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
C_p	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 Centerline
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)
Air Movement	Q	Airflow volume
	ρ	Density (kg/m^3)
	A	Duct cross sectional area
	ACH	Air changes per hour
	C	Duct fitting coefficient
	d	Diameter
	HT	Height
	L/s	Litres per second
	LG	Length
	m	Meters
	m/s	Meters per second
	m^3/s	Cubic meters per second
	Pa	Pascals
	SP	Static pressure
	T	Absolute Temp (°K = 273 + °C)
	TP	Total pressure
	V	Velocity
	Vm	Measured velocity (m/s)
	VP	Velocity pressure
	WD	Width
	P_{ab}	Absolute Pressure (kPa) (Barometric Pressure + SP)

Equation	Units
$Q = V \times A \times 1000$	L/s
$Q = V \times A$	m^3/s
$A_{rectangle} = HT \times WD$	m^2
$A_{oval} = (HT \times (WD - HT) + (\pi \times \left(\frac{HT}{2}\right)^2))$	m^2
$A_{round} = \pi \times \left(\frac{d}{2}\right)^2 = \pi \times r^2$	m^2
$TP = VP + SP$	Pa
$\rho = 3.48 \frac{P_{ab}}{T}$	kg/m^3
$V = 1.414 \times \sqrt{\frac{VP}{\rho}}$	m/s
$VP = 0.5 \times \rho \times V^2$	Pa
or for standard air density (ρ) where = 1.204 kg/m^3	
$V = \sqrt{1.66\ VP}$	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	$°C = (°F - 32) \div 1.8$	°C
	°F	Degrees Fahrenheit	$K = (°C + 273)$	K
	K	Kelvin	$T_{ma} = (\%_{oa} \times T_{oa}) + (\%_{ra} \times T_{ra})$	°C
	T	Temperature	$h_{ma} = (\%_{oa} \times h_{oa}) + (\%_{ra} \times h_{ra})$	$kJ/kg_{dry\ air}$
	%	Percentage	$\%_{oa} = \left(\frac{(h_{ra} - h_{ma})}{(h_{ra} - h_{oa})}\right) \times 100$	%
	h	Humidity	$\%_{oa} = \left(\frac{(T_{ra} - T_{ma})}{(T_{ra} - T_{oa})}\right) \times 100$	%
	oa	Outside air		
	ra	Return air		
	ma	Mixed air		
Air Heat Flow	Q	Heat flow	$Q = C_p \times \rho \times L/s \times \Delta t$	W
	Cp	Specific Heat (kJ/kg · °C)	for standard air: $(C_p = 1.005\ kJ/kg \cdot °C)$	
	ρ	Density (kg/m^3)	$SHR = Q_{sensible} \div Q_{total}$	%
	Δt	Temperature difference (°C)	$Q_{total} = Q_{latent} + Q_{sensible}$	W
	L/s	Litres per second	$Q = A \times U \times \Delta t$	W
	ΔW	Humidity Ratio (g H_2O/kg dry air)	$Q_{(sens)} = 1.23 \times L/s \times \Delta t$	W
	Δh	Enthalpy difference (kJ/kg dry air)	$Q_{(sens)} = 1.23 \times m^3/s \times \Delta t$	kW
	U	Heat transfer coefficient ($W/m^2 \cdot °C$)	$Q_{(lat)} = 3.0 \times L/s \times \Delta W$	W
	R	Sum thermal resistances ($m^2 \cdot °C/W$)	$Q_{(total\ heat)} = 1.20 \times L/s \times \Delta h$	W
	P	Absolute Pressure (kPa)	$Q = A \times U \times \Delta t$	W
	V	Total volume (m^3)	$R = \frac{1}{U}$	kJ/kg · °C
	T	Absolute Temp (°K = 273 + °C)	$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = RM$	RM
	R	Gas constant (kJ/kg · °C)		
	M	Mass (kg)		
	W	Watts		
	kW	Kilowatt		
	A	Cross sectional area (m^2)		
	SHR	Sensible Heat Ratio		
	Lat	Latent		
	Sens	Sensible		

Category	Abbr	Description (unit)	Equation	Units
Fan Equations	D	Diameter		
	Q	Airflow Volume	$\frac{Q_2}{Q_1} = \frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{rad/s_2}{rad/s_1} = \frac{rev/s_2}{rev/s_1}$	L/s, m^3/s, rad/s, rev/s
	m	Meters		
	m/s	Meters per second		
	L/s	Litres per second	$\frac{P_2}{P_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{m^3/s_2}{m^3/s_1}\right)^2$	Pa, L/s, m^3/s
	rad/s	Radians per second		
	rev/s	Revolutions per second		
	ρ	Density (kg/m^3)		
	kW	Kilowatts	$\frac{kW_2}{kW_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{m^3/s_2}{m^3/s_1}\right)^2$	kW, L/s, m^3/s
	RPM	Revolutions per minute		
	CL	Centre Line Distance (mm)		
	PD	Pitch Diameter (mm)	$\frac{\text{rad/s (fan)}}{\text{rad/s (motor)}} = \frac{\text{Pitch diam. motor pulley}}{\text{Pitch diam. fan pulley}}$	rad/s
	mm	Millimetres		
	FBL	Fan Belt Length		
	TS	Tip Speed		
			$\frac{\text{RPM (fan)}}{\text{RPM (motor)}} = \frac{\text{Pitch diam. motor pulley}}{\text{Pitch diam. fan pulley}}$	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	Litres per second		
	m^3/s	Cubic meters per sec	$\frac{\triangle P_2}{\triangle P_1} = \left(\frac{L/s_2}{L/s_1}\right)^2 = \left(\frac{RPM_2}{RPM_1}\right)^2$	kPa, L/s, RPM
	△P	Differential pressure (kPa)		
	Kv	Valve constant (m^3/h @ 1 bar)		
	kW	Kilowatts		
	Bar	Pressure equivalent to 100 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^3/s, RPM
	△t	Temperature difference (°C)		
	D	Impeller diameter (mm)		
	RPM	Revolutions per minute	$\frac{L/s_2}{L/s_1} = \frac{m^3/s_2}{m^3/s_1} = \frac{D_2}{D_1}$	L/s, m^3/s, D
	WP	Waterpower		
	H	Head		
	SpGr	Specific gravity (H_20 = 1.0)		
	BP	Brake power (kW)	$\frac{kW_2}{kW_1} = \left(\frac{RPM_2}{RPM_1}\right)^3 = \left(\frac{L/s_2}{L/s_1}\right)^3$	kW, RPM, L/s
	E_p	Pump efficiency		
	Pa	Pascals		
	m	meters		
			$WP = 9.81 \times m^3/s \times H_m \times SpGr$	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_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 Atm. pressure (Pa) Std =101.325 Pa Pressure at pump centreline (Pa) Absolute vapour pressure (Pa)	$\mathrm{NPSHA} = P_a \pm P_s + \left(\frac{V^2}{2g}\right) - P_{vp} - P_f$ $h = f \times \frac{L}{D} \times \frac{V^2}{2g}$ $L/s = \frac{Kv}{36} \times \sqrt{\triangle P}$ $\triangle P = \left(\frac{36 \times L/s}{Kv}\right)^2$ Coil $\triangle P$: $P_2 = P_1 \times \left(\frac{L/s_2}{L/s_1}\right)^2$	m 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	$E = I \times R$ $P = E \times I$ $kW = \frac{(E \times I)}{1000}$ Single Phase: $kW = \frac{(E \times I \times P.F \times Eff)}{1000}$ Three Phase: $kW = \frac{(E \times I \times P.F \times Eff \times 1.732)}{1000}$ Fan $kW = \frac{(m^3/s \times TP \times SpGr)}{(1000 \times Eff)}$ Actual FLA $= \frac{FLA^* \times Voltage^*}{Actual\ Voltage}$ $BP = kW^* \times \frac{Motor\ Amps - (NLA \times 0.5)}{FLA - (NLA \times 0.5)}$ *Nameplate rating	V W kW A 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												