

SECTION 230700 – INSULATION SYSTEMS

- 1.0 ASHRAE 90.1 Compliance: University of Pennsylvania buildings shall comply with the Commercial Energy Efficiency Requirements of ASHRAE Standard 90.1-2016. The ASHRAE 90.1-2016 compliance paths shall be followed instead of the International Energy Conservation Code (IECC) requirements as permitted by 2018 IECC Section 401.2 Application.
- 2.0 This section defines insulation system guidelines and requirements for piping, ductwork, and equipment insulation. (Interior piping and equipment, exterior piping, interior ductwork, and exterior ductwork).
- 3.0 Insulation shall be applied to mechanical systems to limit heat loss or gain, prevent condensation, protect people from hot or extremely cold surfaces, and improve the operating efficiency of all systems. Insulation types and thicknesses for services are specified within this Section and are generally applicable to most projects. For specialty systems and for large specialty projects, studies of alternative insulation systems shall be initiated and justified on a case by case basis.
- 4.0 Insulation materials approved for use in the University buildings shall have a fire hazard rating not to exceed 25 for flame spread and 50 for fuel contributed and smoke developed. All materials shall be factory tested as an assembly. Fire ratings shall be determined by the standard method of testing for surface-burning characteristics of building materials, ASTM E 84. Insulation approved for use shall have a UL label or a certified test report from an approved testing laboratory.
- 5.0 Insulation materials shall not be installed on systems until all necessary tests have been conducted and insulated surfaces have been thoroughly cleaned and are in a dry state.
- 6.0 Protect insulation during construction by covering with plastic to prevent accumulation of dust and debris. Protection should be kept in place until completion of construction.
- 7.0 All adhesives sealers, vapor barrier coatings, etc. used in conjunction with insulation shall be compatible with the material to which they are applied. Any cement, sealer, or coating used shall be resistant to vermin and mold and shall be durable. Solvent based adhesives, coatings and sealants shall not be used in occupied areas. The use of solvent based adhesives, coatings and sealants for new construction shall be coordinated with building occupancy and other environmental health and safety issues during construction.
- 8.0 All insulation surfaces shall be durable and where exposed, protected from damage due to maintenance operations, vandalism, weather, and normal wear and tear.
- 9.0 Pipe fittings, specialties, equipment and valves shall be protected using custom premolded fitting covers and insulation (as defined below) to allow frequent removal and reinstallation without damaging the jacket.
 - A. Insulate all medium and high pressure (above 50 PSIG) steam piping fittings, flanges, valves, strainers, pressure reducing valves. For welded construction where routine access is not required, insulation shall match piping insulation. For non-welded construction and specialties requiring access, custom made insulated canvas jackets with "Velcro" type fastening devices shall be used.
 - B. Where lower temperature systems (low pressure steam, hot water, refrigerant hot gas piping, etc.) are exposed in routinely accessed areas the same consideration as above shall be given for personnel safety.
 - C. Systems subject to condensation such as chilled water systems shall be subject to the above insulation requirements.

- 10.0 Metallic components used for the installation of insulation systems shall be suitable for the intended environment and shall not corrode. Exposed external corners on duct and equipment insulation in occupied or mechanical areas shall be protected by corner beads consisting of 2 inch by 2 inch by 0.016 inch thick aluminum or 316 stainless steel.
- 11.0 Insulation systems shall be specified to meet or exceed the minimum requirements as defined by ASHRAE 90.1-2016 Tables 6.8.2 and 6.8.3, and installation requirements shall, as a minimum, include the following:
- A. Insulation shall be continuous at all hangers, hanger rods, supports, sleeves, and openings. Vapor seals must be provided for all cold surfaces and shall be continuous. Where supports must occur below insulation surface, the thickness shall be maintained over the support and extend sufficiently beyond the support to prevent condensation. Insulation shall be sealed where it terminates because of a valve, union, flange, etc.
 - B. All insulation shall be arranged to permit expansion and contraction of systems without causing damage to the insulation or surface.
 - C. The actual insulation thickness must be at least equal to the minimum specified at all locations, including supports in contact with cold surfaces.
 - D. It is critical that insulation materials be installed in a professional manner with smooth and even surfaces. Scrap pieces of insulation shall not be permitted where a full-length section will fit.
 - E. Insulate pipe saddles and welded pipe standoffs at all points of pipe support.
 - F. High density insulation inserts shall be used for pipe sizes 4" and larger, where pipe saddles are located. High density insulation inserts for shields shall extend 1" on all sides of the shield. Shields shall be constructed of 16 gauge minimum galvanized steel.
 - G. All valves and strainers shall be insulated for all welded piping construction as defined above. Custom-fabricated jackets shall be used where defined above.
 - H. Strainers requiring insulation shall be insulated to permit removal of the basket without disturbing the insulation of the strainer.
 - I. On ductwork or equipment, accessories shall be provided as required to prevent distortion and sagging of insulation. Welded pins, adhesive, seal staples, vapor barrier coatings, sealing tape, steel bands, and wire ties shall be provided as recommended by the insulation manufacturer. The following attachment methods are preferred:
 - 1. Mineral Fiber Board: Brushed on adhesive plus welded pins. (For use in mechanical rooms and exposed areas)
 - 2. Mineral Fiber Wrap: Brushed on adhesive with welded pins on bottom of ducts greater than 24 inches wide.
 - 3. Calcium Silicate: Non-corroding wire.
 - 4. Ceramic Fiber Insulation: Stainless steel bands.
 - J. Duct and equipment insulation shall cover all metal surfaces with full-thickness insulation. Duct standing seams require only minimal insulation to prevent condensation. If condensation will not occur, insulation at standing seams can be reduced from the duct main insulation.
 - K. Equipment Insulation
 - 1. Water pumps (Chilled Water, Glycol/Water Solution, Condenser Water, Condensate Drainage for Air Conditioning Equipment, Cooling Tower Makeup Water, and Heat Exchanger Systems) shall be insulated with removable and replaceable square or rectangular covers consisting of full minimum 16 gauge aluminum or 316 stainless steel metal jackets reinforced at corners and edges and lined with insulation. Pumps with split casings shall be constructed with insulated housing in two or more sections with the upper section removable for access to the casing. Cover sections shall be flanged, gasketed, and joined with stainless steel sheet metal

- screws. Lube fittings and drain valves shall extend outside of insulated covers.
2. For Evaporators, Water Chillers, Air Separators, Humidifier Separators, Expansion Tanks, Condenser Water Strainer, Water Storage Tanks and Water-to-Water Heat Exchangers, fit board type insulation by scoring, cutting and mitering to fit the contour of the equipment. Fill all voids with insulating cement. Insulate the water boxes or heads of evaporators by fabricating an enclosure from No. 18 gauge thick galvanized steel sheet. Attach insulation to the inside of the enclosure with adhesive. Slip enclosure over the insulation on the shell and draw tight. Where marine water boxes of chillers are to be insulated, insulate the water box head separately to permit removal of the head.
 3. Alternately, equipment may be insulated with removable insulation covers custom made for equipment insulation, such as Pacor Rapidwrap. For these covers: Enclosures shall be encased in vinyl cloth, aluminized cloth, or a coated fiberglass cloth. Filler shall be aerogel, microlite AA or fiberglass blanket. Closure system shall be Velcro (high temperature for high temperature applications) or belts & straps. All covers shall be custom made and guaranteed to fit.
- L. Where deemed necessary by the A/E or the University Engineering Department, specific insulation details shall be added to the Contract Documents to improve the insulation performance for specialty areas such as at roof drain bodies and horizontal rain water conductors, or insulation in high humidity areas such as shower rooms and sterilizer areas may require special details for vapor barriers.
- 12.0 Insulation may be omitted on the following items at the discretion of the University Engineering Department:
- A. Exposed brass or copper pipe specified to be chrome plated (typically applies to toilet rooms).
 - B. All fire protection.
 - C. ASME stamps on equipment.
 - D. Access plates of fan housings.
 - E. Cleanouts or handholes.
 - F. Factory-preinsulated flexible ductwork.
 - G. Factory-preinsulated HVAC equipment.
 - H. Manufacturer's nameplates.
 - I. Vibration-isolating connections.
- 13.0 The minimum insulation standards for University projects and for the services listed are as indicated in the following Tables for Piping, Equipment, and Ductwork insulation. The A/E shall select the most suitable product for each individual service.
- Tables that follow are:
- Mechanical Equipment Insulation Schedule
 - Sheet Metal Ductwork Insulation Schedule
 - Piping Insulation Schedule

MECHANICAL EQUIPMENT INSULATION SCHEDULE							
EQUIPMENT TYPE	SURFACE METAL TEMP (DEGREES F)	INSULATION TYPE	EQUIPMENT LOCATION		INSULATION		JACKET
			IN-DOOR	OUT-DOOR	DENSITY (PCF)	THICKNESS (INCHES)	
Cooling Coil Sections and Cooling Coil Condensate Pump Tanks	55	Mineral Fiber Board	X		3	2	All-Service
Supply Fan, De-humidifier, Air Blender, and Heating Coil Casings/ Sections	55 to 140	Mineral Fiber Board	X		3	2	All-Service
Pumps Serving Cold Water Systems	40 to 180	Mineral Fiber Board or Custom Removable Covers	X		3	2	See Paragraph 9.0.J
Sidestream Filters, Air Purgers and Air Separators Serving the Chilled Water and Hot Water Heating Systems	40 to 180	Mineral Fiber Board	X		3	2	See Article 9.0.J
Water-to-Water Heat Exchangers	50 to 180	Mineral Fiber Board or Custom Removable Covers	X		6	1.5	See Paragraph 9.0.J
Chiller Evaporator and Condenser Marine Water Boxes, Condenser Water Strainer and Water Storage Tanks	40	Mineral Fiber Board	X		6	2	See Paragraph 9.0.J

MECHANICAL EQUIPMENT INSULATION SCHEDULE							
EQUIPMENT TYPE	SURFACE METAL TEMP (DEGREES F)	INSULATION TYPE	EQUIPMENT LOCATION		INSULATION		JACKET
			IN-DOOR	OUT-DOOR	DENSITY (PCF)	THICKNESS (INCHES)	
Steam-to-Water Heat Exchangers	250	Calcium Silicate or Custom Removable Covers	X		13	3	Cement Finish
Steam Condensate Pumps, Condensate Receivers, Condensate Coolers and Flash Tanks	250	Calcium Silicate	X		13	3	Cement Finish
Water Treatment Chemical Mixing/ Storage Tanks	170	Mineral Fiber Board	X		6	1.5	18 Gauge Metal Jacket
Expansion Tanks and Humidifier Separators	40 to 180	Mineral Fiber Board	X		3	2	See Paragraph 9.0.J
Duct-Mounted Sound Attenuators in Supply Air Ducts	75	Mineral Fiber Board	X		3	1	All-Service
INSULATION SPECIFICATION: Flexible Cellular: ASTM C 534, $k = 0.27 \text{ Btu}\cdot\text{in}/\text{h}\cdot\text{ft}^2$ at 75 °F Cellular Glass Block: ASTM C 552, $k = 0.35 \text{ Btu}\cdot\text{in}/\text{h}\cdot\text{ft}^2$ at 75 °F Calcium Silicate: ASTM C 533, $k = 0.38 \text{ Btu}\cdot\text{in}/\text{h}\cdot\text{ft}^2$ at 100 °F Mineral Fiber Board (w/ vapor barrier): ASTM C 612, $k = 0.23 \text{ Btu}\cdot\text{in}/\text{h}\cdot\text{ft}^2$ at 75 °F Mineral Wool Felt (block or blanket): ASTM C 592, $k = 0.50$ to $0.58 \text{ Btu}\cdot\text{in}/\text{h}\cdot\text{ft}^2$ at 600 °F							

SHEET METAL DUCTWORK INSULATION SCHEDULE						
PLENUM OR DUCTWORK TYPE	INSULATION TYPE	PLENUM OR DUCT LOCATION		INSULATION		JACKET
		INDOOR	OUTDOOR	DENSITY (PCF)	THICKNESS (INCHES)	
Rectangular Supply and Return Ductwork in Mechanical Rooms, All Exposed Areas and Duct Shafts	Rigid Mineral Fiber Board	X		3	1.5	All-Service
			X	6	2	+
Rectangular Supply and Return Ductwork in Concealed Areas Note: Return ductwork in plenum return spaces and /or conditioned areas is not required.	Rigid Mineral Fiber Board	X		3	1.5	All-Service
	OR Mineral Fiber Wrap		X	6	2	+
Outside Air Intake, Relief and Exhaust Plenums	Rigid Mineral Fiber Board	X		6	2	All-Service
			X	6	2	+
Louver Blank-Off Panels	Rigid Mineral Fiber Board	X		6	2	Galvanized Sheet Metal (Two Sides)
Round and Flat-Oval Supply and Outside Air Ductwork, and Return Ductwork in Mechanical Rooms	Mineral Fiber Wrap	X		1	2	All-Service
	OR Rigid Mineral Fiber Board		X	6	2	+
Kitchen Hood Exhaust Ductwork	Calcium Silicate	X		13	1	None
	OR Ceramic Fiber Blanket	X		8	1	None
	OR Fire Rated Ductwrap System	X			3 (two 1.5-inch layers)	

SHEET METAL DUCTWORK INSULATION SCHEDULE						
PLENUM OR DUCTWORK TYPE	INSULATION TYPE	PLENUM OR DUCT LOCATION		INSULATION		JACKET
		INDOOR	OUTDOOR	DENSITY (PCF)	THICKNESS (INCHES)	
Emergency or Standby Power Generator Air Intake Plenum, Intake Ductwork and Intake Attenuator	Rigid Mineral Fiber Board	X		6	1.5	All-Purpose Jacket with Vapor Barrier
Ductwork Requiring Noise Transmission Control (as indicated on the Drawings)	Rigid Mineral Fiber Board	X		6	2	Noise Barrier Jacket

+ = For rectangular ducts and plenums exposed to weather, pitch ductwork or insulation board minimum 1/4 inch per foot to prevent rainwater from accumulating on top of duct or plenum. Cover insulation board with corrugated rolled aluminum jacketing installed in strict accordance with manufacturer's recommendations.

++ = Use double-layer application of two 2 inch thick panels to ensure overlapping of all seams and joints to minimize heat loss and hot spots.

INSULATION SPECIFICATION:

Rigid and Semi Rigid Mineral Fiber Board (w/ vapor barrier): ASTM C 612, k = 0.23 Btu-in/h-ft² at 75 °F

Mineral Fiber Wrap (w/ vapor barrier): ASTM C 553, k = 0.27 Btu-in/h-ft² at 75 °F

Calcium Silicate: ASTM C 533, k = 0.38 Btu-in/h-ft² at 100 °F

Ceramic Fiber Blanket: k = 0.27 Btu-in/h-ft² with a melting point of 3200 °F and a 3-hour fire rating for 5-inch thickness when tested in accordance with ASTM E119

Thermal Insulating Wool: k = 0.22 Btu-in/h-ft² at 100 °F

Flexible Cellular: ASTM C 534, k = 0.27 Btu-in/h-ft² at 75 °F

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r(1 + \frac{t}{r})^{K/k} - 1$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness from ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Fluid: Refrigerant Suction - Temp: 45°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.21 to 0.27																				
Flexible Cellular (K=0.27)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
K	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
k	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
UPenn	0.5	0.5	0.5	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
90.1-2016	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: Brine - Temp: <40°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.20 to 0.26																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
UPenn	2	2	2	2	2	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
90.1-2016	0.82	0.78	0.76	0.75	1.58	1.53	1.49	1.47	1.44	1.39	1.41	1.40	1.39	1.38	1.38	1.37	1.37	1.37	1.37	1.36
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: Chilled Water - Temp: 50°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.21 to 0.27																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
UPenn	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
90.1-2016	0.39	0.40	0.40	0.41	0.80	0.81	0.82	0.82	0.83	0.84	0.83	0.84	0.84	0.84	0.84	0.84	0.85	0.85	0.85	0.85
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r(1 + kr^{2k}) - 1$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness fom ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Fluid: Chilled Water - Temp: 50°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.21 to 0.27																				
Flexible Cellular (K=0.27)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
K	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
k	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
UPenn	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
90.1-2016	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: Chilled Water - Temp: 50°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.21 to 0.27																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
UPenn	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
90.1-2016	0.77	0.74	0.72	0.71	1.49	1.45	1.41	1.39	1.37	1.33	1.35	1.34	1.33	1.33	1.32	1.32	1.32	1.32	1.31	1.31
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: Heating Hot Water- Temp: 180°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.25 to 0.29																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
UPenn	1	1	1.5	1.5	1.5	1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
90.1-2016	0.95	0.99	1.01	1.03	1.36	1.40	1.43	1.45	1.48	1.53	1.51	1.52	1.53	1.54	1.54	1.55	1.55	1.56	1.56	1.57
Compliant	YES	YES	YES	YES	YES	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r(1 + \frac{t}{r})^{K/k} - 1$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness fom ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Fluid: Heating Hot Water- Temp: 180°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.25 to 0.29																				
Flexible Cellular (K=0.27)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
K	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
k	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
UPenn	1.5	1.5	1.5	1.5	2	2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
90.1-2016	1.29	1.31	1.32	1.33	1.77	1.78	1.80	1.81	1.82	1.84	1.83	1.84	1.84	1.84	1.84	1.85	1.85	1.85	1.85	1.85
Compliant	YES	YES	YES	YES	YES	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Fluid: Lab and Domestic Hot Water (Mains)- Temp: 140°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.22 to 0.28																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	1.0	1.0	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
UPenn	1	1	1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
90.1-2016	0.70	0.72	0.74	0.75	1.11	1.13	1.15	1.16	1.17	1.21	1.19	1.20	1.20	1.21	1.21	1.21	1.21	1.22	1.22	1.22
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: Lab and Domestic Hot Water (Branches)- Temp: 140°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.22 to 0.28																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	1.0	1.0	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
UPenn	1	1	1	1	1.5	1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
90.1-2016	0.70	0.72	0.74	0.75	1.11	1.13	1.15	1.16	1.17	1.21	1.19	1.20	1.20	1.21	1.21	1.21	1.21	1.22	1.22	1.22
Compliant	YES	YES	YES	YES	YES	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r((1 + \frac{t}{r})^{2Kk} - 1)$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness fom ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Fluid: Lab and Domestic Hot Water (Branches)- Temp: 140°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.22 to 0.28																				
Flexible Cellular (K=0.27)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.31	0.44	0.56	0.69	0.81	1.06	1.44	1.75	2.25	5.56	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	1.0	1.0	1.0	1.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
K	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
k	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
UPenn	1	1	1	1	1.5	1.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
90.1-2016	0.93	0.94	0.94	0.95	1.42	1.42	1.43	1.43	1.43	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Compliant	YES	YES	YES	YES	YES	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Fluid: HPS (125 to 235 psig) - Temp: 401°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.32 to 0.34																				
Calcium Silicate (K=0.38)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	4.5	4.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
K	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
k	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
UPenn	6.5	6.5	7	7	6.5	6.5	6.5	6.5	6.5	6.5	6	6	6	6	6	6	6	6	6	6
90.1-2016	6.15	6.03	6.63	6.50	6.43	6.33	6.24	6.16	6.07	6.00	5.95	5.88	5.83	5.80	5.79	5.76	5.75	5.73	5.71	5.69
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: HPS (125 to 235 psig) - Temp: 401°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.32 to 0.34																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	4.5	4.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
UPenn	5	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
90.1-2016	4.87	4.85	5.37	5.34	5.33	5.31	5.29	5.27	5.25	5.24	5.23	5.21	5.20	5.20	5.19	5.19	5.18	5.18	5.18	5.17
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r((1 + \frac{K}{k})^{R/k} - 1)$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness from ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Fluid: HPS (100 psig) - Temp: 337°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.29 to 0.32																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
90.1-2016	1.48	1.54	2.03	2.11	2.38	2.47	2.55	2.62	2.71	2.77	2.82	2.90	2.95	2.98	3.00	3.03	3.05	3.06	3.09	3.11
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: HPS (100 psig) - Temp: 337°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.29 to 0.32																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	4	4	5	5	6	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
90.1-2016	3.74	3.69	4.94	4.87	5.47	5.40	5.34	5.29	5.23	5.19	5.15	5.11	5.08	5.06	5.05	5.03	5.02	5.01	5.00	4.99
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: MPS (50 psig) - Temp: 298°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.29 to 0.32																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	2	2	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
90.1-2016	1.48	1.54	2.03	2.11	2.38	2.47	2.55	2.62	2.71	2.77	2.82	2.90	2.95	2.98	3.00	3.03	3.05	3.06	3.09	3.11
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r((1 + t/r)^{K/k} - 1)$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness from ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
<u>Fluid: MPS (50 psig) - Temp: 298°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft²) Range: 0.29 to 0.32</u>																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	4	4	5	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5
90.1-2016	3.74	3.69	4.94	4.87	5.47	5.40	5.34	5.29	5.23	5.19	5.15	5.11	5.08	5.06	5.05	5.03	5.02	5.01	5.00	4.99
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

<u>Fluid: LPS (15 psig) - Temp: 250°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft²) Range: 0.27 to 0.30</u>																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
UPenn	1.5	1.5	2	2	2	2	3	3	3	3	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
90.1-2018	1.44	1.49	1.53	1.58	1.60	1.64	1.68	1.71	2.06	2.09	2.12	2.15	2.18	2.19	2.20	2.21	2.22	2.23	2.24	2.25
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

<u>Fluid: LPS (15 psig) - Temp: 250°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft²) Range: 0.27 to 0.30</u>																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
UPenn	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
90.1-2016	3.61	3.53	3.44	3.37	3.33	3.27	3.22	3.18	3.80	3.75	3.72	3.67	3.64	3.62	3.61	3.60	3.59	3.58	3.57	3.56
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r(1 + \frac{t}{r})^{R/k} - 1$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness fom ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Fluid: HPC - Temp: 337°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.29 to 0.32																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
90.1-2016	1.48	1.54	2.03	2.11	2.38	2.47	2.55	2.62	2.71	2.77	2.82	2.90	2.95	2.98	3.00	3.03	3.05	3.06	3.09	3.11
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: HPC - Temp: 337°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.29 to 0.32																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	4	4	5	5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5
90.1-2016	3.74	3.69	4.94	4.87	5.47	5.40	5.34	5.29	5.23	5.19	5.15	5.11	5.08	5.06	5.05	5.03	5.02	5.01	5.00	4.99
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: MPC - Temp: 298°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.29 to 0.32																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
90.1-2016	1.48	1.54	2.03	2.11	2.38	2.47	2.55	2.62	2.71	2.77	2.82	2.90	2.95	2.98	3.00	3.03	3.05	3.06	3.09	3.11
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

PIPING INSULATION SCHEDULE

- T Minimum Thickness (in.) $T = r((1 + \frac{t}{r})^{2k} - 1)$
- r Pipe Outside Radius (in.)
- t Min Insul. Thickness fom ASHRAE Table (in.)
- K Proposed Conductivity (btu-in./h-ft²)
- k ASHRAE Table Upper Conductivity (btu-in./h-ft²)

Fluid: MPC - Temp: 298°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.29 to 0.32																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	3.0	3.0	4.0	4.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
UPenn	4	4	5	5	6	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5
90.1-2016	3.74	3.69	4.94	4.87	5.47	5.40	5.34	5.29	5.23	5.19	5.15	5.11	5.08	5.06	5.05	5.03	5.02	5.01	5.00	4.99
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: LPC - Temp: 250°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.27 to 0.30																				
Mineral Fiber (K=0.23)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
K	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
k	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
UPenn	1.5	1.5	2	2	2	2	2	2	2.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
90.1-2016	1.44	1.49	1.53	1.58	1.60	1.64	1.68	1.71	2.06	2.09	2.12	2.15	2.18	2.19	2.20	2.21	2.22	2.23	2.24	2.25
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Fluid: LPS Temp: 250°F - ASHRAE 90.1-2016 Thermal Conductivity (btu-in./h-ft ²) Range: 0.27 to 0.30																				
Cellular Glass (K=0.35)																				
	0.5	0.75	1	1.25	1.5	2	2.5	3	4	5	6	8	10	12	14	16	18	20	24	30
r	0.42	0.53	0.66	0.83	0.95	1.19	1.44	1.75	2.25	2.78	3.31	4.31	5.38	6.38	7.00	8.00	9.00	10.00	12.00	15.00
t	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
K	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
k	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
UPenn	4	4	3.5	3.5	3.5	3.5	3.5	3.5	4	4	4	4	4	4	4	4	4	4	4	4
90.1-2016	3.61	3.53	3.44	3.37	3.33	3.27	3.22	3.18	3.80	3.75	3.72	3.67	3.64	3.62	3.61	3.60	3.59	3.58	3.57	3.56
Compliant	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES