An Introduction to Air Conditioning of Industrial Shops and Plants

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CONTENTS

1. PLANT HVAC DESIGN GUIDELINES. The following guidelines are offered to assist designers with little or no experience in plant HVAC system design. The material presented is only a starting point. The material is based on the experience of previous designers and accepted industry codes and standards. In many cases, especially minimum ventilation requirements, the material presented is subject to change due to periodic revisions of codes and standards. The information or materials presented in these guidelines are not intended to circumvent the requirements of applicable codes or standards. The HVAC system designer is ultimately responsible for verifying compliance with the requirements of the latest codes and standards. Where codes and standards differ from these guidelines, the more stringent requirement should be applied in the design.

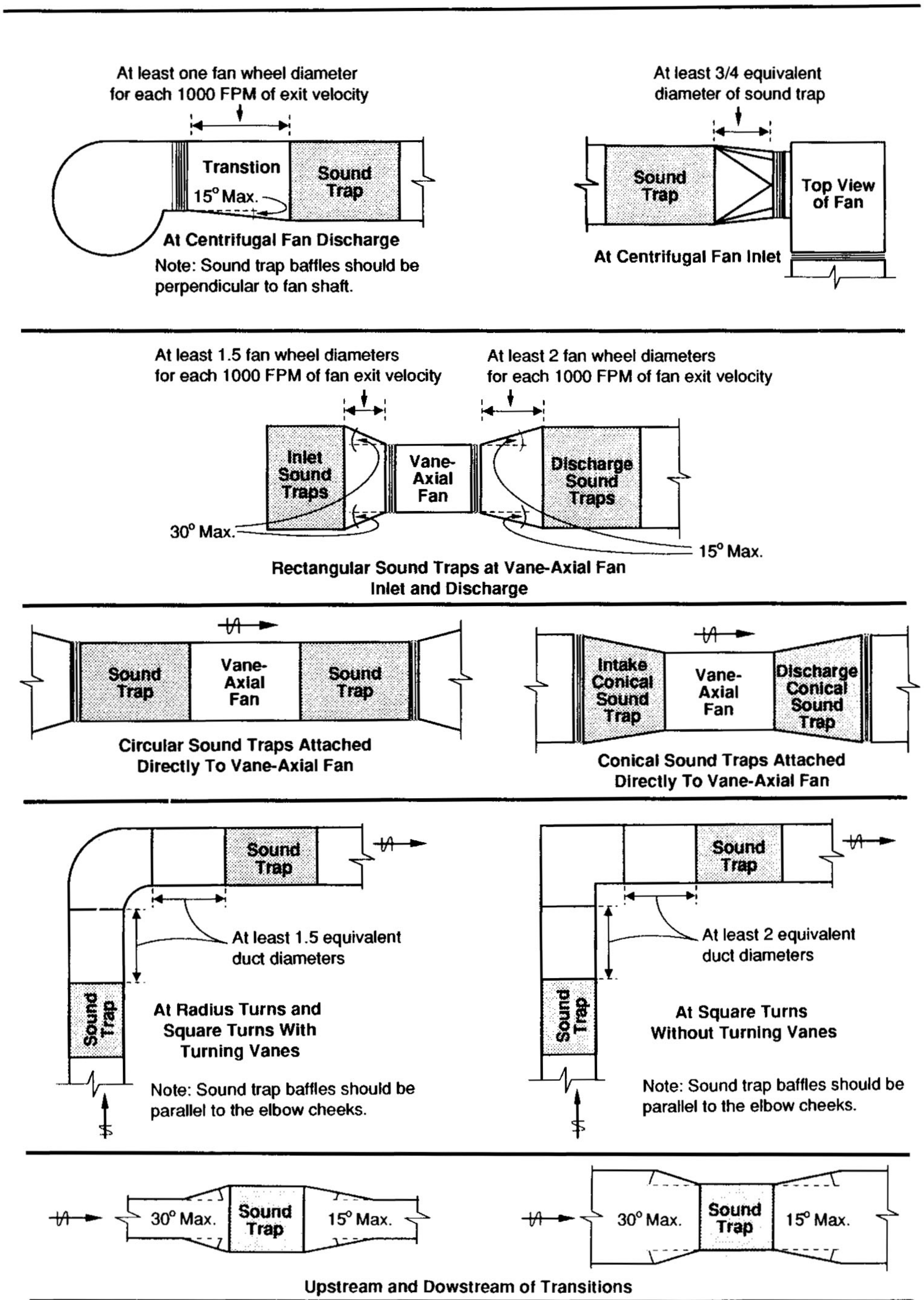

Figure 31

Guidelines for sound trap placement near fans and duct fittings.

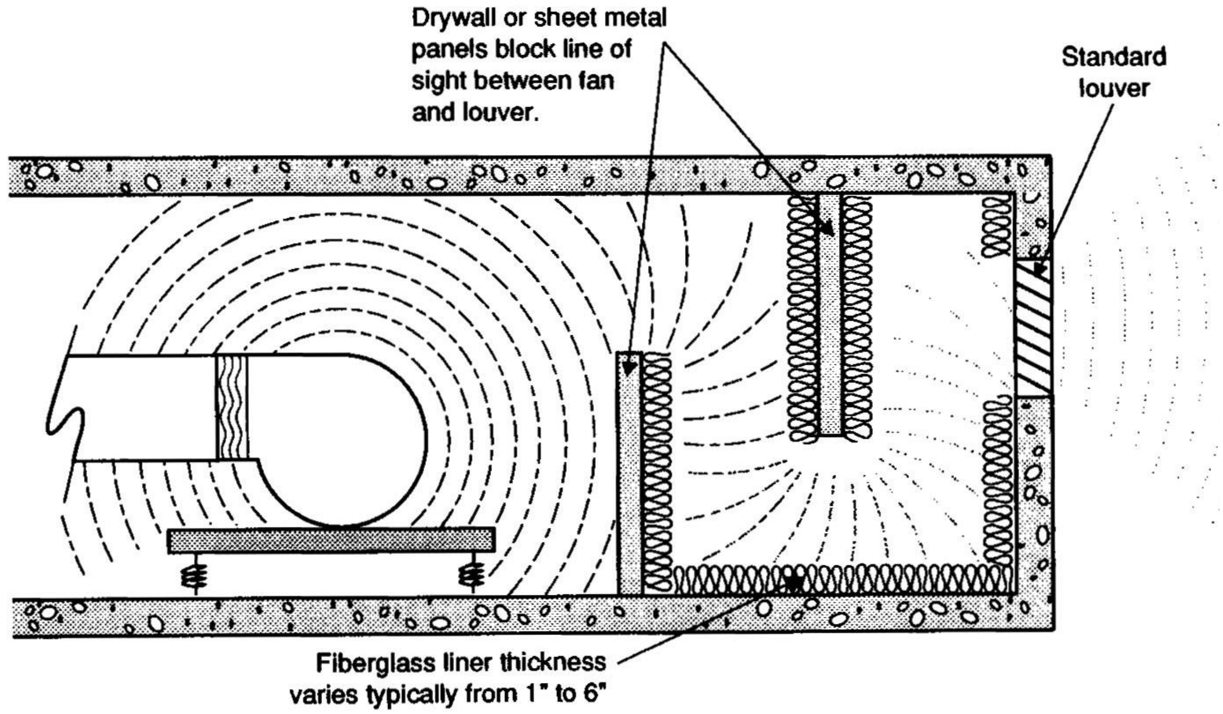

Figure 32

Labyrinth air path used for sound attenuation.

2. HUMAN COMFORT HEALTH AND SAFETY APPLICATIONS. When human comfort, health, and safety are the primary concern, the HVAC system must control air temperature, humidity, cleanliness, and air distribution to maintain an acceptable environment for personnel. The following conditions should be maintained for the level of activity noted.

2.1 LOW ACTIVITY AND SEDENTARY WORK

- Temperature above 68 ºF and below 78 ºF.
- Humidity above 30 percent and below 70 percent relative humidity.
- Cleanliness above 85 percent.
- Air motion above 50 ft/min and below 75 ft/min.
- Provide minimum outdoor air ventilation of 15 cfm per person in non-smoking areas and 60 cfm per person in smoking areas.

2.2 HIGH ACTIVITY OR MAINTENANCE WORK

- Temperature above 45 ºF and below 85 ºF.
- Humidity above 20 percent and below 80 percent relative humidity.
- Cleanliness above 85 percent.
- Air motion above 100 ft/min and below 300 ft/min.
- Provide minimum outdoor air ventilation of 15 cfm per person or as required to control contaminants in the space, whichever is higher.

3. EQUIPMENT PROTECTION APPLICATIONS. When equipment protection is the major objective, the air temperature, humidity, cleanliness, and air distribution must be controlled to protect equipment from freezing, corrosion, and high temperatures.

3.1 STANDING WATER OR WATER PIPES. Where equipment contains standing water, or water in small pipes, the ambient temperature should be maintained above 45 ºF.

3.2 OIL AND CHEMICAL STORAGE. In areas where equipment contains chlorine, oils, and solvents, the ambient temperature should be maintained above 60 ºF and provide minimum ventilation.

3.3 MOTOR ROOMS. In areas containing motors maintain space temperature below 104 ºF.

3.4 COMPUTER ROOMS

- Temperature between 72 ºF and 78 ºF.
- Humidity between 45 percent and 55 percent relative humidity.
- Cleanliness above 90 percent.
- Provide minimum outdoor air ventilation of 15 cfm per person.

3.5 CONTROL ROOMS

- Temperature between 68 ºF and 80 ºF.
- Humidity between 40 percent and 80 percent relative humidity.
- Cleanliness above 90 percent.
- Provide minimum outdoor air ventilation of 15 cfm per person.

4. MECHANICAL EQUIPMENT ROOMS

4.1 LOCATION. Mechanical equipment rooms should be located away from areas intended for human occupancy such as offices, control rooms, lunch rooms, and computer rooms. Locate to allow reasonable access to outside air and exhaust air louvers.

4.2 FLOOR SPACE. Allow a minimum of 10 to 15 ft^2 of floor space per 1000 cfm of airflow from fans or air handling units. Allow a minimum of 12 to 15 ft of ceiling height.

4.3 EQUIPMENT CLEARANCES.

- Allow a minimum of 3 feet of clearance between the equipment and walls. Increase space according to equipment manufacturer's recommendations.
- Allow a minimum of 4 feet of clearance in front of electric power and control panel doors. In retrofits, minimum clearances listed in NEMA codes must be provided.

5. LOUVERS

5.1 STYLE. Most plant designs specify louvers with 4-inch frame depth, 4-inch blade spacing, and 45º blade angle, and 45 percent free area. However, the louver free areas may vary considerably depending on the size, blade spacing, blade angle, and dimensional orientation. Louvers with dimensions yielding gross areas less than 4 ft^2 will generally have free areas of 35 to 37 percent. For any given dimensions, a taller louver will usually have a larger free area than a wider louver. If higher free areas are required, louvers with wider blade spacing, i.e. 6-inch or smaller, blade angle of 30º can be used.

5.2 AREA AND VELOCITY

5.2.1 OUTDOOR AIR GROSS AREA VELOCITY. To estimate wall openings required, stationary louver should be sized for a maximum airflow velocity of 400 ft/min.

5.2.2 OUTDOOR AIR FREE AREA. To prevent moisture entrainment, reduce noise, and minimize pressure loss, the free area velocity should not exceed 800 to 1100 ft/min and a maximum pressure drop of 0.15-in. w.g.

5.2.3 EXHAUST AIR. Size stationary louvers should be sized for a maximum free area velocity of 500 to 600 ft/min and a maximum pressure drop of 0.25-in. w.g.

5.3 LOCATION. Locate louvers a minimum of 2 feet above ground level to reduce clogging by debris.

5.4 CONSTRUCTION

5.4.1 FRAMES AND BLADES. When louvers are to be installed near ground level or where they may be subject to vandalism, use 16 gage steel construction. Louvers located high enough from the ground, and not subject to vandalism may be aluminum.

5.4.2 SCREEN. Provide galvanized or stainless steel insect or bird screens on all louvers. Screen may be specified as a single number, i.e. 2 mesh, or two numbers, such as 2 x 2 mesh. The single number (2) format corresponds to the center-to-center distance in inches between the wires. The two digit (2 x 2) format corresponds to the number of openings per inch of screen. Locate insect screens on the outside face of the louver to prevent insect and bird nests. Where bird screens are deemed more desirable than insect screens; use 2 x 2 x 0.063 diameter wire screens. This screen has a free area of approximately 76 percent. The pressure loss due to the reduced free area of the screen is not included in the louver static pressure and must be added to the system losses.

6. AIR FLOW VELOCITIES

6.1. AIR SYSTEM SUPPLY

6.1.1 MAIN DUCTS. Up to 3000 ft/min not to exceed a friction loss of 0.25 inch w.g. per 100 feet. Normally the duct size is based on 0.1 inch w.g. per 100 feet of duct.

6.1.2 BRANCH DUCTS. Up to 2100 ft/min not to exceed a friction loss of 0.2 inch w.g. per 100 feet of duct. Normally the duct size is based on 0.1 inch w.g. per 100 feet of duct.

6.1.3 DISCHARGE VELOCITIES INTO ROOMS. Vary from 600 ft/min to 1800 ft/min, depending on the air terminal device deflection pattern (0º, 22–1/2º, or 45º) and desired throw (maximum of 3/4 of the distance to the opposite wall). The Noise Criteria (NC) rating of air terminal devices should not be ignored when selecting grilles and registers. NC ratings should not exceed 45.

6.2 EXHAUST SYSTEM VELOCITIES. Exhaust velocities, commonly referred to as transport velocities, depend on the type of material to be conveyed by the ductwork. Exhaust velocities for the most common applications in facilities are provided below. For applications where ducts do not require a minimum transport velocity, a pressure drop of 0.10-in/100-ft of duct is normally used to size ducts.

- Chlorine rooms.—3,600 ft/m
- Oil storage rooms.—3,000 ft/m
- Toilet rooms.—1,200 ft/m
- Paint storage rooms and booths.—2,000 ft/min minimum.
- Welding fumes.—2,000 ft/min minimum.
- Battery rooms.—2,000 ft/min minimum.

7. VENTILATION REQUIREMENTS. Whenever possible, the airflow requirements should be based on the actual hazard conditions encountered in the space. The air change method is satisfactory for standard or commonly occurring situations. However, caution should be exercised when using the air change method to determine ventilation rates for any application, especially those not identified below. Where significant amounts of hazardous substances are generated in work areas or occupied spaces, the number of air changes may not provide adequate control. The sources for the ventilation rates tabulated below have been provided. Because ventilating requirements may change, the sources should be consulted to ensure the recommended ventilation rates reflect current requirements. Where the multiple ventilation criteria are shown, i.e. air changes/hr, cfm/ft^2, and cfm,–the criteria resulting in the highest ventilation requirement should be used.

7.1 OIL STORAGE AND OIL TRANSFER ROOMS. Provide 1 cfm/ft^2 of floor area but not less than 150 cfm/min. Ventilate continuously (see NFPA 850). Maintain a slight negative pressure in the room. All air from the space must be direct exhausted to outdoors. Provide a fan airflow switch and indicating lights (green–on, red–off) to verify fan operation. Locate monitoring lights and fan motor starter outside the room near entry door to verify fan operating status.

7.2 TOILETS, LOCKER ROOMS, AND SHOWERS. Operate fan when space is occupied and for 15 minutes thereafter. Maintain slight negative pressure. All air from the space must be direct exhausted to outdoors. For each condition below, ventilate at rate producing the highest cfm (see ASHRAE Standard 62).

7.2.1 TOILET SPACES. 2 cfm/ft^2 of floor space; 25 cfm/toilet; 200 cfm minimum.

7.2.2 LOCKER ROOMS. 1 cfm/ft^2 of floor space for coat hanging or clean clothes change room. 3 cfm/ft^2 for sweaty or wet clothing

7.2.3 SHOWERS. 2 cfm/ft^2 of floor space; 50 cfm/shower head minimum; 200 cfm minimum.

7.3 PAINT STORAGE ROOMS. Provide 10 to 12 air changes per hour. Ventilate continuously. Maintain slight negative pressure by making exhaust air equal to 105 percent of supply air (see American Conference of Governmental Industrial Hygienists (ACGIH) Industrial Ventilation – A Manual of Recommended Practice), all air from the space must be direct exhausted to outdoors. Provide fan airflow switch, and indicating lights (green–on, red–off) to verify fan operation. Locate lights and fan motor starter outside room near entry door.

7.4 PAINT BOOTHS. Ventilating air requirements vary depending on type and size of booth, i.e. walk-in type or operator outside, and type of equipment used, i.e. air or airless. Consult ACGIH for specific requirements. Ventilate at 150 cfm/min per ft^2 but not less than 20 air changes per minute for preliminary estimates. All air from the space must be direct exhausted to outdoors. Operate fan when booth is occupied. Provide fan airflow switch and indicating lights (green–on, red–off) to verify fan operation. Locate lights and fan motor starter outside room near entry door.

7.5 WELDING ROOMS OR AREAS. Actual amount of air depends on welding rod size and rate of consumption, number of welders used, and type of exhaust system – local or general. For local exhaust systems with fixed bench hoods, see figure 33. For fixed overhead exhaust systems with movable local exhaust hoods, the ventilation rate depends on the distance between the welding rod and the face of the hood, see figure 34. Where local exhaust is not possible, general ventilation rates vary between 1,000 to 4,500 ft^3/min per welder depending on welding rod size see figure 34. Typical welding rod sizes used at many facilities are 1/4-inch or less. Therefore, a general ventilation rate of 2,500 to 3,500 cfm/welder or 6 to 12 air changes per hour in a welding room should be satisfactory. Provide one portable welding exhaust system with air cleaners capable of removing particulates and odors, and recirculating air.

7.6 BATTERY ROOMS. Provide continuous ventilation to maintain hydrogen gas concentration below 0.8 percent by volume during maximum gas generation conditions. The following should be noted when determining the required exhaust fan size:

7.6.1 WHEN THE BATTERY IS FULLY CHARGED. Each charging ampere supplied to the cell produces about 0.016 cubic feet of hydrogen per hour from each cell. This rate of production applies at sea level, when the ambient temperature is about 77 ºF, and when the electrolyte is "gassing or bubbling."

7.6.2 NUMBER OF BATTERY CELLS. And maximum charging rate (not float rate) can be obtained from specifications or field inspection.

7.6.3 HYDROGEN GAS LOWER EXPLOSIVE LIMIT. Is 4 percent by volume. Good practice dictates a safety factor of 5, which reduces the critical concentration to 0.8 percent by volume. This large safety factor is to allow for hydrogen production variations with changes in temperature, battery room elevation, and barometric pressure and also allows for deterioration in ventilation systems. The following example illustrates the procedure for determining battery room ventilation requirements. Assume a battery room volume (Vr) of 900 ft3, a 60-cell battery with a charge rate of 50 amps per hour, and a maximum H^2 concentration of 0.8 percent by volume. The total H^2 generation is given by:

$G_t = G_c NA$

Where: G_t = total hydrogen generated, ft^3/hr
G_c = hydrogen generation per cell, $ft^3/hr/cell$
N = number of cells
A = charging rate, amps

$G_h = (0.016)(60)(50) = \underline{48\ ft^3/hr}$

The maximum acceptable volume of H_2 is given by:

$V_h = V_r C$

Where: V_h = volume of hydrogen, ft^3
V_r = total room volume, ft^3
C = acceptable hydrogen concentration, percent

$V_h = (900)(0.008) = \underline{7.2\ ft^3}$

The time, T, to reach critical concentration is given by:

$T = V_h/G_h = 7.2/48 = \underline{0.15\ hrs\ or\ 9\ minutes}$

The minimum number of air changes per hour, N, is determined by:

$N = 60/9 = \underline{6.7\ changes/hr}$

The minimum airflow, Q, required, is given by:

$Q = V_r N/60 = (900)(6.7)/60 = \underline{100\ cfm}$

Ventilation rates for battery rooms are usually small (less than 100 cfm). For preliminary sizing of ventilating requirements, assume 1 cfm/ft^2, or 6 air changes/hr. Maximum hydrogen gas generation occurs when batteries are approaching full charge. Locate air intakes near floor. Locate exhaust openings near ceilings. Locate air intakes and exhaust openings so that they are diametrically opposed if possible. Avoid routing miscellaneous ducts through battery rooms. Ventilate continuously with a dedicated exhaust fan. Maintain slight negative pressure. The fan should be spark resistant construction and should be located outside the room if possible. If the fan must be located in the battery room, the fan, controls etc. must comply with NEC explosion-proof criteria that will increase cost significantly. Fan controls should not be designed for automatic fan shutdown by the fire detection and alarm system when fire or smoke is detected outside the room. Locate fan motor starter and control switch outside the room adjacent to entry door. Provide a differential pressure switch and indicating lights (green–on, red–off) outside room but near entry door to verify fan operating status.

7.7 CHLORINE STORAGE ROOMS INSIDE THE STRUCTURE. Ventilate with 100 percent outdoor air. Provide 15 air changes per hour continuously and 60 air changes per hour when occupied by maintenance personnel. Position air intake near floor and no higher than one duct diameter. Provide an external hazard warning sign, and an internal gas detection device with a red indicating light outside the room or enclosure.

7.8 SEWAGE ROOMS. Provide 12 air changes per hour continuously (from NFPA 820). Exhaust directly to outdoors.

7.9 PLANT SUMPS. Provide 12 air changes per hour continuously. (from NFPA 820). Exhaust directly to outdoors.

7.10 ALL OTHER FLOORS, ROOMS AND GALLERIES. Ventilate at 1 cfm/ft^2 of floor area or as dictated by the heating or cooling requirements for each space.

7.11 ANY ROOM WITH COMBUSTIBLE GASES. The following methods can be used to determine the time required for ventilation, the number of air changes required to dilute a known concentration, and the time to reach a combustible concentration level. The equations, procedures, and examples are extracted from NFPA 69:

7.11.1 TIME REQUIRED FOR VENTILATION. The time required to reduce a given concentration of an explosive vapor to a safe concentration can be obtained by solving the following equation for time t:

$$ln\ (C/C_o) = (-Q/V)\ Kt$$

Where: C = desired gas concentration, percent
C_o = initial gas concentration, percent
Q = airflow rate, cfm
V = volume of room, ft^3
K = mixing efficiency of ventilating scheme.
t = time required to reach the desired concentration, min.

Values for K are shown in table 12, however, most authorities recommend a K value no greater than 0.25.

Values for K are shown in table 12, however, most authorities recommend a K value no greater than 0.25.

Method of supplying	Efficiency (K)[1] values	
	Single exhaust opening	Multiple exhaust openings
No positive supply		
1. Infiltration through cracks	0.2	0.3
2. Open doors or windows	0.2	0.4
Forced air supply		
1. Grilles and registers	0.3	0.5
2. Diffusers	0.5	0.7
3. Perforated ceiling	0.8	0.9

[1]Few data exist on defining the degree of mixing. Most authorities recommend a K value no greater than 0.25. NFPA 69.

Table 12

Mixing efficiency for various ventilation arrangements

Example: A 1000 ft^3 room contains a gasoline vapor concentration of 20 percent by volume. Determine the time required to reduce the concentration to the lower flammable limit (LFL) of 1.4 percent if the space is ventilated with 2,000 cfm air.

$$\ln(1.4/20) = (-2{,}000/1{,}000)(0.20)\,t$$

$$t = \underline{6.65 \text{ minutes}}$$

If the concentration was reduced to 25 percent of the LFL (0.35 percent concentration), the time required would be 10 minutes. 0.20 mixing efficiency is used as a conservative design assumption.

7.11.2 AIR CHANGES TO INERT. The number of air changes required for entering a combustible gas is obtained by solving the following equation for N:

$$ln\ (C/C_o) = -KN$$

Where: C, C_o, *and* K are as defined above.
N = number of air changes

Example: Using the previous example, determine the number of air changes required to reach the LFL.

$$ln\ (1.4/20) = (0.20)\ N$$

$$N = \underline{2\ changes\ per\ minute}$$

Therefore, the time required to achieve 13.3 air changes is 13.3/2, which is exactly equal to the 6.65 minutes determined in the previous example.

7.11.3 TIME TO REACH A CONCENTRATION. Time to reach a given concentration can be obtained by rewriting equation 2 as follows:

$$C = (G/Q)(1 - e^{-KN})$$

This equation can be rewritten as:

$$-KN = ln\ [1 - (CQ/G)]$$

Where: C = target concentration, percent
G = combustible gas entering space, cfm
Q = air entering space, cfm
K = mixing efficiency factor
N = number of theoretical air changes

Example: Assume a gas leak, Q_L, of 100 ft^3/min of a 15 percent combustible gas/air mixture into a 1000 ft^3 room. Determine the time to reach a 5 percent concentration throughout the room.

Based on the statement of the problem, the amount of gas entering the space is 15 percent of the total leak rate or 0.15(100) = <u>15 ft^3/min</u>. The amount of air is 100– 15 = <u>85 ft^3/min</u>. Assume K = 0.2

The number of air changes required to achieve a 5 percent concentration of the combustible gas is determined as follows:

$$-0.02N = \ln [1 - (0.05(85)/15)]$$

$$N = \underline{1.67}$$

Since the room volume and leakage rate are known, the time to reach the expected concentration is determined as follows:

$$t = (V/Q_L)\, N = (1000/100)1.67 = \underline{16.7 \text{ min.}}$$

8. RECOMMENDED SPACE TEMPERATURES. Recommended ambient space temperatures are shown on table 13.

9. RECOMMENDED RELATIVE HUMIDITY. Recommended relative humidity values are shown on table 14. In general, plants are often considered unmanned structures and no attempt is made to control humidity through addition of water to the supply air. Computer rooms are the exception where minimum and maximum humidity levels are critical and closely controlled. Maximum humidity is controlled when using evaporative cooling systems because of the significant amount of moisture added to cool the supply air.

10. BUILDING PRESSURIZATION. Negative pressures may cause unsatisfactory conditions in the plant. See table 15. When appropriate, air conditioning systems should be designed to pressurize the structure to restrict the entry of dust, and control temperature and humidity due to drafts through door cracks and other openings. The amount of outdoor air induced into the building through the main air conditioning units must be equal to the amount of contaminated air exhausted from the main air handling systems and all continuously operating exhaust fans.

Space	Minimum		Maximum	
	°F	°C	°F	°C
Oil storage and transfer rooms	45	7.2	80	26.6
Toilets and janitor rooms	65	18.3	85	29.4
Paint storage rooms	45	7.2	80	26.6
Paint booths	65	18.3	80	26.6
Welding rooms	65	18.3	80	26.6
Battery rooms	50	10	80	26.6
Chorine storage indoors	45	7.2	90	32.2
Generator room level	45	7.2	80	26.6
Generator room ceiling level			120	48.9
Pipe galleries	45	7.2	80	26.6
Electrical galleries	45	7.2	104	40
Visitor facilities	68	20	80	26.6
Control rooms	68	20	80	26.6
Computer rooms	72	22.2	78	25.5
UPS rooms	65	18.3	90	32.2
Lunch rooms	68	20	80	26.6
Offices	68	20	80	26.6
HVAC machinery	55	12.8	90	32.2
Air compressor and pump rooms	45	7.2	90	32.2

Table 13

Recommended space temperatures

Spaces	Minimum	Maximum
Pipe Galleries		80
Electrical Galleries	40	80
Visitors facilities	30	80
Control rooms	40	80
Computer rooms	45	55
Offices	30	70
Lunch rooms	30	70
Intake air supply		80

Table 14

Recommended relative humidity

10.1 RECOMMENDED PRESSURE. To provide positive pressure within the building, the amount of outdoor air should be increased to approximately 105 percent of the amount exhausted or be balanced to give a positive gage building pressure difference of 0.08 to 0.16 inch of water.

10.2 EFFECT OF PRESSURE ON DOOR OPENING FORCES. Positive pressure may affect occupants' ability to open doors or may prevent doors from completely closing; therefore, excessive positive pressure should be avoided. According to the NFPA 101 Life Safety Code, the forces required to fully open any door manually in a means of egress shall not exceed 30 lbs to set the door in motion. For additional discussions concerning the effects of positive building pressurization and procedures for calculating door opening forces refer to NFPA 92A.

11. WATER PIPING

11.1 DESIGN GUIDES. Water distribution systems should be designed in accordance with the UPC (Uniform Plumbing Code) and the ASHRAE Handbook of Fundamentals.

11.2 MATERIALS. Copper piping conforming to ASTM B33 Type K should be used to prevent corrosion. Water flow velocities in copper piping should not exceed 5 ft/sec to prevent erosion.

11.3 DIELECTRIC JOINTS. Where dissimilar metal piping must be connected, insulating flange sets or insulating unions must be provided between the piping.

11.4 VALVE STRAINERS. Control valves should be protected by properly sized strainers immediately upstream of the valve. Provide blow-off valve on strainer.

11.5 FREEZE PROTECTION. Piping located outdoors, or indoors in unheated areas, is subject to freezing. This is especially true for pipe systems containing standing water. Insulation will delay but not prevent freezing of still water or water flowing at a rate insufficient for the available heat content to offset the heat loss. The time required for standing water to cool to 32 °F can be estimated with the following equation from 1997 ASHRAE Fundamental Handbook:

$$\theta = \rho c_p \pi (D_i/2)^2 (R_T) \ln [(t_i - t_a)/(t_f - t_a)]$$

Where:

θ	=	time for water to cool to freezing, h
ρ	=	density of water = 62.4 lb/ft^3
c_p	=	specific heat of water = 1.0 Btu/lb F
D_i	=	inside diameter of pipe, ft
D_p	=	outer diameter of pipe or inner diameter of insulation, ft
D_l	=	outer diameter of insulation, ft
R_T	=	$R_p + R_l + R_a$ = total resistance: pipe, insulation, air film, ft · °F · h/Btu
R_a	=	$1/(h_a \pi D_l)$ = resistance between ambient air and outer surface of insulation per foot of pipe, ft · °F · h/Btu
h_a	=	air heat transfer coefficient
R_l	=	$\ln(D_l/D_p)/(2\pi k_l)$ = resistance of thermal insulation per foot of pipe, ft · °F · h/Btu
R_p	=	$\ln(D_p/D_i)/(2\pi k_p)$ = resistance of pipe per foot of pipe, ft · °F · h/Btu (R_p = 0 for metal pipe)
k_l	=	thermal conductivity of insulation, Btu/h · ft · °F

k_p = thermal conductivity of pipe material, Btu/h ft °F
t_a = ambient air temperature, °F
t_i = initial water temperature, °F
t_f = freezing temperature, °F

The water flow required to prevent freezing can be estimated as follows:

$$L/W = c_p\,(R_T + R_W)\,ln\,[\,(R_T)(t_i - t_a)\,/\,(R_T + R_W)(t_f - t_a)]$$

Where: W = flow rate required to keep pipe free of ice – lb/h
L = length of exposed pipe – ft
R = $1/(\pi k_w Nu)$ = resistance between water and inner surface of pipe per foot of pipe = 0.23 ft · °F · h/Btu.
k_w = thermal conductivity of water = 0.32 Btuh/h · ft · °F
Nu = Nusselt number for water = 4.36 for fully developed laminar flow and constant heat flux.

When appropriate, the piping system design should include thermostatically controlled valves to automatically drain the system when a low-limit temperature sensor detects a fall in temperature below a predetermined set point – usually 35 ºF. Once outdoor temperature falls below freezing, cooling water is rarely required to maintain ambient conditions. In these cases, the HVAC controls should include a manual reset to prevent refilling the system after a shutdown initiated by the freeze protection system. Occasionally, some components such as pump casings and strainers cannot be completely drained. If complete draining is not possible, or desirable, the piping and components should be wrapped with electric heat tape. Heat tape and sizing requirements are discussed below.

11.6 HEAT TRACING. Heat tracing may be accomplished with fluids such as hot water and steam, or electric cable. Due to lack of steam, or hot water in sufficient quantities, heat tracing in most facilities is accomplished with electric cables.

11.6.1 APPLICATIONS:

11.6.1.1 FREEZE PROTECTION. A self-regulating electric cable is used to prevent freezing of water pipes. This is primary consideration for outdoor piping applications and indoor applications where space heating is not required or is impractical. Most applications fall under this category.

11.6.1.2 MAINTAIN TEMPERATURE. A constant Watt cable with temperature controls is used to maintain a specific fluid temperature. This application has very limited use in facilities because most systems tolerate fairly wide operating ranges.

11.6.1.3 SNOW AND ICE MELTING. Cable can be installed to prevent undesirable ice formation on or around equipment.

11.6.2 SIZING HEAT CABLE:

11.6.2.1 ESTABLISH DESIGN CONDITIONS:

T_m = maintenance temperature, °F
T_s = startup temperature, °F
T_a = ambient temperature, °F
D_p = nominal pipe diameter
Insulation type: See table 16 – K factors for various insulation types
Insulation thickness: inches
Maximum wind speed
Heat loss safety factor
Location of pipe: indoor, outdoor, underground

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Insulation thickness: inches
Maximum wind speed
Heat loss safety factor
Location of pipe: indoor, outdoor, underground

Temperature (° F)	0	50	100	150	200	250	300	350	400
Fiberglass	0.23	0.25	0.27	0.29	0.32	0.34	0.37	0.39	0.41
Calcium silicate	0.35	0.37	0.40	0.43	0.45	0.47	0.50	0.53	0.55
Urethane	0.18	0.17	0.18	0.22	0.25	–	–	–	–
Cellular glass	0.38	0.40	0.46	0.50	0.55	0.58	0.61	0.65	0.70

[1] Select the K factor equal to or below the maintenance temperature for K_{1m} or the K factor equal to or below the ambient temperature for K_{1a}.

Table 16

K factor chart for various insulation types1

11.6.2.2 HEAT LOSS FROM THE PIPE:

$$Qp = [2\pi K (T_m - T_a)] \div [z \ln (D_o / D_i)]$$

Where: Q_p = heat loss, Watts/ft of pipe
K = thermal conductivity of insulation, Btu in/hr ft^2 °F
D_o = outside diameter of insulation, inches
D = inside diameter of insulation, inches
z = 40.994 Btu in/W hr ft

Q_p can also be determined from table 17. To determine the heat loss/ft of pipe, multiply the table value by the difference between the maintenance and ambient temperatures $(T_m - T_a)$.

11.6.2.3 CORRECTION FACTORS:

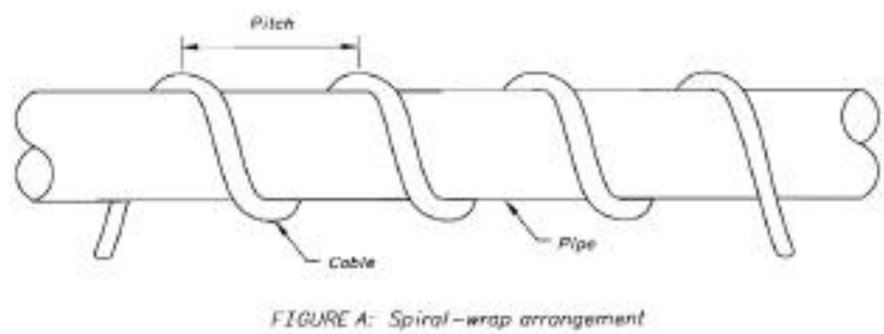
- **LOCATION**. Note that table 17 is based on outdoor applications. For indoor installation apply a correction factor of 0.9 to heat losses determined by table 17, i.e. multiply Qp by 0.9. For underground installations (including below frost line), or for plastic pipe, apply a 25 percent safety factor, i.e. multiply by 1.25. For underground plastic pipe apply a 50 percent safety factor to account for poor heat transfer characteristics, i.e. multiply by l.50.

- **WIND SPEED**. Note that table 17 is based on 20 mph wind velocities. Apply a wind speed correction factor of 5 percent/5 mph wind speed over 20 mph not to exceed 10 percent to Q_p.
- **K FACTOR EFFICIENCY.** Multiply Q_p by a correction factor of $2(kT_m + kT_a)$ where kT_m and kT_a are the thermal conductivities at the maintenance and ambient temperatures respectively.

Pipe size (IPS)	Insulation thickness (inches) ½	¾	1	1 ½	2	2 ½	3	4
½	0.054	0.041	0.035	0.028	0.024	0.022	0.020	0.018
¾	0.063	0.048	0.040	0.031	0.027	0.024	0.022	0.020
1	0.075	0.056	0.046	0.036	0.030	0.027	0.025	0.022
1 ¼	0.090	0.066	0.053	0.051	0.034	0.030	0.028	0.024
1 ½	0.104	0.075	0.061	0.046	0.038	0.034	0.030	0.026
2	0.120	0.086	0.069	0.052	0.043	0.037	0.033	0.029
2 ½	0.141	0.101	0.080	0.059	0.048	0.042	0.037	0.032
3	0.168	0.118	0.093	0.068	0.055	0.048	0.042	0.035
3 ½	0.189	0.113	0.104	0.075	0.061	0.052	0.046	0.038
4	0.210	0.147	0.115	0.083	0.065	0.056	0.050	0.041
4 ½	0.231	0.161	0.125	0.090	0.072	0.061	0.054	0.044
5	0.255	0.177	0.137	0.098	0.078	0.066	0.058	0.047
6	0.300	0.207	0.160	0.113	0.089	0.075	0.065	0.053
7	0.342	0.235	0.181	0.127	0.100	0.084	0.073	0.059
8	0.385	0.263	0.202	0.041	0.111	0.092	0.080	0.064
9	0.427	0.291	0.222	0.156	0.121	0.101	0.087	0.070
10	0.474	0.323	0.247	0.171	0.133	0.110	0.095	0.076
12	0.559	0.379	0.290	0.200	0.155	0.128	0.109	0.087
13	0.612	0.415	0.316	0.217	0.168	0.168	0.118	0.093
16	0.696	0.471	0.358	0.246	0.189	0.155	0.133	0.104
18	0.781	0.527	0.401	0.274	0.210	0.172	0.147	0.115
20	0.865	0.584	0.443	0.302	0.231	0.189	0.161	0.125
24	0.134	0.696	0.527	0.358	0.274	0.226	0.189	0.147
Tank	0.161	0.107	0.081	0.054	0.040	0.032	0.027	0.020

Table 17.—Heat losses from insulated metal pipes
w/ft of pipe per temperature differential (° F)

11.6.2.4 SELECT A CABLE. Refer to manufacturers product data and select a cable with a heat output that exceeds the heat loss. If the heat loss exceeds the heat output of the cables available, the cable must be wrapped around the pipe as shown in figure 35.



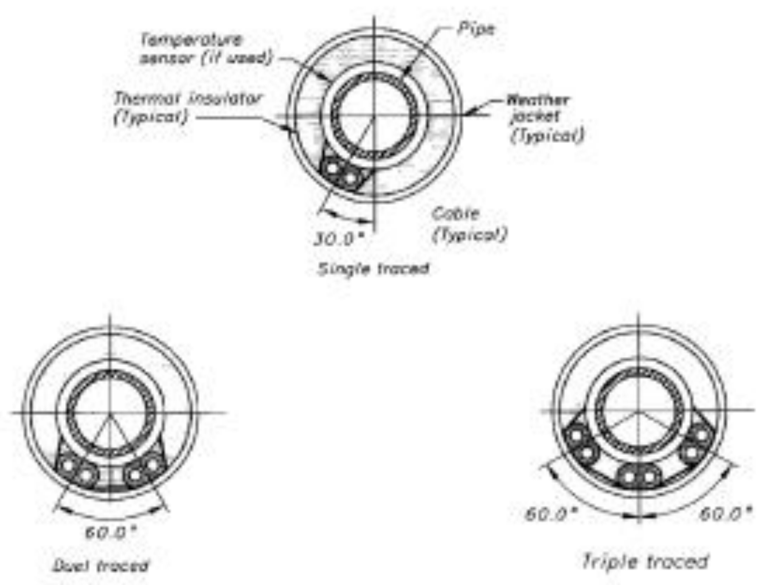


Figure 35.

Spiral wrap.

11.6.2.5 DETERMINE LENGTH OF CABLE REQUIRED. By adding the following to the length of pipe:

- Component allowances for each occurrence of the following items:

    Flange pair: 1.5 ft

    Pipe support: 2.0 ft

    Butterfly valve: 2.5 ft

    Ball valve: 2.7 ft

    Globe valve: 4.0 ft

    Gate valve: 5.0 ft

- Wrapping allowance. If the cable is wrapped around the pipe, refer to table 18 to determine the additional length of cable and the pitch.

Pipe size	Pitch (inches)																	
	2	3	4	5	6	7	8	9	10	11	12	14	16	18	24	30	36	42
½	1.90	1.47	1.29	1.19	1.14	1.10	1.08	1.06	—	—	—	—	—	—	—	—	—	—
¾	2.19	1.64	1.40	1.27	1.19	1.14	1.11	1.09	1.07	1.06	—	—	—	—	—	—	—	—
1	2.57	1.87	1.55	1.38	1.27	1.21	1.16	1.13	1.11	1.09	1.07	—	—	—	—	—	—	—
1 ¼	3.07	2.18	1.76	1.53	1.39	1.30	1.24	1.19	1.16	1.13	1.11	1.08	1.06	—	—	—	—	—
1 ½	3.43	2.41	1.92	1.65	1.48	1.37	1.29	1.24	1.20	1.16	1.14	1.10	1.08	1.06	—	—	—	—
2	4.15	2.86	2.25	1.90	1.67	1.52	1.42	1.34	1.28	1.24	1.20	1.15	1.12	1.10	1.05	—	—	—
2 ½	4.19	3.36	2.61	2.17	1.89	1.70	1.56	1.46	1.39	1.33	1.28	1.21	1.17	1.13	1.08	1.05	—	—
3	5.88	3.99	3.06	2.52	2.17	1.93	1.76	1.63	1.53	1.45	1.39	1.30	1.23	1.19	1.11	1.07	1.05	—
4	7.43	5.01	3.82	3.11	2.65	2.33	2.09	1.92	1.78	1.67	1.58	1.45	1.36	1.29	1.17	1.11	1.08	1.06
5	9.09	6.10	4.63	3.75	3.17	2.77	2.47	2.24	2.06	1.92	1.81	1.63	1.51	1.42	1.25	1.17	1.12	1.09
6	10.75	7.20	5.44	4.40	3.70	3.22	2.86	2.58	2.36	2.19	2.04	1.83	1.67	1.55	1.34	1.23	1.16	1.12
8	13.88	9.28	6.99	5.63	4.72	4.08	3.60	3.23	2.94	2.17	2.51	2.22	2.00	1.83	1.53	1.36	1.26	1.20
10	17.20	11.49	8.65	6.94	5.81	5.01	4.41	3.95	3.58	3.28	3.03	2.65	2.37	2.15	1.75	1.52	1.38	1.29
12	20.34	13.58	10.21	8.19	6.85	5.89	5.18	4.62	4.18	3.83	3.53	3.07	2.73	2.40	1.97	1.68	1.51	1.39
14	22.30	14.89	11.18	8.97	7.49	6.44	5.66	5.05	4.57	4.17	3.85	3.34	2.96	2.67	2.11	1.79	1.59	1.46
16	25.44	16.98	12.75	10.22	9.53	7.33	6.42	5.74	5.18	4.72	4.35	3.77	3.33	3.00	2.34	1.97	1.73	1.57
18	28.58	19.07	14.31	11.47	9.57	8.22	7.21	6.42	5.80	5.29	4.86	4.20	3.71	3.33	2.58	2.15	1.88	1.69
20	31.71	21.16	15.88	12.72	10.61	9.11	7.99	7.11	6.42	5.85	5.38	4.64	4.09	3.66	2.82	2.34	2.03	1.81
24	37.99	25.34	19.02	15.22	12.70	10.90	9.55	8.50	7.66	6.98	6.41	5.52	4.85	4.34	3.32	2.72	2.33	2.07

Note: To determine the wrapping factor, divide the calculated heat loss by the heat output of the cable. Locate the value that is equal to or the next highest in the row for the pipe size in your application. The value at the top of the column is the pitch or spacing from center to center of the cable along the pipe.

Table 18

Wrapping factor (feet of cable per foot of pipe)