PIPA PLASTICS INDUSTRY PIPE ASSOCIATION OF AUSTRALIA LIMITED

# POLYOLEFINS AND PVC GUIDELINES POP206

## Thermal Insulation of Hot Water Pipes for Plumbing Applications

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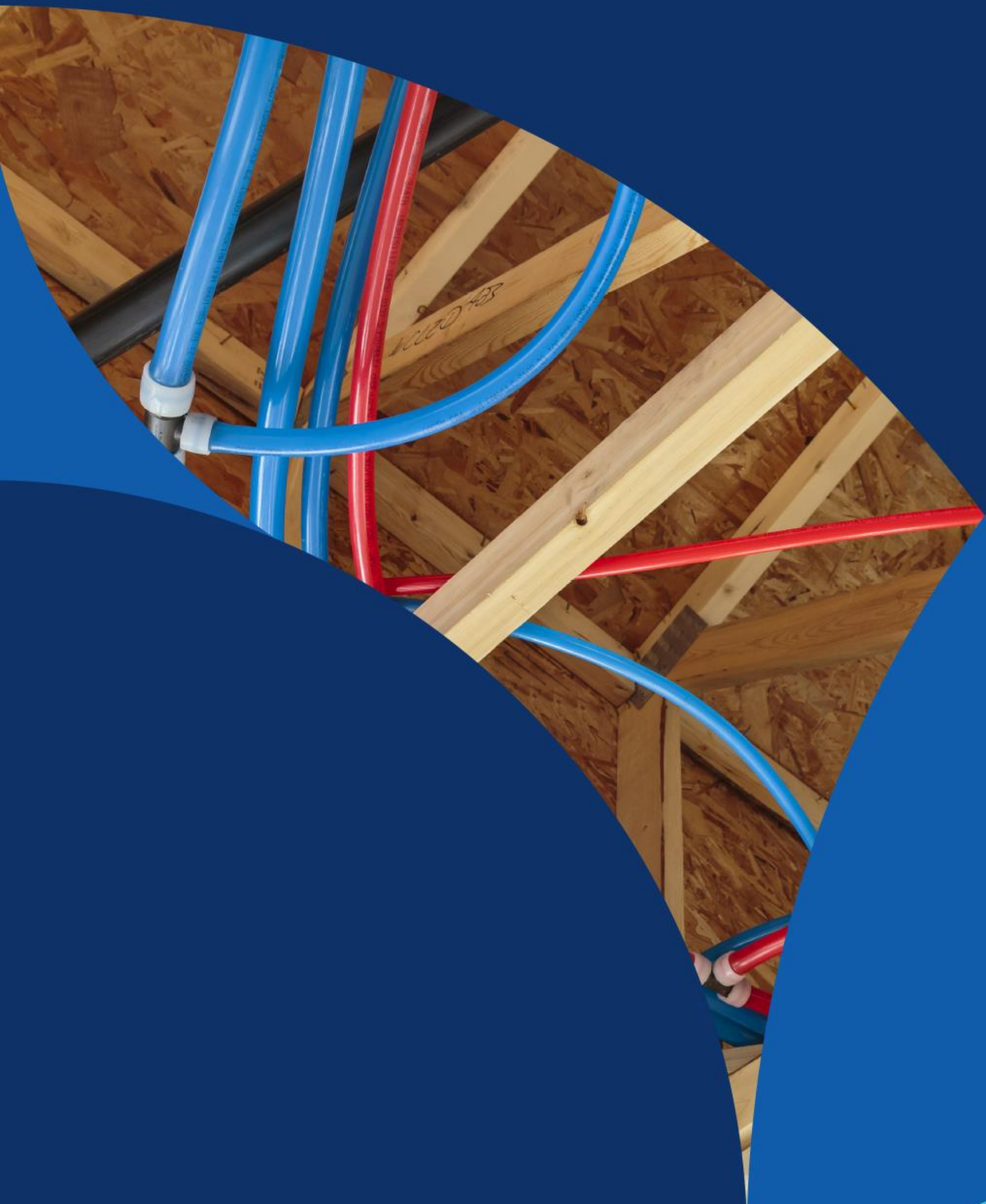

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# Thermal Insulation of Hot Water Pipes for Plumbing Applications

The hot water carried through pipe-work from a water heater to a fixture such as a kitchen sink or shower head loses heat to the surroundings. This heat loss can be significant, especially in colder climates or where the pipe-work is exposed. The rate of the heat loss is affected by many factors including the thermal conductivity of the pipe material.

It should be noted that although there are substantial differences in the coefficients of thermal conductivity of plastics pipes compared to metal ones, the insulation requirements of plastics and metal pipes do not differ very much. The thermal conductivity of the pipe material being only one of many variables in determining the rate of heat loss. Although a plastics pipe is made of a material with a comparatively low thermal conductivity and experiences a lower rate of heat loss through its wall, it also emits more heat from its surface into the air than an equivalent metal pipe. The higher heat losses from it surface can be due to a rougher surface finish, higher emissivity and the larger outer diameters of plastic pipes compared to their corresponding metal pipes. Because of this, the overall difference in heat loss might not be great and both pipes might need similar amounts of thermal insulation.

The insulation requirements for hot water pipes for plumbing applications are described in Section 8 of Australian/New Zealand Standard AS/NZS3500.4 *Plumbing and drainage, Part 4: Heated water services*. The requirements in Section 8 for insulation of pipe-work are expressed in terms of the total R-Value of the pipe and insulation and, in the case of pipework within a conduit, the airspace in the conduit. The Notes 2 of Tables 8.1 and 8.2 of AS/NZS3500.4 nominate a thickness of closed cell polymer insulation required to achieve these minimum R-Values.

An equation is provided in Clause 8.6, to enable the total R-value of a pipe and insulation to be calculated. However, the equation is only an approximation and does not take into account the geometrical factors that influence the thermal resistance of an insulated pipe.

## BACKGROUND

The requirements that appeared in AS/NZS 3500.4-2003, relating to the insulation of heated water pipe-work, originated in work that was conducted on behalf of the Australian Building Codes Board (ABCB). The results of this work were published in 2001 in two documents:

RD 2001-1: *Proposals for Services and Interim Roof Insulation*

RIS 2001-1: *Regulatory Impact Statement for RD 2001-1*

The insulation requirements proposed in RD 2001-1 strongly resemble the requirements adopted in AS/NZS 3500.4-2005. In particular, the need for certain pipes to be insulated to “R-Values” of 0.3, 0.6, 1.0 or 1.2 depending on the location and type of the pipe and the geographical area.

The document defines the “R-Value” as the “thermal resistance ($m^2$.K/W) of a material calculated by dividing the thickness by the thermal conductivity”. It also includes the following table (Table 3.12.5.4 in RD 2001-1, Attachment A):

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### Table 1
### Acceptable pipe insulation for 15mm copper pipe.

| R-VALUE | INSULATION |
|---|---|
| 0.3 | 13mm of foamed nitrile rubber |
| 0.6 | 25mm of foamed nitrile rubber or fibreglass |
| 1.0 | 38mm of fibreglass |
| 1.2 | 50mm of fibreglass |

**The Regulatory Impact Statement** (RIS) describes the method by which the optimum insulation thickness was determined, by minimising "the combined cost of the insulation and heat loss from the pipe". The results quoted in the RIS are all on the basis of the thickness of a specified insulation material. It is only in the final proposed amendment to the Building Code that this is translated into an R-Value.

A problem arose from the fact that the definition for R-Value used in the document RD 2001-1 is unsound. The definition implies that thermal resistance is a property of the material. This is incorrect, because thermal resistance is a function of both the material properties and geometry.

From the definition in RD 2001-1, we have:

$$R = \frac{t}{\lambda} \qquad (1)$$

**Where:**

$R$ = Thermal resistance ($m^2 .K/W$)

$t$ = Thickness of insulation (m)

$\lambda$ = Thermal conductivity of material (W/m.K)

Formula (1) is strictly true only for a sheet of insulation material of infinite length and width.

According to ISO 12241 *Thermal insulation for building equipment and industrial installations – calculation rules*, the thermal resistance per unit length for uniform insulation around a pipe is given by:

$$R_L = \frac{1}{2\pi\lambda}\ln\left(\frac{d+2t}{d}\right) \qquad (2)$$

**Where:**

$R_L$ = Linear thermal resistance (m.K/W)

$d$ = Diameter of pipe (m)

$t$ = Thickness of insulation (m)

λ = Thermal conductivity of insulation material (W/m.K)

This means that for a unit length of pipe, the total rate of heat flow through the insulation will be:

$$\dot{Q}_L = \frac{\Delta T}{R_L}$$

$$= \frac{2\pi\lambda\Delta T}{\ln\left(\frac{d+2t}{d}\right)} \qquad (3)$$

**Where:**

$\dot{Q}_L$ = Rate of heat flow, per unit length (W/m)

$\Delta T$ = Temperature difference between inside and outside of insulation (K)

The surface area of unit length of pipe is $\pi d$, and so the rate of heat flow per unit area of the pipe surface is:

$$\dot{q} = \frac{\dot{Q}}{\pi d}$$

$$= \frac{2\lambda\Delta T}{d\ln\left(\frac{d+2t}{d}\right)} \qquad (4)$$

Thus, the thermal resistance of the insulation around the pipe is:

$$R = \frac{\Delta T}{\dot{q}}$$

$$= \frac{d}{2\lambda}\ln\left(\frac{d+2t}{d}\right) \qquad (5)$$

An examination of equation (5) indicates a given thickness of insulation will result in a higher R-value for a larger diameter pipe than a smaller one.

Applying equation (5) to the standard size pipes used for domestic plumbing, it is possible to calculate the actual thermal resistance for foamed nitrile rubber of the thicknesses specified in Table 1. The results are shown in Table 2.

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**Table 2**
**R-Values for foamed nitrile rubber insulation on domestic plumbing pipes**

| ASSUMED R-VALUE | MATERIAL THICKNESS (MM) | CALCULATED R-VALUE ($m^2$.K/W) DN15 | DN20 | DN25 |
|---|---|---|---|---|
| 0.3 | 13 | 0.17 | 0.20 | 0.21 |
| 0.6 | 25 | 0.24 | 0.29 | 0.33 |
| 1.0 | 38 | 0.29 | 0.37 | 0.42 |
| 1.2 | 50 | 0.33 | 0.42 | 0.48 |

**Note** *The calculated R-values in this table have been determined assuming a thermal conductivity (λ) of 0.042 W/m.K for the insulation material. Using formula (1), this value of λ gives R-Values of 0.309 and 0.595 for 13 mm and 25 mm thicknesses, respectively (compared with 0.3 and 0.6 quoted in Table 1).*

Thus, the R-Values quoted in the two documents RD 2001-1 and RIS 2001-1 are significantly different from the actual thermal resistance for insulation around a pipe.

As a consequence, AS/NZS3500.4 was amended in 2005 (Amendment 1) so that the minimum total R-value of the pipe and insulation combination for heated water pipes is tabulated for a range of climatic conditions. The thickness of closed cell polymeric foam insulation that will achieve the minimum required R-value is noted for Tables 8.1 and 8.2 of AS/NZS3500.4.

## CALCULATION OF R-VALUE FOR DIFFERENT PIPE OR INSULATION MATERIALS

According to Amendment 1 of AS/NZS3500.4, the total R-value of a pipe fitted with a single layer of insulation may be calculated approximately as follows:

$$R = \frac{x_i}{k_i} + \frac{x_p}{k_p} \qquad (6)$$

**Where:**

$R$ = the total thermal resistance ($m^2$.K/W)

$x_i$ = the thickness of the insulation (m)

$k_i$ = the thermal conductivity of the insulation material (W/m.K)

$x_p$ = the thickness of the pipe wall (m)

$k_i$ = the thermal conductivity of the pipe material (W/m.K)

However, equation (6) does not take into account the influence the pipe geometry has on the thermal resistance. When required, equation (7) can be used to more accurately calculate the thermal resistance of a combination of pipe material, insulation material and pipe and insulation dimensions.

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$$R_{ACT} = \frac{d - 2t_{pipe}}{2\lambda_{pipe}} \ln\left(\frac{d}{d - 2t_{pipe}}\right) + \frac{d}{2\lambda_{ins}} \ln\left(\frac{d + 2t_{ins}}{d}\right) \qquad (7)$$

**Where:**

$R_{ACT}$ = Actual thermal resistance of the pipe / insulation combination (m$^2$.K/W)

$d$ = Outside diameter of the pipe (m)

$t_{pipe}$ = Wall thickness of the pipe (m)

$\lambda_{pipe}$ = Thermal conductivity of the pipe material (W/m.K)

$t_{ins}$ = Thickness of the insulation material around the pipe (m)

$\lambda_{ins}$ = Thermal conductivity of the insulation material (W/m.K)

For metallic pipes, the first term in this formula can usually be ignored because the value of $\lambda_{pipe}$ is very large compared with $\lambda_{ins}$. That is, the thermal conductivity of metals is very much larger than the thermal conductivity of the insulation and for metals the first term of the equation is therefore very small with respect to the second term. Plastics materials generally have lower thermal conductivities than metals and the first term of equation (7) is more significant. Typical values of thermal conductivity for a range of pipe materials are given in Table 3.

**Table 3**
**Typical values of thermal conductivity of some common hot-water pipe materials**

| PIPE MATERIAL | TYPICAL THERMAL CONDUCTIVITY (W/m.K) |
|---|---|
| Cross-linked polyethylene (PE-X) | 0.35 – 0.40 |
| Polybutylene (PB) | 0.14 – 0.22 |
| Copper (Cu) | 401 |

## EXAMPLES

1. Calculate $R_{ACT}$, the actual thermal resistance of PN20 cross-linked polyethylene pipe with 13 mm polymeric closed cell insulation shown as the minimum requirement for pipes in Table 8.1 of AS/NZS3500.4 Amdt 1.

   Solution. Using the diameters, thicknesses and thermal conductivities shown in the following table, the thermal resistances of the pipe and insulation are calculated using the first and second terms of Equation (7) respectively. The actual thermal resistance $R_{ACT}$ is the sum of the thermal resistances of the pipe and insulation.

| PIPE OUTSIDE DIAMETER (mm) | PIPE MEAN WALL THICKNESS (mm) | THICKNESS OF INSULATION (mm) | $\Lambda_{PIPE}$ (W/m.K) | $\Lambda_{INS}$ (W/m.K) | THERMAL RESISTANCE VALUE (m2.K/W) PIPE | INSULATION | $R_{ACT}$ (m2.K/W) |
|---|---|---|---|---|---|---|---|
| 16 | 2.4 | 13 | 0.35 | 0.042 | 0.0057 | 0.184 | 0.1895 |
| 20 | 3.0 | 13 | 0.35 | 0.042 | 0.0071 | 0.198 | 0.2054 |
| 25 | 3.75 | 13 | 0.35 | 0.042 | 0.0089 | 0.212 | 0.2211 |

It can be seen the total thermal resistance $R_{ACT}$ increases with increasing pipe diameter.

2. Determine the thickness of polymeric closed cell insulation required to achieve the same total thermal resistance with DN25 cross-linked polyethylene as for DN20 Type A copper.

Solution. Using the diameters, thicknesses and thermal conductivities shown in the following table, the thermal resistances of the pipe and insulation combinations are calculated using the first and second terms of Equation (7) respectively. The actual thermal resistance $R_{ACT}$ is the sum of the thermal resistances of the pipe and insulation.

| MATERIAL | PIPE OUTSIDE DIAMETER (mm) | PIPE MEAN WALL THICKNESS (mm) | THICKNESS OF INSULATION (mm) | $\Lambda_{PIPE}$ (W/m.K) | $\Lambda_{INS}$ (W/m.K) | THERMAL RESISTANCE VALUE (m2.K/W) PIPE | INSULATION | $R_{ACT}$ (m2.K/W) |
|---|---|---|---|---|---|---|---|---|
| PEX-X | 25[a] | 3.75 | 10.9 | 0.35 | 0.042 | 0.0089 | 0.188 | 0.1955 |
| Cu | 19[a] | 1.31 | 13 | 401 | 0.042 | 0.0000 | 0.195 | 0.1950 |

[a] Considered to be equivalent sizes according to AS/NZS3500

It can be seen that even though PE-X has a much lower thermal conductivity than copper, it still requires thermal insulation to satisfy the requirements of AS/NZS3500.4. It is also apparent that a slightly thinner thermal insulation could be used with PE-X compared to copper if the thinner material is commercially available. Alternatively, if 13 mm polymeric closed cell insulation is applied to both products, the total thermal resistance of the PE-X combination will be approximately 13% higher than for copper and will therefore experience slightly lower heat losses in service.

**NOTE:**

This Guideline calculates the R value of the pipe and insulation only by taking into account the dimensions and thermal conductivities of the pipe and insulation. The heat transfer coefficients of the water flowing through the pipe and of the air on the outside of the insulation are not considered, and therefore the true heat loss of the system is not defined by the calculated R value. The boundary conditions between the pipe and insulation are also ignored.

The reason for ignoring the fluid heat transfer coefficients is that they are not constant. For example, the heat transfer coefficient of the water at the inside wall of the pipe will vary with the flow conditions. Similarly, the heat transfer coefficient of the air at the outside wall will vary with the location of the pipework, weather conditions etc. As a consequence, the R values calculated from actual heat flow measurements on an insulated pipe might be higher than the theoretical values calculated according to this guideline.

For example, the heat transfer coefficient of the air on the outside of a typical pipe insulation in still air can add as much as 20% to the R value calculated according to this guideline for 13mm thick insulation.

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