

# Appendix D

## FORMULAS AND CALCULATIONS

### Abbreviations

<b>A</b>	Area
<b>ACH</b>	Air Changes per Hour
<b>A<sub>k</sub></b>	Effective Area
<b>AVG</b>	Average
<b>BHP</b>	Brake Horsepower
<b>BP</b>	Brake Power
<b>Btu</b>	British Thermal Unit
<b>Btu/hr or Btuh</b>	British Thermal Unit Per Hour
<b>CL</b>	Center Distance (used in belt formula)
<b>°C</b>	Degrees Celsius
<b>C</b>	Friction Loss Coefficient (For Duct Fittings)
<b>CCF</b>	100 Cubic Foot
<b>CFM</b>	Volumetric Flow: Cubic Feet Per Minute
<b>C<sub>p</sub></b>	Specific Heat
<b>C<sub>v</sub></b>	Flow Constant (IP)
<b>ρ</b>	Density
<b>d</b>	Diameter
<b>Δ</b>	Difference or Change (Final - Initial)
<b>d<sub>imp</sub></b>	Impeller Diameter
<b>E</b>	Volts
<b>Eff</b>	Efficiency
<b>EP</b>	Pump Efficiency
<b>°F</b>	Degrees Fahrenheit
<b>f</b>	Friction Factor
<b>fc</b>	foot-candle

<b>FLA</b>	Full Load Amps
<b>FPM</b>	Feet Per Minute
<b>ft</b>	Foot
<b>g</b>	Acceleration of Gravity
<b>gal</b>	Gallons
<b>GPM</b>	Gallons Per Minute
<b>h</b>	Enthalpy
<b>H</b>	Head
<b>Hg</b>	Mercury
<b>h<sub>ma</sub></b>	Mixed Air Enthalpy
<b>h<sub>oa</sub></b>	Outside Air Enthalpy
<b>HP</b>	Horsepower
<b>hr</b>	Hour
<b>h<sub>ra</sub></b>	Return Air Enthalpy
<b>HT</b>	Height
<b>in</b>	Inch
<b>I</b>	Amps
<b>J</b>	Joules
<b>K</b>	Kelvin
<b>K<sub>v</sub></b>	Flow constant (SI)
<b>kcal</b>	kilocalorie
<b>kg</b>	Kilogram
<b>kJ</b>	Kilojoule
<b>kPa</b>	Kilopascal
<b>kW</b>	Kilowatt
<b>l or L</b>	Litre
<b>l/s or L/s</b>	Volumetric Flow: Litres Per Second
<b>lb</b>	Pounds
<b>lm</b>	Lumens
<b>ln</b>	natural log
<b>LG</b>	Length
<b>lx</b>	Lux

<b>M</b>	Mass
<b>ma</b>	Mixed Air
<b>m</b>	Meters / Metres
<b>m<sup>3</sup>/s</b>	Volumetric Flow: Cubic Meters Per Second
<b>mbh</b>	1000 Btu/hr
<b>NLA</b>	No Load Amperage
<b>NPSHA</b>	Net Positive Suction Head Available
<b>OA</b>	Outside Air
<b>% OA</b>	% of Outside Air
<b>Ω</b>	Ohm
<b>P</b>	Pressure
<b>Pa</b>	Atmospheric Pressure
<b>P<sub>ab</sub></b>	Absolute Pressure
<b>Pa</b>	Pascals
<b>π</b>	Pi = 3.14
<b>PD</b>	Pitch Diameter
<b>P<sub>CL</sub></b>	Pressure at Pump Centreline
<b>ppm</b>	Parts Per Million
<b>psi</b>	Pounds Per Square Inch
<b>psia</b>	Pounds Per Square Inch Absolute
<b>psig</b>	Pounds Per Square Inch Gauge
<b>P<sub>vp</sub></b>	Absolute Vapor Pressure
<b>Q (flow)</b>	Volumetric Fluid Flow Rate
<b>Q (heat)</b>	Heat Flow Rate
<b>°R</b>	Degrees Rankin
<b>r</b>	Radius
<b>% RA</b>	% of Return Air
<b>R</b>	Resistance
<b>RA</b>	Return Air
<b>rad</b>	Radians
<b>RH</b>	Relative Humidity
<b>RPM</b>	Revolutions Per Minute

<b>Rvalue</b>	Thermal Resistance
<b>s</b>	Second
<b>SHR</b>	Sensible Heat Ratio
<b>SME</b>	Sash Movement Effect Performance Rating (SME-XX yyy)
<b>SP</b>	Static Pressure
<b>Sp Gr</b>	Specific Gravity (for water use 1.00)
<b>T</b>	Temperature
<b>Ta</b>	Absolute Temperature
<b>Tma</b>	Mixed Air Temperature
<b>Toa</b>	Outside Air Temperature
<b>TP</b>	Total Pressure
<b>Tra</b>	Return Air Temperature
<b>TS</b>	Tip Speed
<b>U</b>	Heat Transfer Coefficient
<b>μ</b>	Viscosity, Dynamic
<b>V</b>	Velocity
<b>VP</b>	Velocity Pressure
<b>W</b>	Watt or J/s
<b>WD</b>	Width
<b>wg or wc</b>	water gauge or water column
<b>WHP</b>	Water Horsepower
<b>WP</b>	Water Power
<b>ω</b>	Humidity Ratio

## Formulas

Category	Abbr	Description (unit)	Equation	Units
Air Movement	Q	Airflow volume	$Q = V \times A \times 1000$	L/s
	$\rho$	Density (kg/m <sup>3</sup> )		
	A	Duct cross sectional area	$Q = V \times A$	m <sup>3</sup> /s
	ACH	Air changes per hour	$A_{\text{rectangle}} = HT \times WD$	m <sup>2</sup>
	C	Duct fitting coefficient		
	d	Diameter		
	HT	Height	$A_{\text{oval}} = (HT \times (WD - HT)) + (\pi \times (\frac{HT}{2})^2)$	m <sup>2</sup>
	L/s	Litres per second		
	LG	Length		
	m	Meters	$A_{\text{round}} = \pi \times (\frac{d}{2})^2 = \pi \times r^2$	m <sup>2</sup>
	m/s	Meters per second		
	m <sup>3</sup> /s	Cubic meters per second		
	Pa	Pascals		
	SP	Static pressure	$TP = VP + SP$	Pa
	T	Absolute Temp (°K = 273 + °C)		
	TP	Total pressure		
	V	Velocity		
V <sub>m</sub>	Measured velocity (m/s)	$\rho = 3.48 \frac{P_{\text{ab}}}{T}$	kg/m <sup>3</sup>	
VP	Velocity pressure			
WD	Width			
P <sub>ab</sub>	Absolute Pressure (kPa) (Barometric Pressure + SP)	$V = 1.414 \times \sqrt{\frac{VP}{\rho}}$	m/s	
		$VP = 0.5 \times \rho \times V^2$	Pa	
		or for standard air density ( $\rho$ ) where = 1.204 kg/m <sup>3</sup>		
		$V = \sqrt{1.66 VP}$	m/s	
		Where density is not standard		
		$V = V_m \left( \frac{\rho \text{ (other than standard)}}{1.204} \right)$	m/s	
		$TP = C \times VP$	Pa	
		$ACH = \frac{Q \times 3600}{(LG \times WD \times HT)}$	ACH	

Category	Abbr	Description (unit)	Equation	Units
Air Temperature	°C	Degrees Celsius	$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \div 1.8$	°C
	°F	Degrees Fahrenheit		
	K	Kelvin	$\text{K} = (^{\circ}\text{C} + 273)$	K
	T	Temperature		
	%	Percentage		
	h	Enthalpy	$T_{\text{ma}} = (\%_{\text{oa}} \times T_{\text{oa}}) + (\%_{\text{ra}} \times T_{\text{ra}})$	°C
	oa ra ma	Outside air Return air Mixed air	$h_{\text{ma}} = (\%_{\text{oa}} \times h_{\text{oa}}) + (\%_{\text{ra}} \times h_{\text{ra}})$  $\%_{\text{oa}} = \left( \frac{h_{\text{ra}} - h_{\text{ma}}}{h_{\text{ra}} - h_{\text{oa}}} \right) \times 100$  $\%_{\text{oa}} = \left( \frac{T_{\text{ra}} - T_{\text{ma}}}{T_{\text{ra}} - T_{\text{oa}}} \right) \times 100$	   kJ/kg <sub>dry air</sub>  %  %
Air Heat Flow	Q	Heat flow	$Q = C_p \times \rho \times L/s \times \Delta t$	W
	C <sub>p</sub>	Specific Heat (kJ/kg · °C)		
	ρ	Density (kg/m <sup>3</sup> )		
	Δt	Temperature difference (°C)		
	L/s	Litres per second	for standard air: (C <sub>p</sub> = 1.005 kJ/kg · °C)	
	ΔW	Humidity Ratio (g H <sub>2</sub> O/kg dry air)		
	Δh	Enthalpy difference (kJ/kg dry air)	$\text{SHR} = Q_{\text{sensible}} \div Q_{\text{total}}$	%
	U	Heat transfer coefficient (W/m <sup>2</sup> · °C)	$Q_{\text{total}} = Q_{\text{latent}} + Q_{\text{sensible}}$	W
	R	Sum thermal resistances (m <sup>2</sup> · °C/W)		
	P	Absolute Pressure (kPa)		
	V	Total volume (m <sup>3</sup> )		
	T	Absolute Temp (°K = 273 + °C)	$Q = A \times U \times \Delta t$	W
	R	Gas constant (kJ/kg · °C)		
	M	Mass (kg)		
	W	Watts		
	kW	Kilowatt	$Q_{(\text{sens})} = 1.23 \times L/s \times \Delta t$	W
	A	Cross sectional area (m <sup>2</sup> )	$Q_{(\text{sens})} = 1.23 \times m^3/s \times \Delta t$	kW
	SHR	Sensible Heat Ratio	$Q_{(\text{lat})} = 3.0 \times L/s \times \Delta W$	W
	Lat	Latent	$Q_{(\text{total heat})} = 1.20 \times L/s \times \Delta h$	W
	Sens	Sensible	$Q = A \times U \times \Delta t$	W
		$R = \frac{1}{U}$	kJ/kg · °C	
		$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \text{RM}$	RM	

Category	Abbr	Description (unit)	Equation	Units
Fan Equations	D	Diameter	$\frac{Q_2}{Q_1} = \frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{rad/s_2}{rad/s_1} = \frac{rev/s_2}{rev/s_1}$	L/s, m <sup>3</sup> /s, rad/s, rev/s
	Q	Airflow Volume		
	m	Meters	$\frac{P_2}{P_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{m^3/s_2}{m^3/s_1}\right)^2$	Pa, L/s, m <sup>3</sup> /s
	m/s	Meters per second		
L/s	Litres per second	$\frac{kW_2}{kW_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{m^3/s_2}{m^3/s_1}\right)^2$	kW, L/s, m <sup>3</sup> /s	
rad/s	Radians per second			
rev/s	Revolutions per second	$\frac{rad/s \text{ (fan)}}{rad/s \text{ (motor)}} = \frac{\text{Pitch diam. motor pulley}}{\text{Pitch diam. fan pulley}}$	rad/s	
ρ	Density (kg/m <sup>3</sup> )			
kW	Kilowatts	$\frac{RPM \text{ (fan)}}{RPM \text{ (motor)}} = \frac{\text{Pitch diam. motor pulley}}{\text{Pitch diam. fan pulley}}$	RPM	
RPM	Revolutions per minute			
CL	Centre Line Distance (mm)	$TS = \frac{(\pi \times D \times RPM)}{60}$	m/s	
PD	Pitch Diameter (mm)			
mm	Millimetres	Determining Fan Belt Length		
FBL	Fan Belt Length			
TS	Tip Speed	$FBL = (CL \times 2) + \left(1.57 \times (PD_{large} + PD_{small})\right) + \left(\frac{(PD_{large} - PD_{small})^2}{4 \times CL}\right)$	mm	
Pump	L/s	Litres per second	$\frac{\Delta P_2}{\Delta P_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{RPM_2}{RPM_1}\right)^2$	kPa, L/s, RPM
	m <sup>3</sup> /s	Cubic meters per sec		
	ΔP	Differential pressure (kPa)	$\frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{RPM_2}{RPM_1}$	L/s, m <sup>3</sup> /s, RPM
	Kv	Valve constant (m <sup>3</sup> /h @ 1 bar)		
	kW	Kilowatts	$\frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{D_2}{D_1}$	L/s, m <sup>3</sup> /s, D
	Bar	Pressure equivalent to 100 kPa		
	Δt	Temperature difference (°C)	$\frac{kW_2}{kW_1} = \left(\frac{RPM_2}{RPM_1}\right)^3 = \left(\frac{L/s_2}{L/s_1}\right)^3$	kW, RPM, L/s
	D	Impeller diameter (mm)		
	RPM	Revolutions per minute	$WP = 9.81 \times m^3/s \times H_m \times SpGr$	kW
	WP	Waterpower		
	H	Head	$WP = \frac{(L/s \times H_{Pa} \times SpGr)}{1000}$	W
	SpGr	Specific gravity (H <sub>2</sub> O = 1.0)		
	BP	Brake power (kW)	$BP = \frac{WP}{E_p}$	kW
	E <sub>p</sub>	Pump efficiency		
Pa	Pascals	$E_p = \frac{WP \times 100}{BP}$	%	
m	meters			

Category	Abbr	Description (unit)	Equation	Units
Hydronic	L/s	Litres per second	$\text{NPSHA} = P_a \pm P_s + \left(\frac{V^2}{2}\right) - P_{vp} - P_f$ $h = f \times \frac{L}{D} \times \frac{V^2}{2g}$ $L/s = \frac{Kv}{36} \times \sqrt{\Delta P}$ $\Delta P = \left(\frac{36 \times L/s}{Kv}\right)^2$ $\text{Coil } \Delta P: P_2 = P_1 \times \left(\frac{L/s_2}{L/s_1}\right)^2$	kPa
	$\Delta P$	Differential pressure (kPa)		m
	Kv	Valve constant (m <sup>3</sup> /h @ 1 bar)		L/s
	NPSHA	Net positive suction head available		kPa
	L	Length of pipe (m)		
	D	Internal pipe diameter (m)		
	V	Water velocity (m/s)		
	g	Gravity acceleration (9.807 m/s <sup>2</sup> )		
	f	Friction factor (dimensionless)		
	h	Head loss		
	P	Pressure		
	P <sub>f</sub>	Inlet pipe friction loss		
	P <sub>a</sub>	Atm. pressure Std =101.325 (kPa)		
P <sub>s</sub>	Pressure at pump centreline (kPa)			
P <sub>vp</sub>	Absolute vapour pressure (kPa)			
Hydronic Heat Flow	Q	Heat flow	$Q = 4190 \times m^3/s \times \Delta t$	W
	m <sup>3</sup> /s	Cubic meters per second	$Q = 4.19 \times L/s \times \Delta t$	kW
	$\Delta t$	Temperature difference (°C)		
	C <sub>p</sub>	Specific Heat (kJ/kg · °C)		
	L/s	Litres per second	$Q = C_p \times \rho \times L/s \times \Delta t$	W
Electrical and Power	kW	Kilowatts	$E = I \times R$	V
	I	Current (amps)	$P = E \times I$	W
	E	Energy (volts)	$kW = \frac{(E \times I)}{1000}$	kW
	P.F	Power factor	Single Phase: $kW = \frac{(E \times I \times P.F \times \text{Eff})}{1000}$	A
	R	Resistance (Ω)	Three Phase: $kW = \frac{(E \times I \times P.F \times \text{Eff} \times 1.732)}{1000}$	kW
	P	Power	Fan $kW = \frac{(m^3/s \times TP \times \text{SpGr})}{(1000 \times \text{Eff})}$	kW
	FLA	Full load Amps	Actual FLA = $\frac{FLA^* \times \text{Voltage}^*}{\text{Actual Voltage}}$	I
	BP	Brake power (kW)	BP = $kW^* \times \frac{\text{Motor Amps} - (NLA \times 0.5)}{FLA - (NLA \times 0.5)}$	kW
	SpGr	Specific gravity (H <sub>2</sub> O = 1.0)		
	Eff	Efficiency (%)		
	TP	Total Pressure		
	m <sup>3</sup> /s	Cubic meters per second		
	NLA	No load amps		
			*Nameplate rating	

## Air density correction factors

Altitude (m)		Sea Level	250	500	750	1000	1250	1500	1750	2000	2500	3000	
Barometer (kPa)		101.3	98.3	96.3	93.2	90.2	88.2	85.1	83.1	80.0	76.0	71.9	
Air Temp °C	0°	1.08	1.05	1.02	0.99	0.96	0.93	0.91	0.88	0.86	0.81	0.76	
	20°	1.00	0.97	0.95	0.92	0.89	0.87	0.84	0.82	0.79	0.75	0.71	
	50°	0.91	0.89	0.86	0.84	0.81	0.79	0.77	0.75	0.72	0.68	0.64	
	75°	0.85	0.82	0.80	0.78	0.75	0.73	0.71	0.69	0.67	0.63	0.60	
	100°	0.79	0.77	0.75	0.72	0.70	0.68	0.66	0.65	0.63	0.59	0.56	
	125°	0.74	0.72	0.70	0.68	0.66	0.64	0.62	0.60	0.59	0.55	0.52	
	150°	0.70	0.68	0.66	0.64	0.62	0.60	0.59	0.57	0.55	0.52	0.49	
	175°	0.66	0.64	0.62	0.62	0.59	0.57	0.55	0.54	0.52	0.49	0.46	
	200°	0.62	0.61	0.59	0.57	0.56	0.54	0.52	0.51	0.49	0.47	0.44	
	225°	0.59	0.58	0.56	0.54	0.53	0.51	0.50	0.48	0.47	0.44	0.42	
	250°	0.56	0.55	0.53	0.52	0.50	0.49	0.47	0.46	0.45	0.42	0.40	
	275°	0.54	0.52	0.51	0.49	0.48	0.47	0.45	0.44	0.44	0.43	0.40	0.38
	300°	0.51	0.50	0.49	0.47	0.46	0.45	0.43	0.42	0.42	0.41	0.38	0.36
	325°	0.49	0.48	0.47	0.45	0.44	0.43	0.41	0.40	0.40	0.39	0.37	0.35
	350°	0.47	0.46	0.45	0.43	0.42	0.41	0.40	0.40	0.39	0.38	0.35	0.33
	375°	0.46	0.44	0.43	0.42	0.41	0.39	0.38	0.38	0.37	0.36	0.34	0.32
	400°	0.44	0.43	0.41	0.40	0.39	0.38	0.37	0.37	0.36	0.35	0.33	0.31
425°	0.42	0.41	0.40	0.39	0.38	0.37	0.35	0.35	0.34	0.33	0.32	0.30	
450°	0.41	0.40	0.38	0.37	0.36	0.35	0.34	0.34	0.33	0.32	0.31	0.29	
475°	0.39	0.38	0.37	0.36	0.35	0.34	0.34	0.33	0.32	0.31	0.29	0.28	
500°	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.31	0.30	0.28	0.27	
525°	0.37	0.36	0.35	0.34	0.33	0.32	0.32	0.31	0.30	0.29	0.27	0.26	
Standard Air Density, Sea Level, 20°C = 1.2041 kg/m <sup>3</sup> at 101.325 kPa													

## Velocity Pressure to Velocity Chart

Velocity Pressure	Velocity								
Pa	m/s								
1	1.29	31	7.18	61	10.07	91	12.29	121	14.18
2	1.82	32	7.29	62	10.15	92	12.36	122	14.24
3	2.23	33	7.4	63	10.23	93	12.43	123	14.29
4	2.58	34	7.52	64	10.31	94	12.50	124	14.35
5	2.88	35	7.62	65	10.39	95	12.56	125	14.41
6	3.16	36	7.73	66	10.47	96	12.63	126	14.47
7	3.41	37	7.84	67	10.55	97	12.69	127	14.52
8	3.65	38	7.94	68	10.63	98	12.76	128	14.58
9	3.87	39	8.05	69	10.71	99	12.82	129	14.64
10	4.08	40	8.15	70	10.78	100	12.89	130	14.70
11	4.27	41	8.25	71	10.86	101	12.95	131	14.75
12	4.46	42	8.35	72	10.94	102	12.95	132	14.81
13	4.65	43	8.45	73	11.01	103	13.08	133	14.86
14	4.82	44	8.55	74	11.09	104	13.14	134	14.92
15	4.99	45	8.65	75	11.16	105	13.21	135	14.98
16	5.16	46	8.74	76	11.24	106	13.27	136	15.03
17	5.31	47	8.84	77	11.31	107	13.33	137	15.09
18	5.47	48	8.93	78	11.38	108	13.39	138	15.14
19	5.62	49	9.02	79	11.46	109	13.46	139	15.20
20	5.76	50	9.11	80	11.53	110	13.52	140	15.25
21	5.91	51	9.2	81	11.6	111	13.58	141	15.30
22	6.05	52	9.29	82	11.67	112	13.64	142	15.36
23	6.18	53	9.38	83	11.74	113	13.70	143	15.41
24	6.31	54	9.47	84	11.81	114	13.76	144	15.47
25	6.44	55	9.56	85	11.88	115	13.82	145	15.52
26	6.57	56	9.64	86	11.95	116	13.88	146	15.57
27	6.7	57	9.73	87	12.02	117	13.94	147	15.63
28	6.82	58	9.82	88	12.09	118	14	148	15.68
29	6.94	59	9.90	89	12.16	119	14.06	149	15.73
30	7.06	60	9.98	90	12.23	120	14.12	150	15.79

Based on Standard Air Density of 1.204 kg/m<sup>3</sup>  
 Air Velocity m/sec =  $\sqrt{(VP \times 2) / \rho}$      $\rho$  = Roh = Air Density