



15815

Metal Ducts

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A. Summary

This section contains design criteria for rectangular and round metal ductwork, duct liners, and hangers for supply, return, and exhaust systems.

B. System Design and Performance Requirements

1. Keep the ductwork layout simple. Use short, direct runs where ever possible, and conserve ceiling space.
2. All return/exhaust air must be ducted. The use of ceiling plenums for return/exhaust air is prohibited.
3. Perchloric acid fume exhaust ductwork must be individually ducted without connection to other exhausts.
4. Fume hoods and contaminated or hazardous areas must be exhausted by a system of ducts entirely separate from all other exhaust systems. The location of area exhausts should be carefully coordinated with reference to remoteness from supply air outlets, doors, and windows. Animal areas and toilet rooms shall have separate exhausts. See [Section 00705: General HVAC Design Conditions](#).
5. Wherever possible, exhaust ducts carrying noxious or corrosive fumes must be under negative pressure; connect them on the suction side of the fan.
6. Review appropriate SMANCA sections (laboratory) when designing duct distribution systems.



7. Design of displacement ventilation systems and other specialized systems and other specialized distribution systems shall be reviewed and approved in writing on a job by job basis by Yale Facilities.
8. Keep fan discharge ducts as short as possible, and make them completely air-tight. One method of ensuring tightness is to line the duct with a coating that meets code and NFPA 90A requirements. Install flexible duct connectors on the fan discharge, taking special care to guard against leaks.
9. Provide a volume damper in each (supply and exhaust) branch duct depending on application.
10. For low pressure systems, limit the maximum air velocities and/or friction losses to the figures shown in Table 1. Ductwork sizes must also be consistent with the system sizing requirements described in [Section 15725: Air Handling Units](#).
11. Ductwork located in ceiling space near air handling device with filters is to be routed so that filter access/removal space is maintained.

Table 1. Maximum Duct Air Velocities and Friction Losses

Location	Velocity/Friction
Main supply	1800 fpm/0.08" per 100'
Main return	1800 fpm/0.08" per 100'
Main exhaust	2500 fpm/0.10" per 100'
Branch supply	1600 fpm/0.08" per 100'
Branch return	1400 fpm/0.08" per 100'
Branch exhaust	1800 fpm/0.10" per 100'
At supply outlet	750 fpm
At return/exhaust intake	400 fpm
Within the space	50 fpm

12. Install triple-vaned, full-radius turning vanes within 35' of the air handling unit discharge, within 10' of a FCU discharge, or whenever the velocity exceeds 2000 fpm. Where the velocity exceeds 2500 fpm, use five, full-radius turning vanes. Do not use turning vanes in exhaust or return ductwork.



13. Limit the reduction in area due to obstructions to not more than 10 percent. Streamline obstructions inside ducts. Limit transitions to a 15 degree slope on the upstream side and a 30 degree slope on the downstream side.
14. Install access panels for duct cleaning every 50 l.f. on horizontal ducts, and the inspection or servicing of dampers, controls, or duct-mounted equipment. Install the panels in accessible locations. Panel sizes must be appropriate to the need and may be larger than the minimum sizes listed in Table 2.

Table 2. Minimum Sizes for Access Panels

Location	Minimum Size
Fire dampers	12" x 12"
Combination fire and smoke dampers	12" x 12"
Smoke dampers	6" x 6"
Automatic control dampers	6" x 6"
Manual volume dampers (2 sq ft and larger)	6" x 6"
Inlet side to all coils	12" x 12"
Suction and discharge sides of inline fans	24" x 24"
At additional locations indicated on drawings, or specified elsewhere	12" x 12"
Flow measuring stations	12" x 12"

15. Install access doors ductwork on both sides of fire dampers and duct-mounted coils, where possible.
16. Ductwork should not be lined.
17. Install ducts with the fewest possible joints.
18. Locate ducts vertically, horizontally, parallel, and perpendicular to building lines. Avoid diagonal runs. Install duct systems along the shortest route that does not obstruct useable space or block access for servicing the building and its equipment.
29. Install insulated ducts with a minimum clearance of 1" outside of the insulation.
20. Provide 4" (100 mm) wide galvanized sheet metal collars at sleeves and prepared openings, sized to cover the entire duct penetration, including sleeve and seal, and to accommodate duct insulation, as necessary. Edges must have milled lips ground smooth and painted to match the duct finish.



21. Ductwork must be free from vibration under all conditions of operation.
22. No pipe, conduit, hanger, architectural element, or structural member may pass through any duct.
23. Do not route ductwork through transformer vaults or electrical equipment spaces and enclosures.
24. The maximum length of flexible duct is 6' (1800 mm).
25. Specify that duct system interiors be vacuumed to remove dust and debris before final acceptance.
26. Provide protection on duct openings during construction.

C. Materials

1. Galvanized Steel Supply, Return, and Non-Hazardous Exhaust Ducts per latest SMANCA - Standards

- a. High-pressure ductwork must not be less than 24-gauge.
- b. Low-pressure ductwork must not be less than 26-gauge.
- c. Use the Ductmate, Nexus, or Transverse Duct Connection systems to join galvanized steel exhaust ducts.
- d. Use duct sealant to seal galvanized steel exhaust ducts.
- e. Exhaust ducts must be pitched to drain whenever there is a possibility that water will collect in or on them.

2. Choosing Material for Fume Hood Ducts

- a. Materials for fume hood ducts must be carefully selected. In most cases, Type 316 stainless steel is satisfactory. Use number 2B finish in concealed areas and number 4 finish in exposed areas.
- b. Use Type 316 stainless steel for laboratory or fume hood exhaust. However, in severe applications, a more resistant material should be used.
- c. Final selection should not be made without consulting Yale University's Office of Environmental Health and Safety.



3. Stainless Steel Ducts Used for Fume Hood and Hazardous Exhaust

- a. High-pressure ductwork must not be less than 24-gauge.
- b. Low-pressure ductwork must not be less than 26-gauge.
- c. Stainless steel ducts must be sealed by providing welded joints and pitched so that moisture cannot collect in them.
- d. Fabricate fume hood ductwork in accordance with SMACNA requirements. However, do not cross-break. Increase the gauge to provide a gauge that is 0.5 lbs/sq ft (2.5 kg/m²) heavier than standard.

4. Stainless Steel Ducts Used for Non-Hazardous, Moist Air

- a. Use stainless steel ducts for collecting non-hazardous moist air, such as dishwasher or shower room exhausts. Use Type 304 stainless steel for the following:
 - For all ductwork outside the building
 - For all ductwork outside dishwasher and shower rooms
 - 15 feet downstream of humidifiers and dryer exhausts
 - For any duct containing more than 25percent air from a shower
- b. Use number 2B finish in concealed areas and number 4 finish in exposed areas.
- c. High-pressure ductwork must not be less than 24-gauge.
- d. Low-pressure ductwork must not be less than 26-gauge.
- e. Stainless steel ducts must be sealed using duct sealant and pitched so that moisture cannot collect in them.

5. Additional Materials Requirements (Per Latest SMANCA Sections)

- a. Use stainless steel for exhaust ducts, from inlet to discharge, for glass washers, dish washers, cart washers, and cage washers. Joints must be welded, and the ducts must be pitched to drain.
- b. Kitchen grease exhaust ductwork must be of 16-gauge, welded steel construction, and pitched to meet code and NFPA 96 requirements.



- c. Use galvanized steel for all supply and return and non-hazardous, non-moisture-carrying exhaust ductwork. The ductwork must have a galvanized coating of G-90 (G-60 is not acceptable).
- d. Provide the proper pressure and leakage-rated, gasketed, and duct-mounted access doors or panels. In insulated ducts, access doors must be insulated, double-wall doors. Door material gauges, the number of hinges, and the number and type of door locks must meet SMACNA duct construction standards. Unhinged doors must be chained to the frame with at least 6" of chain to prevent loss of the door. For seal Class A, hinged doors and screwed or bolted access panels are not acceptable. Access doors must be leakage-rated, neoprene-gasketed, UL 94 BF1 listed, DUCTMATE Sandwich doors. Door metal must be the same as the attached duct material. For grease and high temperature ducts, the door assembly must be rated for 2300°F.

D. Installation Guidelines

- 1. Do not route fume or kitchen exhaust through fire walls.
- 2. Keep ductwork routed outdoors and across roofs to a minimum; route ductwork within the building as much as possible.



E. Quality Control—Ductwork Field Tests

If this portion of the project includes commissioning, verify that insertions in the project specifications have been made that refer to the commissioning procedures in the commissioning specification section. Verify that the systems and equipment identified in this section of the standards, and listed in the project specifications, do not conflict with commissioning procedures for testing and training. Provide duct leakage tests.

1. Systems with a Design Static Pressure of Less than 2" Positive or Negative

Before installing exterior duct insulation, test all supply, return, and exhaust ductwork for air leakage. Conduct the tests per the latest edition of the SMACNA HVAC Air Duct Leakage Test Manual. The test pressure must be 25 percent greater than the design duct operating pressure. The total allowable leakage must not exceed 5.0 percent of the total system flow. When partial sections of the duct system are tested, the summation of all sections must not exceed the 5.0 percent total allowable leakage for the system. The test must be witnessed by an independent testing agency.

2. Systems with a Design Static Pressure of More than 2" Positive or Negative

Before installing exterior duct insulation, test all supply, return, and exhaust ductwork for air leakage. Conduct the tests per the latest edition of the SMACNA HVAC Air Duct Leakage Test Manual. The test pressure must be 25 percent greater than the design duct operating pressure. The total allowable leakage must not exceed 1.0 percent of the total system flow. When partial sections of the duct system are tested, the summation of all sections must not exceed the 1.0 percent total allowable leakage for the system. The test must be witnessed by an independent testing agency.



F. Cleaning and Adjusting

Specify that all ductwork and plenums be cleaned before the job is turned over to Yale University. Yale University Facilities must approve before formally accepted. In special areas where extreme cleanliness is required, specify that ducts and plenums be vacuum-cleaned. Before consideration of acceptance of the duct systems or plena inspection, acceptance by Yale University's job coordinator is required.

End of Section



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Duct Accessories

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A. Summary

This section contains design criteria for volume dampers, fire and smoke dampers, vanes, duct silencers, and duct hardware.

B. System Design and Performance Requirements

1. Base control and smoke damper leakage characteristics on tests performed per AMCA Standard 500 test procedures. Limit air leakage to 6 cfm per square foot at 4" wg differential pressure.
2. Dampers larger than 12" in height must be opposed, multi-blade dampers.
3. Make dampers 1/4" undersize.



C. Installation Guidelines

1. Install volume dampers on each supply, return, and general exhaust duct take-off and at each take-off to the register, grille, or diffuser, as close to the main duct as possible.
2. For systems above 15,000 cfm, provide smoke dampers in the return and supply air ducts to isolate the air handling unit. Provide filters in accordance with NFPA 90A. These smoke dampers may also be used for smoke control functions. The unit smoke dampers must be interlocked with the unit supply air fan to close and isolate the unit when the fan stops. To prevent excessive pressures due to supply or return fans still operating, it is necessary to open these dampers before starting the fans.
3. Provide sufficiently sized access doors at all fire dampers to allow for damper/linkage resetting.

D. Quality Control

If this portion of the project includes commissioning, verify that insertions in the project specifications have been made that refer to the commissioning procedures in the commissioning specification section.

End of Section



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Fans

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A. Summary

This section contains design criteria for supply, return, and exhaust system fans.

B. System Design and Performance Requirements

1. General

- a. Base fan size selections on the manufacturer's published sound level, effluent exhaust, and/or cfm and static pressure requirements.
- b. Specify that protective coatings be applied to components in or out of the airstream (or both) to resist chemical attack and corrosion.
- c. Specify whether the fan rotation arrow must be shown as part of the manufacturer's unit or installed by the contractor.



- d. Select all scheduled fan motor sizes, 1/2 hp and larger, as follows for supply fans, return fans, and exhaust fans to provide for increasing the rpm above design, if necessary.
 - (1) Using design air quantity and static pressure (adjusted as necessary for altitude, temperature, fan inlet restrictions, discharge conditions, and system effect factors), select a fan from fan curves that will operate well within the stable range at a reasonable static efficiency. Note fan speed.
 - (2) Add 10 percent, but not to exceed 3/4 inches of water, to design static pressure. Using the same design cfm, check for satisfactory operation of the fan. Note the fan brake horsepower required to prevent overloading at any point on the fan curve.
- e. Select outlet velocities and fan tip speed for quiet operation. Higher outlet velocity and static pressure result in increased sound output. Balance cost and space against sound and efficiency. The fan manufacturer's catalog should be consulted for outlet velocities and fan tip speed.
- f. The largest single factor causing poor fan performance is a poorly-designed inlet connection. See the SMACNA duct design guide for fan inlet and outlet system effect factors that contribute to fan performance loss and increased noise.
- g. Verify that fans have been isolated from the building structure.
- h. Use flexible connectors to isolate all fans connected to ductwork. Use flexible conduit to connect the electric motor to the power source.
- i. Fan performance curves are based on dry, "standard" air at 70°F at sea level. Include temperature and pressure corrections when operating at other conditions. (Note: kitchen fans operate at high temperatures.)
- j. Explosion-proof construction must include an explosion-proof motor; explosion-proof disconnect switch; static resistant belts; and an aluminum, non-sparking wheel.
- k. All fans must be statically and dynamically balanced individually by the manufacturer to within 1 mil double amplitude at 125 percent of the rated speed.



- l. Use direct-drive fans with variable frequency drives whenever possible (depending on the airstream) to avoid losses and maintenance associated with belt-drive units.
- m. Centrifugal fans must meet the class requirements of project design, with a minimum Class II. All motors shall be high efficiency type. All fans greater than 10 hp must have variable frequency drives. All fans must have bearing rated for 200,000 hours.
- n. Fans 50 hp and over must have fixed-pitch sheaves on the fan and motor.
- o. Select fans to operate well within the critical limits of the shaft and bearings.
- p. Air handling unit supply and exhaust air fans serving laboratories must be redundant.
- q. Fans used for fume hood and other contaminated exhaust must have bearings, drives, motors, and all controls located outside the airstream. Fans serving such systems must not be interlocked with the supply units.
- r. All fans that will exhaust fume hoods must be non-sparking and must be either coated steel (Heresite, PVC) or of corrosion resistant construction.
- s. Laboratory exhaust systems must use redundant, high-plume blowers.
- t. Perchloric fume exhaust fans must be of non-sparking construction.
- u. Forward-curved fan wheels can deliver large volumes of air at slow speeds and a steep brake horsepower curve and can be overloaded if the static pressure drops. Where noise might be a factor, use forward-curved fan wheels up to 20" in diameter. Because of its curved shape, a forward-curved fan wheel cannot be used where there is foreign material present in the air that would lodge in the blade cup. Forward-curved fan wheels are used primarily in small ventilating fans, with lower pressures, where the use of a backward-inclined wheel would create too high an operating speed for the bearings. A backward-inclined fan wheel gives the fan a flat horsepower curve, and proper fan motor selection will never cause it to be overloaded.
- v. As a general guideline, use backward curved fans for systems less than 12,000 cfm and less than 4" total design static. Specify air foil fans for conditions in excess of 16,000 cfm or 4" design TSP.



- w. Provide sufficient room so that the fan and fan shaft can be removed.

2. Roof Ventilators

- a. Avoid large roof ventilators servicing extensive duct runs.
- b. Avoid the use of direct-driven roof ventilators with wheels in excess of 20" nominal diameter. Specify V-belt drive arrangements to provide for flexibility.
- c. Specify shaft seals to prevent the entry of contaminated exhaust air into the motor compartment.
- d. Specify a non-fused, disconnect switch in an appropriate enclosure (to suit environmental conditions), mounted adjacent to the motor.
- e. Specify mesh size, material, and function to exclude the entry of birds or insects.
- f. Specify dampers for use with roof ventilator fans.
- g. Specify an aluminum, felt-edged damper that opens when the fan is started and is closed by gravity when the fan is shut off. Do not use gravity dampers when local wind conditions or stack effect will cause the damper to chatter open and closed.
- h. Specify electric motor-operated dampers when positive and tight closure is necessary and shall be provided with electric disconnect switch.
- i. Specify a hinged sub-base for wheel diameter sizes through 36". For larger sizes, specify a mounting pedestal with a removable access panel.
- j. Provide with bird screens.

3. Utility Vent Sets

See the information above for forward- and backward-curved fans.

4. Double-Width Inlet Fans

Allow one fan diameter between the fan and side wall casing and two fan diameters between adjacent double-width fan inlet collars.



5. Propeller Fans

- a. Limit the use of propeller fans to locations with low static pressures and where noise is not a factor. Propeller fans handle large volumes of air at low static pressures and low power consumption. The use of ductwork adversely affects their efficiency, greatly reduces the volume of air they will handle, and increases power consumption.
- b. When propeller fans must operate against an appreciable resistance, and when running at high speeds, they are generally not suited for quiet operation due to high tip speeds.

6. Inline Fans

a. *Centrifugal In-Line Fans*

The wheel may have forward- or backward-curved blades. Forward-curved blades generally produce less head and are economical at low static pressure and low capacity. Backward-curved blades are the most efficient. Centrifugal in-line fans are well-suited for use at high static pressure and high capacity. A variation of the backward-curved blade has an airfoil cross-section that produces quiet and efficient operation in its range, and is well suited for high pressure and high capacity use.

b. *Axial In-Line Fans*

Because of the air turbulence in this type of fan, axial in-line fans are not recommended for quiet operation at high capacity, without providing fan silencers.

c. *Vaneaxial In-Line Fans*

Vaneaxial fans are similar to axial in-line fans and are provided with flow vanes. Vaneaxial fans are well-suited for high pressure and capacity use and are most suitable for variable-volume and/or variable-pressure systems. Sound attenuation is usually required for this type of fan. Vaneaxial fan airflow may be controlled by an adjustable blade pitch or variable frequency drives.



C. Submittals

Submit the following design and certification documentation.

1. Designer Submittals

Submit fan selection calculations.

2. Product Certificates Signed by the Manufacturer

The manufacturer's representative must check each fan of 25 hp and over for proper installation, alignment, belt tension, and operation. The manufacturer's representative must submit a written report to the engineer, with a copy to Yale University, stating that at the time of the report, the fan is running properly and is acceptable to the manufacturer in every respect.

D. Product Standards

Products must conform to AMCA standards—certified and sealed.

E. Manufacturers

Subject to compliance with the design requirements, manufacturers offering products that may be incorporated in the work include, but are not limited to, the following:

1. General Supply and Exhaust Fans

- Greenheck
- Buffalo Forge
- Loren Cook

2. High-Velocity Roof Exhausters for Laboratory Exhaust

- Strobic
- MK Plastic
- Green Neck



3. Belts

- Browning
- Gates

4. Blowers

- Buffalo Forge
- New York Blower
- Aerovent
- Barry Blower
- Hartzell

F. Equipment

1. Centrifugal Fans

- a. Centrifugal fans must have welded steel housings and wheels balanced dynamically and statically.
- b. Provide V-belt, variable-pitch drives, with spring-loaded belt tensioners, for ± 10 percent speed variation.
- c. Fans must be equipped with backward-curved blades connected to an electric motor so that in no instance can the fan motor be overloaded at the capacities shown on the drawing schedule. Provide an open, drip-proof motor on an adjustable base.
- d. Provide V-belt drives sized as recommended by the manufacturer. Belt construction must be rubber and cord. Belt sets must be matched for length. Belt capacity must be 150 percent of the motor horsepower rating. Belts must be stamped A- or B-type. Sheaves must be cast and machined iron steel larger than the minimum diameters recommended for a particular belt. Sheaves must be dynamically and statically balanced.
- e. Provide belt guards of 18-gauge steel mesh, perforated steel sheets, or expanded steel sheets, with angle frames and galvanized steel or rigidly-braced iron trim.
- f. Provide ports for tachometer speed measurements at the fan shaft.
- g. Provide spring vibration isolation bases.



- h. Provide seismic isolation as required by code.
- i. Provide an inlet screen, bolted access door, bearings with an L-10 life of 200,000 hours, and anti-corrosion coatings.
- j. Fan shall be selected not to exceed 1200 rpm.

2. Centrifugal Roof Exhausters

- a. Provide V-belt (dome, low-silhouette, or penthouse), variable-pitch, belt-drive fans certified to bear the AMCA seal.
- b. Provide a 12" high, pre-fabricated aluminum roof curb with a lining that provides at least 30% sound reduction.
- c. Provide the following components:
 - Gravity backdraft dampers
 - Motorized dampers on any fan greater than 1,000 cfms
 - Bird screen
 - Spun aluminum housing
 - Disconnect switch
 - Inlet venturi orifice
 - Vibration isolation
 - Permanently-lubricated ball bearings
 - Enclosed, fan-cooled motor
 - Junction box
- d. Belt drives must have ± 5 percent speed variation and a spring-loaded belt tensioner. Direct drives must have speed controllers in the junction boxes.
- e. Fan must be selected not to exceed 1200 rpm.



3. Centrifugal In-Line Fans

- a. The tubular housing must be heavy-gauge steel, all-welded construction. Provide a bolted and gasketed full-access door with a “swingout” clamshell design to permit inspection or removal of the fan impeller.
- b. The fan wheel and drive assembly must be statically and dynamically balanced at the factory.
- c. V-belt capacity must be 150 percent of the motor horsepower rating. Fan motor pulleys must be adjustable-pitch pulleys. Provide an adjustable motor base. Provide an OSHA-approved belt guard for drive components that are located outside of the fan housing.
- d. Provide ports for tachometer speed measurements at the motor shaft.
- e. Provide self-aligning bearings with a minimum L-10 life of 200,000 hours.
- f. Provide extended lubrication lines.
- g. Fan must be selected not to exceed 1200 rpm.

G. Accessories or Special Features

Provide fan guards for the motor side and the discharge side of propeller fan installations less than 7' above the floor. Provide expandable wire mesh on the intake and motor-operated shutters on the discharge to protect the fan and building interior against rain, snow, and sleet intake when the fan is off. Motorized shutters prevent wind pressure from chattering when the fan is off.

H. Extra Materials

Specify one spare belt set for each type of fan.



I. Quality Control

If this portion of the project includes commissioning, verify that insertions in the project specifications have been made that refer to the commissioning procedures in the commissioning specification section. Verify that the systems and equipment identified in this section of the standards, and listed in the project specifications, do not conflict with commissioning procedures for testing and training.

End of Section



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Air Terminal Units

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Change History

Date	Description of Change	Pages / Sections Modified	Change Approver Initials
4/19/13	Include only AccuSpec, Titus and Phoenix on the list of Manufacturers.	22 – 15840, D. (Air Terminal Units)	SO

A. Summary

This section contains design criteria for constant- and variable-volume air terminal units.



B. System Design and Performance Requirements

1. Verify that VAV boxes can provide turndown to the minimum setpoint cfm when the system static pressure decreases.
2. Do not oversize VAV boxes in an attempt to decrease sound power output. Decreased airflow across the velocity sensor can produce erratic readings at low flow.
3. Consider series-type, fan-powered boxes in lieu of parallel-type boxes. Series boxes provide constant air circulation. Fan and motor noise is also less noticeable than with on-off or parallel-type boxes.
4. Schedule the following:
 - Minimum and maximum air flows
 - NC level, discharge and radiated
 - Duct inlet and outlet sizes
 - Motor horsepower and power requirements
5. Show power connection to VAV boxes.

C. Product Standards

Products must conform to the following standards:

- NFPA 90A
- UL 181
- NEMA 1

D. Manufacturers

Subject to compliance with the design requirements, manufacturers offering products that may be incorporated in the work include, but are not limited to, the following:

- AccuSpec
- Phoenix
- Titus



E. Equipment

1. Air terminal units must be 24-gauge galvanized steel, lined with 1-1/2 pound insulation as required by UL-181 and NFPA-90A. Insulation must be covered with hospital-grade Mylar[®] or foil meeting NFPA fire and smoke requirements.
2. Provide a damper motor suitable for electronic (DDC) control.
3. Responsibilities for providing a damper actuator and DDC VAV box controller, including a velocity pressure transducer and control transformer, are described in [Section 15950: Energy Management and Control Systems](#). The terminal box manufacturer must include with their bid the costs of mounting the controller on their box and piping the controller's transducer to their flow sensor (in accordance with the control manufacturer's instructions).
4. Provide 3' long sound attenuators and a hot water reheat coil. If used, we prefer to use fin tube radiation or 4 pipe chilled beams near the outside walls for heat. Provide an access door at the reheat coil section, before and after the coil.
5. Boxes must have multipoint averaging-type airflow sensors.
6. The contractor must include the following items with the shop drawing submittal:
 - a. The name of the terminal box manufacturer.
 - b. The name of the temperature controls manufacturer.
 - c. A statement that the mechanical division contractor has contacted both vendors and verified that the terminal box and VAV DDC controller are compatible with each other and that they can perform all sequences of operation shown on the control drawings
7. Provide power to VAV boxes using 24 volt transformer or line voltage as required.
8. Provide the following addition AC information for VAV boxes with reheat coils:
 - a. Entering water temperature.
 - b. Leaving water temperature.
 - c. Entering air temperature.
 - d. Leaving air temperature.
 - e. Heating capacity in MBH.



- f. GPM
- g. Water side pressure drop.
- h. Water side rows.

F. Installation Guidelines

1. On drawings, show access space for the VAV box control panel, damper actuator, filter, fan motor, and reheat valve.
2. On drawings, show the access door downstream of the reheat coils.
3. On drawings and in specifications, indicate that a minimum of 2-1/2 duct diameters of straight duct must be maintained for flex duct entering the VAV box.

G. Quality Control

If this portion of the project includes commissioning, verify that insertions in the project specifications have been made that refer to the commissioning procedures in the commissioning specification section. Verify that the systems and equipment identified in this section of the standards, and listed in the project specifications, do not conflict with commissioning procedures for testing and training.

End of Section



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Diffusers, Registers, Grilles, and Louvers

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A. Summary

This section contains design criteria for covers, diffuser, grilles, registers, and intake and discharge louvers.

B. System Design and Performance Requirements

1. Supply, Return and Exhaust Outlets

- a. Equipment must handle air quantities at operating velocities. Select and apply the air distribution apparatus so that the temperature in the occupied zone varies no more than $\pm 2^{\circ}\text{F}$.
- b. Air motion in the occupied space must be between 25 and 45 fpm over the full control range of the variable-volume controller.
- c. The noise criteria level in the space must be no greater than that scheduled on the drawings and 30 noise criteria where not scheduled.
- d. The supply diffuser must be located in the center of the room and uniformly placed in the center of tiles and in logical patterns that include lighting, sprinklers, and other similar types of equipment.
- e. Damper shall be placed at duct branch line off main feeding diffuser or 10 ft minimum from diffuser.



- f. The return or exhaust grille may be located anywhere (with the exception of laboratory fume hoods) in the room, but as far as possible from the supply outlet. Give special attention to laboratory supply diffusers with fume hoods. The location of all supply diffusers must minimize the creation of eddy currents in the fume hood that could spill the fume hood's contents into the laboratory. The velocity of the air in front of the fume hoods must be less than 50 fpm or 1/2 of the hood face velocity.
- g. If fintube radiation is not used (with permission from the Yale University Project Manager and Facilities group), then the supply diffuser must be located on the outside walls and be of the linear type.

2. Air Intakes

- a. Size all intakes (without snow draw potential) to provide an air velocity of 600 fpm or less. Louvers reduce the free area by at least 50 percent and usually much more. Size and locate intakes to prevent the entrance of light fluffy snow (intake velocity < 250 fpm) and polluted air peculiar to the building site.
- b. Intakes near or below ground level not permitted. The minimum height of the bottom of intake must be:
 - 6' above grade
 - 3' above the roof
- c. Examine intake locations for proximity to contaminated air exhausts, such as laboratory discharges.
- d. All intakes must have a 1/2" mesh wire screen on the outside or as required by code.

3. Additional Requirements

- a. Avoid the use of perforated ceilings for the air supply. If such a system seems unavoidable, consult with the Yale University Facilities group before designing the installation to discuss specific requirements.
- b. Supply registers and grilles must be double-deflection type.
- c. Where possible, ceiling diffusers must be adjustable for air pattern.
- d. All registers and grilles must be equipped with appropriate setting frames. Ceiling-mounted devices must match ceiling type.



- e. As a rule of thumb, decrease the selected noise criteria level of selected diffusers by 3 db for every doubling of the number of diffusers in the space.
- f. Minimum throttling cfm to avoid dumping:
 - Perforated diffuser not lower than 0.7 cfm/sq ft
 - Linear diffuser not lower than 0.3 cfm/sq ft
 - Architectural diffuser not lower than 0.3 cfm/sq ft
- g. State in the specification state that the contractor must adjust linear diffuser air directional vanes.

C. Designer Submittals

1. Submit schedules on the drawings of all air distribution apparatus. List the following data in the schedules:
 - Item number, location, and/or area served
 - Style or model
 - Listed size
 - Cubic feet per minute, SP
 - Noise criteria
 - Throw
 - Drop (where applicable)
 - Plan symbol
 - Material
 - Finish
 - Any remarks
 - Frame Type
 - Neck Size
2. Rooms that have pressure requirements different from adjacent rooms must show the relative room pressurization on an airflow drawing. The airflow drawing must show the supply diffusers, exhaust or return grilles, and fume hoods (if any), including the cfm capacity for each unit.



D. Manufacturers

Subject to compliance with the design requirements, manufacturers offering products that may be incorporated in the work include, but are not limited to, the following:

- Titus
- Price
- Metalaire
- Krueger
- Anemostat
- Tuttle and Bailey

E. Materials

Do not use expanded metal or stamped or formed grilles, unless the air intake size is sufficient to provide a velocity of 600 fpm or less and to prevent snow draw through the louver or grille under maximum air flow conditions.

F. Equipment

- a. Each grille, register, and diffuser provided must have the accessories necessary to perform satisfactorily and to be fully adjustable, including opposed-blade volume dampers operable from the front, air deflectors, vanes, blanking quadrants, and similar components. At each inlet and outlet device, provide accessories to accomplish the positive regulation of air volumes and the uniform distribution of airflow over the outlet.
- b. Supply registers must have two sets of directional control blades.
- c. Diffusers within same room or area must be of same type and style to provide architectural uniformity.
- d. Diffusers should be full-size for 24" x 24" tiles or half-size (24" x 24") for 24" x 48" tiles.
- e. Provide surface-mounted diffusers, registers, and grilles with gaskets. Installed them with faces set level, plumb, and tight against the mounting surface.
- f. The architect will determine the finish.



G. Installation Guidelines

Provide volume dampers 10' from supply diffusers.

End of Section



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Air Filtration

This document provides design standards only, and is not intended for use, in whole or in part, as a specification. Do not copy this information verbatim in specifications or in notes on drawings. Refer questions and comments regarding the content and use of this document to the Yale University Project Manager.

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A. Summary

This section contains design criteria for disposable, extended surface, activated carbon, and HEPA air filtration systems.

B. System Design and Performance Requirements

1. Understand the function of the facility and the needs of Yale University and the facility users, as well as the source of outdoor air drawn into the facility for ventilation.
2. Meet with Yale University and the facility users to obtain specific data and information about the nature, concentration, particle size, and distribution rate of airborne contaminants generated within the facility.
3. Meet with Yale University and the facility users to obtain specific data and information about the nature, concentration, particle size, and distribution rate of outdoor contaminants, such as auto or factory pollution, construction dust, contaminants from cooling towers, and vegetation.
4. Consider:
 - Whether a filter with high moisture resistance is needed
 - Pressure drop for energy performance
 - Cost and ease of filter disposal for Yale University



5. Select the minimum efficiency-reporting value (MERV 8) filters necessary to effectively filter particles sizes and gases encountered. Include MERV designations in specifications along with the expected final resistance value.
6. Select absorbents for gas-phase chemical control. Specify with test coupons.
7. In some cases, design conditions might require more efficient filtering than that afforded by non-HEPA filters. In such cases, discuss filtering needs with the Yale University Facilities group and facility users before selecting the air filters.
8. Specify bags, pocket attachment, cubes, framing, and surface area for best dirt holding capacity, pressure drop, and life-cycle use.
9. Select the filter retaining devices and sealing materials—gaskets and seals—to withstand air stream contaminants and ensure that there is no bypass around the filter.
10. Oversize filter banks as much as possible to increase filter life-cycle and decrease fan energy.
11. The design face velocity should not exceed 500 fpm for all filters.
12. Yale University will supply a construction set of filters and a set of filters for c.o. at a cost of \$1000 per AHU.
13. Provide the following for all systems handling 200 cfm or more and for all high-efficiency applications, regardless of size:
 - a. Primary air filters (pre-filters) must be UL Class 2, 1" thick, polyethelene filters. Efficiency must be MERV 8 as measured by ASHRAE test standard 52–76. Design filters to operate up to 350 fpm.
 - b. MERV 6: $35 < E3 < 50$, minimum final resistance of 0.6" wc.
 - c. Secondary filters (final filters) must be UL Class 1 with an efficiency of 90 to 95 percent as measured by ASHRAE test standard 52–76. Design filters to operate up to 500 fpm.
 - d. MERV 14: $75 \leq E185$, $90 < E2$, $90 \leq E3$; minimum final resistance of 1.4" wc.

C. Submittals

Submit the following design and testing documentation.



1. Designer Submittals

- Air contaminants
- Filter selections

D. Product Standards

Products must conform to the following standards:

- Underwriters Laboratories Class 1 or 2
- ASHRAE 51
- ASHRAE 52

E. Manufacturers

Subject to compliance with the design requirements, manufacturers offering products that may be incorporated in the work :

F. Accessories or Special Features

1. Provide filters with a Dwyer magnehelic filter gauge across each filter bank, equipped with an adjustable flag to indicate the need to change filters.
2. The preferred filter face dimension is 24" x 24".

G. Extra Materials

Specify the number of filters to be used during construction, plus one additional filter set to be installed at the end of construction before air balancing.

H. Installation Guidelines

1. Provide access to filters. Ensure that piping, ductwork, and electrical system components do not block access. If installing an air handler in a ceiling space, locate it where the filter access or removal space is away from ductwork.
2. Do not allow the air handling system to be operated during construction without all particle filtration in place. Construction dirt, dust, and debris can accumulate in ductwork and lead to indoor air quality problems and the loss of Leed certification.



I. Quality Control

1. If this portion of the project includes commissioning, verify that insertions in the project specifications have been made that refer to the commissioning procedures in the commissioning specification section. Verify that the systems and equipment identified in this section of the standards, and listed in the project specifications, do not conflict with commissioning procedures for testing and training.
2. Provide minimum of 2" 6" clearance space to change filters.

J. Startup and Training

Include the following statement in the specifications: *“The contractor is responsible for installing new filters throughout the system immediately before the completion of all contract work.”*

End of Section