

**Method for specifying
Thermal insulating
materials on pipes,
ductwork and equipment
(in the temperature
range – 40 °C to
+ 700 °C)**

Matériaux d'isolation thermique des tuyaux,
conduites et matériels (plage de température
comprise entre – 40 °C et + 700 °C)
Méthode de spécification

Anforderungen für Isolierwerkstoffe für
Rohre, Leitungskanäle und Zubehör im
Temperaturbereich von – 40 °C bis + 700 °C

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Refrigeration, Heating and Air Conditioning Standards Policy Committee (RHE/-) to Technical Committee RHE/9, upon which the following bodies were represented:

Autoclaved Aerated Concrete Products Association
British Ceramic Research Ltd.
Chartered Institution of Building Services Engineers
Combustion Engineering Association
Cork Industry Federation
Cranfield Institute of Technology
Department of Health
Department of the Environment (Building Research Establishment)
Department of Trade and Industry
(National Engineering Laboratory)
Department of Trade and Industry
(National Physical Laboratory)
Electricity Supply Industry in England and Wales
Engineering Equipment and Materials Users' Association
Eurisol (UK Mineral Wool Association)
Gypsum Products Development Association
Phenolic Foam Manufacturers' Association
Power Generation Contractors' Association (BEAMA Ltd.)
Royal Institute of British Architects
Thermal Insulation Manufacturers and Suppliers Association (TIMSA)
Thermal Insulations Contractors' Association

This British Standard, having been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 31 July 1990

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First published July 1977
Second edition July 1990

The following BSI references relate to the work on this standard:
Committee reference RHE/9
Draft for comment 87/75429 DC

ISBN 0 580 18167 7

Amendments issued since publication

Amd. No.	Date	Text affected

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Foreword

This British Standard has been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Policy Committee and it supersedes BS 5422 : 1977, which is withdrawn.

The general format of the 1977 edition has been retained but the distinction between industrial, commercial and domestic uses has been set out in greater detail, with domestic applications covered in a new section.

All the tables of thickness have been revised, using current and projected costs of material, labour and fuel. All tables, other than those relating to protection against condensation or freezing, are in terms of economic thickness where the total cost of the installation is balanced against heat loss over a given period. The assumptions on which the tables have been prepared are given in each case; methods of calculation are given in appendices to allow for thicknesses to be determined for conditions other than those appropriate to the tables.

Thicknesses are given for a range of thermal conductivities appropriate to the usual materials used for the application; thicknesses for intermediate thermal conductivities and pipe sizes may be deduced by interpolation. For the choice of type of insulating material and suitable methods of application, reference should be made to BS 5970.

Unless otherwise stated, the temperature of the surface to be insulated is taken to be the temperature of the fluid inside the pipe, duct or vessel.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Section 1. General

1 Scope

This British Standard describes a method for specifying requirements for thermal insulating materials on pipes, ductwork and equipment for certain defined applications and conditions within the temperature range -40°C to $+700^{\circ}\text{C}$. It also specifies physical requirements for the insulating materials.

Appendices A to H give information on the relevant calculations. Appendix J gives outside diameters of steel, copper and thermoplastics pipe. Appendix K gives fuel comparison costs.

This British Standard does not apply to pipelines that are embedded underground, nor does it refer to the insulation of buildings and structures.

Section two relates to the general use of thermal insulating materials and it covers physical characteristics of general applicability, thermal conductivity, temperature limitations and tests.

Section three is on refrigeration applications and it relates to the insulation of pipes, ducts, tanks, etc. containing fluid at temperatures from 0°C to -40°C . It includes references to vapour barriers.

Section four relates to services of chilled water from 0°C to $+10^{\circ}\text{C}$ and of cold water above $+10^{\circ}\text{C}$. Minimum thicknesses are recommended to prevent condensation and protect against freezing. It includes references to vapour barriers.

Section five covers economic thicknesses of insulation for central heating, hot water services and warm-air ductwork, and recommends minimum thicknesses to prevent condensation on chilled-air ductwork.

Section six gives economic thicknesses for central heating and hot water services and recommends minimum thicknesses to protect against freezing of cold water systems.

Section seven gives economic thicknesses for process pipework and equipment up to $+700^{\circ}\text{C}$, with tables of corresponding heat losses. References to thicknesses based on other criteria are included.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard, the definitions given in BS 874 and BS 3533 apply together with the following.

2.1 evaluation period

The time (in operating hours) over which the cost of heat loss from the insulated surfaces is to be calculated.

2.2 thickness of insulation

The thickness of insulating material only, excluding any protective finish or covering composition.

2.3 economic thickness

The thickness of insulation that gives a minimum total cost over a chosen evaluation period.

2.4 incremental cost

The cost per unit volume of an increment of insulation.

NOTE. See E.3.1.

2.5 cold water

The water delivered from the mains or natural supply.

2.6 chilled water

Water after processing through a cooling plant (0°C to $+10^{\circ}\text{C}$).

2.7 finishing materials

All materials used to cover the insulation whether preapplied or applied on site.

2.8 preapplied covering

The surfacing material applied by the insulation supplier.

3 General information to be supplied by the purchaser

The purchaser shall provide the following information in his enquiry, to enable the insulation requirements to be assessed by the contractor or supplier.

(a) Type of insulating material required and the form in which the material is to be provided, and whether any portions are to be specially fabricated for ease of removal.

(b) Type of finish required.

(c) Dimensions of items to be insulated.

NOTE. Unless dimensions are adequately detailed in drawings, information is required relating to surface dimensions of flat or large curved areas, external diameters and internal diameters (bores) of pipes, lengths of each size of pipe, numbers and shapes of bends, numbers and types of fittings (valves, flanges, tees, etc.) and space available for insulation especially at flanges and valves.

(d) Nature of surfaces that are to be insulated and an indication of surfaces for which care is needed and of any specific chemical requirement for the insulation and finish.

(e) Location of plant, i.e. whether the plant to be insulated is indoors, outdoors but protected from the weather, outdoors exposed to the weather or carried in ventilated ducts or open trenches.

(f) Temperature conditions, i.e. the normal operating temperature, the extreme temperature if other than the normal operating temperature, any fluctuating temperatures and the duration of extreme or fluctuating temperatures.

(g) Surrounding atmospheric conditions, including special note of abnormally high or low temperatures, high humidity, flammable conditions, potentially corrosive atmospheres, etc.

(h) Special service requirements.

Any special service requirements additional to those given in the appropriate section shall be notified to the contractor.

NOTE. The additional special requirements could include requirements for the following:

- (1) resistance to compression;
- (2) resistance to fire;
- (3) vibration conditions;
- (4) exposure to mechanical damage;
- (5) the presence of corrosive fluid;
- (6) resistance of surface to ingress of oils and flammable liquids.

(i) Bases on which thickness is to be determined.

NOTE. Some factors that may determine thickness are as follows:

- (a) economic thickness;
- (b) specified heat gain or loss per unit dimension or relative to the complete system;
- (c) specified temperature on the outer surface of the insulation or finish, e.g. for the protection of personnel (see BS 5970);
- (d) specified conditions of fluid at the point of delivery, taking into account the rate of flow;
- (e) special thickness requirements;
- (f) maintenance of the temperature of a bulk of static fluid over a specific period;
- (g) prevention of freezing of the fluid in the system.

Section 2. General use of thermal insulating materials

4 Physical characteristics

4.1 The physical characteristics of the insulating material, including finishing materials whether preapplied or applied on site, shall comply with appropriate British Standard for the material.

4.2 If combustible insulating materials are used, the fire performance shall comply with **10.2**, **14.2**, **17.2**, **20.2** or **23.2** as appropriate.

4.3 The materials shall not contain substances that will support pests or encourage the growth of fungi.

4.4 The materials shall be free from objectionable odour at the temperature at which they are to be used.

NOTE. Transient effects during the initial period of use may generally be ignored.

4.5 The materials shall not suffer permanent structural deterioration as a result of contact with moisture. If subsequent drying is practicable, the material after drying shall recover its physical form and thermal properties.

4.6 The insulation shall be suitable for specified conditions of use without the physical properties falling outside the tolerances allowed in the appropriate British Standard for the material.

4.7 Any materials liable to be in contact with the insulated surface shall not cause corrosion or degradation under normal site conditions.

4.8 The materials shall not cause a known hazard to health at the time of application or while in use.

NOTE. Reference should be made to BS 5970 for health hazards when selecting, storing or removing insulation. Attention should also be paid to the latest edition of the HSE Guidance Note EH 40 'Occupational exposure limits'.

5 Thermal conductivity

5.1 General

The manufacturer of the insulating material shall provide a table of declared thermal conductivity values based on results of tests carried out by the appropriate method of BS 874 in a suitable laboratory and covering a suitable range of hot face temperatures. The corresponding cold face temperatures and the relevant bulk densities shall be stated and the product identification given. Thermal conductivity shall be expressed in watts per square metre for 1m thickness and a temperature difference of 1 K.

NOTE. In terms of unit symbols thermal conductivity should be expressed as $W \cdot m / (m^2 \cdot K)$ but in normal practice it is simplified to $W / (m \cdot K)$.

5.2 Single-layer insulation (or multilayer insulation where the layers are of the same composition)

In all cases the contractor shall state the manufacturer's declared values of thermal conductivity for each material he is proposing to supply. These declared values shall be appropriate to the hot and cold face temperatures of use.

5.3 Composite insulation

When two or more layers of dissimilar insulating material are to be used, the contractor shall either quote the equivalent thermal conductivity based on the manufacturer's declared values or provide a declared value of thermal conductivity for each layer under the appropriate temperature conditions. The thickness of each layer shall also be stated.

NOTE 1. See appendices B and C.

NOTE 2. It is not normally necessary for the user to indicate the thickness of each layer when composite insulation is to be used, as this depends on the appropriate interface temperature.

5.4 Assessment of thermal conductivity

Thermal conductivity values corresponding to the working conditions of the plant concerned shall be calculated by the appropriate method given in appendix C.

NOTE. When using the tables for single-layer insulation it is normally sufficiently accurate to use the thermal conductivity appropriate to the arithmetic mean of the hot face and the ambient air temperature. If greater accuracy is required, particularly with composite insulation, the surface temperature and interface temperature are to be calculated and the thermal conductivity at the mean temperature of two appropriate faces is to be used (see appendix C).

6 Temperature limitations

The manufacturer shall state the maximum and minimum continuous operating temperature and any other temperature limitation appropriate to the anticipated service conditions, e.g. facings, binder and adhesive.

7 Thickness

If the purchaser requires thicknesses other than those given in the tables in the appropriate section, or bases other than those from which they were derived, the purchaser shall state the thickness required or the bases to be used in the calculation.

If the temperature of the surface to be insulated is above the limiting temperature of the preferred main insulating material, composite insulation shall be used to provide an inner layer of an insulating material of greater temperature resistance. In this case the total thickness applied shall be appropriate to the equivalent thermal conductivity. The thickness of each layer shall be calculated to ensure that the interface temperature between the two materials does not exceed the limiting temperature for the material of the outer layer.

NOTE 1. See appendices B and C.

NOTE 2. If the thicknesses given in the tables do not correspond with available commercial thicknesses, the nearest higher commercially available thickness should be considered.

In multilayer applications, where material thicknesses are rounded off to suit available commercial thicknesses, it is essential to check by a further calculation that each interface temperature is below the maximum continuous operating temperature of the materials involved.

8 Tests

8.1 General

If the purchaser requires tests to be carried out on the materials used, the test methods shall be in accordance with the appropriate British Standard, e.g. BS 476 : Parts 4 to 7 and 11, BS 874, BS 2972 and BS 3177.

Where no appropriate British Standard method exists, the purchaser shall authorize the use of a test method.

NOTE. This does not apply to the thermal conductivity test for preformed pipe sections.

8.2 Tests for thermal conductivity

The thermal conductivity of the samples tested shall be not greater than the manufacturer's declared value.

NOTE. There is no suitable test method for the accurate determination of thermal conductivity of insulating material in the form of pipe sections. Flat slabs of the same material, bulk density and structure are used in the hot-plate method in BS 874 : Section 2.1 or 2.2.

8.3 Tests for thickness of plastics composition material

Tests for thickness shall be carried out after application. Local irregularities (e.g. bolt heads) on the surface to be insulated shall be ignored.

Tests for thickness on any part of the insulating material shall show that the material has been applied at the agreed thickness, subject to agreed tolerances.

8.4 Uniformity of thickness of plastics composition material

Uniformity of thickness shall be assessed as in 8.3. Measurements are permitted to vary from the arithmetic mean within a range of ± 3 mm or ± 10 %, whichever is the greater, up to a maximum of ± 10 mm.

8.5 Tests for bulk density

Tests for bulk density of preformed insulating material shall be carried out before application. Tests for bulk density of plastics composition insulating material shall be made after the application of the material. In the latter case, measurements of thickness and area shall be taken before cutting and removal from the insulated surface. The portion of the material represented by the tests shall have been applied at a bulk density within ± 15 % of that quoted as a basis for thermal conductivity declaration.

Section 3. Refrigeration applications

NOTE. If the contained fluid is not static, information on the rate of flow is required. The type of finish used should not contain water unless there is adequate provision for drying out before the temperature of the contained fluid is reduced to below the dew point.

9 Information to be supplied by the purchaser

9.1 General

The requirements of clause 3 apply, as well as those specified in 9.2 and 9.3.

NOTE. See tables 2 to 5.

9.2 Type of insulating material required

The purchaser shall state whether or not the insulating material is to be suitable for the application of a water vapour barrier and whether or not the insulating material is to be resistant to the passage of water.

9.3 Type of finish

The purchaser shall state whether or not the finish is to be a water vapour barrier or a finish suitable for use in association with a water vapour barrier.

NOTE. The purchaser should satisfy himself that a water vapour barrier is not to be used as the surface finish if it is likely to be damaged during installation or in service.

10 Physical characteristics

10.1 General

The physical characteristics of the insulating material including finishing materials and vapour barriers, whether applied during manufacture or on site, shall comply with clause 4 and 10.2 and 10.3.

10.2 Fire performance

10.2.1 All materials shall be designated P when tested in accordance with BS 476 : Part 5

10.2.2 The complete assembly of materials as installed shall achieve class 1 spread of flame when tested in accordance with BS 476 : Part 7.

Certification for faced material shall state the nature of the facing material, the type and weight of any reinforcement, the type and weight of adhesive, the manufacturer of the substrate, its density and any other factors pertinent to the fire performance of the system.

NOTE. When the insulating material itself does not achieve class 1 spread of flame when tested in accordance with BS 476 : Part 7 in an unfaced form, particular care should be taken with the installation technique of such portions as joints, seams and fittings to avoid potential ignition sources during installation. Where the completed assembly is liable to mechanical damage in use, the final finish should be sufficiently strong to ensure that the insulant is not directly exposed.

10.2.3 Insulation systems on the exteriors of pipework or ductwork traversing a fire-resistant division shall incorporate insulation of limited combustibility.

NOTE. See appendix L for explanation of 'limited combustibility'.

10.3 Water vapour barrier

Where the insulating material itself does not comply with the water vapour permeance requirement, a vapour barrier on the outside (warm side) of the insulation shall be used. It shall take the form of a coating or sheet material, adequately sealed, that is resistant to the passage of water vapour. It shall be applied immediately after fitting the insulating material and before the fluid in the pipe or vessel is cooled.

The vapour barrier shall not reduce the fire performance of the complete assembly of insulating and finishing materials below the limits specified in 10.2.

The permeance of the vapour barrier shall be related to the cold surface temperature of the plant in accordance with table 1 and in no case shall the permeance of the material used as a vapour barrier exceed 0.01 g/(s·MN) for refrigeration work.

NOTE. See BS 5970 for recommendations for water vapour permeance.

Table 1. Required water vapour permeance in relation to plant temperature at an ambient temperature of + 10 °C (dry bulb)

Temperature of plant (cold surface)	Water vapour permeance of barrier
°C	g/(s·MN)
0	0.010
-5	0.004
-10	0.002
-15	0.0015
-20 to -40	
0.001	

NOTE. The appropriate permeance values for intermediate temperatures may be deduced from the values given.

11 Thickness

11.1 Minimum thickness to prevent condensation

In the absence of specific instructions from the purchaser, the thickness applied shall be not less than that given in the appropriate table of tables 2 to 5.

NOTE. Tables 2 to 5 give the minimum thicknesses needed to avoid condensation on the outer surface of the insulating material under the stated conditions of ambient temperature, relative humidity and emissivity of the external surface. Thicknesses determined by calculation of economic thickness in accordance with appendix E or for the control of heat gained on the outer surface (see appendix B) will be greater than these.

11.2 Other conditions

If thicknesses other than those given in tables 2 to 5 are required or the ambient conditions are different from those stated, the purchaser shall state the thicknesses required or the relevant ambient conditions and surface emissivity to be used in the calculations.

NOTE. See appendices B, E, F and G as appropriate.

12 Tests

12.1 General

The requirements of clause 8 shall apply as well as those specified in 12.2.

12.2 Water vapour permeance

The method in BS 3177 shall be used to assess the water vapour permeance of a flexible sheet material used for the vapour barrier. The test conditions, e.g. temperate or tropical, and the thickness of the test specimen shall be stated.

If the apparatus for the method in BS 3177 is unsuitable because of the thickness of the test specimen, method 8 of BS 4370 : Part 2 : 1973 shall be used.

Table 2. Minimum thickness of insulation for refrigeration applications to prevent condensation on a high emissivity outer surface (0.9) with an ambient temperature of +20°C and a relative humidity of 70 % r.h.

Outside diameter of steel pipe on which insulation thickness has been based in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m·K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in;bms; ;ems;mm)																			
21.3	5	6	7	9	6	9	12	14	9	12	16	19	11	15	20	22	13	18	22	27
33.7	5	7	8	10	7	10	13	16	9	14	17	20	12	16	21	25	13	19	25	30
60.0	5	7	9	11	7	11	13	17	9	14	19	22	12	17	23	28	13	20	27	33
114.3	5	7	9	11	7	11	14	18	10	15	21	25	12	19	26	32	15	23	31	38
168.3	5	7	9	11	7	11	16	20	11	16	22	27	13	21	28	35	17	25	34	42
273.0	5	7	9	12	8	12	17	21	11	18	24	29	15	23	30	38	18	28	37	46
508.0	5	7	10	13	9	14	17	22	12	19	25	32	16	25	32	40	19	29	40	49

Table 3. Minimum thickness of insulation for refrigeration applications to prevent condensation on a low emissivity outer surface (0.2) with an ambient temperature of +20°C and a relative humidity of 70 % r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m·K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)																			
21.3	8	10	13	16	12	17	21	26	16	22	29	35	20	28	36	43	24	33	42	51
33.7	9	12	15	18	13	19	24	29	18	25	33	39	22	31	40	49	26	37	48	60
60.0	10	13	17	21	15	22	27	34	20	29	38	46	24	36	48	60	29	43	58	73
114.3	10	15	20	25	17	26	33	42	23	36	48	60	29	46	62	75	37	56	73	88
168.3	11	17	22	28	19	30	40	48	28	41	53	65	36	52	67	80	43	61	79	96
273.0	13	19	25	31	22	32	42	52	30	45	58	70	39	56	72	88	46	67	87	106
508.0	13	20	27	33	23	34	45	55	32	47	62	77	41	61	78	96	49	73	95	116

Table 4. Minimum thickness of insulation for refrigeration applications to prevent condensation on a high emissivity outer surface (0.9) with an ambient temperature of +25°C and a relative humidity of 80 % r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m·K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)																			
21.3	9	12	15	18	12	17	21	25	15	21	27	32	18	25	32	37	21	29	36	43
33.7	10	14	17	21	13	19	24	29	17	24	30	35	20	27	35	42	22	32	41	49
60.0	11	15	19	23	15	21	26	32	18	26	33	40	21	30	39	48	24	35	45	56
114.3	11	16	21	26	15	23	29	36	19	29	38	46	23	35	46	57	28	41	54	66
168.3	11	17	22	27	16	24	32	40	21	31	41	51	26	39	51	61	31	45	59	71
273.0	12	18	23	29	18	26	35	43	23	34	45	55	29	41	54	67	33	49	64	79
508.0	12	19	25	32	19	28	36	45	24	36	48	60	30	45	58	72	35	53	69	85

Table 5. Minimum thickness of insulation for refrigeration applications to prevent condensation on a low emissivity outer surface (0.2) with an ambient temperature of +25°C and a relative humidity of 80 % r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)																			
	0				-10				-20				-30				-40			
	Thermal conductivity at mean temperature (in W/(m·K))																			
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)																			
21.3	17	23	29	36	23	32	41	50	29	41	53	65	35	50	65	81	41	59	77	100
33.7	19	27	33	41	26	37	47	58	33	47	62	76	40	57	76	98	46	68	93	115
60.0	22	31	40	49	30	44	57	72	38	57	77	96	46	70	95	114	54	85	109	130
114.3	25	38	51	65	37	57	73	68	49	73	92	110	61	86	109	131	72	99	125	150
168.3	30	45	57	69	43	62	79	95	55	78	99	119	66	94	119	142	77	108	137	164
273.0	33	48	61	74	47	67	86	104	60	85	110	131	73	102	131	157	84	119	152	182
508.0	34	51	66	81	50	73	94	115	64	93	121	147	78	113	145	176	91	132	169	205

Section 4. Chilled and cold water supplies in industrial and commercial applications

13 Information to be supplied by the purchaser

13.1 General The requirements of clause 3 shall apply as well as those specified in 13.2 to 13.5.

NOTE. See tables 6 to 9.

13.2 Type of insulating material required

The purchaser shall state whether or not the insulating materials need to be resistant to the passage of water.

13.3 Water vapour barrier or other finish

If the water temperature is likely to be less than the ambient temperature at any time, a water vapour barrier shall be incorporated.

The purchaser shall state whether or not a water vapour barrier is to be applied to the chilled water services only or to both the chilled and the cold water services, and shall state the type of finish to be applied if an additional or alternative finish is required.

NOTE. The purchaser should satisfy himself that it is not to be used as the surface finish if it is likely to be damaged during installation or in service.

13.4 Special service requirements

If the water in the system is likely to remain static for long periods when the ambient temperature is below freezing, this shall be stated by the purchaser.

13.5 Basis on which thickness is to be determined

If the insulation is intended to provide protection against freezing, the purchaser shall confirm the thicknesses to be used or the conditions on which the thicknesses are to be calculated.

NOTE 1. This requirement is particularly important with the smaller diameters of pipe, where the theoretical thicknesses required may be impracticable.

NOTE 2. Condensation of water vapour will occur on a surface that is at a temperature below the atmospheric dew point. Moisture can be deposited within the insulating material and on the insulated metal surface. If such conditions are transient or periodic there may not be a need to make provision against such condensation since the condensate will evaporate later. If the insulated surface is likely to be at or below the dew point for prolonged periods, an effective vapour barrier should be applied on the warmer face of the insulation to avoid deposition of moisture within the insulating material, thereby preserving its thermal characteristics and lessening the possibility of corrosion of the insulated cold metal surface.

The use of insulation alone does not afford complete protection against the freezing of water in pipes and vessels under all atmospheric conditions. If the ambient temperature remains low enough for a sufficiently long period and the movement of water through the pipe or vessel is very slow or if the water is static, no insulation, however thick, will prevent internal freezing.

Insulation reduces the rate of cooling and delays the onset of freezing, but the formation of ice may be avoided if the time intervals during which the water is static are short enough, or if more heat is supplied from the water passing through the system than is lost from the surface of the insulation together with the associated losses through the metal supports and hangers, or if supplementary heating is used, even if only in local areas.

If heat transfer through supports is considered significant, suitable load-bearing insulating material should be used on the pipe or vessel between the support and the surface to be insulated. If a water vapour barrier is required, the load-bearing material should be sealed to the same requirements as the basic insulation and fitted so that the integrity of the vapour barrier of the system is maintained.

If the heat transfer through the support is not significant but a water vapour barrier is required, it is important that the edges of the insulation, where interrupted at the support, are sealed to maintain the effectiveness of the vapour barrier.

Small diameter pipes and valves are particularly vulnerable to freezing.

As chilled water services (temperature range 0 °C to +10 °C) may require consideration that is different from that for cold water services (temperature above +10 °C), the information for the two types of service should be kept separate.

14 Physical characteristics

14.1 General

The physical characteristics of the insulating material, including fixing and finishing materials whether preapplied or applied on site, shall comply with clause 4 and 14.2 and 14.3.

14.2 Fire performance

14.2.1 All materials shall be designated P when tested in accordance with BS 476 : Part 5.

14.2.2 When tested in accordance with BS 476 : Part 7 the insulation material and the complete assembly of materials as installed shall achieve class 1 spread of flame.

Certification for faced material shall state the nature of the facing material, the type and weight of any reinforcement, the type and weight of adhesive, the manufacturer of the substrate, its density and any other factors pertinent to the fire performance of the system.

14.2.3 Insulating systems on the exteriors of pipework or ductwork traversing a fire-resistant division shall incorporate insulation of limited combustibility.

NOTE. See appendix L for explanation of 'limited combustibility'.

14.3 Water vapour barrier

If a separate water vapour barrier is required it shall be applied immediately after fitting the insulation and before the fluid in the system is cooled.

The water vapour barrier shall not reduce the fire performance of the complete assembly of insulating and finishing materials below the limits specified in 14.2.

The permeance of the material used as a vapour barrier shall not exceed the following values:

- (a) for chilled water supplies 0.015 g/(s·MN);
- (b) for cold water supplies 0.05 g/(s·MN).

NOTE. See BS 5970 for recommendations concerning vapour barriers.

15 Thickness

15.1 Protection against condensation

15.1.1 Minimum thickness to prevent condensation

In the absence of specific instructions from the purchaser, the thickness applied shall be not less than that given in table 6 or table 7 as appropriate.

NOTE. Tables 6 and 7 give the minimum thickness needed to prevent condensation on the outer surface of the insulating material under the stated conditions of ambient temperature, relative humidity and emissivity of the external surface. Even where the ambient conditions are less adverse than those stated, it is recommended that the thicknesses given in tables 6 and 7 are the minimum thicknesses to be used. Thicknesses determined by calculation of economic thickness in accordance with appendix E may be greater than these.

15.1.2 Other conditions

If minimum thicknesses other than those given in tables 6 and 7 are required, or the ambient conditions are more adverse than those stated, the purchaser shall state the thicknesses required or the relevant ambient conditions and surface emissivity to be used in the calculations.

NOTE. See appendix G.

15.2 Protection against freezing

15.2.1 Industrial applications

If protection against freezing is required, specific instructions shall be supplied by the purchaser.

NOTE 1. See 13.5 and notes 1 and 2 to 13.5.

NOTE 2. The time taken for water to reach its freezing point under given initial conditions and ambient temperatures is a function of the ratio between the heat capacity of the system (including that of the containing vessel and of the insulation) and the rate of heat loss from it. Consequently pipes of small bore are more vulnerable than those of larger bore and therefore the smaller pipes require relatively greater thicknesses of insulation for the same degree of protection against freezing. Thicknesses of insulation for reasonable protection against freezing are given in table 8 (see also clause 7). Table 8 is for the following assumed conditions.

(a) Outdoor service, i.e. infinitely high coefficient for the rate of transmission of heat from the external surface which allows for air movement over the exposed surface. Since this is an outdoor application the cooling times given by the equation in H.2.2 are used.

For indoor applications and for commercial and institutional applications see table 10.

(b) Static water in the pipe, initially at a temperature of +5 °C.

(c) Ambient air temperature of -10 °C.

(d) Mild steel pipe of heat capacity 455 J/(kg·K) at a density of 7840 kg/m³.

(e) Thermal conductivities of insulation as given in table 8. These relate to a hot face temperature of +5 °C and a cold face temperature of -10 °C (ambient air temperature).

(f) An elapsed time to 'no ice' or to '10 % ice' (by volume) respectively of 12 h.

(g) Calculations of insulation thickness have been made using the simplified method in H.2.2 which ignores the heat capacity of the insulation.

A separate calculation is required if any of these conditions do not apply.

Obviously, some of the theoretical thicknesses in table 8 are impracticable. In such cases, other means of protection, e.g. trace-heating or water-flow, should be adopted to supplement the protection that is afforded by the reduced thickness of insulating material.

Although the thicknesses given in table 8 are those derived by calculation for a specific temperature/time combination, the same thicknesses could be appropriate for other temperature/time conditions, as indicated in table 9.

Further data on times for the water to reach freezing point under other conditions are given in appendix H.

Thicknesses as given in table 8 can provide periods of protection longer than 12 h when the average ambient air temperature is higher than -10 °C and/or the initial water temperature is higher than +5 °C (see table 9). Conversely, there would be a reduction in the period for temperatures lower than -10 °C for air and +5 °C for water.

If 10 % ice formation by volume is acceptable, the times given in table 9 may be increased, the increment being dependent mainly on the size of the pipe.

Table 6. Minimum thickness of insulation for chilled and cold water supplies to prevent condensation on a high emissivity outer surface (0.9) with an ambient temperature of +25 °C and a relative humidity of 80 % r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)											
	+ 10				+ 5				+ 0			
	Thermal conductivity at mean temperature (in W/(m·K))											
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)											
21.3	6	8	9	11	8	9	12	15	9	12	15	18
33.7	6	8	11	13	8	11	14	16	10	14	17	21
60.0	6	9	12	14	9	12	15	18	11	15	19	23
114.3	6	9	12	14	9	13	16	20	11	16	21	26
168.3	6	9	12	15	9	13	17	21	11	17	22	27
273.0	6	9	13	16	9	14	19	22	12	18	23	29
508.0	7	10	13	16	10	14	19	24	12	19	25	32
Flat surfaces	7	10	14	17	10	15	20	25	13	20	26	33

Table 7. Minimum thickness of insulation for chilled and cold water supplies to prevent condensation on a low emissivity outer surface (0.2) with an ambient temperature of +25 °C and a relative humidity of 80 % r.h.

Outside diameter of steel pipe on which insulation thickness has been based (in mm)	Temperature of contents (in °C)											
	+ 10				+ 5				+ 0			
	Thermal conductivity at mean temperature (in W/(m·K))											
	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
	Thickness of insulation (in mm)											
21.3	10	14	17	20	14	18	23	28	17	23	29	36
33.7	11	16	20	24	15	21	27	32	19	27	33	41
60.0	13	18	23	28	17	25	31	38	22	31	40	49
114.3	14	20	27	33	20	30	38	48	25	38	51	65
168.3	15	23	31	39	22	35	45	54	30	45	57	69
273.0	17	26	34	42	25	37	48	58	33	48	61	74
508.0	19	28	36	44	27	39	51	63	34	51	66	81
Flat surfaces	21	31	41	52	29	44	58	73	37	56	75	94

15.2.2 Commercial and institutional applications

In the absence of specific instructions from the purchaser, the thickness applied shall be not less than that given in table 10.

NOTE 1. Table 10 is for the following assumed conditions:

- (a) indoor installations include roof spaces, ventilated ground floor voids, unheated cellars and garage spaces;
- (b) outdoor installations include pipework inside external ductwork;
- (c) static water in the pipe initially at a temperature of $+5\text{ }^{\circ}\text{C}$;
- (d) mean ambient air temperature over 24 h of $-3\text{ }^{\circ}\text{C}$ indoors and $-5\text{ }^{\circ}\text{C}$ outdoors;
- (e) insulation of heat capacity $840\text{ J/(kg}\cdot\text{K)}$ at a density of 80 kg/m^3 ;
- (f) an elapsed time of 24 h for 50 % ice formation;
- (g) mild steel pipe of heat capacity $455\text{ J/(kg}\cdot\text{K)}$ at a bulk density of 7840 kg/m^3 .

If insulating materials of intermediate thermal conductivity are proposed for the calculation methods, appendix H may be used to ensure that the thickness selected affords at least the same degree of frost protection. Alternatively, the thickness may be selected by interpolation from table 10.

NOTE 2. For indoor conditions the equation in H.2.1 incorporates full heat capacity of insulation. For outdoor conditions the equation in H.2.2 should be used, which ignores heat capacity of insulation.

15.3 Control of heat gain to chilled water lines

Where it is required to verify the thickness of insulation needed to control the heat gain to chilled water lines, the calculations shall be in accordance with appendix B.

NOTE. Normally it is advisable to control the rate at which heat is gained by a chilled water system, in order to conserve the energy input for cooling purposes. The heat gain corresponding to the thickness of tables 6 and 7 can be calculated using the equations in appendix B. When making such calculations, allowance should be made for heat gains through joints, valves and other fittings.

All methods employed to deduce a thickness of insulation to meet a specified heat gain include an element of iteration in the calculation, even when a constant value for thermal conductivity is assumed. Of these, perhaps the most elementary routine is to select a thickness and then calculate the corresponding heat gain, using equations of the type given in appendix B. The procedure is repeated, with an appropriate choice of further thicknesses, until the specified gain, or the one next lower in value, is observed. It should be noted that the symbol q in appendix B relates to the heat transmission per unit area of pipe surface, so that to relate this figure to the external surface over the insulation it is necessary to multiply by a factor which is obtained by dividing the outside diameter of the pipe by the diameter over the external surface of insulation.

Table 8. Calculated minimum thickness of insulation required to give protection against freezing under industrial conditions (See notes to 15.2.1)

Water temperature		+5 °C				+5 °C			
Ambient temperature		-10 °C				- 10 °C			
Evaluation period		12 h				12 h			
Permitted ice formation		Nil				10 %			
Calculation method		H.2.2				H.2.2			
Outside diameter	Inside diameter (bore)	Thermal conductivity (in W/(m·K))							
		0.02	0.03	0.04	0.05	0.02	0.03	0.04	0.05
mm	mm	Thickness of insulation (in mm)							
Steel pipes¹⁾									
21.3	16.0	—	—	—	—	1034	—	—	—
26.9	21.6	5028	—	—	—	179	715	2740	—
33.7	27.2	716	4812	—	—	74	195	473	1121
42.4	35.9	203	708	2349	—	37	75	137	240
48.3	41.8	124	340	875	2195	28	51	85	135
60.3	53.0	66	141	275	513	19	32	48	69
76.1	68.8	41	75	123	193	13	21	30	40
88.9	80.8	31	54	84	122	11	17	24	31
114.3	105.3	22	35	51	70	8	12	17	21
168.3	158.6	14	21	29	37	5	8	10	13
219.1	207.9	10	16	21	27	4	6	8	10

NOTE. For commercial and institutional applications see table 10.

¹⁾Outside diameters shown are as given in table 2 of BS 1387 : 1985 (see also appendix J). Thickness of insulation for other pipe outside diameters can be obtained by interpolation or extrapolation.**Table 9. Time to the onset of freezing for some conditions of ambient air temperature and initial water temperature (other than those in table 8)**

Ice formation	Initial water temperature (in °C)	Ambient air temperature (in °C)		
		-5	-2	-1
		Time (in h)		
Nil	+10	19	31	41
	+5	12	21	31

Table 10. Calculated minimum thickness of insulation to protect against freezing for commercial and institutional applications

Water temperature		+5 °C				+5 °C			
Ambient temperature		-3 °C				- 5 °C			
Evaluation period		24 h				24 h			
Permitted ice formation		50 %				50 %			
Calculation method		H.2.1				H.2.2			
Outside diameter	Inside diameter (bore)	Indoors				Outdoors			
		Thermal conductivity (in W/(m·K))							
		0.025	0.035	0.045	0.055	0.025	0.035	0.045	0.055
mm	mm	Thickness of insulation (in mm)							
Copper pipes ¹⁾									
15.0	13.6	31	56	83	109	109	340	1032	3101
22.0	20.2	13	21	31	45	28	52	93	159
28.0	26.2	8	13	18	24	16	26	40	58
35.0	32.6	7	9	13	16	11	17	24	33
42.0	39.6	5	7	9	12	9	13	17	22
54.0	51.6	4	5	7	8	6	9	12	15
76.1	73.1	3	4	5	6	4	6	8	9
108.0	105.0	2	3	3	4	3	4	5	6
Above 108.0 mm outside diameter and flat surfaces		2	3	3	4	3	4	5	6
Steel pipes ²⁾									
21.3	16.1	23	40	62	85	59	137	303	659
26.9	21.7	13	20	29	43	26	46	77	124
33.7	27.3	9	13	19	25	16	27	40	57
42.4	36.0	6	9	12	15	11	16	22	29
48.3	41.9	5	7	9	12	9	12	17	22
60.3	53.1	4	5	7	9	6	9	12	15
76.1	68.9	3	4	5	6	5	7	9	11
88.9	80.9	3	4	4	5	4	6	7	9
Above 88.9 mm outside diameter and flat surfaces		3	4	4	5	4	6	7	9

¹⁾To table X of BS 2871 : Part 1 : 1971.
²⁾To table 4 of BS 1387 : 1985