PART 21

Auxiliary Equipment

21.01 Fans

A. Fan Types and Size Range are shown in the following table:

FAN TYPE	WHEEL\DRIVE TYPE	SP In.W.G.	WHEEL DIA.In.	CFM	Hp
Utility Sets	FC/B BI/B FC/D	0 - 3 0 - 4 0 - 2.5	8 - 36 10 - 36 6 - 12	200 - 27,500 250 - 27,500 100 - 3,500	1/6 - 30 1/6 - 30 1/6 - 3
Centrifugal	SWSI-BI/B DWDI-BI/B SWSI-AF/B DWDI-AF/B	0 - 12 0 - 12 0 - 14 0 - 14	10 - 73 12 - 73 18 - 120 18 - 120	600 - 123,000 1,300 - 225,000 1,400 - 447,000 2,400 - 804,000	1/3 - 200 1/3 - 400 1/3 - 1500 3/4 - 2500
Tubular Centrifugal	BI/B	0 - 9	10 - 108	450 - 332,000	1/3 - 750
Vane Axial	--/B --/D	0 - 5 0 - 4	18 - 72 18 - 60	1,400 - 115,000 1,200 - 148,000	1/3 - 100 1/3 - 150
TubeAxial	--/B --/D	0 - 1.5 0 - 1	12 - 60 18 - 48	900 - 76,000 2,600 - 48,000	1/3 - 25 1/4 - 15
Propeller	--/B --/D	0 - 1 0 - 1	20 - 72 8 - 48	400 - 80,000 50 - 49,000	1/4 - 15 1/6 - 10
Roof Ventilator	BI/B BI/D	0 - 1.25 0 - 1	7 - 54 6 - 18	100 - 34,000 75 - 3,200	1/4 - 7.5 1/8 - 3/4
RoofUpblast	BI/B BI/D	0 - 1.25 0 - 1.25	9 - 48 9 - 14	200 - 26,000 300 - 3,100	1/4 - 5 1/8 - 1
Sidewall	BI/B BI/D	0 - 1.25 0 - 1	14 - 24 6 - 18	850 - 8,200 80 - 4,000	1/4 - 2 1/8 - 3/4
Inline Centrifugal	BI/B BI/D	0 - 2.25 0 - 1.75	7 - 36 6 - 16	60 - 22,600 60 - 5,100	1/4 - 10 1/8 - 2

Notes:

FC: Forward Curved
BI: Backward Inclined
AF: Backward Inclined Airfoil

B: Belt Drive
D: Direct Drive
DWDI: Double Width, Double Inlet
SWSI: Single Width, Single Inlet

B. Fan Construction Classes are shown in the following table:

FAN CLASS	MAXIMUM TOTAL PRESSURE
I	3-3/4" W.G.
II	6-3/4" W.G.
III	12-3/4" W.G.
IV	Over 12-3/4" W.G.

C. Fan Selection Criteria:

1. Fan to be catalog rated for 15% greater static pressure (SP) than specified SP at specified volume.
2. Select fan so that specified volume is greater than at the apex of the fan curve.
3. Select fan to provide stable operation down to 85% of design volume operating at required speed for the specified conditions.
4. Specified SP at specified air flow.
5. Consider system effects. Fans are tested with open inlets and a length of straight duct on discharge. When field conditions differ from test configuration, performance is reduced. Therefore fan must be selected at slightly higher pressure to obtain desired results.
6. Parallel Fan Operation: At equal static pressure, CFM is additive.
7. Series Fan Operation: At equal CFM, static pressure is additive.
8. Every attempt should be made to have 1.0 to 1.5 diameters of straight duct on the discharge of the fan as a minimum.
9. There should be a minimum of 1.0 diameter of straight duct between fan inlet and an elbow. In plenum installations there should be a minimum of 0.75 of the wheel diameter between the fan inlet and the plenum wall.

D. Fan Terms:

1. Centrifugal: Flow within the fan is substantially radial to the shaft.
2. Axial: Flow within the fan is substantially parallel to the shaft.
3. Static Pressure: Static pressure is the compressive pressure that exists in a confined airstream. Static pressure is a measure of potential energy available to produce flow and to maintain flow against resistance. Static pressure is exerted in all directions and can be positive or negative (vacuum).
4. Velocity Pressure: Velocity pressure is the measure of the kinetic energy resulting from the fluid flow. Velocity pressure is exerted in the direction of fluid flow. Velocity pressure is always positive.
5. Total Pressure: Total pressure is the measure of the total energy of the airstream. Total pressure is equal to static pressure plus velocity pressure. Total pressure can be either positive or negative.
6. Quantity of Airflow: Volume measurement expressed in Cubic Feet per Minute (CFM).
7. Fan Outlet Velocity: Fan airflow divided by the fan outlet area.
8. Fan Velocity Pressure: Fan velocity pressure is derived by converting fan velocity to velocity pressure.
9. Fan Total Pressure: Fan total pressure is equal to the fan's outlet total pressure minus the fan's inlet total pressure.
10. Fan Static Pressure: Fan static pressure is equal to fan's total pressure minus the fan's velocity pressure. Numerically it is equal to the fan's outlet static pressure minus the fan's inlet total pressure.
11. Fan Horsepower: Theoretical calculation of horsepower assuming there are no losses.
12. Break Horsepower (BHP): Break horsepower is the actual power required to drive the fan.
13. System Effect: System effect is the reduced fan performance of manufacturer's fan catalog data due to the difference between field installed conditions and laboratory test conditions (precisely defined inlet and outlet ductwork geometry assuring uniform entrance and exit velocities).
    a. Maintain a minimum of 3 duct diameters of straight duct upstream and downstream of fan inlet and outlet at 2,500 feet per minute (FPM) duct velocity or less. 1 additional duct diameter should be added for each 1,000 FPM above 2,500 fpm.
    b. Recommend maintaining a minimum of 5 duct diameters of straight duct upstream and downstream of fan inlet and outlet at 2,500 feet per minute (FPM) duct velocity

or less. 1 additional duct diameter should be added for each 1,000 FPM above 2,500 FPM.

c. System effect may require a range of 3 to 20 duct diameters of straight duct upstream and downstream of fan inlet and outlet.

E. AMCA Spark Resistant Construction:

1. Type A. All parts of the fan in contact with the airstream must be made of non-ferrous material.
2. Type B. The fan shall have a non-ferrous impeller and non-ferrous ring about the opening through which the shaft passes. Ferrous hubs, shafts, and hardware are allowed if construction is such that a shift of the impeller or shaft will not permit two ferrous parts of the fan to rub or strike.
3. Type C. The fan must be so constructed that a shift of the wheel will not permit two ferrous part of the fan to rub or strike.

F. Centrifugal Fans:

1. Forward Curved Fan (FC):
   a. FC fans have a peak static pressure curve corresponding to the region of maximum efficiency, slightly to the right. Best efficiency at low or medium pressure (0 to 5 in. w.g.)
   b. BHP is minimum at no delivery and increases continuously with increasing flow, with maximum BHP occurring at free delivery.
   c. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly effect CFM.
   d. Fan blades curve toward direction of rotation.
   e. Advantages:
      1) Low cost. Less expensive than BC, BI, or AF fans.
      2) Low speed (400 to 1,200 RPM) minimizes shaft and bearing sizes.
      3) Large operating range: 30–80% wide open CFM.
      4) Highest Efficiency occurs: 40–50% wide open CFM.
   f. Disadvantages:
      1) Possibility of paralleling in multiple fan applications.
      2) Possibility of overloading.
      3) Weak structurally: Not capable of high speeds necessary for developing high static pressures.
   g. Used primarily in low to medium pressure HVAC applications: central station air handling units; rooftop units, packaged units, residential furnaces.
   h. High CFM, Low Static Pressure.
2. Backward Inclined (BI) and Backward Curved (BC) Fans:
   a. BC fans have a peak static pressure curve which occurs to the left of the maximum static efficiency. Best efficiency at medium pressure (3.5 to 5.0 in. w.g.).
   b. BHP increases to a maximum then decreases. They are non-overloading fans.
   c. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly effect CFM.
   d. Fan operates at high speeds—1,200 to 2,400 RPM—about double that of FC fans for similar air quantity.
   e. Blades curve away from or incline from direction of rotation.
   f. BI fans are less expensive than BC fans but do not have as great a range of high efficiency operation.
   g. Advantages:
      1) Higher Efficiencies.

2) Highest Efficiency occurs: 50–60% wide open CFM.
3) Good pressure characteristics.
4) Stronger structural design makes it suitable for higher static pressures.
5) Non-overloading power characteristics.

h. Disadvantages:
1) Higher speeds require larger shaft and bearings.
2) Has larger surge area than forward curved fan.
3) Operating range 40 to 80% of wide open CFM.
4) Can be noisier.
5) More expensive than FC fans.

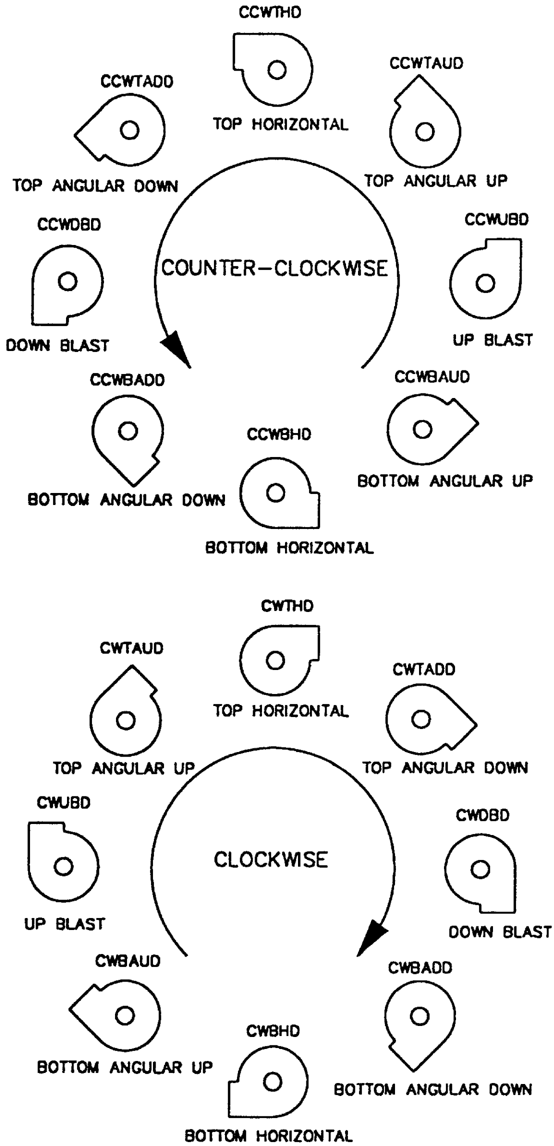
i. Used primarily in large HVAC applications where power savings are significant. Can be used in low, medium, and high pressure systems.

3. Airfoil Fans (AF):
a. AF fans have a peak static pressure curve which occurs to the left of the maximum static efficiency.
b. BHP increases to a maximum then decreases. They are non-overloading fans. Best efficiency at medium pressure (4.0 to 8.0 in. w.g.).
c. They have a steep pressure volume performance curve; therefore, a slight change in pressure will not greatly effect CFM.
d. Fan operates at high speeds—1,200 to 2,800 RPM—about double that of FC fans for similar air quantity.
e. Blades have an aerodynamic shape similar to an airplane wing and are backwardly curved (away from direction of rotation).
f. Advantages:
1) Higher Efficiencies.
2) Highest Efficiency occurs: 50–60% wide open CFM.
3) Good pressure characteristics.
4) Stronger structural design makes it suitable for higher static pressures.
5) Non-overloading power characteristics.

g. Disadvantages:
1) Higher speeds require larger shaft and bearings.
2) Has larger surge area than forward curved fan.
3) Operating range 40 to 80% of wide open CFM.
4) Can be noisier.
5) Most expensive centrifugal fan.

h. Used primarily in large HVAC applications where power savings are significant. Can be used in low, medium, and high pressure systems.
i. Airfoil blade fans have slightly higher efficiency and surge area is slightly larger than backward inclined or backward curved fans.

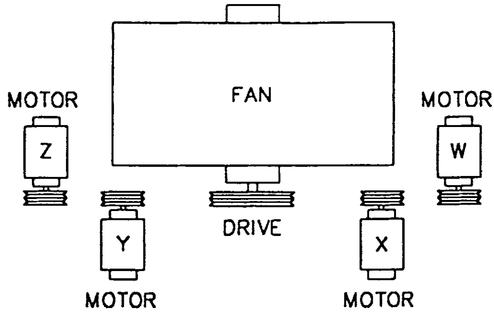
4. Radial (RA) Fans:
a. Radial fans have self-cleaning blades.
b. Fan horsepower increases with increase in air quantity (overloads) while static pressure decreases.
c. RA fans operate at high speed and pressure—2,000 to 3,000 RPM.
d. Blades radiate from center along radius of fan.
e. Used in industrial applications to transport dust, particles, or materials handling. Not commonly used in HVAC applications.



NOTES:

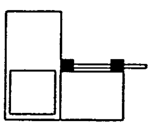
1. DIRECTION OF ROTATION IS DETERMINED FROM DRIVE SIDE OF FAN
2. ON SINGLE INLET FANS, THE DRIVE SIDE OF THE FAN IS ALWAYS CONSIDERED THE SIDE OPPOSITE THE FAN INLET.
3. ON DOUBLE INLET FANS, WHEN THE DRIVES ARE ON BOTH SIDES OF THE FAN, THE DRIVE SIDE OF THE FAN IS THE SIDE HAVING THE HIGHER HORSEPOWER DRIVING UNIT.
4. DIRECTION OF DISCHARGE IS DETERMINED IN ACCORDANCE WITH THE DIAGRAMS. ANGULAR DISCHARGE IS REFERENCED TO THE HORIZONTAL AXIS OF THE FAN AND DESIGNATED IN DEGREES ABOVE OR BELOW THIS REFERENCE.
5. FANS INVERTED FOR CEILING SUSPENSION, OR SIDE WALL MOUNTING, DIRECTION OF ROTATION AND DISCHARGE IS DETERMINED WHEN FAN IS RESTING ON THE FLOOR.

FAN ROTATION AND DISCHARGE POSITIONS

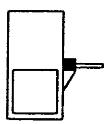


LOCATION OF MOTOR IS DETERMINED BY FACING THE DRIVE SIDE OF THE FAN OR BLOWER AND DESIGNATING THE MOTOR POSITION BY LETTERS W, X, Y, AND Z AS SHOWN ABOVE.

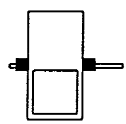
FAN MOTOR POSITIONS



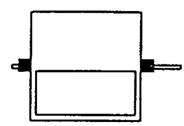
ARRANGEMENT #1 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS ON BASE



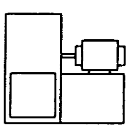
ARRANGEMENT #2 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, BEARINGS IN BRACKET SUPPORTED BY FAN HOUSING



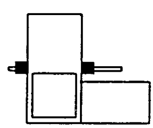
ARRANGEMENT #3 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING



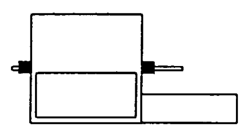
ARRANGEMENT #3 DWDI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING



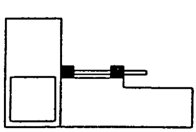
ARRANGEMENT #4 SWSI
FOR DIRECT DRIVE CONNECTION, IMPELLER OVERHUNG ON PRIME MOVER SHAFT, NO BEARINGS ON FAN, PRIME MOVER BASE MOUNTED OR INTEGRALLY CONNECTED



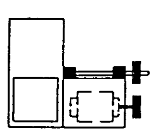
ARRANGEMENT #7 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING, BASE FOR PRIME MOVER



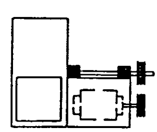
ARRANGEMENT #7 DWDI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, ONE BEARING ON EACH SIDE AND SUPPORTED BY FAN HOUSING, BASE FOR PRIME MOVER



ARRANGEMENT #8 SWSI
FOR BELT DRIVE OR DIRECT DRIVE CONNECTIONS, IMPELLER OVERHUNG, TWO BEARINGS ON BASE, EXTENDED BASE FOR PRIME MOVER



ARRANGEMENT #9 SWSI
FOR BELT DRIVE CONNECTION, IMPELLER OVERHUNG, TWO BEARINGS ON BASE, PRIME MOVER OUTSIDE BASE



ARRANGEMENT #10 SWSI
FOR BELT DRIVE CONNECTION, IMPELLER OVERHUNG, TWO BEARINGS ON BASE, PRIME MOVER INSIDE BASE

FAN DRIVE ARRANGEMENTS

G. Axial Fans:

1. Propeller Fans:
   a. Low pressure, high CFM fans.
   b. Horsepower lowest at maximum flow.
   c. Maximum efficiency is approximately 50% and is reached near free delivery.
   d. No ductwork.
   e. Blade rotation is perpendicular to direction of airflow.
   f. Advantages:
      1) High volumes, low pressures.
      2) BHP lowest at free delivery.
      3) Inexpensive.
      4) Operates at relatively low speeds—900 to 1,800 RPM.
   g. Disadvantages:
      1) Cannot handle static pressure.
      2) BHP increases with static pressure; could overload and shut off.
      3) Air delivery decreases with increase in air resistance.
2. Tubeaxial Fans:
   a. Heavy duty propeller fans arranged for duct connection. Fan blades have aerodynamic configuration.
   b. Slightly higher efficiency than propeller fans.
   c. Discharge air pattern is circular in shape and swirls, producing higher static losses in the discharge duct.
   d. Used primarily in low and medium pressure, high volume, ducted HVAC application where discharge side is not critical. Also used in industrial application: fume hoods, spray booths, drying ovens.
   e. Fans operate at high speeds—2,000 to 3,000 RPM.
   f. Fans are noisy.
   g. Fans may be constructed to be overloading or non-overloading. Non-overloading type fans are more common.
   h. Advantages:
      1) Straight through design.
      2) Space savings.
      3) Capable of higher static pressures than propeller fans.
   i. Disadvantages:
      1) Discharge swirl creates higher pressure drops.
      2) High noise level.
3. Vaneaxial:
   a. Vaneaxial fans are tubeaxial fans with additional vanes to increase efficiency by straightening out airflow.
   b. Vaneaxial fans are more costly than tubeaxial fans.
   c. High pressure characteristics with medium flow rate capabilities.
   d. Fans operate at high speeds—2,000 to 3,000 RPM.
   e. Fans are noisy.
   f. Fans may be constructed to be overloading or non-overloading. Non-overloading type fans are more common.
   g. Typical Selection: 65–95% wide open CFM.
   h. Used in general HVAC applications, low, medium, and high pressure where straight through flow and compact installation are required. Also used in industrial applications: usually more compact than comparable centrifugal type fans for the same duty.

i. Advantages:
   1) Discharge vanes increase efficiency and reduce discharge losses.
   2) Reduced size and straight through design.
   3) Space savings.
   4) Capable of higher static pressures than propeller fans.

j. Disadvantages:
   1) Maximum efficiency only 65%.
   2) Selection Range: 65–90% wide open CFM.
   3) High noise level.

H. Clearance Requirements:

1. Minimum recommended clearance around fans is 24 inches. Maintain minimum clearance as required to open access and control doors on fans for service, maintenance, and inspection.
2. Mechanical room locations and placement must take into account how fans can be move into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

21.02 Pumps

A. Available RPM:

1. 1,150 (1,200).
2. 1,750 (1,800).
3. 3,500 (3,600).

B. Pump Types are shown in the following table:

PUMP TYPE	GPM	HEAD FT. H_2O	HORSEPOWER
Circulators	0 - 150	0 - 60	1/4 - 5
Close Coupled, End Suction	0 - 2,000	0 - 400	1/4 - 150
Frame Mounted, End Suction	0 - 2,000	0 - 500	1/4 - 150
Horizontal Split Case	0 - 12,000	0 - 500	1 - 500
Vertical Inline	0 - 2,000	0 - 400	1/4 - 75

C. Pump Location:

1. Heating Water Systems: Boilers to be on suction side of pumps; pumps to draw through boilers.
2. Chilled Water Systems: Chillers to be on discharge side of pumps; pumps to pump through chillers.

D. Pump Layout and Design Criteria:

1. Pump suction piping should be kept as short and direct as possible with a minimum length of straight pipe upstream of the pump suction as recommended by the pump manufacturer. Manufacturers recommend 5 to 12 pipe diameters.

2. Pump suction pipe size should be at least one pipe size larger than the pump inlet connection.
3. Use flat on top, eccentric reducer to reduce pump suction piping to pump inlet connection size.
4. Pump suction should be kept free from air pockets.
5. Horizontal elbows should not be installed at the pump suction. If a horizontal elbow must be installed at the pump suction, the elbow should be installed at a lower elevation than the pump suction. A vertical elbow at the pump suction with the flow upward toward the pump is desirable.
6. Maintain a minimum of 5 pipe diameters of straight pipe immediately upstream of pump suction unless using suction diffuser.
7. Variable speed pumping cannot be used for pure lift applications, because reduced speeds will fail to provide the required lift.
8. Variable speed pumping is well suited for secondary and tertiary distribution loops of primary/secondary and secondary/tertiary hydronic distribution systems (chilled water and heating water systems).
9. Pump Discharge Check Valves:
   a. Pump discharge check valves should be center guided, spring loaded, disc type check valves.
   b. Pump discharge check valves should be sized so that the check valve is full open at design flow rate. Generally this will require the check valve to be one pipe size smaller than the connecting piping.
   c. Condenser water system and other open piping system check valves should have globe style bodies to prevent flow reversal and slamming.
   d. Install check valves with 4 to 5 pipe diameters upstream of flow disturbances is recommended by most manufacturers.
10. Differential pressure control of the system pumps should never be accomplished at the pump. The pressure bypass should be provided at the end of the system or the end each of the subsystems regardless of whether the system is a bypass flow system or a variable speed pumping system. Bypass flow need not exceed 20 percent of the pump design flow.

E. Pump Selection Criteria:

1. Impeller size for specified duty should not exceed 85% of volute cutwater diameter.
2. Maximum cataloged impeller size should be rated to produce not less than 110% of specified head at specified flow.
3. Specified head at specified flow.
4. 110% of specified flow at specified head.
5. Parallel Pump Operation: At equal head, GPM is additive.
6. Series Pump Operation: At equal GPM, head is additive.
7. Selection Regions:
   a. Preferred Selection—85 to 105% Design Flow.
   b. Satisfactory Selection—66 to 115% Design Flow.
8. Pumps curves:
   a. Flat. 12% rise from design point to shutoff head (0 flow). Flat curves should be used for variable flow systems with single pumps. A flat pump curve is a pump curve where the head at shutoff is approximately 25% higher than the head at the best efficiency point.
   b. Steep. 40% rise from design point to shutoff head (0 flow). Steep curves should be used for variable speed and constant flow systems where two or more pumps are used.

c. Hump. Developed head rises to a maximum as flow decreases and then drops to a lower value at the point of shutoff. Hump curves should be used for constant flow systems with single pumps due to increased efficiency.

9. Select pumps so that the design point is as close as possible or to the left of the maximum efficiency point.
10. Boiler warming pumps should be selected for a flow rate of 0.1 GPM/BHP (range 0.05 to 0.1 GPM/BHP).

F. Pump Seals:

1. Mechanical Seal: Closed Systems.
2. Stuffing Box Seals: Open Systems.

G. Cavitation. Net Positive Suction Head (NPSH):

1. Cavitation: "If the pressure at any point inside the pump falls below the operating vapor pressure of the fluid, the fluid flashes into a vapor and forms bubbles. These bubbles are carried along in the fluid stream until they reach a region of higher pressure. Within this region the bubbles collapse or implode with tremendous shock on the adjacent surfaces. Cavitation is accompanied by a low rumbling and/or a sharp rattling noise and even vibration causing mechanical destruction in the form of pitting and erosion."[1]
2. Causes:
   a. Discharge heads far below the pump's calibrated head at peak efficiency.
   b. Suction lift or suction head lower than the pump rating.
   c. Speeds (RPM) higher than pump rating.
   d. Liquid temperatures higher than that for which system was designed.
3. Remedies:
   a. Increase source fluid level height.
   b. Reduce the distance and/or friction losses (larger pipe) between source and pump.
   c. Reduce temperature of the fluid.
   d. Pressurize source.
   e. Use different pump.
   f. Place balancing valve in pump discharge or trim pump impeller.
4. Systems most susceptible to NPSH problems:
   a. Boiler Feed Water Systems (steam systems).
   b. Cooling Tower and other open systems.
   c. Medium and high temperature water systems.
5. Potential problems increase as:
   a. Elevation above sea level increases.
   b. Height above pump decreases.
   c. Friction losses increase.
   d. Fluid temperature increases.

H. Pump Terms:

1. Friction Head: Friction head is the pressure expressed in psi or in feet of liquid needed to overcome the resistance to the flow in the pipe and fittings.
2. Suction Lift: Suction lift exists when the source of supply is below the centerline of the pump.

[1]Carrier Corporation, *Carrier System Design Manuals, Part 8—Auxiliary Equipment*, (Syracuse: Carrier Corporation, 1971), pp. 8–11.

3. Suction Head: Suction head exists when the source of supply is above the centerline of the pump.
4. Static Suction lift: Static suction lift is the vertical distance from the centerline of the pump down to the free level of the liquid source.
5. Static Suction Head: Static suction head is the vertical distance from the centerline of the pump up to the free level of the liquid source.
6. Static Discharge Head: Static discharge head is the vertical elevation from the centerline of the pump to the point of free discharge.
7. Dynamic Suction Lift: Dynamic suction lift includes the sum of static suction lift, friction head loss, and velocity head.
8. Dynamic Suction Head: Dynamic suction head includes static suction head minus the sum of friction head loss and velocity head.
9. Dynamic Discharge Head: Dynamic discharge head includes the sum of static discharge head, friction head, and velocity head.
10. Total Dynamic Head: Total dynamic head includes the sum of the dynamic discharge head plus the dynamic suction lift or discharge head minus dynamic suction head.
11. Velocity Head: Velocity head is the head needed to accelerate the liquid. See the following table:

VELOCITY FT/SEC.	VELOCITY HEAD FEET	VELOCITY FT/SEC.	VELOCITY HEAD FEET	VELOCITY FT/SEC.	VELOCITY HEAD FEET
0.5	0.004	7.5	0.875	14.5	3.269
1.0	0.016	8.0	0.995	15.0	3.498
1.5	0.035	8.5	1.123	15.5	3.735
2.0	0.062	9.0	1.259	16.0	3.980
2.5	0.097	9.5	1.403	16.5	4.232
3.0	0.140	10.0	1.555	17.0	4.493
3.5	0.190	10.5	1.714	17.5	4.761
4.0	0.248	11.0	1.881	18.0	5.037
4.5	0.314	11.5	2.056	18.5	5.321
5.0	0.389	12.0	2.239	19.0	5.613
5.5	0.470	12.5	2.429	19.5	5.912
6.0	0.560	13.0	2.627	20.0	6.219
6.5	0.657	13.5	2.833	21.0	6.856
7.0	0.762	14.0	3.047	22.0	7.525

12. Specific Gravity: Specific gravity is the direct ratio of any liquid's weight to the weight of water at 62°F. (62.4 Lbs./Cu.Ft. or 8.33 Lbs./Gal.).
13. Viscosity: Viscosity is a property of a liquid that resists any force tending to produce flow. It is the evidence of cohesion between the particles of a fluid which causes a liquid to offer resistance analogous to friction. A change in the temperature may change the viscosity depending upon the liquid. Pipe friction loss increases as viscosity increases.
14. Static Pressure: Static pressure is the water pressure required to fill the system.

15. Static System Pressure: Static system pressure is the water pressure required to fill the system plus 5 psi.
16. Flow Pressure: Flow pressure is the pressure the pump must develop to overcome the resistance created by the flow through the system.

I. Clearance Requirements:

1. Minimum recommended clearance around pumps is 24 inches. Maintain minimum clearance as required to open access and control doors on pumps for service, maintenance, and inspection.
2. Mechanical room locations and placement must take into account how pumps can be move into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

21.03 Motors

A. Motor Types. Items 1, 2, and 3 are the most common HVAC motor types.

1. Open Drip Proof (ODP): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance—use indoors and in moderately clean environments.
2. Totally Enclosed Fan Cooled (TEFC): A fan on the motor shaft, outside the stator housing and within the protective shroud, blows air over the motor—use in damp, dirty, corrosive, or contaminated environments.
3. Explosion Proof (EXPRF): Totally enclosed with enclosure designed to withstand internal explosion of a specific gas-air or dust-air mixture to prevent escape of ignition products. Motors are approved for a specific Hazard Classification as covered by the NEC. Class I Explosion Proof and Class II Dust Ignition Resistant are the two most common type of hazardous location motors.
4. Open Drip Proof Air Over (ADAO): Ventilation openings arranged to prevent liquid drops falling within an angle of 15 degrees from the vertical from affecting motor performance—use indoors and in moderately clean environments. Rated for motor cooling by airflow from driven device.
5. Totally Enclosed Non-Ventilated (TENV): No ventilation openings in housing. Motor rated for cooling by airflow from driven device. TENV motors are usually under 5 horsepower.
6. Totally Enclosed Air Over (TEAO): No ventilation openings in housing. Motor rated for cooling by airflow from driven device. TEAO motors frequently have dual horsepower ratings depending on speed and cooling air temperature.

B. Motor Horsepowers, Voltage, Phase, and Operating Guidelines:

1. Suggested horsepower and phase:
   a. Motors ½ Horsepower and larger: 3 Phase.
   b. Motors less than ½ Horsepower: Single Phase.
   c. Considering first cost economics only, it is less costly, on average, to have motors smaller than 1 Hp to be single-phase. At ¾ Hp, single-phase and 3-phase motors cost about the same, but branch circuits and control equipment for 3-phase motors are usually more expensive.
   d. When life cycle owning and operating costs are considered, it is often more economical to provide motors as specified in a. and b. above.
2. Do not start and stop motors more than 6 times per hour.
3. Motors of 5 horsepower and larger should not be cycled; they should run continuously.
4. Specify energy efficient motors.

5. Do not use energy efficient motors with variable speed/frequency drives.
6. For best motor life and reliability, do not select motors to run within the service factors.
7. For every 50°F. (10°C.) increase in motor operating temperature, the life of the motor is cut in half. Conversely, for every 50°F. (10°C.) decrease in motor operating temperature, the life of the motor is doubled.
8. Energy efficient motors have a higher starting current than their standard efficiency counterparts.
9. The best sign of motor trouble is smoke and/or paint discoloration.
10. In general, motors can operate with voltages plus or minus 10% of their rated voltage.
11. Motors in storage should be turned by hand every six months to keep the bearings from drying out.
12. Available Voltages are given in the following table:

PHASE	NOMINAL VOLTAGE	NAMEPLATE VOLTAGE
SINGLE PHASE	120	115
	240	230
	277	265
3 PHASE	208	200
	240	230
	480	460
	600	575

C. Standard Motor Sizes are given in the following table:

MOTOR SIZES (Hp)	RECOMMENDED STARTER TYPE	STANDARD SERVICE FACTORS
1/8; 1/10; 1/12; 1/15; 1/20; 1/25; 1/30; 1/60; 1/100	SPC or PSC	1.40
1/6	SPC or PSC	*
1/4; 1/3	CS	*
1/2; 3/4; 1	MS	*
1-1/2; 2	MS	*
3; 5; 7-1/2; 10; 15; 20; 25; 30; 40; 50; 60; 75; 100; 125; 150; 200; 250	MS	*
300; 350; 400; 450; 500; 600; 700; 750; 800; 900; 1000; 1250; 1500; 1750; 2000; 2250; 2500; 3000; 3500; 4000; 4500; 5000; 5500; 6000 **	MS	*

Notes:
SPC: Split Phase Capacitor Start
PSC: Permanent Split Capacitor Start
CS: Capacitor Start
*See item E.
**Motors generally not used in HVAC applications.

MS: Magnetic Start; Polyphase Induction Motors (Squirrel Cage)
½ Hp thru 50 Hp — Across-the-Line Starter
60 Hp and Larger — Reduced-Voltage Starter

D. Standard Motor RPM: 3,600, 1,800, 1,200, 900, 720, 600, 514.

E. NEMA Motor Service Factors are given in the following table:

HP	3600 RPM	1800 RPM	1200 RPM	900 RPM
1/6 - 1/3	1.35	1.35	1.35	1.35
1/2	1.25	1.25	1.25	1.15
3/4	1.25	1.25	1.15	1.15
1	1.25	1.15	1.15	1.15
1-1/2 - 250	1.15	1.15	1.15	1.15
300 - 2500	1.15	1.15	1.15	1.15

F. Locked Rotor Indicating Code Letters are given in the following table:

LOCKED ROTOR INDICATING CODE LETTERS			
CODE LETTER	KVA/HP	CODE LETTER	KVA/HP
A	0 - 3.14	L	9.00 - 9.99
B	3.15 - 3.54	M	10.00 - 11.19
C	3.55 - 3.99	N	11.20 - 12.49
D	4.00 - 4.49	O	NOT USED
E	4.50 - 4.99	P	12.50 - 13.99
F	5.00 - 5.59	Q	NOT USED
G	5.60 - 6.29	R	14.00 - 15.99
H	6.30 - 7.09	S	16.00 - 17.99
I	NOT USED	T	18.00 - 19.99
J	7.10 - 7.99	U	20.00 - 22.39
K	8.00 - 8.99	V	22.40 - AND UP

1. Standard 3 phase motors often have these locked rotor codes:
   a. 1 Horsepower and smaller: Locked Rotor Code L
   b. 1½ to 2 Horsepower: Locked Rotor Code K
   c. 3 Horsepower: Locked Rotor Code J
   d. 5 Horsepower: Locked Rotor Code H
   e. 7½ to 10 Horsepower: Locked Rotor Code G
   f. 15 Horsepower and Larger: Locked Rotor Code F
2. Standard single phase motors often have these locked rotor codes:
   a. ½ Horsepower and smaller: Locked Rotor Code L

b. ¾ to 1 Horsepower: Locked Rotor Code K
c. 1½ to 2 Horsepower: Locked Rotor Code J
d. 3 Horsepower: Locked Rotor Code H
e. 5 Horsepower: Locked Rotor Code G

G. Motor Insulation Classes are given in the following table:

MOTOR TYPE	MOTOR INSULATION CLASS TEMPERATURE RISE							
	A		B		F		H	
	°C	°F	°C	°F	°C	°F	°C	°F
1. Motors with 1.0 Service Factor(except 3 & 4 Below)	60	140	80	176	105	221	125	257
2. All Motors with 1.15 Service Factor or Higher	70	158	90	194	115	239	---	---
3. Totally-Enclosed Non-Ventilated Motor with 1.0 Service Factor	65	149	85	185	110	230	135	275
4. Motors with Encapsulated Windings and with 1.0 Service, All Enclosures	65	149	85	185	110	230	---	---

Notes:

1. **Abnormal deterioration of insulation may be expected if the ambient temperature of 40°C/104°F is exceeded in regular operation.**
2. **Temperature rise based on 40°C/104°F ambient. Temperature rises are based on operation at altitudes of 3,300 feet or less.**
3. **Class A Motors: Fractional Hp motors, Small Appliances; Maximum Operating Temperature 105°C/221°F.**
4. **Class B Motors: Motors for HVAC Applications, High Quality Fractional Hp Motors; Maximum Operating Temperature 130°C/266°F.**
5. **Class F Motors: Industrial Motors; Maximum Operating Temperature 155°C/311°F.**
6. **Class H Motors: High Temperature, High Reliability, High Ambient; Maximum Operating Temperature 180°C/356°F.**

H. NEMA Motor Design Designations:

1. Design A motors are built with high pullout torque and are used on injection molding machines.
2. Design B motors are built with high starting torque with reasonable starting current and are used with fans, pumps, air handling units, and other HVAC equipment. They are the most common HVAC motor.
3. Design C motors are built with high starting torque and used with hard to start loads and are used with conveyors.
4. Design D motors are built with high starting torque, low starting current, and high slip and are used with cranes, hoists, and low speed presses.

I. Clearance Requirements:

1. Minimum recommended clearance around motors is 24 inches.
2. Mechanical room locations and placement must take into account how motors can be move into and out of the building during initial installation and after construction for maintenance and repair and/or replacement.

J. Motor Efficiencies: *ASHRAE Standard 90.1-1989:*

1. NEMA Design B; Single Speed; 1,200, 1,800, or 3,600 RPM; Open Drip Proof (ODP) or Totally Enclosed Fan Cooled (TEFC) Motors 1 Hp and Larger that operate more than 500 hours per year must meet the following minimum nominal efficiencies:

Horsepower	Minimum Nominal Efficiency
1 - 4	78.5
5 - 9	84.0
10 - 19	85.5
20 - 49	88.5
50 - 99	90.2
100 - 124	91.7
125 or Greater	92.4

***Note:* Above table is based on *ASHRAE Standard 90.1* prior to adoption of Addendum 90.1c by ASHRAE Board of Directors.**

2. NEMA Design A and B; Open Drip Proof (ODP) or Totally Enclosed Fan Cooled (TEFC) Motors 1 Hp and Larger that operate more than 1,000 hours per year must meet the following minimum nominal efficiencies; Minimum Acceptable Nominal Full-Load Motor Efficiency for Single Speed Polyphase Squirrel-Cage Induction Motors having Synchronous Speed of 3,600, 1,800, 1,200, and 900 RPM.:

Full Load Efficiencies—Open Motors

HP	2-POLE		4-POLE		6-POLE		8-POLE	
	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.
1.0	---	---	82.5	81.5	80.0	78.5	74.0	72.0
1.5	82.5	81.5	84.0	82.5	84.0	82.5	75.5	74.0
2.0	84.0	82.5	84.0	82.5	85.5	84.0	85.5	84.0
3.0	84.0	82.5	86.5	85.5	86.5	85.5	86.5	85.5
5.0	85.5	84.0	87.5	86.5	87.5	86.5	87.5	86.0
7.5	87.5	86.5	88.5	87.5	88.5	87.5	88.5	87.5
10.0	88.5	87.5	89.5	88.5	90.2	89.5	89.5	88.5
15.0	89.5	88.5	91.0	90.2	90.2	89.5	89.5	88.5
20.0	90.2	89.5	91.0	90.2	91.0	90.2	90.2	89.5
25.0	91.0	90.2	91.7	91.0	91.7	91.0	90.2	89.5
30.0	91.0	90.2	92.4	91.7	92.4	91.7	91.0	90.2
40.0	91.7	91.0	93.0	92.4	93.0	92.4	91.0	90.2
50.0	92.4	91.7	93.0	92.4	93.0	92.4	91.7	91.0
60.0	93.0	92.4	93.6	93.0	93.6	93.0	92.4	91.7
75.0	93.0	92.4	94.1	93.6	93.6	93.0	93.6	93.0
100.0	93.0	92.4	94.1	93.6	94.1	93.6	93.6	93.0
125.0	93.6	93.0	94.5	94.1	94.1	93.6	93.6	93.0
150.0	93.6	93.0	95.0	94.5	94.5	94.1	93.6	93.0
200.0	94.5	94.1	95.0	94.5	94.5	94.1	93.6	93.0

Note: Above table is based on *ASHRAE Standard 90.1, Addendum 90.1c.*

Full Load Efficiencies—Enclosed Motors

HP	2-POLE		4-POLE		6-POLE		8-POLE	
	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.	NOMINAL EFF.	MINIMUM EFF.
1.0	75.5	74.0	82.5	81.5	80.0	78.5	74.0	72.0
1.5	82.5	81.5	84.0	82.5	85.5	84.0	77.0	75.5
2.0	84.0	82.5	84.0	82.5	86.5	85.5	82.5	81.5
3.0	85.5	84.0	87.5	86.5	87.5	86.5	84.0	82.5
5.0	87.5	86.5	87.5	86.5	87.5	86.5	85.5	84.0
7.5	88.5	87.5	89.5	88.5	89.5	88.5	85.5	84.0
10.0	89.5	88.5	89.5	88.5	89.5	88.5	88.5	87.5
15.0	90.2	89.5	91.0	90.2	90.2	89.5	88.5	87.5
20.0	90.2	89.5	91.0	90.2	90.2	89.5	89.5	88.5
25.0	91.0	90.2	92.4	91.7	91.7	91.0	89.5	88.5
30.0	91.0	90.2	92.4	91.7	91.7	91.0	91.0	90.2
40.0	91.7	91.0	93.0	92.4	93.0	92.4	91.0	90.2
50.0	92.4	91.7	93.0	92.4	93.0	92.4	91.7	91.0
60.0	93.0	92.4	93.6	93.0	93.6	93.0	91.7	91.0
75.0	93.0	92.4	94.1	93.6	93.6	93.0	93.0	92.4
100.0	93.6	93.0	94.5	94.1	94.1	93.6	93.0	92.4
125.0	94.5	94.1	94.5	94.1	94.1	93.6	93.6	93.0
150.0	94.5	94.1	95.0	94.5	95.0	94.5	93.6	93.0
200.0	95.0	94.5	95.0	94.5	95.0	94.5	94.1	93.6

Note: Above table is based on *ASHRAE Standard 90.1, Addendum 90.1c.*

K. Single Phase ODP is given in the following table:

Single Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/6	48	41	48
	1/4	48, 56	41	51
	1/3	48, 56	56	55
	1/2	56	62	60
	3/4	56, 143T	68	68
	1	184	65	62
	1-1/2	215	67	60
	2	215	68	65
	3	215	75	80
1800	1/8	48	49	58
	1/6	48	49	58
	1/4	48, 56	53	52
	1/3	48, 56	56	55
	1/2	48, 56	64	65
	3/4	56	63	64
	1	56, 143T, 182T	68	72
	1-1/2	56, 145T, 184T	70	64
	2	56, 145T, 182T	73	72
	3	184T	78	78
	5	184T, 213T	74	76
	7-1/2	215T	77	85
	10	215T	84	90
3600	1/3	48, 56	55	68
	1/2	48, 56	57	71
	3/4	56	62	75
	1	56	63	69
	1-1/2	56, 143T	68	77
	2	56, 145T	71	75
	3	56, 182T	76	88
	5	184T	76	88
	7-1/2	213T	81	82
	10	215	83	86

L. Single Phase TEFC is given in the following table:

Single Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/6	48	41	48
	1/4	48, 56	44	50
	1/3	48, 56	57	56
	1/2	56	59	63
	3/4	56, 143T	68	68
	1	184	67	67
	1-1/2	215	71	69
	2	215	82	84
	3	215	80	82
	5	256	80	82
1800	1/12	42	47	55
	1/8	42	47	55
	1/6	42, 48	49	58
	1/4	48, 56	53	52
	1/3	48, 56	56	55
	1/2	48, 56	63	67
	3/4	56	66	68
	1	56, 143T	68	72
	1-1/2	56, 145T	73	77
	2	182T	75	81
	3	184T	78	87
	5	213T	82	87
	7-1/2	215T	84	87
	10	215T	84	87
3600	1/8	42	45	62
	1/6	42	52	57
	1/4	42	52	57
	1/3	48, 56	55	68
	1/2	48, 56	57	71
	3/4	56	66	74
	1	56	66	81
	1-1/2	56, 143T	70	82
	2	145T	74	78
	3	182T	76	87
	5	184T	84	96
	7-1/2	213T	82	89
	10	215T	86	98

M. Single Phase Explosion Proof is given in the following table:

Single Phase Explosion Proof

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/3	56	54	56
	1/2	56	59	63
	3/4	56	65	67
	1	184	67	67
	1-1/2	215	71	69
1800	1/3	56	56	58
	1/2	56	65	65
	3/4	56	66	68
	1	56, 143T	66	67
	1-1/2	184	70	70
	2	182T	75	81
	3	215	79	77
	5	215	74	81
3600	1/2	56	55	69
	3/4	56	62	75
	1	56	66	81
	1-1/2	143T	70	82
	2	145T	74	82
	3	182T, 184T	76	87

N. Standard Efficiency 3-Phase ODP is given in the following table:

Standard Efficiency 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/2	56, 143T	71	57
	3/4	145T	74	56
	1	182T	71	66
	1-1/2	184T	74	67
	2	213T	73	63
	3	215T	76	60
	5	254T	80	60
	7-1/2	256T	85	62
1200	1/4	48, 56	71	58
	1/3	48, 56	71	58
	1/2	48, 56	71	58
	3/4	56, 143T	77	67
	1	56, 145T	77	69
	1-1/2	56, 145T, 182T	78	77
	2	184T	78	72
	3	213T	79	72
	5	215T	83	76
	7-1/2	254T	85	78
	10	256T	86	78
	15	284T	87	82
	20	286T	87	81
	25	324T	88	84
	30	326T	88	80
	40	364T	91	85
	50	365T	88	87
	60	404T	90	82
	75	405T	90	83
	100	444T	91	85
	125	445T	91	85
	150	445T	91	84
	200	447T	91	84
	250	449T	91	84
1800	1/4	48	74	63
	1/3	48, 56	74	63
	1/2	48, 56	74	63
	3/4	48, 56	74	60
	1	56, 142T, 143T	75	64
	1-1/2	56, 145T	79	69
	2	56, 145T	80	70
	3	56, 145T, 182T	81	77
	5	184T	84	82

Standard Efficiency 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	7-1/2	213T	86	76
	10	215T	87	78
	15	254T	87	77
	20	256T	89	86
	25	284T	89	83
	30	286T	90	86
	40	324T	91	85
	50	326T	91	85
	60	364T	90	83
	75	365T	90	86
	100	404T	91	86
	125	405T	92	86
	150	445T	92	88
	200	445T	92	89
	250	447T	92	90
	300	447T	92	90
	350	449Z	92	90
	400	449Z	92	90
	450	449Z	92	90
3600	1/4	48, 56	74	63
	1/3	48, 56	74	63
	1/2	48, 56	75	73
	3/4	48, 56	67	63
	1	56	75	64
	1-1/2	56, 143T	78	82
	2	56, 145T	80	86
	3	56, 145T	81	84
	5	56, 182T	81	88
	7-1/2	184T	84	85
	10	213T	87	89
	15	215T	87	91
	20	254T	89	86
	25	256T	89	87
	30	284T	87	87
	40	286T	90	87
	50	324T	88	89
	60	326T	90	88
	75	364T	90	84
	100	365T	93	83
	125	404T	89	88
	150	405T	90	89
	200	444T	91	89
	250	445T	92	90

O. Energy Efficient 3-Phase ODP is given in the following table:

Energy Efficient 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/2	56, 143T	71	70
	3/4	145T	74	70
	1	182T	71	79
	1-1/2	184T	74	79
	2	213T	73	79
	3	215T	76	85
	5	254T	80	85
	7-1/2	256T	85	85
1200	1/4	48, 56	71	70
	1/3	48, 56	71	70
	1/2	48, 56	71	70
	3/4	56, 143T	77	70
	1	145T	81	72
	1-1/2	182T	83	73
	2	184T	85	75
	3	213T	86	60
	5	215T	87	65
	7-1/2	254T	89	73
	10	256T	89	74
	15	284T	90	77
	20	286T	90	78
	25	324T	91	74
	30	326T	91	78
	40	364T	93	77
	50	365T	93	79
	60	404T	93	82
	75	405T	93	80
	100	444T	93	80
	125	444T	93	84
	150	445T	91	84
	200	447T	91	84
	250	449T	91	84
1800	1/4	48	74	63
	1/3	48, 56	74	63
	1/2	48, 56	74	70
	3/4	48, 56	74	70
	1	143T	82	84
	1-1/2	145T	84	85
	2	145T	84	85
	3	182T	86	86
	5	184T	87	87

Energy Efficient 3-Phase ODP

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	7-1/2	213T	88	86
	10	215T	89	85
	15	256T	91	85
	20	256T	91	86
	25	284T	91	85
	30	286T	92	88
	40	324T	92	83
	50	326T	93	85
	60	364T	93	88
	75	365T	93	88
	100	404T	93	83
	125	405T	93	86
	150	445T	93	85
	200	445T	94	85
	250	447T	92	85
	300	447T	92	90
	350	449Z	92	90
	400	449Z	92	90
	450	449Z	92	90
3600	1/4	48, 56	74	63
	1/3	48, 56	74	63
	1/2	48, 56	74	70
	3/4	48, 56	75	70
	1	56	75	79
	1-1/2	143T	82	85
	2	145T	82	87
	3	145T	84	85
	5	182T	85	86
	7-1/2	184T	86	88
	10	213T	87	86
	15	215T	89	89
	20	254T	90	89
	25	256T	90	92
	30	284T	91	91
	40	286T	92	92
	50	324T	93	89
	60	326T	93	91
	75	364T	93	88
	100	365T	92	88
	125	404T	89	88
	150	405T	90	88
	200	444T	91	88
	250	445T	92	88

P. Standard Efficiency 3-Phase TEFC is given in the following table:

Standard Efficiency 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/4	56	68	48
	1/3	56	68	48
	1/2	56, 143T	68	48
	3/4	145T	73	57
	1	182T	68	64
	1-1/2	184T	74	65
	2	213T	75	66
	3	215T	75	60
	5	254T	80	60
	7-1/2	256T	81	63
	10	284T	88	67
	15	286T	89	66
	20	324T	90	68
	25	326T	88	69
1200	1/6	48	71	58
	1/4	48, 56	71	58
	1/3	56	71	58
	1/2	56	71	58
	3/4	56, 143T	76	68
	1	56, 145T	77	67
	1-1/2	56, 145T, 182T	77	71
	2	184T	80	73
	3	213T	79	73
	5	215T	83	73
	7-1/2	254T	85	75
	10	256T	86	82
	15	284T	88	79
	20	286T	88	81
	25	324T	90	80
	30	326T	91	81
	40	364T	90	85
	50	365T	89	88
	60	404T	91	82
	75	405T	92	81
	100	444T	92	85
	125	445T	93	87
	150	445T	92	88
	200	447T	92	88
	250	449T	92	88
1800	1/8	42	74	63
	1/6	42	74	63
	1/4	48	74	63

Standard Efficiency 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	1/3	48, 56	74	63
	1/2	48, 56	74	63
	3/4	48, 56	74	60
	1	56, 143T	77	62
	1-1/2	56, 145T	79	66
	2	56, 145T	81	74
	3	182T	82	78
	5	184T	84	82
	7-1/2	213T	86	79
	10	215T	88	81
	15	254T	90	80
	20	256T	90	83
	25	284T	90	84
	30	286T	91	85
	40	324T	91	84
	50	326T	92	84
	60	364T	91	83
	75	365T	92	86
	100	405T	92	89
	125	444T	92	89
	150	445T	93	89
	200	445T	84	89
	250	447T	84	89
3600	1/6	42	67	63
	1/4	42	67	63
	1/3	48	67	63
	1/2	48, 56	67	63
	3/4	48, 56	75	73
	1	56	75	76
	1-1/2	56, 143T	74	80
	2	56, 145T	76	89
	3	56, 145T, 182T	81	87
	5	184T	85	94
	7-1/2	184T, 213T	86	85
	10	215T	87	92
	15	215T, 254T	89	92
	20	254T, 256T	87	89
	25	256T, 284T	88	87
	30	286T	88	90
	40	324T	86	90
	50	326T	89	91
	60	364T	89	91
	75	365T	89	91
	100	405T	89	91

Q. Energy Efficient 3-Phase TEFC is given in the following table:

Energy Efficient 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
900	1/4	56	68	48
	1/3	56	68	48
	1/2	56, 143T	68	70
	3/4	145T	73	70
	1	182T	68	79
	1-1/2	184T	74	79
	2	213T	75	79
	3	215T	75	85
	5	254T	80	85
	7-1/2	256T	81	85
	10	284T	88	85
	15	286T	89	85
	20	324T	90	85
	25	326T	88	85
1200	1/6	48	71	70
	1/4	48, 56	71	70
	1/3	48, 56	71	70
	1/2	56	71	70
	3/4	56, 143T	76	70
	1	145T	81	72
	1-1/2	182T	83	65
	2	184T	85	68
	3	213T	85	63
	5	215T	86	66
	7-1/2	254T	89	68
	10	256T	89	75
	15	284T	90	72
	20	286T	90	76
	25	324T	90	71
	30	326T	91	79
	40	364T	92	78
	50	365T	92	81
	60	404T	92	83
	75	405T	92	80
	100	444T	93	83
	125	445T	93	85
	150	445T	92	85
	200	447T	91	85
	250	449T	91	85
1800	1/8	42	47	55
	1/6	42, 48	49	58
	1/4	48, 56	53	52

Energy Efficient 3-Phase TEFC

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1800	1/3	48, 56	56	55
	1/2	48, 56	74	70
	3/4	48, 56	74	70
	1	143T	82	84
	1-1/2	145T	84	85
	2	145T	84	85
	3	182T	87	83
	5	184T	88	83
	7-1/2	213T	89	85
	10	215T	90	84
	15	254T	91	86
	20	256T	91	85
	25	284T	92	84
	30	286T	93	86
	40	324T	93	83
	50	326T	93	85
	60	364T	93	87
	75	365T	93	87
	100	405T	94	86
	125	444T	94	87
	150	445T	94	88
	200	447T	95	87
	250	447T	84	85
3600	1/6	42	67	63
	1/4	42	67	63
	1/3	48	67	63
	1/2	48, 56	67	70
	3/4	48, 56	75	70
	1	56	75	79
	1-1/2	143T	82	85
	2	145T	82	87
	3	182T	82	87
	5	184T	85	88
	7-1/2	213T	86	86
	10	215T	86	86
	15	254T	88	91
	20	256T	89	89
	25	284T	90	92
	30	286T	91	92
	40	324T	91	91
	50	326T	90	92
	60	364T	91	93
	75	365T	91	91
	100	405T	92	92

R. 3-Phase Explosion Proof is given in the following table:

3-Phase Explosion Proof

RPM	HP	NEMA FRAME	PERCENT EFFICIENCY	PERCENT POWER FACTOR
1200	1/3	56	71	58
	1/2	56	71	58
	3/4	56, 143T	72	70
	1	56, 145T	77	69
	1-1/2	56, 145T, 182T	78	77
	2	184T	84	68
	3	213T	80	75
	5	215T	80	75
	7-1/2	254T	80	75
	10	256T	80	75
	15	284T	80	75
1800	1/3	56	74	60
	1/2	56	74	60
	3/4	56	76	69
	1	56, 143T	75	74
	1-1/2	56, 145T	78	80
	2	56, 145T	80	80
	3	182T	82	75
	5	184T	85	80
	7-1/2	213T	86	82
	10	215T	89	82
	15	254T	87	82
	20	256T	92	84
	25	284T	92	86
	30	286T	92	87
	40	324T	92	88
	50	326T	93	86
	60	364T	93	86
	75	365T	93	86
	100	405T	93	86
3600	1/2	56	68	77
	3/4	56	72	79
	1	56	74	79
	1-1/2	143T	74	80
	2	145T	76	89
	3	145T, 182T	81	87
	5	184T	84	94
	7-1/2	184T, 213T	84	90
	10	215T	87	92
	15	254T	86	85
	20	256T	86	85
	25	284T	86	85
	30	286T	86	85
	40	324T	86	85
	50	326T	86	85

21.04 Starters, Disconnect Switches, and Motor Control Centers

A. Starter Types:

1. Manual: (Manual Control):
   a. Reversing/Non-reversing.
   b. Push Button/Toggle Switch.
   c. Available for single phase or 3-phase electrical power.
2. Magnetic: (Automatic Control):
   a. Full Voltage/Across the Line.
   b. Reversing/Non-reversing.
   c. Reduced Voltage:
      1) Reactor.
      2) Resistance.
      3) Auto Transformer.
      4) Wye-Delta/Star Delta.
      5) Full Voltage Part Winding.
      6) Reduced Voltage Part Winding.
   d. 2-Speed Starting:
      1) One Winding. Full Speed; Half Speed.
      2) Two Winding. Full Speed; ⅔ Speed.
      3) Constant Torque.
      4) Variable Torque.
      5) Constant Horsepower.
   e. Available for single phase or 3-phase electrical power.
3. Combination Starter Disconnect Switch: See Magnetic Starter:
   a. Fused.
   b. Non-fused.
   c. Disconnect Switches (Locking/Non-Locking—Recommend Locking Switches).
   d. Available for 3-phase electrical power only, but 3-phase starter can be used with single phase motor (although expensive).

B. Starter Accessories:

1. Pilot Lights: Green, Run; Red, Off.
2. Switches (Locking/Non-Locking—Recommend Locking Switches).
   a. Hand-Off-Auto (HOA).
   b. Push Button.
   c. Toggle Switch.
3. Control Transformer.
4. Overload Protection:
   a. Fused.
   b. Non-fused.
   c. Motor Circuit Protector.
   d. Molded Case Circuit Breaker.
   e. Circuit Fuse Protection: Size based on circuit ampacity and wire size.
   f. Overload Heaters: Size based on motor overload capacity.
   g. Two Levels of Overload Protection:
      1) Type 1: Considerable damage occurs to the contactor and overload relay when an overload happens but the enclosure remains externally undamaged. Parts of the starter or the entire starter may need to be replaced after an overload.

2) Type 2: No damage occurs to the contactor or overload relay except light contact burning is permitted when an overload happens.

h. The choice between circuit breakers and fuses is purely a matter of user preference.

5. Auxiliary Contacts (No-Normally Open/NC-Normally Closed).
6. Relays.

C. Disconnect Switch Sizes and Accepted Fuse Sizes are given in the following table:

SAFETY SWITCH SIZE AMPS	ACCEPTABLE FUSE SIZES AMPS	SAFETY SWITCH SIZE AMPS	ACCEPTABLE FUSE SIZES AMPS
30	15, 20, 25, 30	1600	1600
60	35, 40, 45, 50, 60	2000	2000
100	70, 80, 90, 100	2500	2500
200	110, 125, 150, 175, 200	3000	3000
400	225, 250, 300, 350, 400	4000	4000
600	450, 500, 600	5000	5000
800	700, 800	6000	6000
1200	1000, 1200	----	----

D. Standard Fuse and Circuit Breaker Sizes (Amperes): 1, 3, 6, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, 6000.

E. Starter Types by Starting Method are given in the following table:

STARTING METHOD	INRUSH CURRENT % LRA	STARTING TORQUE % LRT
Across-the-Line	100	100
Auto-Transformer		
80% Tap	71	64
65% Tap	48	42
50% Tap	28	25
Primary Resistor or Reactor		
80% Applied Voltage	80	64
65% Applied Voltage	65	42
58% Applied Voltage	58	33
50% Applied Voltage	50	25
Star Delta	33	33
Part Winding	60	48
Part Winding w/Resistors	60-30	48-12
Wound Rotor (Approx.)	25	150
Solid State	3 x RLA	---

Notes:
1. % LRA = Percent full voltage locked rotor current (amps).
2. % LRT = Percent full voltage locked rotor torque.
3. RLA = Rated Load Amps or Running Load Amps.

F. Motor Size, Starter and Disconnect Switch Size, and Fuse and Circuit Breaker Size are given in the following tables. The following notes are applicable to all schedules:

1. Starters and/or Disconnect Switches. Fuses shall be Class RK5 Time Delay, Dual Element Fuses. Circuit breakers shall be Thermal Magnetic Circuit Breakers.
2. Motor data, starters, disconnect switches, and fuses based on *1993 NEC* and Square D Company.

115 VOLT (120 VOLT) SINGLE PHASE MOTOR STARTER SCHEDULE					
MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/8	1	3.0	30	4.5	15
1/6	1	4.4	30	7	15
1/4	1	5.8	30	9	15
1/3	1	7.2	30	12	15
1/2	1	9.8	30	15	20
3/4	1	13.8	30	20	25
1	1	16.0	30	25	30
1.5	1	20.0	30	30	40
2	1	24.0	30	30	50
3	2	34.0	60	50	70
5	3	56.0	100	80	90
7.5	4	80.0	100	100	110
10	-	-	-	-	-

230 VOLT (240 VOLT) SINGLE PHASE MOTOR STARTER SCHEDULE					
MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/8	1	1.7	30	2.5	15
1/6	1	2.2	30	3.5	15
1/4	1	2.9	30	4.5	15
1/3	1	3.6	30	5.6	15
1/2	1	4.9	30	8	15
3/4	1	6.9	30	10	15
1	1	8.0	30	12	15
1.5	1	10.0	30	15	20
2	1	12.0	30	17.5	25
3	1	17.0	30	25	35
5	2	28.0	60	40	60
7.5	2	40.0	60	60	80
10	3	50.0	60	60	90

200 Volt (208 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	2.3	30	3.5	15
3/4	1	3.2	30	5	15
1	1	4.1	30	6.25	15
1.5	1	6.0	30	10	15
2	1	7.8	30	12	15
3	1	11.0	30	17.5	20
5	1	17.5	30	25	35
7.5	1	25.3	60	40	50
10	2	32.2	60	50	60
15	3	48.3	60	60	90
20	3	62.1	100	90	100
25	3	78.2	100	100	110
30	4	92.0	200	125	125
40	4	120.0	200	175	175
50	5	150.0	200	200	200
60	5	177.0	400	250	250
75	5	221.0	400	300	300
100	6	285.0	400	400	400
125	6	359.0	600	500	600
150	6	414.0	600	600	600
200	7	552.0	-	-	800

230 Volt (240 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	2.0	30	3.2	15
3/4	1	2.8	30	4.5	15
1	1	3.6	30	5.6	15
1.5	1	5.2	30	8	15
2	1	6.8	30	10	15
3	1	9.6	30	15	20
5	1	15.2	30	25	30
7.5	1	22.0	30	30	45
10	2	28.0	60	40	60
15	2	42.0	60	60	80
20	3	54.0	100	80	90
25	3	68.0	100	100	100
30	3	80.0	100	100	110
40	4	104.0	200	150	150
50	4	130.0	200	200	200
60	5	154.0	200	200	225
75	5	192.0	400	300	250
100	5	248.0	400	350	350
125	6	312.0	400	400	450
150	6	360.0	600	500	600
200	6	480.0	600	600	800
250	7	600.0	800	800	800
300	7	720.0	1200	1000	1000
400	-	-	-	-	-

460 Volt (480 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	1.0	30	1.6	15
3/4	1	1.4	30	2.25	15
1	1	1.8	30	2.8	15
1.5	1	2.6	30	4	15
2	1	3.4	30	5.6	15
3	1	4.8	30	8	15
5	1	7.6	30	12	15
7.5	1	11.0	30	17.5	20
10	1	14.0	30	20	25
15	1	21.0	30	30	40
20	1	27.0	60	40	60
25	2	34.0	60	50	70
30	2	40.0	60	60	80
40	3	52.0	100	80	90
50	3	65.0	100	100	100
60	3	77.0	100	100	110
75	4	96.0	200	150	125
100	4	124.0	200	175	200
125	5	156.0	200	200	225
150	5	180.0	400	250	250
200	5	240.0	400	350	350
250	6	300.0	600	500	500
300	6	360.0	600	600	600
400	6	480.0	800	700	700
500	7	540.0	1200	800	800

575 Volt (600 Volt) Three-Phase Motor Starter Schedule

MOTOR HP	NEMA STARTER SIZE	FULL LOAD AMPS PER PHASE	DISC. SWITCH SIZE	FUSE SIZE AMPERES	CIRCUIT BREAKER SIZE AMPERES
1/2	1	0.8	30	1.25	15
3/4	1	1.1	30	1.6	15
1	1	1.4	30	2.25	15
1.5	1	2.1	30	3.5	15
2	1	2.7	30	4.5	15
3	1	3.9	30	6.25	15
5	1	6.1	30	10	15
7.5	1	9.0	30	15	15
10	1	11.0	30	17.5	20
15	2	17.0	30	25	35
20	2	22.0	30	30	45
25	2	27.0	60	40	60
30	3	32.0	60	50	60
40	3	41.0	60	60	80
50	3	52.0	100	80	90
60	4	62.0	100	90	100
75	4	77.0	100	110	110
100	4	99.0	200	150	150
125	5	125.0	200	175	200
150	5	144.0	200	200	200
200	5	192.0	400	300	250
250	6	240.0	600	350	350
300	6	290.0	600	400	400
400	6	385.0	600	500	500
500	7	480.0	800	800	700

G. Motor Control Centers (MCC's):

1. NEMA Class I, Type A:
   a. No Terminal boards for load or control connections are provided.
   b. Numbered terminals for field wired power and control connections are provided on starter.
   c. Starter unit mounted pilot devices are internally wired to starter.
2. NEMA Class I, Type B:
   a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   b. Unit control terminal boards for each combination motor controller are provided for field wiring.
   c. Both terminal boards are factory wired and mounted on, or adjacent to, unit.
   d. No load terminal boards for feeder tap units are provided.
   e. Starter unit mounted pilot devices internally wired to starter.
   f. NEMA Class I, Type B will be suitable for most HVAC applications.
3. NEMA Class I, Type C:
   a. Factory wired master section terminal board, mounted on the stationary structure, is provided for each section.
   b. Terminal boards for load connections, are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   c. Unit control terminal boards for each combination motor controller are provided for field wiring.
   d. Complete wiring between combination controllers or control assemblies and their master terminal boards are factory installed. No wiring between sections or between master terminals is provided. No interconnections between combination controllers and control assemblies.
   e. No load terminal boards for feeder tap units are provided.
4. NEMA Class II, Type B:
   a. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   b. Unit control terminal boards for each combination motor controller are provided for field wiring.
   c. Both terminal boards are factory wired and mounted on, or adjacent to, unit.
   d. Complete wiring between combination controllers or control assemblies in the same and other sections are factory wired.
   e. No load terminal boards for feeder tap units are provided.
5. NEMA Class II, Type C:
   a. Factory wired master section terminal board, mounted on the stationary structure, is provided for each section.
   b. Terminal boards for load connections are provided for Size 3 and smaller controllers. For controllers larger than Size 3, numbered terminals for field wired power connections are provided on starter.
   c. Unit control terminal boards for each combination motor controller are provided for field wiring.
   d. Complete wiring between combination controllers or control assemblies and their master terminal boards in the same section and other sections are factory wired.
   e. No load terminal boards for feeder tap units are provided.
6. MCCs are available in NEMA enclosure types 1, 2, 3R, and 12.

21.05 Adjustable (Variable) Frequency Drives (AFDs or VFDs)

A. AFD Components (from power side to load side):

1. Rectifier Section: Silicon controlled rectifiers (SCRs) or diodes change single or 3-phase AC power to DC power.
2. DC Bus Section: Capacitors and an inductor smooth the rippled DC power supplied by the rectifier.
3. Inverter Section: An inverter converts the DC bus power to 3-phase variable frequency power.
4. Controller Section: The controller turns the inverter on and off to control the output frequency and voltage.

B. AFD Types:

1. Variable Voltage Inverters (VVI) use a silicon controlled rectifier (SCR) to convert incoming AC power to a varying DC power and then they use an inverter to convert the DC power to 3 phase variable voltage and variable frequency power. The disadvantages of VVIs are:
   a. Incoming line notching, which requires isolation transformers.
   b. Power factor is proportional to speed, which may require power factor correction capacitors.
   c. Torque pulsations are experienced at low speeds.
   d. Non-sinusoidal current waveform produce additional heating in the motor.
2. Current Source Inverters (CSI) use SCRs in the rectifier and inverter sections and only and inductor in the DC bus section. The disadvantages of CSIs are:
   a. Incoming line notching, which requires isolation transformers.
   b. Power factor is proportional to speed, which may require power factor correction capacitors.
   c. Motor drive matching is critical to proper operation.
   d. Non-sinusoidal current waveform produce additional heating in the motor.
3. Pulse Width Modulated (PWM) Drives use a full wave diode bridge rectifier to convert the incoming AC power to DC power. Most PWM drives use a 6-pulse converter and some offer a 12-pulse converter in the rectifier section. The DC bus section consists of capacitors and in some cases an inductor. The inverter section uses Insulated Gate Bipolar Transistors (IGBTs), Bipolar Junction Transistors (BJTs), or Gate Turn off Thyristors (GTOs) to convert the DC bus power to a 3-phase variable voltage and variable frequency power. PWM drives are the most common AFD in use in the HVAC industry today despite the fact that it can punish motors electrically, especially 460 and 575 volt motors. The advantages of PWM drives are:
   a. Minimal line notching.
   b. Better efficiency.
   c. Higher power factor.
   d. Larger speed ranges.
   e. Lower motor heating.

   The disadvantages of the PWM drives are:
   a. Higher initial cost.
   b. Regenerative braking is caused because power is allowed to flow in both directions and can act as a drive or a brake.

C. AFD Design Guidelines:

1. For best motor life and reliability, do not operate motors run by AFDs into their service factor and do not select motors to run within the service factors.

2. Do not run motors below 25% of their rated speed or capacity.
3. Use inverter duty motors whenever possible. Inverter duty motors are built with winding thermostats that shut down the motor when elevated temperatures are sensed inside the motor. In addition, these motors are built with oversized frames and external blowers to cool the motor through the full range of speeds.
4. Motors which are operated with AFDs should be specified with phase insulation, should operate at a relatively low temperature rise (most high efficiency motors fit this category), and should use a high class of insulation (either insulation class F or H).
5. Generally, AFDs do not include disconnect switches; therefore the engineer must include a disconnect switch in the project design. The disconnect switch should be fused with the fuse rated for the drive input current rating.
6. Multiple motors can be driven with one AFD.
7. All control wiring should be run separate from AFD wiring.
8. Most AFDs include the following features as standard:
   a. Overload protection devices.
   b. Short Circuit Protection.
   c. Ground Fault Protection.
9. Provide AFDs with a manual bypass in the event the drive fails.

D. AFDs produce non-linear loads, which cause the following unwanted effects:

1. AC system circuits containing excessive currents and unexpectedly higher or lower voltages.
2. Conductor, connector, and component heating which is unsafe.
3. Loss of torque on motors.
4. Weaker contactor, relay, and solenoid action.
5. High heat production in transformers and motors which can be destructive.
6. Poor power factor.

21.06 NEMA Enclosures

A. NEMA Type 1: **Indoor General Purpose, Standard**

B. NEMA Type 2: **Indoor Dripproof**

C. NEMA Type 3R: **Outdoor, Rain Tight, Water Tight, Dust Tight**

D. NEMA Type 4, 4X, 5: **Outdoor Rain Tight, Water Tight, Dust Tight, Corrosion Resistant**

E. NEMA Type 7X: **Explosionproof**

F. NEMA Type 12: **Indoor Oil and Dust Tight**

21.07 Humidifiers

A. Number of Humidifier Manifolds required is given in the following table:

DUCT HEIGHT	NUMBER OF MANIFOLDS
Less than 37"	1
37" - 58"	2
59" - 80"	3
81" - 100"	4
101" and Over	5

B. Humidifier Installation Requirements:

1. Humidifiers shall be installed a minimum of 3′-0″ from any duct transformation, elbow, fitting, or outlet.
2. Consideration must be given to length of vapor trail and air handling unit and ductwork design must provide sufficient length to prevent vapor trail from coming in contact with items downstream of humidifier before vapor has had time to completely evaporate.

C. Humidifier Makeup Requirements:

1. Steam or Electric Humidifiers:	5.6 GPM/1000 KW Input or 5.6 GPM/3413 MBH
2. Evaporative and Spray Coil Humidifiers:	5.0 GPM/1000 Lbs./Hr.

21.08 Insulation

A. Materials:

1. Calcium Silicate Temperature Range:	0–+1200°F.
2. Fiberglass Temperature Range:	–20–+1000°F.
3. Mineral Wool Temperature Range:	+200–+1900°F.
4. Urethane, Styrene, Beadboard Temperature Range:	–350–+250°F.
5. Cellular Glass Temperature Range:	–450–+850°F.
6. Ceramic Fiber Temperature Range:	0–+3000°F.
7. Flexible Tubing and Sheets Temperature Range:	–40–+250°F.

B. General:

1. Insulation, adhesives, mastics, sealants, and coverings shall have a flame spread rating of 25 or less and a smoke developed rating of 50 or less as determined by an independent testing laboratory in accordance with *NFPA 255* and *UL 728* as required by *ASHRAE 90A* and *90B.* Coatings and adhesives applied in the field shall be non-flammable in the wet state.
2. Hangers on chilled water and other cold piping systems should be installed on the outside of the insulation to prevent hangers from sweating.

C. Pipe Insulation:

1. Insulation shall be sectional molded glass fiber, minimum 3.0 lb. per cubic foot density, thermal conductivity not greater than 0.24 Btu-in/sq.ft./°F./hour at a mean temperature

difference of 75°F. and factory applied jacket of white, flame retardant vapor barrier jacket of 0.001″ aluminum foil laminated to kraft paper reinforced with glass fibers, or all service jacket.

2. Insulation shall be flexible foamed plastic, minimum 5.0 lb. per cubic foot density, thermal conductivity not greater than 0.28 Btu-in/sq.ft./°F./Hour at a mean temperature difference of 75°F.
3. Insulation shall be cellular glass, thermal conductivity not greater than 0.40 Btu-in/sq.ft./°F./hour at a mean temperature difference of 75°F.
4. Insulation shall be foamglass, minimum 8.5 lb. per cubic foot density, thermal conductivity not greater than 0.35 Btu-in/sq.ft./°F./hour at a mean temperature difference of 75°F.
5. Insulation Thickness is given in the following table:

PIPING SYSTEM (7)	PIPE SIZES	INSULATION THICKNESS VS TYPE(1,8)			
		A	B	C	D
CHILLED WATER - 40 °F TO 60 °F (3)	6" & SMALLER 8" & LARGER	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
CHILLED WATER - 32 °F TO 40 °F (3)	1" & SMALLER 1-1/4" - 6" 8" & LARGER	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.5	1.5 2.5 3.0
CHILLED WATER - BELOW 32 °F (3)	2" & SMALLER 2-1/2" - 6" 8" & LARGER	1.5 2.0 2.5	2.0 2.5 3.0	2.5 3.5 4.5	2.5 3.0 4.0
CONDENSER WATER	ALL SIZES	(2)	(2)	(2)	(2)
HEATING WATER - LOW TEMPERATURE 100 °F TO 140 °F (4)	4" & SMALLER 5" & LARGER	1.0 1.5	1.5 2.0	2.0 2.5	1.5 2.5
HEATING WATER - LOW TEMPERATURE 141 °F TO 200 °F (4)	ALL SIZES	1.5	2.0	2.5	2.5
HEATING WATER - LOW TEMPERATURE 201 °F TO 250 °F (4)	2" & SMALLER 2-1/2" - 6" 8" & LARGER	1.5 2.0 3.5	2.0 2.5 4.5	2.5 3.5 6.0	2.5 3.0 5.5
HEATING WATER - MEDIUM TEMPERATURE 251 °F TO 350 °F (4)	1" & SMALLER 1-1/4" - 4" 5" & LARGER	2.0 2.5 3.5	(10)	3.5 4.5 6.0	3.0 4.0 5.5
HEATING WATER - HIGH TEMPERATURE 351 °F TO 450 °F (4)	2" & SMALLER 2-1/2" - 4" 5" & LARGER	2.5 3.0 3.5	(10)	4.5 5.0 6.0	4.0 4.5 5.5
DUAL TEMPERATURE	ALL SIZES	(9)	(9)	(9)	(9)
HEAT PUMP LOOP	ALL SIZES	(2)	(2)	(2)	(2)
STEAM AND STEAM CONDENSATE - LOW PRESSURE (5)	2" & SMALLER 2-1/2" - 6" 8" & LARGER	1.5 2.0 3.5	2.0 2.5 4.5	2.5 3.5 6.0	2.5 3.0 5.5
STEAM AND STEAM CONDENSATE - MEDIUM PRESSURE (5)	1" & SMALLER 1-1/4" - 4" 5" & LARGER	2.0 2.5 3.5	(10)	3.5 4.5 6.0	3.0 4.0 5.5
STEAM AND STEAM CONDENSATE - HIGH PRESSURE (5)	2" & SMALLER 2-1/2" - 4" 5" & LARGER	2.5 3.0 3.5	(10)	4.5 5.0 6.0	4.0 4.5 5.5
REFRIGERANT SUCTION AND LIQUID LINES (6)	1" & SMALLER 1-1/4" - 6" 8" & LARGER	1.0 1.5 2.0	1.5 2.0 2.5	2.0 2.5 3.5	1.5 2.5 3.0
REFRIGERANT HOT GAS (6)	ALL SIZES	0.75	1.0	1.5	1.0
AIR CONDITIONING CONDENSATE	ALL SIZES	0.5	0.5	1.0	0.75

Notes:

1. **Type A: Fiberglass Insulation.**
   Type B: Flexible Foamed Plastic Insulation.
   Type C: Cellular Glass Insulation.
   Type D: Foamglass Insulation.
2. **Insulation not required on systems with temperatures between 55°F and 105°F., unless insulating pipe for freeze protection; then use chilled water (40°F. and above) thicknesses.**
3. **Chilled water system piping is often insulated with fiberglass insulation; however, cellular glass and flexible foamed plastic may be more appropriate for moisture condensation protection. Other types of insulation may be used.**
4. **Heating water system piping is generally insulated with fiberglass pipe insulation. Other types of insulation may be used.**
5. **Steam system piping and steam condensate system piping are generally insulated with fiberglass pipe insulation. Other types of insulation may be used.**
6. **Refrigerant system piping is generally insulated with flexible foamed plastic. Other types of insulation may be used. Normally only refrigerant suction lines are insulated, but liquid lines should be insulated where condensation will become a problem and hot gas lines should be insulated where personal injury from contact may pose a problem.**
7. **Table meets or exceeds *ASHRAE Standard 90.1-1989.***
8. **For piping exposed to ambient temperatures increase insulation thickness by 1.0 inch.**
9. **For dual temperature systems use insulation thickness for more stringent system, usually the heating system.**
10. **System temperature exceeds temperature rating of insulation.**

D. Duct Insulation

1. Internal Duct Liner:
   a. 1″ thick, 1½ pounds per cubic foot density amber color glass fiber blanket with smooth coated matte facing to conform to *TIMA Standard AHC-101, NFPA 90A, NFPA 90B, NFPA 255, UL 181,* and *UL 723.* Duct lining shall have a thermal conductance (k) not greater then 0.26 Btu/sq.ft./°F./hour at a mean temperature difference of 75°F. Vinyl spray face shall not be permitted.
   b. Thicknesses: 1″, 1½″, 2″.
2. External Duct Insulation:
   a. Duct Wrap: Insulation shall be flexible glass fiber blanket, 2″ thick, minimum ¾ lb. per cubic foot density, thermal conductivity not greater than 0.31 Btu-in./sq.ft./°F./hour at a mean temperature difference of 75°F and factory applied jacket of minimum 0.001″ aluminum foil reinforced with glass fiber bonded to flame resistant kraft paper vapor barrier. Thicknesses: 1″, 1½″, 2″.
   b. Duct Board: Insulation shall be glass fiber, 2″ thick, minimum 3.0 lb. per cubic foot density, thermal conductivity not greater than 0.24 Btu-in./sq.ft./°F./hour at a mean temperature difference of 75°F and factory applied jacket of white, flame retardant vapor barrier jacket of 0.001″ aluminum foil reinforced with glass fibers bonded to flame resistant kraft paper. Thicknesses: 1″, 1½″, 2″, 3″, 4″.
   c. Duct Board: Insulation shall be rigid glass fiber board, 2″ thick, minimum 6.0 lb. per cubic foot density, thermal conductivity not greater than 0.22 Btu-in./sq.ft./°F./hour at a mean temperature difference of 75°F and factory applied jacket of white, flame retardant vapor barrier jacket of 0.001″ aluminum foil reinforced with glass fibers bonded to flame resistant kraft paper. Thicknesses: 1″, 1½″, 2″.

3. Insulation Thickness is given in the following table:

DUCT LOCATION	COOLING (3)		
	ANNUAL COOLING DEGREE DAYS BASE 65 °F.	INSULATION R-VALUE	INSULTION THICKNESS (2)
EXTERIOR OF BUILDING:	BELOW 500 500 TO 1150 1151 TO 2000 ABOVE 2000	3.3 5.0 6.5 8.0	0.75 1.5 1.5 2.0
INSIDE BUILDING OR IN UNCONDITIONED SPACES (1): $\Delta T \leq 15$ $15 < \Delta T \leq 40$ $\Delta T > 40$	 --- --- ---	 NONE REQ'D 3.3 5.0	 --- 0.75 1.5

DUCT LOCATION	HEATING (3)		
	ANNUAL HEATING DEGREE DAYS BASE 65 °F.	INSULATION R-VALUE	INSULTION THICKNESS
EXTERIOR OF BUILDING:	BELOW 1500 1500 TO 4500 4501 TO 7500 ABOVE 7500	3.3 5.0 6.5 8.0	0.75 1.5 1.5 2.0
INSIDE BUILDING OR IN UNCONDITIONED SPACES (1): $\Delta T \leq 15$ $15 < \Delta T \leq 40$ $\Delta T > 40$	 --- --- ---	 NONE REQ'D 3.3 5.0	 --- 0.75 1.5

Notes:

1. **Δ T (Temperature difference) is the difference between space design temperature and the design air temperature in the duct.**
2. **Minimum insulation thickness required. Internally insulated (lined) ducts usually use 1″ thickness. Externally insulated ducts usually use 1½″ or 2″ thickness.**
3. **Table based on *ASHRAE Standard 90.1-1989.***

E. Insulation Protection:

1. Aluminum roll jacketing and fitting covers produced from 0.016 inch thickness, H-14 temper with a smooth finish or approved equal. Install in accordance with manufacturer's recommendations.
2. Prefabricated PVC fitting covers and jacketing with the same insulation and thickness as specified. Install in accordance with manufacturer's recommendations.

21.09 Firestopping and Through-Penetration Protection Systems

A. All openings in fire-rated and smoke-rated building construction must be protected from fire and smoke by systems that seal these openings to resist the pas-

sage of fire, heat, smoke, flames, and gases. These openings include passages for mechanical and electrical systems, expansion joints, seismic joints, construction joints, control joints, curtain wall gaps, the space between the edge of floor slab and the exterior curtain wall and columns, and other openings or cracks.

B. Terms:

1. Firestopping. Firestopping is non-combustible building materials or a system of lumber pieces which are installed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through small concealed spaces. The term *firestopping* is used with all types of building construction except with non-combustible and fire-resistive construction.
2. Through-Penetration Protection Systems (TPPS). TPPS are building materials or assemblies of materials specifically designed and manufactured to form a system designed to prevent the movement of fire, heat, smoke, flames, and gases to other areas of the building through openings made in fire-rated floors and walls to accommodate the passage of combustible and non-combustible items. The term *TPPS* is used with non-combustible and fire-resistive building construction.
3. Combustible Penetrating Items. Combustible penetrating items are materials such as plastic pipe and conduit, electrical cables, and combustible pipe insulation.
4. Non-Combustible Penetrating Items. Non-combustible penetrating items are materials such as copper, iron, or steel pipe; steel conduit; EMT; electrical cable with steel jackets; and other non-combustible items.
5. Annular Space Protection. Annular space protection is the building materials or assembly of materials which protect the space between non-combustible penetrating items and the rated assembly. In concrete or masonry assemblies, the materials generally used for annular space protection are concrete, grout, or mortar. In all other assemblies, the materials must be tested and meet *ASTM E119* standard under positive pressure.
6. Single-Membrane Protection. Single-membrane protection is the building materials or assembly of materials which protect the opening through one side, or a single membrane of a fire-resistive wall, roof/ceiling, or floor/ceiling to accommodate passage of combustible or non-combustible items. Materials protecting single membranes are annular space protection systems or TPPS.
7. Shaft Alternatives. A fire-rated shaft or enclosure is not required if a TPPS system with an F-Rating and a T-Rating equal to the rating of the assembly is used to protect openings made in fire-rated floors and walls to accommodate the passage of combustible and non-combustible items.

C. System Ratings:

1. F-Ratings (Flame Ratings) define the period of time for which the firestopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly, in accordance with *ASTM E814.* To receive an F-Rating, the system must also pass the hose stream test. F-Ratings are needed for all applications. F-Ratings must be equal to the rating of the assembly.
2. T-Ratings (Thermal Ratings) define the period of time for which the firestopping or TPPS system prevents the passage of flames and hot gases to the unexposed side of the assembly (F-Rating), and must also restrict the temperature rise on the unexposed surface to 325°F. in accordance with *ASTM E814.* T-Ratings must be equal to the rating of the assembly and at least 1 hour. T-Ratings are rarely applied because most penetrations in commercial structures tend to be in non-combustible concealed spaces and are generally only applied where codes require open protectives.

D. TPPS Materials:

1. Intumescent materials expand to form an insulating char.
2. Subliming materials pass from solid to vapor when heated without passing through the liquid phase.
3. Ablative materials char, melt, or vaporize when heated.
4. Endothermic materials, such as concrete and gypsum, absorb heat using chemically bounded water of the material.
5. Ceramic fibers are high temperature refractory materials.

E. Material Forms:

1. Caulks.
2. Putties.
3. Mixes.
4. Sheets, strips or collars.
5. Kits.
6. Devices.