
MECHANICAL INSULATION—MASTERFORMAT 95

This section includes thermal & acoustic insulation for piping and equipment, and thermal & acoustic insulation applied to ductwork.

This section is based on CSI MASTER FORMAT Section 15080, Mechanical Insulation, and has been revised to include Knauf Insulation products and installation recommendations. When a project requires more detailed specification statements, one should consult Section 15083-Piping Insulation, Section 15082-Equipment Insulation, or Section 15081-Ductwork Insulation.

PART 1—GENERAL

1.1 SECTION INCLUDES

- A. Piping Insulation, jacketing and accessories.
- B. Equipment insulation and jacketing or coatings.
- C. Ductwork insulation, jacketing and lining.

1.2 REFERENCES

- A. ASTM
- B. ASHRAE
- C. NAIMA
- D. NFPA
- E. SMACNA
- F. Underwriter's Laboratories (UL)
- G. GREENGUARD

1.3 DEFINITIONS

- A. GREENGUARD: GREENGUARD Environmental Institute, independent testing of products for emissions of respirable particles and Volatile Organic Compounds (VOCs), including formaldehyde and other specific product-related pollutants. Provides independent, third-party certification of IAQ performance. Certification is based upon criteria used by EPA, OSHA and WHO.
- B. IAQ: Indoor Air Quality
- C. EPA: Environmental Protection Agency
- D. WHO: World Health Organization
- E. ASJ+: All Service Jacket composed of aluminum foil reinforced with glass scrim bonded to a kraft paper interleaving with an outer film layer leaving no paper exposed.
- F. ASJ: All Service Jacket
- G. SSL: Self-Sealing Lap
- H. FSK: Foil-Scrim-Kraft; jacketing
- I. PSK: Poly-Scrim-Kraft; jacketing
- J. PVC: Polyvinyl Chloride
- K. FRP: Fiberglass Reinforced Plastic
- L. ECOSE® Technology: a revolutionary new binder system based on rapidly renewable bio-based materials rather than petroleum-based chemicals commonly used in other fiberglass insulation products. ECOSE® Technology reduces our binder embodied energy by up to 70% and does not contain phenol, formaldehyde, acrylics or artificial colors.

1.4 SUBMITTALS FOR INFORMATION

- A. Product data: To include product description, manufacturer's installation instructions, types and recommended thicknesses for each application, and location of materials.
- B. Samples and mock-ups of systems shall be provided upon engineer's request.

1.5 ENVIRONMENTAL REQUIREMENTS

- A. Maintain ambient conditions required by manufacturers of tapes, adhesives, mastics, cements, and insulation materials.
- B. Insulation and related materials shall have surface burning characteristics determined by test performed on identical products per ASTM E 84 mounted and installed as per ASTM E 2231. All testing shall be performed by a testing and inspecting agency acceptable to authorities having jurisdiction. Insulation, jacket materials, adhesives, mastics, tapes and cement material containers shall be labeled with appropriate markings of applicable testing and inspecting agency.
 - 1. Insulation installed indoors: Flame-spread index of 25 or less, and smoke-developed index of 50 or less.
 - 2. Insulation installed outdoors: Flame-spread index of 75 or less, and smoke-developed index of 150 or less.
- C. Follow manufacturer's recommended handling practices.
- D. Supply fiber glass products that are manufactured using a minimum of 40% "post-consumer" recycled material.
- E. Supply fiber glass products that have a bio-based binder rather than non-renewable petroleum-based chemicals and does not contain phenol, formaldehyde, or acrylics.
- F. Supply fiber glass products that have achieved GREENGUARD for Children & Schools certification.
- G. Fiber Glass and Mold: Contractor shall take precaution to protect insulation materials from moisture exposure or physical damage. Any fiber glass insulation that becomes wet or damaged shall be replaced at no additional cost.
 - 1. HVAC duct work insulation used in the air stream must be discarded if exposed to liquid water.
 - 2. Pipe Insulation with factory applied ASJ+ facing having been fully installed with all pipe insulation system joints (including fittings, flanges, valves, and other in-line devices) sealed per manufacturer's installation recommendation which may experience casual and intermittent exposure to liquid water after installation may be exempted from removal and replacement. Contractor must be prepared to provide proof that insulation glass fiber has not been exposed to liquid water.

PART 2—PRODUCTS

2.1 PIPE INSULATION AND ACCESSORIES

- A. Manufacturers: Knauf Insulation, Proto Corporation, or pre-approved substitute.
- B. Glass Fiber: Knauf Insulation Earthwool™ 1000° Pipe Insulation with ECOSE® Technology or Knauf Insulation Earthwool™ Redi-Klad® 1000° Pipe Insulation with ECOSE® Technology meeting ASTM C 547 Type IV Grade A, ASTM C 585, and ASTM C 795.
 - 1. 'K' ('ksi') Value: ASTM C 335, 0.23 at 75°F (0.033 at 24°C) mean temperature.
 - 2. Maximum Service Temperature: 1000°F (538°C).
 - 3. Vapor Retarder Jacket: ASJ+/SSL conforming to ASTM C 1136 Type I,II, III, IV, &VIII secured with self-sealing longitudinal laps and matching butt strips.

4. Redi-Klad Jacket: Venture Clad 5-ply weather and abuse resistant with self-sealing lap. Zero permeability per ASTM E 96-05; puncture resistance 35.4 kg (189.3 N) per ASTM D 1000; tear strength 4.3 lb (19.4 N) per ASTM D 624; thickness 14.5 mils (0.0145"); tensile strength 68 lb/inch width [306 N (32 kg)/25 mm].
- C. Glass Fiber: Knauf Pipe & Tank Insulation with ECOSE® Technology; semi-rigid, limited combustible meeting requirements of NRC 1.36; ASTM C 795 and MIL-I-24244 C.
 1. 'K' ('ksi') Value: ASTM C 177, 0.25 at 75°F (0.036 at 24°C) mean temperature.
 2. Maximum Service Temperature: 850°F (454°C).
 3. Compressive Strength: not less than 150 PSF (7.18 kPa) @ 10% deformation for 2 inch (51 mm) thickness per ASTM C 165.
 4. Vapor Retarder Jacket: ASJ conforming to ASTM C 1136 Type II.
- D. Glass Fiber: Knauf KwikFlex™ with ECOSE® Technology; semi-rigid fiber glass blanket in roll form meeting requirements of ASTM E 84; UL 723, ASTM C 1393 and ASTM C 356.
 1. 'K' ('ksi') Value: ASTM C 516, 0.24 at 75°F (0.035 at 24°C) mean temperature.
 2. Maximum Service Temperature: 850°F (454°C); Maximum surface temperature for faced product: 150°F (66°C); Maximum thickness @ 850°F: 4" (102 mm).
 3. Compressive Strength: not less than 25 PSF (1.2 kPa) @ 10% deformation per ASTM C 165.
 4. Vapor Retarder Jacket: ASJ, FSK or PSK conforming to ASTM E 96, Procedure A.
- E. Field-Applied Jackets or Fitting Covers
 1. PVC: Proto Corporation 25/50 or Indoor/Outdoor, UV-resistant fittings, jacketing and accessories, white or colored. Fitting cover system consists of pre-molded, high-impact PVC materials with fiber glass inserts. Fiber glass insert has a thermal conductivity ('K') of 0.26 at 75°F. ('ksi' - 0.037 at 24°C) mean temperature.
 - a. Closures: stainless steel tacks, matching PVC tape, or PVC adhesive per manufacturer's recommendations.
 2. Metal: Aluminum, 0.016" (0.406 mm) thick or Stainless Steel, 0.010" (0.254 mm) thick in smooth, corrugated, or embossed finish with factory-applied moisture barrier. Overlap shall be 2" (50 mm) minimum. Fittings shall be die-shaped with factory-applied moisture barrier.
 3. Laminated Self-Adhesive Water and Weather Seals: permanent acrylic self-adhesive System; weather resistant, high puncture and tear resistance; meeting or exceeding requirements of UL 723; applied in strict accordance with manufacturers' recommendations.
- F. Fitting Insulation
 1. Pre-formed molded fiber glass or mitered fiber glass pipe insulation sections in lieu of PVC systems. These fittings shall be further protected by field-applied PVC fitting covers, metal fitting covers, or glass fabric and mastic sealed as necessary.

2.2 EQUIPMENT INSULATION

- A. Manufacturer: Knauf Insulation or pre-approved substitute.
- B. Rigid Fiber Glass Board: Knauf Insulation Board with ECOSE® Technology meeting ASTM C 612 Type IA and IB; rigid.
 1. Maximum Service Temperature: 450°F (232°C).
 2. Concealed Areas
 - a. Density: Minimum 3 PCF (48 kg/m³).
 - b. 'K' ('ksi') Value: ASTM C 177, 0.23 at 75°F (0.033 at 24°C) mean temperature.
 - c. Vapor Retarder Jacket: ASJ conforming to ASTM C 1136 Type I, or FSK or PSK conforming to ASTM C 1136 Type II.

3. Exposed Areas
 - a. Density: Minimum 6 PCF (96 kg/m³).
 - b. 'K' ('ksi') Value: ASTM C 177, 0.22 at 75°F (0.032 at 24°C) mean temperature.
 - c. Vapor Retarder Jacket: ASJ conforming to ASTM C 1136 Type I, or FSK or PSK conforming to ASTM C 1136 Type II in combination with protective jacket where necessary.
- C. Rigid Fiber Glass Board: Knauf Elevated Temperature (ET) Board with ECOSE® Technology meeting ASTM C 612 Type IA, IB, and II; rigid, noncombustible.
 1. Maximum Service Temperature: 1000°F (538°C).
 2. Density: 2.8 PCF (45 kg/m³).
 3. 'K' ('ksi') Value: ASTM C 177, 0.25 at 100°F (0.036 at 38°C) mean temperature.
- D. Semi-Rigid Fiber Glass Board: Knauf Elevated Temperature (ET) Panel with ECOSE® Technology meeting ASTM C 612 Type II and III; semi-rigid, noncombustible.
 1. Maximum Service Temperature: 1000° F (538°C).
 2. Density: 2.4 PCF (38 kg/m³).
 3. 'K' ('ksi') Value: ASTM C 177, 0.25 at 100°F (0.036 at 38°C) mean temperature.
- E. Flexible Fiber Glass Blanket: Knauf Elevated Temperature (ET) Blanket with ECOSE® Technology; flexible, noncombustible.
 1. Maximum Service Temperature: 1000°F (538°C).
 2. Density: 1.1 PCF (18 kg/m³).
 3. 'K' ('ksi') Value: ASTM C 177, 0.28 at 100°F (0.040 at 38°C) mean temperature.

2.3 DUCTWORK INSULATION

- A. Manufacturer: Knauf Insulation or pre-approved substitute.
- B. Flexible Fiber Glass Blanket: Knauf Friendly Feel® Duct Wrap with ECOSE® Technology meeting ASTM C 553 Types I, II and III, and ASTM C 1290; Greenguard compliant; flexible, limited combustible.
 1. 'K' ('ksi') Value: ASTM C 177, 0.29 at 75°F (0.042 at 24°C) mean temperature.
 2. Maximum Service Temperature
 - a. Faced: 250°F (121°C).
 - b. Unfaced: 350°F (177°C).
 3. Vapor Retarder Jacket: FSK or PSK conforming to ASTM C 1136 Type II.
 4. Installation: Maximum allowable compression is 25%.
 5. Securement: Secured in place using outward cinching staples in combination with appropriate pressure-sensitive aluminum foil or PSK tape, or in combination with glass fabric and vapor retarder mastic.
 6. Density:
 - a. Concealed areas: Minimum 0.75 PCF (12 kg/m³).
 - b. Exposed areas: Minimum 1.0 PCF (16 kg/m³).
- C. Glass Fiber: Knauf KwikFlex with ECOSE® Technology; semi-rigid fiber glass blanket in roll form meeting requirements of ASTM E 84; ASTM C 1393 and ASTM C 356.
 1. 'K' ('ksi') Value: ASTM C 516, 0.24 at 75°F (0.035 at 24°C) mean temperature.
 2. Maximum Service Temperature: 850°F (454°C); Maximum surface temperature for faced product: 150°F (66°C); Maximum thickness @ 850°F: 4" (102 mm).
 3. Compressive Strength: not less than 25 PSF (1.2 kPa) @ 10% deformation per ASTM C 165.
 4. Vapor Retarder Jacket: ASJ, FSK or PSK.

- D. Rigid Fiber Glass Board: Knauf Insulation Board with ECOSE® Technology meeting ASTM C 612 Type IA and IB; rigid.
1. 'K' ('ksi') Value: ASTM C 177, 0.23 at 75°F (0.033 at 24°C) mean temperature.
 2. Maximum Service Temperature: 450°F (232°C).
 3. Vapor Retarder Jacket: ASJ conforming to ASTM C 1136 Type I, or FSK or PSK conforming to ASTM C 1136 Type II.
 4. Securement: Secured in place using adhesive and mechanical fasteners spaced a minimum of 12" (300 mm) on center with a minimum of 2 rows per side of duct. Insulation shall be secured with speed washers and all joints, breaks and punctures sealed with appropriate pressure-sensitive foil tape, or glass fabric and vapor retarder mastic.
 5. Density:
 - a. Concealed areas: Minimum 3 PCF (48 kg/m³).
 - b. Exposed areas: Minimum 6 PCF (96 kg/m³).
- E. Outdoor Ductwork
1. Aluminum Jacket: 0.016" (0.406 mm) thick in smooth, corrugated, or embossed finish with factory applied moisture barrier. Overlap shall be 2" (50 mm) minimum.
 2. PVC Jacket: Proto Corporation Indoor/Outdoor, UV-resistant, white. Closure shall be solvent weld adhesive or per manufacturer's recommendations.
 3. Laminated Self-Adhesive Water and Weather Seals: applied per manufacturers' recommendations.
- F. Internal Duct Lining: Knauf Sonic XP™ Duct Liner with ECOSE® Technology conforming to ASTM C 1071 Type I and NFPA 90A & 90B; Greenguard compliant, or Knauf Rigid Plenum Liner with ECOSE™ Technology complying with ASTM C 1071 Type II and NFPA 90A & 90B.
1. 'K' ('ksi') Value: ASTM C 177, 0.24 at 75°F (0.035 at 24°C) mean temperature.
 2. Noise Reduction Coefficient (NRC): ASTM C 423 Type A Mounting, 0.45 or higher for ½" product, 0.70 or higher for 1" product.
 3. Maximum Air Velocity: 6000 FPM (1829 mpm) for Type I product, 5000 FPM (1524 mpm) for Type II product.
- G. Fiber Glass Ductwork: Knauf Eclipse™ Air Duct Board with ECOSE® Technology or Knauf Air Duct Board M with ECOSE® Technology. Product shall conform to UL-181 Class 1 and NFPA 90A & 90B.
1. 'K' ('ksi') Value: ASTM C 177, 0.23 at 75°F (0.033 at 24°C) mean temperature.
 2. Maximum Temperature: 250°F (121°C).
 3. Maximum Internal Static Pressure: +/- 2" water gauge.
 4. Maximum Air Velocity: 5000 FPM (1524 mpm).
 5. Type shall be EI-475 with FSK facing. In applications where additional rigidity is required, for large spans, where extra strength is needed, or where energy codes require R-6 or greater, type shall be EI-800.

PART 3—EXECUTION

3.1 EXAMINATION

- A. Verify that all piping, equipment, and ductwork are tested and approved prior to insulation installation.
- B. Verify that all surfaces are clean, dry and without foreign material before applying insulation materials.

3.2 INSTALLATION

- A. All materials shall be installed by skilled labor regularly engaged in this type of work. All materials shall be installed in strict accordance with manufacturer's recommendations, building codes, and industry standards.
- B. Locate insulation and cover seams in the least visible location. All surface finishes shall be extended in such a manner as to protect all raw edges, ends and surfaces of insulation.
- C. On cold surfaces where a vapor retarder must be maintained, insulation shall be applied with a continuous, unbroken moisture and vapor seal. All hangers, supports, anchors, or other projections secured to cold surfaces shall be insulated and vapor sealed to prevent condensation.
- D. All pipe or duct insulation shall be continuous through walls, ceiling or floor openings, or sleeves except where firestop or firesafing materials are required.
- E. Piping Insulation – Fiber Glass
 - 1. Locate all seams in the least visible location.
 - 2. Insulation installed on piping operating below ambient temperatures must have a continuous vapor retarder. All joints, seams and fittings must be sealed.
 - 3. All ends must be firmly butted and secured with appropriate butt-strip material. On high-temperature piping, double layering with staggered joints may be appropriate. When double layering, the inner layer should not be jacketed.
 - 4. Metal shields shall be installed between hangers or supports and the piping insulation. Rigid insulation inserts shall be installed as required between the pipe and the insulation shields. Inserts shall be of equal thickness to the adjacent insulation and shall be vapor sealed as required. Insulation inserts shall be no less than the following lengths:

1½" to 2½" IPS	10" long
3" to 6" IPS	12" long
8" to 10" IPS	16" long
12" and over IPS	22" long
 - 5. For piping exposed in mechanical rooms or high traffic areas, insulation shall be protected from abuse by the use of appropriate thickness of PVC jacketing or metal jacketing.
 - 6. For piping exposed to the elements, jacketing shall be Outdoor Weatherable PVC with a minimum thickness of 0.020 inches, or 0.016 inches thick aluminum or stainless steel with a factory applied moisture barrier. Fitting covers shall be of similar materials. The insulation and jacketing shall be held firmly in place with a friction type Z lock or a minimum 2" overlap joint. All joints shall be sealed completely along the longitudinal seam and installed so as to shed water. All circumferential joints shall be sealed by use of preformed butt strips; minimum 2" wide or a minimum 2" overlap. Butt strips shall overlap the adjacent jacketing a minimum ½ inch and be completely weather sealed. PVC Jacketing shall be limited to a maximum 20-inch OD of the insulation when exposed to direct sunlight. A 6" to 10" unsealed slide joint shall be installed every 25 to 30 lineal feet for the thermal expansion of the pipe and jacketing. In addition, a thin bead of silicone grease may be applied in the overlap to prevent water migration while allowing the joint to slide. Where distance between fittings exceeds 8 lineal feet, an unsealed slide joint shall be installed. Insulation thickness for piping covered by PVC Jacketing shall be such that the surface temperature of the PVC does not exceed 125°F.

7. Insulate valves, balancing valves and other devices requiring access with removable covers. Insulation shall have a minimum k-factor of .26 using fiberglass blanket. Flame and smoke spread shall be 25/50 per ASTM E-84. Covers shall be completely overlapping and completely cover the adjacent insulation. All seams and butt ends shall be secure.
 8. Cold Piping Insulation
 - a. On below freezing applications and in high abuse areas, the ASJ jacket shall be protected with a PVC vapor retarding outer jacket. In addition, exposed ends of the insulation shall be sealed with a vapor retarder mastic installed per the manufacturer's recommendations. Vapor seals at butt joints shall be applied at every fourth pipe section joint and at each fitting to isolate any water incursion.
 - b. On chilled water systems operating in conditions of Design RH of 90% and above, it is recommended that the same guidelines be followed as listed above for below freezing applications.
- F. Piping Insulation: Pipe & Tank Insulations—Pipe & Tank Insulation or KwikFlex.
1. Apply on clean, dry surfaces.
 2. Cut to appropriate length using manufacturers' stretchout guide to for the specific pipe size. Add an additional 2" (51 mm) to 4" (102 mm) for a staple flap.
 3. Wrap around the pipe to ensure proper fit.
 4. Staple the lap on 3" (76 mm) centers with outward clinching staples.
 5. Ends shall be firmly butted and secured with matching butt strip material at each joint.
 6. On below ambient piping, vapor retarder mastic shall be applied to the ends at every fourth section joint and at each fitting before taping.
- G. Equipment Insulation – Fiber Glass
1. Apply insulation with joints firmly butted as close as possible to the equipment surface. Insulation shall be secured as required with adhesive, mechanical fasteners or banding material. Fasteners shall be located a maximum of 3" from each edge and spaced no greater than 12" on center.
 2. Vapor retarders shall overlap a minimum of 2" at all seams and be sealed with appropriate pressure-sensitive tape or mastic. All penetrations, facing damage, and mechanical fasteners shall be covered with a minimum 2" overlap of tape or mastic.
 3. Equipment insulation exposed to the elements shall be finished with minimum 0.030" thick Outdoor Weatherable PVC, weatherproof mastic and glass cloth, or metal. All joints shall be positioned so as to shed water; with a minimum 3" overlap, and completely weather sealed.
 4. For high-temperature applications, insulation may be mounted against the hot surface, in H-bar configuration, or in panels mounted away from the operating surface. Insulation may be applied over welded pins or studs up to ½" in diameter. Insulation shall be held in place using mesh reinforcement or steel bands. Insulation shall not be compressed beyond a maximum of 5% at any point. Pins and studs shall be spaced a maximum of 4" from each edge and no greater than 16" on center. For temperatures above 550°F and design thicknesses over 3", insulation shall be applied double-layer with staggered joints. Finish shall be minimum 0.020" thick PVC Jacketing, insulating cement with canvas, glass cloth with mastic, or metal as specified on the drawings.
 5. For Equipment insulation exposed in mechanical rooms or subject to mechanical abuse, finish with minimum 0.020" thick PVC Jacketing or metal. All other insulation shall be finished as appropriate for the location and service or as specified on the drawings.

H. Internal Duct Lining

1. Duct Lining shall be applied in strict accordance with the latest edition of SMACNA's "HVAC Duct Construction Standard Metal & Flexible" and NAIMA's "Fibrous Glass Duct Liner Standard".
2. Length of mechanical fasteners shall be selected in accordance with the manufacturer's recommendation as listed on each product. Mechanical fasteners shall be installed perpendicular to the duct surface, and in no instance shall the pin compress the liner more than $\frac{1}{8}$ " relative to the nominal thickness of the insulation.
3. Adhesive shall conform to ASTM C 916. Adhesive shall be applied to the sheet metal with a 90% minimum coverage. All exposed edges of the duct liner shall be coated with the same adhesive. All rips and tears shall be repaired using an adhesive that conforms to ASTM C 916.
4. All internal duct areas shall be covered with duct liner. Transverse joints shall be firmly butted with no gaps and coated with adhesive. Longitudinal corner joints shall be overlapped and compressed.
5. When air velocities are 4000 to 6000 FPM, metal nosing shall be applied to all upstream transverse edges to additionally secure the insulation.

I. Flexible Fiber Glass Blanket

1. Install Duct Wrap to obtain specified R-value using a maximum compression of 25%. Installed R-value shall be per ASHRAE 90.1-1999 or other design criteria.
2. Firmly butt all joints.
3. The longitudinal seam of the vapor retarder must be overlapped a minimum of 2". A 2" tab is provided on Knauf Friendly Feel™ Duct Wrap for the circumferential seam.
4. Where vapor retarder performance is required, all penetrations and damage to the facing shall be repaired using pressure-sensitive foil tape, or mastic prior to system startup.
5. Pressure-sensitive foil tapes shall be a minimum 3" wide and shall be applied with moving pressure using a squeegee or other appropriate sealing tool.
6. Closure shall have a 25/50 Flame Spread/Smoke Developed Rating per UL 723.
7. Duct Wrap shall be additionally secured to the bottom of rectangular ductwork over 24" wide using mechanical fasteners on 18" centers. Care should be exercised to avoid over-compression of the insulation during installation.
8. Unfaced Duct Wrap shall be overlapped a minimum of 2" and fastened using 4" to 6" nails or skewers spaced 4" apart, or secured with a wire/banding system. Care should be exercised to avoid damage to the Duct Wrap.

J. Round Ductwork: Pipe & Tank Insulation or KwikFlex.

1. Apply on clean, dry surfaces.
2. Cut to appropriate length using manufacturers' stretchout guide to for the specific pipe size. Add an additional 2" (51 mm) to 4" (102 mm) for a staple flap.
3. Wrap around the pipe to ensure proper fit.
4. Staple the lap on 3" (76 mm) centers with outward clinching staples. Ends shall be firmly butted and secured with matching butt strip material at each joint.
5. On below ambient ductwork, appropriate UL approved vapor retarder shall be applied to all longitudinal and circumferential joints before application of butt strip material.

K. Fiber Glass Ductwork

1. Ductwork shall be fabricated and installed in strict accordance with the latest edition NAIMA's "Fibrous Glass Duct Construction Standard" and manufacturer's recommendations.
2. Closure system shall be UL 181 tested and listed:

- a. Pressure-Sensitive Aluminum Foil Tapes: UL 181 Part I (marked UL 181 A-P).
 - b. Heat Sealable Closures: UL 181 Part II (marked UL 181 A-H).
 - c. Mastics: UL 181 Part III (marked UL 181 A-M) with 3" wide glass fabric.
3. All longitudinal and transverse joints having a 1½" staple flap shall be secured with outward-cinching staples on approximate 2" centers and sealed with approved closure system.
 4. Transverse shiplap joints not having staples flaps, or transverse butt joints shall be secured with 8" long cross tabs running perpendicular to the joint seam on 12" centers. Cross tabs shall be made from an approved closure tape. The seam of the joint shall then be sealed with an approved closure system.
 5. Duct sections shall be additionally reinforced per NAIMA's and manufacturer's recommendations when necessary. Reinforcement is dependent on duct width and operating pressure.
 6. Ductwork shall be suspended and supported as required on straight runs, at all turns, and at transitions to maintain proper alignment. Hangers and supports shall be in strict accordance with NAIMA's and manufacturer's recommendations.

3.3 SCHEDULES

A. ASHRAE 90.1-2007 Requirements, Pipe Insulation

1. The minimum insulation thicknesses based upon ASHRAE 90.1 **do not necessarily represent the Economic Thickness of Insulation or the thickness required for proper condensation control.** Rather, they serve as minimum recommendations for commercial applications. For recommended Economic Thickness and Systems Design, install according to NAIMA ETI program (3E Plus) or as specified.

Minimum Pipe Insulation (in.)^a

Fluid Design Operating Temp. Range (°F.)	Insulation Conductivity		Nominal Pipe or Tube Size (in.)				
	Conductivity Btu-in./[hr·ft ² ·°F)	Mean Rating Temp. °F.	<1	1 to <1½	1½ to <4	4 to <8	≥8
Heating Systems (Steam, Steam Condensate, and Hot Water)^{b,c}							
>350	0.32 – 0.34	250	2.5	3.0	3.0	4.0	4.0
251 – 350	0.29 – 0.32	200	1.5	2.5	3.0	3.0	3.0
201 – 250	0.27 – 0.30	150	1.5	1.5	2.0	2.0	2.0
141 – 200	0.25 – 0.29	125	1.0	1.0	1.0	1.5	1.5
105 – 140	0.22 – 0.28	100	0.5	0.5	1.0	1.0	1.0
Domestic and Service Hot-Water Systems							
105+	0.22 – 0.28	100	0.5	0.5	1.0	1.0	1.0
Cooling Systems (Chilled Water, Brine, and Refrigerant)^d							
40 – 60	0.22 – 0.28	100	0.5	0.5	1.0	1.0	1.0
<40	0.22 – 0.28	100	0.5	1.0	1.0	1.0	1.5

^a For insulation outside the stated conductivity range, the minimum thickness (T) shall be determined as follows:

$$T = r[(1 + t/r)^{K/k} - 1]$$

where T = minimum insulation thickness (in.); r = actual outside radius of pipe (in.); t = insulation thickness listed in this table for applicable fluid temperature and pipe size (in.); K = conductivity of alternate material at the mean rating temperature indicated for the applicable fluid temperature (Btu-in./[hr·ft²·°F]); and k is the upper value of the conductivity range listed in this table for the applicable fluid temperature.

^b These thicknesses are based on energy *efficiency* considerations only. Additional insulation is sometimes required relative to safety issues/surface temperature.

^c Piping insulation is not required between the control valve and coil on run-outs when the control valve is located within 4 ft. of the coil and the pipe is 1 in. or less.

^d **These thicknesses are based on energy *efficiency* considerations only. Issues such as water vapor permeability or surface condensation sometimes require vapor retarders or additional insulation.**

B. Necessary Pipe Insulation Thickness to Prevent Surface Condensation

Jacket: ASJ ($\epsilon = 0.9$) Wind Speed = 0 mph Ambient Temperature = 80°F

Pipe Size	Relative Humidity & Operating Temperature					Relative Humidity & Operating Temperature					Relative Humidity & Operating Temperature				
	70% RH					80% RH					90% RH				
	35°F	40°F	45°F	50°F	55°F	35°F	40°F	45°F	50°F	55°F	35°F	40°F	45°F	50°F	55°F
0.5	0.5"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	0.5"	0.5"	1.5"	1.5"	1.5"	1.0"	1.0"
1	0.5"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	0.5"	0.5"	1.5"	1.5"	1.5"	1.5"	1.0"
1.5	0.5"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	1.0"	0.5"	2.0"	2.0"	1.5"	1.5"	1.5"
2	0.5"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	1.0"	0.5"	2.0"	2.0"	1.5"	1.5"	1.5"
4	1.0"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	1.0"	0.5"	2.0"	2.0"	2.0"	1.5"	1.5"
6	1.0"	0.5"	0.5"	0.5"	0.5"	1.5"	1.0"	1.0"	1.0"	0.5"	2.5"	2.5"	2.0"	2.0"	1.5"
8	1.0"	0.5"	0.5"	0.5"	0.5"	1.5"	1.0"	1.0"	1.0"	0.5"	2.5"	2.5"	2.0"	2.0"	1.5"
10	1.0"	0.5"	0.5"	0.5"	0.5"	1.5"	1.0"	1.0"	1.0"	0.5"	2.5"	2.5"	2.0"	2.0"	1.5"
12	1.0"	1.0"	1.0"	1.0"	0.5"	1.5"	1.0"	1.0"	1.0"	1.0"	2.5"	2.5"	2.0"	2.0"	1.5"

Jacket: ASJ ($\epsilon = 0.9$) Wind Speed = 0 mph Ambient Temperature = 90°F

Pipe Size	Relative Humidity & Operating Temperature					Relative Humidity & Operating Temperature					Relative Humidity & Operating Temperature				
	70% RH					80% RH					90% RH				
	35°F	40°F	45°F	50°F	55°F	35°F	40°F	45°F	50°F	55°F	35°F	40°F	45°F	50°F	55°F
0.5	0.5"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	0.5"	0.5"	2.0"	1.5"	1.5"	1.0"	1.0"
1	0.5"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	1.0"	0.5"	2.0"	2.0"	2.0"	1.5"	1.5"
1.5	1.0"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	1.0"	1.0"	2.0"	2.0"	2.0"	2.0"	1.5"
2	1.0"	0.5"	0.5"	0.5"	0.5"	1.0"	1.0"	1.0"	1.0"	1.0"	2.5"	2.0"	2.0"	2.0"	1.5"
4	1.0"	0.5"	0.5"	0.5"	0.5"	1.5"	1.0"	1.0"	1.0"	1.0"	3.0"	2.5"	2.5"	2.0"	2.0"
6	1.0"	1.0"	0.5"	0.5"	0.5"	1.5"	1.0"	1.0"	1.0"	1.0"	3.0"	3.0"	2.5"	2.5"	2.0"
8	1.0"	1.0"	1.0"	0.5"	0.5"	1.5"	1.0"	1.0"	1.0"	1.0"	3.0"	3.0"	2.5"	2.5"	2.0"
10	1.0"	1.0"	1.0"	0.5"	0.5"	1.5"	1.5"	1.0"	1.0"	1.0"	3.5"	3.0"	2.5"	2.5"	2.0"
12	1.0"	1.0"	1.0"	1.0"	0.5"	1.5"	1.5"	1.0"	1.0"	1.0"	3.5"	3.0"	2.5"	2.5"	2.0"

C. ASHRAE 90.1 – 2007 REQUIREMENTS – DUCT

Minimum Duct Insulation R-Value ^a, Cooling and Heating Only Supply Ducts and Return Ducts

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insulated Ceiling	Unvented Attic with Roof Insulation ^a	Unconditioned Space ^b	Indirectly Conditioned Space ^c	Buried
Heating – Only Ducts							
1,2	none	none	none	none	none	none	none
3	R – 3.5	none	none	none	none	none	none
4	R – 3.5	none	none	none	none	none	none
5	R – 6.0	R – 3.5	none	none	none	none	R – 3.5
6	R – 6.0	R – 6.0	R – 3.5	none	none	none	R – 3.5
7	R – 8.0	R – 6.0	R – 6.0	none	R – 3.5	none	R – 3.5
8	R – 8.0	R – 8.0	R – 6.0	none	R – 6.0	none	R – 6.0
Cooling – Only Ducts							
1	R – 6.0	R – 6.0	R – 8.0	R – 3.5	R – 3.5	none	R – 3.5
2	R – 6.0	R – 6.0	R – 6.0	R – 3.5	R – 3.5	none	R – 3.5
3	R – 6.0	R – 6.0	R – 6.0	R – 3.5	R – 1.9	none	none
4	R – 3.5	R – 3.5	R – 6.0	R – 1.9	R – 1.9	none	none
5,6	R – 3.5	R – 1.9	R – 3.5	R – 1.9	R – 1.9	none	none
7,8	R – 1.9	R – 1.9	R – 1.9	R – 1.9	R – 1.9	none	none
Return Ducts							
1 to 8	R – 3.5	R – 3.5	R – 3.5	none	none	none	none

^a Insulation R – values, measured in (hr·ft²·°F)/Btu, are for the insulation as installed and do not include film resistance. The required minimum thicknesses do not consider water vapor transmission and possible surface condensation. Where exterior walls are used as plenum walls, wall insulation shall be required by the most restrictive conditions of Section 6.4.4.2 or Section 5. Insulation resistance measured on a horizontal plane in accordance with ASTM C518 at a Mean temperature of 75° F at the installed thickness.

^b Includes crawlspaces; both ventilated and non-ventilated.

^c Includes return air plenum with or without exposed roofs above.

C. (cont.) ASHRAE 90.1 – 2007 REQUIREMENTS – DUCT

Minimum Duct Insulation R-Value^a, Combined Heating and Cooling Supply Ducts and Return Ducts

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insulated Ceiling	Unvented Attic with Roof Insulation ^a	Unconditioned Space ^b	Indirectly Conditioned Space ^c	Buried
Supply Ducts							
1	R – 6.0	R – 6.0	R – 8.0	R – 3.5	R – 3.5	none	R – 3.5
2	R – 6.0	R – 6.0	R – 6.0	R – 3.5	R – 3.5	none	R – 3.5
3	R – 6.0	R – 6.0	R – 6.0	R – 3.5	R – 3.5	none	R – 3.5
4	R – 6.0	R – 6.0	R – 6.0	R – 3.5	R – 3.5	none	R – 3.5
5	R – 6.0	R – 6.0	R – 6.0	R – 1.9	R – 3.5	none	R – 3.5
6	R – 8.0	R – 6.0	R – 6.0	R – 1.9	R – 3.5	none	R – 3.5
7	R – 8.0	R – 6.0	R – 6.0	R – 1.9	R – 3.5	none	R – 3.5
8	R – 8.0	R – 8.0	R – 8.0	R – 1.9	R – 6.0	none	R – 6.0
Return Ducts							
1 to 8	R – 3.5	R – 3.5	R – 3.5	none	none	none	none

^a Insulation R – values, measured in (hr·ft²·°F)/Btu, are for the insulation as installed and do not include film resistance. The required minimum thicknesses do not consider water vapor transmission and possible surface condensation. Where exterior walls are used as plenum walls, wall insulation shall be required by the most restrictive conditions of Section 6.4.4.2 or Section 5. Insulation resistance measured on a horizontal plane in accordance with ASTM C518 at a Mean temperature of 75° F at the installed thickness.

^b Includes crawlspaces; both ventilated and non-ventilated.

^c Includes return air plenum with or without exposed roofs above.

C. Minimum Duct Wrap R-Value (Installed) to Prevent Surface Condensation

Jacket: Aged Aluminum Foil or Galvanized Sheet Metal ($\epsilon = 0.2$) Wind Speed = 0 mph

Operating Temperature: 45°F					
Rel. Humidity	Ambient Temperature				
	70°F	80°F	90°F	100°F	110°F
60%	2.2	3.3	4.3	4.3	5.4
70%	3.3	5.4	6.5	7.6	**
80%	7.0	**	**	**	**

Operating Temperature: 55°F					
Rel. Humidity	Ambient Temperature				
	70°F	80°F	90°F	100°F	110°F
60%	1.1	2.2	3.3	3.3	4.3
70%	1.1	3.3	4.3	6.5	6.5
80%	3.3	6.5	**	**	**

Operating Temperature: 65°F					
Rel. Humidity	Ambient Temperature				
	70°F	80°F	90°F	100°F	110°F
60%	1.1	1.1	2.2	3.3	4.3
70%	1.1	1.1	3.3	5.4	6.5
80%	2.2	3.3	6.5	**	**
90%	6.5	**	**	**	**

** Necessary R-value is greater than one typically supplied in duct wrap. Please consult manufacturer.

E. Fiberglass Ductwork – Reinforcement Schedules

1. Tie Rod System (Positive Pressure Only)

Positive Static Pressure	Inside Duct Dimension (inches)	TYPE 475 BOARD			TYPE 800 BOARD		
		No. Rods Across Dimension	Maximum Longitudinal Spacing	No. Rods per 4 ft. Section	No. Rods Across Dimension	Maximum Longitudinal Spacing	No. Rods per 4 ft. Section
0 thru ½" W.G.	0-36	*			*		
	37-42	2	24"	4	2		2
	43-48	2	24"	4	2	3	2
	49-60	3	24"	6	3	3	3
	61-64	3	24"	6	3	24"	6
	65-80	4	24"	8	4	24"	8
	81-96	5	24"	10	5	24"	10
Over ½" Thru 1" W.G.	0-24	*			*		
	25-30	1	24"	2	1	48"	1
	31-32	1	24"	2	1	24"	2
	33-36	2	24"	4	2	24"	4
	37-48	2	24"	4	2	24"	4
	49-64	3	24"	6	3	24"	6
	65-80	4	24"	8	4	24"	8
81-96	5	24"	10	5	24"	10	
Over 1" Thru 2" W.G.	0-15	*			*		
	16-18	1	24"	2	*		
	19-24	1	24"	2	1	24"	2
	25-32	1	16"	3	1	24"	2
	33-48	2	16"	6	2	24"	4
	49-60	3	16"	9	3	24"	6
	61-64	3	16"	9	3	16"	9
	65-80	4	16"	12	4	16"	12
81-96	5	16"	15	5	16"	15	

* Straight ducts of these dimensions do not require reinforcement. However, some fittings of these dimensions may require reinforcement.

NOTES: 1. Tie rods and washers must be no more than 16" on center across duct dimension.

2. Ducts of 48" width and over require use of anti-sag devices.

3. For duct dimensions over 96", maintain tie rod spacing on 16-inch center across the duct dimension following longitudinal spacing for the design pressure.

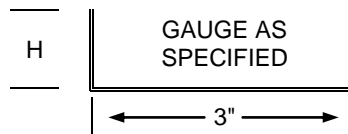
4. If dimensions require, tie rods run in both horizontal and vertical directions.

2. Channel System (Positive and Negative Pressure)

Static Pressure		Max. Inside Duct Dimension (inches)	TYPE 475 BOARD			TYPE 800 BOARD		
			Maximum Longitudinal Spacing	Channel Gauge	H Dimension (see note)	Maximum Longitudinal Spacing	Channel Gauge	H Dimension (see note)
0 thru ½" W.G.	negative	0-30	*			*		
		31-36	24"	22	1"	48"	22	1"
	positive	0-36	*			*		
0 thru ½" W.G.	positive or negative	37-42	24"	22	1"	48"	22	1"
		43-48	24"	22	1"	48"	22	1"
		49-60	24"	22	1"	48"	22	1½"
		61-72	24"	22	1"	24"	22	1"
		73-84	24"	22	1"	24"	22	1"
		85-96	24"	22	1¼"	24"	22	1"
Over ½" Thru 1" W.G.	positive or negative	0-24	*			*		
		25-30	24"	22	1"	48"	22	1"
		31-36	24"	22	1"	24"	22	1"
		37-42	24"	22	1"	24"	22	1"
		43-48	24"	22	1"	24"	22	1"
		49-60	24"	22	1"	24"	22	1"
		61-72	24"	18	1"	24"	18	1"
		73-84	24"	18	1¼"	24"	18	1¼"
		85-96	24"	18	1¼"	24"	18	1¼"
Over 1" Thru 2" W.G.	positive or negative	0-15	*			*		
		16-18	24"	22	1"	*		
		19-24	24"	22	1"	24"	22	1"
		25-36	16"	22	1"	24"	22	1"
		37-48	16"	22	1"	24"	22	1¼"
		49-60	16"	22	1"	24"	22	1¼"
		61-72	16"	18	1"	16"	18	1"
		73-84	16"	18	1¼"	16"	18	1¼"
		85-96	16"	18	1½"	16"	18	1½"

* Straight ducts of these dimensions do not require reinforcement. However, some fittings of these dimensions may require reinforcement.

NOTES: 1. Ducts of 48" width and over require use of anti-sag devices.



F. Fiberglass Ductwork-Maximum Hanger Spacing

Duct Size, Inches	Maximum Hanger Spacing
48" wide or greater	4 ft.
Less than 48" wide and less than 12" high	6 ft.
Width between 24" & 48" and greater than 24" high	6 ft.
Less than 48" wide and height between 12" & 24"	8 ft.
Width 24" or less and height greater than 12"	8 ft.

END OF SECTION