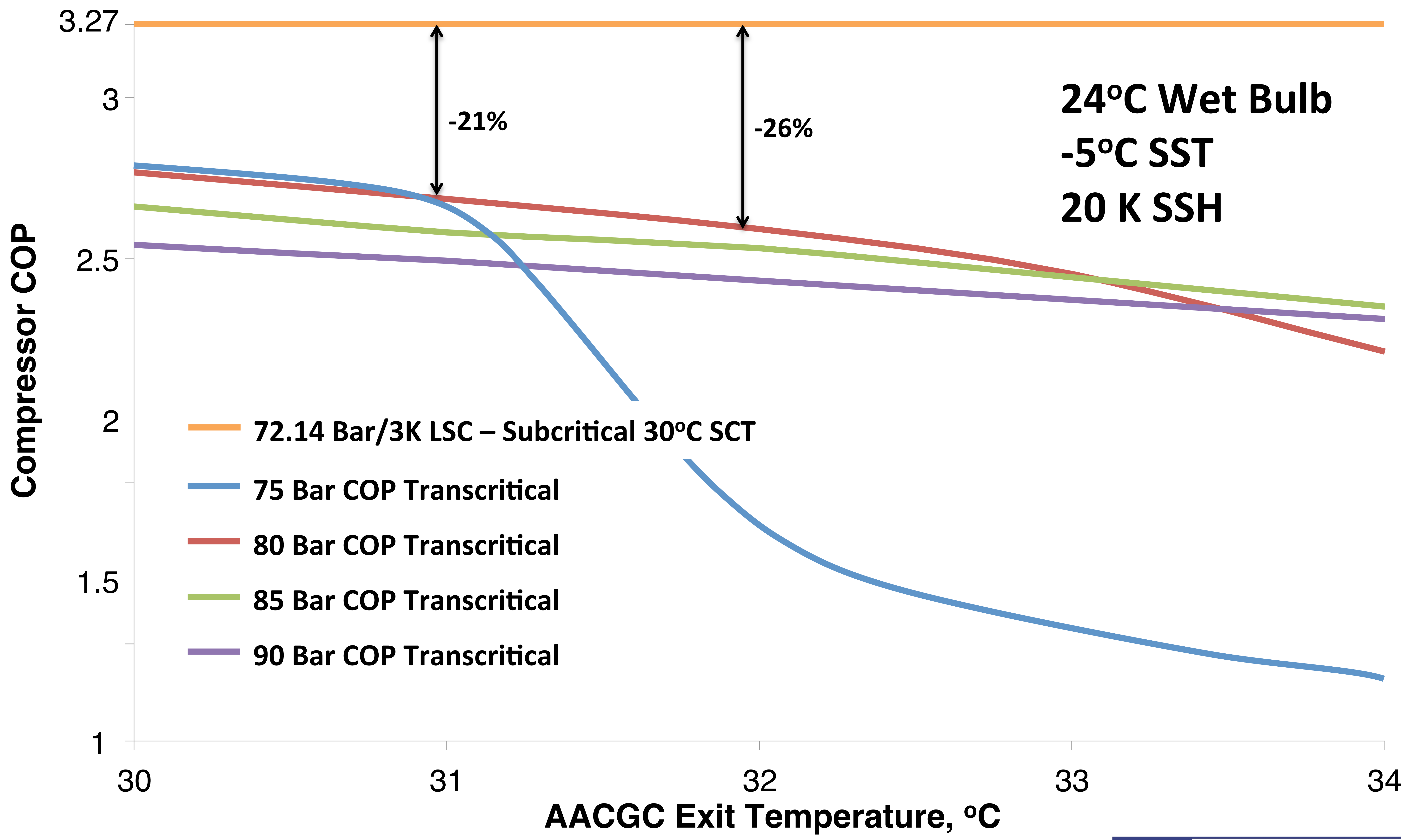


Table 2: Comparison of Specific Water Consumption at Increasing Air Velocities and Increasing Ambient Dry and Wet Bulb Temperatures

Ambient Temp., °C DB/WB	Q kWR	Air Speed m/s	Water Use l/hr	l/h/kWP	Fans kWP
14/10	730	3.7	0	0	18.2
16/10	725	1.0	413	0.57	0.8
18/12	753	1.1	443	0.59	1.0
20/13	749	1.15	458	0.61	1.1
22/14	742	1.2	471	0.63	1.2
24/15	731	1.25	484	0.66	1.3
26/17	740	1.45	504	0.68	1.7
28/18	751	1.65	538	0.72	2.2
30/20	732	1.85	550	0.75	3.0
32/21	724	2.05	588	0.81	3.9
34/22	749	2.50	676	0.90	6.3
36/24	738	3.5	789	1.07	14.8

All at 30°C SCT, 0 K LSC

Figure 6: Calculated Variation Specific Water Consumption in Litres/Hour per kW, and Fan Power Consumption with Fan Speed and Ambient Air Condition Near Sydney

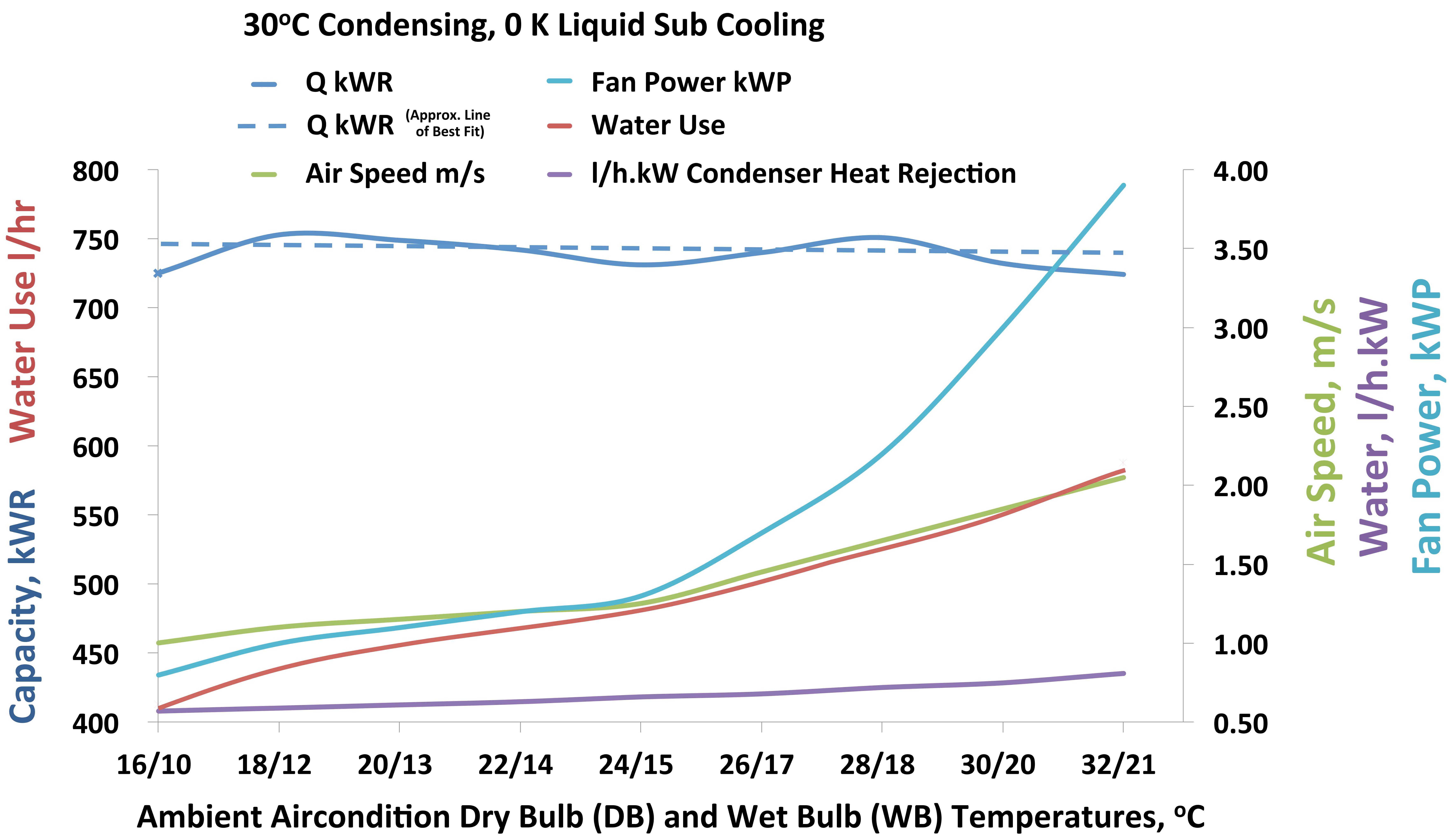


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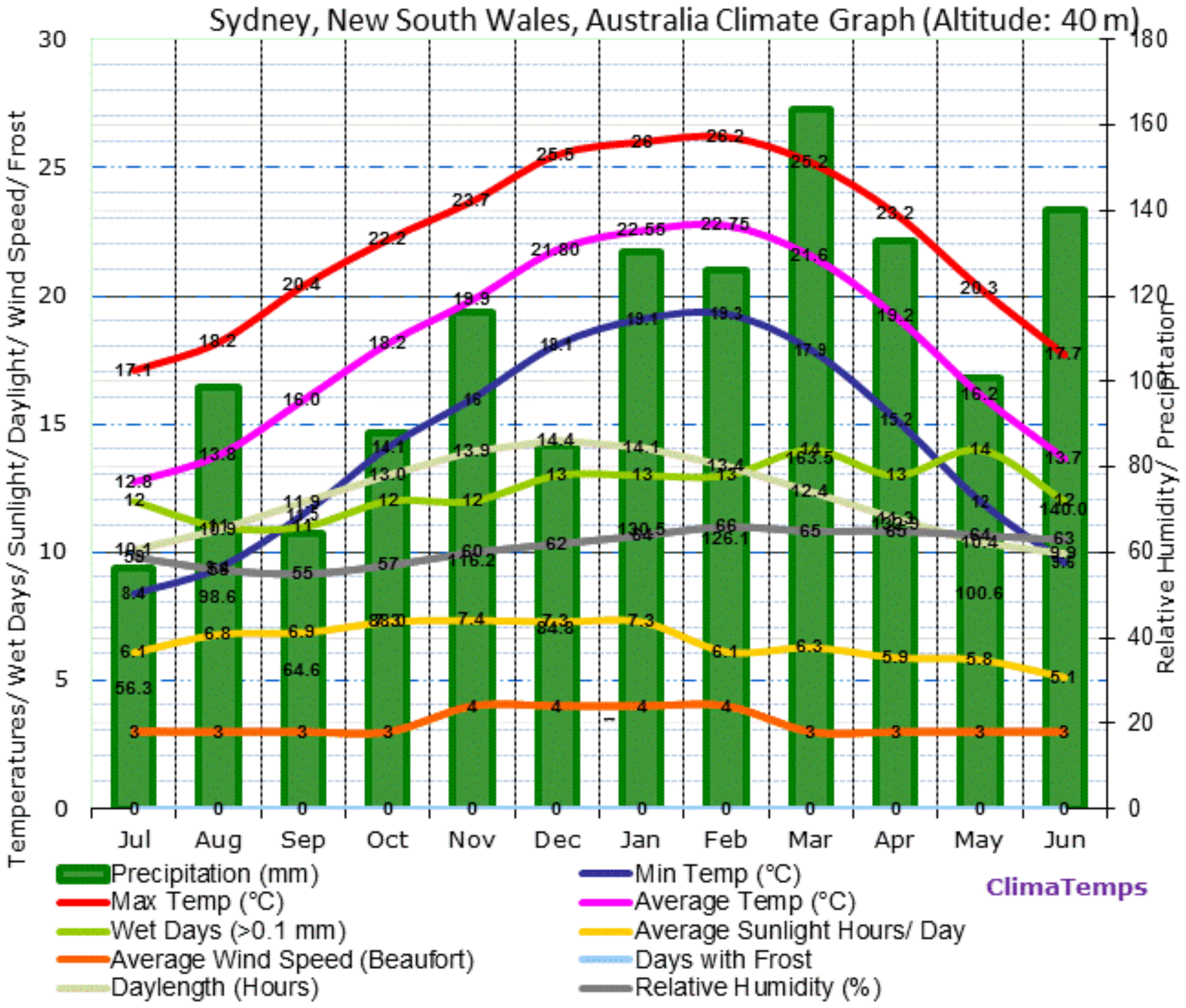
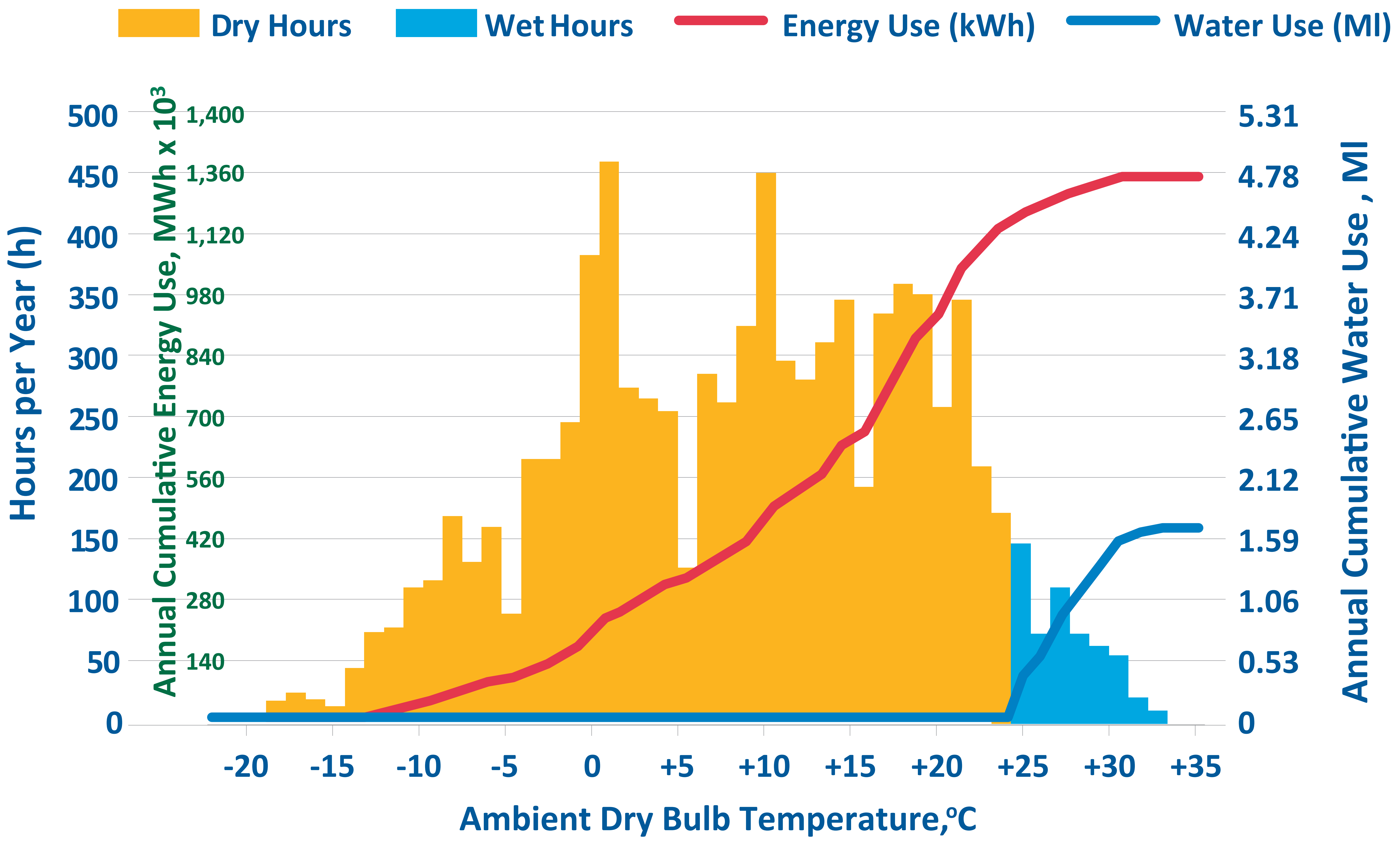
Figure 7: Sydney, NSW, Australia
Annual Climate & Temperature Summary



Source: www.climatemps.com

Climate Variable	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
Average Max Temperature °C (°F)	17 (63)	18 (65)	20 (69)	22 (72)	24 (75)	26 (78)	26 (79)	26 (79)	25 (77)	23 (74)	20 (69)	18 (64)	22 (72)
Average Temperature °C (°F)	13 (55)	14 (57)	16 (61)	18 (65)	20 (68)	22 (71)	23 (73)	23 (73)	22 (71)	19 (67)	16 (61)	14 (57)	18 (65)
Average Min Temperature °C (°F)	8 (47)	9 (49)	12 (53)	14 (57)	16 (61)	18 (65)	19 (66)	19 (67)	18 (64)	15 (59)	12 (54)	10 (49)	14 (58)
Average Precipitation mm (in)	56 (2)	99 (4)	65 (3)	88 (3)	116 (5)	85 (3)	131 (5)	126 (5)	164 (6)	133 (5)	101 (4)	140 (6)	1302 (51)
Number of Wet Days (probability of rain on a day %)	12 (39)	11 (35)	11 (37)	12 (39)	12 (40)	13 (42)	13 (42)	13 (46)	14 (45)	13 (43)	14 (45)	12 (40)	150 (41)
Average Sunlight Hours/ Day	6h 05'	6h 48'	7h 06'	7h 17'	7h 36'	7h 17'	7h 17'	6h 43'	6h 17'	6h 06'	5h 48'	5h 18'	6h 38'
Average Daylight Hours/ Day	10h 07'	10h 54'	11h 56'	13h 01'	13h 55'	14h 21'	14h 07'	13h 22'	12h 22'	11h 17'	10h 23'	9h 55'	12h 00'
Percentage of Sunny (Cloudy) Daylight Hours	61 (39)	63 (37)	60 (40)	57 (43)	55 (45)	51 (49)	52 (48)	51 (49)	51 (49)	55 (45)	57 (43)	54 (46)	55 (45)
Sun altitude at solar noon on the 21st day (°)	35.6	44	55.3	66.5	75.6	79.6	75.9	66.6	56	44.4	36	32.7	55.7

Figure 8: Annual Usage: Adiabatic in Water Priority Mode



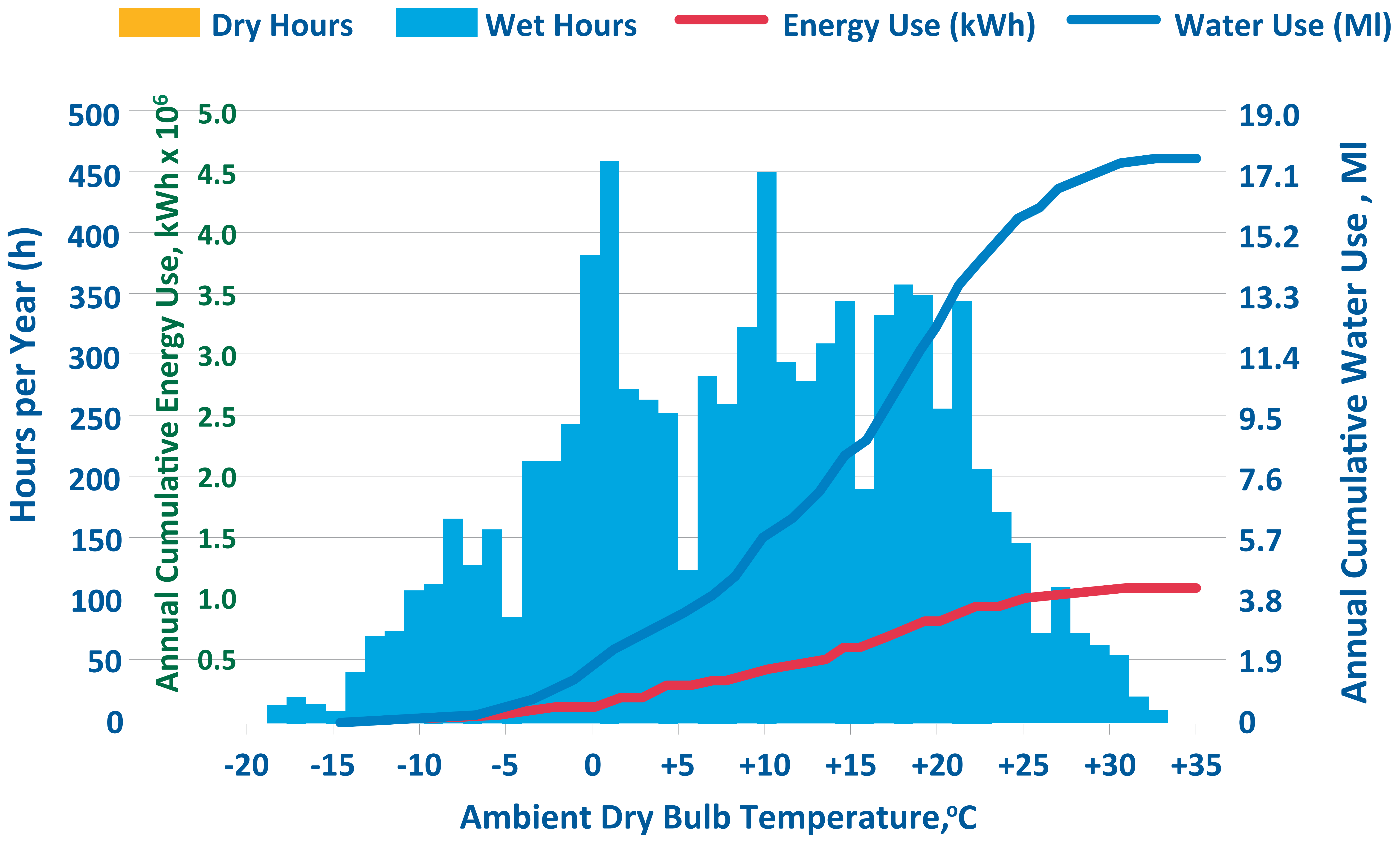
1,407 kWR
Annual Water and Energy Cost:

Adiabatic: US $173,000
Evaporative: US $205,000

Source: Güntner

Example of Evaporative vs. Adiabatic analysis for Binghamton, NY, illustrating cost savings based on water and electrical consumption.

Figure 9: Annual Water and Power Usage: Evaporative Condenser



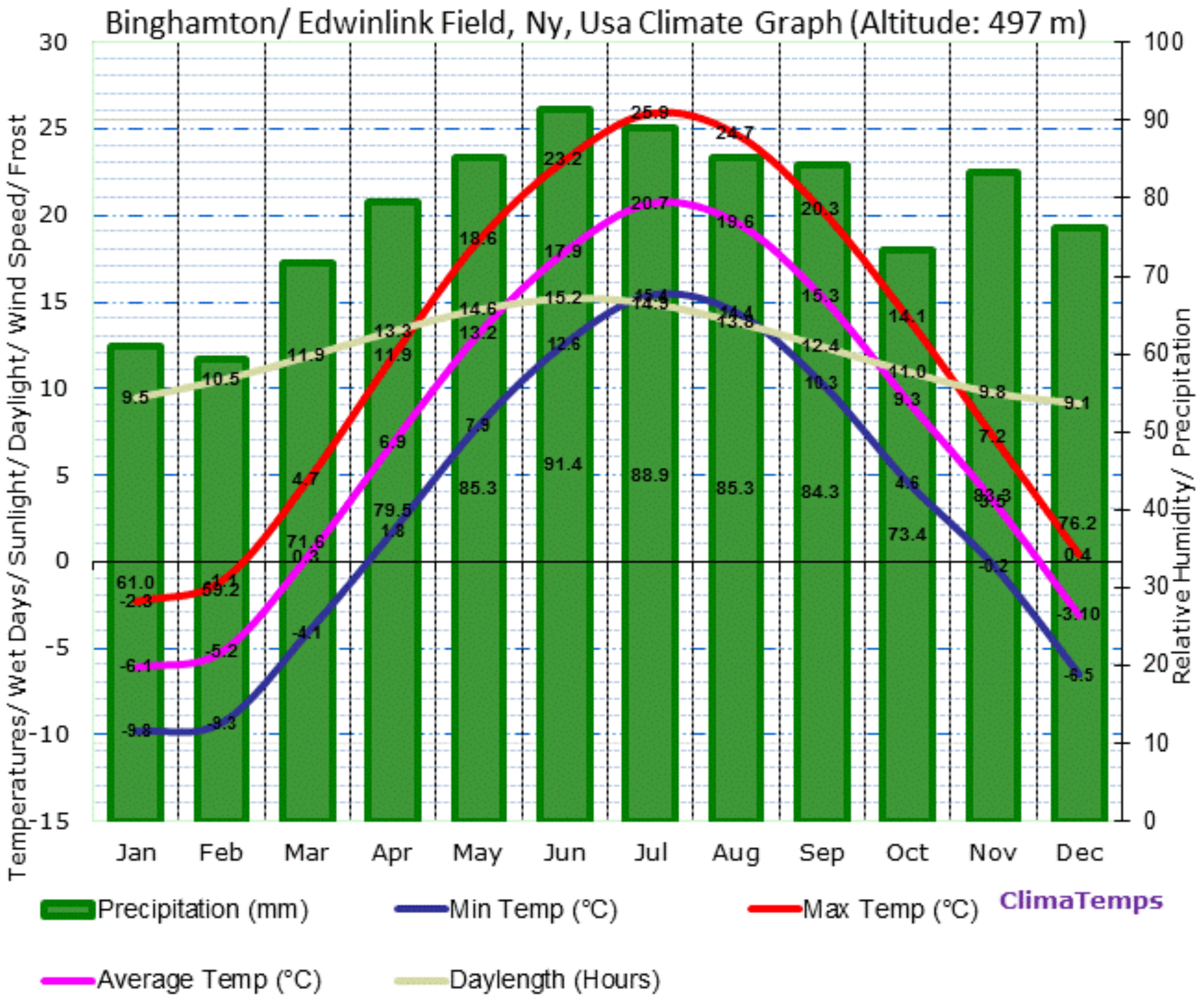
Power and Water Rates:		
Electricity Rate	$0.10	$ / kWh
Demand Charge	$11.00	$ / kW / mo.
Water & Sewage	$2.11	$ / kl
Water Treatment	$1.06	$ / kl

Annual Energy Saving	250,000 kWh
Extra Water Consumption	15.8 Ml
Estimated Extra Cost for Water	Approx. $20,000

Source: Güntner

Example of Evaporative vs. Adiabatic analysis for Binghamton, NY, illustrating cost savings based on water and electrical consumption.

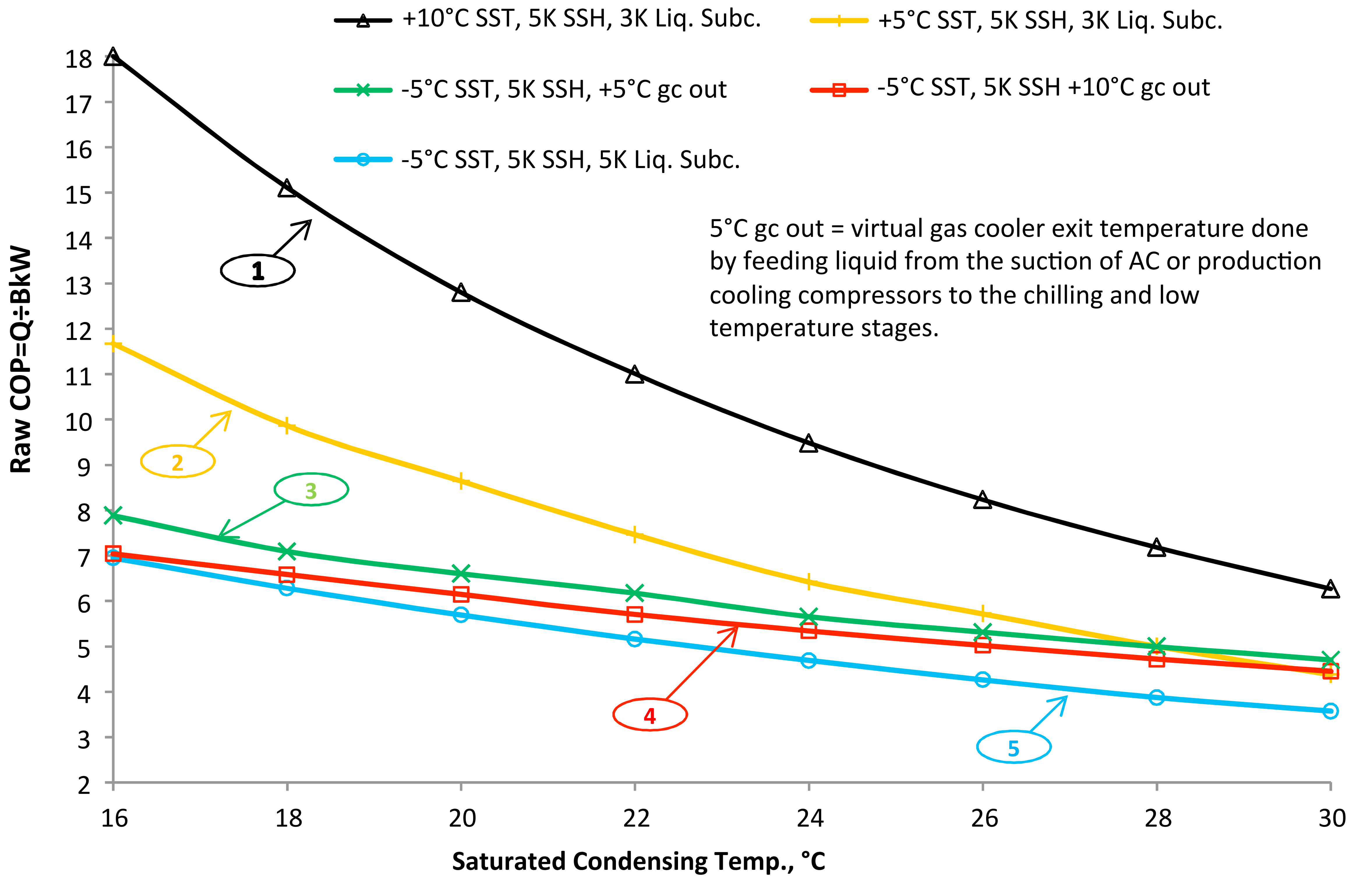
Figure 10: Binghamton / Edwinlink Field, NY, USA
Annual Climate & Temperature Summary

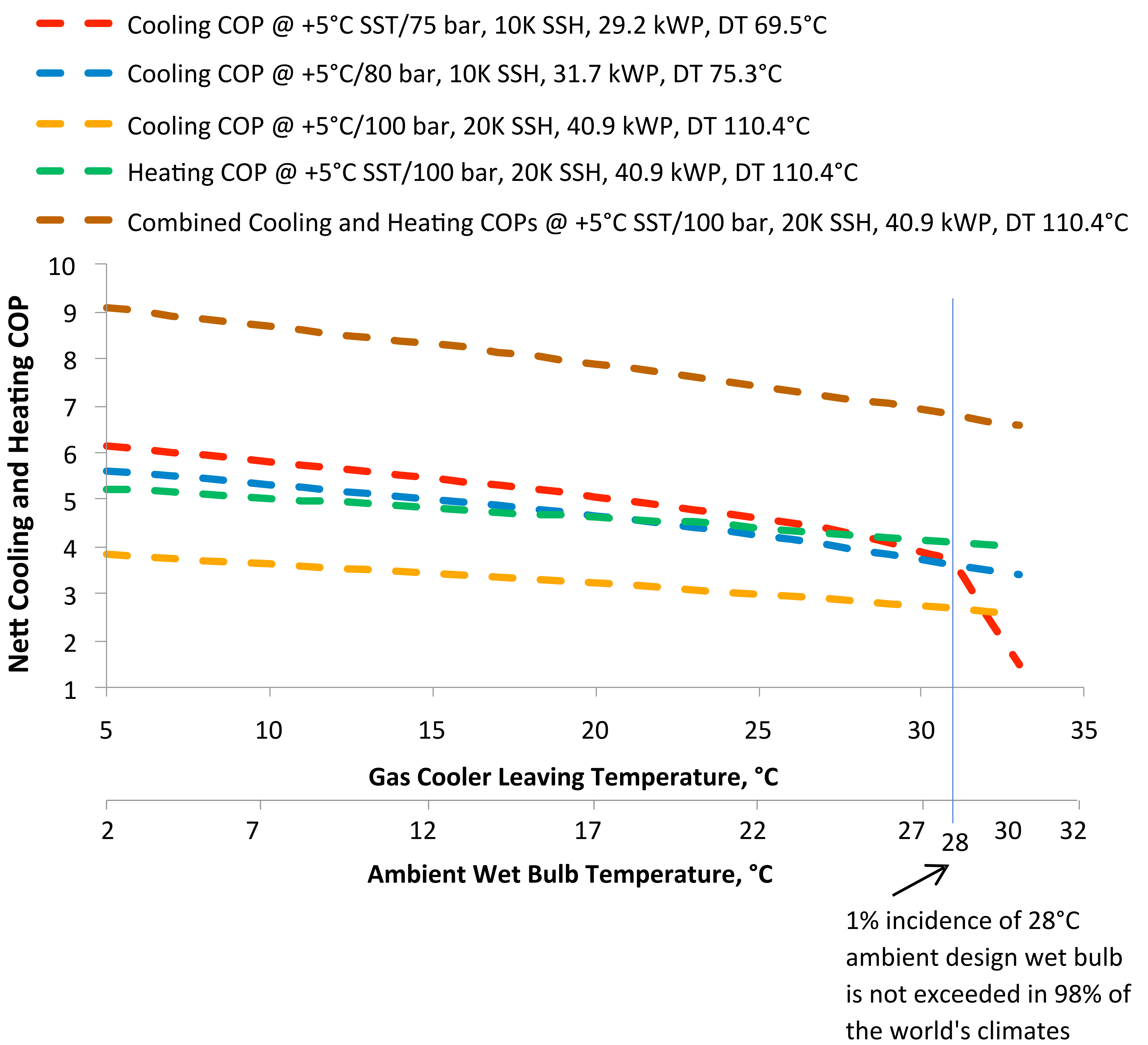


Source: www.climatemps.com

Climate Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max Temperature °C (°F)	-2 (28)	-1 (30)	5 (40)	12 (53)	19 (65)	23 (74)	26 (79)	25 (76)	20 (69)	14 (57)	7 (45)	0 (33)	12 (54)
Average Temperature °C (°F)	-6 (21)	-5 (23)	0 (33)	7 (44)	13 (56)	18 (64)	21 (69)	20 (67)	15 (60)	9 (49)	4 (38)	-3 (26)	8 (46)
Average Min Temperature °C (°F)	-10 (14)	-9 (15)	-4 (25)	2 (35)	8 (46)	13 (55)	15 (60)	14 (58)	10 (51)	5 (40)	0 (32)	-7 (20)	3 (38)
Average Precipitation mm (in)	61 (2)	59 (2)	72 (3)	80 (3)	85 (3)	91 (4)	89 (4)	85 (3)	84 (3)	73 (3)	83 (3)	76 (3)	939 (37)
Average Daylight Hours/ Day	9h 28'	10h 30'	11h 52'	13h 19'	14h 34'	15h 12'	14h 55'	13h 50'	12h 26'	10h 58'	9h 45'	9h 08'	12h 00'
Sun altitude at solar noon on the 21st day (°).	28	37.3	48.2	59.8	68	71.2	68.1	59.8	48.3	36.8	27.7	24.4	48.1

Figure 11 & 12: Coefficients of Performance (COPs) of a Commercially Available Semi-Hermetic Transcritical CO_2 Compressor at 75, 80 and 100 bar Discharge Pressure at 5°C and 10°C Evaporating Temperature, Including Heating COPs to Heat Water from 20°C to 65°C





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COP = Coefficient of Performance
SST = Saturated Suction Temperature, °C
SSH = Suction Super Heat, °C
kWP = compressor power consumption
bar = compressor discharge pressure
DT = compressor Discharge Temperature, °C
K = degree Kelvin for temperature difference
°C = Degree Celsius

Figure 13 :- Variation of Compressor, Condenser and Compressor plus Condenser kW with Condenser Capacity %

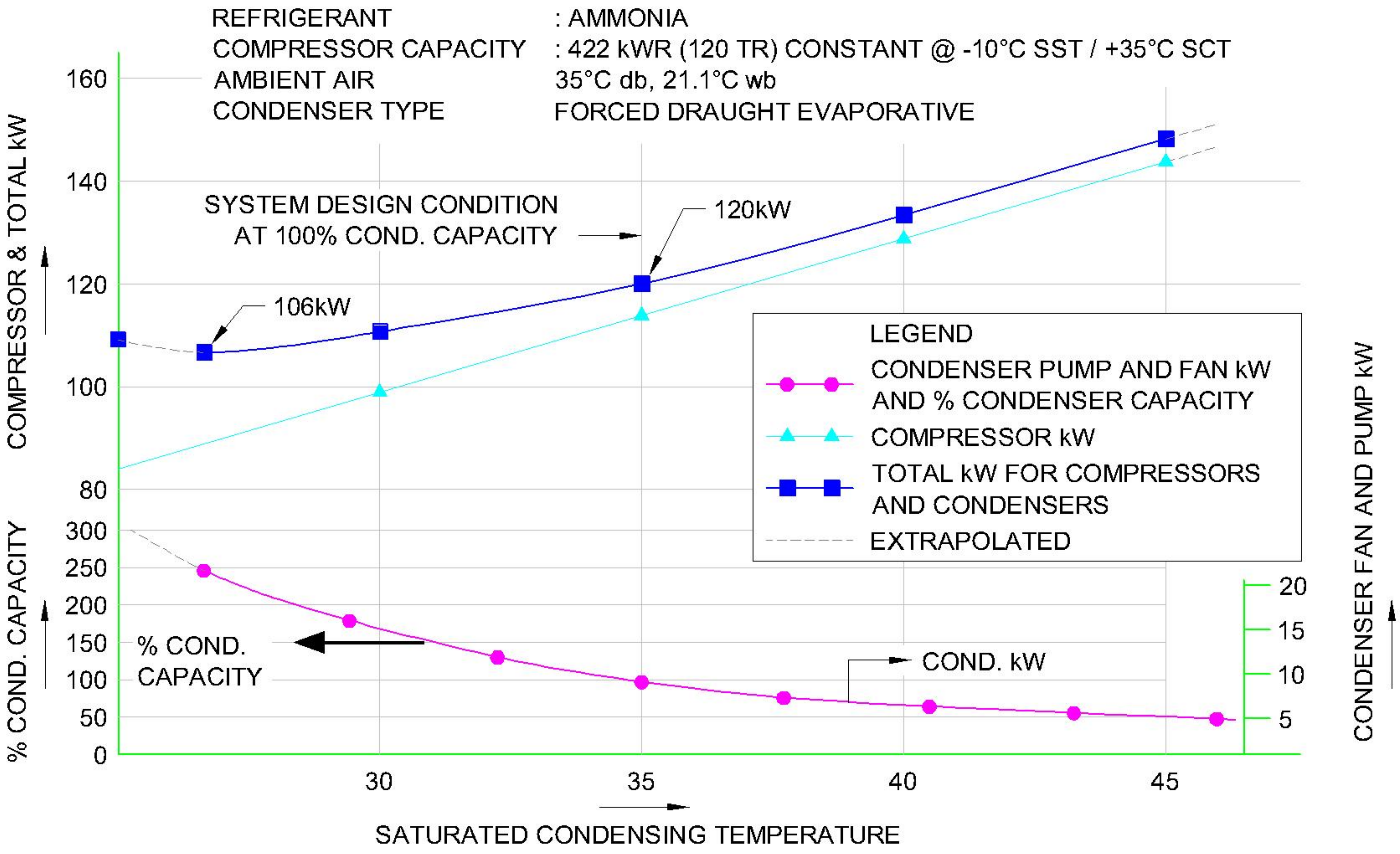

Table 3: Annual Temperature Comparisons Between Sydney, NSW, AU and Binghamton, NY, USA ^{o}C

Temperature Designation	Sydney, NSW	Binghamton, NY
Annual Average Maximum	22	12
Annual Average	18	8
Annual Average Minimum	14	3

Conclusions

1. All applications of water to the condensing and cooling of sub and transcritical CO_2 are meant to reduce the energy consumption by lifting the COP.
2. Adiabatically Assisted Air Cooled CO_2 gas coolers (AAACGCs) perform reasonably well in cold to temperature cool climates in terms of satisfactory COPs and minimum water consumption.
3. Hybrid CO_2 Evaporative Condenser/Gas Coolers (HECGC) may be applied all over the world to achieve efficient CO_2 refrigeration with minimum water consumption.
4. The water consumption of both devices increases with reducing relative humidity.
5. With HECGCs it is relatively easy to achieve at least 3 K Liquid Sub Cooling (LSC) to the liquid draining to the Liquid Receiver. This makes a major contribution to obtaining a high compressor COP, enhancing energy efficiency.
6. The application of HECGCs results in firstly, energy consumption reduction to operate the HECGCs and, secondly, the reduced energy consumption of the compressor.

Conclusions Cont…

7. Both systems are suitable for heat pump application enhancing energy efficiency and reducing costly water consumption.
8. High COPs are achieved with floating condensing pressures in both systems at the cost of higher water consumption.
9. High energy consumption = high Global Warming Emission. High Global Warming Emissions = reduction in water availability Low Energy Consumption = Low GWEs = better water availability but higher H_2O consumption.
10. Fan speed control on HECGCs optimises energy and water consumption when maintaining a constant discharge pressure.
11. Only where cooling water is in very short supply should air cooled gas cooling be applied in warm to hot climates.
12. HECGCs offer much greater overall energy efficiency all over the world and unless no cooling water is available HECGCs should be used in preference to AAACGCs.


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Thank you very much! Questions?
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