Appendix D

FORMULAS AND CALCULATIONS

Abbreviations

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

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

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

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

Formulas

Category	*Abbr*	*Description (unit)*	*Equation*	*Units*
Air Movement	Q ρ A ACH C d HT L/s LG m m/s m^3/s Pa SP T TP V Vm VP WD P_{ab}	Airflow volume Density (kg/m^3) Duct cross sectional area Air changes per hour Duct fitting coefficient Diameter Height Litres per second Length Meters Meters per second Cubic meters per second Pascals Static pressure Absolute Temp (°K = 273 + °C) Total pressure Velocity Measured velocity (m/s) Velocity pressure Width Absolute Pressure (kPa) (Barometric Pressure + SP)	$Q = V \times A \times 1000$ $Q = V \times A$ $A_{rectangle} = HT \times WD$ $A_{oval} = (HT \times (WD - HT) + (\pi \times \left(\frac{HT}{2}\right)^2))$ $A_{round} = \pi \times \left(\frac{d}{2}\right)^2 = \pi \times r^2$	L/s m^3/s m^2 m^2 m^2
			$TP = VP + SP$	Pa
			$\rho = 3.48 \frac{P_{ab}}{T}$	kg/m^3
			$V = 1.414 \times \sqrt{\frac{VP}{\rho}}$ $VP = 0.5 \times \rho \times V^2$ or for standard air density (ρ) where = 1.204 kg/m^3 $V = \sqrt{1.66\ VP}$ Where density is not standard $V = V_m \left(\frac{\rho\ (\text{other than standard})}{1.204}\right)$	m/s Pa m/s 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 °F K T % h oa ra ma	Degrees Celsius Degrees Fahrenheit Kelvin Temperature Percentage Enthalpy Outside air Return air Mixed air	$°C = (°F - 32) \div 1.8$ $K = (°C + 273)$ $T_{ma} = (\%_{oa} \times T_{oa}) + (\%_{ra} \times T_{ra})$ $h_{ma} = (\%_{oa} \times h_{oa}) + (\%_{ra} \times h_{ra})$ $\%_{oa} = \left(\frac{(h_{ra} - h_{ma})}{(h_{ra} - h_{oa})}\right) \times 100$ $\%_{oa} = \left(\frac{(T_{ra} - T_{ma})}{(T_{ra} - T_{oa})}\right) \times 100$	°C K °C $kJ/kg_{dry\ air}$ % %
Air Heat Flow	Q Cp ρ △t L/s △W △h U R P V T R M W kW A SHR Lat Sens	Heat flow Specific Heat (kJ/kg · °C) Density (kg/m³) Temperature difference (°C) Litres per second Humidity Ratio (g H_2O/kg dry air) Enthalpy difference (kJ/kg dry air) Heat transfer coefficient (W/m² · °C) Sum thermal resistances (m² · °C/W) Absolute Pressure (kPa) Total volume (m³) Absolute Temp (°K = 273 + °C) Gas constant (kJ/kg · °C) Mass (kg) Watts Kilowatt Cross sectional area (m²) Sensible Heat Ratio Latent Sensible	$Q = C_p \times \rho \times L/s \times \Delta t$ for standard air: ($C_p = 1.005$ kJ/kg · °C)	W
			$SHR = Q_{sensible} \div Q_{total}$ $Q_{total} = Q_{latent} + Q_{sensible}$	% W
			$Q = A \times U \times \Delta t$	W
			$Q_{(sens)} = 1.23 \times L/s \times \Delta t$ $Q_{(sens)} = 1.23 \times m^3/s \times \Delta t$ $Q_{(lat)} = 3.0 \times L/s \times \Delta W$ $Q_{(total\ heat)} = 1.20 \times L/s \times \Delta h$ $Q = A \times U \times \Delta t$	W kW W W W
			$R = \frac{1}{U}$	kJ/kg · °C
			$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = RM$	RM

Category	*Abbr*	*Description (unit)*	*Equation*	*Units*
Fan Equations	D Q m m/s L/s P rad/s rev/s ρ kW RPM CL PD mm FBL TS	Diameter Airflow Volume Meters Meters per second Litres per second Pressure (Pa) Radians per second Revolutions per second Density (kg/m^3) Kilowatts Revolutions per minute Centre Line Distance (mm) Pitch Diameter (mm) Millimetres Fan Belt Length Tip Speed	$\frac{Q_2}{Q_1} = \frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{rad/s_2}{rad/s_1} = \frac{rev/s_2}{rev/s_1}$	L/s, m^3/s, rad/s, rev/s
			$\frac{P_2}{P_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{m^3/s_2}{m^3/s_1}\right)^2$	Pa, L/s, m^3/s
			$\frac{kW_2}{kW_1} = \left(\frac{L/s_2}{L/s_1}\right)^3 = \left(\frac{m^3/s_2}{m^3/s_1}\right)^3$	kW, L/s, m^3/s
			$\frac{rad/s\ (fan)}{rad/s\ (motor)} = \frac{Pitch\ diam.\ motor\ pulley}{Pitch\ diam.\ fan\ pulley}$	rad/s
			$\frac{RPM\ (fan)}{RPM\ (motor)} = \frac{Pitch\ diam.\ motor\ pulley}{Pitch\ diam.\ fan\ pulley}$	RPM
			$TS = \frac{(\pi \times D \times RPM)}{60}$	m/s
		Determining Fan Belt Length $FBL = (CL \times 2) + \left(1.57 \times (PD_{large} + PD_{small})\right) + \left(\frac{(PD_{large} - PD_{small})^2}{4 \times CL}\right)$		mm
Pump	L/s m^3/s P Kv kW Bar △t D RPM WP H SpGr BP E_P Pa m	Litres per second Cubic meters per sec Pressure (kPa) Valve constant (m^3/h @ 1 bar) Kilowatts Pressure equivalent to 100 kPa Temperature difference (°C) Impeller diameter (mm) Revolutions per minute Waterpower Head Specific gravity ($H_20 = 1.0$) Brake power (kW) Pump efficiency Pascals meters	$\frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{RPM_2}{RPM_1}$	L/s, m^3/s, RPM
			$\frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{D_2}{D_1}$	L/s, m^3/s, D
			$\frac{P_2}{P_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{RPM_2}{RPM_1}\right)^2$	kPa, L/s, RPM
			$\frac{kW_2}{kW_1} = \left(\frac{RPM_2}{RPM_1}\right)^3 = \left(\frac{L/s_2}{L/s_1}\right)^3$	kW, RPM, L/s
			$WP = 9.81 \times m^3/s \times H_m \times SpGr$	kW
			$WP = \frac{(L/s \times H_{Pa} \times SpGr)}{1000}$	W
			$BP = \frac{WP}{E_P}$	kW
			$E_P = \frac{WP \times 100}{BP}$	%

Category	*Abbr*	*Description (unit)*	*Equation*	*Units*
Hydronic	L/s $\triangle P$ Kv NPSHA L D V g f h P P_f P_a P_s P_{vp}	Litres per second Differential pressure (kPa) Valve constant (m^3/h @ 1 bar) Net positive suction head available Length of pipe (m) Internal pipe diameter (m) Water velocity (m/s) Gravity acceleration (9.807 m/s^2 Friction factor (dimensionless) Head loss Pressure Inlet pipe friction loss Atm. pressure Std =101.325 (kPa) Pressure at pump centreline (kPa) Absolute vapour pressure (kPa)	$\text{NPSHA} = P_a \pm P_s + \left(\frac{V^2}{2}\right) - P_{vp} - P_f$ $h = f \times \frac{L}{D} \times \frac{V^2}{2g}$ $L/s = \frac{Kv}{36} \times \sqrt{\triangle P}$ $\triangle P = \left(\frac{36 \times L/s}{Kv}\right)^2$ $\text{Coil } \triangle P\text{: } P_2 = P_1 \times \left(\frac{L/s_2}{L/s_1}\right)^2$	kPa m L/s kPa kPa
Hydronic Heat Flow	Q m^3/s $\triangle t$ Cp ρ L/s	Heat flow Cubic meters per second Temperature difference (°C) Specific Heat (kJ/kg · °C) Density (kg/m^3) Litres per second	$Q = 4190 \times m^3/s \times \triangle t$ $Q = 4.19 \times L/s \times \triangle t$ $Q = C_p \times \rho \times L/s \times \triangle t$	W kW W
Electrical and Power	kW I E P.F R P FLA BP SpGr Eff TP m^3/s NLA	Kilowatts Current (amps) Energy (volts) Power factor Resistance (Ω) Power Full load Amps Brake power (kW) Specific gravity ($H_20 = 1.0$) Efficiency (%) Total Pressure Cubic meters per second No load amps	$E = I \times R$ $P = E \times I$ $kW = \frac{(E \times I)}{1000}$ $\text{Single Phase: } kW = \frac{(E \times I \times P.F \times Eff)}{1000}$ $\text{Three Phase: } kW = \frac{(E \times I \times P.F \times Eff \times 1.732)}{1000}$ $\text{Fan } kW = \frac{(m^3/s \times TP \times SpGr)}{(1000 \times Eff)}$ $\text{Actual FLA} = \frac{FLA^* \times \text{Voltage}^*}{\text{Actual Voltage}}$ $BP = kW^* \times \frac{\text{Motor Amps - } (NLA \times 0.5)}{FLA \text{ - } (NLA \times 0.5)}$ *Nameplate rating	V W kW kW kW kW I kW

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	0.43	0.40	0.38
	300˚	0.51	0.50	0.49	0.47	0.46	0.45	0.43	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	0.39	0.37	0.35
	350˚	0.47	0.46	0.45	0.43	0.42	0.41	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	0.37	0.36	0.34	0.32
	400˚	0.44	0.43	0.41	0.40	0.39	0.38	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	0.34	0.33	0.32	0.30
	450˚	0.41	0.40	0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.29
	475˚	0.39	0.38	0.37	0.36	0.35	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	0.32	0.31	0.30	0.28	0.27
	525˚	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.29	0.27	0.26
Standard Air Density, Sea Level, 20˚C = 1.2041 kg/m^3 at 101.325 kPa												

Velocity Pressure to Velocity Chart

Velocity Pressure	Velocity	Velocity Pressure	Velocity	Velocity Pressure	Velocity	Velocity Pressure	Velocity	Velocity Pressure	Velocity
Pa	m/s	Pa	m/s	Pa	m/s	Pa	m/s	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	9.00	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^3

Air Velocity m/s $V = \sqrt{\frac{2 \cdot VP}{\rho}}$ ρ *(rho) = Air Density* (kg/m^3)