All About INSULATION

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Indian Society of Heating, Refrigerating
and Air Conditioning Engineers

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Disclaimer: This book is a compilation of data from various open sources.

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Foreword

The air conditioning industry is growing exponentially across all applications including comfort, process and manufacturing. Similarly, the importance of the refrigeration industry cannot be ignored, with the growing focus on cold chain, food processing and storage, pharmaceuticals and domestic refrigeration needs. Specifically, in India, the installed capacity across all segments and requirements is going to multiply over the next few years. This will mean a rise in energy requirements, and care will have to be taken to mitigate the adverse impact on the environment.

Insulation plays a very important role in improving the energy efficiency of a system, reducing the heat gain or loss across a structure or component, enhancing process performance, and effecting moisture control apart from many other functions like acoustical performance, temperature control and personnel safety – with all this leading to reduction in carbon emission.

ISHRAE, as a part of its objective to disseminate knowledge, has taken initiatives to publish Guide Books, Standards and Data Books to address various HVAC&R requirements specifically in the Indian context. This Guide Book is one of the many initiatives undertaken in the same direction to impart learning and knowledge in this all-important field of Insulation spanning across all possible applications.

The book is an outcome of the dedication and passion of the Insulation Technical Group chaired by Mr. Ramesh Paranjpey and well supported by a team of passionate volunteers.

ISHRAE has a very active Technical Committee well supported by nearly 30 technical groups addressing all possible aspects of the HVAC&R industry. We seek interested and knowledgeable professionals to come forward and volunteer to serve the Society and the industry, and help the journey towards technical excellence.

Vishal Kapur
Chair, ISHRAE Technical Committee

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Mr. Ramesh Paranjpey,
Lead Author and Chair, Insulation Technical Group – ISHRAE

Team Members

- Mr. K. K. Mitra
- Mr. Sandeep Mendiratta
- Mr. U. Haridas
- Mr. Samkit Shah
- Mr. Ramchandra Raju
- Mr. Isaac Emmnuel

Preface to First Edition

I am happy to present this book 'All About Insulation' to practicing air conditioning and refrigeration engineers.

The book covers various types of insulating materials commonly used in air conditioning and refrigeration projects. It covers the use of insulation in major applications including cold storages, industrial refrigeration systems, air conditioning plants and transport refrigeration. The book covers only applications for cold insulation, and does not deal with hot insulation or cryogenic applications and materials.

The first two chapters are introductory, giving the basics of insulation and the terminology used while dealing with insulation material.

I cannot claim personal credit for the entire contents of the book as it is a compilation of dispersed information on insulation available at various sources such as the internet, text books, manufacturers' catalogues, ASHRAE Handbooks, and contributions by other members of the Insulation Handbook Committee of ISHRAE. I have tried my best to present the information in an organised manner.

My special thanks to the Committee comprising of industrial stalwarts in this field who guided my effort, viz. Mr. K. K. Mitra, Mr. U. Haridas, Mr. Isaac Emmanuel, Mr. Sandeep Mendiratta, Mr. Ramchandra Raju and Mr. Samkit Shah. Mr. Kundan Adhikari provided administrative support, for which I am thankful. I am especially indebted to two Committee members, Mr. K. Ramachandran and Mr. Vishal Kapur, for the guidance and encouragement given to me from time to time.

This is my second publication for ISHRAE; in the year 2002 – exactly 20 years back – I had written a book titled 'ABC of Air Conditioning'. I am sure this first edition of the book is just the beginning; once the readers go through it, there would be many suggestions, improvements and additional information that would be addressed in the next edition.

I am also thankful to the Editor of ISHRAE's Air Conditioning and Refrigeration Journal, Mr. Rakesh Kumar, who has edited all the chapters speedily to meet the target date.

Ramesh Paranjpey
Chair,
Guide Book Committee and Technical Group, ISHRAE

October 2020

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PART 1

FUNDAMENTALS

CHAPTER 1

Basics of Insulation

When there is a temperature difference between two objects, heat flow is inevitable. Heat will always flow from higher temperature to lower temperature irrespective of the size, mass or position of the objects.

An air conditioned or refrigerated space is normally at a lower temperature than the surroundings and heat would, therefore, try to penetrate from outside to the inside colder area.

Refrigeration/air conditioning is a process in which the temperature is lowered by pumping out heat from a colder place where it is not required to a warmer place where it is not objectionable, and is exactly the reverse of the natural phenomenon; therefore, to achieve it requires external energy.

Cold insulation is, therefore, required where operating temperatures are below ambient temperatures to prevent or reduce heat gain, condensation or freezing.

Thermal insulation provides a layer of material that reduces thermal conduction or heat ingress and reflects thermal radiation rather than letting it be absorbed by the lower temperature body.

Heat Transfer

Heat transfer takes place in three different ways: conduction, convection and radiation.

Conduction is the transfer of heat from molecule to molecule through a substance by chain collision. Heat added at one point causes the temperature of the substance to go up because the molecules move more rapidly. These high velocity molecules start chain collision with molecules near them. While conduction takes place in liquids and gases, it is most prominent in solids where the density is the highest, which means that the molecules are more closely packed.

Convection is heat transfer by the movement of molecules from one place to another.

Forced convection is the flow caused by external influences such as wind, ventilators and fans.

Radiation transfers heat by passing from a source to an absorbent surface without heating the space in between.

Heat transfer through insulation material occurs by means of conduction, while heat loss to or heat gain from the atmosphere occurs by means of convection and radiation.

Heat passes through solid materials by means of conduction, and the rate at which this occurs depends on thermal conductivity (expressed in W/m·K) of the material in question and the temperature difference.

In general, the greater the density of a material, the greater is the thermal conductivity; for example, metals have high density and high thermal conductivity.

Materials with low thermal conductivity are those that have a high proportion of small voids containing air or gas.

If the density of insulation is low, air or gas voids are comparatively large, and it is the best insulation for low to medium temperatures. Thermal insulation materials fall into this category. Thermal insulation materials may be natural substances or man-made.

Thermal Insulation

Thermal insulation is a material used in the air conditioning and refrigeration industry to act as a resistance or a barrier to transfer of heat from higher temperatures to lower temperatures.

The temperature range within which the term thermal insulation is applicable is from -75°C to +815°C. All applications below -75°C are termed cryogenic, and those above +815°C are termed refractory.

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

Low Temperature Thermal Insulation

1. From 15°C to 1°C, e.g. cold or chilled water and fresh fruit/vegetable storage cold rooms.
2. From 0°C to -40°C, e.g. refrigeration or glycol brine chillers, frozen food storage.

3. From -40°C to -75°C, e.g. blast freezers, plate freezers, IQF, refrigeration and brine process plants.
4. From -76°C to -273°C (absolute zero), i.e. cryogenic (not addressed in this book).

Intermediate Temperature Thermal Insulation

1. From 16°C to 100°C, e.g. hot water and steam condensate.
2. From 101°C to 315°C, e.g. steam, high temperature water.

High Temperature Thermal Insulation

1. From 316°C to 815°C, e.g. turbines, breechings, stacks, exhausts, incinerators, boilers.

Why is Insulation Necessary?

A thermal insulation system is a combination of material, ancillaries for application, and application methodology that resists the flow of environment heat to the inside of a building or enclosure that is required to be maintained at a much lower temperature than outside (a typical Indian situation where ambient temperatures are high during most parts of the year).

Thermal insulation will resist the flow of heat by acting as a barrier. The most effective insulation material will provide the maximum resistance and will be defined by a particular R value, which will depend upon its thermal conductivity value and thickness.

The lower the thermal conductivity of an insulation material, the more effective it will be.

The higher the resistance R, the better will the insulation be.

In addition, the density of the insulation material is also important. Higher density will increase the heat capacity of the material and result into a lower thermal diffusivity value. A material with lower diffusivity value will be able to maintain a constant temperature or cause a slow rise in the temperature inside a building in a situation when internal cooling is switched off or not working.

Benefits of Using Insulation

1. Reduces heat gain or heat loss
2. Prevents moisture penetration and acts as a vapour barrier
3. Acoustical performance of insulating material helps reduce noise level in ducting, equipment, etc.
4. Prevents condensation and water dripping from ducting, piping, drain pans, ceiling, etc.
5. Prevents ice accumulation and protects the freezer
6. Enhances process performance, reducing energy consumption
7. Controls surface temperatures to avoid contact burns (hot or cold), improving personnel protection
8. Promotes fire safety by helping to slow down the spread of fire in buildings
9. Provides more accurate control of process temperatures by minimising fluctuations and protecting the product
10. Prevents gas condensation inside pipes
11. Limits temperature change of process fluid and helps protect the freezer
12. Improves appearance of equipment and piping
13. Helps reduce carbon emission

Moisture and the Need for Vapour Retarders

Temperature is an easily measurable parameter. However, moisture in the air is in vapour form and is invisible. The presence of moisture in the air is an important parameter for insulation selection. As heat flows from a higher temperature to a lower temperature, moisture travels from higher vapour pressure of outside air to lower vapour pressure of inside air.

Since moisture is a good thermal conductor, its presence in an insulation system is highly detrimental; refrigeration systems face increased energy cost and condensation, which often leads to complete system failure.

With the prevailing high energy costs, the design thickness of insulation in almost all refrigeration applications is dictated by what is needed to prevent moisture penetration and condensation, rather than by economic payback.

The importance of thermal insulation as a vapour barrier would be discussed in greater details in Chapter 5, *Cold Storage Applications*.

Insulation Applications in Air Conditioning and Refrigeration

1. The major use of insulation in cooling applications is in cold storages for walls, ceiling, flooring and doors. Cold storages can be for positive or negative temperature use. Blast freezer rooms, individual quick freezers and plate freezers also require some insulation.
2. Refrigerant pipe lines that are at lower temperature than ambient.
3. Refrigeration equipment such as shell and tube water/glycol/brine and other special-

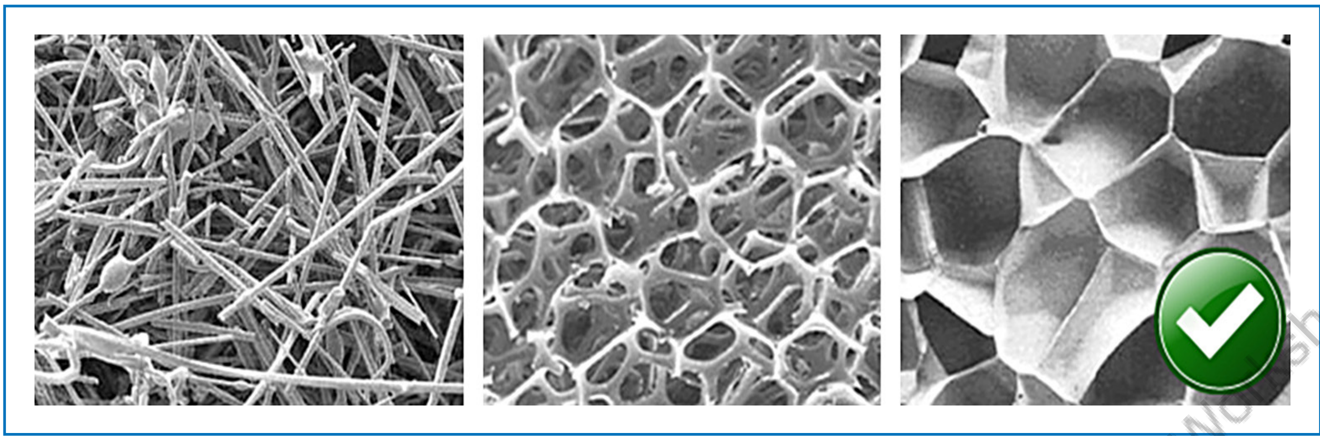


Figure 1-1: *Open cell, microporous, and closed cell structure*

fluid chillers, inter-stage coolers, low pressure/temperature vessels, surge drums, knock out drums, accumulators, suction/liquid line heat exchangers, refrigerant and chilled water circulation pumps and any other equipment that has temperature lower than ambient.

4. In air conditioning applications, insulation is used for water chillers, refrigerant piping, air handling units and ducting.
5. The transport refrigeration industry uses insulation for constructing truck bodies.
6. Package chillers installed on a terrace use insulation for the casing.
7. In ice plants like block ice maker tanks, flake ice and tube ice makers.
8. Ice rinks and amusement parks with ice rooms require insulation.
9. Morgues, since they are maintained at low temperatures.
10. Super markets use insulation for display cabinets, etc.

In brief, wherever the temperature is maintained at a lower level than the surrounding temperature by artificial means, to resist heat flow from a higher temperature to a lower temperature area, insulation is essential to save energy and avoid the undesirable effects mentioned above.

In subsequent sections we shall discuss each application in more detail to assist design and application engineers and installers.

Insulation Materials for Cooling Applications

Insulation can have open cell structure, closed cell structure, or semi-open structure.

Closed cell foam has higher R value compared to open cell foam and is a better insulation.

Examples of these insulation materials are:

Open Cell

i. Rockwool or mineral wool
ii. Glass wool
iii. Cork
iv. Melamine foam
v. Expanded polystyrene (EPS)
vi. Polyurethane foam (PUF)

Semi-open Cell (Microporous)

i. Polyisocyanurate (PIR)
ii. Extruded polystyrene (XPS)
iii. Polyethylene (PE)

Closed Cell

i. Foam glass (foam)
ii. Cross linked polyethylene (XLPE)
iii. Nitrile butadiene rubber foam (NBR)
iv. Polyolefin foam – physically cross linked
v. Polyurethane foam

Note: *Polyurethane foam comes in two forms:*

1. Open structure for indoor applications
2. *Closed cell for outdoor applications*

Flexible Elastomeric Forms

As elastomer is a polymer with the property of elasticity. It is a polymer that deforms under stress and returns to its original shape when the stress is removed. The term elastomer is a contraction of elastic polymer. The elastomer group consists of the following:

1. Nitrile butadiene rubber (NBR)
2. Ethylene propylene diene monomer (EPDM)
3. Styrene butadiene rubber (SBR)
4. Neoprene

Cross Linked Polyolefin or Polyethylene

Polyolefin is the name of a group of plastics. Polyethylene is the specific name of one type of polyolefin. The plastics in this group are:

- Polyethylene (PE)
- Polypropylene (PP)
- Polymethyl pentene (PMP)
- Polyethylene Vinyl Acetate (PVA)

Types of Insulation

Fibrous Insulation

It is composed of small diameter fibres that finely divide the air space. The fibres may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together. Silica, rock wool, slag wool and alumina silica fibres are used. The most widely used insulations of this type are glass fibre and mineral wool. Glass fibre and mineral wool products usually have their fibres bonded together with organic binders that supply the limited structural integrity of the products.

Cellular Insulation

It 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, polyisocyanurate and elastomeric.

Granular Insulation

It is composed of small nodules that may contain voids or hollow spaces. It is not considered a true cellular material since gas can be transferred between individual spaces. This type may be produced as a loose or pourable material or combined with a binder and fibres or undergo a chemical reaction to make a rigid insulation. Examples of such insulations are calcium silicate, expanded vermiculite, perlite, cellulose, diatomaceous earth and expanded polystyrene.

Vacuum Insulation

Insulation for cryogenic applications uses vacuum to eliminate convection paired with multiple layers of material. These layers are normally of aluminium, copper or gold, separated by small air spaces. This type of multilayer insulation may contain as many as 60 layers per inch, and with each layer of metal emitting as little as 2-3% of insulation, radiation is virtually eliminated as well.

Reflective Insulation

Reflective paints and surfaces are added to the surface to lower long wave emittance, thereby reducing radiant heat transfer from the surface.

Forms of Insulation

Insulation materials are produced in a variety of forms suitable for specific functions and applications. The combination of form and type of insulation determines its proper method of installation. The forms most widely used are:

1. Rigid boards, blocks, sheets, and pre-formed shapes such as pipe insulation, curved segments and lagging. Cellular, granular, and fibrous insulations are produced in these forms.
2. Flexible sheets and pre-formed shapes. Cellular and fibrous insulations are produced in these forms.
3. Flexible blankets. Fibrous insulations are produced in flexible blankets.
4. Cements (insulating and finishing) are produced from fibrous and granular insulations and cement. They may be of hydraulic setting or air-drying type.
5. Foams. These are poured or froth foam is used to fill irregular areas and voids; spray is used for flat surfaces.

Common Insulation Materials Used by AC&R Industry

The most common insulation materials known to the air conditioning and refrigeration industry are:

1. Fibreglass
2. Mineral wool
3. Polystyrene
4. Polyurethane
5. Polyisocyanurate
6. Polyolefin and elastomeric rubber

More details of each insulation material are given in Chapter 3, *Properties of Insulation Materials*.

CHAPTER 2

Important Formulæ

In this Chapter, we shall discuss the important formulæ used while selecting insulation material, and the desired properties of insulation for various applications.

Conversion of Values between SI and FPS System

Engineers depend on conversion tables for converting values from one system to another. Most of the software available for calculation of heat load are in FPS units, and excel formats prepared by users are combinations of SI and FPS system. For example, transmission load is calculated in FPS units and the results are then converted into SI units.

It is therefore necessary to learn how to convert values from one system to another without referring to conversion charts or tables. The ASHRAE Handbook, or any other book such as SI Units for the HVAC/R Professional by W. F. Stoecker, gives only conversion tables but does not indicate how the values have been arrived at.

This chapter will help engineers and designers to easily convert values from one system to another if conversion tables are not readily available.

We shall explain some of the essential conversion calculations and important properties to be considered while selecting insulation material.

1. Thermal Conductivity

k or λ = W/(m·K)

Thermal conductivity (λ) is a specific material property. It represents the heat flow in watts (W) through 1m² surface and 1m thick flat layer of a material when the temperature difference between the two surfaces in the direction of heat flow is 1 Kelvin (K). The unit of measurement for thermal conductivity in SI units is W/(m·K).

In FPS units (Btu/hr·ft²·°F per inch thickness), it is the rate of heat transfer in British Thermal Units per hour per square foot of area per degree Fahrenheit temperature difference per inch thickness.

Thermal conductivity depends on the temperature and pressure for materials and fluids. For some materials, thermal conductivity may also depend upon the direction of heat transfer.

The thermal conductivity values of building insulation materials are generally given at 24°C, according to ASTM standards.

Thermal conductivity of materials increases as the temperature increases.

In order to convert the k value given in Btu. in/h·ft²·°F, we need to multiply the FPS value by 0.1442 to get the k value in SI (W/m·K) as given in conversion tables.

How this has been worked out is explained below:

Thermal conductivity, k

$$= 1\ \text{Btu/hr}\cdot\frac{\text{ft2}}{\text{in.}}\cdot{}^{\circ}\text{F x } 0.1442 = 1\ \text{W}/\frac{\text{m2}}{\text{m}\cdot}.\text{K}$$

$$= \frac{1 \text{ x } 1055.056\ \text{J}(\text{J} = \text{W}\cdot\text{s})}{\text{inch x } 3600\text{s x } (3.2808\text{ft x } 12) \text{ x } \frac{1}{3.2808\text{ft}} \text{ x } \frac{1}{3.2808\text{ft}} \text{ x } \frac{1}{1.8\text{F}}}$$

$$= \left[\frac{1055.056\ \text{J(W.s) x } 3.2808\text{ft x } 3.2808\text{ft x } 1.8\text{F}}{3600 \text{ x } 3.2808\text{ft x } 12\text{in}}\right] = 0.1442$$

Hence, when we multiply thermal conductivity in FPS units by 0.1442, we get thermal conductivity in SI units (W/m·K).

Please note the major difference between FPS system and SI.

In FPS system, k value is expressed in per inch thickness, whereas in SI it is expressed in per metre thickness,

Hence k value in SI is not W/m²· K, but W/m²/m·K or W/m·K.

Many engineers have the misconception that the units mentioned above for calculations are incorrect, and hence the need for this clarification.

2. Thermal Resistance

R = m²·K/W

Thermal resistance (R) describes the thermal insulation effect of a constructional layer. It is obtained by dividing the thickness (d) by the thermal conductivity value of a building component or material. R = d/λ (in accordance with EN ISO 6946). The unit of thermal resistance is (m^2·K)/W (m÷W/m·K = m x m x K/W)). In building components comprising several layers, the thermal resistances of the individual layers are added together.

In order to calculate heat gain, we need to first calculate the overall thermal resistance R offered by the structure comprising of various materials.

The formula for overall thermal resistance in FPS units is

R = hr·°F·ft^2/Btu,

and in SI units it is

R = m^2·K/W

$$= \frac{3600}{1055.056\text{J}\left(\frac{\text{W}}{\text{s}}\right) \text{ x } 1.8\text{F x } 3.2808\text{ft x } 3.2808\text{ft}} = 0.17611$$

We therefore need to multiply the FPS value of R by 0.17611 to get its value in SI units.

3. Thermal Conductance

C = W/m²·K or Btu/hr·ft²·°F

Thermal conductance is the reciprocal of thermal resistance.

Btu/hr·ft^2·°F x 5.678(1/0.17611) = W/m^2·K

Conductance equals conductivity multiplied by thickness, in units of W/m^2·K.

The difference between thermal conductivity W/m·K and thermal conductance (W/m^2·K) is that thermal conductivity is a material property and means its ability to conduct heat through its internal structure; conductance, on the other hand, is an object property and depends on both the material and its thickness.

Conductance depends on the dimensions of the conductor, but conductivity does not depend on dimensions.

4. Overall Heat Transfer Coefficient or Thermal Transmittance

U = W/m²·K

Thermal transmittance is the heat flow in watts (W) through 1m^2 of a building component when the temperature difference between the surfaces in the direction of heat flow is 1K. U value can be calculated from the relation U = 1/R for a given construction, and is generally represented in W/(m^2·K).

The overall heat transfer coefficient U is the reciprocal of all resistances acting as barriers to the travel of heat from outside to inside the refrigerated space, since heat would always try to travel from higher temperature to lower temperature space.

Overall heat transfer coefficient is the reciprocal of R or 1/0.17611 = 5.67823.

The calculation is:

Overall heat transfer coefficient Btu/hr·ft^2·°F x (5.678263) = W/m^2·K

$$\text{U} = \frac{1055.056\text{ J(W.s)}}{3600 \text{ x } \frac{1}{3.2808\text{ft}} \text{ x } \frac{1}{3.2808\text{ft}} \text{ x } \frac{1}{1.8\text{F}}}$$

$$= \left[\frac{1055.056\text{J(W.s) x } 3.2808\text{ft x } 3.2808\text{ft x } 1.8\text{F}}{3600}\right] = 5.67823$$

Therefore, when we convert from U in FPS units to SI units, we need to multiply by 5.67823.

5. Surface Film Conductance

f = W/m²·K or Btu/hr·ft²·°F

The surface of any material offers resistance to heat flow. The value depends upon its reflectivity, degree of roughness, whether horizontal or vertical in direction, length and air velocity over the surface.

The reciprocal of this resistance is the surface film conductance (f), which is expressed in the same units as conductance (C).

6. Volumetric Heat Capacity

Cp: J/m³·K

Volumetric heat capacity is the change in heat stored in a unit volume of material (m^3) for a unit change in temperature (K).

7. Specific Heat Capacity

c = J/kg·K

The specific heat capacity of a material is the amount of heat needed to raise the temperature of 1kg of the material by 1K (or 1°C). A good insulator has a high specific heat capacity, because it takes longer to absorb more heat before its temperature rises to transfer the heat. High specific heat capacity is a feature of materials providing thermal mass or thermal buffering (decrement delay).

Table 2-1: *Specific heat capacity of common materials*

Material	c = J/(kg·K)
Water	4190
Wood and wood-based materials	1600
Rigid polyurethane foam (PUR/PIR)	1400 – 1500
Wood-fibre insulation boards	1400
Mineral wool	1030
Air (ρ=1.25 kg/m^3)	1000
Aluminium	1000
Other metals	800

8. Heat Flux or Thermal Flux

q": W/m²

It is sometimes also referred to as heat flux density, heat flow density or heat flow rate intensity, and is the flow of energy per unit area per unit time.

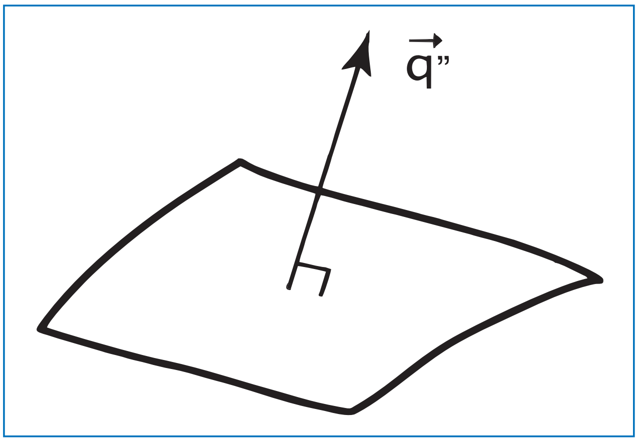


Figure 2-1: Heat flux is heat flow through unit area

In SI, its unit is watts per square metre. It is the time rate of heat transfer through unit area.

9. Thermal Diffusivity

α = mm²/s

Thermal conductivity of a material is a measure of the ability of the material to conduct heat through it. Thermal diffusivity of a material, on the other hand, is the thermal inertia of the material. This is the main difference between thermal conductivity and thermal diffusivity.

Thermal diffusivity measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. For example, metals transmit thermal energy rapidly (cold to touch), whereas wood is a slow transmitter. Insulators should have low thermal diffusivity. Thermal diffusivity of copper is 98.8 mm^2/s; whereas for wood it is 0.082 mm^2/s. The lower the thermal diffusivity, the better is the insulator. The equation for thermal diffusivity is:

Thermal diffusivity (mm^2/s) = Thermal conductivity/density x specific heat capacity

10. Thermal Emissivity, ε

Surface emissivity is the amount of infrared energy emitted by a material. In the insulation industry, surface emissivity is a major factor in the effectiveness of the product, yet it is often overlooked and overshadowed by thermal conductivity or k value.

Emissivity is a measure of the efficiency with which a surface emits thermal energy. It is defined as the fraction of energy being emitted relative to that emitted by a thermally black surface (black body).

A black body is a material that is a perfect emitter of heat energy and has emissivity value as 1. A material with an emissivity of 0 would be considered a perfect thermal mirror.

For example, if an object had the potential to emit 100 units of energy but emits only 90, it has an emissivity of 0.9. In the real world there are no perfect black bodies and very few perfect infrared mirrors, so most objects have emissivity between 0 and 1.

Placing a layer of low-emissivity material (like aluminium or copper) in the insulation acts as a radiant barrier, and decreases the amount of infrared radiant heat that reaches the insulation below.

Depending on the level of existing insulation, low emissivity metal can reduce the total heat flux through the ceiling by as much as 50%. It is especially effective in warm climates where a large portion of a home's energy usage goes toward cooling.

The accuracy of the values given is almost impossible to guarantee as the emissivity of a surface will not only alter with its texture and colour, but also with its actual temperature at the time of measurement.

Reflective Thermal insulation

Reflective thermal insulation material is typically fabricated from aluminium foil with a variety of core materials such as low-density polyethylene foam, fibreglass or similar insulation materials. When aluminium foil is used as a facing material, reflective thermal insulation can stop 97% of the radiant heat transfer.

11. Vapour Resistance and μ Value

Vapour resistance is a measure of the material's reluctance to let water vapour pass through. It takes into account the material's thickness, hence can only be specified for a particular thickness of material. It is usually measured in meganewton seconds per gram (MN·s/g). If the quantity is measured in MN·s/g·m (notice the small 'm' at the end), it is actually vapour resistivity.

The μ-value (mu-value) of a material, also known as water vapour resistance factor, is measured in comparison to the properties of air.

The μ-value is a property of the bulk material and needs to be multiplied by the material's

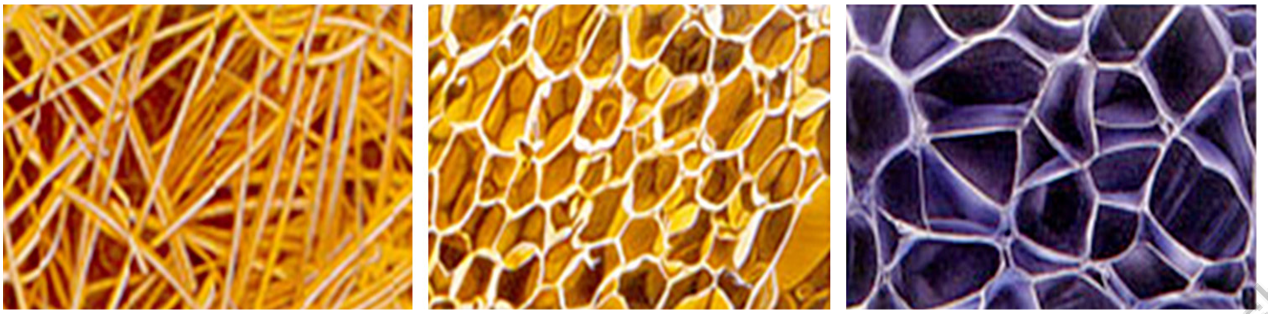


Figure 2-2: *Open cell insulation with low μ value, semi-closed cell insulation with moderately high μ value, and closed cell insulation with high μ value above 8000*

thickness when used in a particular construction. Because the μ-value is a relative quantity, it is just expressed as a dimensionless number (it has no units).

Calculating the μ-value

Multiply vapour resistance by 0.2 gm/MN·s (This is a typical value in the UK for vapour permeability of still air, and converts vapour resistance to the 'equivalent air layer thickness'.)

Divide by the thickness in meters. This gives the μ value.

Example

For a material with vapour resistance = 10,000 MN·s/g and thickness = 100 mm,

μ value = 10,000 MN·s/g x 0.2 gm/MN·s ÷ 0.1 m = 20,000

(Reference BS 5250: 2002 Annex E)

In rating the effectiveness of insulating material, two terms – namely Permeability and Permeance – also need to be understood.

12. Permeability, kg/Pa·s·m

This is the term used to describe moisture transmission of a material. It is a theoretical number calculated by multiplying Permeance by the thickness of the polymer. It is stated in perm inches. The moisture transmission rate of a material is referred to as its permeability.

This number is not dependent on material thickness.

For example, aluminium foil has a permeability of 0.05 US perm = 2.9 SI perm.

13. Permeance or Perm

It is the moisture transmission rate of the membrane. It is a performance measure and is expressed in perms. It can be for any material that has a water vapour transmission rate less than 1 perm.

1.0 US perm = 1.0 grain/square foot per hour per inch of mercury vapour pressure (7,000 grains = 1 pound)

1.0 perm = 57 SI perm = 57 ng/s·m^2·Pa

or 1 perm = 1/7,000 pound

Dividing the permeability of a material by its thickness gives the material's permeance, expressed in perms. Permeance is the number that should be used to compare various materials for moisture transmission resistance. Lower numbers indicate better performance.

Permeance to water vapour (pv)

It is defined as the quantity of water vapour that passes through a unit of area of a material of unit thickness, when the difference in water pressure between both faces of the material is one unit. It is expressed as g·cm·mmHg^{-1}·m^{-2}·day^{-1}, or in SI system as g·m·MN^{-1}·s^{-1} (grams meter per mega newton per second).

Resistance to water vapour (rv)

It is the reciprocal of the permeance to water vapour and defined as rv = 1/pv.

Which Material is Suitable as Insulation?

Having discussed various properties of insulation materials, it is now time to discuss how to select the right kind of insulation for the given requirement.

There are plenty of low cost and common insulation materials available in the market today. Many of these materials have been around for quite some time. Each of these insulation materials has its own pros and cons. As a result, when deciding which insulation material to select, one should be sure that the material would work the best in the given situation.

Closed-cell insulation is the most commonly specified material for cold work, because it possesses a degree of resistance to water vapour and because the thermal conductivity (k value) of some of these materials is better than fibrous alternative products.

Materials that have a low thermal conductivity are those that have a high proportion of small voids containing air or gas. These voids are not large enough to transmit heat by convection or radiation, and therefore reduce the flow of heat. Thermal insulation materials are generally man-made, but they could also be natural substances in certain applications.

It is very important to understand that insulation material itself has hardly any insulating property. It is the trapped air/gas bubbles inside the insulation that impart it the insulating properties. The more the trapped air bubbles, the better the insulation.

If the density of insulation is low, the air or gas voids are comparatively large, and this makes for the best insulation for low to medium temperatures where compression and/or vibration is not an important factor.

The density of insulating material may be increased to a point. If the density is increased too high, the solid content of the insulation material overcomes the insulating effect of the voids, reducing the ability to prevent heat flow and ingress. In fact, the material of the insulation becomes a conducting medium, and heat flow and ingress increase.

Desirable Properties of Insulation Material

While selecting the insulation material, one should look for the following properties. These are the major properties; however, depending upon the application, certain additional properties such as appearance, resistance to wind erosion, resistance to bacteria, UV resistance, dimensional stability, etc. also need to be considered.

1. Insulation material should have low thermal conductivity. Thermal conductivity is a material property. It will not vary with the dimensions of a material, but is dependent on the temperature, density and moisture content of the material. Thermal conductivity normally found in tables is the value valid for normal room temperature. Light materials are generally better insulators than heavy materials, because light materials often contain air enclosures. Dry still air has a very low conductivity.
   When a material, for instance the insulating material, becomes wet, the air enclosures fill with water and, because water is a better conductor than air, the conductivity of the material increases. That is why it is very important to install insulation materials when they are dry and to take care that they remain dry.
2. Insulation material should have a high R-value. In order to increase the R-value, the insulation material has to be able to trap air inside as part of its structure.
3. Insulation material should be water resistant, with very low moisture permeability and water retention capacity. Thus, water absorption becomes negligible, thereby minimising condensation and corrosion. This will be discussed in more detail in Chapter 5, *Cold Storage Applications*.
4. Insulation material should be *non-flammable and fire resistant*.

***Table 2-2:** Classification as per British Standard 476*

Class A1/A2	Non-combustible
Class 0	Additional protection to class A with help of paints/varnishes or reflective paints for walls and ceilings for use in high risk areas such as escape routes
Class B	Combustible material – very limited contribution to fire
Class C	Combustible material – limited contribution to fire
Class D	Combustible material – moderate contribution to fire
Class E	High contribution to fire
Class F	Easily flammable

Factory Mutual (FM) is the world's leading commercial insurance body that provides client risk management through its product certification system to safeguard the client's property. FM approval for fire resistance is a must.

5. Insulation material should be wind resistant.
6. Insulation material should be UV resistant.
7. Insulation material should be light in colour so that solar radiation is reflected back and little is absorbed (low emissivity).
8. Insulation material should be such that it protects the environment; more efficient and

Table 2-3: Important characteristics for selection of insulation material

Abbreviation	Factor	Unit	Relationship to insulation value
k	Conductivity	W/m·K	Lower is better
C	Conductance	$W/m^2 \cdot K$	Lower is better
U	Overall heat transfer coefficient	$W/m^2 \cdot K$	Lower is better
D	Thermal diffusivity	m^2/s	Lower is better
E	Permeability	Perm	Lower is better
ε	Thermal emissivity	Dimensionless (1 to 0)	Lower is better
f	Surface film conductance	$W/m^2 \cdot K$	Lower is better
ρCp	Volumetric heat capacity	$J/m^3 \cdot K$	Lower is better
q”	Heat flux	W/m^2	Lower is better
R	Resistance	m^2K/W	Higher is better
μ-value	Vapour resistance	MN·s/g·m	Higher is better
c	Specific heat capacity	J/kg·K	Higher is better

stringent insulation regulations can cut CO_2 emissions by 5% (Kyoto requirements).

9. Insulation material should have sufficient compressibility and strength, especially when used for flooring in cold storages involving continuous movement of trolleys and people.
10. Insulation material should have sufficient load bearing capacity where it has to support heavy product loads, as in cold storages.
11. Insulation material should have low density and light weight; it should be easy to handle.
12. Insulation material should be durable and should not get damaged by pests and rodents.
13. Insulation material should be easy to apply.
14. Insulation material should be locally available.

CHAPTER 3

Properties of Insulation Materials

In this Chapter, we shall discuss the properties of each type of insulation material, their advantages and disadvantages, and applications.

Natural Insulation Materials

Fibreglass

Fibreglass is a low-density insulation material. It is sold in two forms: blankets (either long rolls or batts) and slabs. The former come with paper or aluminium foil backing for installation between the studs in walls and the joists in floors, or for use in ceilings.

Glass fibre mineral wool insulation is made from molten glass and flux of silica rocks in a furnace and spun into fibres, sometime with 20% to 30% recycled industrial waste and post-consumer content. (Fibreglass loose-fill insulation is made from molten glass that is spun or blown into fibres. Most manufacturers use 40% to 60% recycled glass content.) The material is formed from fibres of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass fibres, and these pockets result in high thermal insulation properties. The density of the material can be varied through pressure and binder content.

Figure 3-1: Fibreglass

Properties

a. Thermal conductivity λ = 0.035 W/m·K
b. Thermal resistance at 100 mm = 2.85 K·m^2/W
c. Specific heat capacity = 1,030 J/(kg·K)
d. Density = 12 to 48, 64 and 80 kg/m^3
e. Thermal diffusivity = 1.6x10^{-6} m^2/s
f. Embodied energy = 26 MJ/kg
g. Vapour permeable: Yes

As a thermal insulator, fibreglass is used in both residential and commercial applications. By trapping pockets of air, it keeps rooms warm in the winter and cool in the summer, and thereby serves as a convenient method to increase energy efficiency. Fibreglass is an attractive choice for home insulation because it poses no fire hazard. According to some estimates, thermal insulation made from fibreglass and its alternatives conserves 12 times as much energy as is lost in its production, and it may reduce residential energy costs by up to 40%, especially in countries with very cold climates, though its installation requires safety precautions. The installer must use eye protection, mask and gloves while handling this product.

In homes, fibreglass insulation can be installed in various parts of the building envelope. It comes in pink, yellow, white or green colour, depending on its manufacturer, and has a spongy feel. Commonly found in blanket form called batts and slabs, it is available in bags containing standard pre-cut lengths and widths. Batts are typically stapled into place. Fibreglass insulation also comes in bags as loose fill that can be blown into attics, walls and floor cavities. Most fibreglass batts are manufactured with a paper or foil backing that faces the direction of warmth. When installed correctly, it creates a continuous membrane that retards the passage of moisture and reduces the likelihood of fibrous particles entering the living space. It is important that the backing always faces the warm side of the structure in which the insulation is installed. Fibreglass is also available in pipe sections for chilled water piping insulation.

Figure 3-2: *Fibreglass bag, slabs and roll*

For more details, the North American Insulation Manufacturers Association (NAIMA) Standard AH 121 may be referred.

As per the International Agency for Research on Cancer and World Health Organisation (Joint Monograph, Volume 81, 2002), glass wool is not classifiable as carcinogenic, hence it is included in Class 3.

People who work with fibreglass, or who have worn-out duct work lined with fibreglass in their homes or workplace, may have long-term exposure to fibreglass. There is no evidence that fibreglass causes cancer in people. Animal studies have shown an increased risk of cancer when glass fibres were implanted in the lung tissue of rats, but these studies are controversial because of how the fibres were implanted. Based on these animal studies, the International Agency for Research on Cancer has classified some fibres used in fiberglass as possible human carcinogens.

There is some data which suggests that fibreglass in the lungs may cause cancer by slicing the DNA and causing cell mutation, in the same way as mineral wool.

Some fibreglass insulation still uses formaldehyde as a binder, which leaks out into the air. This may be carcinogenic.

Advantages

- Fibreglass insulation is inexpensive and effective.
- It does not shrink.
- Most manufacturers supply the material in sealed batts, covered with plastic film (perforated polyethylene or polypropylene, specifically) to avoid issues with accidental breathing of fibres.
- The plastic covering on fibreglass batts acts as an effective vapour barrier.
- Fibreglass insulation does not burn.
- Some fibreglass insulation uses recycled glass, reducing its ecological footprint.
- Fibreglass insulation is available in low-, medium- and high-density options (roughly R-11 and R-15 for a standard 2 x 4 wall).
- Insects do not eat fibreglass insulation. (It is not nutritive for them, so they have no reason to nibble it).
- Blown fibreglass surrounds everything inside wall cavities, providing a consistent layer of insulation.

Disadvantages

- Protective gear must be worn while installing fibreglass insulation, since its slivers are small enough to be lodged in the skin or inhaled. Inhaled slivers of fibreglass irritate the alveoli and can cause lung disease.
- Unless one uses plastic-sealed batts, fibreglass insulation requires a vapour barrier to protect it from moisture.
- Fibreglass blankets do not seal wall and ceiling spaces very tightly.
- Low density fibreglass settles and sags, so its R-value decreases over time.
- Standard fibreglass can be crammed into smaller spaces to improve its R-value but in this case, it needs venting to avoid moisture build-up, which can destroy its efficiency.

Fibreglass for Air Ducts

Fibreglass is applied over GI sheet ducts and held in position with bands and stick pins. Usually aluminium foil laminated fibreglass rolls and slabs are used.

Fibrous glass insulation is mainly used in air duct systems for four basic reasons:

i. Temperature control: Delivery of cooled air at comfort levels suited to building occupancy requirements.

ii. Acoustical control: Absorption of noise generated by central air handling equipment

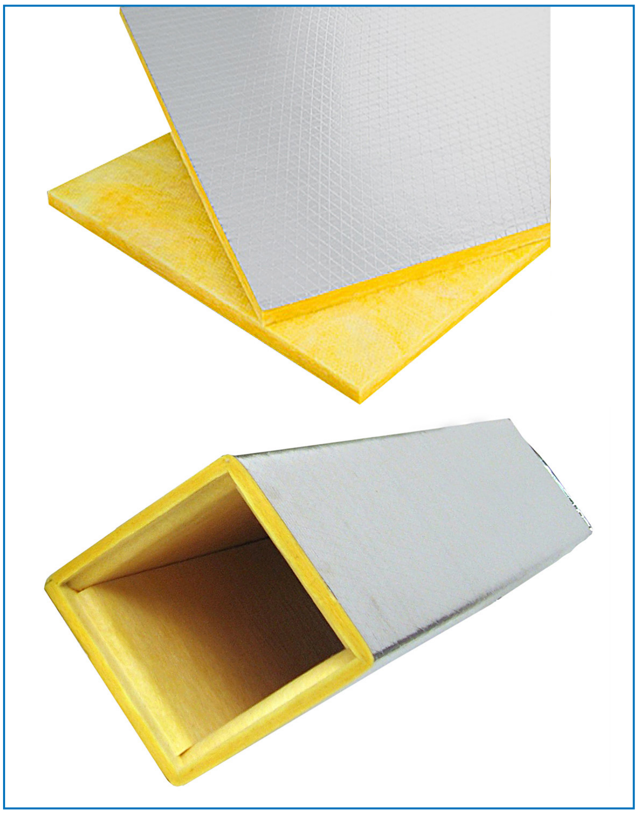


Figure 3-3: Fibreglass duct boards

and movement of air through the ducts, as well as cross-talk carried by ducts from one space to another.

iii. Condensation control: Prevention of condensation in or on ducts when installed R-value recommendations are followed, reducing the likelihood of moisture damage to ceilings and other interior finishes.

iv. Energy conservation: Reduction of HVAC system operating costs by controlling heat loss or gain through air duct walls, helping the system run more efficiently.

Fibreglass duct board is a rigid fibreglass board with a damage resistant, flame retardant, reinforced aluminium foil facing with excellent thermal and acoustical insulating properties. It is used for indoor commercial and residential heating, ventilation and air conditioning of duct systems.

Fibreglass boards having 48 kg/m^3 density are available with glass tissue and glass reinforced aluminium foil laminations. These are extensively used for prefabricated ducting in buildings and marine applications due to their fire safety features. These are also used for ducts and plenum acoustic lining, especially for sound recording studios and television broadcasting facilities, due to their high acoustic properties.

Features

i. Absorbs noise and reduces popping noises caused by expansion, contraction and vibrations.
ii. Assured thermal R-value performance.
iii. Bacterial and fungal growth resistant.
iv. Thermal/acoustical insulation board plus jacket forms a single component duct system, reducing inspection time.
v. Lightweight boards are easier to transport and handle than insulated sheet metal ducts.
vi. Virtually eliminates air leakage.

Properties

a. Thermal conductivity λ = 0.041 W/m·K
b. Thermal resistance at 100 mm = Not Applicable (NA)
c. Specific heat capacity = 1,000 J/(kg·K)
d. Density = 48 kg/m^3
e. Thermal diffusivity = 4.2 to 10.7 m^2/s
f. Embodied energy = NA
g. Vapour permeable: No

Resin bonded fibreglass is suitable for applications ranging from -100°C to +230°C. For special applications up to 450°C, high temperature binder is available. Aluminium foil facing is suitable up to 120°C.

Glass Wool

The Material

Glass wool is one of the most time-tested and proven insulation materials. It is manufactured when fused borosilicate glass from an electrode melting trough is directed to a spinning machine to form spun glass fibres of longer length. The fibres are applied with chemical binder, collected, uniformly distributed and cured in an oven to produce blankets or boards of insulation. The entire process is high-speed and online, and requires minimum human intervention. Even the laminations are applied online on the faces of the insulation. The laminar structure of glass wool insulation with interconnected air pockets helps to create adequate resistance to the air flow path, causing reduction of sound and heat transmission through it. Hundred per cent of the raw material is converted to high performing insulation without any impurities. The material is packed under compression and transported in rolls or cartons.

The Product

Glass wool insulation is graded in different densities and thicknesses to address various thermal and acoustic requirements. *Table 3-1* lists some indicative applications of this insulation.

Table 3-1: Applications of glass wool insulation

Weight	Density (kg/m³)	Thickness (mm)	Applications
Lighter range	10,12,16, 20, 24	25, 50, 75, 100	Roofing, dry wall, ceiling, duct wrap, cavity (masonry) wall
Medium range	32, 40, 48	25, 50, 75, 100	Under-deck, mechanical room acoustic, façade, duct acoustic, DG set acoustic
Higher range	56, 64, 96	25, 50, 75	Marine, industrial chimney, furnace

Table 3-2: Facing options for glass wool

Broad Category	Facings	Applications
Aluminium based facing	Foil-scrim-kraft (FSK) Foil-kraft-scrim-polyethylene (FKSP) FSK with high density reinforcement	Duct wrap, roofing, wall thermal
Polypropylene based facing	Polypropylene-scrim-kraft (PSK) Polypropylene-scrim-kraft metallised polyester	Roofing, wall
Textile	Aluminium glass cloth, black glass cloth, white glass cloth	Roofing, mechanical room acoustic, marine, duct acoustic
Tissue	White glass tissue (WGT) Black glass tissue (BGT)	Duct acoustic, mechanical room, marine

Facing options for glass wool insulation are enumerated in *Table 3-2.*

Product Features

High Thermal Insulation

Glass wool is one of the best and most sustainable thermal insulation materials. It meets the thermal requirement of Energy Conservation Building Code 2007 and helps to achieve the prescribed U-value and R-value for building envelopes and HVAC ducts respectively. That is why it is one of the recommended products in IGBC Green Product Directory, and approved as per GRIHA rating system.

Thermal Conductivity and Resistance Value

Thermal conductivity and resistance values of glass wool at different densities are given in *Table 3-3*.

Table 3-3: Thermal conductivity and resistance value of glass wool

Density (kg/m³)	Thermal Conductivity (W/m·K) at 25°C	Thermal Resistance (m²·K/W) for 25 mm thick product
12	0.041-0.045	0.55-0.61
16	0.039-0.042	0.59-0.64
20	0.036-0.039	0.64-0.69
24	0.033-0.036	0.69-0.76
32	0.032-0.034	0.73-0.78
48	0.030-0.032	0.78-0.83

High Acoustic Parameter

Resilient and laminar glass wool insulation helps to provide the required resistance to the air flow path and absorbs noise to reduce sound transmission. Within a dry wall cavity, it helps to absorb sound to improve on transmission loss or isolation.

Table 3-4: Noise reduction coefficient of glass wool

Density	Thickness	Noise Reduction Co-efficient (NRC)
12	85	0.95
20	50	0.9
24	50	0.9
48	50	0.95

Fire Safety

Glass wool insulation is manufactured at 1,100°C and its basic material is glass, which is fire safe. It complies with the following fire safe requirements for a building:

- A1 reaction to fire as per EN 13501-1.
- Non-combustible when tested as per BS 476 Part 4.
- Class P (not easily ignitable), highest class as per BS 476 Part 5.
- Limited fire propagation indices ($I<12$, $i_1<6$) as per BS 476 Part 6.

- Class 1 (least spread of flame) surface as per BS 476 Part 7.
- Class O as per BS 476 Part 6 and 7 together.
- FM approved for fire-insured projects.
- Non-toxic and non-smoke emitting as per BS 6853.
- In dry wall systems, because of its thermal insulation property, it helps to reduce heat transmission or maintain a temperature gradient across the hot and cold faces, and hence facilitates higher fire ratings.

Non-settling Fibres

Under vibration and jolting test as per IS 8183, glass wool shows no settlement of fibres when applied inside a vertical cavity.

Chemical Stability

Glass wool insulation is quite inert and its pH value is close to 7. It is free from corrosive agents like slags, sulphur and chloride. Hence the insulation is chemically stable and does not have any reaction with metals, accessories and supporting systems.

Moisture Content and Water Absorption

Moisture content and water absorption is less than 2% and meets the requirement of IS 8183.

Mould Inhibitor

Glass wool insulation material is inorganic in nature and does not allow mould or vermin to grow.

Advantages

- Energy efficiency: Glass wool insulated walls, façades and roof systems help to achieve significant reduction in heat load of the building and improve its energy efficiency.
- Acoustic privacy: Acoustic ceiling insulation and insulated partitions help to maintain acoustic privacy in the building with the required sound absorption and isolation respectively.
- Fire safety: Unlike organic insulation, inorganic glass wool reduces fire load of the building and helps it to comply with fire safety recommendations.
- Economies of scale: Glass wool can be applied as the insulation solution for walls, roofs, acoustic ceilings, partitions, HVAC duct – thermal and acoustic, mechanical room acoustic, pipe insulation and flexible ducting. Because of its large range of applications, it can be offered with better economy in projects.
- Long performing life: Being inorganic, hydrophobic and pure, glass wool insulation has a long service life.
- Environment friendly: Energy efficiency, high re-usability, recyclable raw materials, low embodied energy, and health safety are some of the factors that support glass wool as one of the best green and environment-friendly insulation materials.

Safety and Handling

- Loose clothing and gloves: Loose clothing and full-sleeve shirts help prevent the fibres from rubbing against the skin. Depending upon the job conditions, gloves may also be necessary.
- Goggles or safety glasses: Eye protection is recommended during insulation tear-out, blowing operations, and overhead application of the insulation.
- Work area cleanliness: It is advisable to avoid unnecessary handling of scrap glass wool by keeping waste disposal equipment as close to the working area as possible. Scrap material or debris should not be allowed to pile up on the floor or other areas. An organised housekeeping programme should be followed.

Tools and Consumables

- A cutter or knife helps to cut glass wool to the desired sizes, and is required in all applications (e.g. drywall insulation).
- An adhesive is generally used to wrap glass wool on metal duct surfaces, and is required in HVAC applications.
- Self-adhesive tapes help to seal laminated glass wool boards.
- Pin and washer are used to apply insulation on boilers and similar flat or curved metal applications (e.g. in shipbuilding).

Storage

The insulation should be inspected upon arrival at the job site to ensure that it is exactly as ordered. If there is anything wrong with the insulation, it should not be installed, and the supplier should be contacted immediately.

Insulation should be stored in a dry, protected area.

All packages should be elevated above the ground or slab, preferably on a flat surface, to prevent contact with accumulated surface water. The facing should be protected from tears and punctures to maintain the continuity of the vapour retarder.

Poly-bags should be kept open well before application (one to two hours) to aerate the insulation. It is also suggested that flexible blanket insulation should be given some time to regain its original thickness after unpacking.

Packages can be left uncovered during the day, weather permitting, but should be protected at night with polyethylene film, canvas or other covering.

Note: The insulation should be used as soon as possible after it arrives at the job site. The sooner the insulation is installed, the less likely it is to get damaged in storage.

Disposal

The scrap can be put into plastic bags such as zipper storage bags or similar closed polyethylene bags. Before sealing the bags, they should be squeezed so as to reduce their volume and avoid popping of glass wool. Local sanitation or waste transfer agencies can transport these bags to a designated landfill.

Mineral Wool

Mineral wool is sometimes referred to as glass wool, which is fibreglass manufactured from recycled glass. It is sometimes referred to as rock wool, which is a type of insulation made from basalt rocks. Sometimes it is referred to as slag wool, which is produced from the slag from steel mills.

Figure 3-4: *Glass wool slabs, roll and bulk wool*

Mineral wool is sometimes referred to as glass wool, which is fibreglass manufactured from recycled glass. It is sometimes referred to as rock wool, which is a type of insulation made from basalt rocks. Sometimes it is referred to as slag wool, which is produced from the slag from steel mills.

Mineral wool has an R-value around 2.8 to 3.5.

It can be in the form of batts or loose material. It is non-combustible. When used in conjunction with other, more fire-resistant forms of insulation, mineral wool can be a very effective insulation. It does not contain any binder.

Properties

a. Thermal conductivity λ = 0.032 to 0.044 W/m·K
b. Thermal resistance at 100 mm = 2.70 to 2.85 K·m^2/W
c. Specific heat capacity = NA
d. Density = up to 120 kg/m^3 for mattress
e. Thermal diffusivity = NA
f. Embodied energy = NA
g. Vapour permeable : Yes
h. Temperature range = 200-800°C

Superfine loose mineral wool in bulk form is used for industrial insulation as loose fill, stitched mattresses and spray applications.

Classification for Adverse Effect on Humans

Various insulation materials are classified as regards their adverse effect on humans.

Group 1	: Carcinogenic to humans.
Group 2A	: Probably carcinogenic to humans.
Group 2B (1987)	: Possibly carcinogenic to humans.
Group 3 (2001)	: Not carcinogenic to humans.
Group 4	: Possibly not carcinogenic to humans.

(Source: International Agency for Research on Cancer – WHO)

Polyurethane foam insulation and polystyrene belong to the same group as glass wool.

Special purpose glass fibres such as 'E' glass and '475' glass fibres and refractory ceramic fibres fall udder Group 2B, which may possibly be carcinogenic to humans.

Insulation glass wool, continuous glass filaments, rock wool and slag wool are not carcinogenic; they fall under Group 3.

A NAIMA study in 1997 and a Duke University medical study in 2001 showed glass wool does not affect indoor air quality.

Erosion test under air stream as per European test standard showed negligible fibre migration and compliance to IAQ requirements.

Rockwool

Rockwool falls under Group 3, the same as glass wool.

It is made from fibres generated by melting basalt rocks mainly containing oxides of iron, silica and alumina and bonded with phenol formaldehyde resin. It is used as thermal and acoustic insulation for both commercial and residential buildings, ships, piping, ducts, partitions, railway coaches, etc. It is non-combustible and specially used in fire-safe building roof and wall insulation and fire-rated duct and piping insulation. It saves energy in buildings by drastically reducing heat ingress, and has R values ranging from 1.72 to 4.14 m^2·°C/W or 9.79 to 23.50 ft^2·hr·°F/Btu-in.

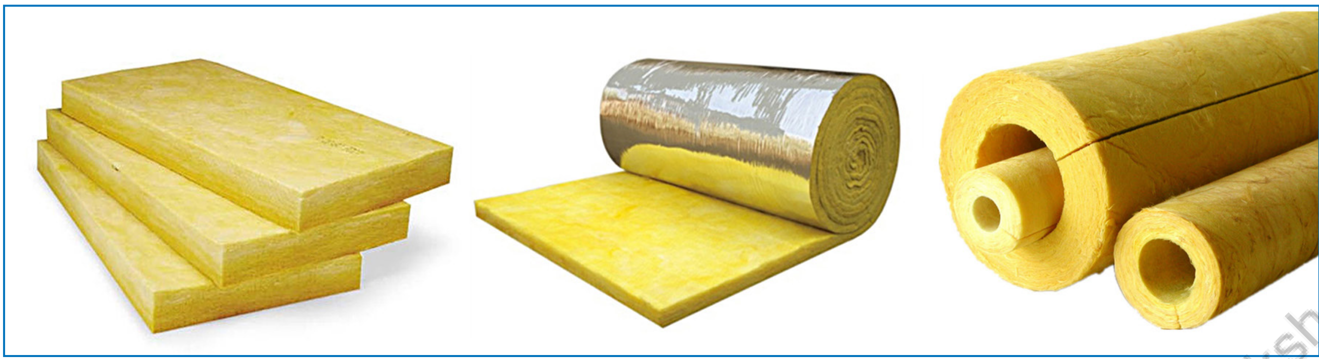


Figure 3-5: *Rockwool slabs, roll and pipe section*

Rockwool is human friendly; it does not affect persons handling it and does not hamper productivity. It is water repellent. It can be used for under-deck ceiling insulation in buildings as well as on the walls. It is used as a cavity fill insulation below external building façades, and stops spread of fire owing to its non-combustible property. It is used as an in-fill between metallic sheets to manufacture prefabricated panels, and is used on the roofs and walls of steel framed building such as pre-engineered buildings. Rockwool is also used as in-fill for noise barriers on highways, railway tracks, flyovers and metro corridors.

Rockwool is available in the form of slabs, rolls, blankets, boards, pipe sections and loose wool. It is also available with laminations like aluminium foil and various cloth types. Rockwool conforms to IS 8183 and IS 9842. It is non-combustible as per BS 476, Part-4 and water repellent as per BS 2972. It controls condensation in ducts and piping. It is non-carcinogenic. It has a thermal conductivity value of 0.029 W/m·K at 10°C mean temperature, and density from 40 to 160 kg/m^3 generally. It has embodied energy of 3.1 MJ. Its thermal diffusivity value ranges between 0.0006 and 0.0018.

Being available in higher densities results in higher diffusivity values and extra energy savings, as there will be more fibres entrapping a greater number of air cells, thereby reducing heat and cold ingress.

The Product

Resin bonded rockwool insulation, a manmade inorganic fibrous material, is manufactured from siliceous raw materials like slag, which is a steel industry waste, and selected rocks like basalt and igneous containing oxides of iron, silica and alumina and bonded with phenol formaldehyde resin. The raw materials are melted at 1600°C and spun into chemically inert fine fibres that are impregnated with resin and water repellent chemicals, felted and cured to form rigid, semi-rigid and flexible slabs, rolls and pipe sections. It is an asbestos, CFC and HCFC free product and is environment friendly. The waste of rockwool is both recyclable as well as useable for landfill and hydroponics.

Rockwool insulation conforming to IS 8183 and of water repellent grade tested as per BS 2972 is used for thermal and acoustic insulation for commercial and residential buildings, ships, piping, ducts, partitions, railway coaches, etc.

Rockwool Insulation does not promote the growth of fungi, moulds or bacteria and sustains vermin attack. It is a rot-proof material. It is suitable for building insulation like underdeck, false ceilings, cavity walls, exterior and interior walls, partition walls, pipes and equipment as well as acoustic insulation.

Rockwool has high fire performance characteristics and is rated as non-combustible. It is used in fire-safe buildings in accordance with BS 476 Part-4, IS 3144 and IMO A163.

Properties

a. Thermal conductivity λ = 0.029 to 0.044 W/m·K
b. Thermal resistance at 100 mm = 2.70 to 2.85 K·m^2/W
c. Specific heat capacity = NA
d. Density = NA
e. Thermal diffusivity = 40 to 160 m^2/s
f. Temperature range = -100 to +800°C
g. Embodied energy = 3.1 MJ/kg
h. Vapour permeable: Yes

Rockwool slabs are fire rated for one hour for a thickness of 80-100 mm and density 160 kg/m^3. Rockwool has A-60 classification.

Rockwool is relatively inexpensive and widely available.

Product Features

Rockwool Insulation is available in varying densities, each having its own specific attributes.

Table 3-5: Forms of rockwool insulation and attributes

	Dimensions (mm)	Density (kg/m3)	Thickness (mm)
Slabs	1000 x 500, 1200 x 750	48, 64, 96, 144	25, 40, 50, 65, 75, 100
Rolls	1000 x 500	48	25, 50

Rockwool is available with aluminium foil, vinyl cloth, kraft paper or other customised facing. Owing to its efficient thermal and acoustic performance, rockwool insulation finds a special place in various building standards such as Energy Conservation Building Code, IGBC Green Product Directory, and GRIHA rating system.

Thermal Conductivity and Resistance Value

Thermal conductivity and resistance values of rockwool insulation at different densities conforming to IS 8183 are given in *Table 3-6.*

Table 3-6: Thermal conductivity value of rockwool insulation

Mean Temperature (°C)	k-Value (W/m·K)
10	0.029
24	0.033
50	0.043
100	0.052
200	0.068

Table 3-7: Thermal resistance and transmittance value of rockwool insulation

Thickness (mm)	R-Value		U-Value	
	m^2·°C/W	ft^2·h·°F/Btu-in	W/m^2·°C	Btu-in/ft^2·h·°F
50	1.72	9.79	0.580	0.102
65	2.24	12.73	0.446	0.079
75	2.59	14.69	0.387	0.068
120	4.14	23.50	0.242	0.043

Acoustic Properties

Rockwool insulation provides excellent sound absorption properties, making it a suitable material for acoustic insulation.

Table 3-8: Noise reduction coefficient of glass wool

Thickness (mm) → Density (Kg/m^3)	25*	50*	25**	50**
48	0.65	1.00	0.78	1.04
64	0.73	1.03	0.84	1.11

**with rigid backing, **with 1" air gap*

It is available in higher densities also.

Water Repellent

Rockwool fibres can be treated to make the product water repellent in accordance with BS 2972, with 0.31% in 48 hours partial dipping.

Handling and Storage

Rockwool, being light in weight and properly constructed, is very easy to handle. Its products are supplied in flexible packs. It needs to be stored safely inside a covered space avoiding overloading, which can cause compression. If it needs to be stored outside, it should be stacked clear of the ground and covered with an outer cover impermeable to moisture. If it becomes wet during installation, it should be allowed to dry out naturally before the final finish is applied.

Applications

For thermal and acoustical insulation of ceilings, walls, floors, partitions, ducts, enclosures and industrial appliances. Rockwool rolls and slabs are suitable for underdeck insulation of metal buildings for high thermal and acoustical insulation and fire protection.

Cellulose

Cellulose is perhaps one of the most eco-friendly forms of insulation. It is a plant-based insulator and is the oldest form of home insulation. At different times, it has been produced from sawdust, cotton, straw, hemp, and other plant materials with low thermal conductivity. These days it is produced from recycled newspapers, which are later treated with chemicals that reduce its ignition potential.

Cellulose must be chemically treated in order to reduce its flammability; such additives may have the potential to burn exposed skin or other membranes, so caution should be exercised when handling it.

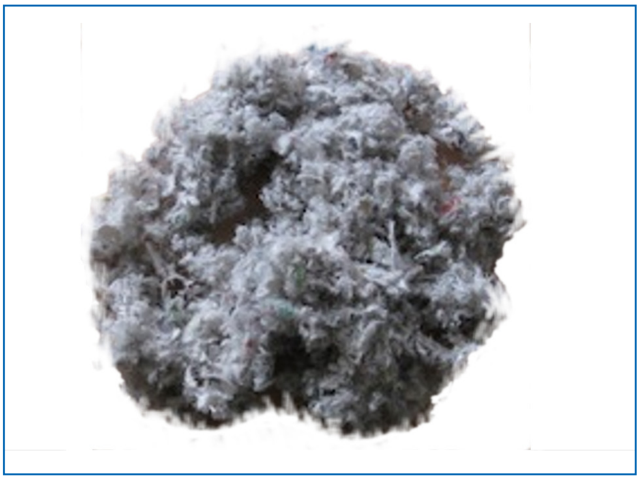


Figure 3-6: Cellulose insulation

Cellulose insulation is relatively inexpensive and reduces air flow significantly. It is possible that the material can produce harmful off-gassing from the ink contained in the newspapers, but insulation is generally contained in sealed locations, so this is not likely to be a health concern. As is true with fibreglass, one must protect one's lungs with a breathing mask when handling cellulose insulation.

Cellulose has an R-value between 3.1 and 3.7. Some recent studies on cellulose have shown that it might be an excellent product for use in minimising fire damage. Because of the compactness of the material, cellulose contains next to no oxygen within it. This helps to minimise the amount of damage that a fire can cause.

So, not only is cellulose perhaps one of the most eco-friendly forms of insulation, but is also one of the most fire-resistant. However, there are certain downsides to this material as well, such as the allergies that some people may have to newspaper dust. Also, finding individuals skilled in using this type of insulation is relatively hard compared to, say, fibreglass. Still, cellulose is a cheap and effective means of insulating.

Of late, the use of cellulose insulation has increased again in the United States. Part of the reason for this growth could be related to studies that suggest cellulose may actually protect a building from damage in a fire better than fibreglass, because cellulose is denser and restricts the oxygen necessary to burn structural members. Several studies of the National Research Council, Canada have backed these claims. Another major reason for the comeback of cellulose might be the increased interest in Green buildings. Cellulose has the highest recycled content of any insulation material and also has less embodied energy than fibreglass and other furnace-produced mineral insulation materials.

Properties

a. Thermal conductivity λ = 0.035 W/m·K in lofts; 0.038 to 0.040 W/m·K in walls.
b. Thermal resistance at 100 mm = 2.632 K·m^2/W
c. Specific heat capacity = 2,020 J/(kg·K)
d. Density = 27 to 65 kg/m^3
e. Thermal diffusivity = NA
f. Embodied energy = 0.45 MJ/kg
g. Vapour permeable: Yes

Aerogel

Aerogel is a synthetic porous ultra-light material derived from a gel, in which the liquid component of the gel is replaced with a gas. The result is a solid with extremely low density and low thermal conductivity. Its nicknames include frozen smoke and solid air, or blue smoke owing to its translucent nature and the way light scatters in the material. It feels like fragile expanded polystyrene to the touch. Aerogels can be made from a variety of chemical compounds.

Aerogels are good thermal insulators because they almost nullify two of the three methods of heat transfer (convection, conduction, and radiation). They are good conductive insulators because they are composed almost entirely of gas, and gases are very poor heat conductors. They are good convective inhibitors because air cannot circulate through their lattice. Aerogels are poor radiative insulators because infrared radiation (which transfers heat) passes through them.

Silica aerogel is the most common type of aerogel. The silica solidifies into three- dimensional, intertwined clusters that comprise only 3% of the volume. Conduction through the solid is therefore very low. The remaining 97% of the volume is composed of air in extremely small nano-pores. The air has little room to move, inhibiting both convection and gas-phase conduction.

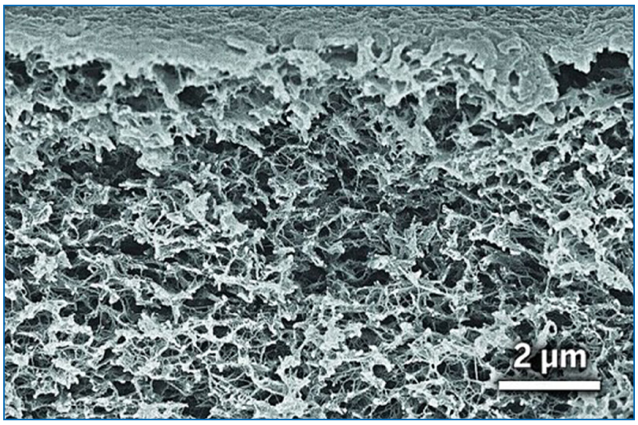


Figure 3-7: *Aerogel*

Properties

a. Thermal conductivity λ = 0.014 W/m·K
b. Thermal resistance at 50 mm = 3.8 K·m^2/W
c. Specific heat capacity = 1,000 J/(kg·K)
d. Density = 150 kg/m^3
e. Thermal diffusivity = NA
f. Embodied energy/kg = 53.9 MJ/kg
g. Vapour permeable: Yes

(Sources: Spacetherm and Thermablok)

Cryogel is used for low temperature applications, whereas Pyrogel is used for high temperature applications.

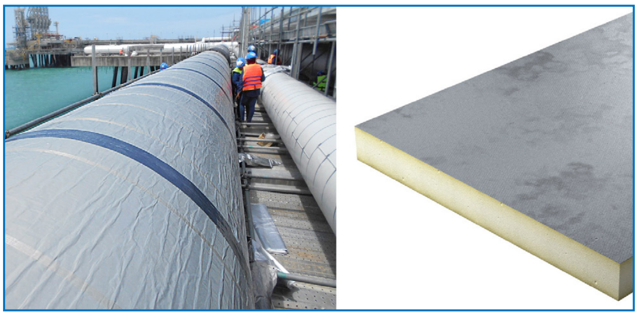


Figure 3-8: Cryogenic insulation for pipes, and in blanket form

Cryogel is an insulation material made from nano-porous aerogel, the world's lowest density solid and most effective thermal insulator. It is a flexible insulation designed for sub-ambient and cryogenic applications. Cryogel can be bought as rolls or can be fabricated into a variety of customer specified parts. It has an additional integral vapour barrier to prevent surface condensation.

The major properties of all the natural insulation materials covered in this section are summarised in *Table 3-9*.

Synthetic Insulation Materials

Synthetic insulation materials fall under two groups: Polystyrene and Polyurethane.

Polystyrene

Polystyrene has been manufactured using styrene monomer as the raw material for more than 60 years, and is used for a wide range of products. Polystyrene rigid foam is one of the oldest foam materials used for packaging solutions and insulation applications.

Polystyrene rigid foam comes in two types or variants:

- Expanded polystyrene (EPS)
- Extruded polystyrene (XPS)

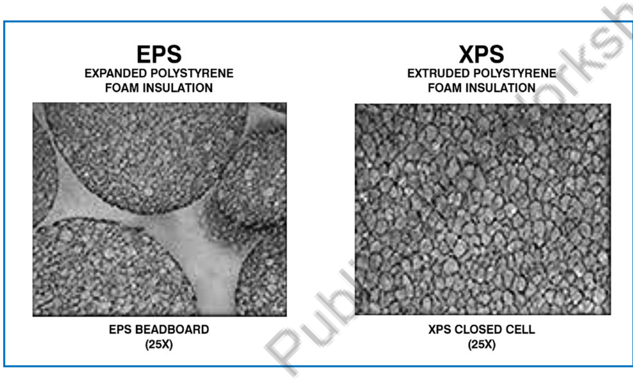


Figure 3-9: EPS beadboard and XPS closed cell insulation

Polystyrene insulation has a uniquely smooth surface. The two types differ in performance ratings and cost. These materials give good insulation against heat and cold. Since they are petroleum products, their solvent resistance is poor.

Expanded Polystyrene (EPS)

EPS is a rigid, closed cell, thermoplastic foam material. It is produced from solid beads of polystyrene. Expansion is achieved by virtue of small

Table 3-9: Summary of properties of natural insulation materials

Property	Fibreglass	Fibreglass Board	Mineral Wool	Rock Wool	Cellulose	Aerogel
Thermal conductivity, W/m·K	0.035	0.041	0.032-0.044	0.029	0.35-0.40	0.014
Thermal resistance, K/m²·W	2.85	N.A.	2.70-2.85	2.70-2.85	2.632	3.8 for 50 mm
Specific heat capacity, J/(kg·K)	1,030	1,000	N.A.	NA	2,020	1,000
Density, kg/m³	12-80	115	Maximum 120	40-160	27-65	150
Thermal diffusivity, m²/s	1.6x10^{-6}	4.2-10.7	N.A.	NA	N.A.	N.A.
Embodied energy, MJ/kg	26	N.A.	N.A.	NA	0.45	53.9 MJ/kg
Vapour permeable	Yes	No	Yes	Yes	Yes	Yes
Operating temperature range, °C	-30 to +540	-30 to +540	0 to +250	-100 to +760	Glass cellular: -268°C to +427°C	Cryogel and Pyrogel, used across temperatures from -273ºC to +650ºC

Figure 3-10: *EPS*

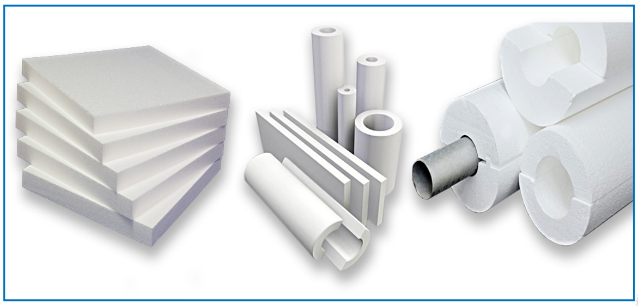


Figure 3-12: *EPS sheets and moulded products*

amounts of gas contained within the polystyrene beads. The gas expands when heat in the form of steam is applied, thus forming closed cells of EPS. These cells occupy approximately 40 times the volume of the original polystyrene bead. The pre-formed beads can be converted to large blocks, which can be fabricated as per specification to form customised shapes. EPS beads can also be moulded into shape for various pipe sections. Sheets of the desired density and thickness or moulded products are used for insulation applications.

Pre-formed EPS beads can also be mixed with cement to get light-weight concrete or insulating mortar, which can be used as a pouring insulation for concrete blocks or hollow wall cavities. Care has to be taken during mixing to get a homogeneous matrix and low static electric charge.

Extruded Polystyrene (XPS)

Manufacturing of XPS foam begins with solid granules of crystal polystyrene. The crystals, along with special additives and a blowing agent, are fed into an extruder. Within the extruder the mixture is combined and melted under controlled conditions of high temperature and pressure into a viscous plastic fluid. The hot, thick liquid is then forced in a continuous process through an extruder die. As it emerges from the die, it expands to produce foam, which is shaped, cooled, and trimmed to the desired size.

Figure 3-13: *XPS foam blocks*

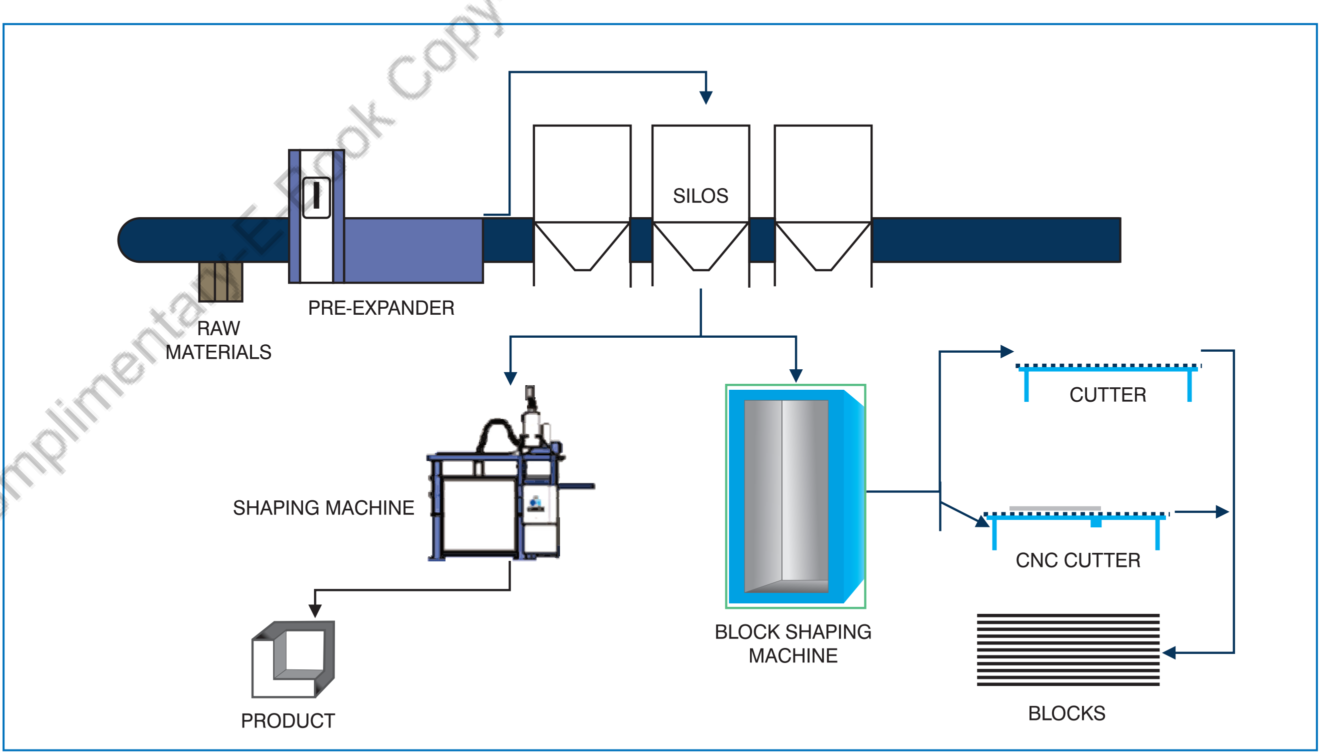


Figure 3-11: *Manufacturing process of customised EPS shapes*

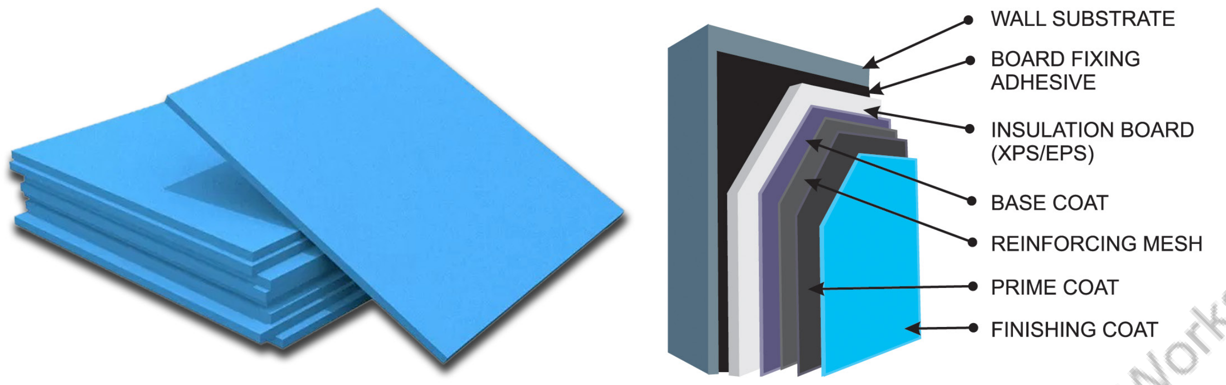


Figure 3-14: *XPS board, and the method of fixing it on the wall*

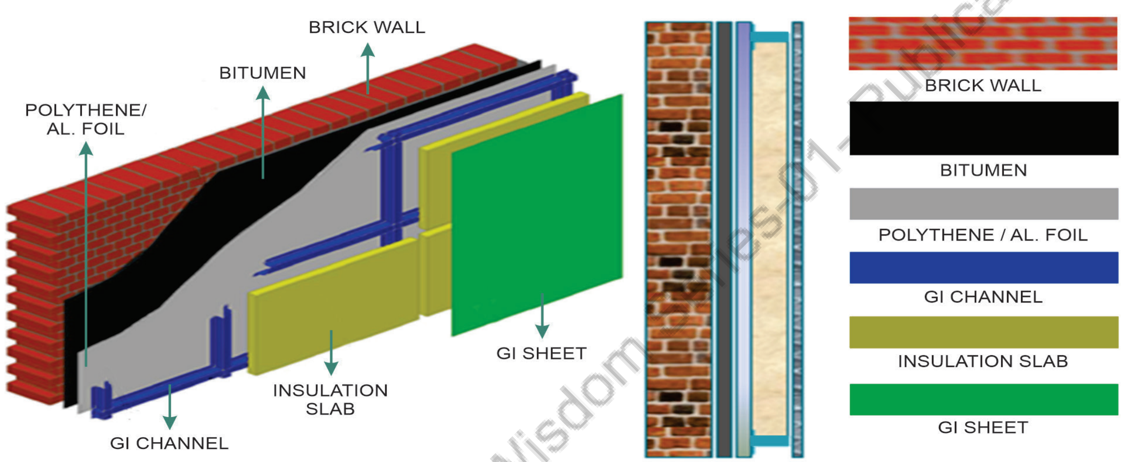


Figure 3-15: *Method of fixing the insulation on the wall*

The standard size of the boards may vary from 1250 mm (L) x 600 mm (W) to 2400 mm (L) x 1200 mm (W), and the thickness from 20 mm to 100 mm.

EPS and XPS are widely used for insulation in cold storages. The sheets are cladded on the walls of the building from the exterior side and further rendered to protect the insulation board as well as provide an aesthetic look to the structure.

XPS is preferred over EPS when properties like very good insulation, compressive strength, negligible water absorption and flammability are important for project performance. EPS is a material of choice because of lower density, lesser

Table 3-10: *Major properties of EPS and XPS*

Test Parameter	Unit	Test Method	EPS	XPS
Density	Kg/m³	ASTM D 1622	21	34
Equivalent thermal conductivity, maximum	W/m·K	ASTM C 518	0.0376	0.0289
Compressive strength at 10% deflection, minimum	kPa (psi)	ASTM C 1621	102 (14.80)	350 (51)
Water absorption, maximum	% v/v	ASTM C 272	1.13	0.3
Water vapour permeance, maximum	ng/Pa·s·m²	ASTM E 96	Moderate (28)	63
Perm rating	perm		0.5	1
Flammability	Class	DIN 4102 Part 1	NA	B2
Surface burning characteristics	Class	ASTM E 84	NA	A

(Source: Supreme Petrochem Ltd. and others)

cost and easy availability, yet with good insulation properties.

XPS is preferred over EPS when properties like very good insulation, compressive strength, negligible water absorption and flammability are important for project performance. EPS is a material of choice because of lower density, lesser cost and easy availability, yet with good insulation properties.

Water vapour permeance improves with insulation thickness. If an insulant's permeability is 1.65 perm-in, a 2.5 inch thick pipe half-shell would have a permeance of 0.66.

Comparing Polystyrenes EPS and XPS

In contrast to liquid water, water vapor (humidity in air) can diffuse (penetrate) through the cell walls of polystyrene foam insulation. EPS and XPS can serve as vapour barriers or as vapour retarders (up to a certain thicknesses/density).

- Impermeable Vapour Barrier (Class I): $<$ 0.1 perm or $<$ 5.7 ng/Pa·s·m²
- Semi-impermeable Vapour Retarder (Class II): 0.1-1 perm or 5.7-57 ng/Pa·s·m²
- Semi-permeable Vapour Retarder (Class III): 1-10 perm or 57-575 ng/Pa·s·m²

Perm Rating Comparison

A perm rating – short for permeance – is a standard measure of water vapour permeability of a material. The higher the number, the more easily gaseous water can diffuse through the material. When using XPS insulation in wall assemblies, the perm rating drops from 1.1 to 0.7 to 0.6, as the thickness goes from 25 to 50 to 75 mm (1 to 2 to 3 in.). A material with a lower perm rating is better at retarding the movement of water vapour. If the perm rating is low, the material is considered a vapour retarder. If it has a very low perm rating, it is labelled a 'vapour barrier.' It all ties in with substrate longevity.

The general rule is the better the vapour barrier and the drier the conditions, the less is the venting required. In colder regions, vapour barriers should be installed on the warm-in-winter side of walls, while in humid areas, such as the Gulf Coast and Florida, they should be placed on the exterior walls. A vapour barrier on the warm side should be constructed with a venting path on the cold side of the insulation, because no vapour barrier can keep all water out of a structure.

A perm rating of less than 0.1 is considered a Class I impermeable vapour retarder, and is classified as a vapour barrier. A rating between 0.1 and 1 is a Class II semi-permeable vapour retarder, and a perm rating between 1 and 10 is a Class III permeable vapour retarder. Any product with a perm rating greater than 10 is highly permeable and is not considered a vapour retarder. Unfaced 25 mm (1 inch) thick XPS has a perm rating around 1, and is classified as semi-permeable. The perm rating for EPS is 5. More information about vapour barriers and vapour retarders is available from the U. S. Department of Energy (DOE).

Benefits of Foamed Polystyrene

- Lightweight: EPS is made of 98% air, making it one of the lightest materials. It adds very little to the weight, so transport costs and fuel emissions are kept to a minimum. The 2% polystyrene cellular matrix gives high impact resistance and toughness.
- Insulating: The thermal insulating properties of EPS and XPS help keep food fresh and prevent condensation throughout the distribution chain. It is used in the fish industry for the packaging of chilled products, in the agricultural sector for seed trays and the packing of fruit and vegetables, and in the pharmaceutical industry for the transportation of temperature sensitive medicines and vaccines. It keeps products cold or warm, depending on the application.
- Hygienic and safe: EPS and XPS are non-toxic and chemically inert. Fungi and bacteria cannot grow on them. There is no skin irritation during handling and installation.
- Waterproof: EPS and XPS are insoluble in water and non-hygroscopic in nature. Though closed cell foams, both are not entirely waterproof or vapour proof. In EPS, the fusion of pre-foamed granules should be good, otherwise interstitial gaps can get filled with water. In applications where the products are exposed to high humidity or direct contact with water, an exterior vapour barrier such as impermeable plastic sheeting is necessary to prevent saturation.
- Customisable: Both EPS and XPS can be custom-shaped.
- Low carbon impacts: Clean manufacturing technologies mean minimal energy and water inputs with no production waste.
- Economy: Highly efficient manufacture and localised production units make the use of these materials economical and hence a low-cost solution.

Thermal Conductivity

- The low thermal conductivity of EPS is a result of the combination of:

- Thermal conductivity of air within the cellular structure.
- Conduction of the solid polystyrene.
- Radiation across the fine cellular structure of each bead that forms the sheet.

- The smallest contributor to thermal conductivity of EPS is the polystyrene itself, and this contribution is of the order of 10% of the total.
- Air that is not moving is an excellent insulating material. Because of this, the permanently entrapped air within the cells of EPS ensures its very low conductivity.
- These factors give EPS its high thermal insulation properties.
- The thermal conductivity of XPS is even lower than EPS by virtue of its closed cell structure resulting from the extrusion process.

Thermal Resistance

- Thermal resistance (R value in m^2K/W) is a measure of the ability of a particular thickness of the material to resist heat flow. The long-term minimum R-value of EPS and XPS is maintained throughout the service life because of low to negligible water absorption.
- EPS has a low water transmission rate. It has excellent breathability characteristics and allows moisture to escape from a wall or floor element and does not form vapour dams.
- EPS and XPS are the most resistant to the adverse effects of moisture. Condensation, which may build up with any insulation material under critical vapour flow conditions, only marginally affects their thermal performance. Even if condensation develops through improper use, the insulation boards retain their dimensional stability and superior insulation values.

Environmental Facts

- EPS and XPS rigid insulation have always been considered Green products.
- EPS sheets are manufactured using modified beads because of their fire performance, structural performance, and environmental advantages. The beads contain no formaldehydes or toxic chemicals, and use fewer resources to manufacture than raw materials for other insulation products.
- The manufacture of EPS is a low pollution process. Steam is the key ingredient and the water is re-used many times. There is no waste in the process as all cut-offs and rejects are re-used.
- EPS and XPS are HFC, CFC and HCFC free. Pentane, which is used as the blowing agent, has a low GWP of less than five.
- EPS does not contain any ozone depleting chemicals and is 100% recyclable and environmentally safe.
- The carbon footprints of EPS and XPS are lower than many other materials used for insulation applications.
- EPS and XPS are extremely lightweight. This helps to reduce fuel consumption when goods are transported compared to other heavier packaging materials, and to save resources of energy and materials.
- The highest environmental attribute is the ability to insulate, and thus reduce energy loss.
- At end of life, EPS and XPS can be successfully recovered and recycled where facilities exist. However, due to their extremely light weight, they are currently not recycled on a worldwide scale.
- In the absence of recycling facility, polystyrene rigid foams can be incinerated in modern plants at very high temperatures to recover the energy released due to their high calorific value comparable to that of natural gas. There are no toxic emissions in this method of waste management. The bye-products are only steam, carbon dioxide and very low levels of non-toxic ash.

EPS Sandwich Panels

EPS is a lightweight cellular plastic material produced in a wide range of densities, providing a varying range of physical properties, and used in the manufacture of sandwich panels in continuous and batch processes with customised dimensions. These panels are used for construction of cold rooms and deep freezers, and are widely used in the building and construction industry. Its applications include insulated panel systems for walls, roofs and floors as well as facades for both domestic and commercial buildings.

High-density XPS Panels

Extruded polystyrene panels are custom made for reefer container bodies and insulated doors because of their high compressive strength besides excellent insulation properties. XPS panels are also used for fish hold insulation and cold rooms in the marine sector. While these panels can also be used for normal cold room walls, ceiling and floor construction, they are seldom preferred due to the high cost of the material.

Figure 3-16: High-density XPS panels

Polyurethane and Polyisocyanurate

Polyurethane (PUR/PU) is a polymer composed of organic units joined by carbamate (urethane) links. Polyurethane can be made in a variety of densities and harnesses by varying the proportion of its constituents: isocyanate, polyol and additives.

PU and PUR are not the same. They are closely related, but PU and PUR flooring will offer you totally different properties. PU is a lightweight version of polyurethane that is there to protect the floor during construction and the post-installation clean-up process. More of a short-term damage control solution than a long-term benefit, PU flooring is great as an initial barrier against damage but will require top ups of polish and/or additional treatments further down the line.

PUR is a much heavier weight version of polyurethane. While PU is just a coat over the top, PUR flooring has been treated and then cured under a UV light. The extra grease during the manufacturing process ensures a number of performance advantages. The biggest advantage of PUR is the lifetime polish-free maintenance that it promises, which drastically reduces the cost of upkeep. Some studies have even shown that customers who went for a PUR treated floor are able to save between 30% and 45% on maintenance costs. With the polishing treatment already cured into the surface wear layer, appearance retention is also very good.

Polyisocyanurate (PIR) is a thermoset plastic typically produced as a foam and used as rigid thermal insulation. Its chemistry is similar to polyurethane, except that it has a higher proportion of methylene diphenyl diisocyanate (MDI) and a polyester-derived polyol is used in the reaction instead of a polyether polyol. Catalysts and additives used in PIR formulations also differ from those used in PUR.

PU and PIR foams have R-vales ranging from 1.43 to 3.57 $m^2 \cdot °C/W$ or 8.11 to 20.28 $ft^2 hr \cdot °F/Btu\text{-}in$.

Polyurethane Foam

Polyurethane foams (PUF) are excellent forms of insulation. Nowadays, polyurethane foams use a non-CFC gas for use as a blowing agent. This helps to decrease the amount of damage to the ozone layer. They are relatively light, weighing approximately two pounds per cubic foot. They have an R-value of approximately 6.3 per inch of thickness. Low-density foams are also available that can be sprayed into areas that have no insulation. These types of polyurethane insulation tend to have an R-value of approximately 3.6 per inch of thickness. Another advantage is that they are fire resistant.

Polyurethane is a foam insulation material that contains a low-conductivity gas in its cells. Polyurethane foam insulation is available in closed-cell and open-cell formulations. In closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Open-cell foam cells are not as dense and are filled with air, which gives the insulation a spongy texture and a lower R-value.

Open cell polyurethane is intended for indoor use, particularly for insulating walls and roofs as well as increasing the acoustic comfort of a room, as polyurethane foam – besides its thermal insulation properties – has a very high noise reduction coefficient. Open cell foam is vapour-permeable, so a surface covered with it ‘breathes’. Sprayed from the inside, directly on the roof, it can be easily used on a membrane or boarding.

Open-cell foam has a density of 7-14 kg/m^3, while its thermal conductivity coefficient ranges from 0.034 to 0.039 W/(m·K). Among the types of open-cell polyurethane foam, there are materials with different fire ratings. The best ones are rated Class E.

Closed-cell polyurethane foam – due to its high water resistance, higher rigidity, and strength, is used outdoors and in rooms with high humidity. Its structure contains more than 90% of closed cells and its density ranges from 32 to 60 kg/m^3. The thermal conductivity coefficient of closed-cell polyurethane foam ranges from 0.017 to 0.023 W/(m·K). Closed-cell foam types differ in parameters depending on their application. On the one hand, they are perfect for insulating foundations, walls, ceiling structures, roofs and floors. On the other hand, they can be used in industrial and agricultural buildings, for example to insulate production floors, warehouses, cold storages and livestock buildings.

Polyurethane foam is formed out of a chemical reaction whereby a closed cell product is developed. It has closed cell content of minimum 90%, thus providing very good insulation properties. The open cells are filled with low conductivity gases unlike air, which ensures a long-standing thermal conductivity value. The thermal conductivity of PUF is 0.017 W/m·K for slab and pipe sections, and 0.023 W/m·K for spray applications at10ºC mean temperature. Being closed cell, it absorbs negligible amount of moisture and water. It is self-extinguishing and not easily ignitable as per BS 476 Part 6 and 7. PUF conforms to IS 12436. It is available in densities from 32 to 60 kg/m^3, generally in the form of slabs and pipe sections. It is available with aluminium foil lamination on pipe sections to act as readymade chilled water pipe insulation material with water vapour. Slabs are suitable for building roof over-deck insulation and external wall insulation, duct insulation and equipment insulation. It is Class P rated for fire. Its diffusivity value is 0.0018 to 0.0024.

PUF has R-values ranging from 1.43 to 3.57 m^2·°C/W or 8.11 to 20.28 ft^2·hr·°F/Btu-in.

The Product

Polyurethane foam (PUF) is an excellent form of insulation. It is formed out of a chemical reaction that uses a non-CFC gas as a blowing agent, which reduces the amount of damage to the ozone layer and conforms to IS 12436. Polyurethane is a foam insulation material that contains a low-conductivity gas in its cells and is relatively light, weighing approximately two pounds per cubic foot. Polyurethane foam insulation is available in closed-cell and open-cell formulations.

In closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Due to its high water resistance, higher rigidity, and strength, it is used outdoors and in rooms with high humidity. Its structure contains more than 90% closed cells, and it is available in density ranging between 32 to 60 kg/m^3. It is available in slab and pipe section form. Closed-cell foam types differ in parameters depending on their application. On the one hand, they are suitable for insulating foundations, walls, ceiling structures, roofs and floors. On the other hand, they can be used in industrial and agricultural buildings, for example to insulate production floors, warehouses, cold stores and livestock buildings.

In contrast, open-cell foam cell structure is not as dense as the closed cell foam and is filled with air, which gives the insulation a spongy texture and a lower R-value. Open cell polyurethane is intended for indoor use, particularly for insulating walls and roofs as well as increasing the acoustic comfort of a room, as polyurethane foam – besides its thermal insulation properties – has a very high noise reduction coefficient. Open cell foam is vapour-permeable, so a surface covered with it 'breathes'. Sprayed from the inside directly on the roof, it can be easily used on a

Table 3-11: *Properties of PUF and PIR slabs*

Property	Polyisocyanurate Foam (PIR) Slab	Polyurethane Foam (PUF) Slab
Density	32 ± 2 kg/m^3 - Higher densities are available on request	36 ± 2 kg/m^3 - Higher densities are available on request
Compression strength (in direction of rise)	172 kN/m^2 (1.75 kgf/cm^2)	172 kN/m^2 (1.75 kgf/cm^2)
Thermal conductivity (k) at 10°C mean temperature (W/m·K)	0.021	0.021
Temperature Limit	150°C to -200°C	110°C to -180°C
Fire resistance: surface spread of flame (BS 476 Part-7: 1987)	Class 1	-
Ignitability (BS 476 Part-5: 1968)	Class P (not easily ignitable)	Class P (not easily ignitable)
Mean extent of burn (BS:4735, 1974)	Less than 25 mm	Less than 125 mm
Toxicity as per NES Smoke as per NES Oxygen as per NES	1.0142 780.89 25	- - -
Availability	Slabs - Size 1m x 0.5m	Slabs - Size 1m x 0.5m
Zero ODP foam (cyclopentane blown) is available on request		

membrane or boarding. Open-cell foam is available in density ranging between 7 and 14 kg/m^3.

Being closed cell, it absorbs negligible amount of moisture and water. It is self-extinguishing and not easily ignitable as per BS 476 Part 6 and 7.

It is available with aluminium foil lamination on pipe sections to act as readymade chilled water pipe insulation material. Slabs are suitable for building roof over-deck and external wall, duct and equipment insulation. It is Class P rated for fire. Its diffusivity value is 0.0018 to 0.0024.

Properties

a. Thermal conductivity k = 0.019 to 0.023 W/m·K
b. Thermal resistance at 100 mm = 4.50 K·m^2/W
c. Specific heat capacity = NA
d. Density = 32 to 60 kg/m^3
e. Thermal diffusivity = NA
f. Embodied energy = 101 MJ/kg
g. Vapour permeable: No
(Source: TPM Industrial Insulation and others)

Table 3-12: *R and U value of PUF slabs*

Thickness (mm)	R-Value		U-Value	
	(m²·°C/W)	(ft²h·°F/ Btu-in)	(W/ m²·°C)	(Btu-in/ ft²·h·°F)
30	1.43	8.11	0.700	0.123
50	2.38	13.52	0.420	0.074
65	3.10	17.58	0.323	0.057
75	3.57	20.28	0.280	0.049

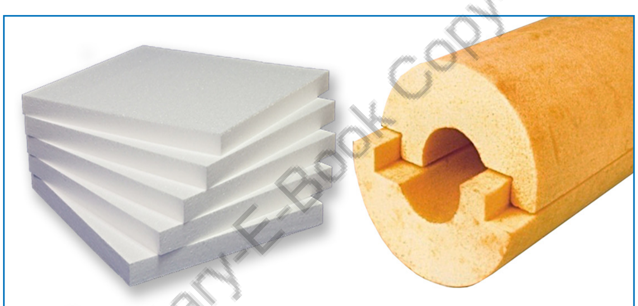


Figure 3-17: *PUF sheets and pipe sections*

Polyisocyanurate

Polyisocyanurate (PIR) is manufactured by the same process as polyurethane foam, except that it is further heated with chemicals to make it fire safe. PIR foam is categorised as Class O as per BS 476 Part 6 and 7. It is CFC and HCFC free with zero ODP, and highly environment friendly. It has a high noise reduction coefficient.

Properties

a. Thermal conductivity λ = 0.019 to 0.023 W/m·K
b. Thermal resistance at 100 mm = 4.50 K·m^2/W
c. Specific heat capacity = NA
d. Density = 32 to 60 kg/m^3
e. Thermal diffusivity m^2/s = NA
f. Embodied energy MJ/kg = 101 MJ/kg
g. Vapour permeable: No
h. Water/moisture absorption = Negligible (0.03%)
i. Air pressure = Up to 1,000 Pa
j. Air velocity = Up to 35 m/s
k. Coefficient of friction = 0.0135
l. Closed cell content ≥ 95%

Fire and Safety

- Toxicity as per Naval Engineering Standard (NES): 1.0142
- Smoke as per NES: 780.89
- Oxygen as per NES: 25
- PIR is fire safe and Class O rated as per BS 476 Part 6 and 7
- Surface spread of flame as per BS 476 Part 7: Class 1
- Smoke development index as per ASTM E-84: Class A

Pre-insulated Ducts

Pre-insulated ducts are manufactured out of CFC and HCFC free and zero ODP category closed cell polyisocyanurate foam slabs conforming to IS12436 and ASTM C591. The slabs are laminated with aluminium foil or kraft paper on both sides, providing a very sturdy rigid finish. The aluminium foil is reinforced and with stucco embossed finish. PIR has superior thermal insulation property ensuring energy savings. It is light weight and easy to handle.

The laminated PIR slabs are cut to size on a CNC machine, shaped and joined to each other with a glue and aluminium tape at the corners to fabricate a duct. The ducts are provided with suitable fixtures made from polymer plastic or extruded aluminium for jointing between two ducts and fixing of accessories like grills. The ducts are manufactured as per EN 13403.

The ducts are fabricated by skilled manpower at the factory, who also carry out installation at site. The finished and assembled product is high-quality insulation formed by a combination of energy-efficient PIR slabs and embossed aluminium foil. This combination is light weight, provides a longer life to the ducting system, and leads to cleaner indoor air quality, aesthetic look, easy installation and longer life. It is corrosion free, rodent free, hygienic, needs less maintenance, gives energy savings and offers value for money.

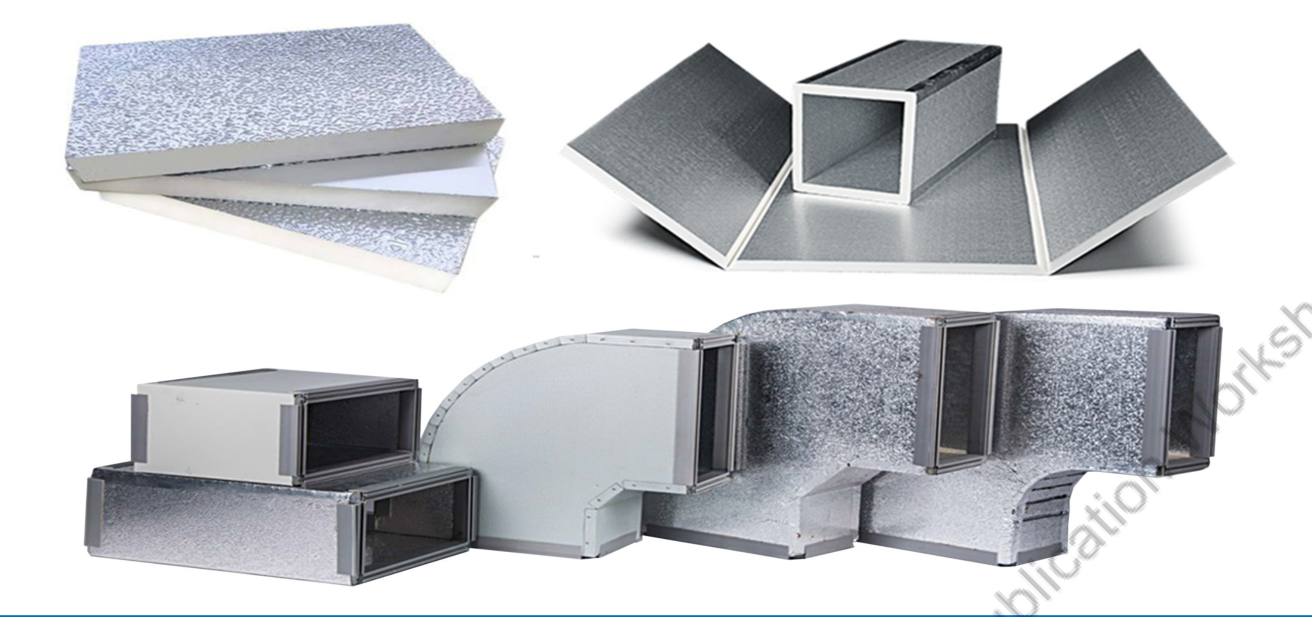


Figure 3-18: Pre-insulated PIR ducts and fittings

Polyisocyanurate (PIR) is a form of polyurethane (PUR or PU) with significantly increased levels of fire retardant added. Many PIR panels would be LPPS 1181 Approved and/or FM 4880 Approved as per Factory Mutual Fire Approval for Panels, UK, but explicit evidence should be requested. PIR is usually a paler yellow in colour than PUR, crunchy when pressed and slightly gritty when rubbed between the fingers.

Polyurethane is a polymer composed of organic units joined by carbamate (urethane) links. Polyurethane can be made in a variety of densities and harnesses by varying the proportion of isocyanate, polyol or additives.

Polyisocyanurate is a thermoset plastic typically produced as a closed-cell foam and used as rigid thermal insulation. Its chemistry is similar to polyurethane except that the proportion of methylene diphenyl diisocyanate (MDI) is higher and a polyester-derived polyol is used in the reaction instead of a polyether polyol. Catalysts and additives used in PIR formulations also differ from those used in PUR.

Polyisocyanurate or polyiso contains a low-conductivity, HCFC-free gas in its cells. Polyisocyanurate insulation is available as a liquid, sprayed foam, and rigid foam board. It can also be made into laminated insulation panels with a variety of facings. Foamed-in-place applications of polyisocyanurate insulation are usually cheaper than installing foam boards, and perform better because the liquid foam moulds itself to all the surfaces.

PIR typically has an MDI/polyol ratio, also called its index (based on isocyanate/polyol stoichiometry to produce urethane alone) higher than 180. By comparison, PUR indices are normally around 100. As the index increases material stiffness, the brittleness also increases, although the correlation is not linear. Depending on the product application, greater stiffness, chemical and/or thermal stability may be desirable. As such, PIR manufacturers can offer multiple products with identical densities but different indices in an attempt to achieve optimal end use performance.

Over time, the R-value of polyisocyanurate insulation can drop as some of the low-conductivity gas escapes and air replaces it – a phenomenon known as thermal drift or ageing. Experimental data indicates that most thermal drift occurs within the first two years after the insulation material is manufactured.

Foil and plastic facings on rigid polyisocyanurate foam panels can help stabilise the R-value. Testing suggests that the stabilised R-value of rigid foam with metal foil facings remains unchanged after 10 years. Reflective foil, if installed correctly and facing an open-air space, can also act as a radiant barrier. Depending upon the size and orientation of the air space, this can add another R-2 to the overall thermal resistance.

Some manufacturers use polyisocyanurate as the insulating material in structural insulated panels (SIPs). Foam board or liquid foam can be used to manufacture a SIP. Liquid foam can be injected between two wood skins under considerable pressure and, when hardened, the foam produces a strong bond between the foam and the skins. Wall panels made of polyisocyanurate are typically 3.5 inches (89 mm) thick. Ceiling panels are up to 7.5 inches (190 mm) thick. These panels, although more expensive, are more fire and water vapour-diffusion resistant than EPS. They also insulate 30% to 40% better for a given thickness.

Comparison between PUR and PUF Boards

High density PUF/PIR products are used for pipe and vessel supports. More information would be given in Chapter 4.

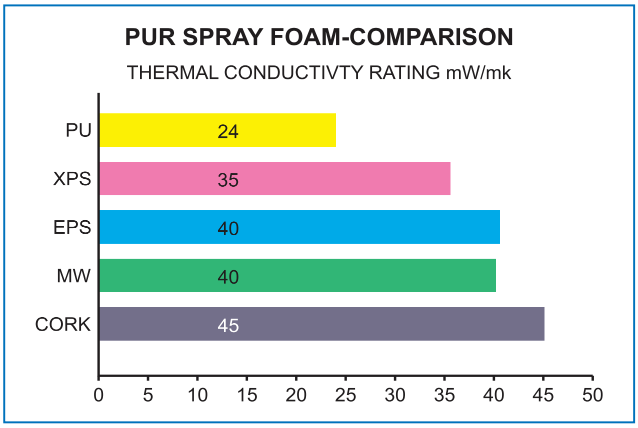


Figure 3-19: *Thermal conductivity comparison between insulation materials*

Polyurethane Foam Spray

Spray-applied rigid polyurethane foam is designed to combine highly efficient thermal insulation with ease of application. It is suitable for insulation on roofs. By nature, liquid applied foam adheres strongly to almost any surface regardless of the foam. As foam does not sag, buckle or mat in use, it retains its insulation value for the life of the insulation.

The seamless and monolithic nature of the sprayed foam provides a fool-proof method of sealing cracks and rendering any surface moisture-resistant and draught-proof. The closed cell foam has a low water vapour transmission property and inhibits ingress of moisture.

The excellent adhesion of the sprayed material makes mechanical fastening redundant. The low density of the material adds little weight to overall loading. The firm bonding to the substrate can also add significantly to reducing the vibration of thin membrane roofs and the structural strength of the building itself.

The process of applying rigid polyurethane foam by spray eliminates separate fixing procedures. It is sprayed with the help of two-component spray foam machines, which are capable of maintaining the mix ratio with $\pm$2% accuracy and controlling the component temperatures in the optimum range.

On roof work, the insulation effect of the foam reduces thermal movement of the roof deck and helps prevent failure of the roof covering. In addition to flat surface, spray applied foam is ideal for curved, corrugated and irregular surfaces.

Besides external use, spray foam can be applied internally as long as the building is suitable, with easy and convenient access for application and good ventilation. The foam can be sprayed on to the underside of roofs or suspended floors and the inner and outer surfaces of walls.

Although the foam forms a weather resistant membrane, a final water-proof coating is required as an additional protection against UV radiation in exterior applications. In the same way as any other organic material, polyurethane foam can eventually be attacked by the ultra-violet rays of the sun, hence a protective covering or coating is necessary.

PU spray foam conforms to IS 13205 and IS 12432.

Table 3-13: *Properties of PUF Spray*

Density	40-50 kg/m³
Compressive strength	>205 kPa
Tensile strength	280 kPa
Shear strength	210 kPa
Closed cell content	92% by volume
Thermal conductivity	0.023 W/m·K at 10°C mean temperature
Water absorption (96h)	Maximum 2% by volume
Water vapour transmission	2.9 ng/Pa·s·m²
Temperature limit	100°C (maximum)
Extent of burn	125 mm

Table 3-14: *R and U Value of PUF spray*

Thickness (mm)	R-Value		U-Value	
	(m²·°C/W)	(ft²h·°F/ Btu-in)	(W/ m²·°C)	(Btu-in/ ft²·h·°F)
30	1.43	8.11	0.700	0.123
50	2.38	13.52	0.420	0.074
65	3.10	17.58	0.323	0.057
75	3.57	20.28	0.280	0.049

Figure 3-20: *Spraying of polyurethane, and filling cracks in cold room floors*

Figure 3-21: *Use of spray foam on roofs*

Sandwich Panels

Double skin insulated sandwich panels, as the name implies, are manufactured with rigid PUF or PIR sandwiched between the inner and outer skin metal sheets (generally pre-painted galvanised sheets). The process of manufacturing PUF/PIR panels involves injecting a blend of two different chemicals, originally in liquid form, under pressure. The chemicals are polyol and MDI in a definite proportion along with a blowing agent. The injecting machine is programmable to control the quantity of the chemical injected, thereby maintaining a uniform density of the resulting PUF/PIR. The reaction of the two chemicals is non-reversible, and they form into solidified rigid foam.

PUF and PIR panels are manufactured on either a continuous line or a discontinuous line. In either case, a jig is required. In the discontinuous line, once the cut-to-size bottom sheet and top sheet are placed in position in the jig – separated by suitable insulation space inserts and the required quantity of cam locks positioned and the jig tightly secured – the blend of chemicals is injected from the sides. External pressure is applied on the top side of the jig to ensure uniform flow of chemical in the space between the two plates. The chemical blend starts to solidify as soon as it starts flowing inside the jig, resulting in the formation of PUF/PIR between the two sheets. The PUF/PIR also gets adhered to the inner sides of the two outer sheet metal skins. Once the process of injection is complete, the panels are allowed to settle down for 30 to 60 minutes for panel thickness of 60 to 200 mm, after which they are removed from the jig and cleaned on the edges. The panels are now ready for final inspection and dispatch.

Cam Lock Panels

A cam lock is a device that is embedded at precise locations alongside the edges of an insulated panel. The cam lock fasteners come in pairs: a male cam lock latch and a female cam lock receptacle. Insulated panels are joined together in the required lengths to assemble partition walls, ceilings and floor.

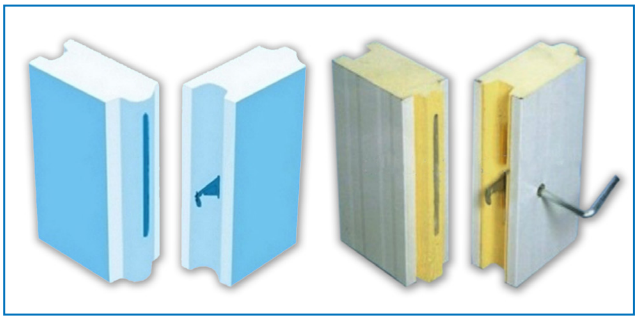


Figure 3-22: *Cam lock panel and cam locking mechanism*

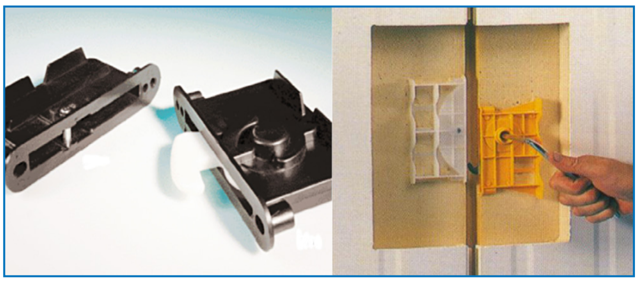


Figure 3-23: *Cam locks with plastic hook*

The tongue and groove system utilises cam locks to achieve tightness and make the insulation fully effective. Panels slip into place allowing for easy and rapid installation, whilst improving the structural strength and thermal efficiency and offering a clean, smooth aesthetic look. They give us the following advantages in cold room applications:

- Rigidity and good weatherproofing
- Better transportability
- More cold storage volume for a given space
- Ease and speed of cold storage unit installation

Cam lock panels are preferred for small cold rooms and applications with high air volumes like blast freezer rooms. As the strength of the locked joint is high, the panels can withstand high pressures without distortion.

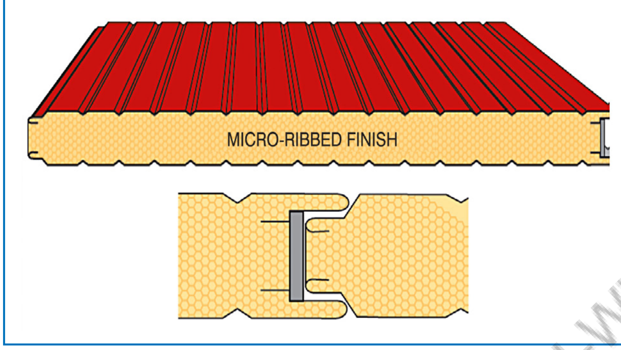


***Figure 3-24:** Single tongue-and-groove joint*

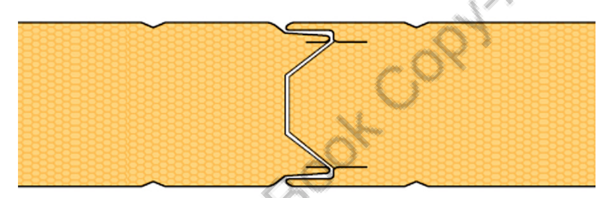


***Figure 3-25:** Double tongue-and-groove joint*

Panel manufactured with cam locks have the advantage of locking each other firmly. Such panels are mainly used for small cold rooms and blast freezers where air pressures inside the chamber is high. The panels can be manufactured in any size and thickness as per the requirement.

Cam locks can be embedded only in discontinuous panel production (batch process). Panels produced in a continuous production line have a tongue and groove with press type snap lock, or a similar mechanism, to ensure an air tight panel joint. Cam lock panels are recommended for deep freeze storages.

Continuous Panels

In the continuous line of production, the chemical is sprayed between the two sheets continuously with a moveable gun. There is no constraint on the length of the panel that can be manufactured, and 12-20m long panels are often manufactured. The limitation is the maximum length that can be transported.

The outer and inner skin sheets are serrated using a serration roller before it enters the jig. These profiles aid in enhancing the strength of the panel. For cleanroom applications, plain sheet can be used. The skin sheets are placed in coil form on two fixtures, which can be rotated at a set speed. As they rotate, the top and bottom sheets are drawn into the jig. The jig, which is about 15-20m long, has side containments that control the thickness of the panel. The side containment needs to be changed for each thickness. As the lower sheet travels into the jig, a chemical injection gun – positioned at a location just before the sheet moves into the jig – sprays the chemical in a pre-determined quantity, continuously moving from one end to another over the inner sheet to provide the right density of PUF/PIR. Thereafter, the panel enters a heat treatment press of 20m length for proper curing and setting. The jig here is about 20-40m long. A programmable cutter is positioned at the outlet of the jig, which cuts the panel to length.

The continuous line manufacturing process is fully automatic with a built-in facility for cooling the panels on a specially built conveyor (allowing for PUF/PIR to settle down), visual inspection, strap packing, etc.

A trapezoidal profile on the top and a plain surface on the bottom can also be created in double skin PUF/PIR panels, which are generally used for the top exposed roofing panels.

***Table 3-15:** Thermal and load characteristics of panels*

Thickness	mm	60	80	100	120	150	200
'U' value	W/m²·K	0.36	0.26	0.21	0.19	0.14	0.11
Panel wt.	kg/m²	11.25	12.05	12.85	13.65	14.85	16.85

***Table 3-16:** 'U' value of panels*

Thickness (mm)	'U'-Value	
	(W/m²·K)	(Btu-in/ft²h·°F)
80	0.288	0.051
100	0.230	0.041
150	0.153	0.027
200	0.115	0.020

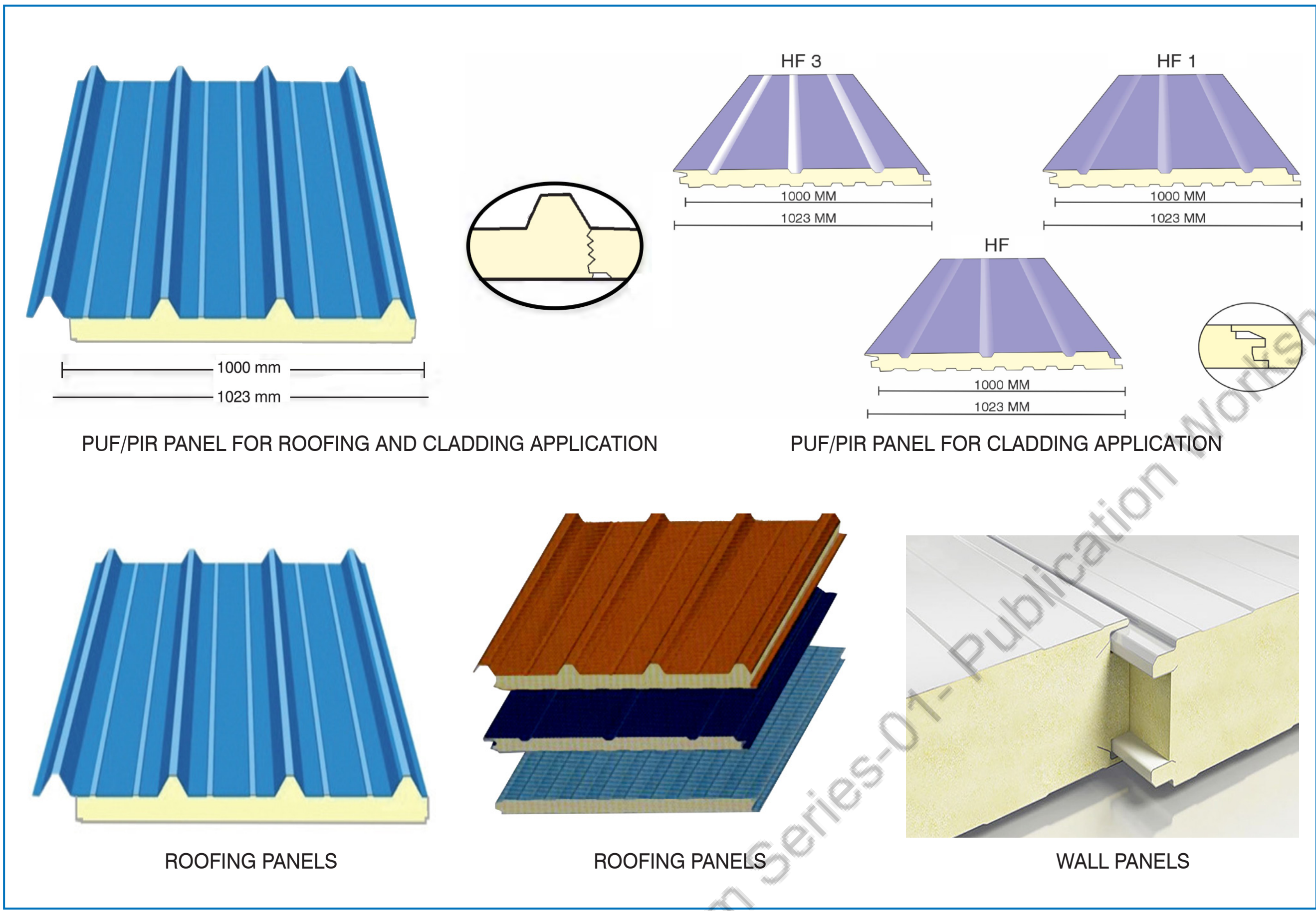


Figure 3-26: *Applications of PUF/PIR panels*

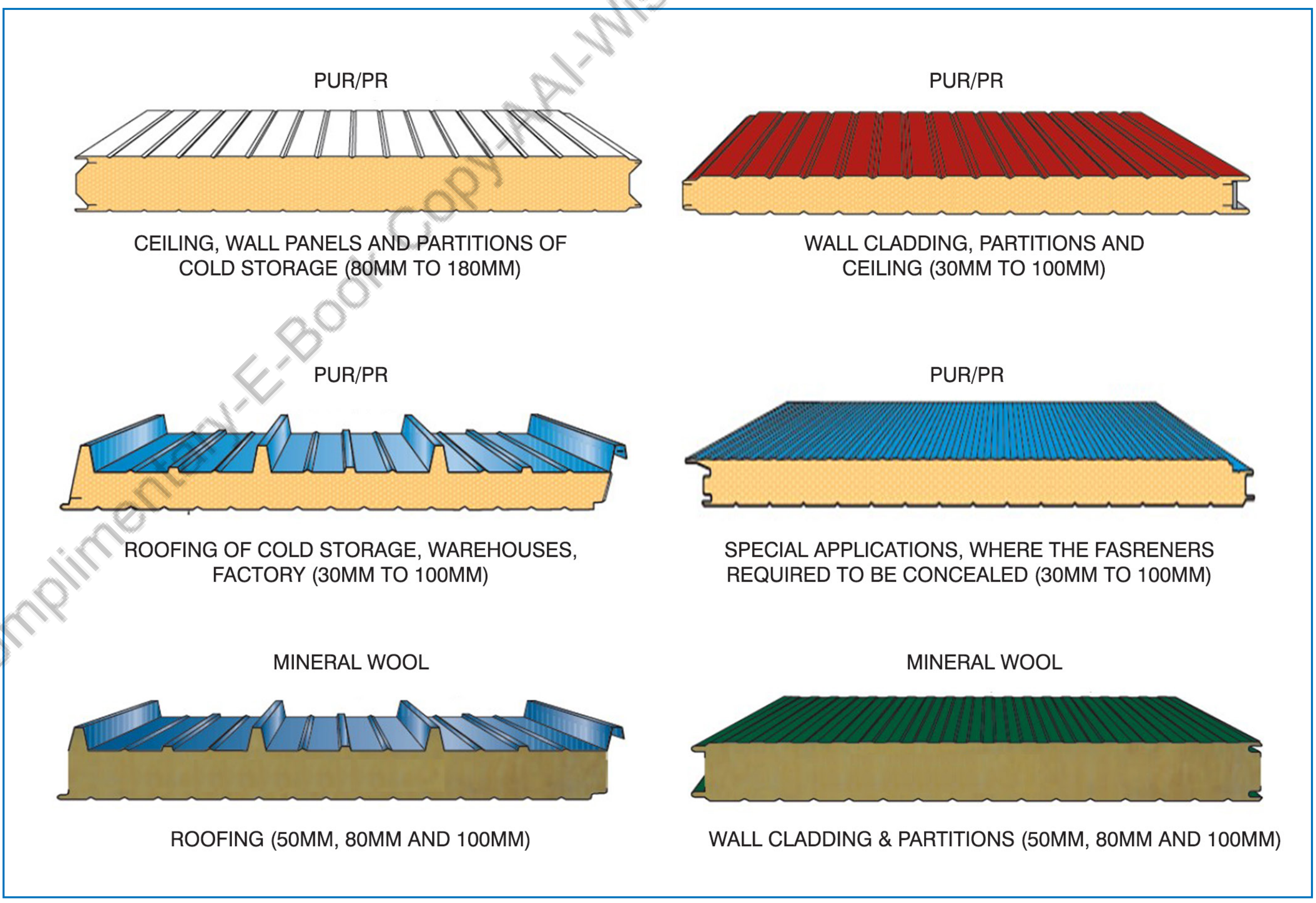


Figure 3-27: *Application details of PUF/PIR*

Table 3-17: Insulation characteristics of PUF and PIR

Insulation properties	CFC and HCFC free rigid polyurethane foam (PUF) as per IS: 12436	CFC and HCFC free rigid polyisocyanurate foam (PIR) as per IS: 12436
Foam overall density	40 ±2 kg/m³	45 ±2 kg/m³
Foam thermal conductivity (k-value) at 10°C mean temperature.	0.023 W/m·K	0.023 W/m·K
Compressive strength at 10% deformation	2.10 kg/sq.cm.	2.10 kg/sq.cm.
Tensile strength	2.5 kg/sq.cm.	2.5 kg/sq.cm.
Flexural/bending strength	3.0 kg/sq.cm.	3.0 kg/sq.cm.
Shear strength	2.5 kg/sq.cm.	2.5 kg/sq.cm.
Close Cell Contents	90-95%	90-95%
Horizontal burning characteristics	125 mm (extent of burn) – maximum, fire retardant, self-extinguishing	25 mm (extent of burn) – maximum, fire retardant, self-extinguishing
Water absorption	0.2% volume at 100% RH – maximum	0.2% volume at 100% RH – maximum
Water vapour permeability	0.12 ng/Pa·s·m² at 88% RH and 38°C – maximum	0.12 ng/Pa·s·m² at 88% RH and 38°C – maximum
Dimensional stability at -25⁰C cold temperature + 70⁰C hot temperature	±2% ±2%	±2% ±2%
Fire rating	-	1 hour with 100 mm thickness
FM approval		Yes

The above data is based on test results carried out as under:

1. Test Report of various tests carried out on 80mm thick PUF panel as per IS 12436:1988 by Bharat Test House, Delhi in 2011, 2012 and 2015 and Spectro Analytical Lab, Greater Noida.
2. Brief Evaluation Report of Ignitability Evaluation carried out on 50mm thick PUF panel as per BS 476-Part 5 by CBRI, Roorkee in 2011.
3. Brief Evaluation Report of Fire Propagation of carried out on 50mm thick PUF panel as per BS 476-Part 6 by CBRI, Roorkee in 2011.
4. Brief Evaluation Report of Surface Spread of Flame carried out on 50mm thick PUF panel as per BS 476-Part 7 by CBRI, Roorkee in 2011.
5. Falling Hammer Impact Test carried out on 25mm thick PUF panel as per IS 2380(Part 10):1977 by CBRI, Roorkee in 2011.
6. Density of PUF as per IS 7888:1976 by Shriram Institute for Industrial Research, Delhi in 2011.
7. Test Report of various tests carried out on 50mm thick PUF panel as per IS 11239 (Part 1): 1985 and IS 101 (Part3/Sec2): 1989 by Aglow Quality Control Lab, Kolkata, NABL in 2017.
8. Test Results of the samples carried out on 40mm thick PUF panel as per IS 12436:1988 and IS 11239 (Part 12):1985 by PEC University of Technology, Chandigarh in 2017.
9. Test Report.
10. Fire Test evaluation report carried out by Spectro Analytical Lab, Greater Noida on 100mm PIR Panels for one-hour fire rating as per BS EN 1364-1:2015.

Continuous Sandwich Panels with Steel Structure

As the name suggests, sandwich panels consist of several layers – usually two thin covering sheets with a core in between. The manufacturing process involves expanding PIR or PUF rigid foam between two skins of colour bond steel, forming an exceptionally strong, durable and fire-retardant building panel. The individual layers are firmly connected with each other, and are therefore often referred to as composite panels.

Figure 3-28: *Cold storages with continuous panels and steel structure*

Figure 3-29: *Cold storages with continuous panels and steel structure under construction*

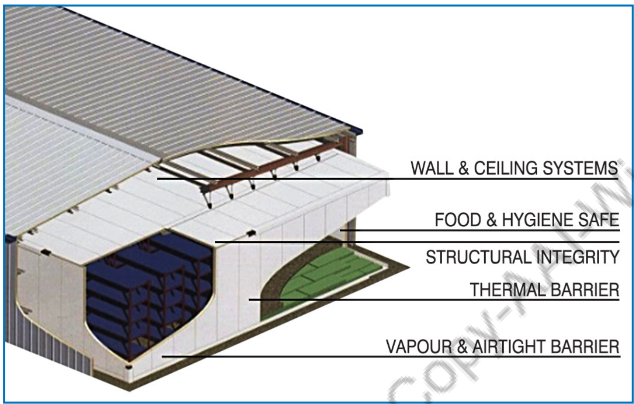


Figure 3-30: *Details of cold storage with continuous panels and steel structure*

Pre-fabricated PIR sandwich panels are manufactured with corrosion-protected, corrugated steel facings bonded to a core of PIR foam and used extensively as roofing insulation and vertical walls (e.g. for warehousing, factories and office buildings).

Insulated panels, or composite panels, or sandwich panels, come in a wide variety of designs. In most cases, the outer shell consists of a galvanised steel sheet. The inner shell can be made of galvanised steel sheet, thin aluminium sheets, stainless steel or glass-fibre reinforced plastic (GRP). The core is generally made of insulating material such as polyurethane or polyisocyanurate. The joining of the outer and inner layers helps to combine the properties of the materials used; bending or breaking of the surface is made difficult thanks to the core. In turn, the stability of the surface protects the soft core from external influences.

The insulation core provides effective insulation and strong bonding for better structural stability to facilitate higher loading and wider spans. These panels are available for both walls and roofs. This system can incorporate all types of architectural features like coving, boxes, cantilevers, projections, infill walls and mezzanine floors. The system can also incorporate all types of services such as electrical, gas and plumbing. The design and engineering of the structures is executed by following the norms and guidelines stipulated in relevant Indian Standards.

The extraordinary strength of the sandwich panel can be attributed to its layers of separate materials bonded together to work as a single entity, with strength far beyond its weight.

Main Features of Panel Construction

- The panel system incorporates a special 'L' shaped single piece panel for the corners. This avoids wall to wall direct jointing, and provides additional stability, strength, aesthetic appearance, easy housekeeping, etc.
- For additional reinforcement, 'U' or 'L' shaped flashing is provided at the wall-to-ceiling joints.
- Rain guard profile sheet is provided over the ceiling panels.

Fire Performance

Like all organic building materials such as wood, paper, plastics and paints, rigid polyurethane insulation is combustible, although its ignitability and rate of burn depend largely on the fire resistance properties of the material used as skin to the panels. Insulated panels with fire rated cores have performed well in actual fires and do not contribute significantly to the fire load in the building.

Typical construction material specifications are given below:

- Galvanised steel sheet skin material as per Indian Standards IS 277, IS 513 and IS 14246. Galvalume steel as per AS 1346.
- Total galvanised zinc coating surface: 120 to 275g/m^2.
- Plate thickness: 0.4 to 0.6 mm base metal and 0.45 to 0.65 mm total coated thickness.
- Paint coating: 25 microns on the exposed side and 5 to 7 microns on the back side.
- Core: PU rigid foam, aqueous blowing agent with stabilising gas R134a; CFC and HCFC free and zero ODP category.
- Polyisocyanurate foam panel of 100 mm thickness is available with one hour fire rating as per BS EN 1364-1:2015.

Laminated Panels

A pre-coated galvanised iron (PCGI) laminated panel has the following layers:

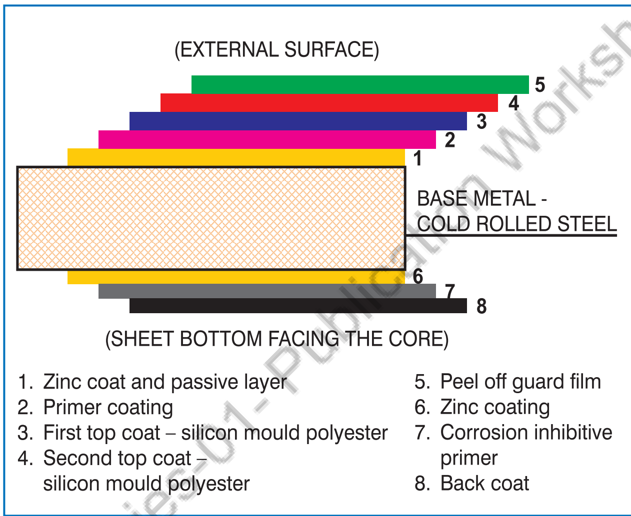


Figure 3-31: *Structure of PCGI laminated panel*

Table 3-18: *Quality assurance plan for continuous PUF sandwich panels*

S. No.	Parameters to be Inspected	Requirement	Test Method	Frequency of Testing
Raw Material				
1	Pre-coated GI sheets	Shall be free from any surface defects	IS 277:2003	For every batch
2	Mechanical, chemical and coating properties of GI sheets	Shall conform to IS14246: 2013	IS14246:2013	Monthly
3	PU chemical	Shall be as per manufacturer's specifications	As per manufacturer's specifications	For every batch
4	Polyol glue	Shall be as per manufacturer's specifications	As per manufacturer's specifications	For every batch
CSP				
1	Thickness	Shall be within tolerance limit of ±1 mm	Measurement with Vernier callipers	Every two months
2	PUF/PIR density	Shall not be less than 40 kg/m^3	IS 11239 (Part 2): 1985	Every two months
3	Thermal conductivity	Shall be 0.023 W/m·K	ASTM C 518-98, IS 12436	Every year
4	Compressive strength	110-210 KPa	ASTM D 1621-94	Every six months
5	Tensile strength	370 KPa	ISO 1926: 2005	Every six months
6	Dimensional stability	0.1% at -30°C	ISO 2796: 1986	Every six months
7	Water absorption	0.2% maximum	ISO 2896: 2001	Every six months
8	Horizontal burning	Less than 125 mm	IS 11239 (Part 12): 2008	Every six months
9	Fire property	Not easily ignitable / self-extinguishing	BS 476 (Part 5)	Every year
10	Water vapour transmission	5.5 ng/Pa.s.m^2	IS 11239 (Part 4): 2014	Every six months
11	Fire rating	Surface spread of flame: Class I	BS 476 (Part 7)	Not applicable

1. Zinc coat and passive layer
2. Primer coating
3. First top coat: silicon mould polyester
4. Second top coat: silicon mould polyester
5. Peel off guard film
6. Zinc coating
7. Corrosion inhibitive primer
8. Back coat

Technical Specifications

i. Polyurethane foam: It is a thermosetting material; when exposed to fire, does not drip or melt; forms a strong carbonaceous char that protects the core and prevents the spread of flame. It is CFC-free and self-extinguishing, and conforms to IS 12436: 1988.

ii. GI pre-painted sheet (PPGI): The pre-coated sheet should have minimum yield strength of 240 MPa conforming to IS 14246: 2013, with zinc coating of minimum 120 gm/m^2 as per IS 277: 2018. The sheet should have 5-7-microns epoxy primer on both sides and polyester top coat of 15-18 microns. The sheet should also have a plastic protective guard film of minimum 25 microns to avoid scratches during transportation.

iii. U channel: Made of PPGI sheet conforming to IS 14246: 2013, and with zinc coating of minimum 120 gm/m^2 as per IS 277: 2018.

iv. PU chemical: As per the manufacturer's specifications.

v. Polyol glue: As per the manufacturer's specifications.

The most common use of polyurethane foam panels is in cold storages, and we shall give more information on PUF panels in Chapter 5 on cold storage applications.

Flexible Thermal Insulation and Acoustic Insulation

Flexible insulation is used in refrigeration, chilled water and air conditioning services for chilled water piping, ducting and refrigerant piping as well as heat exchangers and vessels.

Chilled water air conditioning systems are used in applications that need large cooling capacity, such as supermarkets, industrial processes and commercial air conditioning systems for offices and factories. The system pumps cool water to load terminals and back to chillers via supply and return piping in a closed circuit. For industries and commercial buildings with large cooling capacity requirements, refrigeration and air conditioning systems account for a significant proportion of overall site energy costs. The correct use of insulation can significantly improve system efficiency, with thermal performance and prevention of condensation being the key considerations.

Moisture condensing from the air on the cold pipe surfaces can cause damage to building materials, equipment, furniture, carpets, etc. An incorrect choice of insulation, with an open or partially open cell structure reliant on an external vapour barrier, can quickly become saturated and lose thermal performance. Once moisture diffuses into the material through gaps or holes in the external vapour barrier, it results in energy efficiency losses, corrosion, mould growth and ultimately reduction of the service life of the equipment or the system.

Flexible, closed cell structure prevents such moisture ingress owing to its superior water vapour diffusion resistance value of ≥7,000µ. Products with ≥10,000µ with anti-microbial protection are also available. Some manufacturers provide an

Table 3-19: *Summary of properties of listed materials*

Property	Expanded Polystyrene (EPS)	Extruded Polystyrene (XPS)	Polyurethane/ Polyisocyanurate (PUF/PIR)
Thermal conductivity, W/m·K	0.034-0.038	0.026-0.028	0.019-0.023
Thermal resistance, K/m^2·W	3.52	3	4.50
Specific heat capacity, J/(kg·K)	1,030	NA	N.A.
Density, kg/m^3	15-30	30-32	30-60
Embodied energy, MJ	19	19	101
Vapour permeable	No	No	No
Operating temperature range, °C	-50 to +75	-210 to +120	PUF: -210 to +120 PIR: -180 to +150

integral barrier to water vapour ingress with no external foil vapour barrier required, unlike with mineral wool or phenolic foam alternatives. The combination of water vapour resistance and low thermal conductivity ensures long-term reliability of the material. The additional anti-microbial protection prevents mould and bacteria growth.

These materials are fully vapour sealed using specially formulated contact adhesives to fuse adjoining sections of the closed cell insulation together. This means that adhered seams and joints do not represent thermal bridges or water vapour bridges unlike other materials. If a cross-section of a sealed piece is taken, the fusion of the cells is such that no joint is visible, acting as a seamless installation.

Primarily, insulation used on cold lines must effectively prevent condensation and should achieve the following characteristics:

Effective Water Vapour Barrier

Without an effective and integral water vapour barrier, condensation can directly diffuse through to the cold surface of the pipe.

Non-wicking Cell Structure

Open cell pipe insulation materials are protected by an external water vapour barrier. Once moisture is able to penetrate through gaps or holes in the system, it is able to migrate throughout the material – a process known as 'wicking' – which accelerates corrosion and mould growth.

No Thermal Bridging

When valves, pipe hangers and flanges are left un-insulated, condensation and significant energy losses will occur at these 'thermal bridges. Flexible materials that can insulate all of the pipework and associated equipment can eliminate condensation at these points.

Low Environmental Impact Values

To reduce carbon emissions, insulation with only low ODP and GWP values are acceptable. Some flexible materials have zero ODP and GWP, an independently verified Environmental Product Declaration and a Building Research Establishment Environmental Assessment Method (BREEAM) Green Guide A rating to certify its low environmental impact.

Long-term Stability of Values

Thermal properties of insulation typically vary over time. It is usually essential that the material prevents condensation over the lifetime of the installation, and this requires integral resistance to moisture vapour in order to maintain highly stable thermal values.

HVAC Ductwork

In large commercial premises and public buildings, heated and cooled air is distributed using ductwork systems including warm air return, supply, and exhaust systems. Rectangular ductwork is used for the main supply of heating and cooling systems, with circular ductwork and flexible hose sections used to branch off supply and return ducts to specific areas.

To maintain the desired temperature of heated or cooled air, the large surface areas of rectangular and circular ductwork require insulation to prevent heat losses or heat gain. Ductwork can also be a condensation risk and a source of unwanted noise and air pollutants that can contribute towards the 'sick building' syndrome, causing problems such as viral infections, fatigue and a wider loss of productivity. A wrong choice of insulation can contribute to these problems in terms of condensation damage and pollutants in the form of dust, fibres and mould growth.

Pairing excellent thermal values with a closed cell structure, insulation can meet the energy efficiency targets for ductwork without any risk of impacting the indoor air quality or contributing towards the sick building syndrome.

Insulations are available with anti-bacterial protection to restrict mould growth, making them an obvious choice for improved air quality in schools, hospitals and offices. The fibre free materials are also easy to handle and work with, with no dust mask or gloves required.

In addition, flexible closed cell foams have excellent acoustic properties and can be used as a combined thermal and acoustic insulation solution.

Factors for Selection of Ductwork Insulation

The following factors should be considered when selecting insulation for use on ductwork.

Ductwork and Building Comfort

Many modern buildings are air-tight and rely on recirculating filtered but stale air. Almost all gases remain within the envelope, and ventilation ductwork is an essential part of removing any contaminants and maintaining occupant comfort. However, it can also provide an inconvenient means of spreading unwanted noise and air pollution throughout a building. It is important to specify insulation products that can isolate any structure-borne noise and absorb airborne sound.

Indoor Air Quality and Mould Growth

Air is always contaminated with pollutants. These pollutants include not only naturally

Table 3-20: Technical data of flexible closed-cell insulation

Brief Description	Flexible closed-cell insulation material for use in hot and cold water services, chilled water, heating systems, air conditioning ductwork and refrigeration pipework	
Colour	Black	
Parameter	***Value***	***Test Method***
Service temperature	Maximum: +110°C (+85°C for flat surfaces)	EN 14706, EN 14707 and EN 14304
	Minimum: -50°C	
Thermal Conductivity at 0°C	0.033 W/(m·K) (tubes 6-19 mm and sheets 3-32 mm)	EN 12667 & EN ISO 8497
	0.036 (W/(m·K) (tubes 25-32 mm)	
Water vapour diffusion resistance	μ ≥10,000 (tubes 6-19 mm and sheets 6-25 mm)	EN 12086 & EN 13469
	μ ≥ 7,000 (tubes 25-32 mm and sheets 32-50 mm)	
Fire performance	Class O	BS 476 part 6
	Class 1	BS 476 part 7
	B_L-s3, d0 (tubes)	EN 13501-1
	B -s3, d0 (sheets)	
Approvals	FM Approved	
UV resistance	UV protected with paint	
Health aspects	Dust and fibre free	
Antimicrobial behaviour	In-built antimicrobial protection; active protection against bacteria and mould growth	
Environmental aspects	Zero ODP and GWP	

generated gases such as carbon dioxide, but also volatile organic chemicals, industrial fibres, acidic particles of dust and spores of mould and bacteria. While breathing these pollutants may not result in any immediate signs of ill health, they may contribute towards building related symptoms. Selecting dust- and fibre-free insulation on ductwork systems can minimise any potential contribution to indoor air pollution.

Cross-linked Polyethylene

Cross-linked polyethylene, commonly abbreviated as PEX, XPE or XLPE, is a form of polyethylene with cross links. It is used predominantly in building pipework systems, hydronic radiant heating and cooling systems, domestic water piping, and insulation of high tension (high voltage) electrical cables. It is also used in natural gas and offshore oil applications, chemical transportation, and transportation of sewage and slurries. PEX is an alternative to polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC) and copper tubing for use in residential water pipes.

Low-temperature impact strength, abrasion resistance and environmental stress cracking resistance can be increased significantly by crosslinking, whereas hardness and rigidity are somewhat reduced. PEX does not melt any more (analogous to elastomers) and is thermally resistant (over longer periods up to 120°C, and for short periods without electrical or mechanical load up to 250°C). By increasing the crosslinking density, the maximum shear modulus increases (even at higher temperatures). PEX has significantly enhanced properties compared with ordinary PE. Crosslinking enhances the temperature properties of the base polymer. Adequate strength to 120-150°C is maintained and chemical stability enhanced by resisting dissolution. Low temperature properties are improved. Impact and tensile strength, scratch resistance, and resistance to brittle fracture are enhanced.

Almost all PEX used for pipes and tubing is made from high-density polyethylene (HDPE). PEX contains cross-linked bonds in the polymer structure, changing the thermoplastic to a thermoset. Cross-linking is accomplished during or after the extrusion of the tubing. The required degree of cross-linking, according to ASTM F876, is between 65% and 89%. A higher degree of cross-linking could result in brittleness and stress cracking of the material, while a lower degree of cross-linking could result in a product with poorer physical properties.

Cross-linked polyethylene is used in air ducts and piping insulation in automobile applications.

Cross-linked Polyolefin Foam

Physically Cross-linked Polyolefin Foam

Physically cross-linked polyolefin foams are the most refined grade of polyolefin foams with uniform and very fine cell sizes and structure. The process involves bombardment of an electron beam using a high voltage current accelerator into the extruded polyolefin sheets that pass through the crosslinking chamber to cross-link the molecules. The process gives the advantage of controlling the cell sizes of the foam, which in turn affects the physical as well as mechanical properties of the material. These fine cells are highly resistant to water and chemical, which supports a very stable product.

The major properties getting affected due to these engineered cell sizes are thermal conductivity, water absorption, vapour permeability resistance factor, uniformness of density and thickness and skin finish of the material. The above properties make the physically cross-linked closed cell polyolefin foam an excellent thermal insulation for application in the temperature range of -80 to +100°C, and open cell polyolefin foam an excellent acoustic lining material for HVAC ducts to reduce the fan noise.

Physically cross-linked closed cell polyolefin foam has one of the lowest thermal conductivity values in the range of flexible insulation material, which in turn helps building owners to conserve energy and reduce the operational cost of the building.

Low water vapour absorption and high permeability resistance of the material enhances the life of the product as well as minimises the change in thermal insulation properties of the material over the period of time.

The process of manufacturing physically cross-linked polyolefin foam is very clean and does not use any kind of peroxides, PVC, CFCs or HCFCs, making it an environment-friendly product and complying to some of the stringent directives like Restriction of Hazardous Substances (RoHS) and Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH). This makes it an ideal product for use in green building and environmentally safe projects.

Physically crosslinked polyolefin foam with additives and laminates are highly fire resistant and low smoke generating materials, making them very safe for use inside the buildings where

Table 3-21: Comparison of physically cross-linked and chemically cross-linked foams

Property	Test	Physically Cross-linked Foam	Chemically Cross-linked Foam
Material of construction	NA	Closed cell polyolefin foam with factory applied reinforced aluminium foil and acrylic tissue adessive	Chemically cross-linked polyolefin foam with factory applied foil and adhesive (non-repositionable)
Structure	NA	Very fine cells with completely closed cell structure; no loose fibres	Large cells, closed cell foam
Density		25 kg/m^3	30 kg/m^3
Thermal conductivity	ASTM C518	0.028W/m·K (0°C) 0.032W/m·K (23°C) 0.036W/m·K (36°C)	0.034W/m·K (0°C) 0.036W/m·K (23°C) 0.039W/m·K (36°C)
Fire rating	BS 476 Part 6 and 7	Class O	Class O
	FM 4924	FM Approved	Not Approved
NFPA 90A/90B compliance	ASTM E84/C411	Yes	No
Water absorption		Less than 0.8%	Less than 3%
Chemical resistance		Inert to acids and alkalis	Inert to acids and alkalis

fire and smoke norms of the region need to be adhered.

Being a highly flexible insulation material with skin finish, physically crosslinked polyolefin foams are easy to install on HVAC ducts, chilled water and hot water pipes, chilled liquid storage tanks, and floor and underdeck insulation.

Chemically Cross-linked Polyolefin Foam

As against physically cross-linked polyolefin foam, a chemically cross-linked PE foam is also available. In this process, chemicals are induced in the foam to effect cross-linking. There is a limitation of this process in that the density cannot go below 30 kg/m^2 and hence the k value is higher at 0.037 W/m·K at 23°C mean temperature. Also, other properties like resistance to water vapour permeability and water absorption are much better for physically cross-linked PE foam.

A comparison of physically and chemically cross-linked foams is given in *Table 3-21.*

Vacuum Insulation

Vacuum insulation is an advanced thermal insulation technology that significantly outperforms closed-cell foams, foam beads and fibre blankets. While these traditional systems attempt to trap gases to reduce the transfer of heat, vacuum insulation removes the gases within the insulating space. With the space evacuated or placed 'under vacuum', the molecular presence and movement needed to transfer heat is greatly reduced.

Vacuum Insulation Panels

Vacuum Insulation panels, or VIPs, consist of a filler material called the core, which is encapsulated by a thin, super-barrier film such as a metal foil or metallic film laminate. The encapsulated system is then evacuated to a vacuum between 0.13 and 1.30 Pa and sealed. The actual vacuum required depends on the specific core material used and the desired thermal resistance or R-value of the finished panel. The core, when under vacuum, serves to interrupt the mean free path of whatever few heat transmitting molecules remain in the panel, while also withstanding external pressures that can be as high as 101.3 kPa due to the forces exerted on the VIP by atmospheric pressure. Being nearly impervious to outside gases, the barrier film sustains the required vacuum level (and thus, its R-value) for the desired life of the panel. To trap any molecules entering the panel or the modest out-gassing that may occur from the VIP component materials, water and/or gas adsorbing materials are also placed inside the panel to maintain the vacuum for the intended life of the VIP.

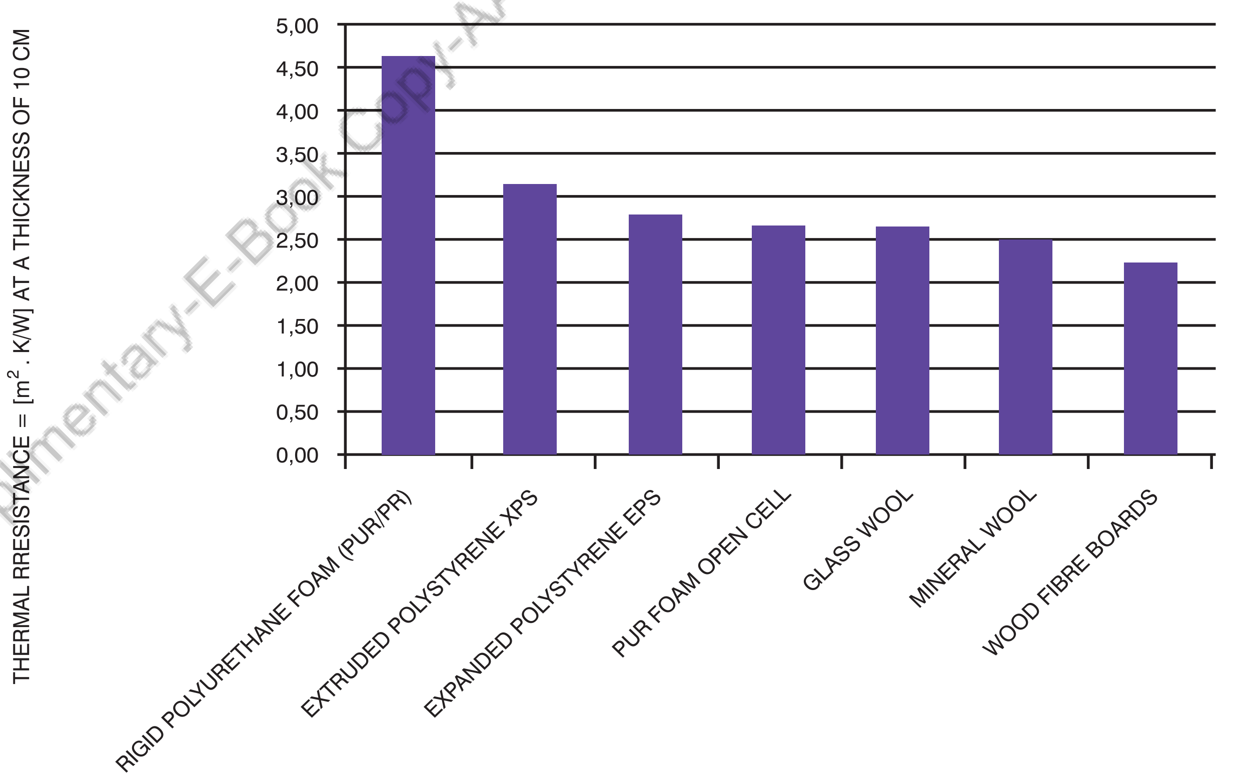


Figure 3-32: *Comparison of thermal insulation properties of commercially available insulation materials*

Summary of Insulation Material Properties

Table 3-22: *Comparison of physical properties of insulating materials*

S. No.	Characteristics	Rigid Polyisocyanurate Foam (PIR)	Rigid Polyurethane Foam (PUF)	Rigid Phenolic Foam	Expanded Polystyrene (EPS)	Bonded Rockwool	Bonded Glass Wool
1	Relevant IS code	IS 12436	IS 12436	IS 13204	IS 4671	IS 8183	IS 8183
2	Useful forms	Slabs and pipe sections	Slabs and pipe sections	Slabs and pipe sections	Slabs and pipe sections	Slabs and pipe sections	Slabs and pipe sections
3	Density, kg/m^3	30-38	34-38	32-60	15-35	Slab: 48 pipe section: 144	Slab: 32, pipe section: 80
4	Thermal conductivity at 10°C, W/m·K	0.023 at 32 kg/m^3	0.023 at 36 kg/m^3	0.026 at 50 kg/m^3	0.037 at 15 kg/m^3	0.033 at 48 kg/m^3	0.033 at 32 kg/m^3
5	Thermal diffusivity, m^2hr	0.0018-0.0024	0.0018-0.0024	0.0016-0.0029	0.0037-0.0078	0.0006-0.0018	0.0011-0.0027
6	Water vapour transmission rate, ng/Pa·s·m^2, maximum	5.5	5.5	5.5	7.95	-	-
7	Water absorption after 24 hr immersion, % by mass	0.1	0.1	0.1	1.0	2.3	2.3
8	Compressive strength for 10% deformation in kN/m^2, minimum	115 kN/m^2	115 kN/m^2	100 kN/m^2	0.7	-	-
9	Cross breaking strength in kg/cm^2, minimum	-	-	-	1.4	-	-
10	Water vapor permanence in g/m^2·24hr, maximum	-	-	-	50	-	-
11	Thermal stability, %, maximum	-	-	-	1	-	-
12	Moisture absorption, %	-	-	-	2	-	-
13	Horizontal burning mm, maximum	25	125	25	-	-	-
14	Closed cell content, %, minimum	86	85	60	-	-	-

CHAPTER 4

Insulation Thickness

In this Chapter, we shall give the recommended thickness for different insulation materials for cold rooms and piping, based on outdoor and indoor temperatures.

The objectives while selecting the thickness of an insulation material are:

1. Optimised thickness to reduce heat gain/ loss.
2. Preventing moisture transmission/ condensation.

The insulation thickness that has the minimum total cost is taken as the optimum insulation thickness.

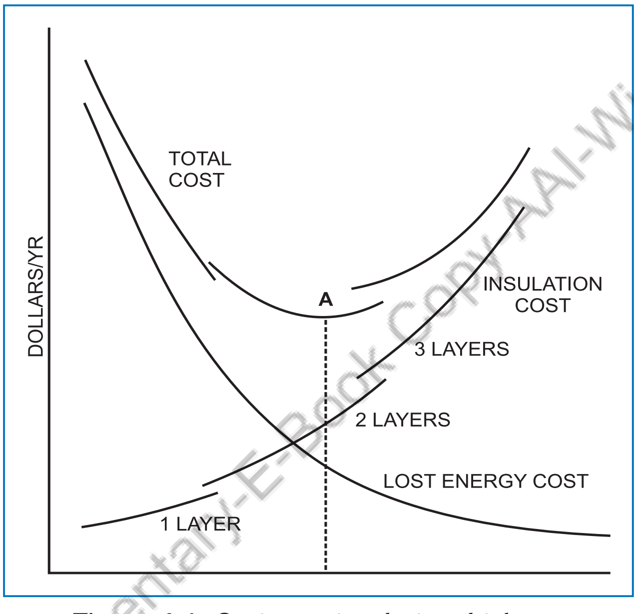


Figure 4-1: *Optimum insulation thickness (Source: ASHRAE Fundamentals, Chapter 23)*

To determine the insulation thickness required, it is necessary to understand heat transmission fundamentals.

Transmission Load

Heat transfer through conduction directly depends upon thermal conductivity, surface area, temperature differential and time. It varies inversely with thickness of the material used for construction of the cold room, which means the more the thickness, the less is the heat ingress.

Heat transmission into a refrigerated space through its ceiling, floor and walls depends on

a. Outside surface area of the cold room.
b. Temperature differential between the cold room and its surrounding area.
c. Wall construction details and thermal conductivity of the insulation used.

The equation for calculating transmission heat load is:

Heat Gain, Q = 'U' x A x ΔT,

where

Q = Overall heat gain, W or BTU/h

U = Overall heat transfer coefficient, W/m².K or BTU/h·ft²·°F

A = External area of the envelope consisting of four walls, ceiling and floor (total six surfaces), m² or ft²

ΔT = Difference between outside air temperature and temperature of the refrigerated space, °C or °F

To calculate the 'U' value, one has to first add all the resistances acting as barriers to heat flow, and take the reciprocal of the total to arrive at the 'U' value. The overall resistance of a compound structure is equal to:

$$R_{Total} = \frac{1}{F_i} + \frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3} + \frac{1}{F_o}$$

Then, 'U' $= \frac{1}{R_{Total}}$

$$U = \frac{1}{\frac{1}{F_i} + \frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3} + \frac{1}{F_o}}$$

where,

U = Overall heat transfer coefficient, BTU/h·ft²·°F or W/m²·k

R = Resistance offered by each element, ft²·h·°F/ BTU or m²·K/W

x_1, x_2, x_3 = Thicknesses of materials used in the wall layers, inches or metres

k_1, k_2, k_3 = Thermal conductivity of materials, BTU·in/h·ft²·°F or (W/m·K)

Table 4-1: Calculation of total resistance

Item	Thickness, in	Resistance (R), ft². h.˚F/BTU	Thickness, m	Resistance, m².K/W
F_o	15 mph (velocity)	1/6=0.166	25 kmh (velocity)	1/11 = 0.0909
Cement plaster	½"	0.5/5 = 0.1	20 mm	0.017
Brick wall	18" (100 lb/ft³)	18/5 = 3.6	450 mm	0.45/0.92 = 0.489
Insulation	4" EPF	4/0.18 = **22.22**	100 mm	0.1/0.023 = **4.347**
Cement plaster	½"	0.5/5 = 0.1	20 mm	0.017
F_i	Still air	1/1.6 = 0.625		1/9.5 = 0.105
Total Resistance		**26.8110**		**5.066**

F_i = Convective coefficient of heat transfer on inner surface of wall, BTU/h·ft²·°F or (W/m²·K)

F_o = Convective coefficient of heat transfer on outer surface of wall, BTU/h·ft²·°F or (W/m²·K)

The values of resistance 'R' of various materials of construction are given in the tables in ASHRAE Fundamentals 2013, Chapter 26.

Thermal conductivity values of various insulating materials are given in ASHRAE Refrigeration 2014, Chapter 24.1.

Polyurethane board (R-11 expanded) has a thermal conductivity of 0.16 to 0.18 BTU·in/h·ft²·˚F, or 0.023 to 0.026 W/m·K.

Example

Let us consider an old type of cold storage construction for the sake of calculations and understanding.

If one wants to calculate the 'U' value accurately for a cold storage constructed of brick walls, using expanded polystyrene and finished with sand and cement plaster, the procedure is given in *Table 4-1*.

We shall take 'R' values from ASHRAE Fundamentals 2013, Chapter 26 as an example.

1. F_o or outside surface conductance = 6 BTU/h·ft²·°F (11W/m²· K) based on 15 mph (25 km/h) wind velocity; Resistance 0.166
2. ½" cement plaster outside: conductivity = 5 BTU·in/h·ft²·°F, R = 0.5/5 = 0.1
3. 18'' brick construction wall with 100 lb·/ft³ density: K = 5 BTU·in/h·ft²·°F, R = 18/5 = 3.6
4. 4" EPS insulation: K = 0.18 BTU·in/h·ft²·°F, and R= 4/0.18 = 22.22
5. 1/2'" cement plaster on inside surface of the cold room = 0.1
6. F_i or Inside surface conductance = 1.6 BTU·in/h·ft²·˚F (9.5 W/m²·K) based on still air, R = 0.625

We shall now calculate the total resistance offered by this construction, both in FPS and SI units.

For converting 'R' value from FPS to SI, the formula is:

ft²·h·°F/BTUx0.176110 = m²·K/W

An important point to be noted is that the resistance offered by the insulating material indicated in **bold** is far greater than the other resistances.

It is therefore common practice to ignore the resistances of the surface films on both sides, since their overall effect is very small. (Source: ASHRAE Refrigeration 2010, Chapter 24.1.)

With modern construction of cold storages using factory-made PUF panels, it is adequate to consider only the resistance offered by insulation panels for the sake of simplicity, and neglect other resistances especially where the insulation thickness is 100 mm or more.

Cold rooms require insulated panels; they are described in detail in Chapter 3, *Properties of Insulation Materials*, and Chapter 5, *Cold Storage Applications*.

This Chapter covers the recommended insulation thicknesses for:

1. Flat surfaces in cold storages and elsewhere using rigid PUF/PIR panels.
2. Round surfaces like pipes using closed cell rigid and flexible insulation.

Recommended Insulation Thicknesses for Cold Storages

The most important consideration is to achieve the expected overall heat transfer coefficient to ensure economic insulation thickness irrespective of the insulation material.

We have taken the reference of Standard IS 661: 2000, which gives the recommended thickness for various insulation materials for different storage temperatures at the design ambient temperature of +40°C and 50% relative humidity.

Insulation Selection in Cold Storage Design as per IS 661: 2000

Table 4-2: *Recommended R and U values for cold storage structure*

Storage Temperature Range (˚C)	Maximum 'R' Value ($m^2 \cdot K/W$) and 'U' Value ($W/m^2 \cdot K$)							
	Exposed walls		Intermediate walls		Roofs		Floors	
	R	U	R	U	R	U	R	U
-30 to -20	5.88	0.17	2.12	0.47	7.14	0.14	5.00	0.20
-20 to -15	4.76	0.21	2.12	0.47	5.88	0.17	4.34	0.23
-15 to -4	4.34	0.23	2.12	0.47	4.76	0.21	3.70	0.27
-4 to +2	3.70	0.27	1.72	0.58	4.16	0.24	3.44	0.29
+ 2 to 10	2.85	0.35	1.07	0.93	3.44	0.29	2.12	0.47
10 to 16	2.12	0.47	1.07	0.93	3.44	0.29	1.56	0.64
16 and above	0.78	1.28	0.68	1.47	0.95	1.05	0.61	1.63

Table 4-3: *Insulation thickness at different storage temperatures for exposed walls*

Storage Temperature Range (˚C)	Insulation thickness for different materials (in mm)					
	PUF/PIR	Phenolic foam	EPS	Rock wool	Glass wool	PUF/PIR Panel
-30 to -20	120	140	200	180	180	130
-20 to -15	100	110	160	150	150	100
-15 to -4	90	100	150	130	130	90
-4 to +2	80	90	120	110	110	80
+2 to +10	60	60	90	80	80	60
+10 to +16	40	50	70	60	60	50
+16 and above	10*	10*	10*	10*	10*	10*

**For manufacturing and commercial viability, insulation materials are available in 25 mm thickness, and in increments of 5 mm; PUF/PIR panels in 50 mm (minimum)*

Table 4-4: *Insulation thickness at different storage temperatures for intermediate walls*

Storage Temperature Range (˚C)	Insulation thickness for different materials (in mm)					
	PUF/PIR	Phenolic foam	EPS	Rock wool	Glass wool	PUF/PIR Panel
-30 to -20	50	50	70	60	60	50
-20 to -15	50	50	70	60	60	50
-15 to -4	50	50	70	60	60	50
-4 to +2	40	40	60	50	50	40
+2 to +10	20	20	30	30	30	20*
+10 to +16	20	20	30	30	30	20*
+16 and above	10*	10*	20*	20*	20*	10*

**For manufacturing and commercial viability, insulation materials are available in 25 mm thickness, and in increments of 5 mm; PUF/PIR panels in 50 mm (minimum)*

Table 4-5: Insulation thickness at different storage temperatures for roofs

Storage Temperature Range (˚C)	Insulation thickness for different materials (in mm)					
	PUF/PIR	Phenolic foam	EPS	Rock wool	Glass wool	PUF/PIR Panel
-30 to -20	160	180	260	230	230	160
-20 to -15	130	140	210	190	190	130
-15 to -4	110	120	170	150	150	100
-4 to +2	90	100	150	130	130	90
+2 to +10	80	90	120	110	110	80
+10 to +16	80	90	120	110	110	80
+16 and above	20*	20*	30	30	30	20*

For manufacturing and commercial viability, insulation materials are available in 25 mm thickness, and in increments of 5 mm; PUF/PIR panels in 50 mm (minimum)

Table 4-6: Insulation thickness at different storage temperatures for floors

Storage Temperature Range (˚C)	Insulation thickness for different materials (in mm)					
	PUF/PIR	Phenolic foam	EPS	Rock wool	Glass wool	PUF/PIR Panel
-30 to -20	110	130	180	160	160	110
-20 to -15	100	110	150	140	140	100
-15 to -4	80	90	130	120	120	80
-4 to +2	80	90	120	110	110	80
+2 to +10	50	50	70	60	60	50
+10 to +16	30	40	50	50	50	30
+16 and above	10*	10*	20*	20*	20*	10*

For manufacturing and commercial viability, insulation materials are available in 25 mm thickness, and in increments of 5 mm; PUF/PIR panels in 50 mm (minimum)

Summary

Table 4-7: Recommended insulation thickness at different storage temperatures, with design ambient of 40-47°C and 85-95% RH

Material	Minimum Density, kg/m³	Thickness, mm Temperature range, °C						
		-30 to -20	-20 to -15	-15 to -4	-4 to +2	+2 to +10	+10 to +16	+16 and above
Rigid Polyisocyanurate Foam	32	110	90	75	60	45	30	30
Rigid Polyurethane Foam	36	110	90	75	60	45	30	30
PU Panel for close construction buildings	40±2	120	100	80	60	60	-	-
PU Panel for green field (open area)	40±2	150	120	100	80	60	-	-
Rigid Pheonolic Foam	50	110	90	75	60	45	30	30
Expaned Polystyrene	18	175	150	125	100	75	50	50
Bonded Rockwool	48	175	150	125	100	75	50	50

Insulation Thickness for Piping

Refrigerant lines at temperatures below ambient are installed with insulation to primarily accomplish the following objectives, which guide the decision on the required thickness:

- Minimise heat gain to the internal fluids
- Control surface condensation (surface temperature should be higher than the dew point temperature)
- Control moisture
- Prevent ice accumulation on pipes
- Reduce noise
- Ensure personal safety

Since moisture is a good thermal conductor, its presence in an insulation system is highly detrimental. Refrigeration systems facing condensation may often leads to complete system failure. Even with today's high energy costs, the design thickness in most refrigeration applications is, therefore, dictated by what is needed to prevent condensation, rather than by economic payback.

Refrigeration systems typically operate in the range of +5°C to as low as -45°C. They can use a variety of refrigerants and fluids in addition to HFCs, HCFCs, ammonia, glycol, brine, and other specialty fluids. Copper, iron, stainless steel, or other piping materials may be used to carry the cooling medium.

All applications share common concerns regarding condensation control and long-term reliability, but they also have particular issues with installation, such as the required thickness, and the environmental conditions in which they operate.

Condensation on Pipes

Normally designers and installers easily understand temperatures, but moisture content in the air is in vapour form and invisible; hence, to understand the driving force for moisture to settle on piping requires understanding of the psychrometric properties of air.

Figure 4-2: Condensation on pipe

Just as temperature difference is the driving force for heat, vapour pressure difference is the driving force for vapour and leads to moisture condensation if adequate consideration is not given to this important issue.

Air at 40˚C temperature and 20% RH contains more moisture (9.24 g/kg) than at 5˚C temperature and 95% RH (5.14g/kg), i.e. nearly double.

We shall take a typical example to highlight this issue.

Example

Let us take the city of Lucknow and find out the properties at the highest and the lowest vapour pressure.

Table 4-8: *Highest and lowest vapour pressure in Lucknow*

Date	DBT, °C	WBT, °C	Dew Point, °C	RH, %	Absolute Humidity, g/kg	Vapour Pressure, mm Hg	Enthalpy, kJ/kg
18-August	32.5	29.8	29.1	82.179	26.2	30.2	99.88
13-March	28.4	14.1	1.8	17.505	4.4	5.2	32.72
Difference				64.674	21.8	25.0	67.16

Many engineers depend on RH for selection, which is incorrect. We shall illustrate similar conditions for the highest and the lowest RH.

Table 4-9: *Highest and lowest RH in Lucknow*

Date	DBT, °C	WBT, °C	Dew Point, °C	RH, %	Absolute Humidity, g/kg	Vapour Pressure, mm Hg	Enthalpy, kJ/kg
14-January	4.8	4.3	3.8	92.786	5.0	6.0	17.50
15-June	44.3	22.5	11.2	14.130	10.0	10.0	62.27
Difference				78.656	-5.0	-4.0	-44.77

It can be seen from these tables that insulation thickness selection based on the difference between the highest and the lowest RH would be incorrect. Therefore, selection should be based on vapour pressure difference or absolute humidity or dew point temperature.

The most important issue with refrigeration and air conditioning piping and ductwork is surface condensation, which not only accelerates the rate of pipe corrosion but can severely impact the health of building occupants, because it results in mould growth. Insulation used on refrigeration and air conditioning piping and ductwork must therefore prevent condensation if it is to extend the working life of the system. Apart from this, the role of insulation is to maximise energy efficiency of the system.

Correct installation is important, too. If air, which always contains moisture in the gaseous state, can get to the coolant pipe, condensation will still form. To avoid condensation, it is important that insulation is installed without air gaps.

Installation considerations should include environmental conditions during installation, time frame allotted to complete the job, and worker training.

System operation is generally continuous, so vapour drive is unidirectional. Water vapour that condenses on the pipe surface or in the insulation remains there. The vapour retarder must be continuous and effective 100 percent of the time to limit the amount of vapour entering the system.

The following are some important features of piping insulation:

- Thermal conductivity, or k-value
- Water vapor transmission properties
- Water absorption properties
- Coefficient of thermal expansion
- Moisture wicking
- Fire and smoke performance to meet building codes

For selecting the insulation thickness for piping, the thickness should be such that the surface temperature is above the dew point temperature.

Table 4-10 is a ready reckoner for finding the dew point temperature at various ambient conditions, to avoid the need to repeatedly look up air properties from a psychrometric chart.

Table 4-10: *Dew point at various RH values at ambient still air temperature from -20°C to +50°C, at standard barometric pressure (Source: BS 5422: 1990)*

Ambient temperature (in °C)	Relative Humidity (in %)									
	50	55	60	65	70	75	80	85	90	95
	Dew point temperature (in °C)									
-20	-27.7	-26.0	-25.2	-24.5	-23.7	-22.9	-22.3	-21.7	-21.1	-20.5
-15	-22.3	-21.3	-20.4	-19.6	-18 8	-18.0	-17 5	-16 7	-16.2	-15.6
-10	-17.6	-16.6	-15.7	-14.7	-13.9	-13.2	-12.5	-11.8	-11.2	-10.6
-8	-15.7	-14.7	-13.7	-12.8	-12.0	-11.3	-10.5	-9.8	-9.2	-8.6
-6	-13.9	-12.8	-11.8	-10.9	-10.1	-9.9	-8.6	-7.9	-7.2	-6.6
-4	-12.0	-10.9	-9.9	-9.0	-8. 1	-7.4	-6.6	-5.9	-5.3	-4.6
-2	-10.1	-9.0	-8.0	-7.1	-6.2	-5.4	-4.6	-3.9	-3.3	-2.6
0	-8.1	-7.1	-6.0	-5.1	-4.2	-3.4	-2.7	-1.9	-1.3	-0.6
2	-6.5	-5.4	-4.4	-3.4	-2.6	-1.7	-1.0	-0.2	0.5	1.3
4	-4.9	-3.8	-2.7	-1.5	-0.9	0	0.9	1.1	2.5	3.3
6	-3.2	-2.1	-1.0	0.1	0.9	2.0	2.8	3.7	4.5	53
8	-1.5	-0.5	-0.7	1.8	2.9	3.9	4.8	5.7	6.5	7.3
10	0.1	1.4	2.6	3.7	4.8	5.8	6.7	7.6	8.4	9.2
12	1.9	3.4	4.5	5.7	6.7	7.7	8.7	9.6	10.4	11.2
14	3.7	5.1	6.4	7.5	8.6	9.7	10.5	11.5	12.4	13.2
16	5.6	6.9	8.1	9.4	10.5	11.6	12.5	13.4	14.3	15.2
18	7.4	8.8	10.1	11.3	12.4	13.5	14.5	15.5	16.3	17.2
20	92	10.7	12.0	13.2	14.4	15.4	16.4	17.4	18.3	19.2
22	11.0	12.6	13.9	15.1	16.3	17.5	18.4	19.4	20.3	21.2
24	12.9	14.4	15.8	17.0	18.2	19.3	20.3	21.3	22.2	23.1
26	14.8	16.2	17.6	18.9	20.1	21.2	22.3	23.3	24.2	25.1
28	16.6	18.1	19.5	20.8	22.0	23.1	24.2	25.3	26.2	27.1
30	18.4	19.9	21.4	22.7	23.9	25.1	26.2	27.2	28.1	29.1
35	23.0	24.5	26.0	27.4	28.7	29.9	31.0	32.1	33.1	34.1
40	27.6	29.3	30.7	32.2	33.5	34.7	35.9	37.0	38.0	39.0
45	32.2	33.8	35.4	37.0	38.2	39.5	40.7	42.0	42.9	44.0
50	36.7	38.5	40.1	41.6	43.0	44.7	45.5	46.8	47.9	49.0

Chilled and Cold Water

ASHRAE Standard 90.1 uses the economic thickness concept to specify insulation thickness for a variety of pipe sizes and applications. Selection on this basis leads to reasonable achievement of the energy conservation objective as well. Depending upon the location of the chilled water/brine piping, additional thickness may be required to eliminate or minimise moisture condensation on the exterior surface of the insulation. The Standard should, therefore, be viewed as a guide for minimum thicknesses, and higher thickness may be necessary as per requirement.

For cold systems, avoiding surface condensation requires keeping the temperature of the exposed surface above the dew point temperature of the surrounding air. Insulation also helps by reducing heat flow to the cold pipe by effectively raising the surface temperature.

This approach is effective so long as the relative humidity of the surrounding air is below 90%. Above 90% RH, the thickness required to prevent surface condensation becomes impracticable, and other approaches are required to avoid condensation.

We shall now show calculations involved in selecting the economic insulation thickness for pipe sections.

The economic thickness is defined as the thickness which minimises the life cycle cost, which considers the initial cost of the insulation system plus the ongoing value of energy savings over the expected service lifetime, as defined in ASHRAE Fundamentals, 2014 Edition, Chapter 23.1.

Labour and installation costs increase with thickness. They increase more rapidly as layers and thickness of insulation increase. Insulation is normally applied to pipes in multiple layers for the following reasons:

1. Many times, insulation materials of sufficient thickness are not manufactured to be used as a single layer.
2. To accommodate expansion and contraction of insulation and pipe systems.

The calculations involved in deciding the insulation thickness are based on the following equation, which holds on the assumption that at steady state, the heat flux from the ambient air to the insulation surface must be equal to the heat flux from the insulation surface to the cold pipe.

$q''_{surf} = q''_{ins}$

Where

q''_{surf} = heat flux from ambient air to the insulation surface or dew point temperature

q''_{ins} = heat flux from the insulation surface towards the cold pipe

The heat flux to the insulation surface can be written as:

$q''_{surf} = h \cdot (T_{amb} - T_{surf})$,

where h = overall heat transfer coefficient

Similarly, the heat flux from the insulation surface can be written as:

$q''_{ins} = k/t \cdot (T_{surf} - T_{cold})$,

where k = thermal conductivity of insulation material

and t = thickness of insulation layer

T_{surf} = surface temperature after insulation or dew point temperature

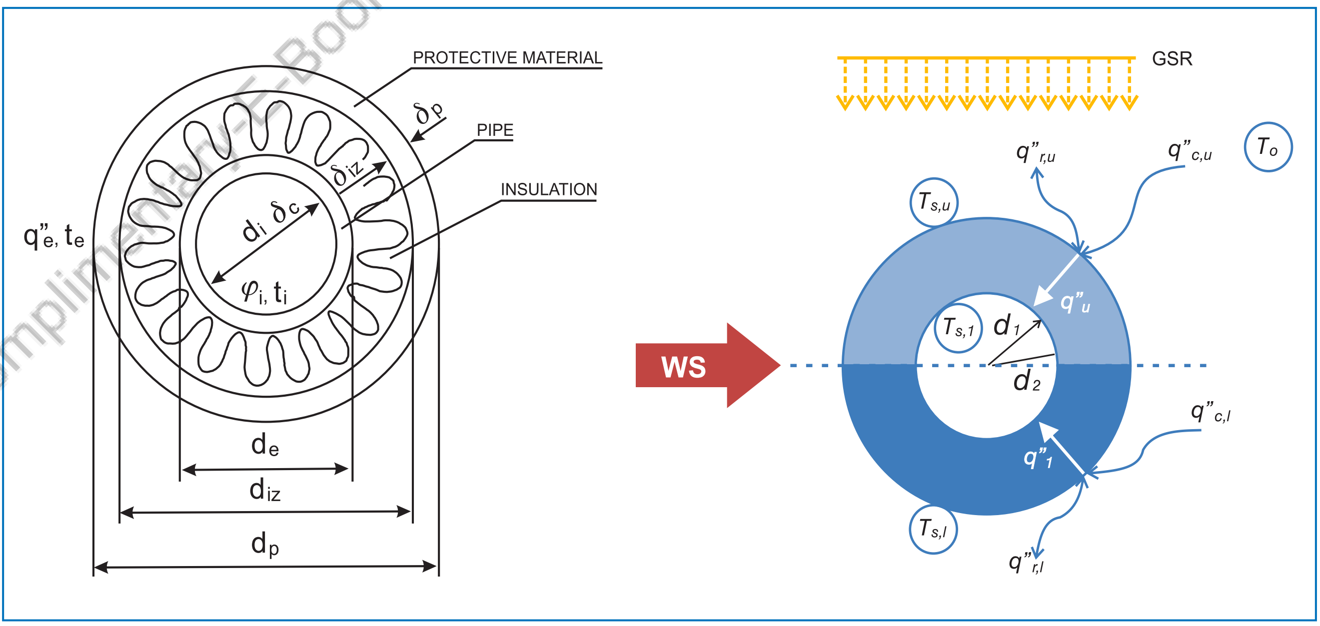


Figure 4-3: *Cross-section of insulated pipe*

T_{cold} = pipe temperature or fluid temperature inside the pipe

T_{amb} = ambient dry bulb temperature

So that

$h \cdot (T_{amb} - T_{surf}) = k/t \cdot (T_{surf} - T_{cold})$

Rearranging,

$$t = \frac{k}{h}\left(\frac{T_{dp} - T_{cold}}{T_{amb} - T_{dp}}\right)$$

$t = (k/h)\ (T_{surf} - T_{cold})/(T_{amb} - T_{surf})$

To prevent condensation, the surface temperature should be greater than the dew point temperature. In other words,

$t > (k/h) \cdot (T_{dp} - T_{cold})/T_{amb} - T_{dp})$

Where T_{dp} is the dew point temperature of ambient air.

So, the designer should know these parameters:

1. k: Conductivity of insulation material, 0.032 W/m·K at 23°C mean temperature
2. h: Surface heat transfer coefficient, 6.81 W/m²·K
3. T_{amb}: Temperature conditions of ambient air
4. T_{cold}: Temperature of fluid inside the pipe
5. T_{dp}: Dew point temperature

We give below a typical calculation for the city of Lucknow, with the following data:

1. Ambient temperature: 43.3°C
2. Corresponding wet bulb temperature: 22.8°C
3. Dew point temperature: 12.4°C
4. Pipe surface temperature: 5°C, assuming a chilled water pipe in the first case
5. Pipe surface temperature: -20°C, assuming a liquid ammonia pump circulation system for spiral freezer in the second case

The above calculations are based only on the minimum thickness required to avoid condensation. However, the actual recommended thickness depends upon several other factors such as heat gain, ease of application, rigidity, and environmental damage.

Table 4-13 gives the recommended thickness for various piping diameters at different temperatures.

Table 4-11: *Insulation thickness required for avoiding condensation in chilled water applications*

Ambient temperature	°C	43.33
Cold surface temperature	°C	5.00
Outside heat transfer coefficient	W/m².°C	6.81
Insulation thermal conductivity	w/m.°C	0.04
Outside DB	°C	43.33
Outside WB	°C	22.80
Dew point	°C	12.40
Required thickness, minimum	mm	1.53

Table 4-12: *Insulation thickness required for avoiding condensation in a liquid ammonia pump circulation system*

Ambient temperature	°C	43.33
Cold surface temperature	°C	-20.00
Outside heat transfer coefficient	W/m².°C	6.81
Insulation thermal conductivity	w/m.°C	0.04
Outside DB	°C	43.33
Outside WB	°C	22.80
Dew point	°C	12.40
Required thickness, minimum	mm	6.66

Table 4-13: *Recommended thickness for various pipe diameters at different temperatures at 38°C ambient temperature for PUF and PIR (Source: ASHRAE Refrigeration Handbook)*

Nominal Pipe Size, mm	Pipe Operating Temperature, °C					
	+5	-7	-20	-30	-40	-50
	Insulation Thickness, mm					
15	25	40	40	50	50	65
20	25	40	50	50	65	65
25	25	40	50	50	65	65
40	40	40	50	50	65	65
50	40	40	50	65	75	75
65	40	40	50	65	75	75
75	40	50	65	75	75	90
100	40	50	65	75	90	90
125	40	50	65	75	90	100
150	50	65	75	75	90	100
200	50	65	75	90	100	115
250	50	65	75	90	100	115
Vertical Flat Surface	50	75	90	100	120	140

Nitrile Rubber Insulation

Table 4-14 to *4-17* give the insulation thickness for nitrile rubber insulation for vessels and pipes.

Table 4-14: Nitrile rubber insulation thickness for vessels

Vessel Type	Temperature, °C	Minimum Insulation Thickness, mm	Nominal Insulation Thickness, mm
Water chiller	+5	39.0	41
Brine flooded chillers	-10	66.4	70
Brine chillers	-20	84.0	89
Ammonia flooded L.P. vessels	-40	117.9	125
Inter-stage vertical coolers for two-stage compressors	-15	75.3	77

Table 4-15: Nitrile rubber insulation thickness for pipes

Pipe Size, mm	Minimum Insulation Thickness, mm	Nominal Insulation Thickness, mm
Piping at -40°C		
25	52.5	56
50	59.7	64
75	64.8	70
100	68.1	70
150	72.8	73
200	76.3	79
250	78.9	79
Piping at -30°C		
25	46.7	48
50	53.0	57
75	57.3	59
100	60.1	63
150	64.4	66
200	67.1	70
250	69.2	70
Piping at -10°C		
25	33.6	34
50	37.8	38
75	40.7	41
100	42.4	45
150	45.0	45
200	46.6	48
250	47.8	48
Piping at +5°C		
25	21.9	25
50	24.4	25
75	25.9	32
100	26.9	32
150	28.1	32
200	28.9	32
250	29.4	32

Table 4-16: Nitrile rubber insulation thickness for vessels in coastal areas

Vessel Type	Temperature, °C	Minimum Insulation Thickness, mm	Nominal Insulation Thickness, mm
Water chiller	+5	48.4	50
Brine flooded chillers	-10	79.5	83
Brine chillers	-20	99.5	100
Ammonia flooded L.P. vessels	-40	137.7	138
Inter-stage vertical coolers for two-stage compressors	-15	90.0	100

Table 4-17: Nitrile rubber insulation thickness for pipes in coastal areas

Pipe Size, mm	Minimum Insulation Thickness, mm	Nominal Insulation Thickness, mm
Piping at -40°C		
25	68.2	69
50	77.8	80
75	84.7	89
100	89.2	91
150	96.0	100
200	101.0	102
250	105.0	105
Piping at -30°C		
25	60.9	64
50	69.4	70
75	75.4	77
100	79.4	80
150	85.5	88
200	89.5	91
250	92.8	96
Piping at -10°C		
25	44.6	45
50	50.6	51
75	54.7	56
100	57.3	59
150	61.0	64
200	63.8	64
250	65.8	70
Piping at +5°C		
25	30.2	32
50	34.0	34
75	36.4	38
100	37.9	38
150	40.0	41
200	41.4	45
250	42.4	32

Equivalent Thickness for Different Insulation Materials

Different insulations materials can achieve similar insulation effect if their thickness is selected appropriately. *Figure 4-4* and *4-5* give comparisons of insulation thicknesses required to achieve the same degree of insulation.

Application of insulation on vessels and pipes will be covered in Chapter 6, *Industrial Applications.*

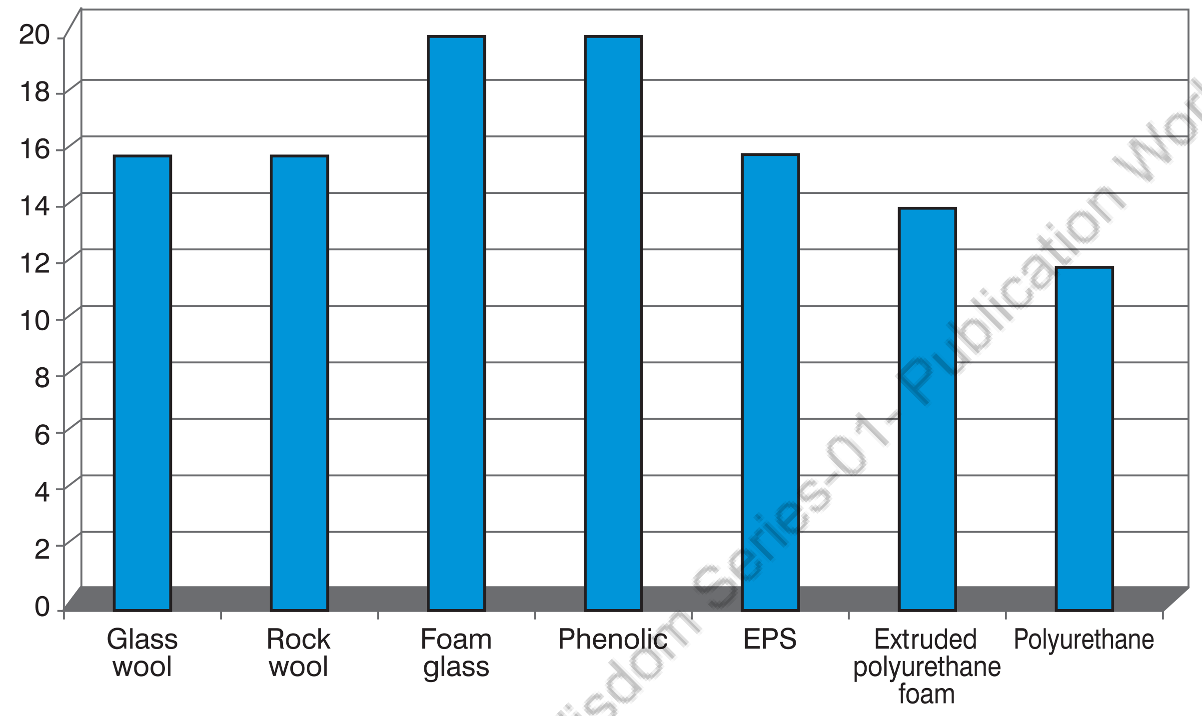


Figure 4-4: *Thickness requirement comparison between insulation materials*

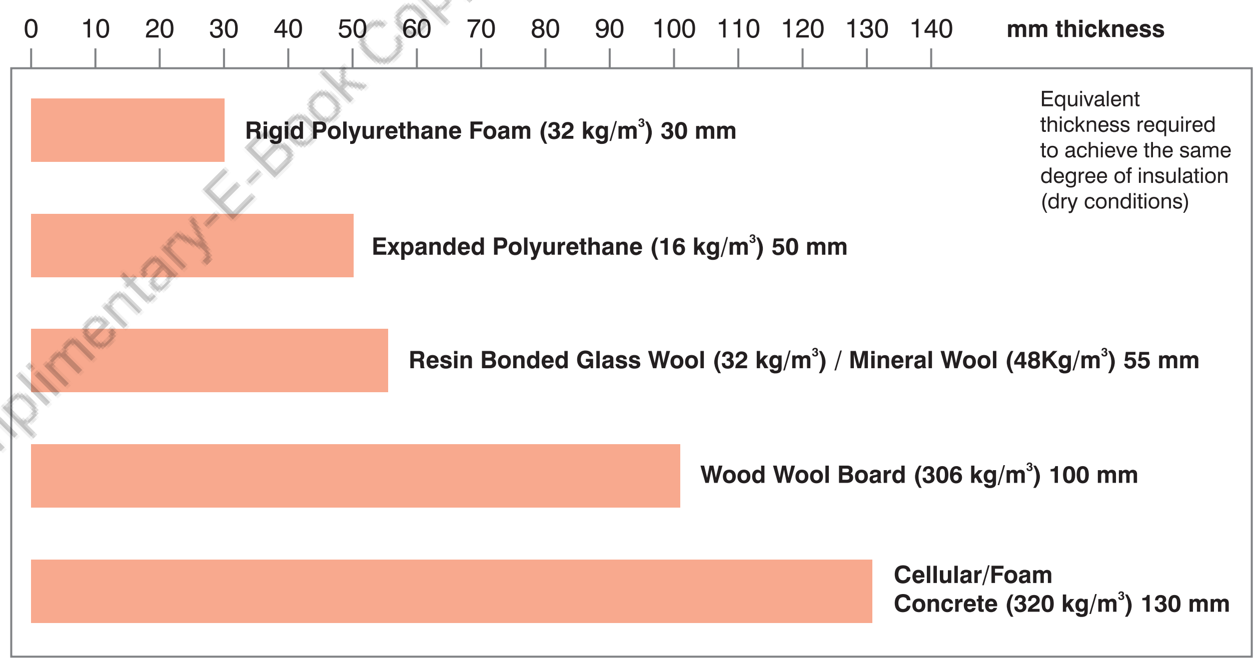


Figure 4-5: *Equivalent thickness required to achieve the same degree of insulation*

PART 2

APPLICATIONS

CHAPTER 5

Cold Storage Applications

In cold storage operations, the refrigeration system brings down the temperature initially during start-up, but thermal insulation maintains the temperature later on continuously. Therefore the importance of insulation is paramount in cold storage design.

Insulation serves two major purposes:

1. Preventing heat flow from outside to inside due to temperature difference.
2. Preventing moisture/vapour flow from outside to inside due to vapour pressure difference.

Besides proper design of the cold storage building, in order to reduce heat ingress, it is essential to provide insulation for the walls, roof and floor. It is estimated that approximately one third of all cold storage heat gain is due to transmission through the insulated envelope.

Characteristics of Cold Storage Insulation

The desired characteristics of insulation for cold storages are:

1. Low thermal conductivity/high thermal resistance.
2. Low thermal diffusivity.
3. Low moisture permeability and retention.
4. Fire resistance, preferably fire rated.
5. Light weight but with sufficient rigidity and structural strength.
6. Compressive strength, especially for load bearing floor insulation.
7. Durability – stability and long life.
8. Ease of application – easy to cut, quick to install, easy to clean.
9. No significant emission to impact the environment.
10. UV resistance.
11. Hygienic and inherently rust proof.
12. Rodent and pest proof.
13. Light external surface colour, high reflectivity, low radiation absorption.

Table 5-1: *Important characteristics for selection of insulation material*

Abbreviation	Property	Unit	Relationship to Insulation Value
k	Conductivity	W/m·K	Lower is better
C	Conductance	$W/m^2 \cdot K$	Lower is better
R	Resistance	$m^2 \cdot K/W$	Higher is better
D	Thermal diffusivity	m^2/s	Lower is better
ε	Low permeability	Perm	Lower is better

Resistance to Heat Flow

Thermal insulation resists the flow of heat by acting as a barrier. The most effective insulation material provides maximum resistance and is defined by a particular 'R' value, which depends upon its thermal conductivity value and thickness. The lower the thermal conductivity and the higher the resistance value of an insulation material, the more effective it is.

Further, adequate density of the insulation material is also important for material selection. Higher density increases the heat capacity of the material and results in a lower thermal diffusivity value.

A material with low diffusivity value will be able to maintain a constant temperature or lead to a slow rise in temperature inside a building in a situation when internal cooling is not working due to some reason.

Economical Thickness Design

Cooling of the cold storage space in hot climates consumes significant amounts of energy, which can be conserved with the help of thermal insulators. It is necessary to conduct a life-cycle cost (LCC) analysis over a period of 10 years to find out the thickness of insulation that would result in a cost-effective selection. The following example is based on the National Horticultural Board (NHB) cold room design document for potato cold storages.

More insulation would lead to less energy consumption and higher saving in running cost, although the initial investment would be higher.

For NHB size cold rooms, using the equation for heat ingress through transmission,

Q = U x A x ΔT = U x 2 (21x16+21x13.7+16x13.7)

Energy savings by using optimum thickness are shown in *Table 5-2*.

Table 5- 2: *Energy savings using optimum insulation thickness*

Insulation Thickness, mm	U Value, W/(m²·K)	Cooling Load, kW
80	0.023/0.080 = 0.2875	20.356
100	0.023/0.100 = 0.23	16.284
120	0.023/0.12 = 0.1966	13.57
Saving in 4 rooms with 120 mm insulation instead of 80 mm		20.356 - 13.57 = 6.786 X 4 = 27.1

Annual saving in Rupees:

27.1 kW x 7 Rs/kW x 20 hours running per day x 300 days = Rs11,38,200

However, insulation thickness cannot be increased indefinitely, as there are economic factors to consider such as the cost of insulation v/s energy cost of refrigeration.

As explained in Chapter 4, as the insulation thickness is increased, there is higher energy saving in transmission load requirements. However, one has to keep the cost also in consideration and provide insulation thickness that is optimum, i.e. energy efficient as well as cost saving.

Resistance to Moisture Ingress

In order to understand the behaviour of moisture/vapour in the air, we need to look at the psychrometric chart and understand some basic air properties such as relative humidity, absolute humidity (humidity ratio), dew point temperature, air velocity and vapour pressure.

Psychrometric Chart

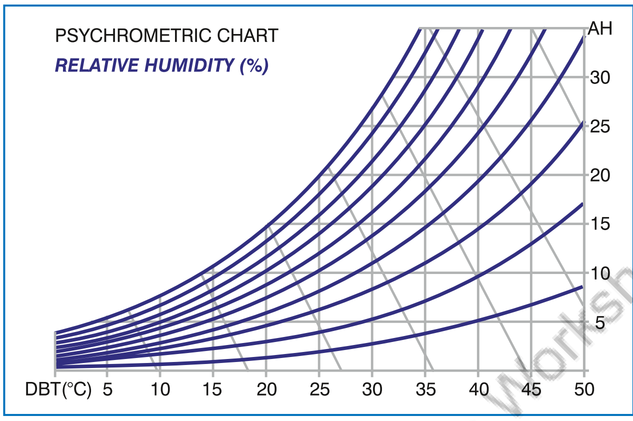


Figure 5-1: *Psychrometric chart*

Table 5-3: Properties of air

Temp., °C	Relative Humidity, %	Absolute Humidity, g/kg of dry air	Partial Pressure of Water Vapour, Pa
40	25	11.59	13.86
5	85	4.60	5.56
-20	95	0.60	0.73
-40	95	0.075	0.019

It is the general perception that higher relative humidity means more moisture content, but it is not true. If we look at the properties of air (*Table 5-3*), we notice that air at 5°C and 85% RH has less moisture content of 4.6 gm/kg_{da}, as against 11.59gm/kg_{da} at 40°C and 25% RH.

If we consider a positive temperature cold storage for vegetables and fruits, the inside temperature is normally maintained around 5°C with RH higher than 85%, at the outside condition of 40°C with 25% RH.

The vapour pressure in the outside air would be 13.86 Pa as against the inside vapour pressure of only 5.56 Pa, i.e. less than half, and water vapour would therefore try to penetrate through the building construction material or insulation inside the cold room.

In cold storages that operate at much lower temperatures of -20°C or blast freezers operating at -40°C, the difference in vapour pressures is still higher, as can be seen from *Table 5-3*, which becomes a driving force for water vapour to enter the cold storage.

For understanding the moisture content in the outside and inside air, we should therefore always consider absolute humidity values and not relative humidity.

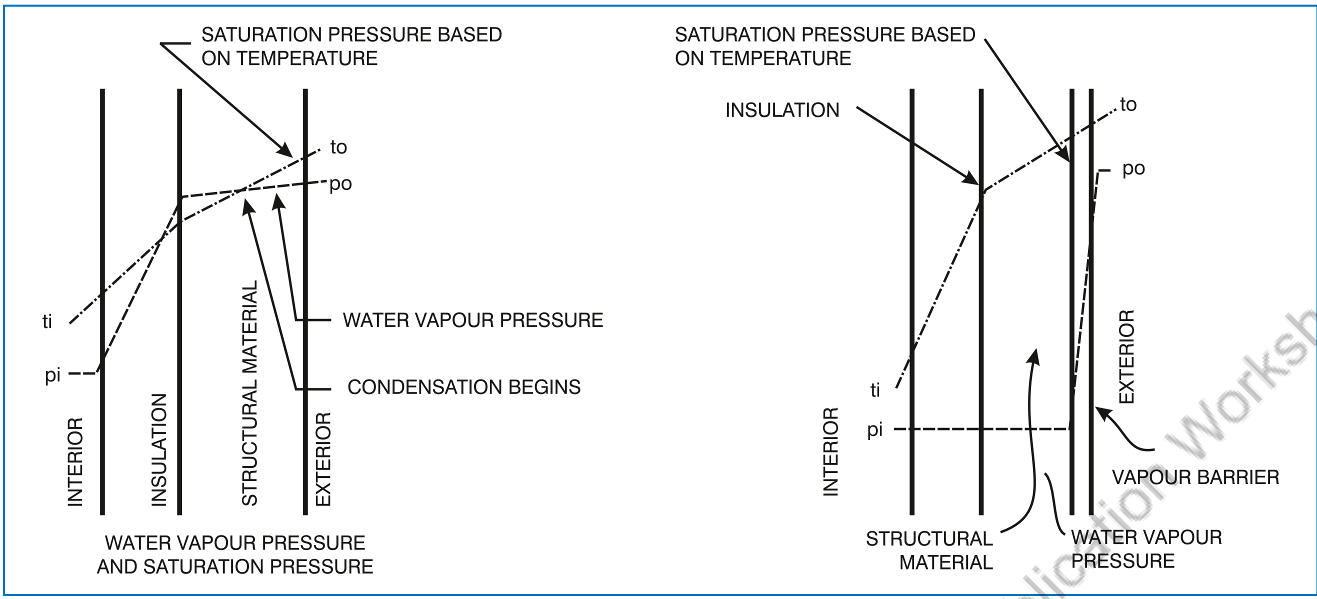


Figure 5-2: *Water vapour pressure and saturation pressure*

Vapour or moisture in superheated condition is a transparent, tasteless and odourless gas capable of permeating through most materials depending on the pressure differential between the two sides of the insulation. *Figure 5-2* illustrates this aspect.

In Chapter 1, we had touched upon the importance of moisture prevention. We shall now explain this aspect in detail, since it is of vital importance for cold storages.

The designers of comfort air conditioning plants are normally less concerned with the moisture penetration aspect as the temperature/vapour pressure differences between outdoor and indoor are comparatively small and thus moisture penetration through the structure is not a major consideration unlike cold storages.

As heat flows from higher temperature to lower temperature, similarly, water vapour migrates from higher water vapour pressure area to lower water vapour pressure area (higher dew point temperature to lower dew point temperature). The moisture content in the atmosphere, termed as humidity, needs to be assessed as to the maximum and minimum levels. Along with moisture, presence of wind is also important as it plays a role in diverting or blowing away moisture in the air. In addition, heat incidence on the roof and walls can be altered by wind.

Most designers consider only the temperature difference between ambient and inside conditions to reduce heat gain for deciding the thickness of the insulation to be provided. But humidity and wind velocity parameters also need to be considered for thickness calculation.

Temperature, being a measurable parameter, can easily be monitored. Designers do not pay enough attention to preventing moisture penetration. Since moisture ingress is invisible, it is normally overlooked but it can affect cold room performance adversely.

It is important to understand that the insulating property of insulation material is mainly due to the trapped air bubbles formed while manufacturing the insulation, and not the material itself. If these air cavities get filled with moisture, the insulating property is nearly lost, and wet insulation is therefore ineffective as water is a good conductor of heat.

If insulation retains the moisture, it also acts as a breeding ground for bacteria and promotes fungus growth besides losing its insulating properties. If there is excessive moisture, it may drip on the product and contaminate it.

Effect of Moisture Ingress on Energy Consumption

It is important to be aware that 1 kg of dry air to be cooled by 1°C requires only 1.004 kJ of heat energy, whereas to condense 1 kg of water vapour to 1 kg of water we require 2,500 kJ/kg, i.e. nearly 2,500 times more energy. To convert this condensed water further to 1 kg of ice, we need additional energy of approximately 334kJ/kg.

Hence, nearly 3,000 times more energy is required to get rid of 1 kg of moisture compared to cooling 1 kg of air by 1°C. A considerable amount of refrigeration plant capacity is, therefore, wasted if water vapour enters the cold room and gets converted to water by condensation or ice by freezing.

Insulation Efficiency

Moisture severely impacts thermal resistance of the insulation material; 1% moisture ingress leads to 5% reduction in thermal resistance.

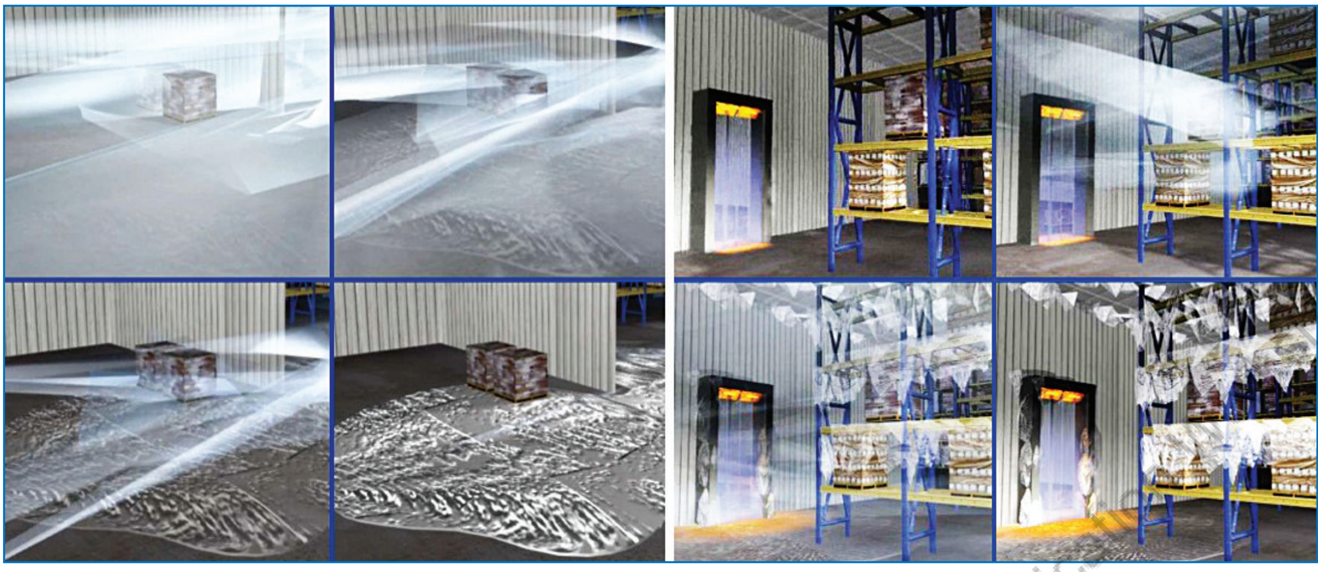


Figure 5-3: *Excessive ice in cold storage due to ineffective vapour barrier*

Moisture and Vapour Barriers/Retarders

In rating the effectiveness of a vapour barrier, two terms, viz. permeability and permeance, need to be understood. These terms are explained in Chapter 2, *Important Formulæ.*

1.0 US Perm = 1 grain/square foot/per hour/per inch of mercury vapour pressure difference

= 57 ng/m²/s/Pa.

Permeability of water through a vapour barrier is expressed in Metric Perms in the metric system. A Metric Perm is the passage of 1 gram of water through a material with a surface area of 1m² for 24 hours and a pressure difference of 1mm Hg.

The primary concern in the design of a low temperature facility is the vapour retarder system.

The insulation envelope must be impermeable to water vapour in order to prevent its migration from the warm ambient environment to the cold space. Failure to prevent this migration results in condensation of water on the interior of the refrigerated space, and ice formation. It also adds to refrigeration load, leading to higher energy bills.

In case of a cold storage, insulation vapour retarder or barrier is required on the inner side or cold side also, as moisture is present inside the cold chamber.

Vapour barrier is the material that tries to prevent transfer of water vapour across the barrier, which could be any external surface or an internal surface of the cold storage envelope such as a wall, roof, ceiling or flooring.

The pressure exerted by water vapour is directly proportional to the quantity of water vapour present, and vapour in the outside air at higher pressure will tend to penetrate/migrate to the area of lower vapour pressure existing in the cold storage. When this vapour is cooled in the cold storage instead of room it condenses and in case of negative temperature cold storage it gets converted to ice. The presence of water inside the cold storage is detrimental as it weakens the insulation and its heat prevention ability, and adds considerably to the refrigeration requirement with increased power consumption and product deterioration in many cases. So, there is a need for a vapour barrier on the inside surface also.

Figure 5-3 illustrates the condition observed in many cold storages that in fact deserve to be called ice manufacturing factories rather than cold storages. There is a lot of ice everywhere – on the coils, floor and walls; even opening a door becomes impossible as it is jammed with ice.

Aluminium foil has a permeability of 0.05 US perm or 2.9 SI perm. Aluminium foil is typically less than 150 μm in thickness. Foils are available in gauges as low as 6.3 μm. Heavier foil gauges (> 17 μm) provide an absolute barrier to gases and liquids. A typical water vapour transmission rate (WVTR) for 9 μm foil is 0.3 g/m² per 24 hours at 38°C and 90% RH. As thickness is reduced, the foil becomes more vulnerable to tearing or pin-holing.

Although one perm sounds very small, it is not good enough for cold storage applications. The recommended vapour retarder perm rating is 0.01 or finer, provided on the warm side of the insulation.

The test methods to measure water vapour permeability are as per ASTM Standard E96. Materials are classified for permeability as follows:

Class I: 0.1 perm or less

Class II: more than 0.1 perm but less than 1.0 perm

Class III: more than 1.0 perm but less than 10.0 perm

Types of Vapour Retarders

Plastic Coatings or Thin Fluids

Examples of materials in this category are fire retardant mastics, asphalt, bituminous emulsions and polymer resins. These types of vapour retarders are applied on the exterior surface of insulation, usually before the insulation is installed.

Sealing Sheets

The examples of this category include asphalt paper, plastic sheets, glass cloth and metal films. Metal films like aluminium foil are inexpensive and excellent vapour barriers, but are difficult to install and it is impossible to make a fool-proof seal without considerable punctures occurring. In addition, if applied to walls directly, there is a possibility of corrosion. Polyethylene installation becomes comparatively easy due to the reduced number of joints and overlapping, and bonding wherever required. Also, polyethylene is quite stretchable before fracture occurs, unlike metal foil. This characteristic is highly desirable in a cold storage vapour barrier in order to absorb building movement without rupture. It should also be noted that two thin layers of film are not as good as one thick layer, since the former has twice as much chances of failure of the vapour barrier and requires double the labour, seals and joint overlaps.

It is also important to install the vapour barrier with proper overlaps and sealed joints without any puncture to get a vapour and air tight envelope. Failure of the vapour retarder system is almost always due to poor installation. The contractor must, therefore, be experienced enough to ensure a vapour tight cold room.

Table 5-4: *Water vapour transmission rate (Source: Typical Permeance Values for Selected Materials – IARW* 1995)*

Material	Perm Value
Concrete block, 8” thick	2.4
Exterior grade plywood, ¼” thick	0.7
Hot melt asphalt, 2 oz/ft²	0.5
Reinforced concrete slab, 8” thick	0.4
Polyethylene film, 0.20 mm thick	0.04
Polyethylene film, 0.25 mm thick	0.03
Metal foil – aluminium	0.3
Urethane foam, R-141b/n-pentane blown	0.4 to 1.6
Polystyrene foam, extruded	0.2

**IARW: International Association of Refrigerated Warehouses*

No vapour retarder system can be 100% effective. A properly designed vapour barrier system is one in which the rate of moisture infiltration, if at all present, is equal to the rate of moisture removal by the refrigeration plant without detectable condensation.

It is strongly recommended that cold storage owners/consultants and contractors seriously consider the important aspect of providing a proper vapour barrier while designing and constructing cold storages, otherwise even a well-designed refrigeration plant may not deliver the desired performance.

Many materials that are moisture resistant are not necessarily vapour resistant. All insulation materials are susceptible to water vapour penetration in various degrees. If penetration is not prevented, water vapour condenses to moisture or ice when its temperature reaches the dew point. This will, in time, saturate the insulation thereby rendering it useless. To prevent this from taking place, a vapour barrier must be applied on the warm side of the insulation.

Even a pin-hole through the vapour barrier can eventually render the insulation system useless; therefore, the selection of a vapour barrier needs careful consideration. Foils and sheets usually have better permeability rating, but a foil has poor resistance to mechanical damage and needs a protective cover or laminate. Sheet metal has a good rating but requires considerable care in the sealing of joints and fastenings.

The design of the cold insulation system should assume that at some time a breakdown of the vapour barrier might occur. In such an event, and in the case of cold rooms, it is better that the water vapour has an unhindered path to the cold surface to enable it to be drawn off by the refrigeration equipment. In the case of pipe work and vessels, it is preferable that the water vapour has free passage to the cold surface where the resultant water or ice will be encased by the insulation. However, there can be chances of pipe corrosion in the long run. In order to prevent corrosion, proper mastic/cold adhesive must be used.

A break in the vapour barrier of the insulation system will eventually cause the system to fail, but its effective life would be prolonged by a design that permits through transmission of water vapour.

Condensation occurs when water vapour in the atmosphere comes in contact with a surface at a temperature less than or equal to the dew point temperature. Therefore, if the surface temperature is less than the dew point, condensation will occur.

The presence of condensation on the warm side of the vapour barrier has no detrimental effect on the insulation; nevertheless, it is a situation to be avoided. To prevent condensation, the insulation thickness should be so designed that the temperature on the warm side of the vapour barrier is above the dew point.

Insulation Materials for Cold Storages

Conventional Cold Storages

Conventionally, cold storages were constructed with RCC frames, brick or concrete walls and RCC slabs for roofs, and expanded polystyrene or fibreglass insulation was stuck to the walls from inside.

Figure 5-4: *A cold storage with conventional design*

In conventional cold storages with brick/ concrete construction, where insulated sandwich panels were not used, it was necessary to provide a proper vapour barrier/retarder on the warmer side of the walls before applying insulation. Due to the conventional method of fixing insulation through wooden gutty, the vapour barrier used to get punctured and some moisture would then enter from outside through the vapour barrier into the layers of insulation.

The inside surface in such cases should, therefore, never be made vapour tight, otherwise moisture would accumulate and get trapped in the insulation and spoil it.

The inside surface should be made in such a manner that it can breathe freely. This would ensure that whatever moisture has entered the insulation is carried to the cooling apparatus and is subsequently removed while defrosting the coils.

Consequently, a vapour tight impermeable finish can also be provided on top of the insulation to stop moisture ingress from inside, which can form ice with the passage of time that can be cleaned if required, without damaging the insulation in the long run.

This aspect is generally overlooked due to the preference for sanitation of the inside surfaces of the rooms and ease of maintenance. This leads to trapped moisture in the insulation, severely affecting the efficacy of insulation.

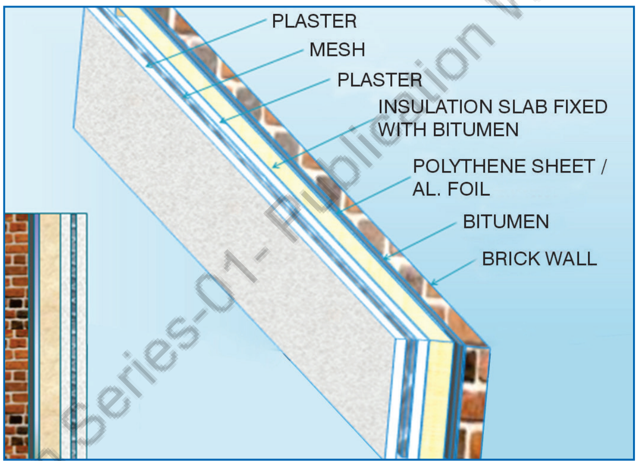


Figure 5-5: *Components of cold storage wall construction*

All components of construction must work together to achieve a system that will enclose the space and hold it at the desired temperature for extended periods of time without any deterioration. For instance, it is recommended that any lumber incorporated into cold storage construction be pressure treated with a wood preservative.

Installation contractors should be aware of unsealed openings around electrical conduits and equipment hangers, structural cracks and poorly constructed joints at the wall such as ceiling lines and construction joints. Warm air can infiltrate the storage area through these imperfections, compromising the environment. When warm, moist air enters a freezer room, it can cause rapid build-up of ice, which may force movement of the structure.

The construction must be tight so that there is no air movement through the structure from the outside to the inside of the room. Air seals and vapour barriers can be located in cold storage rooms. The movement of water vapour must be restricted by the use of vapour barriers or by the vapour barrier characteristics of EPS rigid foam insulation. The placement of air seals and vapour barriers in the construction is imperative to reduce the possibility of leakage.

We shall now discuss various insulation materials used in cold storages maintained at different temperatures.

Expanded Polystyrene

In earlier days, expanded polystyrene (EPS) insulation board was the favourite insulation material for use in walls and roofing systems in the construction of cold storage space. These facilities store food, flowers and other temperature-sensitive commodities. The temperatures range from normal room temperature, viz. 20°C, to cryogenic temperatures of -100°C. As surface temperatures decrease, the quality of construction and sustainability requirement become more critical.

The performance properties of EPS, including constant thermal resistance, dimensional stability, chemical inertness and sustainability, make it well suited for use as insulation. Additionally, its closed-cell structure provides minimal water absorption and low vapour permeance, an important design consideration for damp environments.

Cold storage insulation is normally applied in two or more layers with joints staggered between layers and boards tightly butted. EPS boards must be firmly and permanently bonded to walls, ceilings and roofs using adhesives. The first layer of floor insulation is bonded to the sub-slab, while the second layer is installed dry. Thicker coatings of heavy-bodied adhesives may be used to provide some straightening or bridging on an irregular wall surface. Adhesives are applied to provide 100 percent contact and to fill any voids. Spot or strip applications of adhesives are used only where a vapour or air barrier is installed.

Polystyrene has the following characteristics:

- Light petrochemical beads/globules are compressed and cured with steam.
- Expanded polystyrene has permeable faces and extruded polystyrene has partially/easily damageable impermeable faces.
- It has low temperature ratings (70°C maximum).
- It has high manufacturing/embodied energy.
- It has low density.
- Extruded polystyrene is still primarily imported.
- It is primarily a cold climate product.

PUF/PIR Foam Boards

Typically, the foam is created or cut into blocks, ideal for wall insulation. The foam is flammable and needs to be coated in a fireproofing chemical called hexabromocyclododecane (HBCD). HBCD has come under fire recently for health and environmental risks associated with its use.

The current trend is in favour of polyurethane foam (PUF) or polyisocyanurate foam (PIR) sheets as compared to polystyrene, since the former have better insulation performance. Further, expanded polystyrene and polyurethane foam are self-extinguishing, and polyisocyanurate foam is Class O rated.

However, when selecting a suitable insulation material, the temperature gradient and material cost

Figure 5-6: *Application of EPS to floor*

Figure 5-7: *Application of EPS to wall*

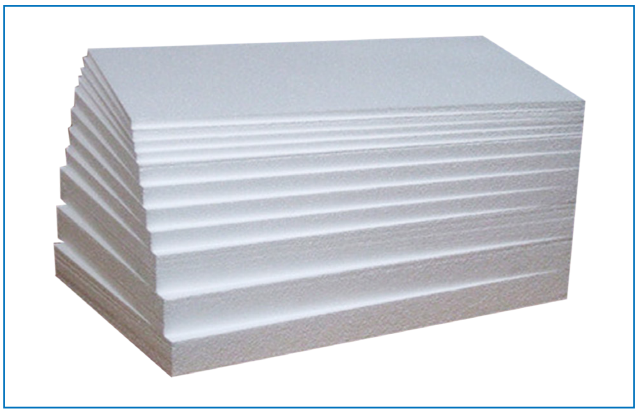


Figure 5-8: *Polystyrene foam boards*

also need to be factored in. Polystyrene is a more cost-effective insulation compared to PUF and PIR. Since a cold room is not expected to experience large temperature gradients, polystyrene might be able to achieve the required performance at a lower cost, making it a practically superior method of insulation especially in case of a cold storage building constructed out of brick/cement structure.

With the advent of EPS sandwich panes with metal lamination having tongue-and-groove joints, the application of insulation in civil constructed cold rooms has become easy, giving neater surface finish compared to conventional multiple layer EPS board insulation for walls and ceilings. EPS/PUF sandwich panels are highly recommended for prefabricated cold/freezer rooms due to their faster installation and elimination of civil work.

Selection of proper insulation material with low k-value is very important.

For example, transmission load with 100 mm EPS (0.043W/m·K) insulation is nearly double the transmission load with 100 mm PUF or PIR (0.021 to 0.023 W/m·K) insulation.

The present trend is, therefore, to construct almost all cold storages with PUF panels on pre-engineered building (PEB) steel structure.

Prefabricated Sandwich Panels

With the advent of EPS sandwich panels – with metal lamination having tongue-and-groove joints – and continuous panels, the application of insulation in civil constructed cold rooms has become easy, giving neater surface finish compared to the conventional multiple layer EPS board insulation for walls and ceiling. EPS/PUF sandwich panels are highly recommended for prefabricated cold/freezer rooms due to their faster installation and elimination of civil work.

Due to energy efficiency and ease of installation, prefabricated sandwich panels are nowadays predominantly used in refrigerated facility designs. The external as well as internal metal surface of the panel acts as a vapour retarder. When using prefabricated panels, care should be taken to ensure continuous and uninterrupted joints between panels, and they should be vapour sealed including all the joints between walls and ceiling and between walls and floor. Panel joints must also be able to survive the differential movement between two panels and the sealant used must have sufficient elasticity to tolerate this movement without breaking down. When the inside temperature is brought

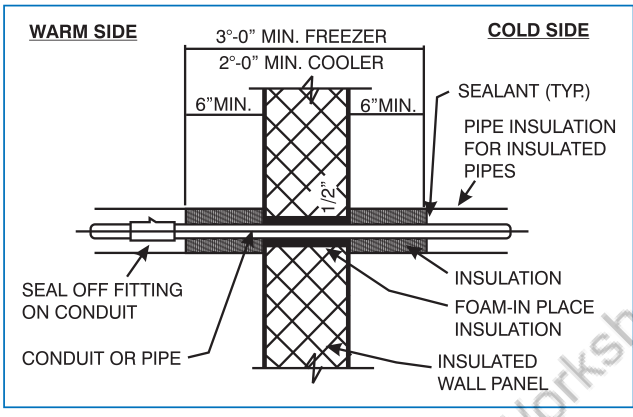


Figure 5-9: *Insulated metal panel wall penetration detail*

down, the chamber contracts and the panel joints bear the pressure and becomes more air tight. The panel joints are typical tongue-and-groove type.

The current practice is to construct cold storages from pre-insulated PUF or PIR panels, which is a best practice to reduce heat ingress as well as moisture penetration.

Vapour Barrier Leakage Test

To ensure adequate vapour seal for cold storages, especially for controlled atmosphere cold storages for produce like apples and many other low temperature applications, they are tested by pressurising the room to about 1" (25.4 mm) water column with a blower, sealing it up, and recording the pressure decay rate. If the pressure drops rapidly, the leaks can be patched up before the cold room is put to use.

This test is best run as soon as the vapour barrier is installed.

It must be remembered that in actual practice, no vapour barrier system is perfect and some localised leaks are bound to occur. The 'fail safe' system is one that provides a highly efficient vapour barrier on the warm side of the insulation with a porous insulation interior finish. This allows any vapour that manages to penetrate the vapour barrier to pass to the coils without any intermediate vapour dams to cause condensation within the insulation system.

Cold storages that are not constructed from PUF panels and use the conventional method of construction should use film type vapour barriers. The film should be wide and with few joints. Polyethylene applied from 20 ft wide rolls and lapped 12" at joints provides nearly fool proof vapour barrier.

Although the laboratory perm rate of polyethylene is higher than that of aluminium foil, the installed performance is far superior with polyethylene due to the reduced number of joints compared to aluminium. Polyethylene is quite extensible – up to 700% – before fracture occurs. This characteristic is highly desirable in a cold storage vapour barrier in order to absorb movement without rupture.

Advantages of Modular Construction with PUF/PIR Sandwich Panels

1. The foremost advantage of modular construction is that it provides the best possible thermal insulation value achievable. PUF sandwich panels save 30 percent in the recommended insulation thickness compared to EPS, due to the lower k value of PUF.
2. Overall construction period is reduced to a great extent.
3. The inside environment becomes hygienic and resistant to attack by fungus and rats. According to available data, this leads to 30 percent saving of the stored products.
4. The possibility of deposition of any kind of impurities over the panels or holes being created by rats is ruled out.
5. Cleaning and washing of the panels is very easy. The panels are maintenance free.
6. Fire-safe cold storages can be constructed with fire-rated PIR panels.
7. Such systems have been in use in India for more than twenty years now.

Insulated panels are available in two varieties: with cam locks, or continuous self-locking. Continuous panels are normally preferred for tall cold storages to avoid joints.

IS 661, which is under revision presently and will be issued in a new version shortly, recommends insulation thicknesses for various insulating materials. However, it does not include PUF sandwich panels. The NHB standard covers both conventional and modern insulation panel systems, and recommends 100 mm thick panels for walls, roofs, ceilings and floors having PUF density of 40 kg/m^3, for -4°C to +2°C cold storages.

Cold Storage Doors

Doors play a large role in the ability to sustain the appropriate temperature. The frequency of door opening and closing is of greater concern than the size of the door. Operational guidelines should be established to expedite the loading and unloading of product in the cold storage. Forklift truck operation and other mechanical systems allow quick opening and closing of doors with mechanical or remote operators. The investment on doors can result in energy savings by reducing the amount of heat transfer. Holding areas with regular doors outside the cold storage can also help reduce the flow of warm air into the cold area.

Horizontal slide manually operating doors include an FRP frame door panel with a foamed-in-place polyurethane core of 4” to 6” thickness, having R value between 26 and 40, vertical casings and headers constructed from moulded plastic polymer (MPP), and heavy-duty hardware and tracks with corrosion resistant coating. The door includes high density guide rails with 1/8” thick neoprene rubber seal around the perimeter of the door opening and cloth reinforced neoprene rubber bottom sweep gasket capable of providing a gas tight seal. Door track is heat treated with extruded aluminium. Each door panel is suspended with two heavy duty 1-1/4” wide x 4” diameter permanently lubricated polyurethane rollers. Each roller has two sealed ball bearings with a capacity of 700 lbs. per roller, attached to 1/2” thick steel hanger brackets. Freezer doors include 115V AC perimeter and bottom-of-door heat cables to prevent gaskets from freezing, heavy duty under-panel track and a panel gasket system.

The door panel is clad with the customer’s choice of metal. Door frame and trim is constructed from FRP. Door casings and track supports are constructed from moulded plastic polymer (no cladding is required). All hardware and mechanisms should be protected against corrosion by galvanising or some other approved method. Doors should be complete with all the components required for installation. Doors with provisions for locking should have safety release hardware on the opposite side. Lock opening knobs should be available on both sides.

In general, any type of cold storage door should have the following technical specifications:

Door Specifications

1. The insulation of the doors should be the same and comparable in value with the cold storage wall insulation.
2. The door should be sturdy, due account being taken of its size.
3. Where possible, the door should be located on the external (warm) side of the cold storage insulation.
4. Suitable gaskets should be provided to form a seal around the door opening.
5. Heater tapes or other suitable heating devices

should be incorporated in the door edge and/or frame reveals and the floor below the door in order to avoid build-up of ice or condensation on cold storages operating below 0°C.

6. Different types of cold storage doors:
   a) Manual hinged
   b) Manual sliding
   c) Automatic sliding
   The sliding doors can be:
   i) Horizontal sliding (one- or two-leaf)
   ii) Vertical sliding
7. Smooth opening and closing of doors should be ensured. Large doors should be supported by a sub-frame independent of the insulating panels.
8. The integrity of the insulating envelope should be maintained when door frames are fitted.
9. Door handles should be located so that their use does not distort the door.
10. Door reveals should be constructed in a manner that avoids cold tracking and the consequent formation of moisture or ice.
11. Equipment for doors operating below 0°C should have appropriate gears, and special consideration should be given to the position and sealing of electrical controls.
12. Compressed air supplied for pneumatically operated doors should be adequately dry so that ice does not form in the air supply pipe work.
13. Automatic doors should open and close promptly.
14. The door threshold should be designed to accommodate the expected traffic and to make due allowance for variations in temperature.
15. Automatic doors should incorporate a safety device to avoid injury to personnel or damage to the product in case of accidental closure.
16. The lock on an automatic door should isolate the drive mechanism when the door is locked.
17. All doors required as means of escape should be easily and immediately operable from the inside at all times. Doors that operate automatically are not acceptable as means of escape unless they have a manual override and can be opened manually in the event of a power failure.
18. Protection barriers should be provided to avoid damage to the door track, door and reveals. The barriers should be securely fixed to the floor. The design of the barriers should allow for their simple removal and repair.
19. Floor guide brackets should be strong enough to hold the door firmly against the jambs when the door is closed and should be so located that they cannot be damaged by the normal use of product handling equipment.
20. Strip curtains or other means may be provided at door openings to reduce ingress of warm air.
21. Emergency doors should be provided with emergency lighting illuminated exit signs.

Figure 5-10: *Range of hinged and sliding doors*

Figure 5-11: *Manually opening single frame door*

Figure 5-12: *Vertical lift doors*

Figure 5-13: Horizontal sliding doors with safety guard

Controlled Atmosphere Stores

The walls, ceilings and partitions of Controlled Atmosphere (CA) Stores are generally constructed of insulated composite structural panels with core insulation of polyurethane or polyisocyanurate foam. The insulated panels are generally 1 to 1.2m wide and in single piece, and are extended from the floor to the ceiling and held together by fasteners and a fixing system. All the joints are sealed with polyvinyl acetate co-polymer, latex emulsion sealer or similar sealing compound for achieving a total gas seal. Special consideration should be given to sealing of all joints for maintaining a gas tight enclosure. In this case also, the walls and ceiling need to be provided with coatings of suitable sealing compounds/polymers.

The floor should also be made gas tight by providing a gas seal of hot mopped asphalt roofing felt or equivalent materials in the sub-floor. It can also be achieved by applying special materials such as chlorinated rubber compounds to the top surface of the floor. In both cases, wall-to-floor sealing of joints is most likely to fail and should be given due consideration during designing and installation.

Doors and inspection windows of different designs can be used in a CA facility. In all cases, the doors are constructed of a solid frame that can be clamped tightly against the gasketed door frame without warping. They can be hinged or sliding type. In a CA cold storage using bin stacking with fork lifts, the doors are 2.4m x 3.0m high to allow fork lift movements. Each door is provided with a hatch window of size 0.6m x 0.75m, which allows entry for checking the product and making repairs without opening the main door. Many CA cold storages also have clear acrylic windows near the top of the wall, in the attic area above the ante-room, to allow inspection of the product without entering the chambers. These windows are usually concave in shape, allowing all areas of the chamber to be seen. In case of smaller capacity CA cold storages with total capacity up to 50 MT with mezzanine floors, the door size could be less.

Specifications

1. The perimeter of the plinth should be level for panel installation.
2. Panels should have cam lock or tongue-and-grove joints.
3. Sheet metal flashing should be provided on all concrete/wall-to-ceiling joints internally and externally. PVC coving or concrete curbing should be provided on wall-to-floor joints.
4. Horizontal tie bracings should be provided between vertical wall panels and external columns, to take care of wind loads.
5. Adequate number of pressure relief ports should be provided on all chambers with electrical connection.
6. Insulated doors should be suitable for panel mounting.

Insulation Retrofit in Existing Cold Storages

In existing cold storages where insulation has become ineffective, fresh insulation can be applied from outside the brick wall and plastered (polymerised). This will also prevent the brick wall from getting exposed to the atmosphere, and improve the overall efficiency. Similarly, the roof can also be insulated from outside.

Wall Revamping

Figure 5-14: Revamping of walls

Roof Revamping

Figure 5-15: Revamping of roof

If a conventional type of cold room needs to be revamped using PUF/PIR panels, it is recommended that a dummy room be constructed inside with pre insulated factory-made panels directly fixed to the main walls and in case of roof, a frame-work involving an insulated 'T' be used, so that a total moisture-proof vapour-tight box is created inside. The procedure to be followed for the wallsis:

- Remove old insulation and plastering from the surface.
- Fix prefabricated polyurethane panels – outer side with metal finish, and inner side with paper or aluminium foil finish.
- Panels should be fixed directly to the walls with self-drilling fasteners.
- Panels should be sealed with silicone sealant.

Cold Storage Details and Accessories

A cold storage should be constructed with either box-in or box-out principle, with no structural members penetrating through the insulation. The structural members act as conducting media leading to heat gain and moisture penetration, so their penetration through the insulated box should be avoided.

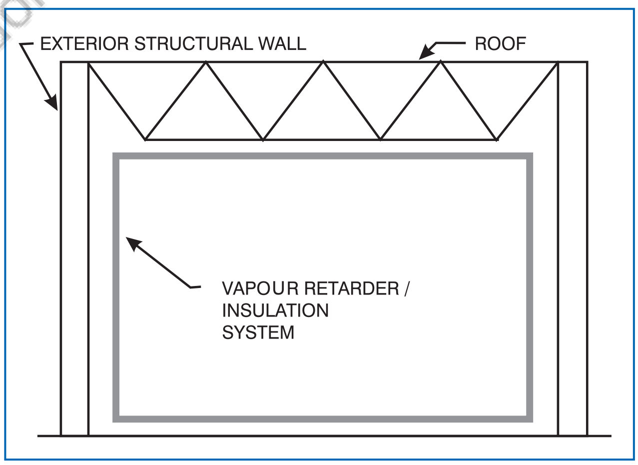


Figure 5-17: Box-in design

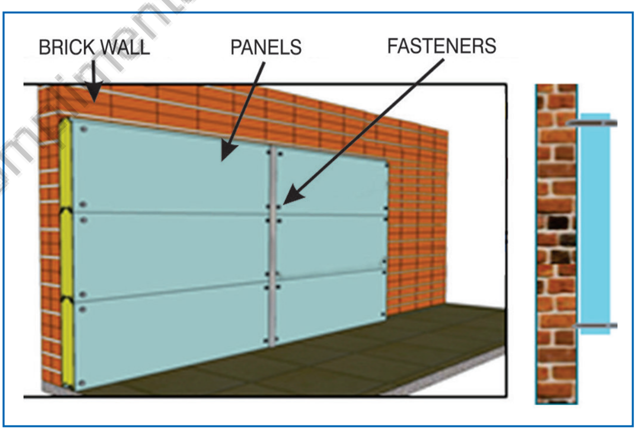


Figure 5-16: Wall revamping detail

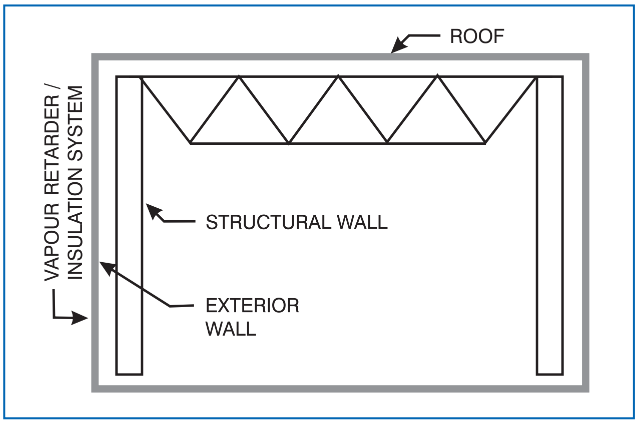


Figure 5-18: Box-out design

Installation Techniques

In addition to the selection of proper insulation material and panels, hardware selection and installation techniques are equally important. The use of right kind of hardware for fixing panels, the correct grade of silicon sealant to be used for joints, the correct way of making roof-and-wall and wall-and-floor joints need special engineering designs and application techniques.

Providing curb walls or barriers to protect insulation panels from getting damaged is essential. If not done through a skilled agency, the effort in selecting good panel material can get neutralised due to poor installation techniques and workmanship.

The selection of proper size of doors with frame, the required thickness of door insulation and most importantly its sealing with the cold room storage frame to prevent air and moisture ingress are essential but often neglected. The doors should be part of the panel and not supported from the floor. If the doors rest on the floor, due to temperature variation when the cold room panels move, the doors do not move along with the panels and a gap is crated in the sealing, leading to air leakages. The door, therefore, should move with the panel so that sealing is not disturbed. A proper door frame is important, and should come together with the insulated door. Sometimes, heating elements are required to be installed inside the frame. Heating is required when the door gets jammed from inside due to continuous cooling and icing.

Important Accessories

Pressure Equalising Relief Valves

Modern cold storages utilising PUF/PIR panel systems are usually very effectively sealed. Reduction in the inside pressure takes place within a refrigerated storage facility due to the change in temperature when cooling starts, as air volume inside the facility reduces due to the density of cold air being more than warm air. This can cause catastrophic damage to the insulated room structure if pressure equalising devices are not fitted on cold room panels. Due to the reduction of inside pressure, the panels move and get distorted, and in extreme cases the entire cold room collapses as the panels cave in.

Pressure relief valves (PRVs) are, therefore, an integral component of any such facility. Cold storage walls are subjected to the strains caused by variations in pressure, either from inside or outside. This can have an effect on the structure of the room, apart from making it difficult to open the door. We have first-hand experience of this phenomenon.

This is similar to keeping a half-filled plastic bottle in a refrigerator. The trapped air inside the bottle reduces in volume due to cooling, and since the seal cap is tight there is no way for the outside air to leak inside to equalise the pressures. When the refrigerator is opened, one can see that the bottle has caved in or collapsed.

In order to ensure that this does not happen, it is essential to provide pressure relief valves (PRVs) or ports on the insulation panels, adequately sized to ensure that they open and equalise the outside and inside pressure, preventing damage to cold room panels.

PRVs can be wall or ceiling mounted. They should always be installed by a competent person.

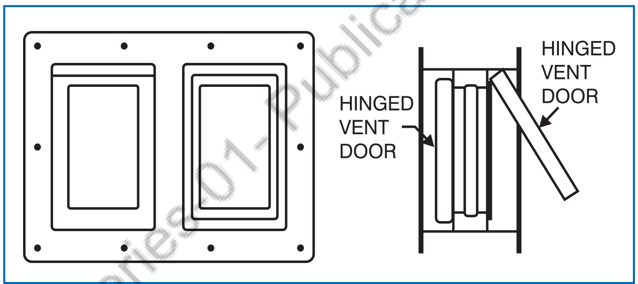


Figure 5-19: *Pressure equalising vent*

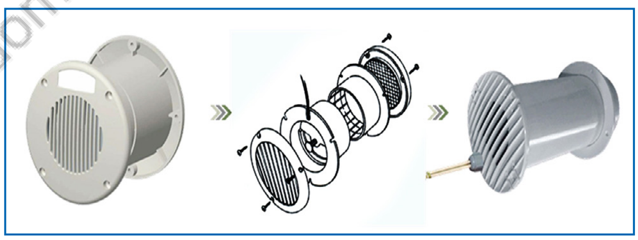


Figure 5-20: *Pressure equalising valve*

Installation Details

Installation details for various elements are depicted in *Figure 5-21* to 5-41.

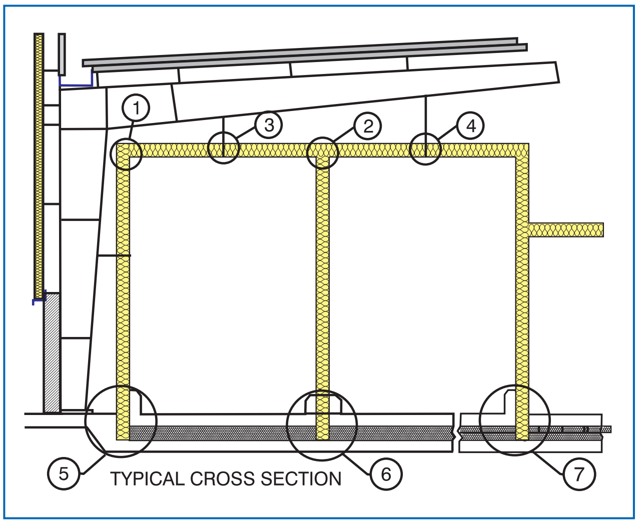


Figure 5-21: *Typical cross-sectional view of cold room*

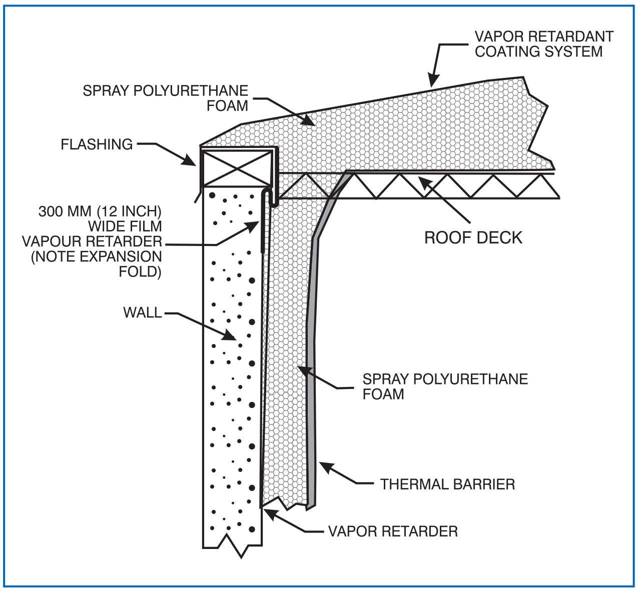


Figure 5-22: *Details of roof to wall junction*

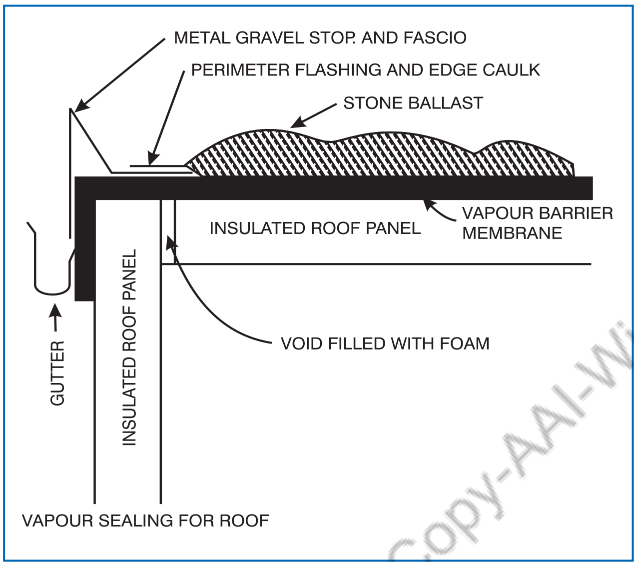


Figure 5-23: *Construction of roof with provision to prevent water falling on panels*

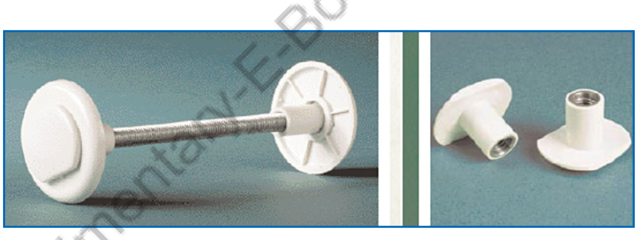


Figure 5-24: *Special screws for hanging to prevent condensation, made of nylon or galvanised steel*

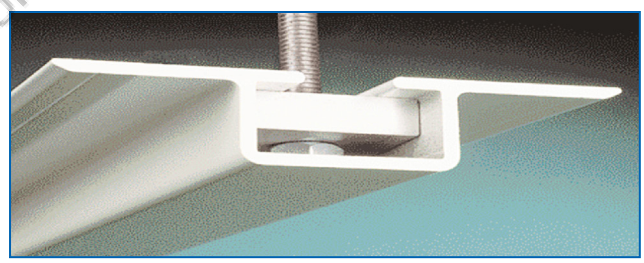


Figure 5-25: *Method of hanging roof channels*

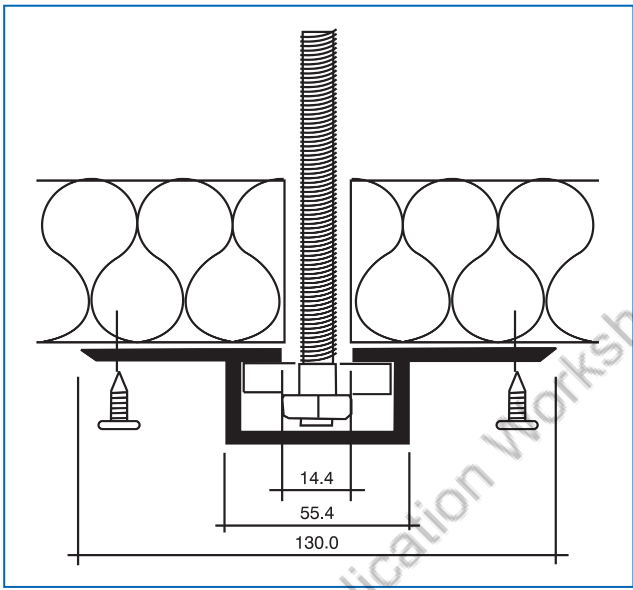


Figure 5-26: *Cross section showing roof panel fixing*

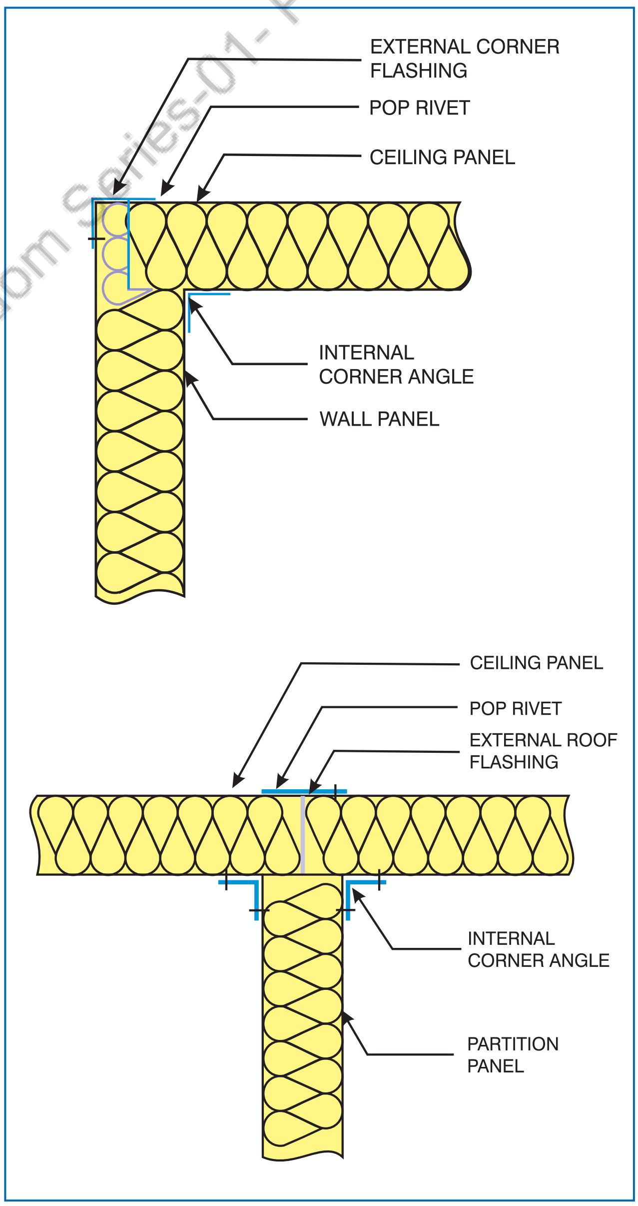


Figure 5-27: *Wall-to-wall corner and partition-to-ceiling details*

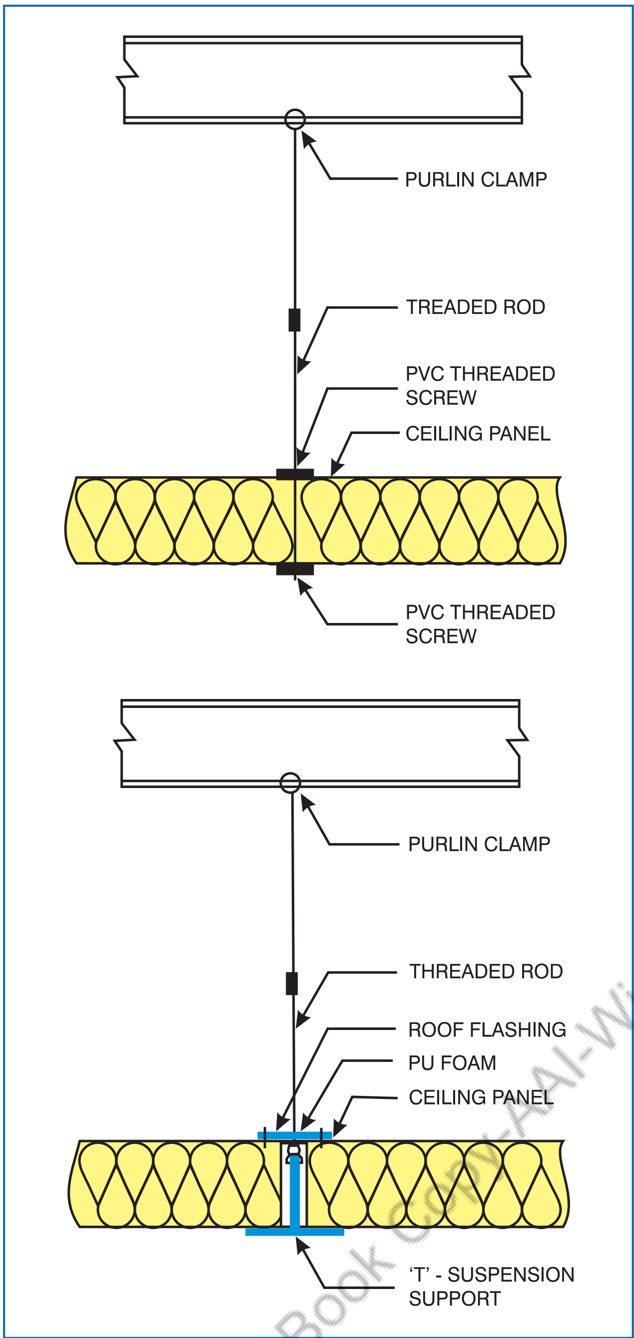


Figure 5-28: *Fixing ceiling suspended panels with PVC threaded screws*

Figure 5-29: *Curb wall of concrete to protect insulation panels*

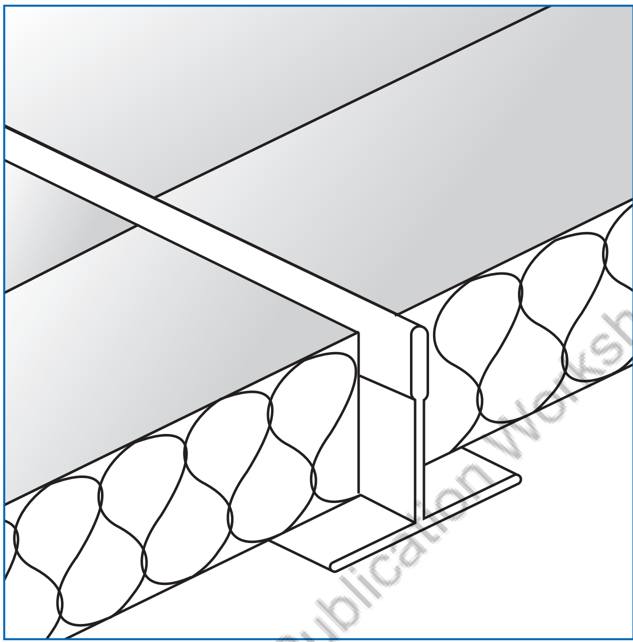


Figure 5-30: *Joining two floor panels*

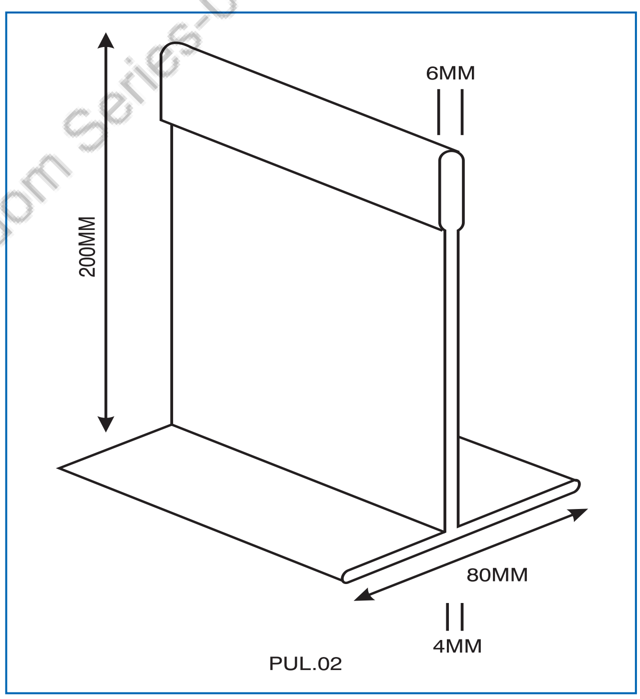


Figure 5-31: *Details of vertical divider between two panels*

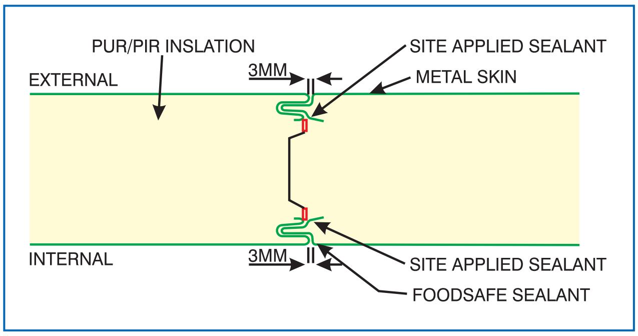


Figure 5-32: *Method of Joining two panels*

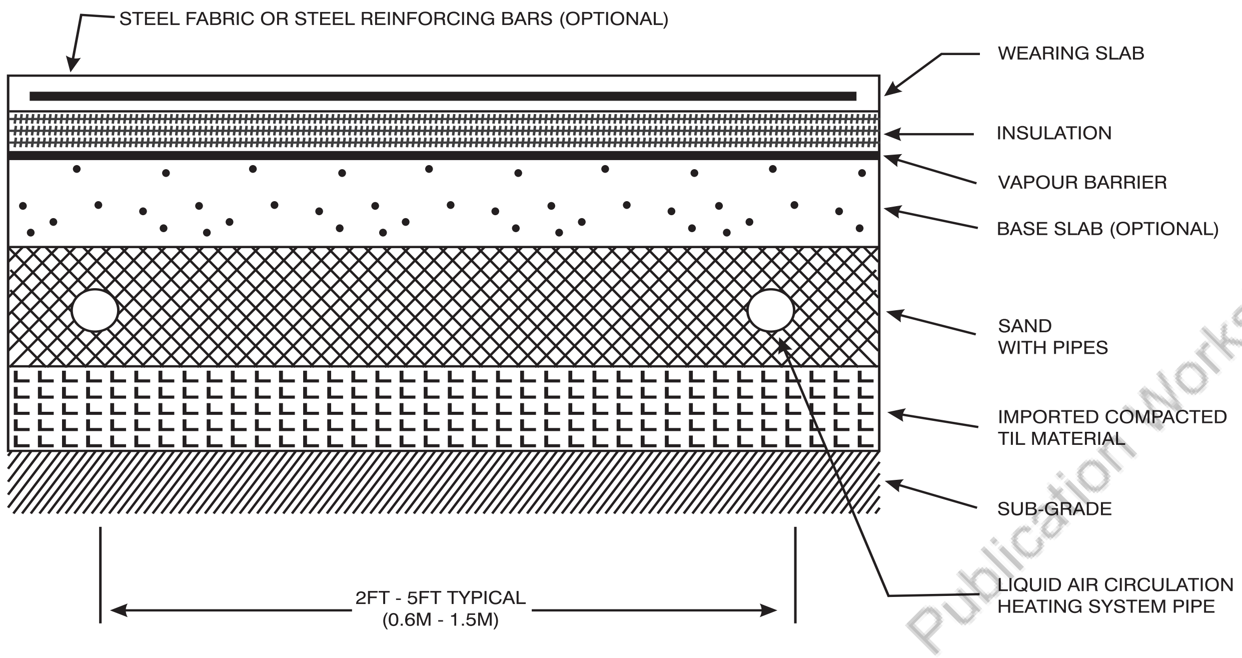
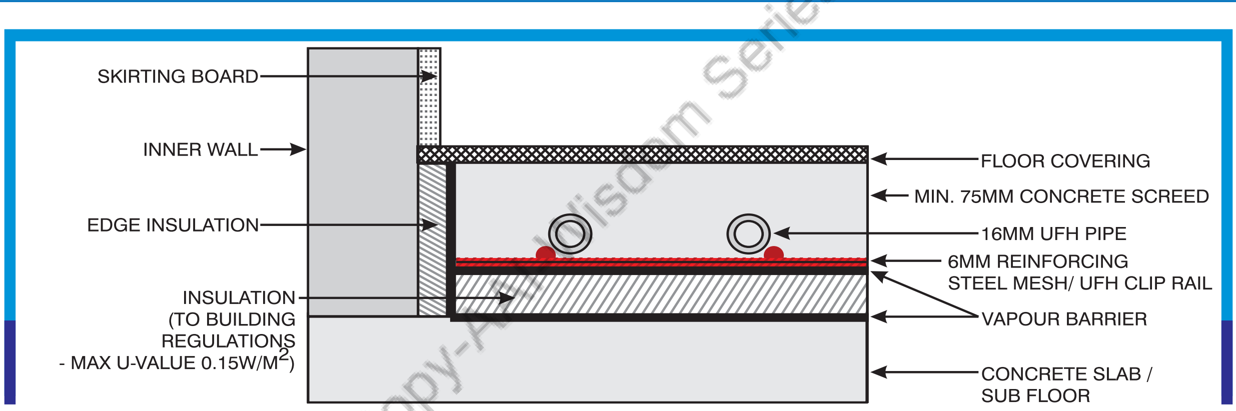


Figure 5-33: *Construction of flooring to prevent floor heaving with glycol circulation*



Notes:
Overlapping layers of vapour barrier from floor to curb
Floor insulation should have adequate compressive strength > 2.11 kg/cm²

Figure 5-34: *Another method to prevent floor heaving by providing air vents*

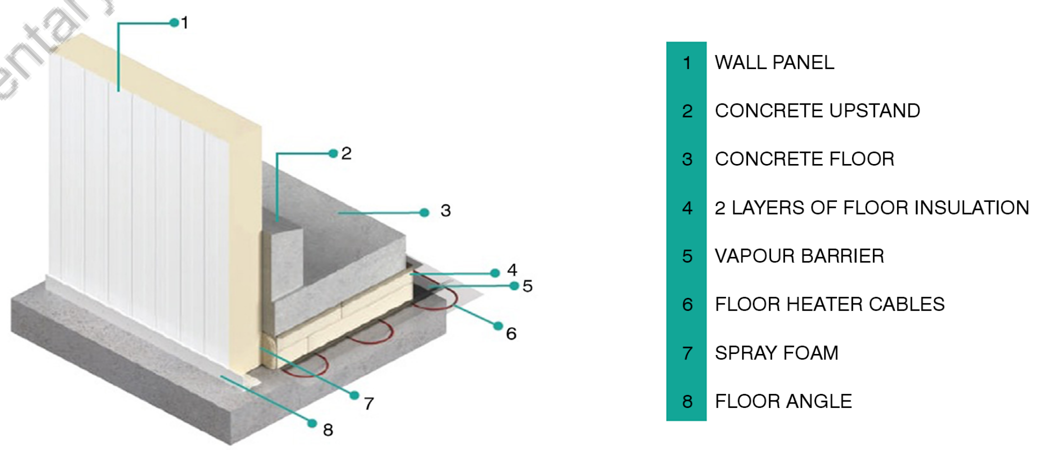


Figure 5-35: *Floor-wall junction details*

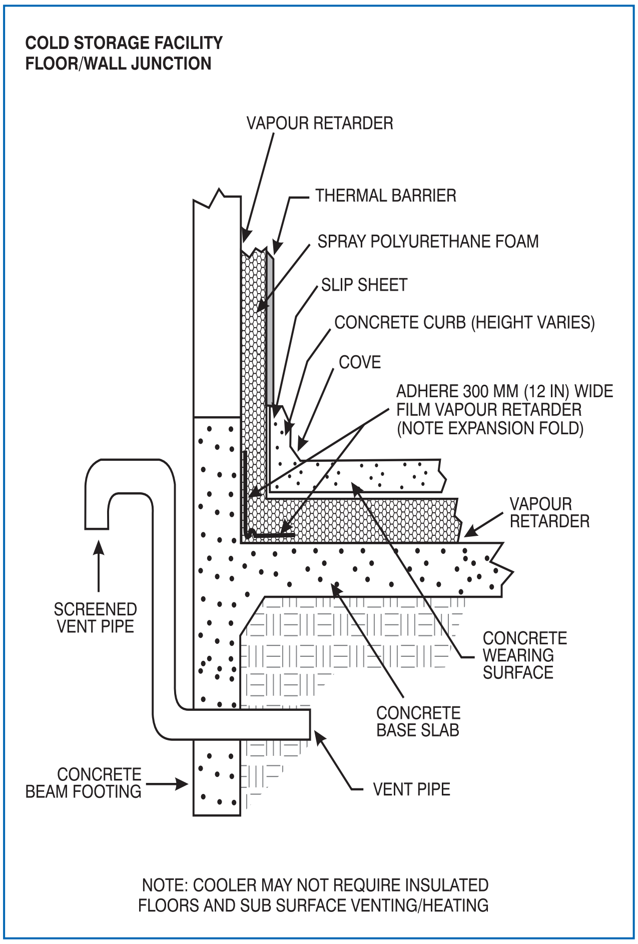


Figure 5-36: *Floor-wall joint*

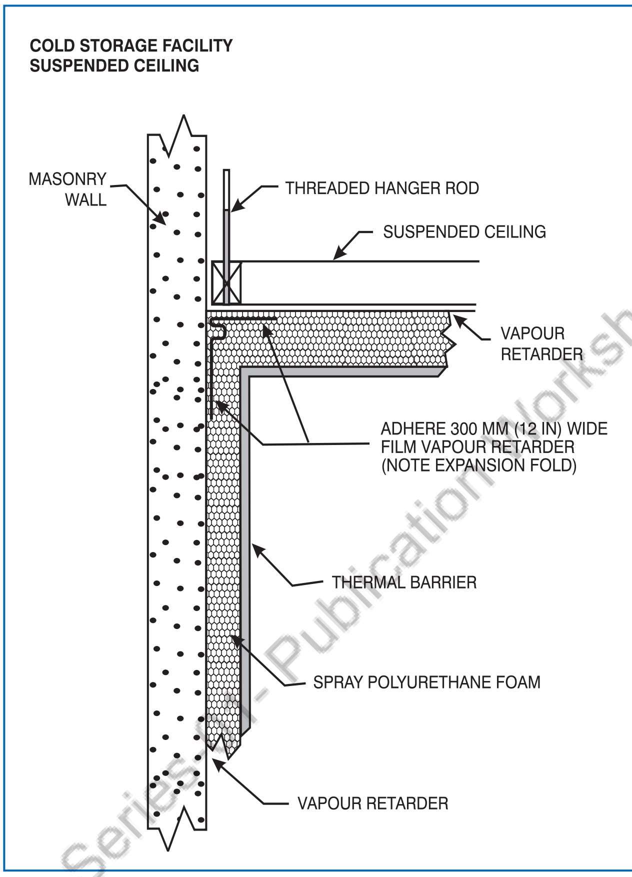


Figure 5-38: *Suspended ceiling details*

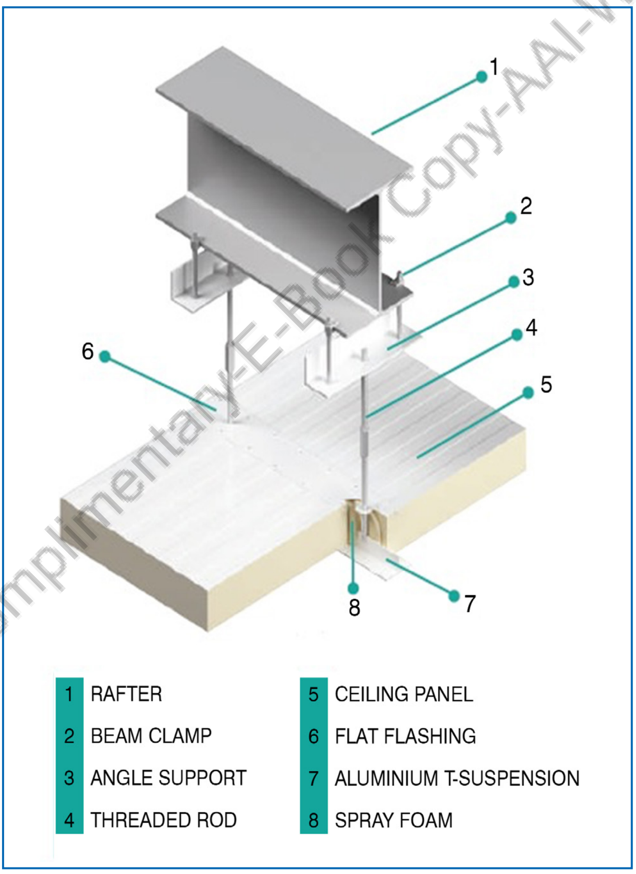


Figure 5-37: *Suspended ceiling*

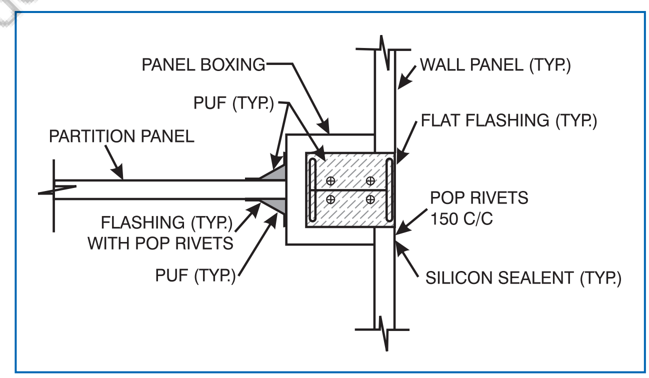


Figure 5-39: *Fixing detail of panel on wall and partition wall*

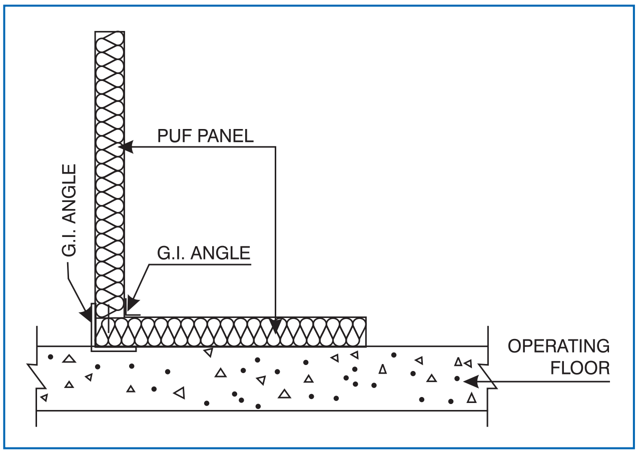


Figure 5-40: *Fixing detail of panel on floor*

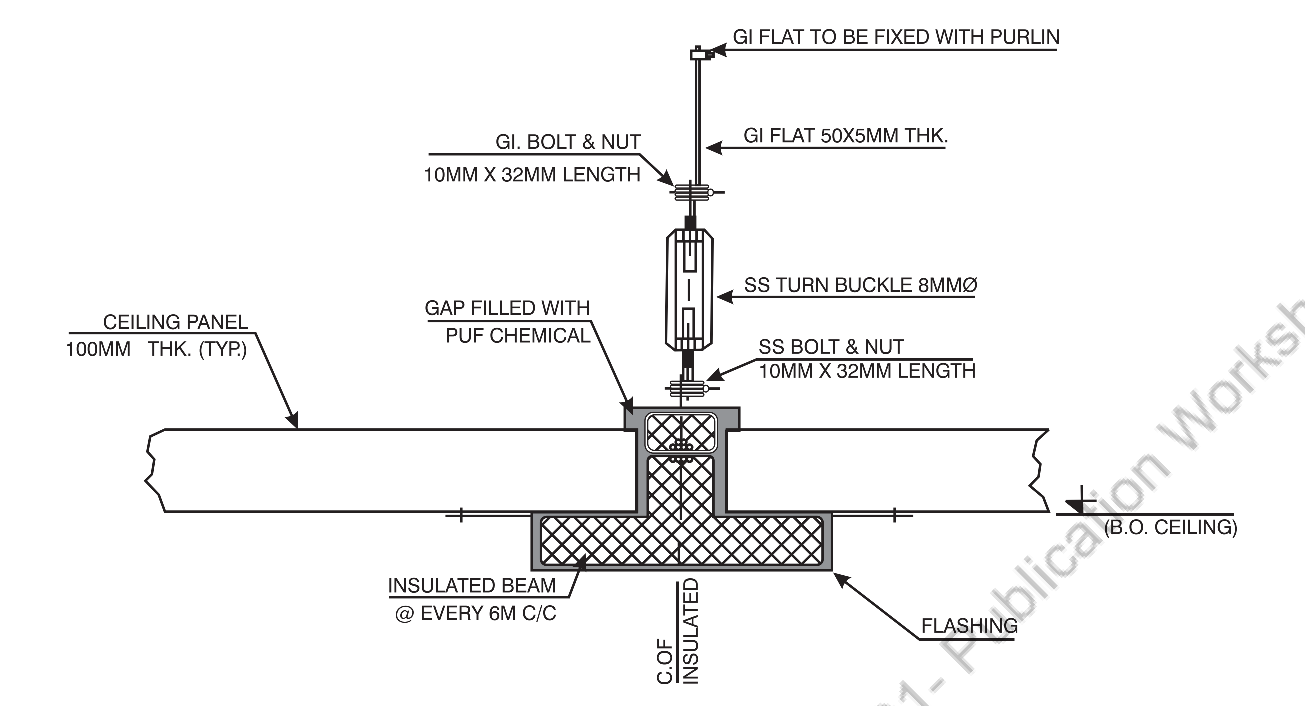


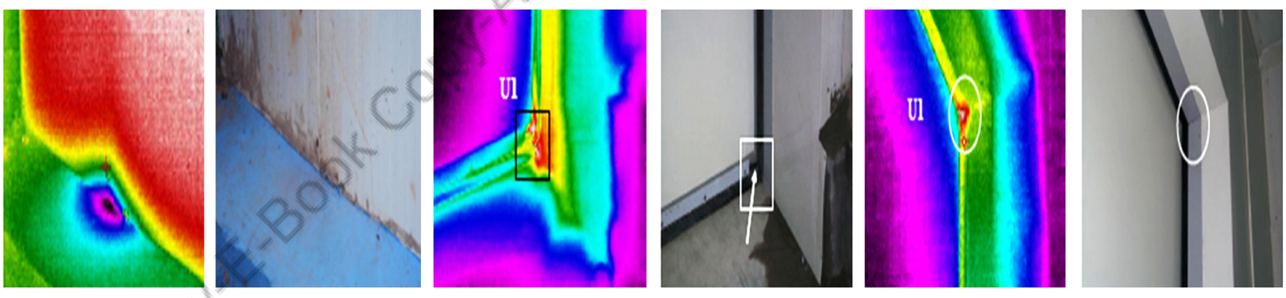
Figure 5-41: Fixing detail of panel on ceiling

Thermography

The ideal way to check whether insulation work has been done properly, there are no air leakage paths and the panel quality is acceptable, is to subject the cold room to thermography analysis.

Thermography is a technique where a camera maps temperature profiles, and from colour codes and software analysis it becomes apparent where the insulation is weak or where there are air leakages. Thermography is therefore essential to check heat leakage points.

Figure 5-42 shows some pictures that illustrate how air leakage points not visible to the eye can be captured by thermographic images.



TEMPERATURE MEASUREMENTS

LABEL	RATED VALUE (°C)	TEMP. DECREASED BY (AS PER MIN) (°C)	OUTLINED AREA TEMP. MIN. (°C)	OUTLINED AREA TEMP. AVG. (°C)	OUTLINED AREA TEMP. MAX. (°C)
U1	23	9.7	13.3	17.1	21.8

TEMPERATURE MEASUREMENTS

LABEL	RATED VALUE (°C)	TEMP. INCREASED BY (°C)	OUTLINED AREA TEMP. MIN. (°C)	OUTLINED AREA TEMP. AVG. (°C)	OUTLINED AREA TEMP. MAX. (°C)
U1	0	21.4	7.2	15.0	21.4

TEMPERATURE MEASUREMENTS

LABEL	RATED VALUE (°C)	TEMP. INCREASED BY (°C)	OUTLINED AREA TEMP. MIN. (°C)	OUTLINED AREA TEMP. AVG. (°C)	OUTLINED AREA TEMP. MAX. (°C)
U1	0	10	2.2	5.8	10.0

Figure 5-42: Air leakage points captured by thermographic images

CHAPTER 6

Industrial Applications

In this Chapter, we shall discuss the insulation requirements of industrial installations such as:

1. Petrochemical complexes
2. Fertiliser plants
3. Chemical and dyestuff plants
4. Nuclear power plants
5. Polyester filament plants
6. Pharmaceutical units
7. Food processing units
8. Flake ice, block ice and tube ice plants
9. Concrete cooling, dams and roads, and construction of airport runways

Types of Industrial Refrigeration Equipment

The refrigeration systems required for such installations are normally of large capacity, and the use of ammonia refrigerant is preferred because of its efficiency being higher than other refrigerants. It is a natural refrigerant without global warming effect, and trained operating personnel are generally available in industrial plants to take care of safety aspects.

The general evaporating temperature range in which most of such plants operate is +10°C to -50°C. (Cryogenic systems are not covered in this book).

Industrial refrigeration plants generally use the following systems:

a. Single stage vapour compression systems,
b. Two stage refrigeration systems, or
c. Cascade refrigeration systems.

These systems normally use flooded evaporators, with either gravity flooding or force feed pump circulation.

Systems using HFC/HCFC or other man-made chemical refrigerants are also used in many applications. Most of them use direct expansion evaporators with the refrigerant in tubes, or flooded evaporators with the refrigerant on the shell side and indirect secondary fluids like water or brine on the tube side.

Plate heat exchangers (PHEs) are used in many water and brine chilling evaporators.

The equipment in all these plants that needs insulation are:

1. Chillers: direct expansion or flooded type using water or brine as a fluid.
2. Surge drums in case of flooded systems.
3. Air cooler accumulators in case of gravity flooded air coolers, if the accumulators are located outside the cold room.
4. Inter-stage coolers for two-stage systems – open type or closed type with coil.
5. Flake ice makers or block ice maker tanks accommodating ice cans.
6. Refrigerant circulation pumps in case of force-feed pump circulation systems.
7. Refrigerant liquid line from inter-stage cooler to Low Pressure (L.P.) vessel.
8. Refrigerant liquid line from L.P. vessel to the processing equipment, which could be plate freezers, individual quick freezers (IQFs), blast /trolley freezers, air coolers, PHEs or any other process equipment.
9. L.P. vessel: low temperature storage vessel storing liquid refrigerant at low temperature.
10. Suction line from the processing equipment back to the L.P. vessel.
11. Suction refrigerant gas line from the L.P. vessel to compressor suction.
12. All chilled water or brine circulation lines going to and returning from processes that are below ambient temperature.
13. All accessories installed on the refrigerant pipes or any other fluid lines such as pumps, valves, fittings, and controls that are below ambient temperature.

Insulation is typically used in all the above equipment to prevent condensation and to limit unwanted parasitic heat gain, to save energy and to avoid cavitation in pump circulation systems.

Insulation Materials

The insulation materials recommended by ASHRAE Handbook for refrigeration applications are: cellular glass, closed-cell phenolic, flexible elastomeric, polyisocyanurate and polystyrene.

All these materials have one property in common: all are closed-cell foam materials, which means they have good Water Vapour Transmission (WVT) and low water absorption characteristics.

For piping, in addition to the above closed-cell foam materials, high density rockwool pipe sections can be used.

Mechanical abuse (by birds, cats, persons, etc.) and environmental abuse (by hail, sand, dirt, wind, rain, etc.) also play their role in reliability and longevity, and must be considered while selecting the material for the insulation system.

The insulation normally used for the above equipment and pipelines is flexible, closed-cell elastomeric or rigid closed-cell.

Pipe Corrosion

Corrosion Under Insulation (CUI) is one of the most common phenomena in process industries, and yet it makes up an inordinately large percentage of global maintenance expenditure. CUI is a subject that is well-researched and understood; extensive studies have been commissioned to determine the causes, effects, prevention and mitigation of CUI.

In the simplest terms, CUI is any type of corrosion that occurs due to the moisture present on the external surface of insulated equipment. The damage/attack can be caused by one of the several factors, and can even occur in equipment operating at ambient conditions.

This corrosion is commonly galvanic, chloride, acidic, or alkaline. The main contaminants that exacerbate corrosion are chlorides and sulphates. If undetected, the results of CUI can lead to leaks and the shutdown of a process unit or an entire facility. Long-term reliability is of prime importance, because downtime and iron pipe replacement are very costly.

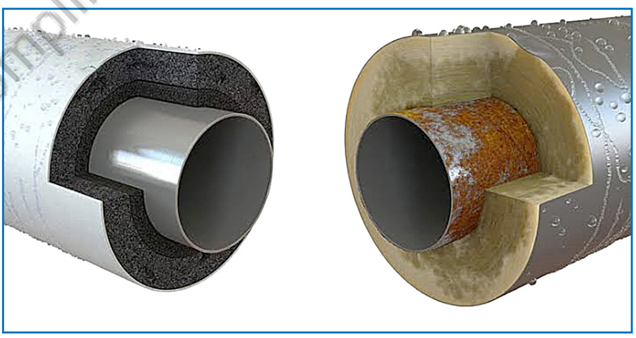


Figure 6-1: *A new and a corroded pipe*

Of key concern is the corrosion of iron pipes. Moisture resistance and moisture absorption characteristics of the insulation material are critical. For these reasons, insulation with high resistance to moisture (low absorption, low permeability and low wicking) should be used. Proper insulation installation (with no open or through seams) is essential, and use of secondary vapour-retarder systems is recommended.

Preventing Corrosion

The major factor in preventing CUI is to keep liquid and moisture from entering the insulation. Water not only decreases the effectiveness of the insulation, but leads to corrosion of pipes and equipment.

There are five ways to prevent CUI:

1. Insulation selection with low vapour absorption and retention ability.
2. Equipment design: correct selection of saddle supports, pipe supports and nozzle lengths, and longer valve stems for insulated pipes.
3. Application of protective paints and coatings before applying insulation is necessary. An epoxy or epoxy-phenolic should be applied in two coats over an abrasive blast cleaned surface. Inspection of the surface preparation is critical at welds.
4. Weather barriers like cladding and jacketing: the weather/vapour jacket of the insulation provides the primary barrier to water. The covering is the only part of the system that can be inspected quickly and repaired economically. It must not only keep liquids out but also allow for evaporation of any liquid that manages to get into the insulation system. Vapour barriers must be built into the insulation material, with the latter having a moisture resistance factor $\mu \geq 7{,}000$ or ≤ 0.02 Perm-inch, with testing performed according to EN 12086, DIN 52615 or ASTM E 96 Procedure A.
5. Routine maintenance and inspection are needed to catch defects due to deterioration or abuse. If the system is opened anywhere for maintenance or inspection, it should be closed promptly after the work is completed.

Unfortunately, insulation selection is often based on the initial material and installation costs, and the hazardous effects of pipe corrosion are not factored in by many plant owners. Energy saving, maintenance and corrosion costs are often overlooked.

Latest Trends in Corrosion Prevention

Manufacturers are moving toward insulation with factory-manufactured, pre-applied UV weather and abuse proof protection, such as coatings, laminations or claddings that offer both performance and appearance benefits.

Indoor safety and health issues at the manufacturing location may not allow the use of solvent-based adhesives, so manufacturers are using products with pre-applied adhesive on sheet and tubular insulation.

Some users find purchasing ready-to-use kits supplied by fabricators as a cost-effective option.

In all cases, the entire system (seams, butt joints and termination points) must be completely sealed with adhesives to protect against air intrusion into the system, which would carry moisture and result in condensation between the cold pipe and the insulation.

Contraction/Expansion of Insulation Material

Thermal contraction and expansion of insulation materials may be substantially different from that of metal pipes. A large difference between the pipe and the insulation may open the joints in the insulation, affecting the integrity of the entire system. The possible negative effects of contraction/expansion of insulation can be eliminated by properly spaced expansion and contraction joints while insulating the pipes.

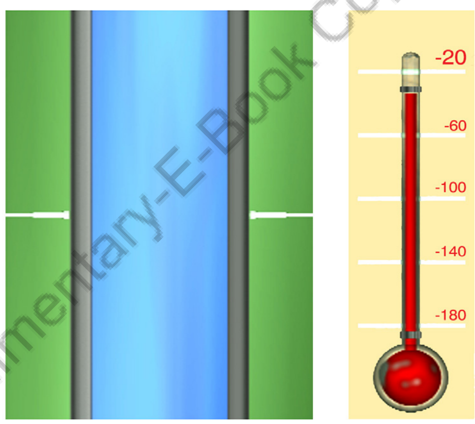


Figure 6-2: *Differential thermal expansion/ contraction of pipe and insulation*

Some ways to mitigate the negative effects of this differential contraction/expansion are:

1. Seams should be minimised.
2. On multilayer systems, the seams should be staggered.
3. The material should be pasted with adhesive, and all joints and seams secured with silver tape.
4. High-density rubber cladding of the bonded type, using an appropriate full contact adhesive with minimum 50 mm overlap at all butt joints and longitudinal seams, should be used.
5. Metal cladding, comprising coated sheet metal, stainless steel or aluminium with all external joints and fixings should be made weather-proof with mastic sealant.

Figure 6-3: *Metal cladding on insulation*

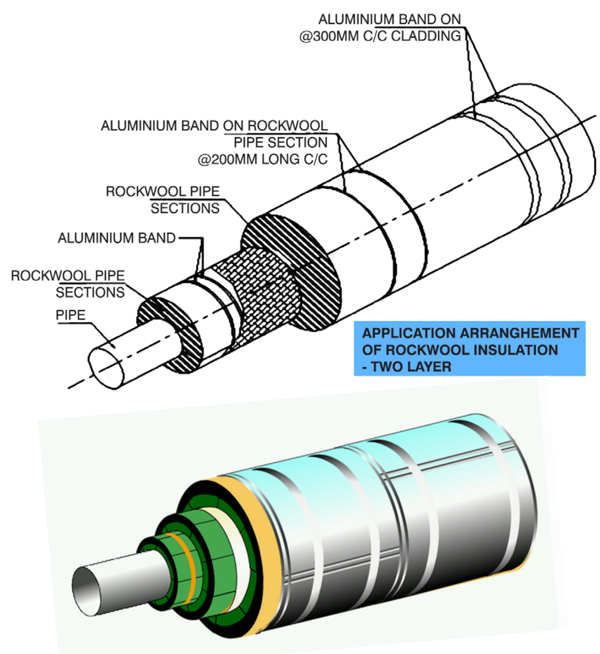


Figure 6-4: *Application of two-layer rockwool insulation with metal cladding*

Insulation Protection

Insulation is required to be protected from mechanical damage and the elements (weather barrier). The protection may consist of metal cladding, jacketing or a coating system. Use of a

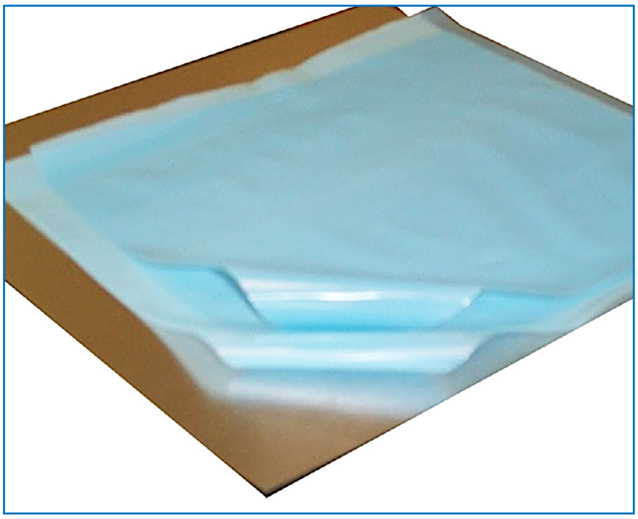


Figure 6-5: *Metal cladding*

cladding, flexible jacketing or coating can improve the appearance, durability, weather resistance and longevity of the insulation.

A majority of the insulation for piping is installed outdoors, hence jacketing selection is critical. Considering the cost and thickness required, polystyrene, polyisocyanurate and nitrile rubber flexible insulation with stainless steel or aluminium jacketing are the most common materials used. Of late, high density polyethylene (HDPE) cladding is also being used considering its seamless finish.

The metals commonly used for cladding are:

- Galvanised steel
- Pre-painted or pre-coated steel
- Aluminium
- Stainless steel
- HDPE
- Other specialised formulations

During the application of cladding, it should be ensured that:

1. Good water shedding exists at all joints, or sealing of joints where this is not possible.
2. At points where dissimilar metals may come in contact with one another, precautions must be taken to prevent galvanic action.
3. All metal joints must be straight and square to preserve a symmetrical appearance.
4. The cladding system must be constructed so that due allowance is provided for the expansion and contraction of the equipment.
5. Where the cladding is applied over a vapour barrier, full care must be taken to avoid puncturing the vapour barrier either during or after erection, for example with a spacer or protective liner.

Copper Pipe Insulation

Guidelines for insulation of copper pipes are as follows:

1. Installation of all refrigerant copper pipes must be free of extraneous chemicals such as corrosive cleaners or building material dust prior to the installation of the insulation.
2. The insulation must be clean and dry prior to installation.
3. Insulation should be slid onto the pipe; longitudinal slitting of the insulation is not allowed except on mitered sections.
4. Insulation must be pushed onto the pipe, not pulled.
5. Insulation must be mitered, pre adhered and longitudinally slit inside the throat to fit over all P-traps, tees, elbows, and bends over 90°.
6. All joints and mitered seams must be made with full coverage adhesive on both surfaces. Insulation must not be stretched during the process.
7. On cold pipe work, it is critical that all seams and joints are glued in their entirety to provide a continuous vapour seal.
8. Butt joints must be fitted under compression.
9. Saddles must be insulated under all insulated lines at clamps, hangers, or locations where insulation may be compressed.
10. All hanging and clipping of pipes must be made with pipe hangers and pipe supports, or with pipe supports made from the same material as the pipe insulation with the inclusion of a PUR/PIR bearing segment to support the pipe weight.
11. Hangers and supports must be constructed with a metal shell or from a suitable material to prevent compression.
12. Pipe supports and hangers must be glued to the adjacent insulation to provide a vapour seal, and the completed assembly must be of suitable construction to prevent thermal bridging.
13. All valves, flanges and fittings must be insulated throughout, using sheet or tube material of the same thickness as the insulation of the main pipework.
14. Vapour barriers must be built into the insulation material, with the latter having a moisture resistance factor $\mu \geq 7{,}000$ or ≤ 0.02 Perm-inch, with testing performed according to EN 12086, DIN 52615 or ASTM E 96 Procedure A.
15. Foam or wood can be used between the support and the pipe to accommodate the weight, if considered necessary.
16. Insulation contraction joints should be provided for firebreaks typically at 20m maximum or where the insulated pipe passes from one building to another.

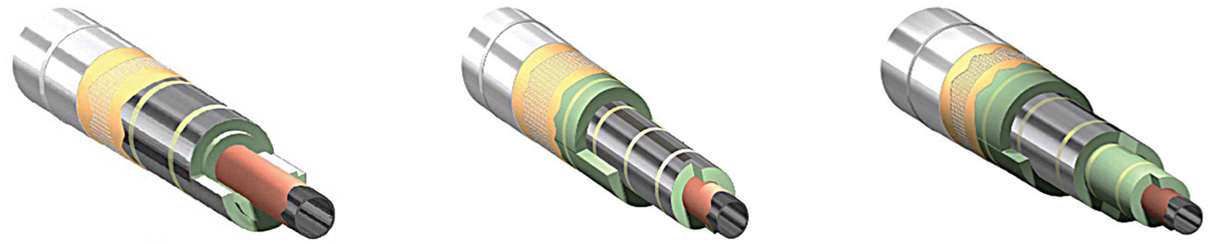


Figure 6-6: *One-layer, two-layer and three-layer insulation on copper pipe*

17. Higher density insulation preformed material often manufactured from PUR, PIC, phenolic foam or wood can be used between the support and the pipe to accommodate the weight, if considered necessary.
18. Where the total thickness of insulation exceeds 50 mm, it should be applied to multiple layers and all joints should be staggered to prevent direct heat paths to the cold face. The creation of cavities should be avoided.

Chiller Insulation

Chiller insulation blankets are becoming the standard replacement for factory-applied chiller insulation. The factory applies insulation to low temperature surfaces such as the evaporator, water boxes and suction elbows. The insulation is usually 20 to 50 mm thick rigid polyurethane or elastomeric foam insulation with a k-factor of 0.021 to 0.035 W/m·K.

During maintenance, removing the insulation sticking to the surface can be avoided by using removable insulation.

Blankets can be fabricated to perfectly fit the low temperature surfaces and avoid the need to physically remove glued-on insulation. Removable insulation drastically reduces the cost of reapplying the insulation after the initial maintenance is completed, and eliminates the need to scrape off the glued-on insulation. Removable insulation blankets offer the user an opportunity to use a far more thermally efficient type of insulation.

Aerogel or microporous blanket insulations, which are hydrophobic and are the most thermally efficient solid insulation available, offer much lower k-factors. Cryogel and aerogel are more appropriate insulation choices as their k-factor for 7°C (typical chiller temperature) is 0.023 W/m·K.

Ropes, usually of fibrous material, are sometimes used for wrapping spirally around small pipes and tubes.

Figure 6-7: *Rope wound around a small pipe*

Insulation of Vertical Vessels

Figure 6-8 shows the method of insulating a vertical vessel with details.

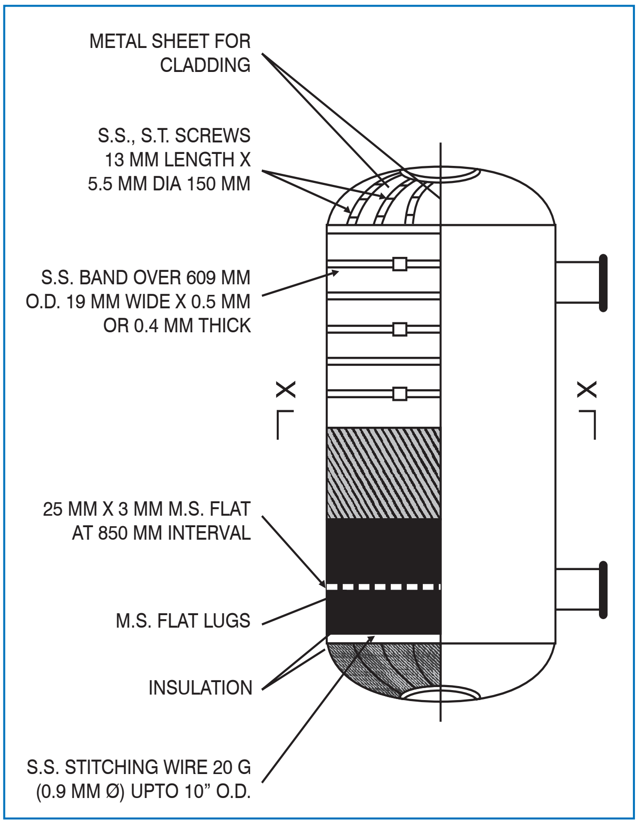


Figure 6-8: *Details of vertical vessel insulation*

Pre-insulated Pipes

Pre-insulated pipes are an advanced system for the transfer of hot and cold fluids. High density polyethylene-jacketed polyurethane or polyisocyanurate insulated piping systems are available. All categories of bare piping – steel, stainless steel, copper, ductile iron and plastics – are available pre-insulated in a wide range of sizes with the correct insulation thickness to meet the particular application. The pre-engineered components range includes straight lengths, elbows, tees, anchors and end seals.

The high thermal efficiency PUF and PIR insulation, conforming to IS 12436, is suitable from medium temperatures to cryogenic applications. It offers a void-free cover over the pipe surface, thereby providing high thermal efficiency.

The cover over the insulation is a high-strength, seamless, high-density polyethylene (HDPE) jacket for high protection from the environment. Elbow insulation jackets are constructed of seamless, moulded HDPE. Tee insulation jackets come in extrusion welded construction. Alternatively, aluminium sheet and galvanised/galvalume colour coated or bare steel sheet jackets can also be used with the joints grooved, overlapped and held with screws.

Pre-insulated pipes are available up to 42" insulation diameter and maximum length of 12m. They are also available in non-combustible and water repellent grade rockwool pipe sections of 144 kg/m^3 density with HDPE cladding. They are suitable for both underground and over-ground installations.

Figure 6-9: *Aluminium sheet pre-insulated pipe*

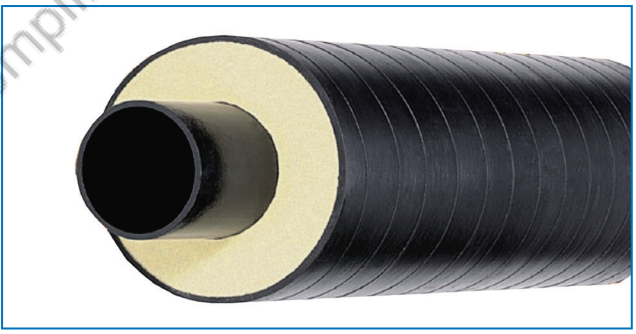


Figure 6-10: *HDPE pre-insulated pipe*

Pre-insulated pipes constitute a fully bonded system, which expands and contracts as a whole. There are no gaps for water to travel through that can degrade the insulation or service pipe.

Insulation Accessories

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

1. Securement of insulation and/or jacketing

As most insulations are not structural materials, they must be supported, secured, fastened or bonded in place. Securements must be compatible with insulation and jacketing materials. Possible choices include:

a. Studs and pins
b. Staples, serrated fasteners, rivets and screws
c. Clips
d. Wire or straps
e. Self-adhering laps
f. Tape*
g. Adhesives*
h. Mastics*

*Ambient temperature, humidity conditions and substrate surface cleanliness affect the efficiency of tapes, adhesives and mastics in certain installations. It is advisable to check the properties of temperature range and vapour permeability before selecting adhesives. Wherever possible, mechanical securements should be used.

2. Reinforcement for cement or mastic applications

Mastics and cements should be reinforced to provide mechanical strength. The following materials can be used:

a. Fibre fabrics
b. Expanded metal lath
c. Metal meshes
d. Wire netting

Compatibility of materials must be considered to prevent corrosion.

3. Stiffening around structures that may not support the weight of high-density insulations

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

4. Support for pipe, vessel and insulation

Pipe supports and accessories may be supplied in part or totally by the insulation contractor. Details of insulation treatment at points of support are illustrated in *Figure 6-11* to *6-14*. Accessories at points of support are:

a. Heavy density insulation inserts
b. Pipe support saddles and shoes

c. Insulation and metal shields used to protect insulation
d. Wood blocks or dowels; these should not be used for all temperatures

Insulation support rings on vertical piping and vessels should be supplied by the piping or vessel contractor, as field welding on coded piping or vessels voids the original coding by the manufacturers. Refer *Figure 6-14* for details.

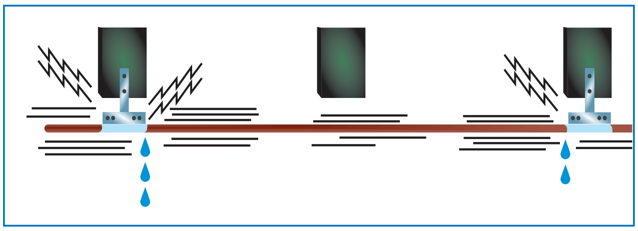


Figure 6-11: *Improper pipe design and support can amplify vibration and noise*

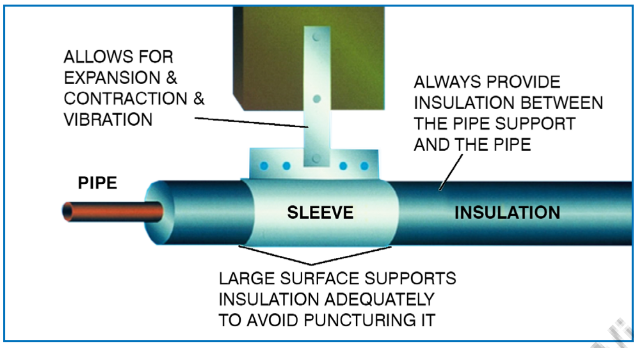


Figure 6-12: *Controlling pipe vibration by providing adequate support*

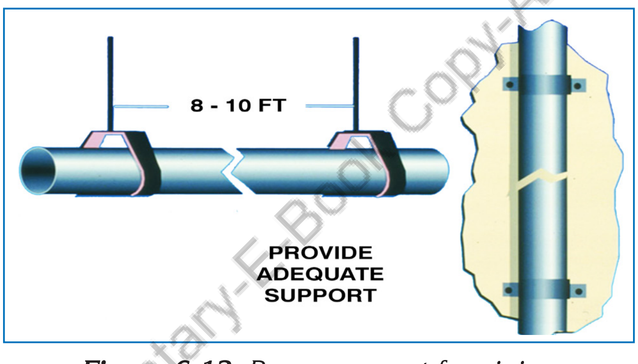


Figure 6-13: *Proper support for piping*

5. Sealing and caulking

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

6. Water flashing

Materials that direct the flow of liquids away from the insulation may be constructed of metal, plastic or mastic.

7. Compensation for expansion/contraction of piping and vessels

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

a. Manufacturer overlapping or slip joints
b. Bedding compounds and flexible sealers

Improper design or application of one or more accessories is a significant factor in the failure of insulation systems.

PUF Pipe Supports

High density PUF pipe supports are special shaped forms of PUF insulation for supporting chilled water pipes. If steel pipes are placed directly over steel supports, condensation will occur. High density PUF pipe supports prevent condensation. Its typical properties are:

- Density: 120-320 kg/m^3
- Compression strength: 1500-8200 kPa
- Tensile strength: 1600-5000 kPa

Figure 6-14: *Insulated pipe supports and saddle supports*

Valve Insulation

Valves with long stems should be used for installation on pipes that need insulation, so that the valve handle wheel can be easily operated.

Valve Insulation is closed-cell polyurethane foam (PUF) with 36-45 kg/m^3 density. It is suitable for an operating temperature range of -40 to

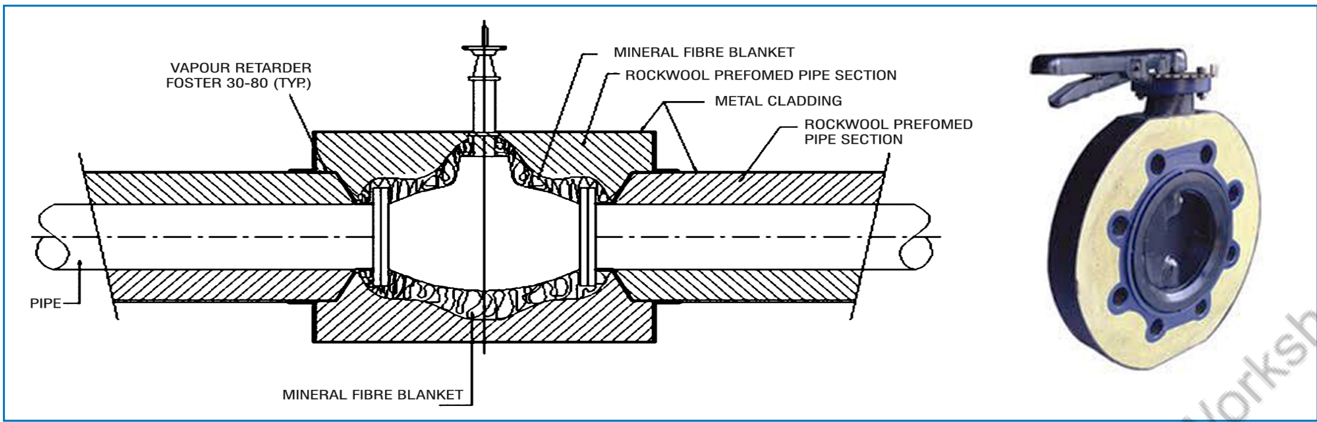


Figure 6-15: *Pre-insulated valve*

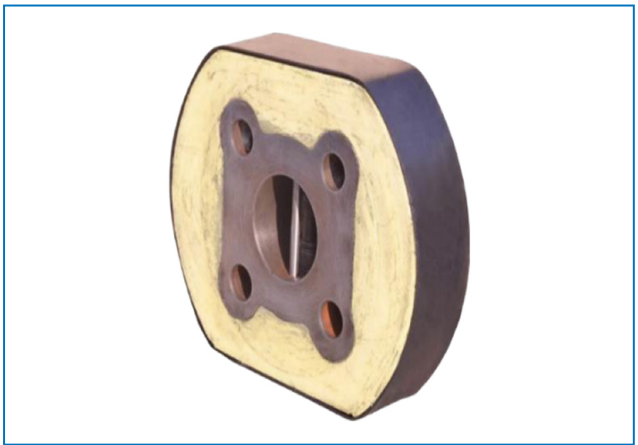


Figure 6-16: *Pre-insulated flange*

120°C. The insulation is protected by an aluminium cladding to ensure long life of the insulation and to prevent its peeling and damage. The insulation has Class P fire performance as per BS 476 Part-5 for ignitability, and mean flame spread of less than 125 mm as per BS 4735. This identifies the material as self-extinguishing with fire retardant properties.

Closed-cell elastomeric foam insulation of 55 kg/m³ density is also suitable. It is provided with thick black cloth lamination or aluminium sheet cladding.

Closed-cell foam types differ in parameters depending on their application. On the one hand, it is suitable for insulating foundation walls, ceiling structures, roofs, and floors. On the other hand, it can be used in industrial and agricultural buildings, for example to insulate production floors, warehouses, cold storages and livestock buildings.

Insulation is carried out in such a way that mounting bolts for the valve are fully enclosed by valve insulation. Standard flanges and bolts can be used with no change in the flange insulation method. Flange bolts must be tightened directly on the metal surface of the flange and not on top of insulation.

The latest trend is pre-insulated valves from the factory. They come with polyurethane foam insulation and HDPE sheet cladding. The foam has 55-70 kg/m³ density, with 3-5 mm thick HDPE sheet of density 966 kg/m³. This is most appropriate to stop condensation. Pre-insulated flanges are also available.

Well-insulated Equipment

Given below are some photographs of well insulated equipment.

Figure 6-17: *Shell and tube screw compressor water chiller with water cooled condenser*

Figure 6-18: *Centrifugal water chiller package*

Figure 6-19: *Pre-insulated chiller*

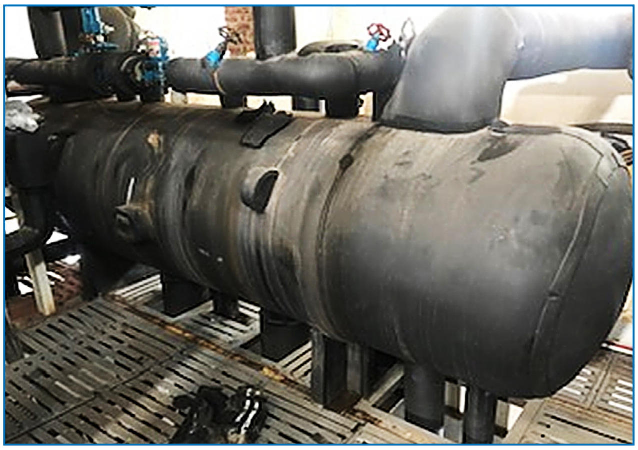


Figure 6-20: *Insulated L.P. vessel in operation for last ten years*

Figure 6-21: *Inter-stage cooler in two stage system*

Figure 6-22: *Liquid ammonia pump insulation*

Figure 6-23: *Chiller insulation with piping*

Figure 6-24: *Chilled water distribution insulation*

Figure 6-25: *Cladding over insulated pipes*

Figure 6-26: *Elastomeric rubber flexible insulation over pipes*

Figure 6-27: *Insulation protected by aluminium foil lamination vapour barrier*

One of the biggest challenges faced with elastomeric rubber insulation is protection against various types of abuses. Even a scratch with a nail on the top skin causes the closed cell network to break, and condensation starts gradually. So, it is recommended to properly clad the equipment and piping for long life and performance.

Figure 6-28: *Pre-insulated tank*

Figure 6-29: *Flake ice makers*

The recommended thicknesses of insulation for vessels and pipes are given in Chapter 4, *Insulation Thickness.*

Vapour Barrier Mastic Coating Paint for Finishing Insulation

A recent development in insulation coating is the UL Listed HVAC vapour barrier mastic coating paint for finishing duct and piping insulation and vessels. It is a latex rubberised, low VOC, water based, fire retardant coating. It provides smooth brushing characteristics due to its good flow properties. The advantages of this coating are:

1. Zero flame spread and smoke development
2. Good vapour barrier and weather protection
3. Good adhesion and high strength
4. Mould and fungus resistant
5. Washable and water resistant
6. Compatible with polystyrene and polyurethane foam insulation
7. Non-toxic and non-flammable
8. UV resistant
9. Antibacterial
10. Does not get discoloured with age

It can be used for outdoors as well as indoors – on metal duct insulation, in areas where high humidity and elevated temperature are major issues, and as a high vapour barrier finish for most types of thermal insulations. It is also suitable for vapour sealing jackets and for coating flexible cellular insulation tubing and sheets. It can also act as a duct closure sealant.

Specification Data

1. Colour: White
2. Physical form: Thixotropic paste
3. Specific gravity (ASTM D 1475-98): 1.30±0.15 kg/L
4. Solids content (ASTM D 1644): 66±3%

Figure 6-30: *Vapour barrier mastic coating paint applied over pipe insulation*

Figure 6-31: *Application over pipe insulation*

5. Viscosity (ASTM D 2196): 25,000-60,000 cP
6. Water vapour permeance (ASTM F 1249): 0.05 perms at 0.80 mm dry film thickness
7. Flash point (ASTM D 93): No Flash to >150°C
8. Drying time (ASTM D 1640): Set to touch: 2 to 3 hours
9. Dry through: 15 to 17 hours
10. Service temperature: -50°C to 120°C (temperature at coated surface)
11. Military specification: MIL-A-3316C, Class 1, Grade A

It conforms to

1. Underwriters Laboratory (UL) 723
2. NFPA 90A and 90B 25/50
3. DCL approved
4. Free of asbestos, lead and mercury compounds

Coverage Range (subject to surface condition):

1. 0.7-1.3 m^2/L per coat to obtain wet film thickness of 1-0.5 mm per coat.
2. The wet coverage shown above is for smooth non-porous surfaces. Porous or rough surfaces may require more litres to obtain the required dry thickness.
3. Application of the coating is through brush or spray.

CHAPTER 7

Air Conditioning Applications

In comfort and process air conditioning, insulation is required for the following:

1. Building insulation to save energy, especially heat gain from the roof
2. Air handling units – indoor and outdoor
3. Ducting – exposed and concealed
4. Chilled water piping, hot water piping, fittings such as valves and other accessories
5. False ceiling

Insulation Work

This section covers the requirements of thermal insulation for chilled water and hot water piping, pumps, tanks and duct work, and acoustic lining in duct work and AHU rooms. It does not cover exposed roof insulation and under-deck insulation work.

Insulation Materials

The insulation material to be used for various applications could be any of the following, as required:

i. For insulation of water piping, pumps and tanks

a. Expanded polystyrene, treated for fire (TF) quality
b. Polyurethane / polyisocyanurate, Class 1 / Class O rated
c. Resin bonded rockwool
d. Resin bonded glass wool
e. Polyvinyl nitrile (closed-cell rubber foam)
f. XLPE (closed-cell cross linked polyolefin foam), expanded polystyrene (TF quality) or PUF/PIR should be used for pipe insulation, such as inside the AC plant room, exposed to outside or buried in ground.

In case of resin bonded glass wool and rockwool, the pipe insulation should be in rigid sections in two halves and preformed to fit snugly on the pipes (up to the pipe sizes for which preformed sections are manufactured by the insulation manufacturer). For higher pipe sizes, insulation slabs must be used. Resin bonded glass wool or rockwool should be used for piping inside the building due to its fire retardant properties, for considerations of fire safety.

Polyvinyl nitrile available in tube shapes for sliding on to small diameter pipes can be used if successfully tested for fire retardant properties. However, all insulation needs to be covered with vapour barrier and cladding with aluminium sheet.

ii. For Insulation of duct work

a. Resin bonded glass wool
b. Resin bonded rockwool
c. Polyvinyl nitrile

iii. For acoustic lining of duct work and AHU rooms

a. Resin bonded glass wool.
b. Resin bonded rockwool.

iv. For suction line, chilled water pipe and chiller insulation

a. Expanded polystyrene (TF)
b. Polyvinyl nitrile, PUF/PIR 120

v. For double skin AHUs

a. Polyurethane foam

Material Specifications

The insulation material must satisfy the following requirements:

i. For thermal application on pipes

Table 7-1: *Insulation characteristics for thermal application on pipes*

Material	Minimum Density (kg/m³)	Maximum Thermal Conductivity (Kcal/hr/°C/m at 10°C mean temperature
Resin bonded glass/ rockwool	32	0.031
Expanded polystyrene (TF)	20	0.035
Polyvinyl nitrile foam	55	0.034

ii. For thermal insulation of ducts

Table 7-2: Insulation characteristics for thermal insulation of ducts

Material	Minimum Density (kg/m³)
Resin bonded glass wool	24
Rockwool	48
Polyvinyl nitrile foam	40

Fibreglass/rockwool insulation used for duct insulation must be factory faced with aluminium foil on one side reinforced with kraft paper and fused to the insulation material. Polyvinyl nitrile foam Insulation used for duct insulation must be factory faced with aluminium foil on one side.

iii. For acoustic lining

Table 7-3: Insulation characteristics for acoustic lining

Thickness	Material	Minimum Density (kg/m³)
Duct 25 mm	Resin bonded glass wool	32
	Rockwool	64
AHU room 50 mm	Resin bonded glass wool	32
	Rockwool	48

Resin bonded glass wool insulation and resin bonded rockwool insulation must conform to IS 8183 as amended up to date.

Expanded polystyrene must conform to IS 4671 as amended up to date.

iv. Expansion tank Insulation

Expanded polystyrene of density not less than 20 kg/m³ must be used.

v. For pipes buried under-ground

For minimum insulation thickness of pipes buried underground refer *Table 7-4*.

Table 7-4: Minimum insulation thickness of pipes buried underground

S. No.	Pipe Diameter, mm	Minimum Thickness of PUF, mm	Minimum Thickness of GI Cladding, mm (gauge)	Minimum Thickness of Aluminium Cladding, mm (gauge)
1	20	32	0.457 (26)	0.559 (24)
2	25	32	0.457 (26)	0.559 (24)
3	32	32	0.457 (26)	0.559 (24)
4	40	32	0.457 (26)	0.559 (24)
5	50	32	0.457 (26)	0.559 (24)
6	65	36	0.457 (26)	0.559 (24)
7	80	42	0.457 (26)	0.559 (24)
8	100	42	0.457 (26)	0.559 (24)
9	125	42	0.457 (26)	0.559 (24)
10	150	42	0.457 (26)	0.559 (24)
11	200	52	0.457 (26)	0.559 (24)
12	250	62	0.457 (26)	0.559 (24)
13	300	62	0.457 (26)	0.559 (24)
14	350	50	0.457 (26)	0.559 (24)
15	400	50	0.457 (26)	0.559 (24)
16	450	50	0.457 (26)	0.559 (24)
17	500	55	0.559 (24)	0.711 (22)
18	550	55	0.559 (24)	0.711 (22)
19	600	55	0.559 (24)	0.711 (22)
20	650	55	0.559 (24)	0.711 (22)
21	700	55	0.559 (24)	0.711 (22)
22	750	55	0.559 (24)	0.711 (22)
23	800	55	0.559 (24)	0.711 (22)

Insulation Thickness

The thickness of insulation must be as indicated below unless specified otherwise in the tender.

i. Pipe insulation (chilled water as well as hot water application):

For pipe size 150 mm and below, 50 mm glass fibre or EPS

For pipe size above 150 mm, 75 mm glass fibre or EPS

ii. Duct insulation with glass fibre:
Thermal insulation for AC area: 12.5 mm
Thermal insulation for non-AC area: 25 mm
Acoustic insulation: 25 mm

Ducting should be insulated along its whole length in order to provide the necessary means of limiting heat gains and/or losses from ducts. Where ducting may be used for both heating and cooling duties at different periods during its life cycle, the provisions for chilled ducting should be adopted, since these are the most onerous. *Table 7-5* indicates the maximum heat loss/gain per unit area required to meet these provisions. As with pipes, additional insulation may be required on ducting to provide adequate condensation control.

Table 7-5: *Recommended duct insulation thickness*

Minimum Air Temperature Inside Duct (°C)	Thickness (mm)	
	ε = 0.05	ε = 0.9
15°C	13	9
10°C	25	13
5°C	32	19
0°C	44	25

Source: BS 5422 Table 12

iii. AHU insulation

Double skin panels must be 25 mm thick, made of 0.8 mm pre-plasticised and pre-painted GSS sheet on outside with PVC guard, and 0.8 mm galvanised sheet inside, and polyurethane foam insulation of density not less than 38 kg/m^3 injected in between with an injection moulding machine.

These panels must be bolted from inside or screwed from outside on to the framework with soft rubber gasket in between to make the joints air-tight. The gaskets must be inserted within the groove in the extruded aluminium profile of the framework. For units installed outdoors, the thickness of double skin panels must be minimum 40 mm.

The drain pan must be fabricated out of minimum 1 mm thick stainless steel sheet covering the entire coil section and extended on one side for accommodating the coil connection valve, etc. and complete with a 25 mm drain connection. The drain pan must be insulated with 10 mm thick closed cell polyethylene foam insulation and jacketed from outside with single piece moulded FRP tray.

Figure 7-1: *Insulated air handling unit*

Figure 7-2: *AHU installed outdoors*

For units installed outdoors, the thickness of double skin panels must be minimum 40 mm.

iv. AHU room acoustic lining

Resin bonded glass wool or resin bonded mineral wool 50 mm

v. Pumps

Expanded polystyrene TF quality 50 mm

vi. Chillers

Polyvinyl rubber insulation not less than 19 mm

vii. Expansion tank

Expanded polystyrene TF quality not less than 50 mm

Application of Insulation

Pipe Insulation

The surface to be insulated must be first cleaned and a coat of zinc chromate primer must be given. The insulation must be fixed tightly to the surface with cold setting rubberised bituminous adhesive. All joints must be staggered and sealed. The second layer of insulation, wherever required, must be similarly applied over the first layer.

Pipes must be preferably pre-insulated at the factory meeting the requirement, or the insulation must be finished at site as under:

a. For pipes laid inside the building, insulation over the pipe work must be finished with 0.63 mm thick aluminium sheet cladding over a vapour barrier of 120 g/m^2 polythene sheet with 50 mm overlap, tied down with lacing wire and complete with type 3, grade I roofing felt strip (as per IS 1322 as amended up to date) at the joints.

b. For pipes outside the building laid above ground, the insulation must be finished with 0.63 mm GS sheet cladding over a vapour barrier of 120 g/m^2 polythene sheet with 50 mm overlap, and tied down with lacing wire and complete with type 3, grade I roofing felt strip applied by means of cold setting rubberised bituminous adhesive.

c. For pipes outside the building laid underground, the insulation must be covered with 500-gauge polythene faced hessian (with polythene facing outwards), with 50 mm overlap. All joints must be sealed with bitumen. A layer of 0.50 mm x 20 mm GI wire mesh netting must be provided over it butting all joints, and it must be laced down with GI wire; sand cement plaster (1:4) 20 mm thick must be provided in 2 layers each of 10 mm and must be water-proofed by applying hot bitumen and fixing tar felt over the plaster. It must be finally finished with a coat of hot bitumen. In case of factory pre-insulated pipes buried underground, a water leakage sensing wire must also be provided to detect the location of water leakage at a later date.

d. In case of factory pre-insulated pipes, all joints must be properly insulated at site as per the manufacturer's recommendation.

All valves, fittings, strainers, etc. must be insulated to the same thickness and in the same manner as for the respective piping, taking care to allow operation of valves without damaging the insulation.

Pump Insulation

Expanded polystyrene (TF quality) of 50 mm thickness must be sandwiched between two aluminium sheets of 0.5 mm thickness and properly clamped to the pump in two semi-circular sections.

Expansion Tank Insulation

Expansion tank insulation should be expanded polystyrene (TF) of thickness not less than 50 mm. It must be applied as under:

i. Surface must be thoroughly cleaned with wire brush and rendered free from all dust and grease.

ii. Two layers of hot bitumen must be applied.

iii. Insulation slabs should then be fixed in one layer, and the joints must be sealed with hot bitumen.

iv. The insulation slab should then be covered with 0.63 mm x 19 mm GI wire mesh netting, which must be fixed to the insulation with brass/ GI nails.

v. The insulation must then be finished finally with aluminium cladding of thickness not less than 0.5 mm.

Thermal Insulation of Ducts

i. The surface of the duct must be thoroughly cleaned with wire brush and rendered free from all dust and grease.

ii. Two coats of cold setting rubberised bituminous adhesive must be applied over the duct. (Any other adhesive recommended by the manufacturer may also be used with the approval of engineer-in charge).

Pre-insulated Chilled Water Pipes

i. The pipe must be MS electric resistance welded (ERW).

ii. Pipe insulation must be polyurethane foam with minimum density of 36 kg/m^3, 90% minimum closed cell content, minimum compressive strength of 2.7 kg/cm^2, and initial thermal conductivity of 0.02 W/m·K. The insulation must completely fill the annular space between the service pipe and jacket, and must be bonded to both.

iii. The cladding must be spirally wound, of GI or aluminium as specified, for pipes installed on the surface.

Acoustic Lining of Ducts

Where specified, ducts must be lined internally with acoustic insulation as detailed below:

i. The inside surface of the duct on which the acoustic lining is to be provided must be thoroughly cleaned with wire brush and rendered free from all dust and grease.

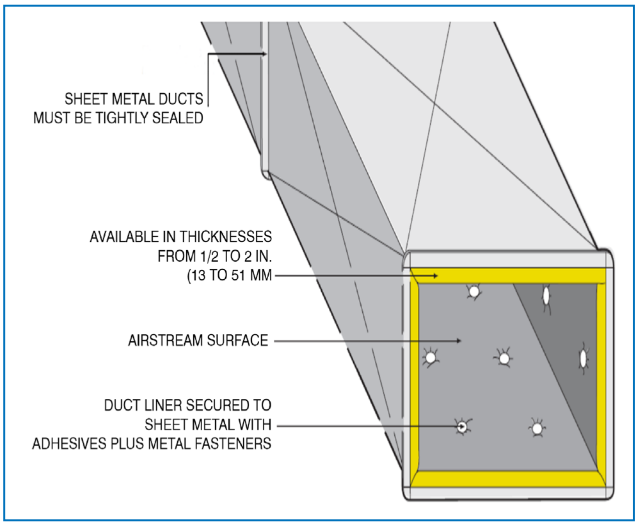


Figure 7-3: *Rectangular duct with glass fibre insulation*

ii. 25 mm x 25 mm section of minimum 1.25 mm thick GI sheet must be fixed on both ends of the duct piece.
iii. Insulation slabs must then be fixed between these sections of ducts using cold setting rubberised bituminous adhesive compound and stickpins.
iv. The insulation must then be covered with reinforced plastic or fibre glass tissue with proper overlap, sealing all the joints so that no fibre is visible.
v. The insulation must finally be covered with minimum 0.5 mm thick perforated aluminium sheet having between 20-40% perforations.

Acoustic Lining of AHU Rooms

i. The wall/roof surface should be thoroughly cleaned with wire brush.
ii. A 610 x 610 mm frame work of 25 mm x 50 mm x 50 mm x 50 mm x 25 mm shape channel made of 0.6 mm thick GSS must be fixed to walls, leaving 610 mm from floor by means of wall plugs in the walls and dash fasteners in the ceiling.
iii. Resin bonded glass wool or rockwool, as specified, cut to size should be friction-fitted in the frame work and covered with tissue paper.
iv. Aluminium perforated sheet having perforation between 20-40%, of thickness not less than 0.8 mm, must be fixed over the entire surface neatly without causing sag or depression in between and held with screws. Sheet joints should overlap minimum 10 mm.
v. Aluminium beading 25 mm wide with thickness not less than 1 mm must be fixed on all horizontal and vertical joints by means of screws.

Measurement of Insulation

a. Pipe insulation must be measured in units of length along the centre line of the insulated pipe. Linear measurements must be taken before the application of the insulation. For piping measurements, all valves, orifice plates and strainers must be considered strictly by linear measurement along the centre line of the pipes, and no special rate must be applicable for insulation of any accessories, fixtures or fittings.
b. Duct insulation and acoustic lining must be measured on the basis of surface area along the outer surface (refer IS 14164: 2008) of insulation thickness. Thus, the surface area of externally thermal insulated or acoustically lined duct must be based on the perimeter at the centre of thickness of insulation, multiplied by the centre-line length of ducting including tapered pieces, bends, tees, branches, etc. as measured for bare ducting. In the case of tapering pieces, their average perimeter must be considered.

Thermal Insulation material is applied on the building envelope, ducting and piping to obstruct the flow of heat through conduction. The adjoining area's presence of windage allows heat transfer by convection. Further, by reflecting, it prevents heat transfer by radiation.

Thermal Insulation of Buildings

There are three broad area of thermal insulation application in a building:

1. Building envelope insulation
2. Air conditioning ducts and chilled water piping insulation

Figure 7-4: *Duct insulation*

Figure 7-5: *Insulation sprayed on roof*

Figure 7-6: *Cavity wall insulation*

3. Pipe lines running inside walls, and diesel generator exhaust pipe.

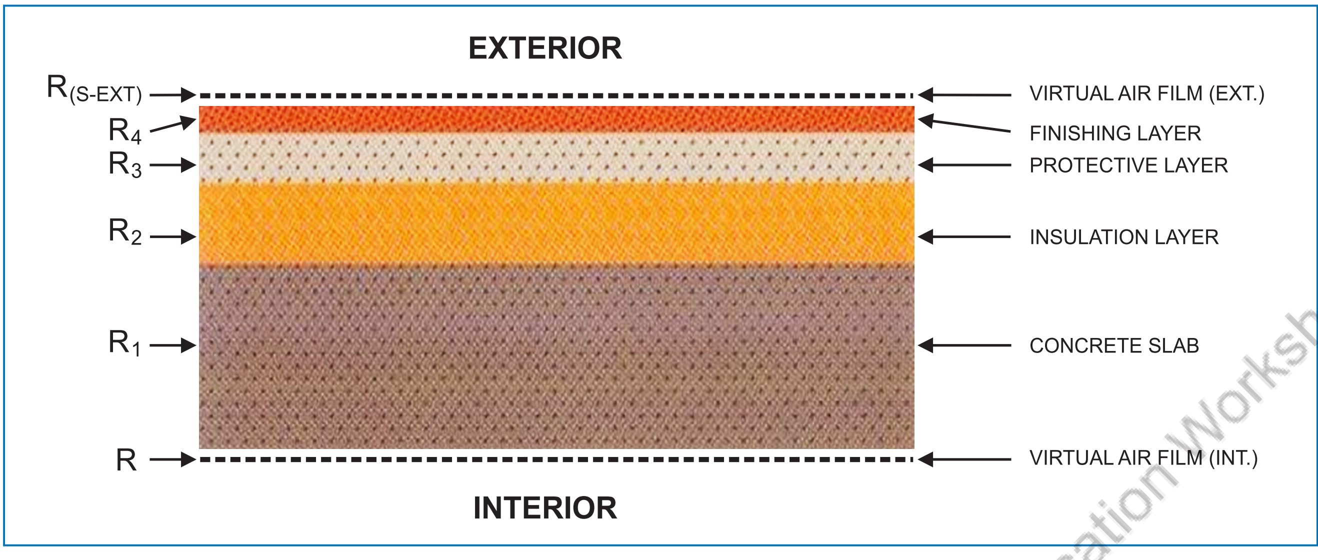


Figure 7-7: *AHU installed outdoors*

i. Type A: For externally insulated round ductwork

Insulation should be of flexible glass fibre, ASTM C 612, commercial grade, k-value of 0.29 at 75°F (24°C); 0.002 inch (0.05 mm) foil-scrim facing.

ii. Type B: For externally insulated square or rectangular ductwork

Insulation should be rigid glass fibre or rockwool, ASTM C 612 Class 1, k-value of 0.24 at 75°F (24°C), 0.002 inch (0.05 mm) foil-scrim facing.

iii. Type C: For internally insulated rectangular ductwork

Insulation should be flexible sheet glass fibre or rockwool, ASTM C 553; k-value of 0.24 at 75°F (24°C), 1.5 lb/ft³ (24 kg/m³) minimum density; coated air side for maximum 4,000 ft/min (1219 m/min) air velocity.

iv. Type D

Same as Type C, except cover with 2 mil mylar sheeting and 22 gauge (0.85 mm) galvanised metal sheeting with 5/32-inch (4 mm) diameter holes staggered 3/16 inch (4.7 mm), with 60 percent minimum open area over mylar sheeting.

v. Type E: For internally insulated round ductwork

Insulation should consist of pre-formed glass fibre sections tightly fit into round ducts and fittings, consisting of ASTM C 553 glass fibre, k-value of 0.24 at 75°F (24°C), 1.5 lb/ft³ (24 kg/m³) minimum density, and coated on the air side.

vi. Type F: For DG set exhaust pipe

Fire rated duct wrap, 3m Firemaster, GLT Firestop blanket, or equal. Duct wrap must be UL Listed for air ducts for 1-hour and 2-hour applications, or meeting BS 476 Part-24. Insulation must be rockwool or glass wool slabs.

vii. Indoor Jacket

Polyvinyl chloride (PVC).

viii. Outdoor Jacket

Aluminium, 0.016 inch (0.4 mm) thickness minimum.

ix. Vapour Barrier

Non-flammable, fire-resistant, polymeric resin, compatible with the insulation.

x. Cellular-Glass, Phenolic, Polyisocyanurate, and Polystyrene Adhesive

Solvent-based resin adhesive, with a service temperature range of -75 to +300°F.

For indoor applications, use adhesive that has a VOC content of 50 g/L or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

xi. Flexible Elastomeric and Polyolefin Adhesive

Comply with MIL-A-24179A, Type II, Class I.

For indoor applications, use adhesive that has a VOC content of 50 g/L or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

xii. Lagging Adhesive

Fire resistive in accordance with ASTM E84, NFPA 255, UL 723 or comparable standard by a nationally recognised testing laboratory (NRTL) recognised under 29 CFR 1910.7. Complying with MIL-A-3316C Class I, Grade A and compatible with insulation materials, jackets, and substrates.

For indoor applications, use lagging adhesives that have a VOC content as specified in the tender or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

xiii. PVC Jacket Flashing Sealants

For indoor applications, use sealants that have a VOC content of 250 g/L or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

ix. Impale Anchors

Galvanised steel, 12 gauge (2.5 mm), self-adhesive pad.

xv. Tie Wire

Annealed steel, 16 gauge (1.5mm).

The use of products with asbestos content is prohibited.

Duct Liners

a. Fibre Glass Duct Liner

Comply with ASTM C 1071, NFPA 90A, or NFPA 90B; and with NAIMA AH124, 'Fibrous Glass Duct Liner Standard'.

Solvent/Water Based Liner Adhesive: Comply with NFPA 90A or NFPA 90B and with ASTM C 916.

For indoor applications, use adhesive that has a VOC content of 80 g/L or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

b. Flexible Elastomeric Duct Liner

Preformed, cellular, closed-cell, sheet materials complying with ASTM C 534, Type II, Grade 1; and with NFPA 90A or NFPA 90B.

Liner Adhesive: As recommended by insulation manufacturer and complying with NFPA 90A or NFPA 90B.

For indoor applications, use adhesive that has a VOC content of 50 g/L or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

c. Natural Fibre Duct Liner

85 percent cotton, 10 percent borate, and 5 percent poly-binding fibres, treated with a microbial growth inhibitor and complying with NFPA 90A or NFPA 90B.

Liner Adhesive: As recommended by insulation manufacturer and complying with NFPA 90A or NFPA 90B.

For indoor applications, use adhesive that has a VOC content of 50 g/L or less when calculated according to 40 CFR 59, Subpart D (EPA Method 24).

Application of Duct Liners

Preparation

i. Install materials after ductwork has been tested and approved.
ii. Clean surfaces for adhesives.
iii. Install materials in accordance with manufacturer's instructions.
iv. Install without sag on underside of ductwork. Use adhesive or mechanical fasteners where necessary to prevent sagging.
v. Seal vapour barrier penetrations by mechanical fasteners with vapour barrier adhesive.

Exterior Insulation (Type A or Type B) Application

i. Secure insulation with vapour barrier with wires. Secure insulation without vapour barrier with staples, tape or wires.
ii. Stop and point insulation around access doors and damper operators to allow operation without disturbing wrapping.
iii. Seal jacket joints with vapour barrier adhesive or tape to match jacket.
iv. Continue insulation with vapour barrier through penetrations.

Rectangular Duct Internal Insulation (Type C and D) Application

Insulate ducts where shown on the drawings, on the inside.

Only where specifically shown on the drawings, provide specified perforated sheet metal liner over mylar sheeting, fully isolating insulation fibres from the air stream

i. Attach insulation to duct with 100 percent coverage adhesive plus 12 gauge or equal, metal clips, with self-locking steel washers, attached to sheet metal with pin welder gun on no less than 18 inches (450 mm) O.C. longitudinally, 6 inches (150 mm) O.C. along joints, and 4" from sides. Installed insulation must be rated for 4,000 ft/min (1219 m/min) air velocity. Clip off pins inside ducts.
ii. Treat factory, shop, and field cut edges with a high-density spray-on and/or brush-on mastic to lock in fibres and to keep the liner from tearing.
iii. Repair damaged liner prior to installing ductwork.
iv. All adhesive and insulation material must be fire-retardant and UL Listed.
v. Submit duct sample of liner, its attachment, and edge treatment.

Round Duct Internal Insulation (Type E) Application

i. As an option to internally lined round duct, provide internally lined rectangular duct with equivalent cross-sectional area and Type C liner.
ii. Insulate ducts where shown on the drawings, on the inside.
iii. Coat interior duct surfaces with adhesive prior to installation.
iv. Insert liner sections into straight ducts and fittings, achieving a tight fit.
v. Treat factory, shop, and field cut edges with high density spray-on and/or brush-on

mastic to lock in fibres and keep the liner from tearing.

vi. Repair damaged liner prior to installing ductwork.

vii. All adhesive and insulation material must be fire-retardant and UL listed.

viii. Submit duct sample of liner, its attachment, and edge treatment.

Fire Rated Duct Wrap (Type F) Application

Install fire-rated duct wrap in accordance with the manufacturer's directions. Provide the number of layers as needed to achieve fire rating. Fire rating must be as shown on the drawings or as needed to continue rating of duct or pipe penetration of rated wall, floor, etc.

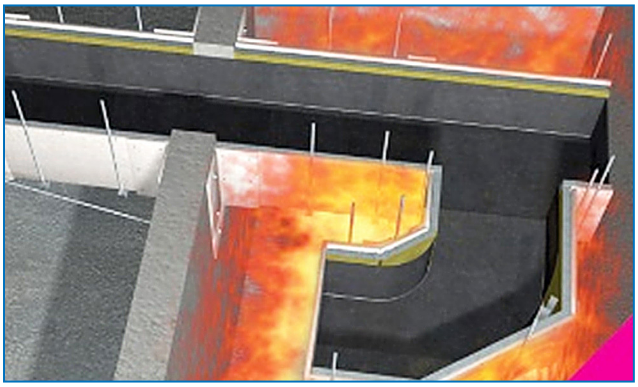


Figure 7-8: *Fire-rated duct insulation*

Figure 7-9: *Flexible duct*

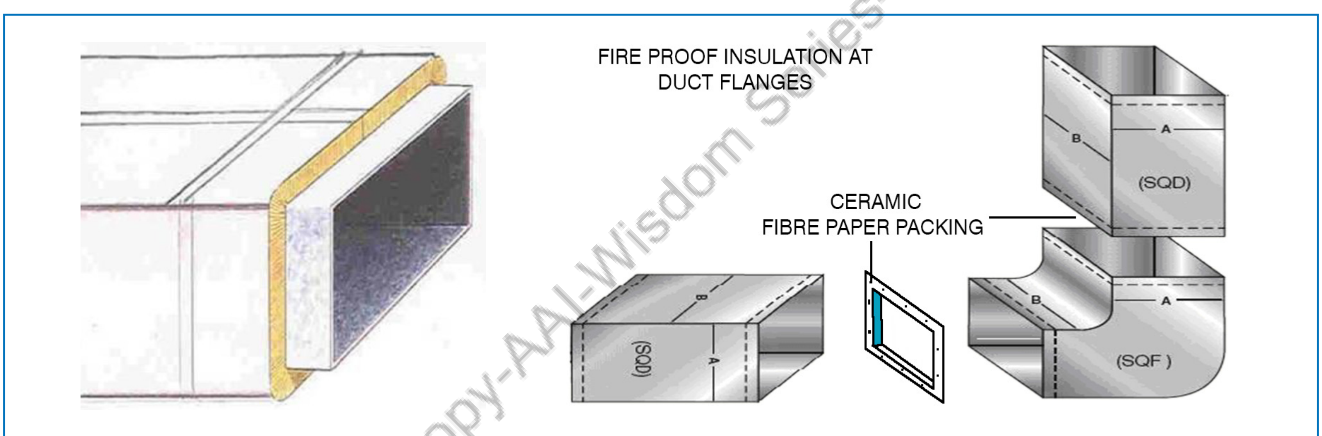


Figure 7-10: *Rigid PUF/PIR/nitrile duct insulation with insulation tape adhesive*

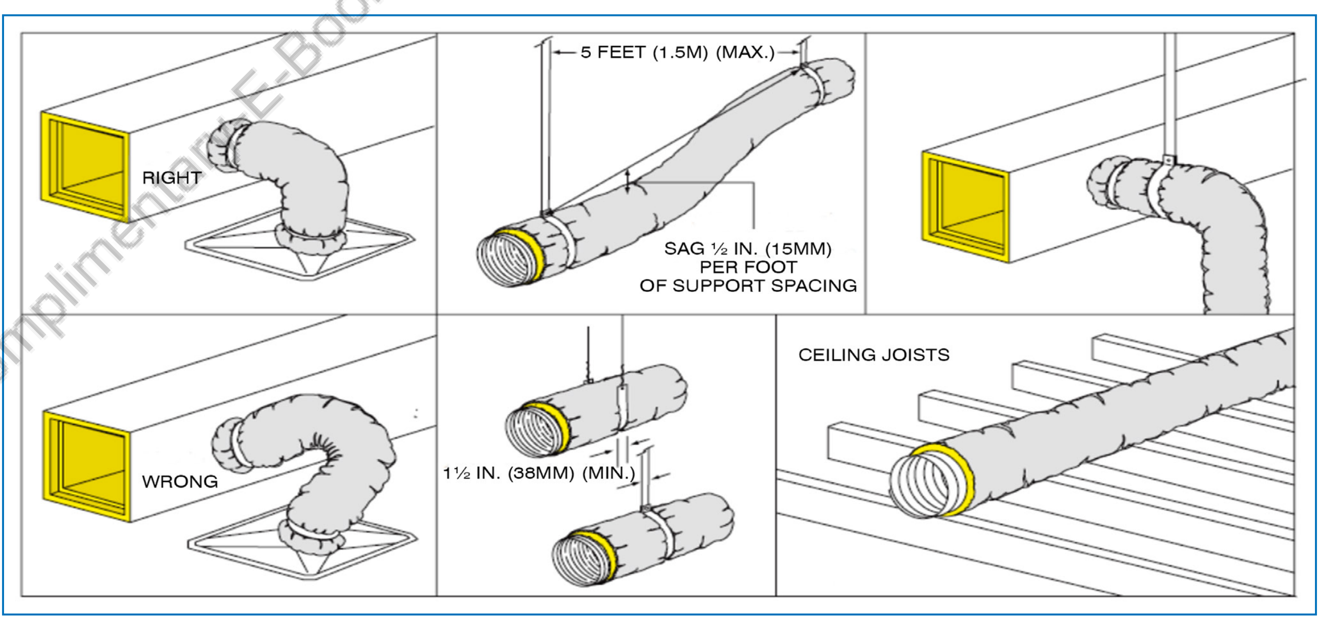


Figure 7-11: *Correct way to connect and support flexible duct*

CHAPTER 8

Transport Refrigeration Applications

The Concept of Cold Chain

India is the second largest producer of vegetables and fruits in the world. However, most of its horticultural produce is destined for local consumption since no proper infrastructure exists for its preservation and more than 30% is, therefore, wasted. Many small farm enterprises produce good quality fruits and vegetables, but post-harvest losses in distribution and transportation, poor road conditions resulting in abnormal travel time, hold ups at docks and procedural paper work delays result in deterioration of product quality.

The cold chain concept is an integrated approach for movement of perishable products from the point of production to the consumer or, as the saying goes, from farm to fork.

An efficient perishable handling system carries not only fresh chilled fruits and vegetables but also other chilled, frozen and processed foods like ice cream, dairy products, seafood and meat. In the entire process, nowhere are the temperature and humidity conditions allowed to be violated. Systems developed for moving products in the cold chain should try to get the product all the way to the consumer in controlled temperature conditions without fluctuations. Transport refrigeration is the most important link in ensuring that the product is transported from the cold storage to the distribution network without deterioration.

Perishable goods are classified on the basis of temperatures at which they are recommended to be transported to minimise deterioration.

Product Load

The products to be transported must be fully cooled prior to loading, to a temperature at which they are intended to be transported. However, some cooling is usually required in transit because the product temperature can rise during loading. During periods of high production, cooling facilities may be overloaded or sufficient time may not be permitted to fully cool the centre of the product. For example, ice cream or meat has to be transported below -20°C. It is essential to measure the core temperature before loading, not only the surface temperature.

If this precaution is not taken, disputes can arise and unnecessary doubts on the adequacy of the refrigeration unit cooling capacity and the ability to transport at the desired temperature may be raised when the fault lies with the product itself contributing heavy extra loads on the system, resulting in higher than expected temperatures inside the box.

Modes of Refrigerated Transport

The method of distribution of cargo depends on the type of cargo, the locality where it is to be distributed, the distance to be covered and the duration of the operation. The modes of transport generally used are listed in *Table 8-1*.

Table 8-1: *Common modes of refrigerated transport for different activities*

Activity	Mode of Transport
Direct delivery from farm to market	Refrigerated trucks
Retail delivery within city	Small refrigerated vans
Intercity	Highway refrigerated trucks or rail carriages
Long distances/ between countries	Marine containers or refrigerated air cargo containers

Refrigerated Trucks

Refrigerated trucks are used for short haul delivery within a population centre or between cities. The vehicles on which refrigerated truck bodies are constructed fall under three categories:

1. Mini-vans up to 8 to 10 m^3 internal box volume.
2. Light commercial vehicles (LCVs) up to 18 m^3 internal box volume.
3. Trucks (heavy commercial vehicles – HCVs) up to 25 m^3 internal box volume.

Local Distribution

Theses vehicle normally start in the morning and return to the depot or cold storage after distributing the product to retail shops. They are characterised by frequent door openings, and more severe duty is imposed on the refrigeration unit.

Highway and Intermodal Trailers

In a case where the cold storage is located at a distance from the city where distribution has to take place, the product once loaded in the truck is carried at a predetermined temperature over a long distance without door openings. The journey takes place over a couple of days/nights at a stretch. The product is then off-loaded in a local cold storage before local distribution. Humidity control also assumes great importance besides temperature, to ensure minimum product weight loss during transit.

In some countries with advanced cold chain infrastructure, refrigerated semi-trailers are used up to 55 ft (16.8m) long, 8.5 ft (2.59m) wide and14 ft (4.27m) high for transportation of frozen and chilled cargo.

Long Distances/ Between Countries

Highway trailers can be removed from their tractors and carried-piggy back on railroad flat cars, container ships or cargo aircraft. Containers normally come in two sizes: 20 ft long and 40 ft long. In the cold chain operational cycle, the product is normally pre-cooled and stored at the desired temperature and then loaded in a refrigerated truck in pre-cooled condition. The temperature throughout the product handling cycle is maintained at the desired temperature and is not allowed to increase at any point till the product is finally handed over to the end user.

Parameters for Truck Construction

While deciding on the construction of a refrigerated truck, a number of parameters need to be considered:

1. Make and model of the truck/vehicle to be used.
2. Maximum external dimensions allowed to be built as per RTO guidelines.
3. Weather data: maximum DB and WB temperatures in the area of operation.
4. Type of cargo to be handled, and size of individual box/carton.
5. Core temperature of the product to be loaded.
6. Temperature to be maintained inside the truck during transit.
7. Duration of the journey.
8. Distance over which the product is to be transported.
9. Time required to load and unload the truck.
10. Facilities available for handling the cargo at the receiving end.
11. Door location – side or/and rear.
12. Size of each door.
13. Whether air curtain is desired on the door opening.
14. Preferred body builder, and his track record of building refrigerated bodies.

The objective would be to design an insulated body matched with a suitable refrigeration system, which would provide economic temperature control and proper humidity to ensure minimum weight loss and product damage.

It should also be kept in mind that the product would be transported in the condition in which it is loaded, and product quality does not improve while it is being transported.

Truck Insulation

The objective of the body builder is to construct a lightweight body, having sufficient strength to meet rough road conditions, and ensuring the insulation stays dry and retains its original insulating value. The desired characteristics of insulation are:

1. Low thermal conductivity.
2. Low moisture permeability and retention.
3. Fire resistance.
4. Lightweight, so that more cargo can be carried.
5. Durability vis-à-vis vehicle life.
6. Ease of application of insulation and vapour retarders.
7. Sufficient strength to retain its shape at extreme temperature conditions without cracking, crumbling, shifting or packing from shocks, vibrations and flexing of the body structure.

The selection of insulation thickness is important. Low thickness and high conductivity require higher refrigerating capacity, whereas insulation with lower k-value and higher thickness requires smaller refrigeration capacity.

In determining the optimum insulation thickness, the insulated truck body and its refrigeration unit must be considered as one system.

Urethane foam is the most preferred insulation as it has k-value as low as 0.026 W/m·K even after ageing.

The recommended insulation thickness for a refrigerated body is 80-100 mm polyurethane of 42±2 kg/m^3 density for products to be carried at 0°C and above temperatures, and 150 mm for products up to -25°C temperature

The major areas contributing to heat ingress in a truck body are:

1. Through insulation.
2. Through structural members.
3. By air and moisture leakage.
4. Door opening while loading/unloading.
5. Product load, if it is not loaded at the temperature at which it is to be transported

A standard, plywood-lined 24-foot van body might be 23 feet 9 inches on the inside, but a refrigerated truck might only be 23 feet, depending on the insulation package, the doors, and other features of the truck. It may be felt that if a client is looking for a truck that can accommodate forklift-pallet loading, and wants to be able to load two pallets side-by-side inside the box, it may not be possible with a five-inch insulation wall. But, if the insulation is reduced by 1 or 2 inches to accommodate the pallets side-by-side, there may not be enough insulation to keep the product frozen.

Critical Areas for Body Builder

Particular attention must be paid by the body builder to the following:

a. Floor Insulation.
b. Moisture penetration.
c. Air leakage.
d. Reduction in heat transmission.

a. Floor Insulation

Floor loads are frequently supported on rigid insulating material to eliminate floor beams. The floor must be strong enough to support a fork lift, especially in large trucks, trailers and containers.

Floor insulation needs special attention since engine heat and radiation from hot road surfaces can raise the temperatures of the exposed under surfaces as much as 10° to 12°C above ambient air temperature.

If the floor is to be constructed of wood, the wooden pieces should have tongue-and-groove joints well treated and well-sealed against water penetration. The floor should allow adequate air movement under load. Several formed or extruded floor surfaces are available.

A metal skirt reaching at least 150 mm up the walls should be bonded to the floor so that water running down the wall or collecting on the floor will not enter the insulation.

Drains must be self-closing to prevent air ingress.

Similarly, the roof requires special attention. When the vehicle is stationary, solar radiation plays a major role in overheating the roof.

Common materials used for body construction are plywood, aluminium, stainless steel and certain plastics for interior wall surfaces. However, glass reinforced plastic materials are finding increased usage in both interior and exterior surfaces.

The front wall is generally constructed in thicker material for structural reasons and for supporting the weight of the refrigeration unit.

b. Moisture Penetration

All exterior surfaces of the insulation body must be made as air-tight and water vapour tight as possible. Water vapour will pass through any openings or non-vapour proof barrier in the outer shell and will condense in the insulation itself or in the cavities in the insulation space. It is a general observation that vehicles not properly insulated or provided with proper moisture protection increase in weight by as much as 250 kg over a period of use, and since wet insulation has higher conductivity, either the required low temperature may not be achieved or a higher load may be imposed on the refrigeration unit with the resultant increased operating and maintenance costs. Use of closed-cell insulation in place of fibrous types minimises moisture build up problems.

c. Air Leakage

Body cracks, although not appearing to be major areas, are in reality serious heat gain sources. The penalty is imposed by air entering the insulation space through cracks in the front of the vehicle caused by the motion of the vehicle. A 2m length of unsealed seam can permit 3,000 m^3/hr of air to enter at a speed of 80 km/hr when the driving force is 30 mm of water. At a temperature difference of 55°C at 50% RH, the additional load could be 4,600 BTU/hr (1350W).

Vehicles leak air even when they are stationary, because of the stack effect due to the temperature difference between inside and outside. Openings with an aggregate area of 6.5 cm^2 each at the top and bottom of the exterior skin would permit an air leakage of about 120 ft^3/hr (4 m^3/hr), by functioning as thin plate orifices. The same openings at 80 km/hr and 33 m^3/hr of air could be driven into the insulation space of the vehicle. At ambient temperature and humidity conditions of 38°C and 50% RH, the heat gain would be 1,100W.

This has another indirect effect: when air moves through the insulated space, the water vapour left behind causes trouble in several ways:

1. Increased heat gain caused by the latent heat of vaporisation.
2. Loss of pay load because of gain in mass.

3. Corrosion.
4. Increased heat gain through insulation.
5. Coating of coils with frost, resulting in loss of refrigeration effect.
6. More frequent defrosting.
7. Physical damage to insulation.
8. Rotting of wood members.
9. Odour.

Additional sealing of the metal skin of a truck is required to make it leak-proof. The methods normally used are:

1. Use of foam in place of plastic insulation.
2. Lining of the thin side of the exterior skin with a non-permeable vapour barrier, such as aluminium foil coated with plastic binder, which can be sealed at joints.
3. Coating of the interior surface of the exterior skin with some type of vapour sealing compound such as neoprene.

Care has to be taken to ensure that the vapour seal is not destroyed where wiring, piping or fumes penetrate the barrier.

The interior skin should not be vapour tight, to ensure that any accidental moisture ingress does not get trapped in the insulation and is freely absorbed by the air circulating inside the vehicle. The surface, however, should be water resistant so cleaning and washing is possible without soaking the insulation.

d. Reduction in Heat Transmission

The insulation should be light weight, with low thermal conductivity and adequate thickness, and having sufficient strength to withstand rough road conditions. The outer surface should be reflective, with light colours to minimise absorption of radiation heat.

Specifications of Refrigerated Truck

Table 8-2 lists the typical specifications of a large refrigerated truck meant for transportation of vaccine.

Table 8-2: *Specifications of a refrigerated truck for vaccine*

Description	Technical Particulars
Applications	A refrigerated vehicle comprises of an insulated container body and a refrigeration unit to give the required temperature inside for the transportation of vaccine.
Temperature range	+2°C to 8°C.
Body Parameters	
Structure	The body comprises of outer and inner panels and an insulating material. The outer and inner panels should be of CR sheet/ stainless steel. The insulated material should be polyurethane foam (PUF) with 42±2 kg/m³ density and minimum 100 mm thickness. Load bearing columns should be of HR steel as per IS 1079 with pressed formed sections. Proper lighting should be provided inside the cabin and thermal insulated container. No fluorescent tube should be used for lighting purpose.
Storage capacity	Minimum 32 m³.
Outer panel – roof and side walls	Minimum 0.5 mm CR sheet bonded with insulation.
Inner panel – side walls and ceiling	Minimum 0.5 mm stainless steel and CR sheet bonded with minimum 6 mm marine grade plywood. All joints should be sealed with a good quality sealant and fastened with SS screws.
Floor	Bottom-most sheet should be minimum 0.6 mm GP sheet bonded with insulation. Upper layer should be of 12 mm (minimum) plywood, and topmost layer of minimum 2 mm aluminium chequered plate.
Door	Two leaves with outer and inner panels and insulation matching the box. It should be completely air sealed with FRP section and suitable EPDM rubber profile.
Door opening angle	Minimum 270°.
Foam density	Minimum 40 kg/m³ PUF.
Thickness of insulation	Minimum 100 mm for side walls and 120 mm for roof and floor.
Insulation thermal conductivity	Maximum 0.025 w/m·K
Hold-over time	The container should hold the inside temperature at least for four hours at the ambient temperature of 43°C when it is not opened.

ATP Requirements for Refrigerated Trucks

The Agreement for Transport of Perishables (formally known as the Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be used for such Carriage – known in French as *Accord relatif aux transports internationaux de denrées périssables et aux engins spéciaux à utiliser pour ces transports*, abbreviated as ATP*)* is a 1970 United Nations treaty that establishes standards for the international transport of perishable food between the states that ratify the treaty. It classifies refrigerated trucks as follows:

Insulation Classification
- Heavily Insulated (IR): ≤ 0.4 W/m² °C
- Normally Insulated (IN): ≤ 0.6 W/m² °C

Temperature Classification
- -20°C or lower (Class C and F)
- -10°C or lower (Class B and E)
- 0°C or lower (Class A and D)

Validity
- Class A: 6 years
- Others: 3 years

Table 8-3: *Classification of refrigerated vehicles*

Ambient: +30°C ATP requirements Refrigeration equipment to cool empty body and maintain		
Class A	Ti	+12 to 0°C
Class B	Ti	+12 to -10°C
Class C	Ti	+12 to -20°C
Class D	Ti	≤ 0°C
Class E	Ti	≤ -10°C
Class F	Ti	≤ -20°C

The insulating material should be PUF with minimum density of 40 kg/m³ and minimum 100 mm thick. The load bearing columns should be of HR steel as per IS 1079, having pressed formed sections. Proper lighting should be provided inside the cabin and thermally insulated container.

The insulated truck trailer compartment is a self-contained atmosphere. The insulation is normally made of high-density polymer foam. This foam is similar to polystyrene foam, though it is usually of a higher density. Additionally, it is a more durable polymer than polystyrene.

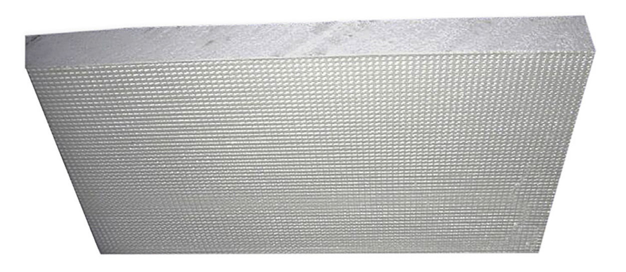


Figure 8-1: *Polystyrene foam*

The insulation, coupled with a seal all around the door, forms an atmosphere that is somewhat heat-tight. The heat that is left inside as well as any heat that goes in after the door is opened needs to be removed. This is achieved through the use of the refrigeration system.

Outer Surface of Van

Aluminium Alloy

Aluminium alloys are suitable for the outer surface, because of their light weight and malleability, which makes them easy to work with. They give the operator the ability to increase the cargo weight during transportation. The need to insulate the container with very thick side walls necessitates the choice of a light weight material such as aluminium.

Steel, which is commonly used in the construction of refrigerated vans, would make the container very heavy, reducing its cargo carrying capacity. An aluminium container is a more suitable way of transporting temperature-sensitive products.

Thermal efficiency and the ability to ensure minimum air leakage are the other aspects why aluminium becomes the favoured option.

A word of caution here pertaining to the maintenance and lifespan of aluminium alloy vans: they have high repair costs, since the welding process is quite demanding. Some of the seams

Figure 8-2: *Aluminium van trailer*

require riveting, making it costly. However, in a severe environment with temperature-sensitive products to transport, the option of an aluminium container is the best.

Fibreglass

Fibreglass is an alternative to aluminium alloys for this application. This material is good for heat insulation – the primary reason why it is used here. In addition, it is cheap and widely used. Here are other reasons why fibreglass has found major applications in this industry:

- The fibreglass material deflects moisture, provides an easy-to-clean surface and is capable of keeping a smooth, attractive look for many years.
- Fibreglass outer surface for the trailer resists dents and scratches that would damage other materials and spoil their looks.
- It is also suitable for printing graphics, adding to the aesthetic quality of the trailer.
- With fibreglass, the seamless glass board interior walls are easy to maintain and clean.

Figure 8-3: *Fibreglass truck body*

Sandwich Panels

This structure is simple and easy to produce. The middle layer is polyurethane and the outer layer is colour coated steel or glass reinforced plastic (GRP) sheet. The polyurethane material is sandwiched in between the steel or GRP walls and pressed together, or manufactured in a continuous line machine.

This provides high protection from the external elements. Polyurethane foam of density 42±2 kg/m^3 ensures consistent density and uniform insulation throughout the floor.

Thermal breaks at the door and the threshold also help in the minimisation of infiltration and in keeping a uniform temperature all through the cargo section. A GRP panel refrigerated body is very light and saves fuel consumption.

Figure 8-4: *Trucks with PUF panels*

Fully insulated walls, floors and ceiling helps to minimise any passive heat transfers and leaks that normally occur at joints and seams. This helps to avoid significant temperature differences inside the cargo section.

The insulation effect created is inferior to the vacuum insulating plate discussed below.

Vacuum Insulating Panels

The van plate is formed by pressing in a machine at high temperature under high pressure and creating a vacuum on the inner side.

Ideally, this is a vacuum heat insulating body made of a superfine glass fibre. An aluminium foil obstruction bag is carefully arranged outside the vacuum plate body, offering insulation against the heat. Sealing ports are then created on one side of the obstruction bag.

The vacuum heat insulating panel is fabricated in such a way that there are two sealing ports, where one is positioned outside the other. This set up offers an insulation film with a small thickness that comes with many other advantages such as:

- It is light weight with high sealing property
- It offers long heat insulation spans

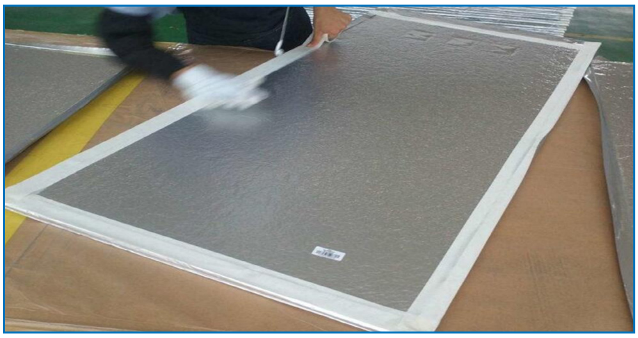


Figure 8-5: *Vacuum insulating panel*

- The effective volume is enhanced
- Decreased costs and increased distance of transportation
- It is most appropriate for products that require high energy conservation

Eutectic Plates

A cold-plate refrigeration method is one that can ensure that there is a temperature balance in the van. This is the ideal choice for high-end cold food. It offers a reliable and affordable way of refrigerating cargo for short distances and city distribution.

The cold plate is electrically powered, and this saves a lot of energy costs when compared to engine-driven refrigeration systems. Combined with the insulation characteristics of the materials used in the construction of a reefer trailer, the plate system together with its blower keeps the products cold.

The important advantages with this kind of system are:

- The refrigeration unit does not rely on engine uptime
- It saves on fuel
- Engine idling during stops is not required
- There is a proper and efficient way of maintaining body temperature
- Low maintenance costs and minimum moving sections make the operation simple
- All parts can be accessed and cleaned
- It provides a simple hot gas defrost procedure, which can be plugged during the night

The disadvantage is the high weight of plates that limits the space for storage of cargo. Also, it cannot be used for long distances and is suitable for city distribution for a maximum period of 8 to 10 hours without exceeding the allowable temperature limits.

Figure 8-6: Eutectic plates

Figure 8-7: Ceiling mounted eutectic plates

Rear Door Selection

Selecting the right type of rear door for a refrigeration trailer may save money. One may opt for roll-up doors instead of hinged doors for ease of use. However, it is important to look at the loss of insulation value that may be experienced over time with the choice of roll-up rear doors.

This would definitely lead to increased temperature control issues and increased operation costs, should the refrigeration unit be inadequately sized to cater to the insulation value loss.

An alternative to this would be going for hinged doors that would be in a position to keep the insulation performance with time.

In the choice of a refrigerated van trailer, one needs to keep in mind the delivery type by considering multiple stops, reducing load all through the day against full capacity load/unload delivery, etc. when spacing the back door.

Not all door types are suitable for the kind of application at hand. For instance, a roll-up door would be the wrong choice for ice cream delivery.

Figure 8-8: Hinged rear doors

It becomes difficult to maintain the temperature in between the stops. The only situation in which a roll-up door could work is when offloading the entire ice cream at one destination.

When specifications for the liftgate are prepared, it is necessary to consider the type of rear door to select. If the operations would require a lot of dock loading, a tuck-away liftgate would be suitable. The rail-style type, which moves up and down along the outer rails of the back door-frame, would not function well with swing doors.

Current Trends in Refrigerated Vans

Flexible Interiors

The interior arrangement of the refrigerated van can be customised to the operator's transport needs. The superstructure can be arranged with compartments and double floors. Multi-temperature cooling can be provided if different products – requiring different temperatures – are to be transported. To enhance the functionality of the superstructure, side doors can be included at any desired position. The refrigerated vans are fitted with mechanical refrigeration systems, with different compartments for chilled and frozen products.

Figure 8-9: *Flexible interior compartments with partitions*

Light-weight Refrigerated Vans

Manufacturers of truck bodies are trying out the use of carbonfibre-reinforced composites. The wall face sheets are made of carbon-fibre-

Figure 8-10: *A light-weight refrigerated van using carbon-fibre-reinforced composites*

reinforced material. This type of construction is a breakthrough in technology, as it leads to very light, strong and stable structure. The product weight carrying capacity increases substantially – nearly double the standard product weight carrying capacity.

Besides the enormous weight reduction, the new carbon structure features vacuum heat insulation; up to 60 percent less energy is required to maintain the low temperature inside the van body.

Solar Powered Refrigerated Trucks

Figure 8-11: *A solar powered refrigerated truck*

Liquid CO_2 Cooling

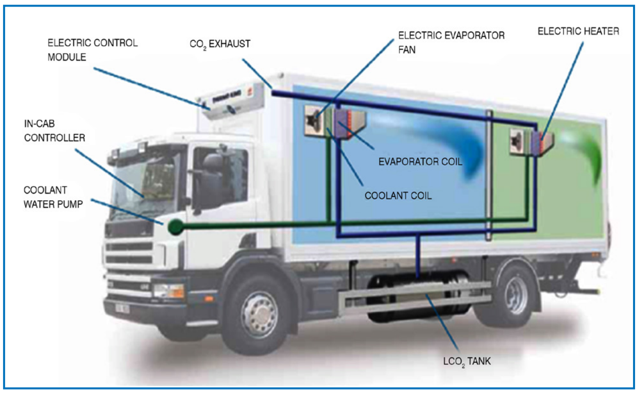


Figure 8-12: *Truck using liquid CO_2 for cooling*

Cargo Transportation by Rail

Figure 8-13: *Rail transportation of cargo*

Refrigerated Containers

Reefer containers are designed for the carriage of frozen and chilled foodstuff and general cargo by road, rail and sea (above or below decks), and are suitable for the environmental conditions imposed by these modes of transports.

The cargo carried in reefer containers includes deep frozen, frozen and chilled (excluding hung-chilled meat) in the temperature range -25°C to +25°C, with the outside temperature ranging from -40°C to +50°C, and is suitable to be subjected to severe thermal shock.

Insulation specifications for reefer containers are:

- Polyurethane foam blown with R141b (non -CFC) foaming agent
- Air leakage Q_{max} = 5m^3/hr at 25.4 mm WPG inside
- Heat transfer rate U_{max} = 20 W/K at 20°C mean temperature

Table 8-4: *Thickness and density of PUR foam thermal insulation*

	Thickness, mm	Minimum Density (kg/m³)
Side	100	40-45
Door	80	40-45
Roof	100	40-45
Floor	100	40-45
Corners		40-45

Figure 8-14: *Refrigerated containers*

Do's and Don'ts for Refrigerated Transport

Some important do's and don'ts are listed in *Table 8-5.*

Table 8-5: *Some important do's and don'ts*

Do's	Don'ts
Pre-chill the container/ truck	Expect refrigeration unit to cool the product
Check the goods prior to loading for temperature and quality	Switch off refrigeration unit at any time
Segregate products to avoid cross contamination	Transport unwrapped raw vegetables, fish or meat together in the same container
Select unit so that water loss is kept minimum	Allow chilling injury and weight loss
Allow sufficient air flow spaces between product and container	Delay loading/unloading to minimise exposure to ambient air
Ensure leak tight insulated body	Open the doors too frequently

Accessories

Depending upon the product to be transported, different types of accessories are needed to be fitted inside the truck. Some of the common accessories are depicted here.

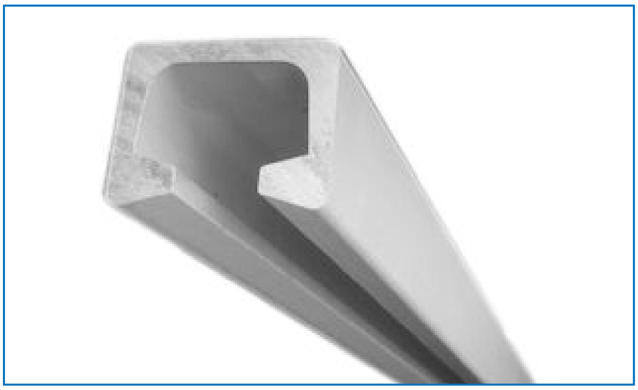


Figure 8-15: Cross section of meat hanging rail

Figure 8-16: Meat hanging hook

Figure 8-17: Meat hanging rail with hooks

Figure 8-18: PVC curtain behind the door to reduce heat gain from outside air

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About the Lead Author

Ramesh Paranjpey is a mechanical engineer with an M. Tech. in refrigeration from IIT Bombay, having over 35 years' experience. He has worked in very senior positions – with Kirloskar Pneumatic in Pune as vice president of air conditioning and refrigeration division, Carrier Transicold in Bengaluru and Singapore as managing director, and Voltas-Air International in Pune as chief executive officer. Currently he works as a technical advisor and consultant.

He is an ASHRAE Fellow, past president of ASHRAE Western India Chapter, and past president of ISHRAE Pune Chapter. He is a recipient of the 50-Year Distinguished Member Award from ASHRAE.

He was the winner of the Bry-Air Systems Design Award for 2009. He won in the Life Time Engineering category of ICE/Danfoss/Global Cold Chain Awards 2012. He has published more than 45 papers in international and national journals, and conducted more than 300 training programs for Honeywell, Alfa Laval, Voltas, Blue Star, Thermax, Emerson, Tata Motors, Elgi, ISHRAE and ASHRAE. He has made presentations at international fora in the USA, Singapore, China, Germany, etc.

He is the author of the following books:

1. Basics of Air Conditioning (2004) – for ISHRAE
2. Cold Room Manual for Freon Systems (2008) – for Emerson
3. How to use Ammonia Controls (2015) – for Danfoss
4. Air Cooler Manual (2016) – for Alfa Laval
5. Suggested Installation/Operation/Maintenance Practices for Closed-Circuit Field Erected Ammonia Refrigeration Systems (2016) – for Association of Ammonia Refrigeration
6. Cold Storage Design manual (2017) – for Association of Ammonia Refrigeration

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The Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE) was founded in 1981 at New Delhi by a group of eminent HVAC&R professionals. ISHRAE has over 13,000 HVAC&R professionals as its members today along with 10,000 student members, and operates from 43 Chapters and sub-Chapters spread all over India, with its HQ in Delhi. It is led by a team of elected officers who are members of the Society working on a voluntary basis, collectively called the Board of Governors. In pursuance of its objectives, ISHRAE works in the areas of Research, Standards, Education and Training, and Publication of Technical Books and a Journal. It also organises world-class annual exhibitions ACREX and REFCOLD, besides hosting technical seminars and conferences. ISHRAE is a responsible and socially-conscious Technical Society.

Objectives

- Advancement of the Arts and Sciences of Heating, Ventilation, Air Conditioning and Refrigeration Engineering and Related Services.
- Continuing education of members and other interested persons in the said sciences through lectures, workshops, product presentations, publications and expositions.
- Rendition of career guidance and financial assistance to students of the said sciences.
- Encouragement of scientific research.

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Knowledge dissemination: ISHRAE conducts conferences, seminars, exhibitions, workshops, panel discussions and product presentations throughout the country with both national and international participants to discuss, promote and display the state-of-the-art technologies, systems, products and services.

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Exhibitions cum Conferences: ISHRAE organises ACREX India, the largest international exposition in South Asia on the Air Conditioning, Refrigeration, Ventilation and Building Services industry. Held annually, ACREX showcases the latest technologies and innovations, and provides a platform for buyer-seller meets for technical and commercial personnel in the HVAC&R field. To serve the interests of the Refrigeration and Cold-chain sector, ISHRAE organises REFCOLD annually. ISHRAE is a member and active supporter of the National Centre for Cold-chain Development (NCCD).

Education: ISHRAE is actively engaged in Education and Training, and offers several courses for technical professionals, some with post-examination certification. This helps to bring trained manpower into the HVACR industry.

Research: ISHRAE promotes research in the field of HVAC&R technologies. It offers financial support to graduate and post-graduate students to carry out innovative R&D work in technology, systems and processes. ISHRAE partners with the industry, academia and the government to carry out scientific research at Institutes of Excellence associated with ISHRAE.

Standards: ISHRAE works in the national interest with various government ministries and departments; for example, in the development of Standards and drafting of the National Building Code for the Bureau of Indian Standards, working on Energy Conservation Building Code with the Bureau of Energy Efficiency, and with the Ozone Cell of the Ministry of Environment, Forest and Climate Change on refrigerant gases. ISHRAE has also developed a pioneering Standard on Indoor Environmental Quality.

Student Activities: ISHRAE student chapters in more than 150 engineering colleges encourage students to opt for careers in the HVAC&R industry with industry exposure including factory visits. The K-12 initiative of ISHRAE reaches out to young school children to make them aware of subjects like energy conservation and environmental concerns through drawing competitions, poster designs, quizzes and more, with emphasis on STEM education to inculcate scientific fervour and help them to grow up as responsible citizens.

Global Reach: ISHRAE works in close co-operation with other similar societies and organisations, both at national and international levels, for the promotion and development of concepts like health and safety, sustainability, Green buildings, energy efficiency and environmental responsibility, often interacting with UN bodies like UNDP and UNEP.

ISHRAE is indeed looked upon as a repository of technical knowledge in the HVAC&R and Building Services Industry globally by peer organisations and the Government.

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