INSULATION FACTS #85

NAIMA
North American Insulation Manufacturers Association

Information from NAIMA:

Facts About Insulation Requirements for Plastic Piping

All current building energy codes and standards require pipe insulation on service hot water and HVAC piping. In this issue we discuss how much insulation is needed for domestic hot and cold service water systems and for HVAC systems in commercial and industrial buildings. While requirements vary, none of the model codes differentiates pipe insulation requirements based on pipe material. The amount of insulation needed depends on the design objectives of the system and the properties of the specific pipe material.

Plastic piping for domestic hot and cold service water systems and for HVAC systems in buildings is the dominant piping material for residential construction, and is also used routinely in commercial and industrial applications. Energy codes do not differentiate insulation requirements based on plastic or metallic pipe wall material.

Plastic vs. Metal Piping Systems

Compared to metallic piping systems, plastic piping materials have a significantly lower thermal conductivity, which translates to lower heat transfer between the fluid and the ambient air. For some normally uninsulated piping systems, this can be advantageous. For example, city water lines entering a building will often sweat due to the relatively cold temperature of the water entering the building.

Where insulation is required by energy codes, however, the impact of the pipe wall material on the overall heat transfer is generally small. For this reason, energy codes do not differentiate insulation requirements based on pipe wall material.

Plastic Piping Material Properties

The physical properties of plastic pipes vary significantly depending on their composition. These variations may make plastic pipes of a given composition more or less desirable for a given application. As an example, a key property for hot systems is the strength at temperature. Since all plastics lose strength as temperature increases, this limits the use of plastic piping to operating temperatures less than about 220°F.

Some manufactures have developed composite systems (e.g. PEX-Al-PEX) for improved high temperature performance. For domestic hot and cold water piping systems, CPVC and PEX are the most common. For chilled water distribution piping, a number of different materials may be used.

From a heat transfer point of view, the key properties are the thermal conductivity and the wall thicknesses of the various pipe products.

Common Plastic Piping Materials

ABS (Acrylonitrile Butadiene Styrene)
CPVC (Chlorinated Polyvinyl Chloride
PB (Polybutylene)
PE (Polyethylene)
PEX (Cross-linked Polyethylene)
PP (Polypropylene)
PVC (Polyvinyl Chloride)
PVDF (Polyvinylidene Fluoride)

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Thermal Conductivity of Piping and Insulation Materials

The thermal conductivity of plastic pipe materials varies. Table 1 shows conductivity values ranging from a low of 0.8 Btu·in/(h·ft²·°F) for PVDF to a high of 3.2 Btu·in/(h·ft²·°F) for PEX. For comparison purposes, the conductivity of copper is approximately 2,720 Btu·in/(h·ft²·°F) at a temperature of 75°F while steel has a conductivity of approximately 314 Btu·in/(h·ft²·°F).

Heat Transfer Calculations

The data from Table 1 clearly demonstrate that the thermal conductivity of metallic piping is from 30x to 3,000x higher than typical plastic piping materials. The table also shows variations in thermal conductivity for the various compositions for plastic pipes. However, the impact on heat transfer to or from the fluid will depend not only on the relative thermal resistances of the pipe wall thickness, but also on the other thermal resistances in the installed system.

Effect of Insulation on Heat Loss

For bare piping of any type, the air surface coefficient normally represents the largest thermal resistance in the system and the wind speeds at the surface, along with the thermal emittance of the surface material, are dominant. As insulation is added to the system, the resistance of the insulation layer begins to dominate and other resistances become less important.

Figure 1 compares the heat loss from a horizontal 2" tube containing water at 140°F in still air at 75°F. For the bare cases the heat loss from the CPVC tubing is significantly less than the copper tubing. At insulation thicknesses above ½" the difference in the heat loss becomes very small. Flexible elastomeric insulation was assumed for this illustration.

Different Size Standards

Plastic piping is manufactured to a number of different size standards:

CPVC is available in either nominal pipe sizes (NPS) from ¼" to 12" or in copper tube sizes (CTS) from ¼" to 2".

NPS sizes are available in either Schedule 40 or Schedule 80 wall thicknesses.

CTS sizes wall thickness have standard dimension ratio (SDR) of 11 (i.e. the outside diameter is 11 times the wall thickness).[1]

PEX is available in CTS sizes from ¼" to 3" with SDRs of approximately 9.[2]

Table 1. Thermal Conductivity of Piping and Insulation Materials[a]

Material	Thermal Conductivity, Btu·in/(h·ft²·°F)	Source
ABS	1.7	ASHRAE Handbook
ABS	1.35	Piping Handbook
CPVC 4120	0.95	ASHRAE Handbook
CPVC	1.0	PPFA Installation Handbook
CPVC	1.0	Piping Handbook
PB	1.5	Piping Handbook
PB 2110	1.5	ASHRAE Handbook
PE	2.6-3.1	Handbook of PE Pipe
PE	3.2	Piping Handbook
PEX	3.2	Piping Handbook
PP	1.3	ASHRAE Handbook
PVC	1.1	Piping Handbook
PVC 1120	1.1	ASHRAE Handbook
PVDF	1.5	Piping Handbook
PVDF	0.8	ASHRAE Handbook
For comparison		
Copper	2,720	ASHRAE Handbook
Mild Steel	314	ASHRAE Handbook
304 Stainless Steel	96	Marks' Handbook
Flexible Elastomeric Insulation	0.28	ASTM C 534
Fiberglass Insulation	0.25	ASTM C 547
Polyisocyanurate Insulation	0.20	ASTM C 591

a. Conductivity values given at room temperature

The relative magnitude of these effects will vary with the situation but they can be estimated using well-established calculation procedures. These are outlined in ASTM Standard C 680[3] and in a number of heat transfer text books.

Examples Illustrate Relationships

The following example applications help illustrate the relationships. All of the examples compare thin walled (Type M) copper tubing to standard size CPVC and PEX tubing. These materials were chosen because together they represent the largest share of products in the marketplace and because they effectively span the range of thermal conductivities for piping. Conductivities and surface emittance used in the analysis are shown in Table 2.

Example 1

This example assumes a ¾" copper tubing size CTS domestic hot water (DHW) line in a commercial building. The operating temperature of this line is 140°F and the ambient conditions are assumed to be 75°F with 0 mph wind speed. For calculation purposes, the insulation material is flexible elastomeric insulation

(ASTM C 534 Grade 1). The 2012 IECC Energy Code requirement for this application calls for 1" of insulation. Calculated heat losses per foot of piping run are summarized in Table 3.

Example 2

This example involves a 1" CTS heating hot water (HHW) line in a commercial building. The line operates at a temperature of 180°F and runs through a return-air plenum with an air temperature of 75°F and an air velocity of 3 mph. For this example, we will use fiber glass insulation (ASTM C 547 Type I). The 2012 IECC insulation requirement for this application is 1-½". Results of calculations are shown in Table 4.

Example 3

This example is a 2" CTS chilled water supply (CWS) line operating in a mechanical room of a commercial building. The operating temperature is 40°F and the ambient temperature is 80°F with a wind speed of 1 mph. The insulation material is flexible elastomeric insulation (ASTM C 534 Grade 1). The 2012 IECC insulation thickness requirement for this application is 1". Results of this example are shown in Table 5.

Energy Code Requirements for Piping

Domestic Hot Water and HVAC Piping

All of the current model energy codes contain insulation requirements for Domestic Hot Water and HVAC piping. Although the details vary somewhat, the requirements are generally given as a minimum insulation thickness without regard to pipe material.

Example: Requirements for service water heating from the 2012 International Energy Conservation Code (2012 IECC) are given in Section C 404.5 and read as follows:

> *C404.5 Pipe insulation. For automatic-circulating hot water and heat-traced systems, piping shall be insulated with not less than 1 inch (25 mm)*

Figure 1: Heat Loss from 2" CTS Tubing at 140°F

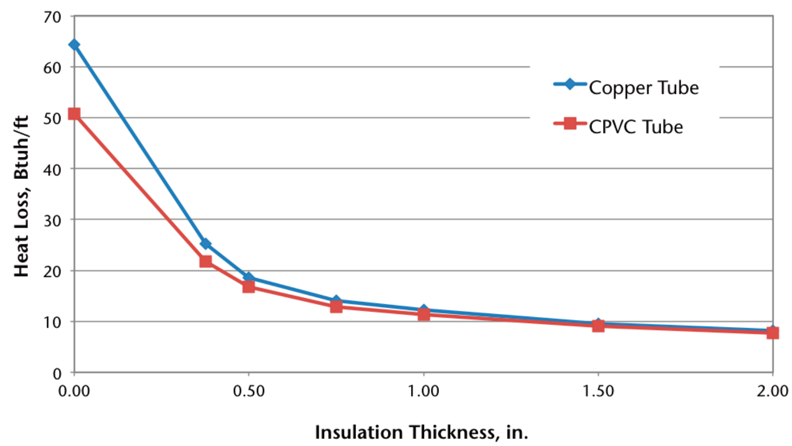

Table 2. Pipe Material Thermal Properties used in Examples 1-3

Pipe Material	Thermal Conductivity, Btu·in/(h·ft2·°F)	Surface Emittance
Copper	2720	0.6
CPVC	1.0	0.9
PEX	3.2	0.9

Table 3. Example 1 Heat Loss Comparison

¾" DHW Line at 140°F, Wind Speed = 0 MPH. Insulation = Flexible Elastomeric

Insulation Thickness, inches	Calculated Heat Loss, Btuh/ft		
	Copper	CPVC	PEX
Bare	29.64	28.30	31.96
⅜	13.26	12.23	12.81
½	10.35	9.72	10.08
¾	8.30	7.89	8.13
1	7.21	6.90	7.08
1-½	5.91	5.71	5.83
2	5.18	5.02	5.11

Note: 2012 IECC Requirement is 1"

Table 4. Example 2 Heat Loss Comparison

1" HHW Line at 180°F, Ambient Temperature = 75°F, Wind Speed = 3 mph, Insulation = Fiberglass

Insulation Thickness, inches	Calculated Heat Loss, Btuh/ft		
	Copper Type M	CPVC SDR 11	PEX
Bare	152	101	131
½	22.7	20.8	21.9
1	14.6	13.8	14.3
1-½	11.6	11.1	11.4
2	10.0	9.6	9.8

Note: 2012 IECC Requirement is 1-½"

of insulation having a conductivity not exceeding 0.27 Btu ·inch/(h·ft²·°F). The first 8 feet (2438 mm) of piping in non-hotwater-supply temperature maintenance systems served by equipment without integral heat traps shall be insulated with 0.5 inch (12.7 mm) of material having a conductivity not exceeding 0.27 Btu·inch/(h·ft²·°F).

The only qualifier here is that the insulation has a conductivity not more than 0.27 Btu·in/(h·ft²·°F). Insulation thickness requirements are the same whether the base material is copper, schedule 40 steel, schedule 80 stainless steel, CPVC, or PEX. While the choice of base material will impact the heat loss or gain of insulation systems, the effect is relatively small for insulated piping and does not justify reducing the insulation thickness requirements.

HVAC Systems in Commercial Buildings

The 2012 IECC requirements for piping for HVAC systems in commercial buildings are summarized in Table 6. The thickness requirements here are differentiated by operating temperature and by nominal pipe or tube size. As before, the thickness requirements are not differentiated by pipe base material or wall thickness.

Thickness requirements are again independent of the insulation material, as long as the conductivity of the material falls within the specified range. If the conductivity of the insulation layer is outside the specified range, the required insulation thickness must be adjusted based on the equation in footnote b. Note that since the emittance of the outer surface is not addressed in Table 6, the thickness requirements are independent of outer jacket material as well.

Table 5. Example 3 Heat Loss Comparison

2" CWS Line at 40°F, Ambient Temperature = 80°F, Wind Speed = 1 mph, Insulation = Flexible Elastomeric

Insulation Thickness, inches	Calculated Heat Loss, Btuh/ft		
	Copper Type M	CPVC SDR 11	PEX
Bare	51.6	37.5	47.4
3/8	15.8	13.8	14.9
½	11.4	10.3	10.9
¾	8.4	7.8	8.1
1	7.2	6.8	7.0
1-½	5.6	5.3	5.5
2	4.7	4.5	4.6

Note: 2012 IECC Requirement is 1"

Results For All Three Examples are Similar and Reveal the Following Important Points:

Heat loss or gain depends on both the thickness of the insulation as well as the choice of the pipe material.

However, the effect of insulation thickness is considerably more significant than the choice of pipe material. In Example 1, adding 1" of insulation to the bare copper line reduces the heat loss by 76% [(29.64 – 7.21)/29.64 = 76%], while changing from copper to CPVC pipe using the same 1" reduces the heat loss by the same amount, 76%. It is interesting to note the bare PEX pipe actually has more heat loss than the bare copper pipe. The PEX has a heat loss of 31.96 Btuh/ft versus 29.634 Btuh/ft for the copper. Pipes with different wall thicknesses will have different amounts of energy loss.

For bare piping, the effect of base pipe material on heat flow is significant.

The largest effect is for the CPVC cases (as CPVC has the lower thermal conductivity). Compared to the copper case, the CPVC cases show reductions of heat flow of 21% [(64.3-50.8)/64.3 = 21%], 34%, and 27% for the three examples respectively. Reductions for the PEX case are less and average 8%. For the still air case, the lower emittance of the copper surface ((=0.6) contributes some thermal resistance relative to the plastic cases (=0.9).

The impact of the base material decreases as the amount of insulation increases.

In Example 1 with 1 inch of insulation the heat loss for the CPVC material is 7% [(12.2-11.3)/12.2 = 7%] less than the comparable copper case. At 2" of insulation, the difference is below 5%. Considering all three examples, the impact at 2" of insulation averages 4.4%.

A trade-off of insulation thickness against lower conductivity pipe material would not work.

In Example 1 at the code required insulation thickness of 1" the heat loss for the copper pipe system is 12.2 Btuh/ft. The alternate design of CPVC with ¾" of insulation (the next smaller increment for this insulation material) yields a higher heat loss of 12.9 Btuh/ft. Examinations of the other cases yield a similar conclusion; plastic pipe lowers the heat flow, but not enough to justify removing a ¼" of insulation.

Code Requirements Silent Relative to Other Pipe System Requirements

The code requirements for piping are also silent relative to other system variables known to impact thermal performance. For example, thickness requirements are independent of location within the building. While it could certainly be argued that hydronic piping to a reheat coil routed through a return air plenum, where moving air is increasing heat loss, should have more insulation than a similar line run through a closed cavity in still air, the energy codes do not require different insulation thicknesses.

Upon consideration, these energy code requirements may appear to be overly simplistic. However, one of the goals of code writing organizations is for the requirements to be as clear and easy to enforce as possible while still meeting the intent of the code. Buildings are complicated with literally thousands of code requirements subject to verification.

A good code requirement must be clear and easily verifiable.

Minimum Thickness Requirements Not Dependent on Pipe Material

While the 2012 IECC minimum thickness requirements for pipe insulation are not dependent on pipe material, it is recognized that code officials may be receptive to alternatives based on a technical analysis demonstrating that the thermal performance of an alternative design is as good as or better than a baseline case meeting the code. By way of example, the ASHRAE 90.1-2010 Standard (which formed the basis for the 2012 IECC requirements) has a footnote to the requirement table:

> *The table is based on steel pipe. Non-metallic pipes Schedule 80 thickness or less shall use the table values. For other non-metallic pipes having thermal resistance greater than that of steel pipe, reduced insulation thicknesses are permitted if documentation is provided showing that the pipe with the proposed insulation has no more heat transfer per foot than a steel pipe with insulation shown in the table.*

This specifically provides flexibility to designers to use thick-walled plastic piping with reduced levels of insulation, provided the alternative design has no more heat transfer than the baseline design.

Green Codes

A number of "Green Codes" or "Stretch Codes" have been developed with the intent of going beyond the minimum requirements in base codes. These model codes are available for use by jurisdictions or owners who desire improved performance. Examples include the International Green Construction Code (IgCC), the IAPMO "Green Plumbing and Mechanical Code Supplement", and ASHRAE Standard 189.1-2011 "Standard for the Design of High-

Table 6. 2012 IECC Minimum Pipe Insulation Thickness for Heating and Cooling Systems (thickness in inches)[a]

Fluid Operating Temperature Range and Usage, °F	Insulation Conductivity		Nominal Pipe or Tube Size (inches)				
	Conductivity, Btu·in/(h·ft2· °F)[b]	Mean Rating Temperature, °F	<1	1 to <1-½	1-½ to <4	4 to <8	≥8
>350	0.32 – 0.34	250	4.5	5.0	5.0	5.0	5.0
251 - 350	0.29 – 0.32	200	3.0	4.0	4.5	4.5	4.5
201 - 250	0.27 – 0.30	150	2.5	2.5	2.5	3.0	3.0
141 - 200	0.25 – 0.29	125	1.5	1.5	2.0	2.0	2.0
105 - 140	0.21 – 0.28	100	1.0	1.0	1.5	1.5	1.5
40 – 60	0.21 – 0.27	75	0.5	0.5	1.0	1.0	1.0
<40	0.20 – 0.26	75	0.5	1.0	1.0	1.0	1.0

a. For piping smaller than 1-½ inch and located in partitions within conditioned spaces, reduction of these thicknesses by 1 inch shall be permitted (before adjustment required in footnote b) but not to a thickness less than 1 inch.

b. 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,
r = actual outside radius of pipe,
t = insulation thickness listed in the table for applicable fluid temperature and pipe size,
K = conductivity of alternate material at mean temperature rating indicated for the applicable fluid temperature,
k = the upper value of the conductivity range listed in the table for the applicable fluid temperature.

c. For direct buried heating and hot-water system piping, reduction of these thicknesses by 1-½ inches shall be permitted (before thickness adjustment required in footnote b but not to thicknesses less than 1 inch.

Performance Green Buildings." While none of these model codes specifically calls out exceptions for insulation on plastic piping, alternative designs are generally allowed if justified by technical analysis. The wording in section 102.1 of the IAPMO Green Supplement is typical:

> *102.1 General. Nothing in this supplement is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this supplement. Technical documentation shall be submitted to the Authority Having Jurisdiction to demonstrate equivalency. The Authority Having Jurisdiction shall have the authority to approve or disapprove the system, method, or device for the intended purpose.*

Conclusion

All current building energy codes and standards require pipe insulation on service hot water and HVAC piping. Requirements vary, but none of the model codes differentiates pipe insulation requirements based on pipe material.

For uninsulated or bare pipe, the higher thermal resistance of the plastic pipe walls can significantly reduce heat flows compared to copper piping. As insulation levels are increased, the impact of pipe wall resistance decreases significantly. At the insulation levels required by current energy codes and standards, the impact heat loss by the pipe wall material is small.

Energy codes do not differentiate insulation requirements based on pipe wall material and the requirements should remain clear and easily verifiable.

Thermal Insulation for Mechanical Systems: Simple and Cost-Effective Technology

Thermal insulation for mechanical systems has proven to be a simple and cost-effective technology for reducing heat losses and gains in building systems. As energy codes and regulations, prescriptive and holistic, become more stringent and building owners, operators, and tenants strive for higher performing and more sustainable buildings, designers should be focusing on how and where to use more, not less, insulation. For example, some designers are considering the contribution of pipe insulation toward conserving scarce water resources as well as energy in domestic hot water delivery systems.[4]

The expected useful life of buildings can be 50 years or more. It is significantly easier and more cost effective to plan for and install proper mechanical insulation systems at the time of construction than to retrofit or upgrade the insulation systems later. Likewise, when facilities are being renovated or repaired, the opportunity to upgrade mechanical insulation systems should not be overlooked. Efforts to "trade-off" mechanical insulation levels to minimize initial costs are counterproductive and are better focused on examining the long-term performance of building systems.

Endnotes

1. Plastic Pipe and Fitting Association, "Installation Handbook: CPVC Hot & Cold Water Piping", 2002.

2. NAHB Research Center, "Design Guide: Residential PEX Water Supply Plumbing Systems", Nov 2006.

3. ASTM C680-10, "Standard Practice for Estimate of the Heat Gain or Heat Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs". ASTM International, West Conshohocken, PA 2010.

4. Klein, G., "Hot Water Distribution Research", *Insulation Outlook*, December 2011.

About NAIMA

NAIMA is the association for North American manufacturers of fiber glass, rock wool, and slag wool insulation products. Its role is to promote energy efficiency and environmental preservation through the use of fiber glass, rock wool, and slag wool insulation, and to encourage the safe production and use of these materials.

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