ENERGY MANAGEMENT SERIES

1

FOR INDUSTRY COMMERCE AND INSTITUTIONS

# Process Insulation

Energy, Mines and Resources Canada
Energie, Mines et Ressources Canada

Canada

## PREFACE

Much has been learned about the art and science of managing energy during the past decade. Today, energy management is a seriously applied discipline within the management process of most successful companies.

Initially, in the early 1970's, energy conservation programs were established to alleviate threatened shortages and Canada's dependency on off-shore oil supplies. However, dramatic price increases quickly added a new meaning to the term "energy conservation" — reduce energy costs!

Many industrial, commercial and institutional organizations met the challenge and reduced energy costs by up to 50%. Improved energy use efficiency was achieved by such steps as employee awareness programs, improved maintenance procedures, by simply eliminating waste, as well as by undertaking projects to upgrade or improve facilities and equipment.

In order to obtain additional energy savings at this juncture, a greater knowledge and understanding of technical theory and its application is required in addition to energy efficiency equipment itself.

At the request of the Canadian Industry Program for Energy Conservation, the Commercial and Institutional Task Force Program and related trade associations, the Industrial Energy Division of the Department of Energy, Mines and Resources Canada has prepared a series of energy management and technical manuals.

The purpose of these manuals is to help managers and operating personnel recognize energy management opportunities within their organizations. They provide the practitioner with mathematical equations, general information on proven techniques and technology, together with examples of how to save energy.

For further information concerning the manuals listed below or material used at seminars/workshops including actual case studies, please write to:

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# INTRODUCTION

Thermal Insulation is defined as those materials or combination of materials which retard the flow of heat energy from a hotter media to a cooler media. Insulation offers the following benefits.

- Improves energy efficiency by reducing heat loss or gain within piping systems, process equipment, duct-work and building structures.
- Controls surface and air temperatures for personnel protection and/or comfort.
- Facilitates temperature control of a process.
- Prevents vapor flow and water condensation on cold surfaces.
- Increases operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power systems found in Industrial, Commercial, and Institutional installations.
- Reduces the size of heating, cooling and ventilating equipment thereby reducing capital and operating costs.

Proper selection and application of insulation material and thickness can provide energy and dollar savings.

## Purpose

The purpose of this module is to present the value of insulation in the effective management of energy in the Industrial, Commercial and Institutional sectors.

This module will focus on the insulation of mechanical systems such as piping, process vessels, equipment and ductwork. The benefits of insulating a building exterior are addressed in Module 18, Architectural Considerations.

Primarily, the aim of the module is to alert managers and technical personnel to the benefits of thermal insulation with respect to existing facilities and new construction. It is also intended to serve as a useful reference for the country's energy users.

Moreover, this module is also intended to provide the reader with sufficient information to analyze situations and to implement in-house insulation programs. It will provide the reader with adequate information to intelligently evaluate insulation requirements. It will also assist the reader throughout the process of engaging insulation contractors, manufacturers and energy consultants whenever their services are deemed necessary.

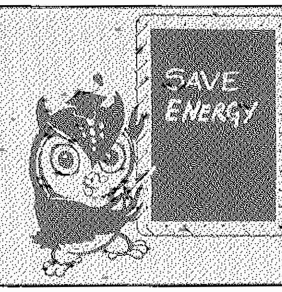
## Contents

This module is subdivided into the following sections.

- *Fundamentals* which describes the effects of insulation materials.
- *Materials/Systems* which describes commonly encountered types of insulation, coverings and protective finishes as well as common applications.
- *Energy Management Opportunities* are described and supported by examples with estimated energy and cost savings as well as simple payback calculations.
- Appendices including a glossary of terms, tables, conversion factors and blank worksheets.

Throughout the text, units are expressed in the SI system of measurements, with Imperial units provided in brackets to assist in text understanding. However, in keeping with Canada's policy of metrification, all worked examples are performed in SI units only.

# FUNDAMENTALS




Insulation can be defined as those materials, or combination of materials, which retard the flow of heat energy. Although not the most exotic of energy management technologies, insulation is certainly among the most effective. An investment in insulation usually results in increased energy efficiency, enhanced profitability and more effective energy management.

The economic benefits of insulation are based on the reduction of heat transfer to minimize the loss of heat energy and its associated cost. Cost saving opportunities from the use of insulation are greatest for applications requiring the transfer, processing and storage of heated and cooled fluids.

## Terms and Definitions

To assist in understanding the material presented in this module, certain key terms are defined. A more extensive glossary of terms is included in the Appendices.

- *Radiation* is the process by which heat flows from a higher temperature body to a lower temperature body when the two bodies are not in contact.
- *Convection* is the process of energy transfer which occurs by the combined action of heat conduction, energy storage and mixing motion.
- *Conduction* is the process by which heat flows from a region of higher temperature to a region of lower temperature within a medium (solid, liquid or gaseous), or between different mediums in direct physical contact. The observable effect of heat conduction is an equalization of temperature. However, if differences in temperature are maintained by the addition or removal of heat at different points, a continuous flow of heat will be established from the hotter to the cooler region.
- *Thermal Conductivity* (k) is a measure of heat energy transmitted through a homogeneous material per unit thickness. A material with a low thermal conductivity is a good insulator. Expressed as $W/(m \cdot {}^\circ C)$ or $(Btu \cdot in)/(h \cdot ft \cdot {}^\circ F)$.
- *Thermal Conductance* (C) is a measure of the heat energy transmitted through a homogeneous material of other than unit thickness or through an assembly. Expressed as $W/(m^2 \cdot {}^\circ C)$ or $[Btu/(ft^2 \cdot hr \cdot {}^\circ F)]$.
- *Thermal Transmittance* (U) is a measure of the heat energy transmitted by a material or assembly including the boundary air films. Expressed as $W/(m^2 \cdot K)$ or $[Btu/(h \cdot ft^2 \cdot {}^\circ F)]$.
- *Thermal Resistance* (RSI or R) indicates the relative insulating value or resistance to heat flow of material. Thermal Resistance is the primary consideration in the choice of an insulating material. The higher the R value the better the insulation.

It should be noted that k, C, U, R can be equated as follows.

$$R = \frac{t}{k} = \frac{1}{C} = \frac{1}{U}$$

Where, t = material thickness (metres or inches)

- *Mean Temperature* is the arithmetic average of the hot and cold insulation surface temperatures through which heat is transmitted.
- *Emissivity* is the ratio of heat energy radiated from a surface compared to the heat energy radiated from an ideal black body at the same temperature.

- *Black Body* is defined either as a body which absorbs all radiation falling upon it and reflects or transmits none, or as a radiator which emits, at any specific temperature, the maximum possible amount of thermal radiation.

# Important Properties in the Selection of Insulation.

The following is a list of important properties which must be considered in the selection of an insulating material.

- *Thermal Resistance.* The higher the thermal resistance value the better the insulating capability of the material.
- *Combustibility.* This becomes significant as it provides an indication of the insulating material's contribution to a fire hazard.
- *Shrinkage.* Shrinkage or drying is significant in high temperature applications. Shrinkage can leave noninsulated gaps.
- *Resistance to Ultraviolet Radiation.* Where the insulating material is exposed to sunlight in outdoor applications, its ability to withstand ultraviolet radiation without degradation is important. This can be overcome by covering the insulating material so that sunlight does not contact the material.
- *Resistance to Fungal or Bacterial Growth.* This property is significant in food or cosmetic processing areas.
- *Chemical Neutrality.* The insulation should be chemically neutral (pH 7) to avoid any deterioration of metal contacting it. This is particularly important in applications where the insulation could be subject to intermittent wetting.
- *Coefficient of Expansion and Contraction.* This property becomes important in the design and location (spacing) of expansion and contraction joints and in multiple layer insulation applications.
- *Compressive Strength.* Compressive strength is significant where the insulating material must support a load or withstand mechanical abuse without crushing.. When cushioning or filling in space is needed, such as in expansion/contraction joints, low compressive strength materials would normally be specified.
- *Breaking Load.* Breaking load is significant in installations where the insulation is applied over irregular or non-uniform surfaces where the insulation must "bridge" over a support discontinuity.
- *Capillarity.* Where insulation material is in contact with dangerous or flammable liquids, or in areas where wash down occurs, the resisting capability of the material to "wick-up" (absorb) liquids by capillary action becomes significant.
- *Appearance.* Appearance is significant in exposed areas and for purposes of identification.
- *Density.* The density of an insulating material affects many other of its properties, especially its thermal properties.

Some of these factors may not apply in all insulation applications, however, each should be considered, and ruled out if not applicable. Worksheet 1-1 has been developed as a checklist to assist in establishing which properties are important in a specific application.

Properly installed, mechanical insulation will have a life equal to the life of the equipment or piping on which it is installed. Mechanical insulation should always be installed according to the manufacturer's installation recommendations.

# Heat Transfer Properties

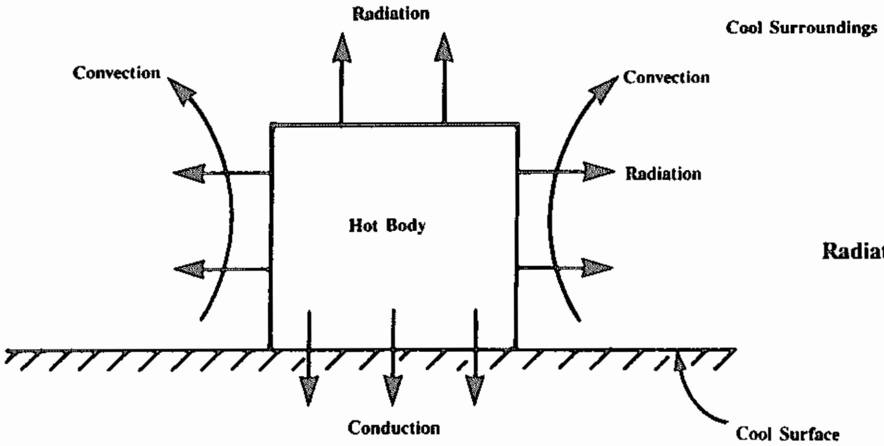
A hot object can lose heat in three ways. (Figure 1)

- Radiation to the surroundings.
- Convection to the fluid surrounding it.
- Conduction to other bodies that are in contact with it.

### Radiation

*Radiation is a process by which heat flows from a higher temperature body to a lower temperature body when the two bodies are not in contact. The energy transmitted in this manner is termed radiant heat.* All bodies emit radiant heat continuously. The intensity of the emission depends on the temperature and nature of the body's surface.

When radiation waves encounter another body, their energy is absorbed near its surface. Heat transfer by radiation becomes increasingly important as the temperature of an object rises. Radiant heating is often neglected at atmospheric temperature conditions.




**Radiation - Convection - Conduction**

Figure 1

### Convection

*Convection* is the process of energy transfer by which by the combined action of heat conduction, energy storage, and mixing motion. Convection is the most important mechanism of energy transfer between a solid surface and a liquid or a gas.

The transfer of energy by convection takes place in several steps. First, heat will flow by conduction from the surface to the adjacent particles of fluid. The energy transferred will increase the temperature and the internal energy of the fluid particles. The fluid particles will move to a region of lower temperature, where they will mix with, and transfer a part of their energy to, other particles. The flow in this case is of fluid, as well as energy. The net effect is a transport of energy, and since it occurs in the direction of a temperature gradient only, it is referred to as *heat flow by convection.*

### Conduction

Conduction is the process by which heat flows from a region of higher temperature to a region of lower temperature within a medium (solid, liquid or gaseous), or between different media in direct physical contact. In conduction heat flow, the energy is transmitted by direct molecular contact without appreciable displacement of the molecules. The observable effect of heat conduction is an equalization of temperature between two bodies in contact. However, if differences in temperature are maintained by the addition or removal of heat at different points, a continuous flow of heat will be established from the hotter to the cooler region.

## Heat Flow

The term *heat flow* refers to the rate at which heat moves from an area of higher temperature to an area of lower temperature. *The purpose of any insulation material is to retard heat flow.* The term thermal conductivity (k) is used to express the quantity of heat which will flow across a unit area when a temperature difference of one degree exists.

Thermal conductivity (k), is expressed as Watts per metre per degree Celcius [W/(m·°C)] or [(Btu)/(h·ft²·°F)].

Thermal Resistance can now be defined as the opposition of the passage of heat through the insulation and is expressed by the following equation.

$$\text{Thermal Resistance} = R = \frac{t}{k} \ [(\text{m}\cdot{}^\circ\text{C})/\text{W}] \text{ or } [(\text{h}\cdot\text{ft}\cdot{}^\circ\text{F})/\text{Btu}]$$

Where, t = insulation thickness [metres or inches].

The higher the value of R, the better the insulation.

The heat flow through the insulation for a flat surface may be calculated using the following equation.

$$\text{Heat flow in one hour} = \frac{DT \times A}{R} \text{ Wh}$$

Where, DT = Temperature difference across the insulating material (°C)

A = surface area ($m^2$)

As an example, consider a $10m^2$ flat surface at a temperature of 140°C. This surface has been insulated with a 51 mm thick insulating material having a thermal conductivity of 0.045 W/(m·°C). The outer surface temperature of the insulation is 10°C. The thermal resistance can be determined as follows.

$$R = \frac{t}{k}$$

$$= \frac{0.051}{0.045}$$

$$= 1.133 \text{ (m·°C)/W}$$

Now the heat flow in one hour through the insulation can be determined.

$$\text{Heat flow in one hour} = \frac{DT \times A}{R}$$

$$= \frac{(140 - 10) \times 10}{1.133}$$

$$= 1147.4 \text{ Wh}$$

Heat flow through pipe insulation is somewhat different since the inner and outer surfaces of the insulation have different areas. This difference in area must be taken into account in heat flow calculations. As the heat from the pipe flows outward through the insulation, the area of the heat flow path becomes greater. This phenomenon has the effect of increasing the value of the thermal resistance.

To compensate for this effect an "equivalent thickness" of insulation must be used. The expression for the thermal resistance for piping insulation can now be rewritten as follows.

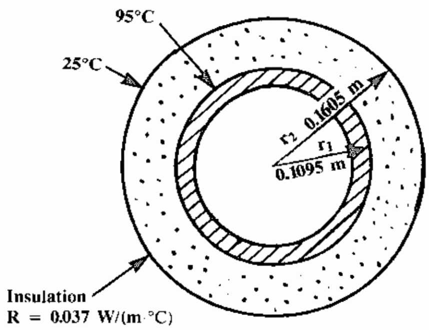
$$R = \frac{\text{equivalent thickness}}{\text{conductivity}} \quad [(m^2·°C)/W]$$

$$= \frac{r_2 \ln \frac{r_2}{r_1}}{k}$$

Where, $r_2$ = outside radius of insulation (m)

$r_1$ = inside radius of insulation (m)

ln = natural (or Napierian) logarithm




**Typical Insulated Pipe**
Figure 2

For example, consider the heat loss from a 1 metre length of 0.219 metre diameter pipe operating at 95°C. The 51 mm thick insulation has a thermal conductivity of 0.037 W/(m·°C) and an outside surface temperature of 25°C. This example is shown in Figure 2. The heat flow through the insulation can be determined as follows.

$$r_2 = \frac{0.219}{2} + 0.051$$

$$= 0.1605 \text{ m}$$

$$r_1 = \frac{0.219}{2}$$

$$= 0.1095 \text{ m}$$

$$R = \frac{r_2 \ln \frac{r_2}{r_1}}{k}$$

$$= \frac{0.1605 \text{ x } \ln \frac{0.1605}{0.1095}}{0.037}$$

$$= \frac{0.1605 \text{ x } \ln (1.466)}{0.037}$$

$$= \frac{0.1605 \text{ x } 0.3825}{0.037}$$

$$= 1.66 \text{ (m}^2\text{·°C)/W}$$

$$\text{Heat Flow in one hour} = \frac{\text{DT x A}}{\text{R}}$$

$$= \frac{(95 - 25) \text{ x } 1.008}{1.66} \text{ Wh}$$

$$= \frac{70 \times 1.008}{1.66}$$

$= 42.51$ Wh/metre of length of the pipe

It must be noted that A in the above equation is the outside surface area of a 1 metre length of the insulated pipe and is calculated as follows.

Where, $\pi = 3.14159$

D = outside diameter of insulation (pipe outside diameter + 2 x insulation thickness)

1 = unit length (in this case 1 metre)

Therefore $A = \pi \times (0.219 + 2 \times 0.051) \times 1$

$= \pi \times (0.321) \times 1$

$= 3.14159 \times 0.321$

$= 1.008\ m^2$

# Protective Coverings and Finishes

The efficiency and service life of insulation is directly dependent upon its protection from moisture entry and mechanical and/or chemical damage. Choices of jacketing and finish materials are based upon the mechanical, chemical, thermal and moisture conditions of the installation, as well as cost and appearance.

Protective coverings are divided into six functional types.

- Weather barriers, which protect the insulation from the effects of weather.
- Vapor retarders, which are designed to retard the passage of water vapor from the atmosphere to the insulation.
- Mechanical protection coverings, which protect against mechanical damage from personnel, equipment and machinery.
- Low flame spread and corrosion resistant coverings, which reduce the effect of flame spread and corrosion.
- Coverings and finishes are available to enhance the aesthetic appearance of insulated surfaces in highly visible areas.
- Hygienic covers, which present smooth surfaces to resist fungal and bacterial growth.

Additional details on protective coverings and finishes may be found in the Material/Systems section of this module.

# Vapor Retarders

A vapor retarder is a material which retards the transmission of water vapor under specific conditions. The Canadian General Standards Board has prepared a Standard, 51-GP-52M, which provides an outline for two different types of vapor retarder jacketing and facings for mechanical systems applications – types 1 and 2.

A vapor retarder is required when insulation is applied to piping or equipment intended for operation below ambient temperature. A type 1 vapor retarder has a low permeance rating and good puncture resistance while a type 2 vapor retarder has a standard permeance rating and moderate puncture resistance.

Permeance is the water vapor transmission capability of a material caused by a unit vapor pressure difference between two specified surfaces. The standard unit of permeance is the perm.

A metric perm = 1 $ng/(Pa \cdot s \cdot m^2)$.

Type 1 vapor retarders are intended for insulation jackets on piping in exposed and concealed areas and for insulation facings on ducts and equipment in exposed areas. A type 1 vapor retarder has a water vapor permeance of 1.10 perm. These jackets are primarily intended for indoor applications.

Type 2 vapor retarders are intended for insulation facings on ducts and equipment in concealed areas. For a type 2 vapor retarders the water vapor permeance is 1.70 perm.

Some insulation materials such as mineral fibers and calcium silicate, are permeable to water vapor and allow moisture to diffuse through the insulation. Some insulations such as foam glass have a low vapor permeability and may, with tight joints, provide a satisfactory vapor retarder.

If condensation of water occurs within insulation, its insulation properties are significantly reduced. The reduction is directly proportional to the volume per cent of water filled insulation. Moisture penetration through the insulation may cause corrosion of the mechanical system. It is important, in high humidity areas, to have a continuous unbroken vapor retarder to prevent these occurrences.

Field-applied, semi-liquid mastic compositions and coating barriers have low permeance after curing. They are intended for application by spraying, brushing or trowelling. The manufacturers' specified thickness must be applied in one or more continuous coatings. Suitable reinforcement may be required as the vapor retarder system must be adequate to resist cracking.

Pressure-sensitive adhesive tapes can also be used as an integral part of the vapor retarder system. Care should be taken to apply adequate pressure to ensure a permanent bond.

## Personnel Safety

One of the roles of insulation is to control surface temperature for personnel protection. The 1985 National Building Code of Canada states that pipes exposed to human contact shall be insulated so the exposed surface does not exceed 70°C. Provincial and local codes and standards must also be followed in any insulation application.

## Insulation Temperature Ranges

The temperature range within which the term "thermal insulation" applies, is from −73°C (−100°F) to 982°C (1800°F). All applications below −73°C (−100°F) are termed *cryogenic* and those above 982°C (1800°F) are termed *refractory*.

Thermal insulation is further divided into three general application temperature ranges.

### Low Temperature Thermal Insulation

Insulation used for low temperature applications is subdivided into three general temperature ranges.

- 16°C (60°F) through 0°C (32°F) – cold or chilled water.
- −1°C (31°F) through −39°C (−39°F) – refrigeration or glycol.
- −40°C (−40°F) through −73°C (−100°F) – refrigeration or brine.

The major problems on low temperature installations are moisture penetration and cost effectiveness. Ideally, the insulation material or system should absorb no moisture and readily give up any that enters. It should also resist water deterioration.

Vapor retarders are used extensively, but in practice, it is almost impossible to achieve a perfect vapor retarder. The pressure of the vapor flow from the warm outside surface is such that, even with water-proof insulations, vapor may enter through unsealed joints or cracks, condense, then freeze, and cause damage. Vapor retarders must have a perm rating well below 1. The colder the equipment, the lower the desirable perm rating.

Since the cost of refrigeration is higher than the cost of heating, more insulation is often justified in low temperature applications. Extra thicknesses of insulation, even beyond what would be economically dictated for cold line application, are sometimes employed to keep the warm surface temperature above the dewpoint.

### Intermediate Temperature Thermal Insulation

This temperature range, from 16°C (61°F) to 315°C (600°F) includes conditions encountered in most industrial processes and in hot water and steam systems found in commercial installations. Selection of material in this range is based more on thermal values than with low temperature applications. However, other factors such as mechanical and chemical properties, availability of forms, installation time and cost are also significant.

### High Temperature Thermal Insulation

High temperature thermal insulation is used in the temperature range of 315°C (600°F) to 870°C (1600°F). As the refractory range of insulation is approached, fewer materials and application methods are available. High temperature materials are often a combination of other materials or of similar materials manufactured using special binders. Jacketing is generally field applied. Industrial power and process piping and equipment, commercial boilers, exhausts, furnaces and incinerators fall within this application range.

## Selection Procedures

Although insulating uninsulated areas means immediate returns in dollars saved, sometimes the long-term potential dollar savings are forgotten. Any facility that has not had its insulation upgraded in the past five years is likely to be under-insulated.

*Immediate savings can be realized from insulating where no insulation exists.* This includes piping, tanks, vessels as well as valves and fittings. With respect to valves and fittings, the insulation would normally be specified to the standards and thicknesses of the surrounding piping insulation, ducting or equipment.

### Recommended Insulation Thickness

Tables 1 and 2 have been included in the Appendices and provide data which is used to perform energy savings calculations. These tables indicate the heat loss from bare steel pipe and bare steel flat surfaces over the range of temperatures normally encountered in most facilities, and are based on an ambient air temperature of 21.1°C.

For process applications, tables based on economics have been developed which provide a recommended insulation thickness for various insulating materials and temperatures. Table 3 is a typical table covering mineral fiber, calcium silicate, and cellular glass insulation for pipes varying from NPS 1/2 to NPS 36 in diameter and process temperatures between 65 °C and 566°C. These tables also include flat surfaces.

It must be noted for a round tank or vessel with diameter greater than 914 mm, the surface is considered flat for purposes of heat loss calculations.

As an example of the use of these tables, consider an NPS 6 steel pipe without insulation operating at 121°C in ambient conditions of 21.1°C. Table 1 indicates this pipe will lose 700 Wh/lineal metre of heat every hour it is in operation. If the recommended thickness of 76 mm of mineral fibre insulation as indicated in Table 3 were installed on this pipe, the heat loss would be reduced to 37 Wh/lineal metre and the outer surface temperature of the insulation would be 23°C.

Insulation manufacturers have prepared tables for other materials since the thermal resistance varies both with the material being used and the process temperature. In the event that tables cannot be obtained, heat loss from piping and flat surfaces may be calculated using the equation in the previous section of this module entitled Heat Flow, and R values as selected from Table 4.

A series of calculations will have to be performed and the energy savings compared to the installed cost of the insulation.

This is necessary to establish the economic thickness of the insulation.

One way of improving cost savings through insulation is to upgrade to the insulation levels shown in the recommended thickness tables (Table 3). These should be used as guidelines.

In some cases these tables will not apply as plant or building conditions may not be the same as those used to determine the thickness charts. In these cases, individual determinations of insulation thickness should be considered to insure a facility is making its optimum investment in insulation.

### Limited Budget Insulation Thickness

Generally for hot mechanical systems, piping will be the source of greatest heat loss. *If on a limited budget, determine where the area of greatest heat loss is and insulate it first.* The first 25 mm of insulation will provide the greatest savings in energy on a system but may not be the optimum insulation level for maximizing investment benefits. This can also be an excellent approach to cost reductions if insulation is to be paid out of an annual maintenance or operating budget. Bear in mind though, if only the minimum 25 mm is applied, the labour component may be the same as if a greater thickness of insulation were used.

## Economic Insulation Thickness

Insulation can be considered a long-term investment with associated financial benefit, following a relatively short initial payback. There are a number of computer programs available to aid in selecting the most economic insulation thickness. This is the thickness which provides the highest insulation value for the lowest cost. For additional information on economic insulation thickness refer to Appendix E.

Economics is the primary concern in evaluating investment alternatives. When applied to an insulation system, economics can be used to establish the following items.

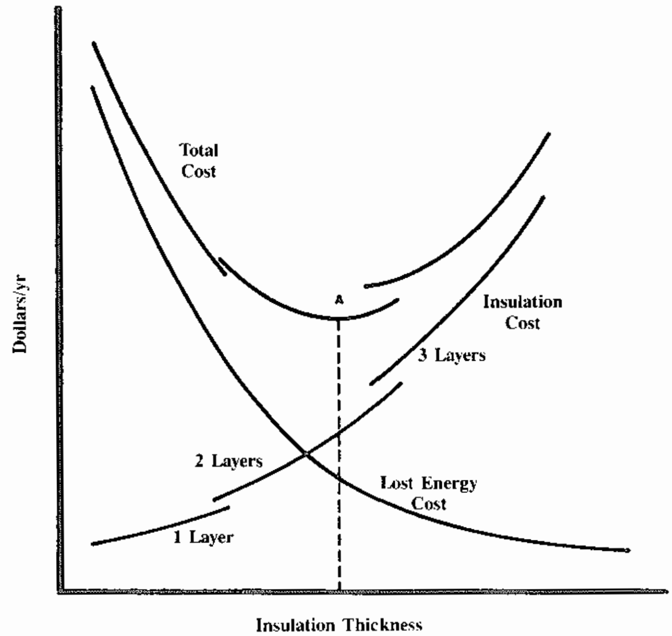
- Evaluation of two or more insulation materials for lowest cost for a given thermal performance.
- Selection of the optimum insulation thickness for a given insulation type.

In either case, economics is used to determine the most cost effective solution for insulating.

Beyond the optimum economic thickness, additional insulation does not yield the maximum rate of return on investment.

Labour and material costs increase with insulation thickness. Insulation must often be applied in multiple layers because materials are not manufactured in single layers of sufficient thickness and/or to alleviate expansion and contraction movements. This results in higher total labour costs than to install one layer equal to the cumulative thickness. Figure 3 is a typical representation of installed costs for a multilayer application. The average slope of the curves increases with the number of layers, because labor and material costs increase at a more rapid rate as insulation thickness increases.

The cost of lost energy is directly related to the rate of heat transfer through the insulation and the dollar value of the energy. As also shown in Figure 3, the cost of lost energy decreases as insulation thickness increases.




**Determination of Economic Thickness of Insulation**
Figure 3

Consider a process application with a flat surface holding a process fluid at 150°C. The ambient temperature is 20°C.

Calculation of heat loss for 50, 75 and 100 mm of glass mineral fiber insulation with a density of 24 kg/m$^3$ can be performed to establish the heat losses at the various insulation thicknesses.

Process temperature: 150°C
Ambient Temperature: 20°C
DT: 150-20 = 130°C

From Table 5 thermal conductivity (k) at a mean temperature of 93.3°C (closest value not exceeding 130°C) is 0.053 W/(m·°C).

The thermal resistance (R) can be calculated for the various insulation thickness using the equation

$$R = \frac{t}{k}$$

$$R_{50} = \frac{0.050}{0.053} = 0.943$$

$$R_{75} = \frac{0.075}{0.053} = 1.415$$

$$R_{100} = \frac{0.100}{0.053} = 1.887$$

The surface area will remain constant for the insulation since this is a flat surface.
Heat loss can now be evaluated for a typical 1 $m^2$ area for each insulation thickness.

$$\text{Heat loss in one hour} = \frac{DT \times A}{R}$$

$$\text{Heat loss (50 mm insulation)/m}^2 \text{ in one hour} = \frac{130 \times 1}{0.943}$$

$$= 137.86 \text{ Wh}$$

$$\text{Heat loss (75 mm insulation)/m}^2 \text{ in one hour} = \frac{130 \times 1}{1.415}$$

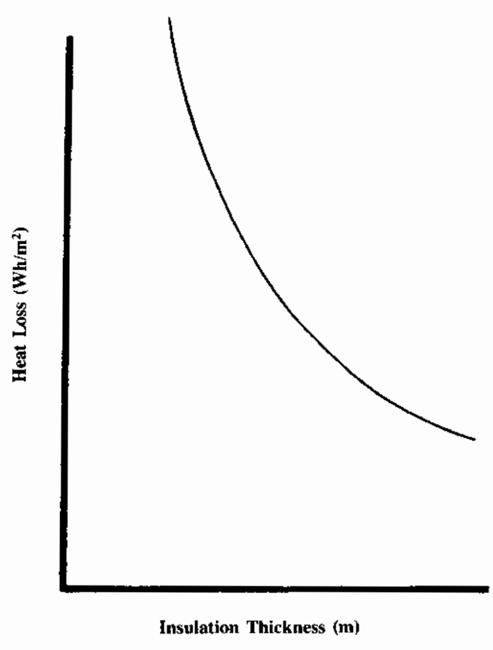
$$= 91.873 \text{ Wh}$$

$$\text{Heat loss (100 mm insulation)/m}^2 \text{ in one hour} = \frac{130 \times 1}{1.887}$$

$$= 68.89 \text{ Wh}$$

Using Table 2 it is established that the heat loss from one square metre of the same surface with no insulation would be approximately 2100 Wh/$m^2$.

These figures can be plotted on a graph (Figure 4) showing insulation thickness versus heat loss to generate a heat loss curve.




**Heat Loss From Flat Surface**
Figure 4

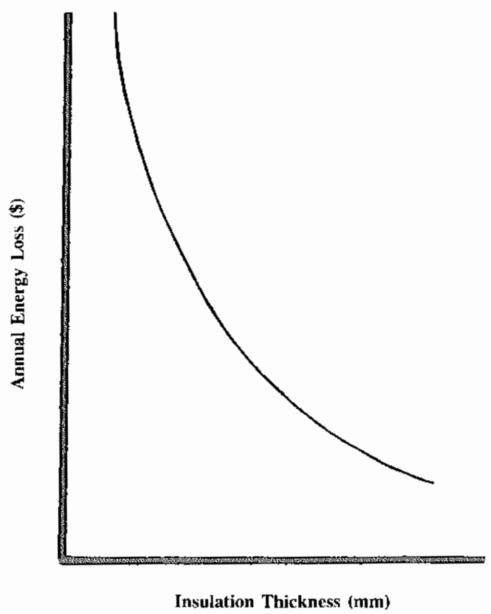
Knowing the value of the heat energy, the cost of lost heat at the various insulation thicknesses can be established by the following equation.

Dollar loss per unit area = Heat loss per unit area x $ per unit of heat energy

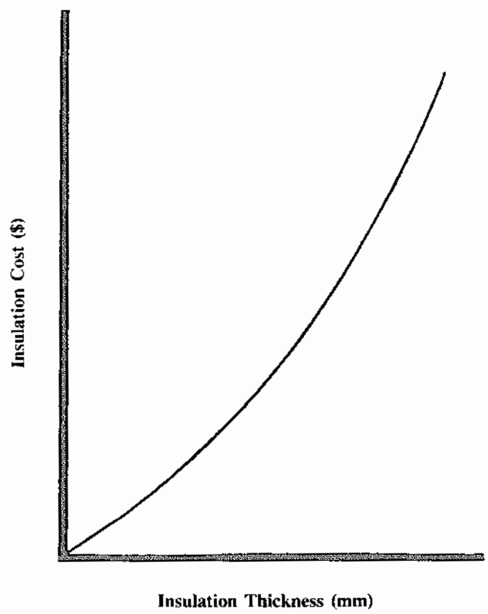
Total dollar loss (Figure 5) = Total area x $ Loss/unit area x hours/year

The installed cost of the insulation for the various thicknesses can now be established and a second curve (Figure 6) can be produced.

Figures 5 and 6 may be superimposed and will produce a curve generally of the shape of Figure 3. If the dollar loss and insulation cost curves are combined, and a new curve plotted, the insulation thickness equivalent to the low point on the new curve will be the economical insulation thickness.




**Cost of Energy Loss at Various Insulation Thicknesses**
Figure 5




**Insulation Cost at Various Thicknesses**
Figure 6

# Energy Audits

An energy audit involves the identification of areas throughout a facility where energy may be wasted because of nonexistent, or inadequate insulation.

The audit may be applied to the facility as a whole, or may be concentrated on specific pieces of process equipment or piping systems.

### Walk Through Audit

The initial action is a *Walk Through Audit* which is a tour through the facility looking for obvious signs of energy waste. The walk through audit is generally more meaningful if it is conducted by an individual who, though not associated with the facility operation, is familiar with both the subject of process insulation and the concept of energy management.

Typical items which could be noticed during a walk through audit would include missing or damaged insulation, hot or cold surfaces, wet insulation, deteriorating insulating coverings or protective finishes, missing or damaged vapor retarders, gaps in insulation at expansion/contraction joints, excessive heat radiating from insulated surfaces and other similar items.

**Diagnostic Audit**

Once items have been identified in the walk through audit, a diagnostic audit is required to determine the existing energy loss, the reduction in energy loss which would result if new or additional insulation or covering were installed and the installed cost of the added material. The reduction in energy consumption establishes the dollar savings.

With this information, simple payback calculations can establish the financial viability of the opportunity.

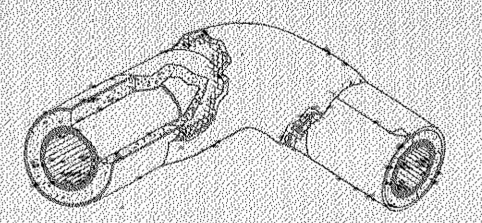
# Energy Management Opportunities

Energy Management Opportunities can be divided into three categories.

- *Housekeeping*, refers to an energy management action that is *repeated on a regular basis and never less than once a year.* Examples include repairing damaged insulation coverings, finishes and insulation.
- *Low Cost*, refers to an energy management action that is *done once, and for which the cost is not considered great*. Examples of low cost items could be the insulation of valves and fittings and the replacement of coverings and finishes.
- *Retrofit*, refer to an energy management action that is *done once, and for which the cost is significant*. Examples of retrofit items could be the insulation of piping, ductwork, vessels, tanks, and equipment, upgrading insulation to the recommended thickness, and upgrading protective coverings on outdoor tanks and vessels.

It must be noted that the dollar division between low cost and retrofit is normally a function of the size, type and financial policy of the organization.

# MATERIALS SYSTEMS



This section of the module describes the types of insulation which would normally be encountered and their potential uses and applications. The review of materials also includes the types of protective coverings and finishes and their applications.

## Types and Forms of Insulations

Insulation materials are addressed in the following text according to their generic *types* and *forms*. *Type* indicates composition and internal structure, while *form* implies overall shape or application.

Types are normally subdivided into the following three groups.

- *Fibrous Insulation* – is composed of small diameter fibers which finely divide the air space. The fibers may be parallel or perpendicular to the surface being insulated and they may be separated or bonded together. Glass, rock wool, slag wool and alumina silica fibers are used. Glass fiber and mineral wool (rock and slag) are the most widely used insulations of this type.
- *Cellular Insulation* – is composed of small individual cells separated from each other. The cellular material may be glass or foamed plastic such as polystyrene (closed cell), polyurethane and elastomeric.
- *Granular Insulation* – is composed of small nodules which contain voids or hollow spaces. It is not considered a true cellular material since gas can be transferred between the individual spaces. This type may be produced as a loose pourable material, or combined with a binder and fibers to make a rigid insulation.

Insulation is produced in a variety of forms suitable for specific functions and applications. The combined form and type of insulation determines the proper method of installation. The forms most widely used follow.

- Rigid boards, blocks, sheets and pre-formed shapes (i.e. pipe covering, curved segments, lagging). Cellular and granular insulations are produced in these forms.
- Flexible sheets and pre-formed shapes. Cellular and fibrous insulations are produced in these forms.
- Flexible blankets. Fibrous insulations are produced in flexible blankets.
- Cements (insulating and finishing). Produced from fibrous and granular insulations and cement. They may be of the hydraulic air setting or air drying type.

## Major Insulation Materials

The following is a general inventory of the characteristics and properties of major insulation materials used in Industrial, Commercial and Institutional installations.

- *Calcium Silicate* is a granular insulation made of lime and silica, reinforced with organic and inorganic fibers and molded into rigid forms. The temperature range covered is from 38°C (100°F) to 982°C (1800°F). Flexural strength is good. Calcium Silicate is water absorbent, however, it can be dried out without deterioration. The material is noncombustible and used primarily on hot piping and surfaces. Jacketing is generally field applied.
- *Cellular Elastomeric* insulation is composed principally of natural or synthetic elastomers, or both, processed to form a flexible, semi-rigid, or rigid foam with a predominantly closed-cell structure. Upper temperature limit is 104°C (221°F).
- *Cellular Glass* is fabricated into boards, pipe covering and other shapes. Service temperatures range from −40°C (−40°F) to 482°C (900°F). This material has a low thermal conductivity at low temperatures, low abrasion resistance, good resistance to substrate corrosion, and good sound absorption characteristics in fiber and cellular form.

- *Fibrous Glass* products are manufactured in a variety of forms including flexible blankets, rigid and semi-rigid boards and pipe coverings. Service temperatures range from −73°C (−110°F) to 538°C (1000°F) depending on structure and binder. Glass fibers are bonded together with heat resisting binders. Conductivity of fibrous glass products is low. Cutting characteristics are good. The resilience of glass fiber is high while the impact resistance is low. Installation costs are low. There are good sound absorption characteristics with glass fiber insulation.
- *Foamed Plastic* insulations are predominantly closed cellular rigid material. Thermal conductivity may deteriorate (i.e. increase) with time due to aging because of air diffusing into the cells. Foamed plastics are light weight with excellent cutting characteristics. The materials themselves are combustible, but can be produced self-extinguishing. They are available in pre-formed shapes and boards. Foamed plastics are generally used in lower and intermediate temperature ranges.
- *Insulating and Finishing Cements* are a mixture of various insulating fibers and binders with water and cement, to form a soft plastic mass for application on irregular surfaces. Installation costs are high, and insulation values are only fair. Cements may be applied to high temperature surfaces. Finishing cements are one-coat cements used in the lower to intermediate temperature range.
- *Mineral Fiber or Mineral Wool* is produced by bonding rock and slag fibers together with a heat resistant binder. The upper service temperature limit can reach 982°C (1800°F). The material is non-combustible. Mineral fiber is available in both rigid pre-formed shapes for piping and vessels, and as a flexible blanket. It is used in high and intermediate temperature ranges.
- *Refractory Fiber Insulations* are mineral or ceramic fibers, including alumina and silica, bound with extremely high temperature binders. They are manufactured in blanket or rigid brick form. Thermal shock resistance and temperature limits are high. The material is non-combustible.

Common insulation materials are summarized in Table 6.

# Insulation Systems

As an owner contemplating the insulation of equipment or mechanical systems, it is helpful to think of an insulation system as having the following three components.

- Insulating material.
- Protective covering or finish.
- Accessories to secure, fasten, stiffen, support, seal or caulk the insulation and its protective covering or finish.

These components must be compatible for the insulation system to function properly.

# Protective Coverings and Finishes

As indicated in Fundamentals, the efficiency and service of insulation is directly dependent upon its protection from moisture entry and mechanical or chemical damage. Choices of jacketing and finish materials are based upon the mechanical, chemical, thermal and moisture conditions of the installation, as well as cost and appearance.

Protective coverings are divided into six functional types.

### Weather Barriers

The basic function of the weather barrier is to prevent the entry of water. If water is deposited within the insulation, its insulation properties will be significantly reduced. Applications consist of either a jacket of metal or plastic, or a coating of weather barrier mastic (Table 7). Jacketing must be overlapped sufficiently to repel water. The use of plastic jacketing materials with low resistance to ultraviolet rays should be avoided unless protective measures are taken.

### Vapor Retarders

Vapor retarders are designed to retard the passage of moisture vapor from the atmosphere to the surface of the insulation (Table 8). Joints and overlaps must be sealed with a vapor tight adhesive or sealer. Refer to Table 8 for detailed information on types of vapor retarders plus characteristics of each type.

Vapor retarders are available in three forms.

- *Rigid jacketing* – reinforced plastic, aluminum or stainless steel fabricated to the exact dimensions and sealed vapor tight.

- *Membrane jacketing* – metal foils, laminated foils and treated or coated papers which are generally factory applied to the insulation material. (Additional sealing beyond the factory seal may be necessary depending on the installation temperature and humidity conditions.
- *Mastic applications* – either emulsion or solvent types which provide a seamless coating but require time to dry.

### Mechanical Abuse Coverings

Metal jacketing provides the strongest protection against mechanical damage from personnel, equipment, and machinery. The compressive strength of the insulation material should also be considered when assessing mechanical protection.

### Low Flame Spread and Corrosion Resistant Coverings

When selecting material for potential fire hazard areas, the insulation material and the jacketing must be considered as a composite unit. Most of the available types of jacketing and mastic have low (less than 25) flame spread rating. This information can usually be obtained from manufacturer's data.

Resistance to corrosion varies among the plastic and metal jacketing materials. Of the metal jackets, stainless steel is the most successful in resisting corrosive atmospheres, spills or leaks. Mastics are also generally resistant to corrosive atmospheres.

### Appearance Coverings and Finishes

Various coatings, finishing cements, fitting covers and jackets are chosen primarily for their appearance value in exposed areas. Typically for piping, jacketed insulations are covered with a reinforcing canvas and coated with a mastic to give a smooth even finish. When dry it can be painted or left as is to give a white colour.

### Hygienic Coverings

Coatings and jackets must present a smooth surface which resists fungal or bacterial growth, especially in food processing areas. High temperature steam or high pressure water wash down conditions require jackets with high mechanical strength and temperature ratings (plastics or metals are typically used).

## Properties of Protective Coverings

Certain properties of jacketing and mastic materials that must be considered to meet the previously listed functions follow.

### Compatibility

Coverings must be compatible with the insulation material over which they are applied, as well as with elements in the environment such as industrial chemicals, salt air and ultraviolet or infrared light.

### Resistance to Internal and External Movement

The ability of a covering to resist movement is an important element to consider if there will be thermal expansion and contraction of the insulation it covers (i.e. shrinkage of high temperature insulation), or if a significant amount of vibration must be considered.

### Temperature Range

The covering must be suitable for the operating temperature of the insulation surface.

### Vapor Permeability

Coverings should have low vapor permeability on low temperature installations to prevent, or at least retard the passage of moisture vapor into the insulation. For high temperature applications, a vapor permeable covering should be used to allow moisture to pass outwards.

## Accessories

The term *accessories* is applied to devices or materials serving one or more of the following functions.

- Securement of the insulation and/or jacketing.

- Insulation reinforcement for cement or mastic applications.
- Stiffening around structures which may not support the weight of high density insulations.
- Supports (pipe, vessel and insulation).
- Sealing and caulking.
- Water flashing.
- Compensation for expansion/contraction of piping and vessels.

Improper application of any of these accessories could be a significant factor in the failure of insulation systems.

**Securements**

Insulation is not a structural material and must be supported, secured, fastened or banded in place. Securements must be compatible with insulation and jacketing materials. Possible choices are listed below.

- Welded studs and pins.
- Staples.
- Clips.
- Wire and metal straps.
- Self-adhering laps on outer jackets.
- Adhesives.

Ambient temperature and humidity conditions affect the effectiveness of tapes and adhesives on certain installations. Check the temperature range and vapor permeability properties before choosing adhesives.

**Insulation Reinforcement for Cement and Mastics**

Whether factory or field applied, mechanical strength can be added to insulations through the application of any of the following items.

- Canvas.
- Glass fiber fabric.
- Expanded metal lath.
- Metal mesh.
- Wire netting (chicken wire).

Compatibility of materials must be considered to prevent corrosion.

**Water Flashing**

Flashing directs the flow of water away from the insulation and may be constructed of metal or plastic.

**Stiffening**

Metal lath and wire netting can be applied on high temperature surfaces before insulation is applied.

**Supports**

Insulation at points of support is necessary to minimize heat loss. Accessories which may be used at points of support are as follows.

- High density insulation inserts to protect insulation at points of support.
- Pipe support saddles and shoes.
- Metal shields used to protect insulation.
- Wood blocks or dowels for load bearing.

**Sealing and Caulking**

A variety of sealers, caulking and tapes are available for sealing vapor and weather barrier jackets, joints and protrusions. These products are manufactured in a large range of temperature and vapor permeability properties. Some are designed specifically for use with one type of insulation or manufacturer's product.

### Expansion/Contraction Compensation

Accessories used in the design of expansion/contraction joints, include the following:

- Manufactured overlapping or slip joints.
- Bedding compounds and flexible sealers.

## Common Applications

The following section deals with typical application methods experienced in the insulation industry. They should not be considered as the only methods of applying insulation and may not be the only methods recommended for an installation. For example, different thicknesses and different insulations may require radically different attachment methods because of weight. Also, system temperature plays a big part in deciding which application method is most suitable. Insulation contractors or manufacturers are usually willing to recommend the most appropriate application method.

Pipe covering is generally the dominant part of a mechanical insulation system. This section describes a number of different pipe insulation installation methods. Typical duct, vessel and tank insulation systems are also shown.

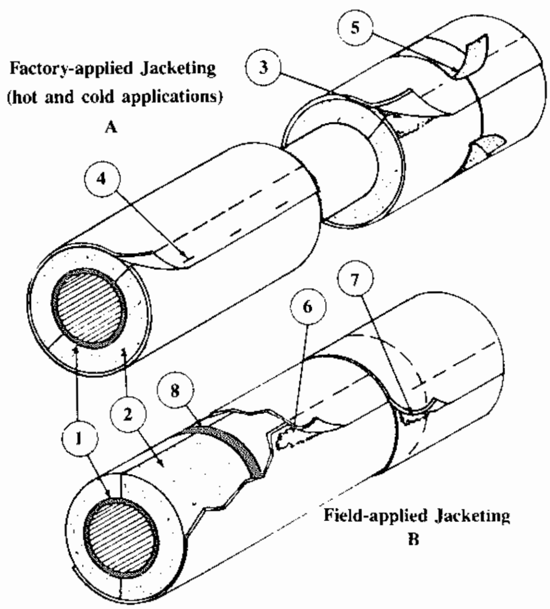
### Multiple Layer Construction

Multiple layer construction is the use of more than one layer of insulation rather than a single layer of equivalent thickness. This application method provides compensation for expansion and contraction where pipe or equipment temperatures are high . Staggering of joints in multiple layer construction reduces heat loss at the joints thus creating a more thermally efficient installation. This method of application may be used where available insulation thicknesses are less than that required, or for retrofitting applications. Care should be taken with pipe insulations to ensure that dimensional measures coincide with standard industry practice to provide a proper fit for multiple layer construction.

### Pipe Insulation for Interior Applications

A jacketing material is generally applied to mineral fiber pipe insulation for the purpose of protection or to act as a vapor retarder. The application is suitable for hot or cold temperature conditions. The type of jacketing used depends on the end use conditions (Figure 7). Generally the jacket is a laminate of kraft and foil with a glass fiber scrim reinforcement. Other materials may be used in cases where greater protection or a different finish is required.

The jacketed product may be left exposed, or finished with a canvas and lagging material to provide a smooth, neat and long lasting finish.




**Field and Factory-Applied Non-Metal Jacketing**
Figure 7

1. Pipe.
2. Insulation.
3. Longitudinal lap on factory-applied jacket (self-adhesive or secured with adhesive.)
4. Longitudinal lap on factory-applied jacket secured with staples (staples are coated with vapor-barrier mastic on cold applications.)
5. Circumferential butt strip. Self adhering or field adhered.
6. Longitudinal overlap on field-applied jacketing is adhered with appropriate adhesive or sealer.
7. Butt joint overlap sealed (tape at overlap joints is optional on cold applications.)
8. Wire, tapes or bands securing insulation in place before the jacket is applied.

### Metal Jacketing

Metal jacketing is generally used to protect insulation from physical damage (Figure 8). It is particularly useful for outdoor applications. The jacketing material may also be chosen to resist chemical attack. For example, a highly corrosive atmosphere may require the application of a stainless steel jacketing system instead of the standard aluminum material.

### Flexible Elastomeric Pipe Covering

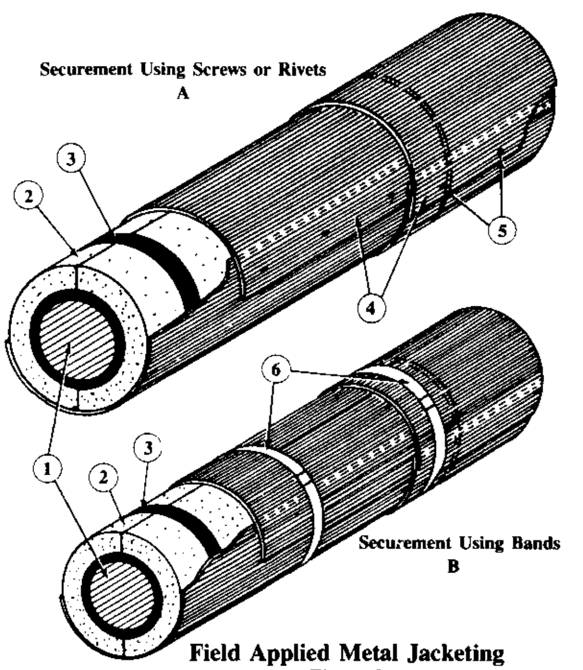
Flexible elastomeric pipe covering is used on cold temperature piping such as air-conditioning systems (Figure 9). It is generally manufactured as a continuous tube which can be pushed over small diameter piping during installation. Slitting before installing is another option. Joints are sealed with contact adhesive.

### Fittings Insulation

Insulation of fittings on a job is an extremely important part of the overall system (Figure 10). The insulation of elbows is usually accomplished by using mitered pipe insulation. Generally the same material and size of insulation is used to make the elbow insulation. Where a Victaulic type pipe fitting is used, insulation is either built up to a greater thickness than the surrounding line pipe insulation, or standard pipe covering is grooved out to fit around the coupling. In some cases, pre-formed fitting insulation is available to simplify the installation. The insulated fitting is then covered with cloth or canvas and lagging material for protection and a neat finish.

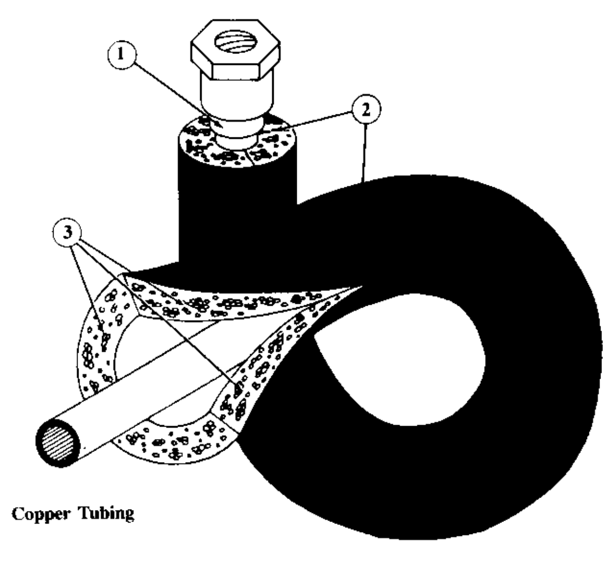
### PVC/Glass Fiber Fitting Insulation

PVC fitting covers are generally used for hot or cold commercial applications where a neat finish is sufficient and a final finishing method (i.e. canvas) is not required (Figure 11). These fittings are easy to install and come in different colours (white being the most common) with either a dull or shiny appearance. PVC jacketing may also be used to protect piping insulation.



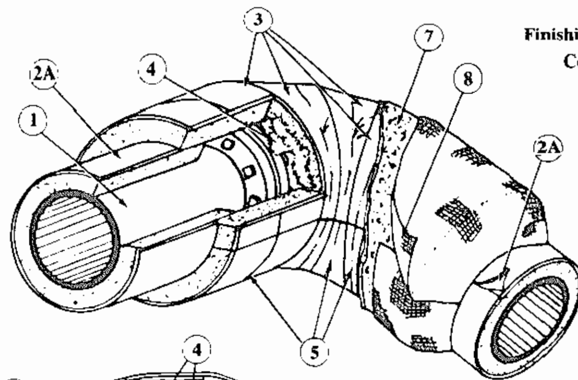

**Field Applied Metal Jacketing**
Figure 8

1. **Pipe.**
2. **Insulation.**
3. **Wire, tape or bands securing insulation in place.**
4. **Overlaps positioned to shed water (butt joint overlaps should be wide enough to provide weatherproofing.)**
5. **Rivets or screws at longitudinal laps for securement.**
6. **Metal bands at butt joint overlaps, and spaced between butt joints for jacket securement.**

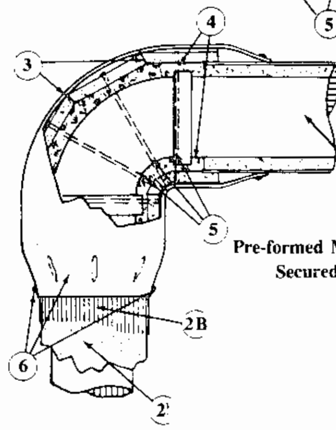



**Flexible Elastomeric Pipe Covering**
Figure 9

1. **Pipe or tubing.**
2. **Insulation (to facilitate sweating of joints, insulation can be pulled back temporarily on either side of the connection then released to extend over the joint before sealing.)**
3. **Contact adhesive is applied to both surfaces of longitudinal and butt joints.**



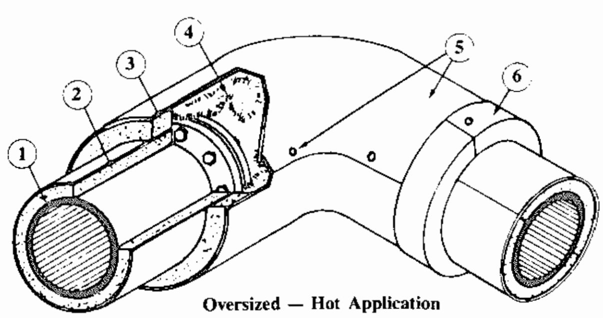
Finishing or Insulating Cement
Covered With Fabric
A



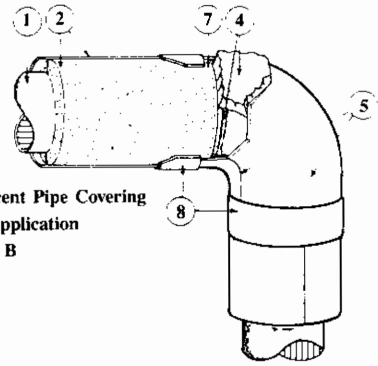
Pre-formed Metal Elbow Cover,
Secured With Screws
B

**Mitered Insulation Elbow**
**Oversized Application**
Figure 10

1. Pipe.
2. Pipe insulation (shown in A) with factory applied non-metal jacketing (metal jecketing shown in B). Jacketing extends under the fitting insulation and finish.
3. Mitered segments of pipe covering, cut to form a tight fit (adhesive between miters on pre-fabricated applications or when required.)
4. Glass fiber fill insulation (optional — used as a means of support when the mitered elbow has not been pre-fabricated into two self supporting halves.)
5. Wire or banding (unnecessary when pre-fabricated)
6. Pre-formed metal elbow cover secured with sheet metal screws.
7. Finishing cement applied to smooth surface.
8. Fabric applied with adhesive on the surface of finishing or insulating cement.



Oversized — Hot Application
A



Direct to Adjacent Pipe Covering
Cold Application
B

**PVC/Glass Fiber Elbow Insulation System**
Figure 11

1. Pipe.
2. Pipe insulation (shown with factory-applied jacket).
3. Collar of oversized pipe insulation.
4. Glass fiber insert wrapped around the elbow.
5. PVC fitting cover.
6. Reducing end cap.
7. Vapor retarder adhesive on all joints and overlaps (cold applications only.)
8. Vapor retarder tape.

## Insulation of In-line Flanges or Couplings

In-line flanges or couplings, are difficult to insulate with standard sized products. In these cases a blanket wrap insulation is used to surround the coupling and is finished with either canvas and lagging, or a PVC fitting cover (Figure 12).

## Removable and Reusable Insulation

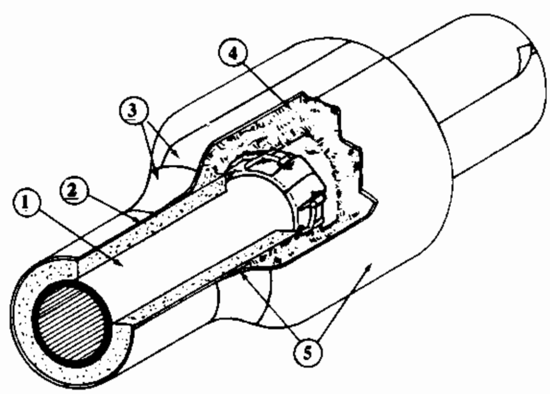
Removable insulations may be used where valves require constant maintenance. These are made of a fabric cover with a contained insulation, and a fastening system such as the one shown (Figure 13).

## Duct Insulation

Ducts can be insulated with either a flexible blanket type product or with a rigid board system (Figure 14). The rigid board system offers superior abuse resistance, but may be more difficult to apply because of the necessity of cutting and fitting around connections and changes in direction.

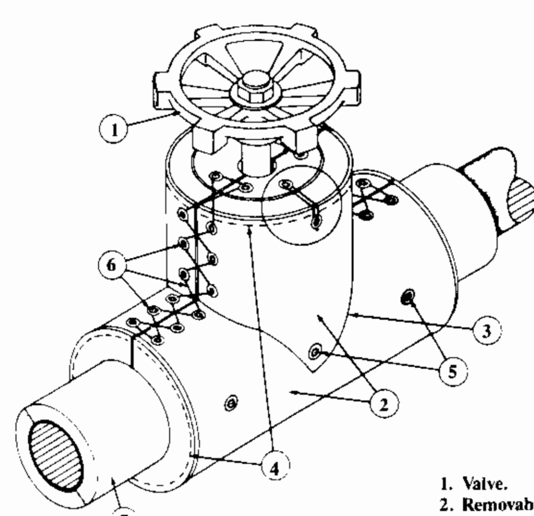
Where a vapor retarder system is required for cold or dual temperature ducting, care should be taken to seal all joints with adhesive to maintain the vapor retarder. Any punctures of the vapor retarder facing should be vapor-sealed.

Rigid board insulations with factory applied jacketing should have joints and edges sealed with an adhesive backed vapor retarder tape. Blanket wrap insulations may be available with a lap joint which can be sealed with a vapor retarder adhesive.



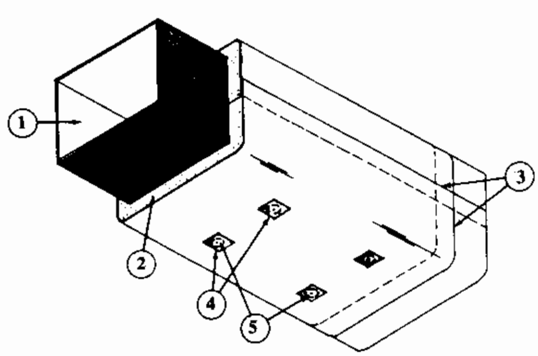

**PVC/Glass Fiber Coupling or In-Line Flange Insulation System**
Figure 12

1. **Pipe.**
2. **Pipe insulation (factory applied jacket).**
3. **Vapor retarder tape along longitudinal seam and around ends.**
4. **Glass fiber insert wrapped around the coupling.**
5. **PVC cover extending over the pipe insulation.**




**Removable and Reusable Insulation**
Figure 13

1. **Valve.**
2. **Removable cover.**
3. **Machine stitching.**
4. **Metal stitching at edges.**
5. **Quilting washer.**
6. **Lacing hooks and wire.**
7. **Adjacent insulation.**




**Flexible Fibrous Blanket Duct Insulation Rectangular/Indoors**
Figure 14

1. **Rectangular duct.**
2. **Blanket insulation (shown with factory-applied vapor retarder jacket).**
3. **Factory lap (sealed with adhesive and/or staples or vapor retarder tape).**
4. **Vapor retarder tape over tears and penetrations of the vapor retarder jacket (optional in hot applications.)**
5. **Mechanical fasteners supporting insulation on the underside of ducts ovedr 24" wide (spaced 3" from the butt joint.)**

### Field Applied Lining

When field applied to the inside surface of housings or shafts, insulation is attached by means of adhesives and mechanical fasteners, depending on the size of the housing and the velocity of the air moving through it (Figure 15). Transverse joints and exposed edges are taped or coated with sealer to hold the insulation firmly in place.

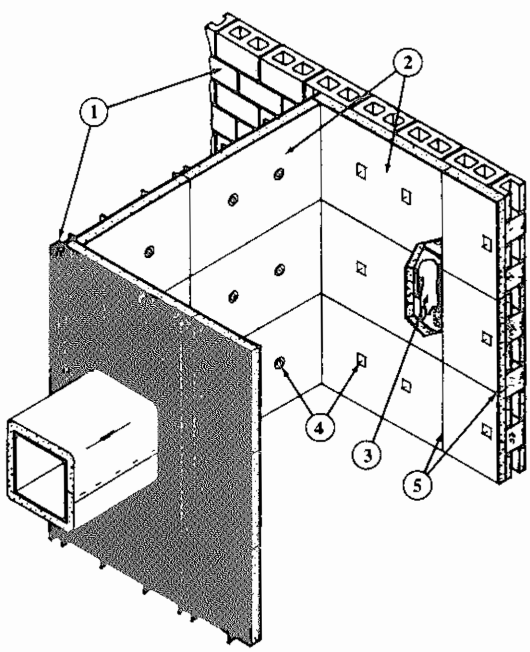
### Insulation of Tanks and Vessels

The choice of application method depends on the conditions of the system. If welding pins onto an existing tank or vessel (Figure 16) is dangerous then the insulation can be secured by banding in place.

Either flexible batt or rigid board insulation may be used to insulate tanks or vessels. Choice of type of product may be recommended by the insulation manufacturer. Rigid insulations such as calcium silicate will have to be scored to conform to the curvature of the tank. Mineral fiber insulations may be bent to conform to the vessel shape.

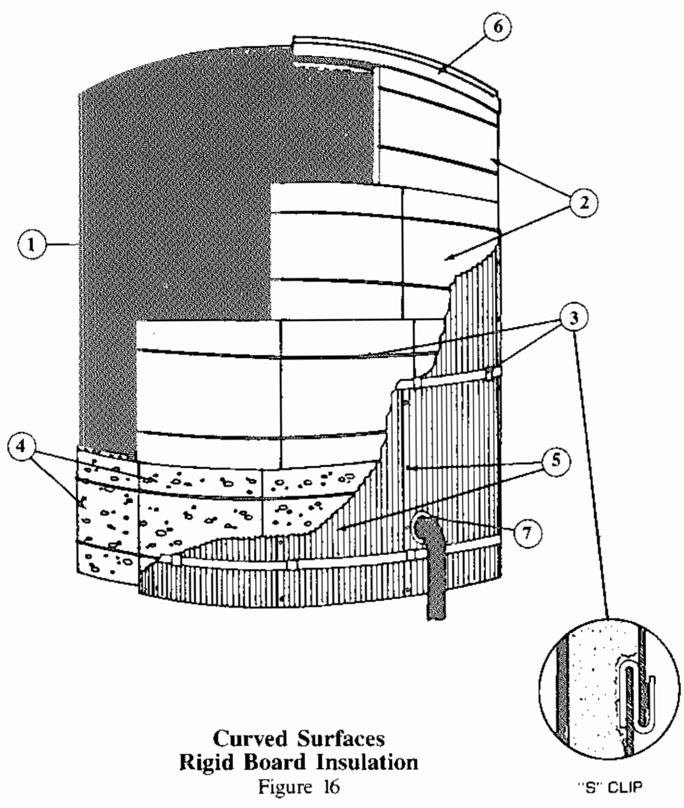
Where the tank or vessel comes in contact with the ground, an insulation material that does not wick or absorb moisture should be used around the base of the tank. Cellular glass is typically used.

Weather protection of insulated outdoor tanks and vessels is a key requirement. Sheet steel or aluminum panels are fastened together with vertical and horizontal laps sufficient to shed rain water to protect the insulation.




**Field Applied Lining**
**Ducts, Plenums and Housings**
Figure 15

1. **Housing or shaft.**
2. **Liner or fibrous board insulation.**
3. **Adhesive.**
4. **Mechanical fasteners.**
5. **Joint sealer**



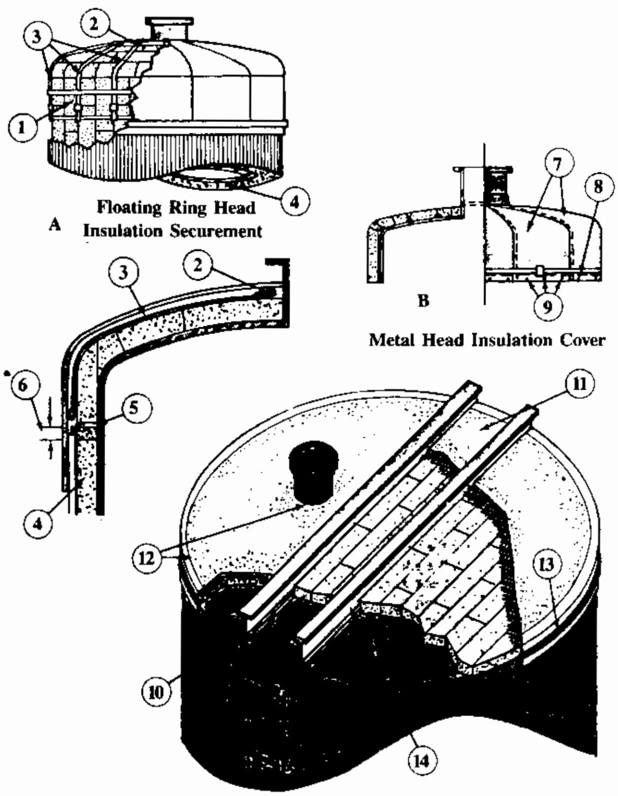

**Curved Surfaces**
**Rigid Board Insulation**
Figure 16

1. **Vessel wall.**
2. **Insulation board, scored or beveled to fit the curvature of the vessel surface.**
3. **Stainless steel bands and "S" clips as required (see inset). An alternate method of securement is impalement of insulation on mechanical fasteners.**
4. **Bottom tier of insulation is cellular glass in areas where water absorption and wicking may occur (optional).**
5. **Corrugated or smooth sheet metal sheathing.**
6. **Head flashing.**
7. **Caulking/flashing at fittings**

## Vessel and Tank Head Insulation

Vessel tops are a major source of heat loss. Thus, the insulation of the tops of tanks and vessels (Figure 17) is important to maintain temperature within the process. Proper protection of the insulation on the top of the tank or vessel is critical to prevent heat loss in the system.

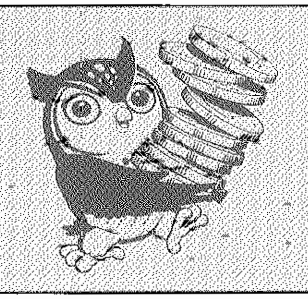
In addition to the insulation method shown, flat tank surfaces are normally insulated by roofing contractors. The nature of the insulation system is critical and should be performed by qualified insulation contractors only.




**Head Insulation, Securement and Cover Fabrication**
Figure 17

1. Head insulation (rigid block is shown).
2. Floating ring of cable.
3. Head bands on 12" centers.
4. Shell insulation.
5. Head insulation supporting ring (not required for horizontal vessels).
6. 1" joint between support ring and shell insulation packed with mineral or glass fibre insulation.
7. Segments of flat sheet metal cut in wedge shapes, to overlap and conform to the surface of the head insulation.
8. Band at base of head insulation cover.
9. Sheet metal screws on 3" centres along horizontal and vertical seams.
10. High density insulation for walkway.
11. Roofing materials or reinforced mastic.
12. Caulking and flashing as required.
13. Banding to secure rim angle.
14. Metal I-beams used to stiffen head structure.

# ENERGY MANAGEMENT OPPORTUNITIES



Energy Management Opportunities is a term that represents the ways that energy can be used wisely to save money. A number of typical Energy Management Opportunities subdivided into Housekeeping, Low Cost, and Retrofit categories are outlined in this section with worked examples to illustrate the potential energy savings. This is not a complete listing of the opportunities available for insulation. However, it is intended to provide ideas for management, operating and maintenance personnel to allow then to identify other opportunities that are applicable to a particular facility. Appropriate modules in this series should be considered for Energy Management Opportunities existing within other types of equipment and systems.

The following text briefly highlights several Energy Management Opportunities and is followed by worked examples or explanatory text for illustrative purposes.

## Housekeeping Opportunities

Implemented housekeeping opportunities are energy management actions that are *done on a regular basis and never less than once a year.* The following are typical Energy Management Opportunities in this category.

1. Repair damaged insulation.
2. Repair damaged coverings and finishes.
3. Maintain safety requirements.

## Housekeeping Worked Examples

**1. Repair Damaged Insulation**

During a walk through audit of a process facility it was noted that the insulation on an NPS 4 pipeline had been damaged and removed for a 10 metre length. This pipeline was carrying high temperature process fluid at 121°C and the ambient temperature was 18°C. The original insulation was 76 mm thick mineral fiber.

A diagnostic audit was performed to establish the heat loss from this section of pipe before and after the damaged insulation had been removed to establish the additional energy loss without insulation.

From Table 1 the heat loss from NPS 4 pipe at 121°C is approximately 530 Wh/m.

From Table 3 the heat loss for the same piping with 76 mm of mineral fiber insulation is 28 Wh/m.

For a 10 metre length, the reduction in heat loss is now calculated.

Heat loss reduction per hour = 10 x (530 − 28)

= 10 x 502

= 5020 Wh/h

If the pipe in question is in operation 8760 hours per year the annual heat loss reduction can be calculated.

Annual heat loss reduction = Hourly heat loss reduction x operating hours per year

= 5020 x 8760

= 43 975 200 Wh/yr or 43 975.2 kWh/yr.

If the process fluid is heated by electricity which costs \$0.05/kWh, the reduction in heat loss can be equated to a dollar savings as follows.

Annual dollar savings = Annual reduction in heat loss x energy unit cost

$$= \frac{43\ 975\ 200\ \text{kWh/yr}}{1000} \times \$0.05/\text{kWh}$$

$$= \$2{,}198.76/\text{yr}$$

The estimated cost to supply and install 10 meters of 76 mm glass fiber insulation was \$500.00

$$\text{Simple payback} = \frac{\$500.00}{\$2198.76}$$

$$= 0.23 \text{ years (3 months)}$$

A further benefit of the insulation is the removal of a potential employee burn hazard. Without insulation, the pipe surface temperature would be approximately 121°C. By adding the insulation the outer surface of the insulation would be 23°C.

This is a housekeeping item even though there is a cost involved for the replacement of the 10 metres of insulation because it is considered as a part of the normal housekeeping/maintenance program in any facility.

To assist in performing the calculation Worksheet 1-2 has been developed and is completed for this specific example.

**2. Repair Damaged Insulation Covers and Finishes**

Damage to the insulation cover and finish can expose the insulation and leave it susceptible to damage by water, sunlight and mechanical abuse. Damage will reduce the effectiveness of an insulation and thus will increase the heat loss and its associated cost.

**3. Maintain Safety Requirements**

As indicated in Fundamentals, the National Building Code of Canada states that "pipes that are exposed to human contact shall be insulated such that the temperature of the exposed surface does not exceed 70°C. At temperatures above the stated 70°C major burn hazards exist. A review of Table 3 shows that the insulation surface temperatures never approach this figure.

## Low Cost Opportunities

Implemented low cost opportunities are energy management actions that are *done once and for which the cost is not considered great*. The following are typical Energy Management Opportunities in this category.

1. Insulate noninsulated pipe.
2. Insulate noninsulated vessels.
3. Add insulation to reach recommended thickness.

## Low Cost Worked Examples

**1. Insulate Noninsulated Piping**

During a walk through audit of a facility it was noted that an NPS 2 branch steam main 20 metres long feeding a new unit heater had not been insulated during the original installation. The steam temperature was 121°C. It was decided to investigate the potential energy and dollar savings if this main was insulated with the recommended thickness of cellular glass insulation. The main was in operation 2880 hours per year.

From Table 3 it was established that the recommended thickness of cellular glass insulation for this application was 64 mm, and the heat loss if this amount of insulation were installed would be 35 Wh/m From Table 1 the heat loss from this same pipe with no insulation is 290 Wh/m.

Using Worksheet 1-2 the annual reduction in heat loss due to the addition of insulation would be 14 688 000 Wh/yr or 14 688 kWh/yr or 52 876.8 MJ/yr.

Steam was produced in a boiler operating at 75 per cent efficiency using natural gas as the fuel at a cost of \$0.21./$m^3$.

From Appendix C it is established that the heating value of natural gas is 37.2 MJ/$m^3$.

$$\text{Dollar savings} = \frac{52\ 876.8 \times 0.21}{37.2 \times 0.75}$$

$$= \$397.99/\text{yr.}$$

Estimated cost to supply and install the insulation is \$400.

$$\text{Simple payback} = \frac{\$400.00}{\$397.99}$$

$$= 1.0 \text{ years}$$

**2. Insulate Noninsulated Vessels**

During a walk through audit of a facility it was noted that a tank 2 m long by 1 m wide by 1 m deep, with a hinged lid, was not insulated, even though the tank was maintained at 177°C for 8760 hours per year.

A diagnostic audit was performed to establish the potential energy and cost savings if the vessel was insulated with the recommended insulation thickness of mineral fiber insulation.

$$\text{Vessel surface area} = A_{Top} + A_{Sides} + A_{Bottom}$$

$$= (2 \times 1) + [(2 \times 1) + (2 \times 1) + (1 \times 1) + (1 \times 1)] + (2 \times 1)$$

$$= 2 + 6 + 2$$

$$= 10 \text{ m}^2$$

From Table 3 the recommended insulation thickness for a flat surface at 177°C is 102 mm, and its heat loss is 63 Wh/$m^2$. Worksheet 1-3 is used to calculate the annual reduction in heat loss due to the addition of insulation as 551 880 kWh/yr.

On the basis that the vessel is heated with electric immersion heaters, and the energy cost for electricity is \$0.05/kWh, the annual potential dollar savings may be calculated.

$$\text{Annual Savings} = 551\ 880 \times \$0.05$$

$$= \$27{,}594$$

Estimated cost to supply and install 100 mm of mineral fiber insulation on the top, side and bottom of the tank is \$3,600.

$$\text{Simple payback} = \frac{\$3{,}600}{\$27{,}594}$$

$$= 0.13 \text{ years } (1\tfrac{1}{2} \text{ months})$$

It should be noted that the surface temperature of the insulation will be 25°C which satisfies the National Building Code Standards.

**3. Add Insulation to Reach Recommended Thickness**

During a walk through audit of a facility, it was noted that a 2 m diameter vessel, with a surface area of 25 $m^2$ containing a liquid being maintained at 65°C was insulated with 25 mm of mineral fiber insulation. The vessel was in operation 8400 hours per year and was heated with electricity at a cost of $0.05/kWh.

Using Table 3 the recommended insulation thickness for this application was 51 mm with an associated heat loss of 32 Wh/$m^2$. A diagnostic audit was performed to establish the energy and cost savings if the insulation was increased in thickness to the recommended 51 mm.

Manufacturer's data for 25 mm of mineral fiber insulation under these conditions indicated the heat loss was 105 Wh/$m^2$ of surface area of the tank.

Worksheet 1-3 is used twice. The first time to calculate the reduction in heat loss from a bare vessel to 25 mm of insulation and the second time to calculate the reduction in heat loss between the bare vessel and 51 mm of insulation.

The energy savings in adding 26 mm of insulation and increasing the overall thickness to 51 mm can be calculated.

Energy Savings = Savings with 51 mm − Savings with 25 mm

= 81 900 000 − 61 950 000

= 19 950 000 Wh/yr

or 19 950 kWh/yr

Dollar Savings = 19 950 x $0.05

= $997.50

Estimated cost to supply and install the additional insulation is $4000.

$$\text{Simple payback} = \frac{\$4000}{\$997.50}$$

= 4.01 years

# Retrofit Opportunities

Implemented retrofit opportunities are energy management actions which are *done once and for which the cost is significant*. Many of the opportunities in this category will require detailed analysis by specialists, and cannot be covered in this module. The following are typical Energy Management Opportunities in the retrofit category.

1. Upgrade existing insulation levels.
2. Review economic thickness requirement.
3. Limited budget upgrade.

# Retrofit Worked Examples

**1. Upgrade Existing Insulation Levels**

During a walk through audit it was noted that an NPS 6 steam header operating at 288°C for 8760 hours per year was insulated with cellular glass insulation. The steam header was 100 metres long.

A review of Table 3 indicated that the heat loss for this main based on the cellular glass insulation was 145 Wh/m. It was further noted that if the insulation was changed to mineral fiber, the heat loss would be reduced to 99 Wh/m. It should be noted that the insulation thickness remained the same.

Annual energy savings of mineral fiber insulation can be calculated.

Annual energy savings = (Cellular glass loss − mineral fiber loss) x Length x operating hours per year

= (147 − 100) x 100 x 8760

= 41 172 000 Wh/yr

or = 41 172 000 x 3.6

= 148 219 200 kJ/yr

or = 148 219.2 MJ/yr

The steam was produced in a boiler operating at 76 per cent efficiency using natural gas at a cost of $0.21/m³ as the fuel.

$$\text{Dollar savings} = \frac{148\ 219.2 \times \$0.21}{37.2 \times 0.76}$$

= $1,100.95/yr

The estimated cost to replace the cellular glass insulation with glass fiber insulation was $11,000.

$$\text{Simple payback} = \frac{\$11{,}000}{\$1{,}100.95}$$

= 10 years

In this case the replacement is not justified based on the payback. However, if the original insulation had been less than the recommended thickness, the heat loss and therefore the savings would have been much greater. This would have to be calculated using insulation manufacturers' published data.

**2. Review Economic Insulation Thickness**

As indicated in the Fundamentals section of this module, in some instances, the economic insulation thickness should be considered and compared to recommended insulation thickness to establish potential savings.

**3. Limited Budget Upgrade**

During a walk through audit of a facility which was being considered for purchase, it was noted that numerous steam branch mains were not insulated. These steam mains varied in size from NPS 1 to NPS 6. It was estimated that the equivalent length would be equal to 350 m of NPS 4. The temperature of the steam was 121°C and the mains were in operation an estimated 4400 hours per year. The steam was produced in a low pressure boiler which used natural gas as the fuel and operated at 77 per cent efficiency. The cost of natural gas at the facility was $0.21/m³.

A review of Table 3 indicated that the recommended mineral fiber insulation thickness for NPS 4 pipe at 121°C would be 76 mm, and that the heat loss would be 28 Wh/m. Table 1 indicates that the heat loss for bare steel pipe at 121°C is 530Wh/m.

Using Worksheet 1-2 it was established that the reduction in heat loss if the bare pipe were insulated to the recommended thickness with glass fiber insulation would be or 2 783 088 MJ/yr.

$$\text{Dollar Savings} = \frac{2\ 783\ 088 \times \$0.21}{37.2 \times 0.77}$$

= $20,404/yr

The estimated cost to supply and install the 76 mm insulation on the uninsulated piping was $10,000.

$$\text{Simple payback} = \frac{\$10{,}000}{\$20{,}404}$$

$$= 0.49 \text{ years (6 months)}$$

However, due to certain financial constraints, management was not prepared to invest this amount of money at this time.

Because of the budget limitations imposed by management, a new set of calculations was performed on the basis of using 25 mm of mineral fiber insulation. The insulation manufacturer indicated that under these conditions the heat loss would be 200 Wh/m for every hour of operation. Using Worksheet 1-2 again, the reduction in heat loss if 25 mm of mineral fiber insulation is used is 1 829 520 MJ/yr

In this case the dollar savings are also calculated.

$$\text{Dollar Savings} = \frac{1\ 829\ 520 \times \$0.21}{37.2 \times 0.77}$$

$$= \$13{,}413/\text{yr}$$

Estimated cost to supply and install the 25 mm of insulation is $8,000.

$$\text{Simple payback} = \frac{\$8{,}000}{\$13{,}423}$$

$$= 0.6 \text{ years}$$

Even though the simple pay back was not as good with the 25 mm as with the 76 mm of insulation, management was prepared to invest the $8,000 for this limited budget upgrade.

## Heat Loss From Piping

Worksheet 1-2

Company: XYZ Co. Date: ______

Location: ANYTOWN By: MBE

HOUSEKEEPING WORKED EXAMPLE NO. 1

Pipe diameter (NPS) 4 Pipe Length 10 m

Pipe temperature 121 °C Operating hours per year 8760 h

Proposed insulation type mineral fiber Proposed insulation thickness 76 mm

| | Uninsulated | Insulated |
|---|---|---|
| Heat loss per metre | 530 Wh/m·h (Table 1) | 28 Wh/m·h (Table 3) |
| | Heat loss/h = Heat loss/m·h x length | Heat loss/m·h x length |
| | 530 x 10 | 28 x 10 |
| | 5300 Wh/h | 280 Wh/h |
| | Annual heat loss = Heat loss/h x h/yr | Heat loss/h x h/yr |
| | 5300 x 8760 | 280 x 8760 |
| | 46 428 000 Wh/yr (1) | 2 452 800 Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= 46 428 000 − 2 452 800

= 43 975 200 Wh/yr

or ______ Wh/yr x 3.6 kJ/Wh

= ______ kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

## Heat Loss From Piping

Worksheet 1-2

Company: ABC CO. Date: ______

Location: ANYTOWN By: MBE

LOW COST WORKED EXAMPLE NO. 1

Pipe diameter (NPS) 2 Pipe Length 20 m

Pipe temperature 121 °C Operating hours per year 2880 h

Proposed insulation type cellular glass Proposed insulation thickness 34 mm

| Uninsulated | Insulated |
|---|---|
| Heat loss per metre 290 Wh/m·h (Table 1) | 35 Wh/m·h (Table 3) |
| Heat loss/h = Heat loss/m·h x length | Heat loss/m·h x length |
| 290 x 20 | 35 x 20 |
| 5800 Wh/h | 700 Wh/h |
| Annual heat loss = Heat loss/h x h/yr | Heat loss/h x h/yr |
| 5800 x 2880 | 700 x 2880 |
| 16 704 000 Wh/yr (1) | 2 016 000 Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= 16704000 − 2 016 000

= 14 688 000 Wh/yr

or 14 688 000 Wh/yr x 3.6 kJ/Wh

= 52 876 800 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

## Heat Loss From Piping

Worksheet 1-3

Company: ABC Co.

Date: ____

Location: ANYTOWN

LOW COST WORKED EXAMPLE NO. 2

By: MBE

Equipment: HEATING TANK No. 1

Operating hours per year: 8760 h

Surface area: 10 m²

Proposed insulation type: mineral fiber

Product temperature: 177 °C

Proposed insulation thickness: 102 mm

| Uninsulated | Insulated |
|---|---|
| Heat loss = 2800 Wh/m² (Table 5) | 63 Wh/m² (Table 3) |
| Total heat loss/h = Surface area x Heat loss | Surface area x Heat loss |
| 10 x 2800 | 10 x 63 |
| 28 000 Wh/h | 630 Wh/h |
| Annual heat loss = Heat loss/h x h/yr | Heat loss/h x h/yr |
| 28000 x 8760 | 630 x 8760 |
| 245 280 000 Wh/yr (1) | 5 518 800 Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= 245 280 000 − 5 518 800

= 239 761 200 Wh/yr

or 234 761 200 Wh/yr x 3.6 kJ/Wh

= 863 140 320 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

## Heat Loss From Piping

Worksheet 1-3

PAGE 1 OF 2

Company: XYZ CO.

Date: 

Location: ANYTOWN

By: MBE

LOW COST WORKED EXAMPLE NO. 3

Equipment HOLDING VESSEL NO. 2

Operating hours per year 8400 h

Surface area 25 m²

Proposed insulation type mineral fiber

Product temperature 65 °C

Proposed insulation thickness 51 mm

| Uninsulated | Insulated |
|---|---|
| Heat loss = 504.7 Wh/m² (Table 5) | 32 Wh/m² (Table 3) |
| Total heat loss/h = Surface area x Heat loss | Surface area x Heat loss |
| 25 x 504.7 | 25 x 32 |
| 12617.5 Wh/h | 800 Wh/h |
| Annual heat loss = Heat loss/h x h/yr | Heat loss/h x h/yr |
| 12617.5 x 8400 | 800 x 8400 |
| 105 987 000 Wh/yr (1) | 6 720 000 Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= 105 987 000 − 6 720 000

= 99 300 000 Wh/yr

or 99 300 000 Wh/yr x 3.6 kJ/Wh

= 357 480 000 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

## Heat Loss From Piping

Worksheet 1-3

PAGE 2 OF 2

Company: XYZ CO | Date: ______

Location: ANYTOWN | By: MBE

LOW COST WORKED EXAMPLE NO. 3

Equipment HOLDING VESSEL NO.2 | Operating hours per year 8400 h

Surface area 25 m² | Proposed insulation type mineral fiber

Product temperature 65 °C | Proposed insulation thickness 25 mm

| Uninsulated | Insulated |
|---|---|
| Heat loss = 504.7 Wh/m² (Table 5) | 115 Wh/m² (Table 3) |
| Total heat loss/h = Surface area x Heat loss | Surface area x Heat loss |
| 25 x 504.7 | 25 x 115 |
| 12617.5 Wh/h | 2875 Wh/h |
| Annual heat loss = Heat loss/h x h/yr | Heat loss/h x h/yr |
| 12617.5 x 8400 | 2875 x 8400 |
| 105 987 000 Wh/yr (1) | 21 150 000 Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= 105 987 000 − 21 150 000

= 81 837 000 Wh/yr

or 81 837 000 Wh/yr x 3.6 kJ/Wh

= 294 613 200 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

## Heat Loss From Piping

Worksheet 1-2

PAGE 1 OF 2

Company: ABC Co. Date: ______

Location: ANYTOWN By: MBE

RETROFIT WORKED EXAMPLE NO. 3

Pipe diameter (NPS) 4 Pipe Length 350 m

Pipe temperature 121 °C Operating hours per year 4400 h

Proposed insulation type mineral fiber Proposed insulation thickness 76 mm

| | Uninsulated | | Insulated | |
|---|---|---|---|---|
| Heat loss per metre | 530 | Wh/m·h (Table 1) | 28 | Wh/m·h (Table 3) |
| Heat loss/h = Heat loss/m·h x length | | | Heat loss/m·h x length | |
| | 530 x 350 | | 28 x 350 | |
| | 185 500 | Wh/h | 9800 | Wh/h |
| Annual heat loss = Heat loss/h x h/yr | | | Heat loss/h x h/yr | |
| | 185 500 x 4400 | | 9800 x 4400 | |
| | 816 200 000 | Wh/yr (1) | 43 120 000 | Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= 816 200 000 − 43 120 000

= 773 080 000 Wh/yr

or 773 080 000 Wh/yr x 3.6 kJ/Wh

= 2 783 088 000 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

## Heat Loss From Piping

Worksheet 1-2

PAGE 2 OF 2

Company: ABC Co. Date: ______

Location: ANYTOWN By: MBE

RETROFIT WORKED EXAMPLE NO. 3

Pipe diameter (NPS) 4 Pipe Length 350 m

Pipe temperature 121 °C Operating hours per year 4400 h

Proposed insulation type mineral fiber Proposed insulation thickness 25 mm

| | Uninsulated | Insulated |
|---|---|---|
| Heat loss per metre | 530 Wh/m·h (Table 1) | 200 Wh/m·h (Table 3) |
| | Heat loss/h = Heat loss/m·h x length | Heat loss/m·h x length |
| | 530 x 350 | 200 x 350 |
| | 185 500 Wh/h | 70 000 Wh/h |
| | Annual heat loss = Heat loss/h x h/yr | Heat loss/h x h/yr |
| | 185 500 x 4400 | 70 000 x 4400 |
| | 816 200 000 Wh/yr (1) | 308 000 000 Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= 816 200 000 − 308 000 000

= 508 200 000 Wh/yr

or 508 200 000 Wh/yr x 3.6 kJ/Wh

= 1 829 520 000 kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

# APPENDICES

A Glossary
B Tables
C Common Conversions
D Worksheets
E Economic Insulation Thickness
F Thermal Insulation Material Specification Standards

# Glossary

**Ambient Temperature** – The temperature of the medium, usually air, surrounding the object under consideration.

**Batt** – A piece of insulation, of the flexible type, cut into easily handled sizes, square or rectangular in shape, usually 609.6 mm (24") or 1219 mm (48") long with a vapor retarder on one side, and with, or without, a container sheet on the other side.

**Blanket** – Insulation, of the flexible type, formed into sheets or rolls, usually with a vapor retarder on one side, and with, or without, a container sheet on the other side.

**Block** – Rigid or semi-rigid insulation formed into sections, rectangular both in plan and cross-section, usually 36" (914.4 mm) to 1219 mm (48") long, 152.4 mm (6") to 609.6 mm (24") wide, and 25.4 mm (1") to 152.4 mm (6") thick.

**Calcium Silicate Insulation** – Insulation composed principally of hydrous calcium silicate, which usually incorporates fibers of varying types to act as a binder.

**Canvas** – A light, plain weave, coarse, cotton cloth with hard twisted yarns, usually not more than 271 grams per square metre.

**Capillarity** – That property of a material which enables it to suck a liquid up into or through itself, with the driving force of the liquid being the surface tension.

**Caulking Compound** – A soft, plastic material, consisting of pigment and carrier, used for sealing joints in buildings, and other structures, where normal structural movement may occur.

**Cellular Elastomeric Flexible Thermal Insulation** – Insulation composed principally of natural or synthetic elastomers in expanded cellular form.

**Cellular Glass Thermal Insulation** – Insulation composed of glass processed by fusion to form a homogeneous rigid mass of closed cells.

**Celsius** – The temperature measuring scale (formerly Centigrade) in which the freezing point of water is taken at 0° and the vaporization point at 100°. Absolute zero on this scale is –273.15°.

**Chemically Foamed Plastic** – A cellular plastic produced by gasses generated from chemical interaction of constituents.

**Chlorinated Solvent** – An organic chemical liquid characterized by a high chlorine content and used in coating products to impart nonflammability.

**Closed-Cell Foamed Plastic** – A cellular plastic in which there is a predominance of noninterconnecting cells.

**Coating** – A liquid, or semi-liquid, protective finish suitable for thermal insulation or other surfaces, usually applied by brush or spray, in moderate thickness, less than 0.80 mm approx. [30 mils (0.030")].

**Coefficient of Expansion (Contraction)** – The increase (decrease) in length of a material, one unit long, due to the increase (decrease) of temperature by one degree.

**Combustible** – Capable of uniting with air or oxygen in a reaction initiated by heating, accompanied by the subsequent evolution of heat and light i.e., capable of burning.

**Combustibility** – That property of a material which measures its tendency to burn. It is normally expressed in the arbitrary terms of "Flame Spread Index" and "Smoke Density Index", according to ASTM Test E-84.

**Compressive Strength** – Resistance to change in dimension when acted on by a compacting force.

**Condensation** – The act of water vapor turning into water upon contact with a surface at a lower temperature than the dew point of the vapor.

**Conduction** – The transfer of energy within a body, or between two bodies in physical contact, from a higher temperature region to a lower temperature region.

**Conductivity** – See Thermal Conductance.

**Contact Adhesive** – An adhesive which is apparently dry to the touch and which will adhere to itself instantaneously upon contact; also called contact bond or dry bond adhesive.

**Corrosion Effect** – The wearing away or destruction of a substrate caused by acid or alkaline reactions between materials contained in the insulation and substrate.

**Coverage-Wet** – The property of a material which measures the thickness of wet material that must be applied to a given area to obtain a specific thickness after it has cured and dried.

**Cryogenic** – Pertaining to the extremely low temperatures, such as the liquifaction points of gaseous elements, usually approaching absolute zero (−273.15°C).

**Curing Agent** – An additive incorporated in a coating or adhesive resulting in increased chemical activity between the components, with an increase or decrease in the rate of cure.

**Curved Segmental Block** – A piece of rigid pipe insulation, molded or cut from a block to fit the exact dimensions of a given size of pipe.

**Density** – The mass per unit volume of a substance.

**Dewpoint** – The temperature at which the quantity of water vapor in a material would cause saturation, with resultant condensation of the vapor into liquid water by any further reduction of temperature.

**Diatomaceous Silica Insulation** – Insulation composed principally of diatomaceous earth with, or without, heat-resistant inorganic binders and which usually incorporates mineral fibers.

**Dimensional Stability** – That property of insulation which enables it to hold its original size, shape and dimensions.

**Drying Time (Adhesives)** – Time elapsed since bonding and the time when no further increase in bond strength is realized.

**Drying Time (Finishes)** – Time elapsed after which no further significant changes take place in appearance or performance properties, due to drying.

**Ductility** – That property of a material which enables it to undergo large deformations without rupture.

**Elastomer** – A material which at room temperature can be stretched repeatedly to at least twice its original length and immediately upon release of the stress will return with force to the approximate original length.

**Emittance** – The ratio of the total heat lost per unit of time through the same unit area of a perfect blackbody.

**Exposed** – Any surface which will be visible in the finished structure.

**Facing** – A thin layer on the surface of an insulating product, acting as either a vapor retarder, weather barrier, protector from damage or a decorative coating.

**Fahrenheit** – The temperature scale of The British System of units in which the freezing point of water is assigned the value of 32° and the vaporization point the value of 212°, with 180 even divisions between, and corresponding divisions above and below. Absolute zero on this scale is –459.67°.

**Felt** – An insulation material composed of fibers which are interlocked and compacted under pressure.

**Fiberglass** – A composite material consisting of glass fibers and a resin binder.

**Filler** – A relatively inert material added to a mastic or coating to modify its strength, permeance, working properties, or other qualities.

**Finishing Cement** – A mixture of fibers, bonding clays, and water mixed to a plastic mass on the job, and used on the surface of insulations to provide a medium-hard to hard, even finish.

**Fire Resistance** – That property of a material which enables it to resist decomposition or deterioration when exposed to a fire.

**Fire Retardance** – That property of a material which delays the spread of fire, either through or over itself.

**Flame Spread** – The rate, expressed in distance and time, at which a material will propagate flame on its surface. As this is a difficult property to measure in time and distance, the measure is now by flame spread index to enable the comparison of materials by one of the following test methods: CAN2- S102-M83 or ASTM E84.

**Flammable** – That property of a material which permits it to oxidize rapidly and release heat of combustion when exposed to flame or fire, and allows continuous burning after the external ignition source is removed.

**Flashing** – A thin strip of metal inserted at the junction of 2 materials to divert water in a specific direction.

**Flash Point** – The lowest temperature of a material at which it gives off vapor, which, when combined with air near the surface, forms an ignitable mixture.

**Flexibility** – That property of a material which allows it to be bent (flexed) without loss of strength.

**Flexural Strength** – That property of a material which measures its resistance to bending (flexing) usually expressed in kg/m (lbs/in).

**Freeze-Thaw Resistance** – The property of a material which permits it to be alternately frozen and thawed through many cycles without damage from rupture or cracking.

**Fuel Contribution** – Flammable by-products of fire generated by, and emitted from, a burning object.

**Hanger** – A device such as a welded pin, stud or adhesive secured fastener which carries the weight of the insulation or piping system.

**Humidity** – A measure of the amount of water vapor in the atmosphere.

**Insulation** – A material of low thermal conductivity used to reduce the passage of heat.

**Insulation Coating** – A material, or materials, used over insulation or over the weather coating to provide the desired colour or texture for decorative purposes.

**Insulation Cover** – The cover for a flange, pipe fitting, or valve, composed of the specified thickness of insulating material, and preformed into the proper shape before application.

**Insulation System** – An application of insulation to piping, ductwork or equipment that may include the use of adhesives, mechanical fastenings, coatings, reinforcing fabrics, sealants and metal covering.

**Jacket** – A covering placed around an insulation to protect it from mechanical damage, and, insofar as it is intrinsically able, from weather, water, ultraviolet light, etc.

**Lag** – A long, narrow piece of rigid insulation, rectangular in plan, trapezoidal in cross-section, molded, or cut from a block of the proper thickness.

**Lagging** – An insulation layer, on a cylindrical surface, composed of lags.

**Laminated Foils** – A product made by bonding a foil sheet to at least one other material such as kraft paper.

**Lap Adhesive (Lap Cement)** – The adhesive material used to seal the side and end laps of insulation jackets.

**Linear Shrinkage** – The property of a material which indicates the proportional loss of dimensions when exposed to high temperatures.

**Loose Fill Insulation** – Particulate material in granular, nodular, fibrous, powdery, or similar form designed to be installed dry by pouring, blowing, or hand placement between retaining surfaces or as a covering layer.

**Mastic** – A relatively thick consistency protective finish capable of application to thermal insulation or other surfaces, usually by spray or trowel, in thick coats, greater than 30 mils (0.80 mm approximately).

**Metal Lath** – A lattice type of material of various gauges and sizes used to provide reinforcement for insulation.

**Mineral Fiber (Wool)** – A generic term for all non-metallic inorganic fibers, which may be natural, or may be manufactured from such sources as rock, slag, or glass.

**Mineral Fiber Blanket Insulation** – A blanket thermal insulation composed of inorganic fibers, with, or without, added binders.

**Mitered Insulation** – Insulation which has been cut in bevelled sections so that when it is fitted together, it follows the contour or curve of the object being insulated.

**Non-Combustible** – A material which will not contribute fuel or heat to a fire to which it is exposed.

**Non-Flammable** – That property of a material which prevents it from oxidizing rapidly and releasing heat or combustion when exposed to fire or flame.

**Pipe Insulation** – Thermal insulation suited for application to cylindrical surfaces of pipe and tubing.

**Preformed Pipe Insulation** – Thermal insulation in cylindrical, semi-cylindrical, or segmental sections to fit pipe and tubing.

**Preformed Thermal Insulation Block** – A rigid or semi-rigid thermal insulating material, either flat or segmental, for application as received.

**Primer** – The first application of a coating system used to seal or condition the surface for the proper bonding of subsequent layers or coats.

**PVC-Polyvinyl Chloride** – A plastic material molded into finished shapes such as fitting covers.

**Reflective Insulation** – Thermal insulation depending for its efficiency in large part on the reduction of radiant heat transfer across spaces by use of one or more surfaces of high reflectance and low emittance.

**Reinforcing Membrane** – A loosely woven cloth or fabric of glass or resilient fibers, placed approximately in the centre of the vapor retarder or weather barrier to act as reinforcing to the mastic of the barrier.

**Scrim** – Woven screening type fabric used to reinforce an insulation covering.

**Tack** – The property of an adhesive that enables it to form a bond of measurable strength immediately after adhesive and adherent are brought into contact under low pressure.

**Temperature Limits** – The upper and lower temperatures at which a material will experience no essential change in its properties.

**Thermal Insulation** – Material having air-filled or gas-filled pockets, void spaces, or heat-reflective surfaces, which, when properly applied will retard the transfer of heat with reasonable effectiveness under ordinary conditions.

**Reinforcing Mesh** – Generic term for poultry netting, chicken wire, etc., usually made from pre-galvanized wire woven in 25.4 mm (1 inch) mesh size. Also available in post-galvanized and rustless metal alloys.

**Relative Humidity** – The ratio of the actual pressure of existing water vapor to the maximum possible (saturation) pressure of water vapor in the atmosphere at the same temperature, expressed as a percentage (See Dewpoint.)

**Resilient** – Capable of recoiling from pressure or shock unchanged or undamaged.

**Sag** – Excessive flow in material after application to a surface, resulting in "curtaining" or running.

**Self-Ignition Temperature (Autogeneous Ignition)** – The lowest temperature of a material which will cause it to ignite without another ignition source.

**Self-Extinguishing** – That property of a material which enables it to stop ignition after external ignition sources are removed.

**Sealer** – A substance, composed of various materials, used as a barrier to the passage of water vapor or water into the joint formed by the mating surfaces of jackets and vapor retarders over insulation. A good sealer will not shrink much. There are several types of sealers, such as non-setting, and heat resisting.

**Service Temperature Limits** – The temperature range within which the applied coating will provide satisfactory service.

**Smoke Density (Smoke Developed)** – The Smoke Density Factor is the amount of smoke given off by the burning material compared to the amount of smoke given off by the burning of a standard material.

**Softening Point** – That temperature at which a material will change its property from firm or rigid to soft or malleable.

**Solvent** – Any substance, usually a liquid, which dissolves another substance. Normally a liquid organic compound used to make a coating work more freely.

**Substrate** – A material upon the surface of which an adhesive or coating is spread.

**Thermal Shock Resistance** – That property of a material which enables it to maintain shape and not distort, crack or shatter, from a sudden temperature change.

**Thermoplastic** – Capable of being repeatedly softened by an increase of temperature. Note: Thermoplastic applies to those materials whose change upon heating is substantially physical.

**Thermoset** – A plastic or other coating which, when cured by the application of heat or chemical means, changes to a substantially infusible and insoluble product.

**Toxicity** – The degree of hazard to health.

**Urethane Resins** – Resins made by the condensation of organic isocyanates with compounds or resins that contain hydroxol groups. Note: Urethanes are a type of isocyanates resins.

**Vapor Retarder** – A material, or materials, which when installed on the high vapor pressure side, retards the passage of the moisture vapor to the lower vapor pressure side.

**Vapor Migration (Permeability)** – That property of a material which measures the rate at which water vapor will penetrate it, due to vapor pressure differences between its surfaces.

**Vapor Pressure** – The gas pressure exerted by the water vapor present in the air.

**Vermiculite** – Light weight insulation material made from the expansion of granules at high temperatures.

**Victaulic** – A trade or patented name for a specific type of coupling.

**Viscosity** – The property of resistance to flow exhibited within the body of a material.

**Water Absorption** – The increase in weight of a material, expressed as a percentage of its dry weight, after immersion in water for a specified time.

**Weather Barrier** – A material, which, when installed on the outside of the insulation, protects the insulation from weather damage due to rain, snow, wind, atmospheric contamination, etc.

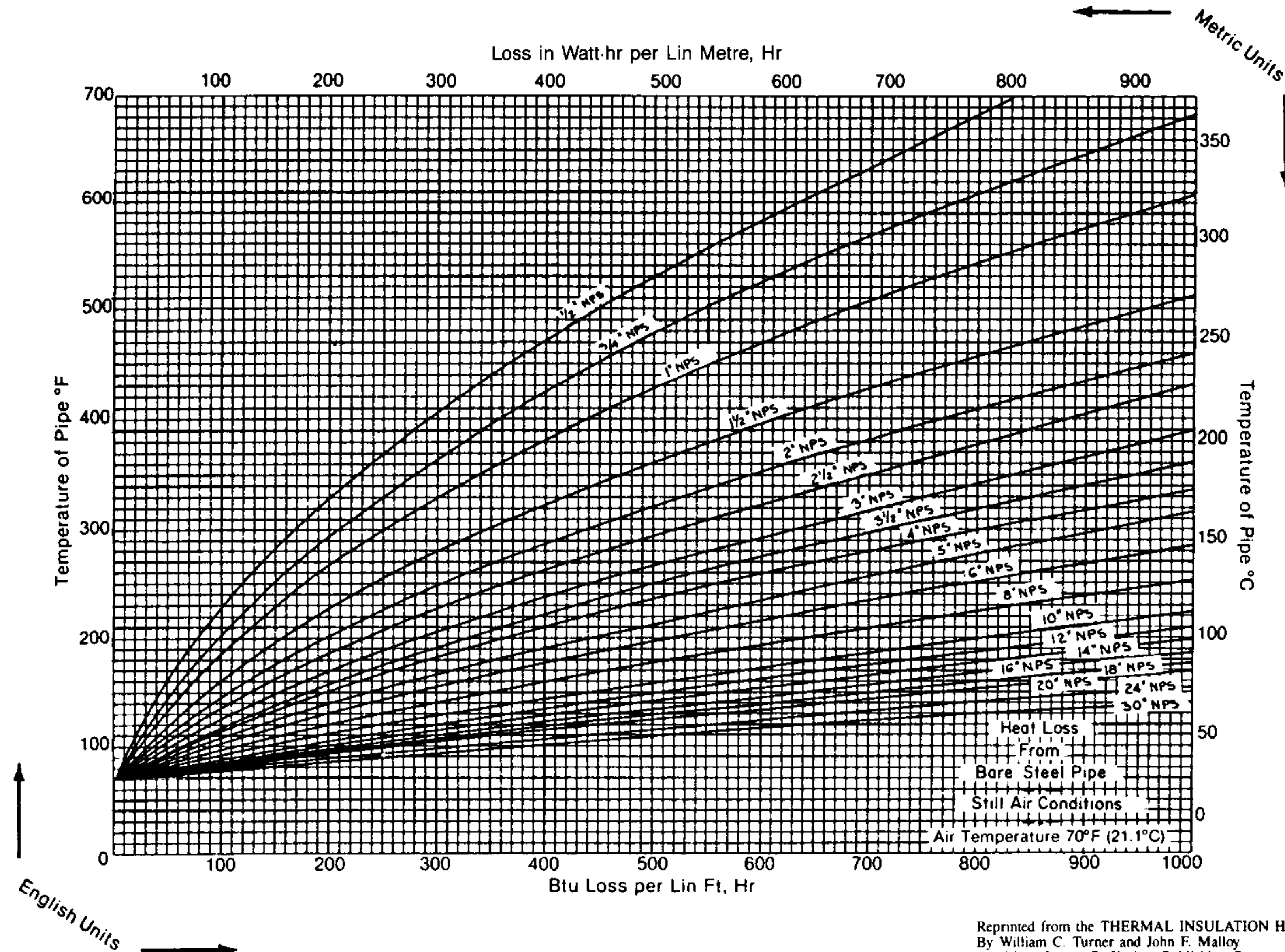
**Weather Coating** – A material, or materials, which, when installed on the outer surface of thermal insulation, protects the insulation from weather, such as rain, snow, sleet, wind, solar radiation, and atmospheric contamination.

**Wire Netting** – Interwoven wires of metal used as reinforcement for insulation.

**Wicking** – The ability of a material to draw up liquids by capillary action.

# HEAT LOSS FROM BARE STEEL PIPE

## TABLE 2

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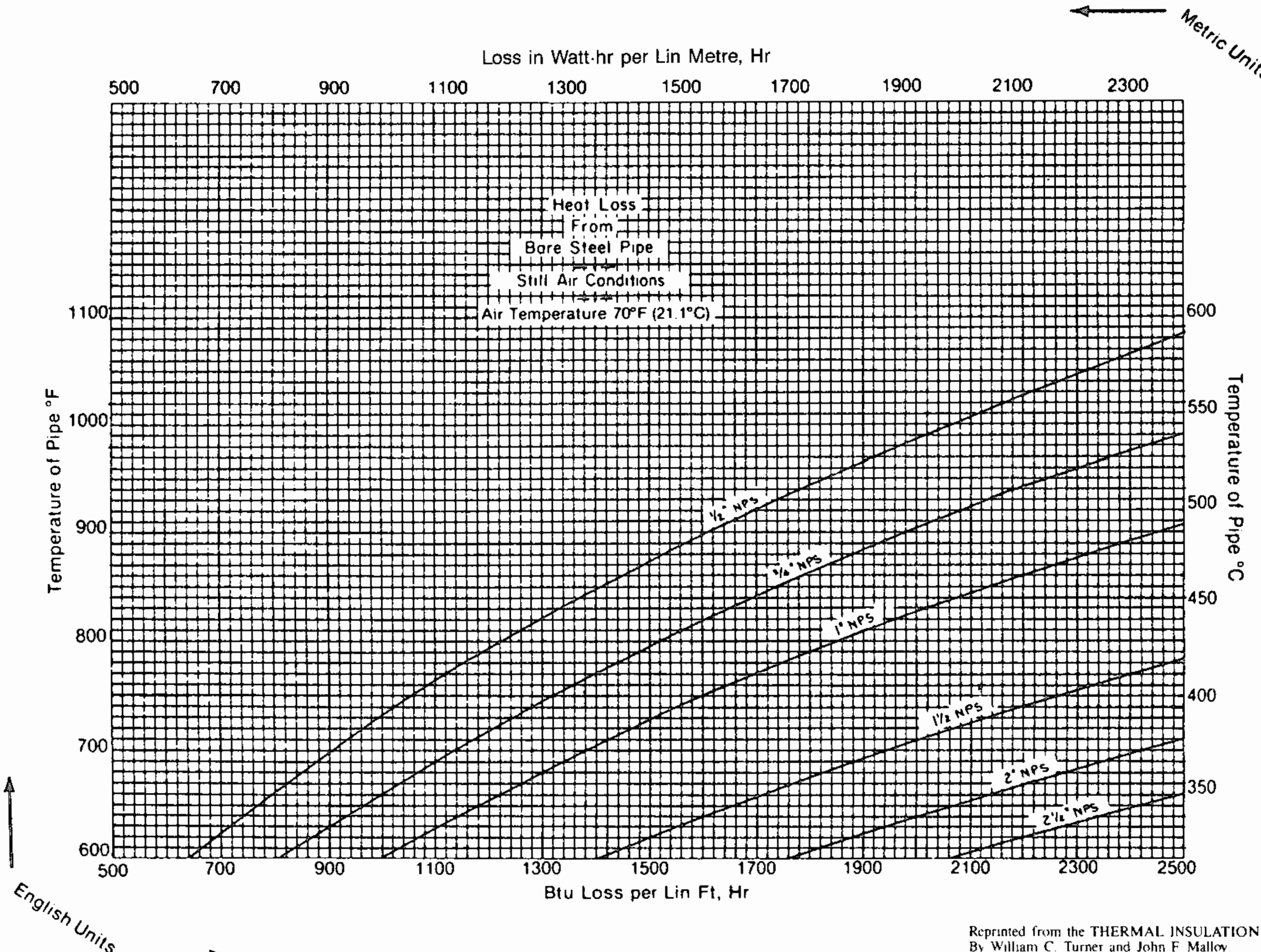
# HEAT LOSS FROM BARE STEEL PIPE
## TABLE 2

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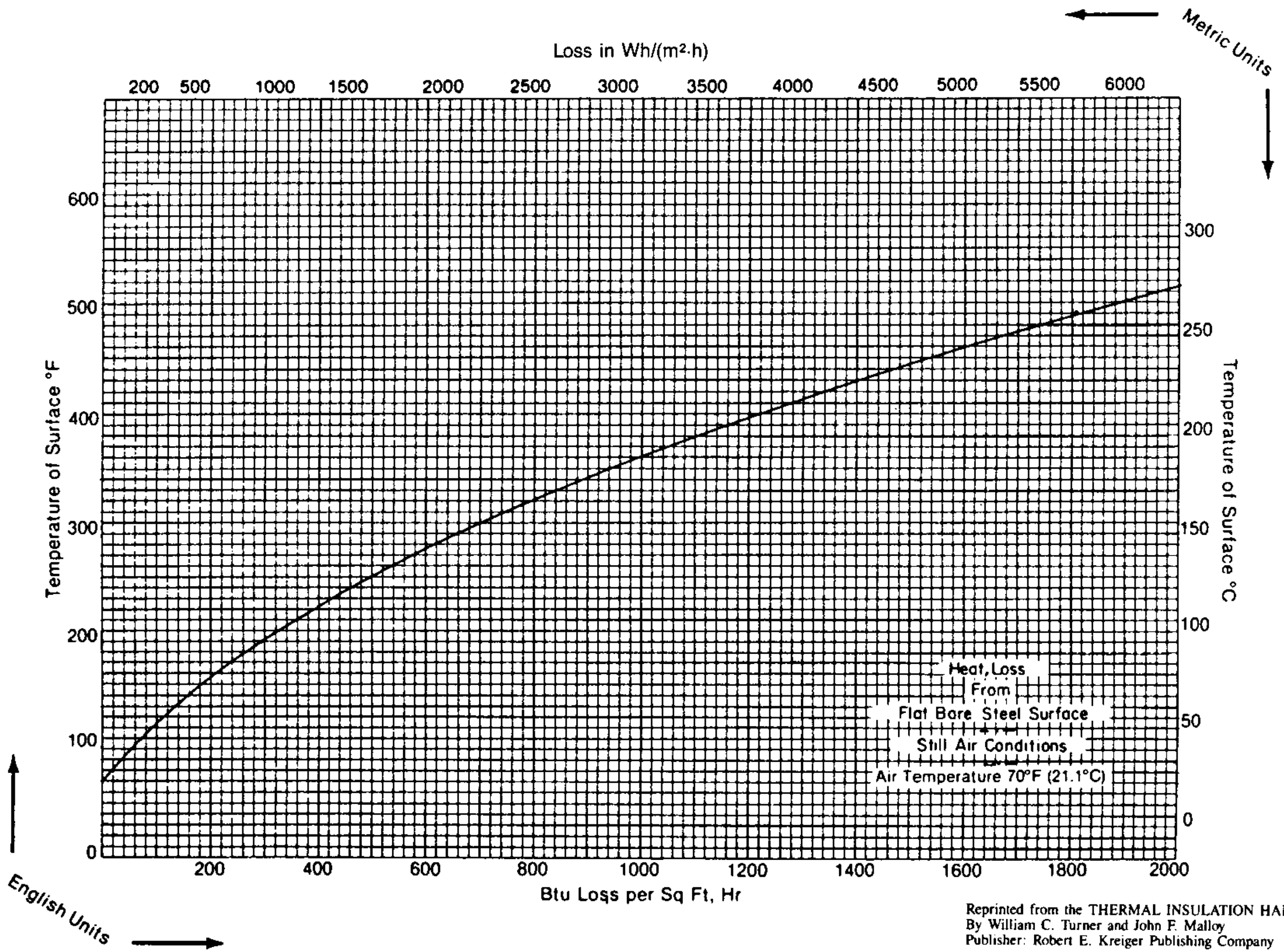
# HEAT LOSS FROM BARE FLAT STEEL SURFACE

## TABLE 2

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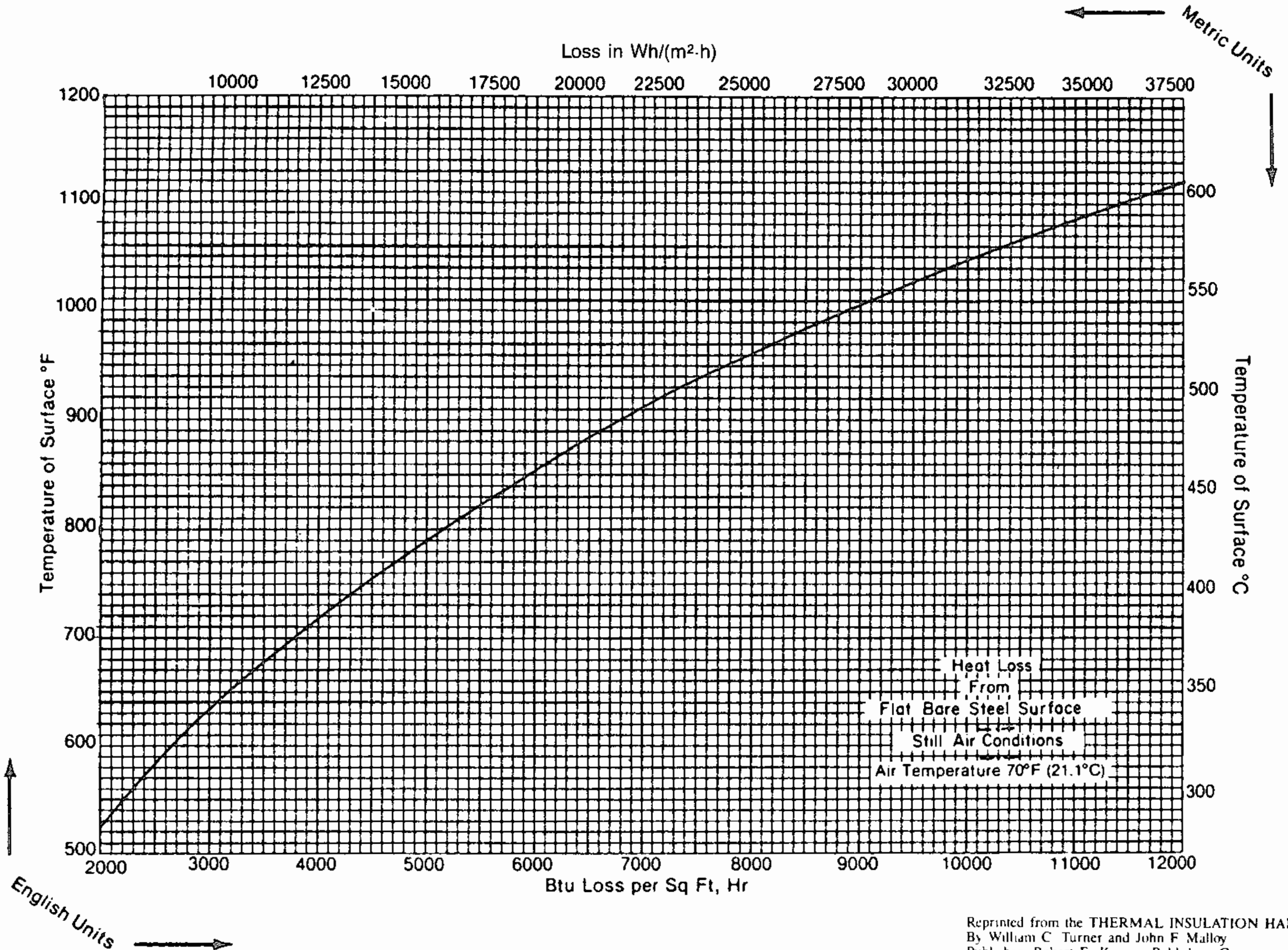
# HEAT LOSS FROM BARE FLAT STEEL SURFACE

## TABLE 2

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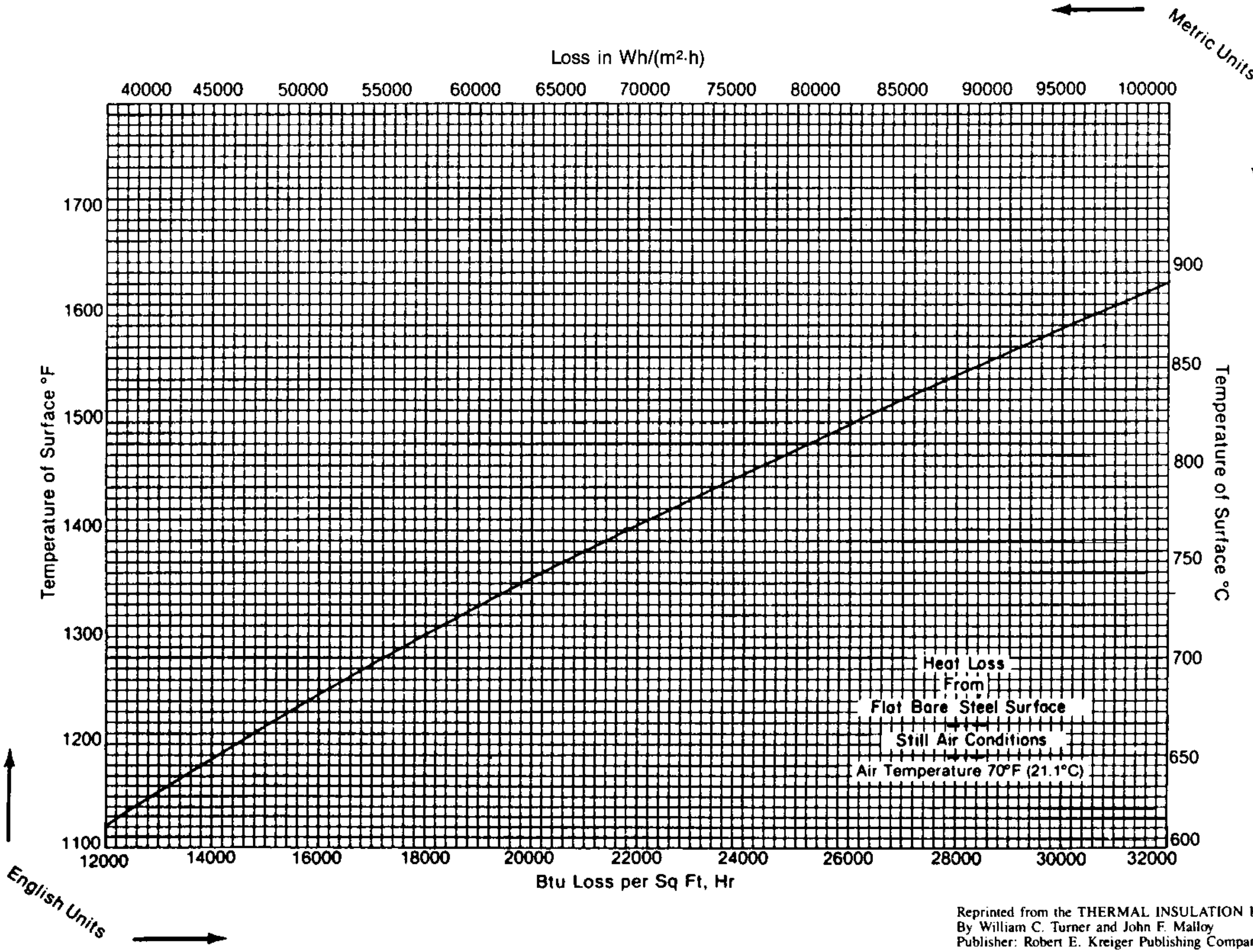
# HEAT LOSS FROM BARE FLAT STEEL SURFACE

## TABLE 2

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## HEAT LOSS THROUGH PIPES WITH VARIOUS THICKNESSES OF INSULATION
## TABLE 3
## CELLULAR GLASS

| NPS | | 66 | 121 | 177 | 232 | 288 | 343 | 399 |
|---|---|---|---|---|---|---|---|---|
| | | PROCESS TEMPERATURE (°C) | | | | | | |
| 0.5 | thickness | 25 | 38 | 51 | 64 | 76 | 89 | 102 |
| | heat loss | 12 | 25 | 37 | 49 | 61 | 72 | 86 |
| | surf. temp. | 24 | 26 | 28 | 28 | 29 | 30 | 31 |
| 1 | thickness | 25 | 51 | 64 | 76 | 89 | 102 | 102 |
| | heat loss | 16 | 28 | 41 | 55 | 68 | 83 | 102 |
| | surf. temp. | 24 | 25 | 27 | 28 | 29 | 30 | 32 |
| 1.5 | thickness | 38 | 64 | 76 | 102 | 102 | 102 | 102 |
| | heat loss | 17 | 31 | 46 | 58 | 77 | 98 | 121 |
| | surf. temp. | 23 | 24 | 26 | 27 | 29 | 31 | 33 |
| 2 | thickness | 38 | 64 | 76 | 102 | 102 | 102 | 114 |
| | heat loss | 14 | 35 | 51 | 64 | 86 | 110 | 128 |
| | surf. temp. | 22 | 25 | 27 | 27 | 29 | 32 | 32 |
| 3 | thickness | 38 | 76 | 89 | 102 | 102 | 114 | 127 |
| | heat loss | 25 | 39 | 60 | 79 | 106 | 127 | 148 |
| | surf. temp. | 24 | 24 | 26 | 26 | 31 | 32 | 33 |
| 4 | thickness | 51 | 76 | 102 | 102 | 102 | 114 | 127 |
| | heat loss | 25 | 46 | 64 | 92 | 123 | 147 | 170 |
| | surf. temp. | 23 | 25 | 26 | 28 | 31 | 32 | 33 |
| 6 | thickness | 51 | 89 | 102 | 102 | 114 | 140 | 152 |
| | heat loss | 34 | 54 | 82 | 118 | 147 | 165 | 193 |
| | surf. temp. | 23 | 24 | 27 | 29 | 31 | 31 | 33 |
| 8 | thickness | 64 | 86 | 98 | 98 | 123 | 135 | 159 |
| | heat loss | 36 | 65 | 99 | 142 | 163 | 196 | 217 |
| | surf. temp. | 23 | 25 | 27 | 31 | 31 | 32 | 33 |
| 10 | thickness | 64 | 102 | 102 | 102 | 140 | 140 | 178 |
| | heat loss | 42 | 70 | 116 | 167 | 179 | 229 | 239 |
| | surf. temp. | 23 | 24 | 28 | 31 | 31 | 33 | 32 |
| 12 | thickness | 64 | 102 | 102 | 102 | 140 | 140 | 191 |
| | heat loss | 48 | 80 | 133 | 191 | 203 | 258 | 258 |
| | surf. temp. | 23 | 25 | 28 | 32 | 31 | 34 | 32 |
| 14 | thickness | 64 | 102 | 102 | 102 | 140 | 140 | 203 |
| | heat loss | 53 | 87 | 142 | 206 | 217 | 277 | 262 |
| | surf. temp. | 23 | 25 | 28 | 32 | 31 | 34 | 31 |
| 16 | thickness | 64 | 102 | 102 | 102 | 140 | 140 | 203 |
| | heat loss | 59 | 96 | 159 | 229 | 240 | 307 | 288 |
| | surf. temp. | 23 | 25 | 28 | 32 | 31 | 34 | 32 |
| 18 | thickness | 64 | 102 | 102 | 102 | 140 | 140 | 203 |
| | heat loss | 65 | 106 | 175 | 252 | 263 | 337 | 314 |
| | surf. temp. | 23 | 25 | 29 | 32 | 31 | 34 | 32 |
| 20 | thickness | 64 | 102 | 102 | 114 | 140 | 140 | 203 |
| | heat loss | 71 | 115 | 191 | 251 | 287 | 365 | 340 |
| | surf. temp. | 23 | 26 | 29 | 31 | 32 | 34 | 32 |
| 24 | thickness | 64 | 102 | 102 | 127 | 140 | 140 | 203 |
| | heat loss | 84 | 135 | 223 | 268 | 333 | 425 | 391 |
| | surf. temp. | 23 | 26 | 29 | 30 | 32 | 35 | 32 |
| 30 | thickness | 64 | 102 | 102 | 140 | 140 | 140 | 203 |
| | heat loss | 103 | 164 | 271 | 300 | 402 | 512 | 467 |
| | surf. temp. | 24 | 26 | 29 | 29 | 32 | 36 | 33 |
| 36 | thickness | 64 | 102 | 102 | 140 | 140 | 140 | 203 |
| | heat loss | 122 | 193 | 319 | 352 | 470 | 600 | 543 |
| | surf. temp. | 24 | 26 | 29 | 29 | 33 | 36 | 33 |
| FLAT | thickness | 64 | 102 | 102 | 140 | 140 | 191 | 216 |
| | heat loss | 41 | 63 | 101 | 107 | 145 | 136 | 148 |
| | surf. temp. | 406 | 25 | 28 | 28 | 31 | 31 | 32 |

Heat loss: Wh/m for pipe, Wh/m² for flat surfaces
Based on 18°C ambient temperature

## HEAT LOSS THROUGH PIPES WITH VARIOUS THICKNESSES OF INSULATION
## TABLE 3
### CALCIUM SILICATE

| NPS | | PROCESS TEMPERATURE (°C) 66 | 121 | 177 | 232 | 288 | 343 | 399 | 454 | 510 | 566 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | thickness | 25 | 38 | 51 | 64 | 76 | 89 | 102 | 102 | 114 | 140 |
| | heat loss | 8 | 15 | 23 | 32 | 41 | 52 | 63 | 81 | 96 | 110 |
| | surf. temp. | 22 | 24 | 24 | 26 | 26 | 27 | 28 | 30 | 31 | 31 |
| 1 | thickness | 25 | 25 | 51 | 64 | 89 | 102 | 102 | 114 | 127 | 140 |
| | heat loss | 11 | 20 | 29 | 39 | 47 | 59 | 76 | 92 | 110 | 130 |
| | surf. temp. | 23 | 24 | 26 | 27 | 26 | 27 | 29 | 30 | 31 | 32 |
| 1.5 | thickness | 25 | 51 | 64 | 76 | 102 | 102 | 102 | 140 | 140 | 152 |
| | heat loss | 13 | 21 | 32 | 43 | 52 | 70 | 90 | 99 | 123 | 146 |
| | surf. temp. | 23 | 23 | 25 | 26 | 26 | 28 | 30 | 29 | 31 | 32 |
| 2 | thickness | 38 | 51 | 76 | 89 | 102 | 102 | 102 | 140 | 152 | 152 |
| | heat loss | 12 | 24 | 23 | 45 | 59 | 78 | 101 | 110 | 132 | 162 |
| | surf. temp. | 22 | 24 | 24 | 25 | 26 | 28 | 31 | 29 | 31 | 33 |
| 3 | thickness | 38 | 64 | 89 | 102 | 102 | 114 | 114 | 152 | 165 | 178 |
| | heat loss | 15 | 27 | 37 | 52 | 72 | 90 | 117 | 128 | 148 | 177 |
| | surf. temp. | 22 | 23 | 24 | 25 | 27 | 28 | 31 | 30 | 31 | 32 |
| 4 | thickness | 38 | 76 | 102 | 102 | 102 | 127 | 140 | 152 | 178 | 191 |
| | heat loss | 18 | 28 | 40 | 61 | 85 | 98 | 121 | 146 | 167 | 198 |
| | surf. temp. | 22 | 23 | 23 | 26 | 28 | 30 | 29 | 31 | 31 | 32 |
| 6 | thickness | 51 | 76 | 102 | 102 | 114 | 127 | 140 | 165 | 191 | 203 |
| | heat loss | 20 | 37 | 52 | 78 | 100 | 125 | 153 | 174 | 200 | 237 |
| | surf. temp. | 22 | 23 | 24 | 26 | 28 | 29 | 31 | 31 | 32 | 33 |
| 8 | thickness | 51 | 86 | 98 | 98 | 123 | 123 | 135 | 172 | 196 | 208 |
| | heat loss | 25 | 40 | 62 | 93 | 112 | 149 | 182 | 196 | 225 | 266 |
| | surf. temp. | 22 | 23 | 24 | 27 | 27 | 29 | 32 | 31 | 32 | 33 |
| 10 | thickness | 51 | 89 | 102 | 102 | 127 | 140 | 140 | 191 | 216 | 229 |
| | heat loss | 31 | 48 | 74 | 111 | 130 | 163 | 212 | 217 | 249 | 295 |
| | surf. temp. | 22 | 23 | 25 | 27 | 28 | 29 | 32 | 31 | 32 | 33 |
| 12 | thickness | 64 | 102 | 102 | 102 | 127 | 140 | 178 | 203 | 216 | 241 |
| | heat loss | 45 | 72 | 116 | 163 | 184 | 256 | 227 | 252 | 288 | 317 |
| | surf. temp. | 23 | 24 | 27 | 30 | 30 | 32 | 31 | 31 | 32 | 33 |
| 14 | thickness | 64 | 102 | 102 | 102 | 127 | 140 | 178 | 203 | 229 | 241 |
| | heat loss | 49 | 78 | 125 | 176 | 197 | 233 | 242 | 252 | 296 | 338 |
| | surf. temp. | 23 | 24 | 27 | 30 | 31 | 32 | 31 | 31 | 32 | 33 |
| 16 | thickness | 76 | 102 | 102 | 102 | 140 | 191 | 203 | 229 | 254 | 254 |
| | heat loss | 48 | 87 | 138 | 196 | 203 | 228 | 255 | 295 | 325 | 358 |
| | surf. temp. | 22 | 24 | 28 | 31 | 29 | 30 | 31 | 32 | 32 | 33 |
| 18 | thickness | 76 | 102 | 102 | 102 | 140 | 165 | 191 | 216 | 229 | 254 |
| | heat loss | 53 | 95 | 153 | 216 | 223 | 249 | 278 | 308 | 353 | 387 |
| | surf. temp. | 23 | 24 | 28 | 31 | 30 | 31 | 31 | 31 | 32 | 33 |
| 20 | thickness | 76 | 102 | 102 | 102 | 140 | 165 | 191 | 216 | 241 | 254 |
| | heat loss | 58 | 104 | 167 | 236 | 242 | 270 | 300 | 333 | 366 | 418 |
| | surf. temp. | 23 | 25 | 28 | 31 | 30 | 31 | 31 | 32 | 32 | 33 |
| 24 | thickness | 76 | 102 | 102 | 102 | 140 | 165 | 191 | 216 | 241 | 254 |
| | heat loss | 68 | 122 | 195 | 276 | 282 | 312 | 346 | 382 | 420 | 478 |
| | surf. temp. | 23 | 25 | 28 | 31 | 31 | 31 | 31 | 32 | 32 | 34 |
| 30 | thickness | 76 | 102 | 102 | 102 | 140 | 178 | 203 | 229 | 254 | 254 |
| | heat loss | 83 | 148 | 237 | 336 | 339 | 354 | 393 | 435 | 479 | 566 |
| | surf. temp. | 23 | 25 | 28 | 31 | 31 | 31 | 31 | 32 | 32 | 34 |
| 36 | thickness | 64 | 102 | 102 | 102 | 165 | 191 | 203 | 229 | 254 | 254 |
| | heat loss | 114 | 174 | 280 | 394 | 345 | 390 | 457 | 504 | 554 | 655 |
| | surf. temp. | 23 | 25 | 28 | 32 | 29 | 30 | 31 | 32 | 33 | 34 |
| FLAT | thickness | 64 | 89 | 102 | 140 | 165 | 191 | 216 | 241 | 254 | 254 |
| | heat loss | 38 | 63 | 88 | 91 | 104 | 114 | 123 | 136 | 155 | 183 |
| | surf. temp. | 23 | 25 | 27 | 27 | 28 | 29 | 29 | 31 | 32 | 34 |

Heat loss: Wh/m for pipe, Wh/m$^2$ for flat surfaces
Based on 18°C ambient temperature

## HEAT LOSS THROUGH PIPES WITH VARIOUS THICKNESSES OF INSULATION
## TABLE 3
### MINERAL FIBER

| NPS | | PROCESS TEMPERATURE (°C) 66 | 121 | 177 | 232 | 288 | 343 | 399 | 454 | 510 | 566 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | thickness | 25 | 38 | 51 | 64 | 76 | 89 | 102 | 102 | 114 | 140 |
| | heat loss | 8 | 15 | 23 | 32 | 41 | 52 | 63 | 81 | 96 | 110 |
| | surf. temp. | 22 | 24 | 24 | 26 | 26 | 27 | 28 | 30 | 31 | 31 |
| 1 | thickness | 25 | 25 | 51 | 64 | 89 | 102 | 102 | 114 | 127 | 140 |
| | heat loss | 11 | 20 | 29 | 39 | 47 | 59 | 76 | 92 | 110 | 130 |
| | surf. temp. | 23 | 24 | 26 | 27 | 26 | 27 | 29 | 30 | 31 | 32 |
| 1 | thickness | 25 | 51 | 64 | 76 | 102 | 102 | 102 | 140 | 140 | 152 |
| | heat loss | 13 | 21 | 32 | 43 | 52 | 70 | 90 | 99 | 123 | 146 |
| | surf. temp. | 23 | 23 | 25 | 26 | 26 | 28 | 30 | 29 | 31 | 32 |
| 2 | thickness | 38 | 51 | 76 | 89 | 102 | 102 | 102 | 140 | 152 | 152 |
| | heat loss | 12 | 24 | 23 | 45 | 59 | 78 | 101 | 110 | 132 | 162 |
| | surf. temp. | 22 | 24 | 24 | 25 | 26 | 28 | 31 | 29 | 31 | 33 |
| 3 | thickness | 38 | 64 | 89 | 102 | 102 | 114 | 114 | 152 | 165 | 178 |
| | heat loss | 15 | 27 | 37 | 52 | 72 | 90 | 117 | 128 | 148 | 177 |
| | surf. temp. | 22 | 23 | 24 | 25 | 27 | 28 | 31 | 30 | 31 | 32 |
| 4 | thickness | 38 | 76 | 102 | 102 | 102 | 127 | 140 | 152 | 178 | 191 |
| | heat loss | 18 | 28 | 40 | 61 | 85 | 98 | 121 | 146 | 167 | 198 |
| | surf. temp. | 22 | 23 | 23 | 26 | 28 | 30 | 29 | 31 | 31 | 32 |
| 6 | thickness | 51 | 76 | 102 | 102 | 114 | 127 | 140 | 165 | 191 | 203 |
| | heat loss | 20 | 37 | 52 | 78 | 100 | 125 | 153 | 174 | 200 | 237 |
| | surf. temp. | 22 | 23 | 24 | 26 | 28 | 29 | 31 | 31 | 32 | 33 |
| 8 | thickness | 51 | 86 | 98 | 98 | 123 | 123 | 135 | 172 | 196 | 208 |
| | heat loss | 25 | 40 | 62 | 93 | 112 | 149 | 182 | 196 | 225 | 266 |
| | surf. temp. | 22 | 23 | 24 | 27 | 27 | 29 | 32 | 31 | 32 | 33 |
| 10 | thickness | 51 | 89 | 102 | 102 | 127 | 140 | 140 | 191 | 216 | 229 |
| | heat loss | 31 | 48 | 74 | 111 | 130 | 163 | 212 | 217 | 249 | 295 |
| | surf. temp. | 22 | 23 | 25 | 27 | 28 | 29 | 32 | 31 | 32 | 33 |
| 12 | thickness | 51 | 89 | 102 | 102 | 127 | 140 | 140 | 191 | 216 | 241 |
| | heat loss | 35 | 55 | 84 | 126 | 148 | 185 | 239 | 243 | 279 | 318 |
| | surf. temp. | 22 | 23 | 25 | 28 | 28 | 30 | 33 | 31 | 32 | 33 |
| 14 | thickness | 51 | 89 | 102 | 102 | 127 | 140 | 165 | 191 | 229 | 241 |
| | heat loss | 38 | 59 | 90 | 136 | 159 | 198 | 227 | 261 | 286 | 338 |
| | surf. temp. | 22 | 23 | 25 | 28 | 28 | 30 | 31 | 32 | 32 | 33 |
| 16 | thickness | 64 | 89 | 102 | 102 | 140 | 178 | 203 | 229 | 254 | 254 |
| | heat loss | 36 | 65 | 101 | 151 | 164 | 219 | 237 | 273 | 313 | 358 |
| | surf. temp. | 22 | 23 | 26 | 28 | 28 | 31 | 30 | 31 | 32 | 33 |
| 18 | thickness | 64 | 89 | 102 | 102 | 140 | 140 | 178 | 203 | 229 | 254 |
| | heat loss | 39 | 72 | 111 | 166 | 180 | 240 | 260 | 298 | 340 | 388 |
| | surf. temp. | 22 | 23 | 26 | 28 | 28 | 31 | 31 | 31 | 32 | 33 |
| 20 | thickness | 64 | 89 | 102 | 102 | 140 | 140 | 178 | 203 | 229 | 254 |
| | heat loss | 43 | 79 | 121 | 182 | 196 | 262 | 281 | 322 | 368 | 419 |
| | surf. temp. | 22 | 24 | 26 | 28 | 28 | 31 | 31 | 32 | 32 | 33 |
| 24 | thickness | 64 | 102 | 102 | 102 | 140 | 152 | 191 | 203 | 229 | 254 |
| | heat loss | 51 | 83 | 141 | 212 | 228 | 284 | 308 | 371 | 422 | 479 |
| | surf. temp. | 22 | 23 | 26 | 28 | 28 | 30 | 30 | 32 | 33 | 34 |
| 30 | thickness | 64 | 102 | 102 | 102 | 140 | 165 | 191 | 216 | 254 | 254 |
| | heat loss | 62 | 101 | 172 | 258 | 275 | 319 | 368 | 422 | 462 | 568 |
| | surf. temp. | 22 | 23 | 26 | 29 | 29 | 29 | 31 | 32 | 32 | 34 |
| 36 | thickness | 64 | 102 | 102 | 102 | 140 | 178 | 203 | 229 | 254 | 254 |
| | heat loss | 74 | 118 | 203 | 304 | 322 | 350 | 406 | 467 | 535 | 657 |
| | surf. temp. | 22 | 23 | 26 | 29 | 29 | 29 | 30 | 31 | 32 | 34 |
| FLAT | thickness | 51 | 89 | 102 | 114 | 140 | 216 | 241 | 254 | 254 | 254 |
| | heat loss | 32 | 44 | 63 | 85 | 98 | 85 | 98 | 120 | 148 | 183 |
| | surf. temp. | 22 | 23 | 25 | 27 | 28 | 27 | 28 | 29 | 32 | 34 |

Heat loss: Wh/m for pipe, Wh/m² for flat surfaces
Based on 18°C ambient temperature

## THERMAL PROPERTIES OF TYPICAL BUILDING AND INSULATING MATERIALS — DESIGN VALUES
## TABLE 4

| Description | Density kg/m³ | Conductivity k W/m·°C | Conductance (C) W/m²·°C | Resistance (R) Per inch thickness (1/k) m·°C/W | Resistance (R) For thickness listed (1/C) m²·°C/W | Specific Heat kJ/(kg·°C) |
|---|---|---|---|---|---|---|
| **INSULATING MATERIALS** | | | | | | |
| **Blanket and Batt** | | | | | | |
| Mineral Fiber, fibrous form processed from rock, slag, or glass | | | | | | |
| approx. 76.2-101.6 mm | 4.8-32.0 | — | 0.52 | — | 1.94 | |
| approx. 88.9 mm | 4.8-32.0 | | 0.44 | — | 2.29 | |
| approx. 139.7-165.1 mm | 4.8-32.0 | — | 0.30 | — | 3.34 | |
| approx. 152.4-177.8 mm | 4.8-32.0 | | 0.26 | | 3.87 | |
| approx. 215.9-228.6 mm | 4.8-32.0 | | 0.19 | | 5.28 | |
| approx. 304.8 mm | 4.8-32.0 | — | 0.15 | | 6.69 | |
| **Board and Slabs** | | | | | | |
| Cellular glass | 136 | 0.050 | — | 19.85 | | 0.75 |
| Glass fiber, organic bonded | 64-144 | 0.036 | — | 27.76 | — | 0.96 |
| Expanded perlite, organic bonded | 16.0 | 0.052 | — | 19.29 | — | 1.26 |
| Expanded rubber (rigid) | 72.0 | 0.032 | — | 31.58 | — | 1.68 |
| Expanded polystyrene extruded | | | | | | |
| Cut cell surface | 28.8 | 0.036 | — | 27.76 | — | 1.22 |
| Smooth skin surface | 28.8-56.0 | 0.029 | — | 34.70 | — | 1.22 |
| Expanded polystyrene, molded beads | 16.0 | 0.037 | — | 23.25 | — | — |
| | 20.0 | 0.036 | — | 27.76 | — | — |
| | 24.0 | 0.035 | — | 28.94 | — | — |
| | 28.0 | 0.035 | — | 28.94 | — | — |
| | 32.0 | 0.033 | — | 30.19 | — | — |
| Cellular polyurethane (R-11 exp.)(unfaced) | 24.0 | 0.023 | — | 43.38 | — | 1.59 |
| Foil-faced, glass fiber-reinforced cellular Polyisocyanurate (R-11 exp.) | 32.0 | 0.020 | — | 49.97 | — | 0.92 |
| Nominal 12.70 mm | | — | 1.58 | — | 0.63 | |
| Nominal 25.40 mm | | — | 0.79 | — | 1.27 | |
| Nominal 50.80 mm | | — | 0.39 | — | 2.53 | |
| Mineral fiber with resin binder | 240 | 0.042 | — | 23.94 | — | 0.71 |
| Mineral fiberboard, wet felted | | | | | | |
| Core or roof insulation | 256-272 | 0.049 | — | 20.40 | — | |
| Acoustical tile | 288 | 0.050 | — | 19.85 | — | 0.80 |
| Acoustical tile | 336 | 0.053 | — | 18.74 | — | |
| Mineral fiberboard, wet molded | | | | | | |
| Acoustical tile | 368 | 0.060 | — | 16.52 | — | 0.59 |
| Wood or cane fiberboard | | | | | | |
| Acoustical tile 12.70 mm | — | — | 4.54 | — | 0.22 | 1.30 |
| Acoustical tile 19.05 mm | — | — | 3.01 | — | 0.33 | — |
| Interior finish (plank, tile) | 240 | 0.050 | — | 19.85 | — | 1.34 |
| Cement fiber slabs (shredded wood with Portland cement binder | 400-432 | 0.072-0.070 | — | 13.88-13.12 | — | — |
| Cement fiber slabs (shredded wood with magnesia oxysulfide binder) | 352 | 0.082 | — | 12.15 | — | 1.30 |
| **FIELD APPLIED** | | | | | | |
| Polyurethane foam | 24.0-40.0 | 0.023-0.026 | — | 43.38-36.50 | — | |
| Spray cellulosic fiber base | 32.0-96.0 | 0.035-0.043 | — | 23.11-28.94 | — | |

# THERMAL CONDUCTIVITY (k) OF INDUSTRIAL INSULATION — DESIGN VALUES
## W/m·°C
## TABLE 5

| Form — Material Composition | Accepted Max Temp for Use, °C | Typical Density (kg/m³) | Typical Conductivity k at Mean Temp °C: −73.3 | −59.4 | −45.6 | −31.7 | −17.8 | −3.9 | 10.0 | 23.9 | 37.8 | 93.3 | 148.9 | 260.0 | 371.1 | 482.2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **BLANKETS & FELTS** | | | | | | | | | | | | | | | | |
| MINERAL FIBER | | | | | | | | | | | | | | | | |
| (Rock, slag or glass) | | | | | | | | | | | | | | | | |
| Blanket, metal reinforced | 650 | 96-192 | | | | | | | | | 0.037 | 0.046 | 0.056 | 0.078 | | |
| | 540 | 40.0-96.0 | | | | | | | | | 0.035 | 0.045 | 0.058 | 0.088 | | |
| Mineral fiber, glass | 180 | less | | | | | | | | | | | | | | |
| Blanket, flexible, fine-fiber | | than | | | | 0.036 | 0.037 | 0.040 | 0.043 | 0.048 | 0.052 | 0.076 | | | | |
| organic bonded | | 12.0 | | | | 0.035 | 0.036 | 0.039 | 0.042 | 0.046 | 0.049 | 0.069 | | | | |
| | | 16.0 | | | | 0.033 | 0.035 | 0.036 | 0.039 | 0.042 | 0.046 | 0.062 | | | | |
| | | 24.0 | | | | 0.030 | 0.032 | 0.033 | 0.036 | 0.039 | 0.040 | 0.053 | | | | |
| | | 32.0 | | | | 0.029 | 0.030 | 0.032 | 0.033 | 0.036 | 0.037 | 0.048 | | | | |
| | | 48.0 | | | | 0.027 | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.045 | | | | |
| Blanket, flexible, textile-fiber | 180 | 10.4 | | | | 0.039 | 0.040 | 0.042 | 0.043 | 0.045 | 0.046 | 0.072 | 0.098 | | | |
| organic bonded | | 12.0 | | | | 0.037 | 0.039 | 0.040 | 0.042 | 0.045 | 0.046 | 0.069 | 0.095 | | | |
| | | 16.0 | | | | 0.035 | 0.036 | 0.037 | 0.039 | 0.042 | 0.045 | 0.065 | 0.086 | | | |
| | | 24.0 | | | | 0.032 | 0.033 | 0.035 | 0.036 | 0.039 | 0.042 | 0.056 | 0.073 | | | |
| | | 48.0 | | | | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.036 | 0.046 | 0.059 | | | |
| Felt, semirigid organic bonded | 200 | 48-128 | | | | | | 0.035 | 0.036 | 0.037 | 0.039 | 0.050 | 0.063 | | | |
| | 450 | 48.0 | 0.023 | 0.024 | 0.026 | 0.027 | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.050 | 0.079 | | | |
| Laminated & felted | 650 | 120 | | | | | | | | | | | 0.050 | 0.065 | 0.086 | |
| Without binder | | | | | | | | | | | | | | | | |
| VEGETABLE & ANIMAL FIBER | | | | | | | | | | | | | | | | |
| Hair Felt or Hair Felt plus Jute | 80 | 160 | | | | | | 0.037 | 0.040 | 0.042 | 0.043 | | | | | |
| **BLOCKS, BOARDS & PIPE INSULATION** | | | | | | | | | | | | | | | | |
| ASBESTOS | | | | | | | | | | | | | | | | |
| Laminated asbestos paper | 370 | 480 | | | | | | | | | 0.058 | 0.065 | 0.072 | 0.086 | | |
| Corrugated & laminated asbestos | | | | | | | | | | | | | | | | |
| Paper | | | | | | | | | | | | | | | | |
| 4-ply | 150 | 176-208 | | | | | | | | 0.078 | 0.082 | 0.098 | | | | |
| 6-ply | 150 | 240-272 | | | | | | | | 0.071 | 0.073 | 0.085 | | | | |
| 8-ply | 150 | 288-320 | | | | | | | | 0.068 | 0.071 | 0.082 | | | | |
| MOLDED AMOSITE & BINDER | 820 | 240-288 | | | | | | | | | 0.046 | 0.053 | 0.060 | 0.075 | 0.089 | 0.104 |
| 85% MAGNESIA | 320 | 176-192 | 192 | | | | | | | | 0.050 | 0.055 | 0.060 | | | |
| CALCIUM SILICATE | 650 | 176-240 | | | | | | | | | 0.055 | 0.059 | 0.063 | 0.075 | 0.089 | 0.104 |
| | 980 | 192-240 | | | | | | | | | | | | 0.091 | 0.107 | 0.137 |
| CELLULAR GLASS | 480 | 136 | 0.039 | 0.040 | 0.042 | 0.043 | 0.045 | 0.046 | 0.048 | 0.050 | 0.052 | 0.060 | 0.071 | 0.101 | 0.148 | |
| DIATOMACEOUS SILICA | 870 | 336-352 | | | | | | | | | | | | 0.092 | 0.098 | 0.104 |
| | 1040 | 368-400 | | | | | | | | | | | | 0.101 | 0.108 | 0.115 |
| MINERAL FIBER | | | | | | | | | | | | | | | | |
| Glass, | | | | | | | | | | | | | | | | |
| Organic bonded, block and boards | 200 | 48-160 | 0.023 | 0.024 | 0.026 | 0.027 | 0.029 | 0.032 | 0.035 | 0.036 | 0.037 | 0.048 | 0.058 | | | |
| Nonpunking binder | 540 | 48-160 | | | | | | | | | 0.037 | 0.045 | 0.055 | 0.075 | | |
| Pipe insulation, slag or glass | 180 | 48.0-64.0 | | | | | | | | | | | | | | |
| | | | | | | | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.042 | | | | |
| | 260 | 48-160 | | | | | 0.029 | 0.032 | 0.035 | 0.036 | 0.037 | 0.048 | 0.058 | | | |
| Inorganic bonded-block | 540 | 160-240 | | | | | | | | | 0.048 | 0.055 | 0.065 | 0.079 | | |
| | 980 | 240-384 | | | | | | | | | 0.046 | 0.053 | 0.060 | 0.075 | 0.089 | 0.107 |
| Pipe insulation slag or glass | 540 | 160-240 | | | | | | | | | 0.048 | 0.055 | 0.065 | 0.079 | | |
| MINERAL FIBER | | | | | | | | | | | | | | | | |
| Resin binder | | 240 | | | 0.033 | 0.035 | 0.036 | 0.037 | 0.040 | 0.042 | | | | | | |
| RIGID POLYSTYRENE | | | | | | | | | | | | | | | | |
| Extruded, Refrigerant 12 exp, smooth skin surface | 80 | 35.2 | 0.023 | 0.023 | 0.024 | 0.023 | 0.024 | 0.026 | 0.027 | 0.029 | | | | | | |
| Extruded cut cell surface | 80 | 28.8 | 0.024 | 0.026 | 0.027 | 0.029 | 0.030 | 0.033 | 0.035 | 0.036 | 0.039 | | | | | |
| Molded beads | 80 | 16.0 | 0.024 | 0.027 | 0.029 | 0.030 | 0.032 | 0.035 | 0.036 | 0.037 | 0.040 | | | | | |
| | | 24.0 | 0.023 | 0.024 | 0.027 | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.037 | | | | | |
| | | 20.0 | 0.024 | 0.026 | 0.027 | 0.029 | 0.032 | 0.033 | 0.035 | 0.036 | 0.039 | | | | | |
| | | 28.0 | 0.023 | 0.024 | 0.026 | 0.027 | 0.029 | 0.032 | 0.033 | 0.035 | 0.036 | | | | | |
| | | 32.0 | 0.022 | 0.023 | 0.026 | 0.027 | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | | | | | |
| RIGID POLYISOCYANDRATE | | | | | | | | | | | | | | | | |
| Cellular, foil-faced glass fiber reinforced Refrigerant 11 exp | 120 | 32.0 | | | | | | 0.017 | 0.019 | 0.020 | 0.022 | | | | | |
| POLYURETHANE | | | | | | | | | | | | | | | | |
| Refrigerant 11 exp (unfaced) | 100 | 24.0-40.0 | 0.023 | 0.024 | 0.026 | 0.026 | 0.026 | 0.024 | 0.023 | 0.023 | 0.024 | | | | | |
| RUBBER, Rigid Foamed | 70 | 72 | | | | | | 0.029 | 0.030 | 0.032 | 0.033 | | | | | |
| VEGETABLE & ANIMAL FIBER | | | | | | | | | | | | | | | | |
| Wool felt (pipe insulation) | 80 | 320 | | | | | | 0.040 | 0.043 | 0.045 | 0.048 | | | | | |
| **INSULATING CEMENTS** | | | | | | | | | | | | | | | | |
| MINERAL FIBER | | | | | | | | | | | | | | | | |
| (Rock, slag, or glass) | | | | | | | | | | | | | | | | |
| With colloidal clay binder | 980 | 384-480 | | | | | | | | | | 0.071 | 0.079 | 0.088 | 0.105 | 0.122 |
| With hydraulic setting binder | 650 | 480-460 | | | | | | | | | | 0.108 | 0.115 | 0.122 | 0.137 | |
| **LOOSE FILL** | | | | | | | | | | | | | | | | |
| Cellulose insulation (milled pulverized paper or wood pulp | | 40.0-48.0 | | | | | | | 0.037 | 0.039 | 0.042 | | | | | |
| Mineral fiber, slag, rock or glass | | 32.0-80.0 | | | 0.027 | 0.030 | 0.033 | 0.036 | 0.037 | 0.040 | 0.045 | | | | | |
| Perlite (expanded) | | 48.0-80.0 | 0.032 | 0.035 | 0.036 | 0.039 | 0.040 | 0.043 | 0.045 | 0.048 | 0.050 | | | | | |
| Silica aerogel | | 122 | | | 0.019 | 0.020 | 0.022 | 0.022 | 0.023 | 0.024 | 0.026 | | | | | |
| Vermiculite (expanded) | | 112-131 | | | 0.056 | 0.058 | 0.060 | 0.063 | 0.065 | 0.068 | 0.071 | | | | | |
| | | 64-96 | | | 0.049 | 0.050 | 0.056 | 0.058 | 0.060 | 0.063 | 0.066 | | | | | |

## BASIC TYPES OF INSULATION
## TABLE 6

| TYPE | FORM | TEMPERATURE RANGE | k-FACTOR* | NOTES |
|---|---|---|---|---|
| Calcium Silicate | Pipe Covering<br>Block<br>Segments | up to 982°C (1800°F) | .066 at 150°C<br>.45 at 300°F | Good mechanical abuse characteristics, non-combustible. Some are water absorbent. |
| Cellular Glass | Pipe Covering<br>Block<br>Segments | −267°C to 482°C<br>(−450°F to 900°F) | .077 to 150°C<br>.53 at 300°F | Good strength, water and vapour resistant, non-combustible. Poor abrasion resistance. |
| Glass Fiber | Pipe Covering<br>Board<br><br><br>Blanket | to 455°C<br>(850°F)<br><br>to 510°C<br>(950°F) | .035 at 24°C<br>.24 at 75°F<br>.050 at 150°C<br>.35 at 300°F<br>varies see<br>manf. data | Properties variable. Good handling and workability. May be water absorbent. Some are non-combustible. |
| Mineral Fiber | Pipe Covering<br><br><br><br><br>Board | to 870°C<br>(1600°F) | .035 at 24°C<br>.24 at 75°F<br>.061 at 150°C<br>.42 at 300°F<br>conductivity<br>varies with<br>density. | Non-combustible, good workability water absorbant. |
| Ceramic Fiber | Blanket or Board | to 1760°C<br>(3200°F) | .30 at 93°C<br>(200°F) | Temperature range varies with manufacturer, style and type. |
| Cements | Hydraulic setting cement<br>High temperature mineral wool<br>Pointing and finishing cement (Mineral or Vermiculite) | to 650°C<br>(1200°F)<br>to 1040°C<br>(1900°F)<br>to 760°C<br>(1400°F) | 1.75 at 315°C<br>(600°F)<br>.69 at 315°C<br>(600°F)<br>.55 at 93°C<br>(200°F) | One coat application — Insulating and finishing.<br>Slow drying, rough texture — filling and insulating. Used over basic insulation — smooth finish, usually 3.175 mm (⅛") to 6.35 mm (¼") thick application. |

*k-Factor = W/(m·°C) or [(BTU·in)/(ft²·hr·°F)]

## PROTECTIVE COVERINGS AND FINISHES
## TABLE 7

### WEATHER BARRIERS

| TYPE | COMPOSITION | FASTENERS | NOTES |
|---|---|---|---|
| JACKETS: | 1. Films laminated to felts or foil | Contact adhesives and/or tape | Corrosion resistant bacteria and mildew resistant. |
| | 2. Stainless steel (various alloys — available with factory-applied moisture barrier) | Corrosion resistant bands, screws or rivets | Excellent mechanical strength, corrosion, mildew and bacteria resistant. |
| | 3. Galvanized Steel (coated and with factory-applied moisture barrier) | Corrosion resistant bands, screws or rivets | Good mechanical strength |
| | 4. Aluminum alloys (usually with factory-applied moisture barrier) | Corrosion resistant bands, screws or rivets | Good mechanical strength, good workability. |
| | 5. Polyvinyl Chloride (PVC) | Mechanical fasteners, adhesive or matching tape | May require protection from ultra-violet radiation. Resists chemicals and bacteria. |
| | 6. High Impact Plastic (ABS) | ABS welding adhesive or mechanical fasteners | |
| | 7. Roofing felt | Bands or wires | Not recommended for rectangular ductwork. |
| MASTICS: | 1. Asphalt emulsion | Apply with reinforcing mesh | Water base, a breather mastic. |
| | 2. Asphalt cut-back | Apply with reinforcing mesh | Solvent base, also a vapor barrier. |
| | 3. Resin emulsion | Apply with reinforcing mesh | Tough, resilient film. |
| | 4. Polyvinyl acetate | Apply with reinforcing mesh | Tough, resilient film. |
| | 5. Acryllic | Apply with reinforcing mesh | Tough, resilient film. |

Covering shall not be termed a weather barrier unless its joints and overlap are adequate to prevent the entry of rainwater.

## VAPOR RETARDERS
## TABLE 8

| TYPE | COMPOSITION | NOTES |
|---|---|---|
| JACKETS: | 1. Foil Scrim Laminate | Seal joints. Mechanical strength is less than metal or plastic. Generally for indoor applications. |
| | 2. Metal Jacketing | Seal joints. Mechanical strength is good. |
| | 3. Polyvinyl Chloride (PVC) | Seal with compatible adhesive and/or tape. |
| | 4. High Impact Plastic (ABS) | Seal with welding adhesive. |
| | 5. Film Laminate | Seal with contact adhesive and/or tape. |
| MASTICS: | 1. Asphalt cut-back | Apply with reinforcing mesh. Combustible. |
| | 2. Resins — advent type | Brush or spray application. |
| | 3. Elastomeric Polymer | Apply with reinforcing mesh. Combustible. |

# COMMON CONVERSIONS

| | |
|---|---|
| 1 barrel (35 Imp gal) (42 US gal) | = 159.1 litres |
| 1 gallon (Imp) | = 1.20094 gallon (US) |
| 1 horsepower (boiler) | = 9809.6 watts |
| 1 horsepower | = 2545 Btu/hour |
| 1 horsepower | = 0.746 kilowatts |
| 1 joule | = 1 N-m |
| Kelvin | = (°C + 273.15) |
| 1 kilowatt-hour | = 3600 kilojoules |
| 1 Newton | = 1 kg-m/s$^2$ |
| 1 therm | = $10^5$ Btu |
| 1 ton (refrigerant) | = 12002.84 Btu/hour |
| 1 ton (refrigerant) | = 3516.8 watts |
| 1 watt | = 1 joule/second |
| Rankine | = (°F + 459.67) |

**Cubes**

| | |
|---|---|
| 1 yd$^3$ | = 27 ft$^3$ |
| 1 ft$^3$ | = 1728 in$^3$ |
| 1 cm$^3$ | = 1000 mm$^3$ |
| 1 m$^3$ | = $10^6$ cm$^3$ |
| 1 m$^3$ | = 1000 L |

**Squares**

| | |
|---|---|
| 1 yd$^2$ | = 9 ft$^2$ |
| 1 ft$^2$ | = 144 in$^2$ |
| 1 cm$^2$ | = 100 mm$^2$ |
| 1 m$^2$ | = 10000 cm$^2$ |

**SI PREFIXES**

| Prefix | Symbol | Magnitude | Factor |
|---|---|---|---|
| tera | T | 1 000 000 000 000 | $10^{12}$ |
| giga | G | 1 000 000 000 | $10^9$ |
| mega | M | 1 000 000 | $10^6$ |
| kilo | k | 1 000 | $10^3$ |
| hecto | h | 100 | $10^2$ |
| deca | da | 10 | $10^1$ |
| deci | d | 0.1 | $10^{-1}$ |
| centi | c | 0.01 | $10^{-2}$ |
| milli | m | 0.001 | $10^{-3}$ |
| micro | u | 0.000 001 | $10^{-6}$ |
| nano | n | 0.000 000 001 | $10^{-9}$ |
| pica | p | 0.000 000 000 001 | $10^{-12}$ |

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# UNIT CONVERSION TABLES
## METRIC TO IMPERIAL

| FROM | SYMBOL | TO | SYMBOL | MULTIPLY BY |
|---|---|---|---|---|
| amperes/square centimetre | $A/cm^2$ | amperes/square inch | $A/in^2$ | 6.452 |
| Celsius | °C | Fahrenheit | °F | (°C × 9/5) + 32 |
| centimetres | cm | inches | in | 0.3937 |
| cubic centimetres | $cm^3$ | cubic inches | $in^3$ | 0.06102 |
| cubic metres | $m^3$ | cubic foot | $ft^3$ | 35.314 |
| grams | g | ounces | oz | 0.03527 |
| grams | g | pounds | lb | 0.0022 |
| grams/litre | g/L | pounds/cubic foot | $lb/ft^3$ | 0.06243 |
| joules | J | Btu | Btu | $9.480 \times 10^{-4}$ |
| joules | J | foot-pounds | ft-lb | 0.7376 |
| joules | J | horsepower-hours | hp-h | $3.73 \times 10^{-7}$ |
| joules/metre, (Newtons) | J/m, N | pounds | lb | 0.2248 |
| kilograms | kg | pounds | lb | 2.205 |
| kilograms | kg | tons (long) | ton | $9.842 \times 10^{-4}$ |
| kilograms | kg | tons (short) | tn | $1.102 \times 10^{-3}$ |
| kilometres | km | miles (statute) | mi | 0.6214 |
| kilopascals | kPa | atmospheres | atm | $9.87 \times 10^{-3}$ |
| kilopascals | kPa | inches of mercury (@ 32°F) | in Hg | 0.2953 |
| kilopascals | kPa | inches of water (@ 4°C) | in $H_2O$ | 4.0147 |
| kilopascals | kPa | pounds/square inch | psi | 0.1450 |
| kilowatts | kW | foot-pounds/second | ft-lb/s | 737.6 |
| kilowatts | kW | horsepower | hp | 1.341 |
| kilowatt-hours | kWh | Btu | Btu | 3413 |
| litres | L | cubic foot | $ft^3$ | 0.03531 |
| litres | L | gallons (Imp) | gal (Imp) | 0.21998 |
| litres | L | gallons (US) | gal (US) | 0.2642 |
| litres/second | L/s | cubic foot/minute | cfm | 2.1186 |
| lumen/square metre | $lm/m^2$ | lumen/square foot | $lm/ft^2$ | 0.09290 |
| lux, lumen/square metre | lx, $lm/m^2$ | footcandles | fc | 0.09290 |
| metres | m | foot | ft | 3.281 |
| metres | m | yard | yd | 1.09361 |
| parts per million | ppm | grains/gallon (Imp) | gr/gal (Imp) | 0.07 |
| parts per million | ppm | grains/gallon (US) | gr/gal (US) | 0.05842 |
| permeance (metric) | PERM | permeance (Imp) | perm | 0.01748 |
| square centimetres | $cm^2$ | square inches | $in^2$ | 0.1550 |
| square metres | $m^2$ | square foot | $ft^2$ | 10.764 |
| square metres | $m^2$ | square yards | $yd^2$ | 1.196 |
| tonne (metric) | t | pounds | lb | 2204.6 |
| watt | W | Btu/hour | Btu/h | 3.413 |
| watt | W | lumen | lm | 668.45 |

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# UNIT CONVERSION TABLES
# IMPERIAL TO METRIC

| FROM | SYMBOL | TO | SYMBOL | MULTIPLY BY |
|---|---|---|---|---|
| ampere/in$^2$ | A/in$^2$ | ampere/cm$^2$ | A/cm$^2$ | 0.1550 |
| atmospheres | atm | kilopascals | kPa | 101.325 |
| British Thermal Unit | Btu | joules | J | 1054.8 |
| Btu | Btu | kilogram-metre | kg-m | 107.56 |
| Btu | Btu | kilowatt-hour | kWh | $2.928 \times 10^{-4}$ |
| Btu/hour | Btu/h | watt | W | 0.2931 |
| calorie, gram | cal or g-cal | joules | J | 4.186 |
| chain | chain | metre | m | 20.11684 |
| cubic foot | ft$^3$ | cubic metre | m$^3$ | 0.02832 |
| cubic foot | ft$^3$ | litre | L | 28.32 |
| cubic foot/minute | cfm | litre/second | L/s | 0.47195 |
| cycle/second | c/s | Hertz | Hz | 1.00 |
| Fahrenheit | °F | Celsius | °C | (°F-32)/1.8 |
| foot | ft | metre | m | 0.3048 |
| footcandle | fc | lux, lumen/ square metre | lx, lm/m$^2$ | 10.764 |
| footlambert | fL | candela/square metre | cd/m$^2$ | 3.42626 |
| foot-pounds | ft-lb | joule | J | 1.356 |
| foot-pounds | ft-lb | kilogram-metres | kg-m | 0.1383 |
| foot-pounds/second | ft-lb/s | kilowatt | kW | $1.356 \times 10^{-3}$ |
| gallons (Imp) | gal (Imp) | litres | L | 4.546 |
| gallons (US) | gal (US) | litres | L | 3.785 |
| grains/gallon (Imp) | gr/gal (Imp) | parts per million | ppm | 14.286 |
| grains/gallon (US) | gr/gal (US) | parts per million | ppm | 17.118 |
| horsepower | hp | watts | W | 745.7 |
| horsepower-hours | hp-h | joules | J | $2.684 \times 10^{6}$ |
| inches | in | centimetres | cm | 2.540 |
| inches of Mercury (@ 32°F) | in Hg | kilopascals | kPa | 3.386 |
| inches of water (@ 4°C) | in $H_2O$ | kilopascals | kPa | 0.2491 |

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# UNIT CONVERSION TABLES
# IMPERIAL TO METRIC (cont'd)

| FROM | SYMBOL | TO | SYMBOL | MULTIPLY BY |
|---|---|---|---|---|
| lamberts | *L | candela/square metre | $cd/m^2$ | 3.183 |
| lumen/square foot | $lm/ft^2$ | lumen/square metre | $lm/m^2$ | 10.76 |
| lumen | lm | watt | W | 0.001496 |
| miles (statute) | mi | kilometres | km | 1.6093 |
| ounces | oz | grams | g | 28.35 |
| perm (at 0°C) | perm | kilogram per pascal-second-square metre | $kg/Pa\text{-}s\text{-}m^2$ (PERM) | $5.721 \times 10^{-11}$ |
| perm (at 23°C) | perm | kilogram per pascal-second-square metre | $kg/Pa\text{-}s\text{-}m^2$ (PERM) | $5.745 \times 10^{-11}$ |
| perm-inch (at 0°C) | perm. in. | kilogram per pascal-second-metre | kg/Pa-s-m | $1.4532 \times 10^{-12}$ |
| perm-inch (at 23°C) | perm. in. | kilogram per pascal-second-metre | kg/Pa-s-m | $1.4593 \times 10^{-12}$ |
| pint (Imp) | pt | litre | L | 0.56826 |
| pounds | lb | grams | g | 453.5924 |
| pounds | lb | joules/metre, (Newtons) | J/m, N | 4.448 |
| pounds | lb | kilograms | kg | 0.4536 |
| pounds | lb | tonne (metric) | t | $4.536 \times 10^{-4}$ |
| pounds/cubic foot | $lb/ft^3$ | grams/litre | g/L | 16.02 |
| pounds/square inch | psi | kilopascals | kPa | 6.89476 |
| quarts | qt | litres | L | 1.1365 |
| slug | slug | kilograms | kg | 14.5939 |
| square foot | $ft^2$ | square metre | $m^2$ | 0.09290 |
| square inches | $in^2$ | square centimetres | $cm^2$ | 6.452 |
| square yards | $yd^2$ | square metres | $m^2$ | 0.83613 |
| tons (long) | ton | kilograms | kg | 1016 |
| tons (short) | tn | kilograms | kg | 907.185 |
| yards | yd | metres | m | 0.9144 |

* "L" as used in Lighting

4138T/T33(-2)

The following typical values for conversion factors may be used when actual data are unavailable. The MJ and Btu equivalencies are heats of combustion. Hydrocarbons are shown at the higher heating value, wet basis. Some items listed are typically feedstocks, but are included for completeness and as a reference source. The conversion factors for coal are approximate since the heating value of a specific coal is dependent on the particular mine from which it is obtained.

| ENERGY TYPE | METRIC | IMPERIAL |
|---|---|---|
| COAL | | |
| — metallurgical | 29,000 megajoules/tonne | $25.0 \times 10^6$ Btu/ton |
| — anthracite | 30,000 megajoules/tonne | $25.8 \times 10^6$ Btu/ton |
| — bituminous | 32,100 megajoules/tonne | $27.6 \times 10^6$ Btu/ton |
| — sub-bituminous | 22,100 megajoules/tonne | $19.0 \times 10^6$ Btu/ton |
| — lignite | 16,700 megajoules/tonne | $14.4 \times 10^6$ Btu/ton |
| COKE | | |
| — metallurgical | 30,200 megajoules/tonne | $26.0 \times 10^6$ Btu/ton |
| — petroleum | | |
| — raw | 23,300 megajoules/tonne | $20.0 \times 10^6$ Btu/ton |
| — calcined | 32,600 megajoules/tonne | $28.0 \times 10^6$ Btu/ton |
| PITCH | 37,200 megajoules/tonne | $32.0 \times 10^6$ Btu/ton |
| CRUDE OIL | 38,5 megajoules/litre | $5.8 \times 10^6$ Btu/bbl |
| No. 2 OIL | 38.68 megajoules/litre | $5.88 \times 10^6$ Btu/bbl<br>$.168 \times 10^6$ Btu/IG |
| No. 4 OIL | 40.1 megajoules/litre | $6.04 \times 10^6$ Btu/bbl<br>$.173 \times 10^6$ Btu/IG |
| No. 6 OIL (RESID. BUNKER C) | | |
| @ 2.5% sulphur | 42.3 megajoules/litre | $6.38 \times 10^6$ Btu/bbl<br>$.182 \times 10^6$ Btu/IG |
| @ 1.0% sulphur | 40.5 megajoules/litre | $6.11 \times 10^6$ Btu/bbl<br>$.174 \times 10^6$ Btu/IG |
| @ .5% sulphur | 40.2 megajoules/litre | $6.05 \times 10^6$ Btu/bbl<br>$.173 \times 10^6$ Btu/IG |
| KEROSENE | 37.68 megajoules/litre | $.167 \times 10^6$ Btu/IG |
| DIESEL FUEL | 38.68 megajoules/litre | $.172 \times 10^6$ Btu/IG |
| GASOLINE | 36.2 megajoules/litre | $.156 \times 10^6$ Btu/IG |
| NATURAL GAS | 37.2 megajoules/$m^3$ | $1.00 \times 10^6$ Btu/MCF |
| PROPANE | 50.3 megajoules/kg<br>26.6 megajoules/litre | $.02165 \times 10^6$ Btu/lb<br>$.1145 \times 10^6$ Btu/IG |
| ELECTRICITY | 3.6 megajoules/kWh | $.003413 \times 10^6$ Btu/kWh |

## Insulation Material Properties Selection Considerations

Worksheet 1-1

Company: ____________________ Date: ____________________

Location: ____________________ By: ____________________

Insulation for: ________________________________________

| Property | Important | Not Important |
|---|---|---|
| APPEARANCE (is insulation exposed?) | | |
| CHEMICAL NEUTRALITY (is insulation subject to intermittent wetting?) | | |
| BREAKING LOAD (must insulation bridge discontinuities in its support?) | | |
| CAPILLARITY (is insulation in a wet area?) | | |
| COEFFICIENT OF EXPANSION AND CONTRACTION (is insulation layered or are expansion joints required?) | | |
| COMBUSTIBILITY (is there a fire hazard in the area?) | | |
| COMPRESSIVE STRENGTH (must insulation support a load or be subject to mechanical abuse?) | | |
| DENSITY | | |
| SHRINKAGE (is this a high temperature application?) | | |
| RESISTANCE TO ULTRAVIOLET RADIATION (is insulation exposed to sunlight?) | | |
| RESISTANCE TO BACTERIAL OR FUNGAL GROWTH (is insulation used in a food or cosmetic preparation area?) | | |

## Heat Loss From Piping
Worksheet 1-2

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Pipe diameter (NPS) ______________________ Pipe Length ______________________ m

Pipe temperature ______________________ °C Operating hours per year ______________________ h

Proposed insulation type ______________________ Proposed insulation thickness ______________________ mm

| | Uninsulated | Insulated |
|---|---|---|
| Heat loss per metre | ____________ Wh/m·h (Table 1) | ____________ Wh/m·h (Table 3) |
| Heat loss/h | = Heat loss/m·h x length | Heat loss/m·h x length |
| | ____________ x ____________ | ____________ x ____________ |
| | ____________ Wh/h | ____________ Wh/h |
| Annual heat loss | = Heat loss/h x h/yr | Heat loss/h x h/yr |
| | ____________ x ____________ | ____________ x ____________ |
| | ____________ Wh/yr (1) | ____________ Wh/yr (2) |

Reduction in heat loss due to addition of insulation

= (1) − (2)

= ____________ − ____________

= ____________ Wh/yr

or ____________ Wh/yr x 3.6 kJ/Wh

= ____________ kJ/yr

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

## Heat Loss From Piping

Worksheet 1-3

Company: ______________________ Date: ______________________

Location: ______________________ By: ______________________

Equipment ______________________ Operating hours per year ____________ h

Surface area ____________________ $m^2$ Proposed insulation type ____________

Product temperature ________________ °C Proposed insulation thickness ________ mm

| Uninsulated | Insulated |
| --- | --- |
| Heat loss = ____________ $Wh/m^2$ (Table 1) | ____________ $Wh/m^2$ (Table 3) |
| Total heat loss/h = Surface area x Heat loss | Surface area x Heat loss |
| ____________ x ____________ | ____________ x ____________ |
| ____________________ Wh/h | ____________________ Wh/h |
| Annual heat loss = Heat loss/h x h/yr | Heat loss/h x h/yr |
| ____________ x ____________ | ____________ x ____________ |
| ____________________ Wh/yr (1) | ____________________ Wh/yr (2) |
| Reduction in heat loss due to addition of insulation | = (1) − (2) |
| | = ____________ − ____________ |
| | = ____________________ Wh/yr |
| | or ____________ Wh/yr x 3.6 kJ/W |
| | = ____________________ kJ/yr |

Annual dollar savings may now be calculated using cost per unit of heating medium. Ensure that units are compatible.

# APPENDIX E

**Economic Insulation Thickness**

The thermal insulation industry encourages all interested parties to contact their local industry association or industry representatives to arrange for an insulation investment analysis.

Within the thermal insulation industry, there are two commonly used computer programs designed to aid insulation investment analysis. One is the Economic Thickness of Industrial Insulation for Hot & Cold Surfaces. This was prepared for the Thermal Insulation Manufacturers' Association (TIMA) by B.F. Lackwell and D.E. McConnell of Louisiana Tech University. (TIMA: 7 Kirby Plaza, Mount Kisco, New York 10549).

The second program is called "Heatalyzer" and it is available through the National Insulation Contractors' Association (NICA). "Heatalyzer" is run on an IBM personal computer. (NICA: 1025 Vermont Avenue N.W. Suite 410, Washington, D.C. 20005).

Both programs rely upon the same logic and both use a number of factors such as fuel type, fuel price, tax rates and inflation rates to analyze the cost/benefit of an insulation investment.

# APPENDIX F

## Thermal Insulation Material Specification Standards

Insulation and related materials are produced in accordance with established standards of quality and acceptability. For Canada the principal insulation standards organizations are listed below.

CGSB — Canadian General Standards Board is one of the five standards-writing organizations accredited by the Standards Council to write National Standards of Canada. CGSB's standards cover a wide range of fields including administrative, building, consumer and construction products. Publications may be obtained from Canadian General Standards Board.

ASTM — The American Society for Testing and Materials founded in 1898, is considered to be the world s largest source of voluntary consensus standards. Publications may be obtained.from American Society for Testing and Materials.

CAN — National Standards of Canada prepared by an accredited standards-writing organization and approved as a national standard by the Standards Council of Canada. Publications may be obtained from the Standards Council of Canada.

Outlined in summary form are the material standards which thermal insulation materials must meet as specified by the Canadian General Standards Board and the American Society of Testing Materials.

| PRODUCT | CGSB | ASTM |
|---|---|---|
| Calcium Silicate Block & Pipe | 51-GP-2M | C-533-80 |
| Board | | C-566-79 |
| Cellular Glass Block & Pipe | 51-GP-38M | C-522-79 |
| Pre-formed Flexible Elastomeric Thermal Insulation (sheet & tube) | 51-GP-40M | C-534-82 |
| Mineral Fiber Pipe | 51-GP-9M | C-547-77 |
| Blanket & Felt | 51-GP-11M | C-533-70 |
| Block & Board | 51-GP-10M | C-612-83 |
| Metal Mesh Covered | | C-592-80 |
| Phenolic Thermal Insulation, for Pipes & Ducts | 51-GP-29M | |
| Rigid Pre-formed Cellular Polystyrene Boards | 51-GP-20M | C-578-83 |
| Rigid Pre-formed Cellular Urethane Pipe & Block (unfaced) | 51-GP-21M | C-591-69 |
| Thermal Insulation, Urethane and Isocyanurate, Boards, Faced | CAN 2-51.26-M | |
| Wicking Type Thermal Insulation, for use over Austenitic Stainless Steel | | C-795-77 |
| Inner and Outer Diameter of Rigid Thermal Insulation — for nominal sizes of pipe and tubing | | C-585-76 |