BRITISH STANDARD

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1983

Electric surface heating —

Part 2: Guide to the design of electric surface heating systems

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Cooperating organizations

The Power Electrical Engineering Standards Committee, under whose direction this British Standard was prepared, consists of representatives from the following:

Associated Offices Technical Committee
British Electrical and Allied Manufacturers' Association (BEAMA)
British Railways Board
British Steel Corporation*
Department of Energy, Electricity
Department of Industry
Electrical Contractors' Association
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Electricity Supply Industry in England and Wales*
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BCIRA
British Gas Corporation
British National Committee for Electroheat
Committee for Electrical Equipment for use in Flammable Atmosphere (BEAMA)
Glass Manufacturers' Federation
Health and Safety Executive
Induction and Dielectric Heating Manufacturers' Association
Lighting Industry Federation Ltd.

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Contents

Foreword

This Part of this British Standard has been prepared under the direction of the Power Electrical Engineering Standards Committee.

It is intended that this standard will comprise the following Parts.

- — *Part 1: Specification for electric surface heating devices;*
- — *Part 2: Guide to the design of electric surface heating systems;*
- — *Part 3: Code of practice for the installation, testing and maintenance of electric surface heating systems.*

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 26, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

0 Introduction

Stabilized electric surface heating systems are designed on the basis that stabilization is achieved at a specified temperature under empty pipe or zero process flow conditions. This leads to stabilization after a specific time when empty, or after a longer specific time with zero process liquid flow, in both cases at the same stabilized temperature. Where a stabilized design cannot be achieved, ESH temperature controllers are incorporated.

1 Scope

This Part of BS 6351 provides a step-by-step guide to the design of a safe ESH system. The guide takes into account energy requirements, temperature considerations and the selection of ESH devices, thermal insulation and control equipment.

The standard requires that the designs take account of the maximum temperature of the process fluid that may flow or be present.

NOTE The titles of the publications referred to in this Part of BS 6351 are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 6351, the definitions given in BS 6351-1 apply.

3 Minimum safety requirements for ESH devices and control equipment

3.1 General. A system of service categories is described which is derived from the consideration of the risks to which an ESH device will be exposed in the environment where it is to be used. Requirements are given for the ESH device and its associated control equipment for use in each service category.

These requirements are considered the minimum permissible; additional constraints may be imposed by special environmental conditions or local regulations and legislation.

Clause **22** of BS 5345-1:1976 gives requirements for earthing in hazardous areas.

3.2 Service category. The first digit of the service category indicates the degree of exposure of the ESH device to water and the second digit of the service category indicates the risk of mechanical damage to the ESH device, as shown in Table 1.

Table 1 — Service categories

Service categories	Probability of presence of water	Risk of mechanical damage
00	None	None
01	None	Low
02	None	High
10	Law	None
11	Law	Low
12	Law	High
20	High	None
21	High	Low
22	High	High

Where there is any doubt as to the degree of risk the higher service category should be assumed, taking into account the risk of damage during installation, operation and maintenance.

The grades of ESH devices described in clause **4** of BS 6351-1:1983 correspond with these service categories. For example, an ESH device graded 11 is the minimum requirement for use in a service category of 11.

3.3 Equipment

3.3.1 *Non-hazardous areas.* The minimum requirements for use in non-hazardous areas are given in Table 2.

Over-current protection should be provided for each heating zone. This may be either a fuse or a miniature circuit-breaker.

It is essential that equipment enclosures have protection appropriate to the areas in which they are installed.

If there is a possibility of damage due to overheating, the system should be designed to stabilize at a safe temperature, or an over-temperature controller should be fitted to each heating zone.

3.3.2 *Type of protection "N".* Minimum requirements for ESH systems with type of protection "N" for use in hazardous areas are given in Table 3.

Over-current protection should be provided for each heating zone. This may be either a fuse or a miniature circuit-breaker.

It is essential that the residual current operated circuit-breaker has a trip current not greater than 100 mA and operates within 100 ms, but values of 30 mA and 30 ms are to be preferred unless there is evidence that this will result in a marked increase in nuisance tripping.

Table 2 — Minimum requirements for ESH systems (see **3.3.1**)

Service category		Minimum grade of ESH device	Over- current protection	Residual current protection with trip indication	Means of isolating system from supply	Over-temperature limitation
Exposure to water	Exposure to mechanical damage					
0	0	00	X		X	see **3.3.1**
0	1	01	X		X	see **3.3.1**
0	2	02	X	X	X	see **3.3.1**
1	0	10	X		X	see **3.3.1**
1	1	11	X		X	see **3.3.1**
1	2	12	X	X	X	see **3.3.1**
2	0	20	X		X	see **3.3.1**
2	1	21	X	X	X	see **3.3.1**
2	2	22	X	X	X	see **3.3.1**
X indicates requirement.						

Table 3 — Minimum requirements for ESH systems with type of protection "N" (see **3.3.2**)

Service category		Minimum grade of ESH device	Over- current protection	Residual current protection with trip indication	Means of isolating system from supply	Over-temperature limitation
Exposure to water	Exposure to mechanical damage					
0	0	11	X	X	X	X
0	1	11	X	X	X	X
0	2	12	X	X	X	X
1	0	21	X	X	X	X
1	1	21	X	X	X	X
1	2	22	X	X	X	X
2	0	21	X	X	X	X
2	1	21	X	X	X	X
2	2	22	X	X	X	X
X indicates requirement.						

It is essential that equipment enclosures have protection appropriate to the areas in which they are installed.

An ESH system has to be designed so that under all conditions that may reasonably be foreseen the surface temperature of the ESH device is limited to the T-classification temperature or lower. This is achieved either by a stabilized design or by fitting two ESH temperature controllers to each heating zone. In the latter case, one has to be an over-temperature controller set to ensure that the maximum temperature of the surface to be heated is not exceeded but the other may be utilized at a lower setting for process or other requirements. The sensors of the controllers have to be located where it may reasonably be foreseen that the maximum temperature will occur and due consideration should be given to the direction of flow, the lowering of liquid level and the material in the vessel or pipe.

Where the maximum withstand temperature of the ESH device is below the T-classification of the area, it is essential that the stabilized design or over-temperature controller specified limits the ESH device to its maximum withstand temperature.

NOTE Should the criteria for a stabilized design have been met apart from exceptional specified operations or conditions, the following may be provided as an alternative to having two ESH temperature controllers.

a) A safe system of work is formally adopted such that the ESH system is de-energized whilst the specified operations are taking place,

and

b) either:

1) an inter-lock system is fitted to prevent specified operations taking place whilst the ESH system is energized;

or

2) one over-temperature controller is fitted which de-energizes the ESH system before the maximum temperature of the surface to be heated is reached.

3.3.3 *Type of protection "e".* Minimum requirements for ESH systems with type of protection "e" for use in hazardous areas are given in Table 4.

Over-current protection should be provided for each heating zone. This may be either a fuse or a miniature circuit-breaker.

It is essential that the residual current operated circuit-breaker has a trip current not greater than 100 mA and operates within 100 ms but values of 30 mA and 30 ms are to be preferred unless there is evidence that this will result in a marked increase in nuisance tripping.

It is essential that equipment enclosures have protection appropriate to the areas in which they are installed.

An ESH system has to be designed so that under all conditions that may reasonably be foreseen the surface temperature of the ESH device is limited to the T-classification temperature or lower. This is achieved either by a stabilized design or by fitting two ESH temperature controllers to each heating zone. In the latter case, one has to be an over-temperature controller set to ensure that the maximum temperature of the surface to be heated is not exceeded but the other may be utilized at a lower setting for process or other requirements. The sensors of the controllers have to be located where it may reasonably be foreseen that the maximum temperature will occur and due consideration should be given to the direction of flow, the lowering of liquid level and the material in the vessel or pipe.

The over-temperature controller should either be a lockout type or be fitted with an over-temperature alarm and has to fail to safety. If an over-temperature alarm is used, provision of adequate monitoring of that alarm, such as 24 h surveillance, is necessary.

Where the maximum withstand temperature of the ESH device is below the T-classification of the area, it is essential that the stabilized design or over-temperature controller specified limits the ESH device to its maximum withstand temperature.

NOTE Should the criteria for a stabilized design have been met apart from exceptional specified operations or conditions the following may be provided as an alternative to having two ESH temperature controllers.

a) A safe system of work is formally adopted such that the ESH system is de-energized whilst the specified operations are taking place,

and

b) either

1) an inter-lock system is fitted to prevent specified operations taking place whilst the ESH system is energized;

or

2) one over-temperature controller is fitted which de-energizes the ESH system before the maximum temperature of the surface to be heated is reached.

3.3.4 *Other types of protection.* For ESH systems having other types of protection (see clause **11** of BS 6351-1:1983), the control equipment may be subject to special consideration.

Table 4 — Minimum requirements for ESH systems with type of protection "e" (see **3.3.3**)

Service category		Minimum grade of ESH device	Over- current protection	Residual current protection with trip indication	Means of isolating system from supply	Over-temperature limitation
Exposure to water	Exposure to mechanical damage					
0	0	22	X	X	X	X
0	1	22	X	X	X	X
0	2	22	X	X	X	X
1	0	22	X	X	X	X
1	1	22	X	X	X	X
1	2	22	X	X	X	X
2	0	22	X	X	X	X
2	1	22	X	X	X	X
2	2	22	X	X	X	X
X indicates requirement.						

4 Thermal insulation

4.1 General. The thermal insulation system, comprising the thermal insulation itself, its weatherproofing and any outer mechanical cladding or finishing, is an integral part of any electric surface heating system.

Details of the thermal insulation system will often be specified to the ESH system designer; on other occasions he will be required to choose the system himself.

Systems should be designed to comply with BS 5970 and BS 5422 unless otherwise specified. Specified thermal insulation for temperatures above 230 °C should be non-combustible as defined by the test in BS 476-4, whilst for temperatures below 230 °C, grade P of BS 476-5 will apply unless there are special circumstances.

4.2 Choice of a thermal insulation system. A number of often conflicting factors should be taken into account when deciding upon a thermal insulation system, including:

a) hot surface temperature;

b) thermal conductivity and its variation with temperature;

c) chemical compatibility with pipe, ESH device and process materials, including the possibility of exothermic reaction with any material which may leak from the pipe;

d) economics;

e) service category (see **3.2**);

f) mechanical properties including strength and water absorption;

g) emissivity of thermal insulation and cladding.

Non-combustible materials should be used wherever possible (see BS 476-4).

It is essential to use data from the thermal insulation manufacturer, particularly in critical cases such as stabilized designs or in hazardous areas, where the use of accurate data is essential for safety.

4.3 Cladding and finishing. Many protective finishes in common use are flammable, such as bituminous compounds and polymers, and even fire retardant compounds may only afford temporary protection. Suitably resistant finishes such as sheet metal or other non-absorbent coatings should be specified, particularly where danger of contamination by oil or other flammable chemicals exists.

It may be noted that galvanized steel is preferred on grounds of resistance to fire hazard but site conditions, particularly outdoors, may militate against its selection.

In conditions where the operating temperature of a plant is below that of the outer surface of the insulation system, water vapour will migrate towards the cooler surface and will condense inside the thermal insulation at the dew point line and possibly become ice at the 0 °C line. To prevent degradation of the system an effective vapour barrier should be applied over the thermal insulation.

5 Wiring systems

5.1 General. The wiring system is that part of the installation between the feeder cable and the ESH device. It includes the distribution board and the wiring between the system components such as temperature controllers and low voltage transformers.

5.2 Design. The regulations, codes and standards applicable to conventional electrical distribution systems and wiring systems apply equally to the design and installation of those for electric surface heating. The whole of any installation is required to be in conformity with the current edition of the Institution of Electrical Engineers' Regulations for the Electrical Equipment of Buildings.

Clause **25** of BS 5345-1:1976 gives an outline of the requirements for wiring systems in hazardous areas.

Electric surface heating systems may, however, exhibit characteristics which influence the design of wiring systems, such as the following.

a) Protective devices require to be rated to allow for any inrush current to the ESH device when cold. The wiring system may be required to be rated for this condition rather than for the normal circuit current.

b) Special wiring methods may be required to allow for vibrations and movements due to expansion or contraction of the heated equipment.

c) Electric surface heating is frequently installed in areas having unusual environmental conditions or requirements.

d) ESH systems frequently have discrete heating zones which require an electrical supply remote from the main distribution source and early consideration should be given to feeder cable sizing.

e) Approval of ESH systems for use in hazardous areas may require the protective devices in the wiring system to have specified characteristics.

6 System design guide

6.1 General. The general principles adopted in this guide are based on current heat transfer theory combined with the experience of major manufacturers, installers and users and the guidance of approval authorities and other interested bodies.

6.2 Heating duties. Required heating duties may be divided into:

a) *Temperature maintenance.* Temperature maintenance requires the provision of power to a surface equal to the rate of heat loss due to the temperature difference between the surface and the surroundings. It is difficult to design a system which provides exactly this balance under all conditions. Therefore it is necessary to design for the worst condition and to provide some form of heat regulation. This may be achieved by stabilization techniques described in this clause or by using ESH temperature controllers. In the latter case it is usual to design the heating system such that the temperature controller is on for no more than 90 % of the time under the most onerous conditions expected. This means that at least 10 % more power is available should conditions on site prove to be worse than anticipated due to variations in thermal insulation materials, etc. However, this extra power has to be taken into account if the system is to be used in a hazardous area or operated close to the material specification limits. Details of the design calculations for heat loss are given in this clause.

b) *Process heating.* The purpose of process heating is to provide an energy input to raise the temperature of a material or system, change the state of a material or to promote or control a chemical reaction. The design of an ESH system will involve the calculation of the powers required for some or all of these, together with compensation for heat losses as in **6.2** a).

Temperature limitation may be achieved by use of ESH temperature controllers or by the stabilization techniques described in this clause.

6.3 Information required. The information required by the ESH system designer will generally be specified in the enquiry documents from which the designer is working but discussions may be required with the plant designer and the user/occupier. Where assumptions have to be made it is essential that they are clearly stated and err on the side of safety.

The information required is as follows:

a) the duty required, whether temperature maintenance or process heating, with required temperatures and rates of heating;

b) full dimensional data of all items of plant including vessels, pipes and pipe fittings, pumps, strainers, supporting structures, etc.;

c) full details of the materials from which the items in b) above are constructed;

d) the layout and relative positions of all items in b) above;

e) full details of the process materials, including spoiling and other critical temperatures such as ignition temperatures;

f) the mass of process material to be heated, together with flow rates and the highest and lowest possible material levels within vessels, pipes, etc.;

g) the highest and lowest possible input temperatures of process materials;

h) full details of the thermal insulation system, where this is specified by other than the ESH system designer, including material types and thicknesses and thermal conductivities;

i) the range of environmental conditions including meteorological data, corrosive or other hostile agencies, etc.; (reference may be made to Appendix E for meteorological data in the absence of other guidance.)

j) service category (see **3.2**);

k) power supply details including voltage, frequency and power available, with tolerances;

l) any special considerations, for example maintenance or access requirements or the need for steam cleaning;

m) where applicable, hazardous area classification, the gas hazard present with ignition temperatures and the temperature classification of the equipment required.

6.4 Heating zones. The electric surface heating system should be so designed as to provide the minimum number of heating zones consistent with the operational requirements of the plant. The method by which the system is divided into heating zones should be decided by reference to the plant layout and process conditions. Heating zones should be determined so that:

a) all ESH devices within a heating zone may be temperature controlled by a single means and may be isolated as a group;

b) attention is given to the location and loading of available power sources;

c) due regard is given to the practical requirements of installation and maintenance;

d) identification of each separate heating zone is possible;

e) heating is not generally applied above the maximum fluid level; (If the properties of the material, e.g. thermal conductivity, viscosity, etc., permit, it is desirable to heat only the area of a vessel or pipe which is wetted at the lowest operational fluid level. If it is necessary to heat a greater area to cater for conditions when the fluid level is above the minimum, it may be important to provide means of switching off sections of the heating systems as the fluid level falls.)

f) if only a small portion of a vessel is heated, it is important to ensure that critical temperatures for the fluid and vessel material are not exceeded.

The layout should be so designed as to ensure that cable runs between circuit junction boxes and ESH temperature controllers and/or supply points are kept as short as possible and that the locations of temperature sensors are such that they are not unduly influenced by adjacent heating zones.

6.5 Design loding. To calculate the design loading it is necessary first to establish the minimum power required for each aspect of the heating duty and then make adjustments for other design considerations.

The minimum total power required is the sum of any powers required for the following.

a) *Temperature maintenance.* The power required for temperature maintenance is calculated in accordance with Appendix A.

b) *Raising the temperature of the workpiece in the required time.* The power required to raise the temperature of a pipeline, vessel or fitting is the product of the mass to be heated, its specific heat and the temperature rise, divided by the required time to raise the temperature.

c) *Raising the temperature of the contents in the required time.* The power required to raise the temperature of the contents is calculated in the same manner as in b), using the mass and specific heat of the contents.

d) *Changing state in the required time.* The power required to change state is the product of the mass and its latent heat, divided by the required time to change state.

e) *Any endothermic reaction.* The power required for an endothermic process should be determined from the client's specification.

NOTE Often the power requirement calculated for b) to e) will be adequate for temperature maintenance.

The total power required, calculated as in a) to e), has to be adjusted to take into account power reductions resulting from declared tolerances on voltage and heating conductor resistance.

The adjusted power is calculated from the following equation:

$$P_A = \frac{P_o\ (R_{\max}/R)}{(V_{\min}/V)^2}$$

where:

P_o is the minimum total power as calculated above;

P_A is the minimum total power adjusted for minimum voltage and maximum resistance;

$R_{\max}$ is the upper limit of resistance;

R is the nominal resistance;

$V_{\min}$ is the lower limit of voltage;

V is the nominal voltage.

It is recommended that this value is further increased to allow for at least 10 % reserve power (see **6.2.1**). The final value is defined as the design loading.

For each heating zone the design loading is the sum of the design loadings for all pipework and fittings within that heating zone. This value should now be compared with the available power at the proposed supply point and *recorded for subsequent documentation.*

NOTE For self-limiting ESH devices the manufacturer's published data should be used to determine the minimum rate of heat output at the operating temperature.

6.6 Selection of ESH device. For a particular application there are some basic design requirements which may limit the choice of the ESH device. These are as follows:

a) the grade of the ESH device has to be equal to or better than the minimum specified for the service category in the appropriate Table 2, Table 3 or Table 4;

b) the maximum withstand temperature of the ESH device has to be greater than the maximum possible workpiece temperature (which may be greater than the normal operating temperature);

c) the ESH device has to be suitable for operation in the environmental conditions specified, for example a corrosive atmosphere or a low ambient temperature;

d) the ESH device has to be suitable for use in the hazardous area, if applicable.

NOTE Any change to certified apparatus may invalidate the certificate.

For any application there is a maximum allowable power density at which an ESH device can be used without damaging either the workpiece or its contents. Sometimes this value is particularly critical, such as with lined pipes, vessels containing caustic soda or with heat sensitive materials. This limiting value has to be *recorded in the system documentation*. Multiple tracing or spiralling of a single heating tape may be required.

The choice of ESH device may further be limited by whether fabrication on site is possible. Site fabricated devices are permissible provided that:

a) installation personnel are well versed in the special techniques required;

b) the ESH device passes the routine tests in **8.2** of BS 6351-1:1983;

c) the ESH device is marked in accordance with clause **9** of BS 6351-1:1983.

ESH devices not excluded by the above considerations are technically suitable for the application, but it is now necessary to determine the maximum allowable power density of each. This is a function of the construction, the maximum withstand temperature, the required temperature classification (if any) of the device, the maximum operating temperature and maximum permissible temperature of the workpiece and thermal insulation.

For each particular ESH device the maximum allowable power density should be determined from the manufacturer's data which are based on tests specified in **8.1.13** and clause **14** of BS 6351-1:1983. The value used should be chosen so that neither the maximum withstand temperature nor the required temperature classification (if any) is exceeded. The limiting value of maximum allowable power density for each ESH device is either the value chosen from the manufacturer's data or that specified for the process, whichever is the lower. However, the power density may be further limited by the need for multiple tracing.

The designer may now select the type, length or size and loading of the ESH device. The actual installed load should be not less than the design loading and the actual power density not greater than that obtained above. The type of ESH device and the values of installed load and power density have to be *recorded in the system documentation*.

6.7 Control system. The control system has to be selected in accordance with **3.3**.

6.7.1 For temperature limitation there is a basic choice between stabilized design and the use of ESH temperature controllers. It is essential that stabilized design is used only if the maximum temperature of the surface to be heated is not exceeded when the maximum installed load is applied with the highest ambient temperature and maximum temperature of workpiece contents (see **A.1.3**).

The maximum installed load occurs at the maximum voltage tolerance and minimum resistance tolerance, as calculated from the following equation:

$$P_{\max} = \frac{P_1(V_{\max}/V)^2}{(R_{\min}/R)}$$

where

$P_{\max}$ is the maximum installed load adjusted for maximum voltage and minimum resistance;

P_1 is the installed load;

$V_{\max}$ is the upper limit of voltage;

V is the nominal voltage;

$R_{\min}$ is the lower limit of resistance;

R is the nominal resistance.

For self-limiting ESH devices reference should be made to the manufacturer's published data to determine the maximum rate of heat output at the operating temperature.

If stabilized design cannot be achieved then one or more ESH temperature controllers should be specified. The over-temperature controller has to be set to ensure that the maximum temperature of the surface to be heated is not exceeded. Allowance has to be made for dynamic conditions and tolerances on the temperature control systems.

Where an over-temperature controller is specified, the temperature sensor has to be located in intimate contact with the surface to be heated, beneath the thermal insulation and not more than 100 mm from the heating cable or tape.

Where a stabilized design is used and is required to be operated from an air thermostat, the thermostat should be located in the most exposed position in the vicinity of the heating system.

6.7.2 Over-current protection devices are required to be in accordance with relevant statutory provisions and the IEE Regulations for Electrical Equipment in Buildings.

6.7.3 Circuit-breakers and residual current circuit-breakers should switch line(s) and neutral. Any other method of protection should provide an equivalent level of safety.

6.7.4 Heating zone isolation may be by an isolating switch or circuit-breaker incorporating over-current and short circuit protection. In either case these should be capable of being locked in the "off" position for safe working during maintenance, tests or repairs.

It is essential that the isolating device interrupts all poles of the supply so that, during maintenance, junction boxes can be opened without the risk of exposure of live terminals.

6.8 Installation data

6.8.1 Having selected the ESH device the method of installation is chosen.

For cable and tape units applied to pipes, the application ratio is calculated as follows:

$$\text{Application ratio } \alpha = \frac{\text{Nett length of ESH device}}{\text{Nett pipe length}}$$

If the application ratio is an integer, single or multiple straight tracing can be used; otherwise either the spiral pitch is calculated, as in Appendix B, or snaking is used.

In all other cases an appropriate method of installation should be specified.

It is essential that the cable or tape spacing is not less than the manufacturer's declared minimum spacing.

6.8.2 Terminations should be sited so as to comply with the requirements of **6.4**.

6.8.3 Junction boxes should be installed as close as possible to the workpiece.

6.8.4 All components within the heating zone should be positioned so as to allow ready access for maintenance.

6.8.5 It is essential that the following design data are made available to the installation supervisor:

a) heating zone layout;

b) schedule of ESH devices;

c) control equipment schedule;

d) schedule of ancillary components;

e) method of installation;

f) schedule of installed loads for each workpiece;

g) maximum withstand temperature of each ESH device;

h) service category for which the ESH system has been designed;

i) hazardous area classification, if any, for which the ESH system has been designed.

6.8.6 It is essential to maintain records of the data supplied to the ESH system designer, the calculations made during the design, the information made available to site under **6.8.5** and any reported site variations. This information has to be *recorded in the system documentation*.

Appendix A Heat loss calculations

A.1 Pipes

A.1.1 *General.* Design data are presented in the form of tables in order to simplify the calculations necessary to determine heat losses and to predict surface temperatures for pipes. Results from the use of these tables should be *recorded in the system documentation.*

The use of the tables is explained in the following paragraphs and a worked example is given in Appendix C.

A.1.2 *Heat loss.* Table 5 gives a normalized loss factor for standard pipe sizes and insulation thicknesses. The table is based on the equation for radial conduction from a cylinder:

$$P = \frac{2\pi k_{\mathrm{e}} l \Delta T}{\log_e(d_2/d_1)}$$

where

P	is the rate of heat loss (in W);
k_{e}	is the effective thermal conductivity [in W/(m·K)];
ΔT	is the temperature of heated surface minus ambient temperature (in K);
d_2	is the outside diameter of thermal insulation (in m);
d_1	is the inside diameter of thermal insulation (in m);
l	is the length (in m).

The table has been normalized to $k_{\mathrm{e}} = 1$, $\Delta T = 1$, $l = 1$.

To use the table follow the steps as shown.

a) Calculate the design temperature difference ΔT_{des} between the lowest ambient and the highest process temperatures.

b) Calculate the average value of the temperature across the insulation and refer to the manufacturer's data for the value of k_{e} at that temperature.

c) From Table 5, read the normalized loss factor for the thermal insulation thickness and pipe size.

d) Multiply the normalized loss factor by k_{e} and $\Delta T_{\mathrm{des.}}$

The result is the maximum heat loss from the pipe in watts per metre of pipe under the worst operational conditions.

NOTE The thermal conductivity of thermal insulation is significantly affected by moisture content. If moisture is likely to be present in the thermal insulation material the manufacturer should be consulted for a revised thermal conductivity value corresponding to the expected moisture content.

A.1.3 *Stabilized design.* The calculation in **A.1.2** yields the heat loss from an insulated pipe at the lowest ambient temperature. In still air, however, the surface of the cladding will be at a significantly higher temperature than the surrounding air. This will reduce the heat loss and, for a given power input from an ESH device, the pipe surface temperature will increase. When considering the possibility of a stabilized design the maximum pipe surface temperature has to be predicted; it is equal to the sum of:

a) the maximum cladding surface temperature; and

b) the maximum temperature differential across the thermal insulation.

The cladding surface temperature is obtained from Table 6 or Table 7 depending on the emissivity of the cladding.

The figures in the table represent the difference in temperature between the cladding and the ambient air and therefore have to be added to the maximum expected ambient temperature to obtain the maximum cladding temperature. The power density figure to be used is P_{max} as derived in **6.7.1**.

The figures in Table 6 and Table 7 have been calculated for an ambient air temperature of 40 °C. If a different ambient temperature is required reference may be made to the heat transfer formulae in Appendix D.

The maximum temperature rise across the thickness of the thermal insulation, $\Delta T_{\max}$, is obtained from the normalized loss factor in Table 5.

$$\Delta T_{\max} = \frac{P_{\max}}{K_e \times \text{normalized loss factor}}$$

A.2 Other items. Calculations of heat losses from flanges, valves, strainers, supports and other associated pipeline fittings may be more complex because of difficulty of assessment of surface area. Many fittings such as flanges and valves are generally manufactured in accordance with relevant British Standards, while others, such as strainers, pumps and instruments, will vary according to the application and manufacturer. The following recommendations are made to assist when determining heat losses:

a) for flanges for pipes up to 8 in nominal bore (n.b.), assume a heat loss equal to that from 0.3 m of the corresponding pipe;

b) for valves for pipes up to 8 in n.b., assume a heat loss equal to that from 1.5 m of the corresponding pipe;

c) for flanges for pipes above 8 in n.b., assume a heat loss equal to that from 1.0 m of the corresponding pipe;

d) for valves for pipes above 8 in n.b., assume a heat loss equal to that from 3.0 m of the corresponding pipe.

NOTE The extra length of heating cable (or tape) resulting from the factors referred to in a) to d) will not necessarily be applied to the flange or valve itself due to practical limitations.

To calculate the theoretical power required for temperature maintenance of other items of plant and vessels, the rates of heat losses are calculated from the formulae:

$$P = \frac{k_e A \Delta T}{X} \text{ for flat surfaces}$$

$$P = \frac{2\pi k_e \Delta T l}{\log_e(d_2/d_1)} \text{ for cylindrical surfaces}$$

where

x is the thickness of thermal insulation (in m);

A is the area of surface (in m^2).

The losses from each part of the surface should be calculated using the appropriate formula and added together to determine the total heat loss.

Table 5 — Normalized loss factor

Pipe nominal bore	Pipe outside diameter	Insulation thickness							
		12 ½	25 1	37 1½	50 2	75 3	100 4	125 5	150 (mm) 6 (in)
in	mm								
¼	13.75	5.99	4.06	—	—	—	—	—	—
⅜	17.15	6.91	4.56	—	—	—	—	—	—
½	21.35	8.01	5.16	4.13	3.58	—	—	—	—
¾	26.70	9.39	5.89	4.65	4.00	3.30	—	—	—
1	33.40	11.34	6.91	5.36	4.56	3.71	—	—	—
1½	48.30	14.86	8.74	6.63	5.54	4.41	—	—	—
2	60.35	17.88	10.28	7.69	6.36	4.98	4.26	—	—
2½	73.05	21.05	11.89	8.79	7.21	5.57	4.72	—	—
3	88.90	25.00	13.90	10.15	8.24	6.29	5.28	—	—
4	114.30	—	17.08	12.30	9.88	7.42	6.15	—	—
6	168.30	—	23.82	16.82	13.30	9.74	7.93	6.83	—
8	219.10	—	30.13	21.04	16.50	11.89	9.57	8.16	7.20
10	273.05	—	36.82	25.53	19.86	14.17	11.29	9.55	8.38
12	323.85	—	43.12	29.73	23.03	16.29	12.90	10.85	9.47
14	355.60	—	47.05	32.36	25.00	17.60	13.90	11.66	10.15
16	406.40	—	53.35	36.56	28.16	19.73	15.50	12.90	11.20
18	457.20	—	59.64	40.76	31.31	21.84	17.08	14.22	12.30
20	508.00	—	65.92	44.96	34.46	23.95	18.67	15.49	13.37
24	609.60	—	78.50	53.35	40.76	28.16	21.84	18.04	15.50
30	762.00	—	97.36	65.92	50.20	34.60	26.58	21.84	18.60

Table 6 — Cladding surface temperature rise above 40 °C for ξ = 0.8

Power density	Overall diameter over cladding												
	0.75 19.0	1 25.4	1.5 38.0	2 50.8	2.5 63.5	3 76.2	4 102.0	5 127.0	6 152.0	8 203.0	10 254.0	12 305.0	16 (in) 406.0 (mm)
W/m	K	K	K	K	K	K	K	K	K	K	K	K	K
1	1.7	—	—	—	—	—	—	—	—	—	—	—	—
2	3.2	2.5	1.8	—	—	—	—	—	—	—	—	—	—
3	4.6	3.7	2.6	2.0	—	—	—	—	—	—	—	—	—
4	6.0	4.8	3.4	2.7	2.2	1.9	—	—	—	—	—	—	—
5	7.3	5.8	4.2	3.3	2.7	2.3	—	—	—	—	—	—	—
7	9.9	7.3	5.7	4.5	3.8	3.2	2.5	2.0	—	—	—	—	—
10	12.9	10.3	7.9	6.0	5.2	4.5	3.5	2.9	2.3	1.9	—	—	—
15	18.9	14.8	10.9	9.0	7.6	6.0	5.0	4.3	3.6	2.8	2.3	—	—
20	23.4	19.3	13.9	11.6	9.1	8.5	6.5	5.6	4.8	3.7	3.1	2.5	2.0
25	27.9	22.3	16.9	13.1	11.9	10.0	8.0	6.8	5.9	4.6	3.8	3.2	2.5
30	32.4	26.8	19.9	16.1	13.4	11.5	9.5	8.1	6.9	5.4	4.5	3.8	3.0
40	41.4	32.8	24.4	20.0	17.9	14.5	12.5	9.6	8.4	6.9	5.9	5.0	3.9
50	48.9	40.3	30.4	24.5	20.9	17.5	14.0	12.6	11.0	8.4	7.2	6.2	4.8
60	56.4	46.3	34.9	29.0	23.9	20.5	17.0	14.1	12.5	9.9	8.5	7.3	5.7
70	63.9	52.3	39.4	32.5	26.9	23.5	20.0	17.1	14.0	11.4	9.8	8.4	6.6
80	69.9	58.3	43.9	36.5	29.9	26.5	21.5	18.6	15.5	12.9	11.1	9.5	7.5
90	77.4	64.3	48.4	39.5	34.4	29.5	24.5	20.1	17.0	14.4	12.3	10.6	8.3
100	83.4	68.8	52.9	42.0	37.4	32.5	26.0	21.6	20.0	15.9	13.5	11.7	9.2
120	95.4	79.3	60.4	50.0	41.9	37.0	30.5	26.1	23.0	18.9	15.0	13.2	10.7
140	107.0	89.8	67.9	56.0	47.9	43.0	35.0	29.1	26.0	20.4	18.0	14.7	12.2
160	118.0	98.8	75.4	62.0	53.9	47.5	38.0	32.1	29.0	23.4	19.5	17.7	13.7
180	128.0	108.0	82.9	68.0	58.4	52.0	42.5	36.6	32.0	24.9	21.0	19.2	15.2
200	139.0	116.0	90.4	74.0	64.4	56.5	45.5	39.6	35.0	27.9	24.0	20.7	16.7
250	163.0	136.0	105.4	87.5	76.4	67.0	54.5	47.1	41.0	33.9	28.5	25.2	19.7

NOTE 1 These tables have been prepared for an ambient temperature of 40 °C to an accuracy of + 0, – 15 %.

NOTE 2 An emissivity of 0.8 represents many typical paint finishes and rough surfaces.

NOTE 3 Linear interpolation between values is permissible.

Table 7 — Cladding surface temperature rise above 40 °C for $\xi = 0.3$

Power density	Overall diameter over cladding												
	0.75 19.0	1 25.4	1.5 38.0	2 50.8	2.5 63.5	3 76.2	4 102.0	5 127.0	6 152.0	8 203.0	10 254.0	12 305.0	16 (in) 406.0 (mm)
W/m	K	K	K	K	K	K	K	K	K	K	K	K	K
1	2.5	2.0	1.5	1.2	1.0	—	—	—	—	—	—	—	—
2	4.5	3.5	2.8	2.2	1.9	1.6	1.3	—	—	—	—	—	—
3	6.5	5.0	4.0	3.2	2.7	2.4	1.9	1.5	—	—	—	—	—
4	8.0	6.5	5.1	4.1	3.5	3.1	2.5	2.1	1.8	—	—	—	—
5	9.3	8.0	6.2	5.0	4.3	3.7	3.0	2.5	2.2	1.7	—	—	—
7	12.5	10.9	7.7	6.5	5.7	5.0	4.1	3.4	3.0	2.4	2.0	1.7	—
10	17.0	13.9	10.7	9.1	7.8	6.5	5.5	4.7	4.1	3.3	2.8	2.4	1.9
15	24.5	19.9	15.2	12.1	10.8	9.5	7.9	6.2	5.6	4.7	4.0	3.4	2.7
20	30.5	24.4	19.7	16.4	13.8	12.4	9.4	8.6	7.1	6.1	5.1	4.5	3.6
25	36.5	30.4	22.7	19.4	16.8	13.9	12.2	10.1	8.6	7.4	6.3	5.4	4.4
30	41.0	34.9	27.2	22.4	18.3	16.9	13.7	11.6	10.0	8.7	7.3	6.4	5.1
40	51.5	43.9	33.2	28.4	24.3	21.4	18.2	14.6	13.1	11.1	8.8	7.9	6.6
50	62.0	51.4	39.2	32.9	28.8	25.9	21.2	17.6	16.1	12.6	11.4	9.4	8.1
60	71.0	60.4	46.7	38.9	33.3	28.9	24.2	20.6	19.1	15.6	14.4	10.9	9.5
70	81.5	67.9	52.7	43.4	37.8	33.4	27.2	23.6	20.6	17.1	15.9	12.4	10.8
80	89.0	75.4	57.2	47.9	42.3	36.4	30.2	26.6	23.6	18.6	17.4	13.0	12.1
90	98.0	81.4	63.2	52.4	45.3	40.9	33.2	29.6	25.1	21.6	18.8	15.4	13.4
100	107.0	88.9	69.2	56.9	49.8	43.9	36.2	31.1	28.1	23.1	20.4	16.9	14.7
120	122.0	102.0	79.7	65.9	57.3	51.4	42.2	37.1	32.6	26.1	23.4	19.9	16.2
140	137.0	114.0	90.2	74.9	64.8	57.4	48.2	41.6	37.1	30.6	26.4	22.9	19.2
160	152.0	127.0	99.2	82.4	72.3	63.4	52.7	46.1	40.1	33.6	29.4	25.9	20.7
180	165.0	138.0	108.2	91.4	78.3	69.4	58.7	50.6	44.6	36.6	32.4	27.4	23.7
200	179.0	150.0	117.2	98.9	85.8	75.4	63.2	55.1	49.1	39.6	33.9	30.4	25.2
250	209.0	177.0	138.2	116.0	110.8	90.4	75.2	65.6	58.1	48.6	41.4	36.4	29.7

NOTE 1 These tables have been prepared for an ambient temperature of 40 °C to an accuracy of + 0, 15 %.

NOTE 2 An emissivity of 0.3 represents many finishes such as aluminium paint, galvanized iron, etc.

NOTE 3 Linear interpolation between values is permissible.

Appendix B Calculation of spiral pitch

It is often the case that more watts are required per metre of pipe than can be supplied by a single straight run of cable or tape. The two most common solutions to this problem are either to straight trace a number of runs or to spiral the cable or tape on to the pipe.

The spiral pitch is obtained from Table 8 as follows.

a) Obtain the pipe outside diameter.

b) Obtain the cable diameter or tape thickness from the manufacturer's data.

c) Obtain the application ratio from the calculation carried out in **6.8.1**, i.e.:

$$\alpha = \frac{\text{nett length of ESH device}}{\text{nett pipe length}}$$

d) Read normalized pitch against the application ratio.

e) Multiply the number shown by the sum of the outside diameter of the pipe and the tape thickness or cable diameter. The value obtained is the pitch in the units used for diameters.

Table 8 — Normalized pitch, N_p

Application ratio (α)	N_p	Application ratio (α)	N_p	Application ratio (α)	N_p
		4.40	0.733	21.00	0.150
		4.60	0.700	22.00	0.143
1.05	9.813	4.80	0.669	23.00	0.137
1.10	6.856	5.00	0.641	24.00	0.131
1.15	5.532	5.20	0.616	25.00	0.126
1.20	4.736	5.40	0.592	26.00	0.121
1.25	4.189	5.60	0.570	27.00	0.116
1.30	3.782	5.80	0.550	28.00	0.112
1.35	3.464	6.00	0.581	29.00	0.108
1.40	3.206	6.20	0.513	30.00	0.105
1.45	2.992	6.40	0.497	31.00	0.101
1.50	2.810	6.60	0.482	32.00	0.098
1.55	2.653	6.80	0.467	33.00	0.095
1.60	2.515	7.00	0.453	34.00	0.092
1.65	2.394	7.20	0.441	35.00	0.090
1.70	2.285	7.40	0.428	36.00	0.087
1.75	2.188	7.60	0.417	37.00	0.085
1.80	2.099	8.00	0.396	38.00	0.083
1.85	2.018	8.40	0.377	39.00	0.081
1.90	1.945	8.80	0.359	40.00	0.079
1.95	1.877	9.20	0.344	42.00	0.075
2.00	1.814	9.60	0.329	44.00	0.071
2.10	1.701	10.00	0.316	46.00	0.068
2.20	1.603	10.50	0.301	48.00	0.065
2.30	1.517	11.00	0.287	50.00	0.063
2.40	1.440	11.50	0.274	52.00	0.060
2.50	1.371	12.00	0.263	54.00	0.058
2.60	1.309	12.50	0.252	56.00	0.056
2.70	1.253	13.00	0.242	58.00	0.054
2.80	1.201	13.50	0.233	60.00	0.052
2.90	1.154	14.00	0.225	62.00	0.051
3.00	1.111	14.50	0.217	64.00	0.049
3.10	1.071	15.00	0.210	66.00	0.048
3.20	1.034	15.50	0.203	68.00	0.046
3.30	0.999	16.00	0.197	70.00	0.045
3.40	0.967	16.50	0.191	72.00	0.044
3.50	0.937	17.00	0.185	74.00	0.042
3.60	0.908	17.50	0.180	76.00	0.041
3.70	0.882	18.00	0.175	80.00	0.039
3.80	0.857	18.50	0.170	84.00	0.037
3.90	0.833	19.00	0.166	88.00	0.036
4.00	0.811	19.50	0.161	92.00	0.034
4.20	0.770	20.00	0.157	96.00	0.033
				100.00	0.031

NOTE Pitch = (pipe outside diameter + heating cable diameter or tape thickness) × N_p.

Appendix C Worked example

C.1 Introduction. The following example illustrates the steps to be taken in the design of an ESH system for type of protection "e".

C.2 Design information. The following information is made available to the designer:

a)	Duty required	Temperature maintenance at 50 °C
b)	The pipe type	3 in nominal bore, 10 m long, mild steel
c)	Fitting type	None
d)	Pipeline layout	Straight
e)	Material in pipeline	Water
f)	Material flow conditions	Zero or empty
g)	Highest input temperature	50 °C
h)	Special conditions	None
i)	Thermal insulation material	25 mm rock wool clad with stainless steel
j)	Environmental conditions	External in London area: ambient air temperatures –5 °C minimum, + 40 °C maximum
k)	Service category	22
l)	Power supply details	240 V nominal, 13 A available
m)	Apparatus group	IIA
n)	Hazardous area classification	Zone 1
o)	Temperature classification	T2

C.3 Heating zone. As the system consists only of one straight pipe there is only one heating zone.

C.4 Design loading

a) $\Delta T_{\mathrm{des}} = 50 - (-5) = 55$ K [see **A.1.2** a)]

b) Average thermal insulation temperature (in °C) for the lowest ambient air temperature is:

$$\frac{50 + (-50)}{2} = 22.5 \qquad \text{[see } \mathbf{A.1.2} \text{ b)]}$$

From manufacturer's data $k_e = 0.035$ W/(m·K) at this temperature.

c) From Table 5 the normalized loss factor for a 3 in n.b. pipe under 25 mm thermal insulation is 13.9, therefore heat loss (in W/m) is:

$P_o = (13.9 \times 55 \times 0.035) = 26.75$ [see **A.1.2** d)]

d) The heat loss obtained in c) has to be corrected for voltage and resistance tolerances (assumed to be 6 % and 10 % respectively):

$$P_A = \frac{26.75\ (1.10)}{(0.94)^2}$$

$$P_A = 33.3 \qquad \text{(see } \mathbf{6.5}\text{)}$$

e) The figure in d) is increased by 10 % to give a design loading of 36.6 W/m (see **6.2.1**).

C.5 Initial selection of ESH device. A range of heating units is selected which operates at 240 V, has a grade 22 and is suitable for use in Zone 1 hazardous location with gases in group 11A. (If there were any special environmental conditions these would be taken into account in the selection.) For this range of heating units hypothetical manufacturer's published specification is given in Table 9.

Table 9 — Hypothetical manufacturer's specification

Voltage rating	240 V
Grade	22
Suitable for	Zone 1, group 11B
Maximum withstand temperature	250 °C
Resistance tolerance	± 10 %
Dimensions	13 mm wide × 3 mm thick
Minimum spacing	65 mm
Lengths available	10 m, 13 m, 19 m and 40 m
Nominal power densities available	10 W/m, 20 W/m, 30 W/m, 40 W/m and 50 W/m

Nominal power density	Maximum temperature of the surface to be heated					
	Non hazardous use	hazardous area use				
		T6	T5	T4	T3	250 °C (T2)
w/m	°C	°C	°C	°C	°C	°C
10	200	50	65	100	170	200
20	160	20	30	75	135	160
30	135	—	10	40	105	135
40	95	—	—	10	65	95
50	60	—	—	—	30	60

From the manufacturer's data it can be seen that any power density between 10 W/m and 50 W/m can be employed safely on a pipe at 50 °C and remain within a T2 temperature classification.

To obtain the required design load per unit length of pipe of 36.6 W/m on a 10 m long pipe the selections shown in Table 10 are appropriate.

Table 10 — Selection of ESH device

Nominal power density	Length of ESH device	Installed load	Application ratio (α)
W/m	m	W/m	
10	40	40	4.0
20	19	38	1.9
30	13	39	1.3
40	10	40	1.0
50	Power density unnecessarily high		

The choice of heating unit will now depend on whether use is made of a stabilized design or of ESH temperature controllers.

For a stabilized design the maximum pipe surface temperature has to be established.

C.6 Maximum pipe surface temperature. From the selections available, a nominal installed load of 40 W/m of pipe is chosen.

$$p_{\max} = \frac{40(1.06)^2}{(0.90)} = 50 \qquad \text{(see } \mathbf{6.7.1}\text{)}$$

The maximum cladding surface temperature is obtained from Table 6 from the outside diameter of the cladding and the above value of $P_{\max}$. The cladding is 12.6 K above ambient, hence at a potential maximum temperature of (12.6 + 40) °C = 52.6 °C.

The temperature differential across the thermal insulation (in K) is obtained from the normalized loss factor (Table 5) at the above $P_{\max}$ and the thermal conductivity of the thermal insulation k_e:

$$T = \frac{50}{0.035 \times 13.9} = 102.8$$

Thus the maximum pipe surface temperature will be (102.8 + 52.6) °C = 155.4 °C.

C.7 Final selection of ESH device

C.7.1 *Stabilized design.* For a stabilized design, the shortest ESH device is selected which achieves the design load of 36.6 W/m of pipe and remains within the temperature classification 250 °C (T2) even when the pipe temperature is 155.4 °C.

From Table 9 only 10 W/m and 20 W/m units are suitable for this condition. Selecting a 19 m length at 20 W/m from Table 10 gives a nominal installed load of 38 W/m of pipe. Assuming this is to be installed in a spiralled fashion, the spiral pitch (in mm), obtained from the normalized pitch (Table 8) at an application ratio of 1.9 is:

$$1.945\ (88.9 + 3.0) = 178.7$$

This gives a spacing greater than the manufacturer's declared minimum spacing and is therefore a suitable design.

C.7.2 *ESH temperature controllers.* If ESH temperature controllers are used the shortest ESH device is selected which achieves the design load of 36.6 W/m of pipe while remaining within the temperature classification 250 °C (T2).

From Table 9, only ESH devices of 40 W/m or less are suitable. From Table 10 a 10 m long ESH device of 40 W/m is selected. When straight traced this will give a nominal load of 40 W/m of pipe.

Two ESH temperature controllers are required, one set at the process temperature of 50 °C and an over-temperature controller set no higher than 85 °C; i.e. the maximum temperature of the surface to be heated (95 °C from Table 9) less an allowance for dynamic conditions and tolerances on the control system assessed at 10 K for the purpose of this example.

C.8 Summary of final designs

C.8.1 *Stabilized design.* A 19 m long ESH device having an output of 20 W/m is applied to the 10 m long pipe at a pitch of 178.7 mm. This gives a nominal installed load of 38 W/m of pipe. As the system will stabilize below 250 °C with a maximum pipe temperature of 155.4 °C, there is no need for ESH temperature controllers to limit the surface temperature of the device on grounds of safety.

C.8.2 *ESH temperature controllers.* A 10 m long ESH device having an output of 40 W/m is straight traced on the 10 m pipe. This gives a nominal installed load of 40 W/m of pipe. As the pipe would stabilize at a temperature in excess of 95 °C, the maximum temperature of the surface to be heated for a 250 °C (T2) classification, it is necessary to fit two ESH temperature controllers. The first temperature controller may be set to the process temperature of 50 °C but the over-temperature controller has to be set no higher than 85 °C.

Appendix D Mathematical formulae

D.1 Normalized loss factor

$$\text{Normalized loss factor} = \frac{2\pi}{\log_e(d_2/d_1)}$$

D.2 Cladding surface temperature

$$W = a\lambda A_1\left(1 + \frac{S}{L_1}\right) L_1^{(3m-1)} \Delta T^{(m+1)} {\gamma_T}^m + 5.73\,\epsilon_1 A_1 \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right]$$

In order to establish the values of a and m:

a) from Figure 1, find the value of γ_T;

b) estimate an approximate value of ΔT;

c) calculate the value of $L_1{}^3\gamma_T\Delta T$;

d) find a and m from the following table:

Value of $L_1{}^3\gamma_T\Delta T$	a	m
$< 10^4$	1.09	$1/6$
10^4 to 10^9	0.53	$1/4$
$< 10^9$	0.13	$1/3$

It is now possible to solve the equation above for T_1 (the cladding surface temperature) by iterative solution. Having calculated T_1, check that the estimated approximate value of ΔT used in b) was adequate, by using the calculated value of T_1 to find ΔT. If this value of ΔT is significantly different from the estimated value, recalculate $L_1{}^3\gamma_T\Delta T$ using the new value of ΔT. If this does not result in the same values of a and m as already used, the process has to be repeated with the new values of a and m.

D.3 Normalized distance between element pitches

Pitch = (pipe outside diameter + heating cable diameter) × N_p

where

$$N_p = \frac{\pi}{\sqrt{(\alpha^2 - 1)}}$$

D.4 Notation. The following notation applies to Appendix D only.

Symbol	**Units**	**Designation**
W	W	Total power dissipated by radiation and convection
A_1	m^2	Total surface area considered to be dissipating by radiation and convection
λ	W/(m·k)	Thermal conductivity of convective medium surrounding the dissipating surface
a	–	Coefficient dependent on L,γ_T and ΔT
ΔT	K	Temperature difference between dissipating surface and intercepting surface (intercepting surface can generally be taken as ambient)
γT	$K^{-1}M^{3}$	$\gamma_T = \dfrac{\rho^2 g_n \beta c}{\mu\gamma}$ at temperature T_2 (see Figure 1)
ρ	Kg·m^{-3}	Density of convective medium
g_n	m.s^{-2}	Acceleration due to gravity
β	K^{-1}	Volumetric coefficient of expansion of convective medium
c	j·kg^{-1} K^{-1}	Specific heat capacity of convective medium at constant pressure

Symbol	**Units**	**Designation**
μ	kg m^{-1} s^{-1}	Viscosity of convective medium
m	—	Index depending on L, γ_T and ΔT
S	m	Stagnant film thickness, variable dependent on geometry. It is generally acceptable to use $S = 0.000\ 45$ m
L_1	m	Height, diameter or characteristic dimension of dissipating surface
A_2	m^2	Surface area of intercepting surface
ϵ_1	—	Emissivity of dissipating surface
d_1	m	Inside diameter of thermal insulation
d_2	m	Outside diameter of thermal insulation
T_1	K	Absolute temperature of dissipating surface
T_2	K	Absolute temperature of intercepting surface (ambient)
α	—	Application ratio
N_p	—	Normalized pitch

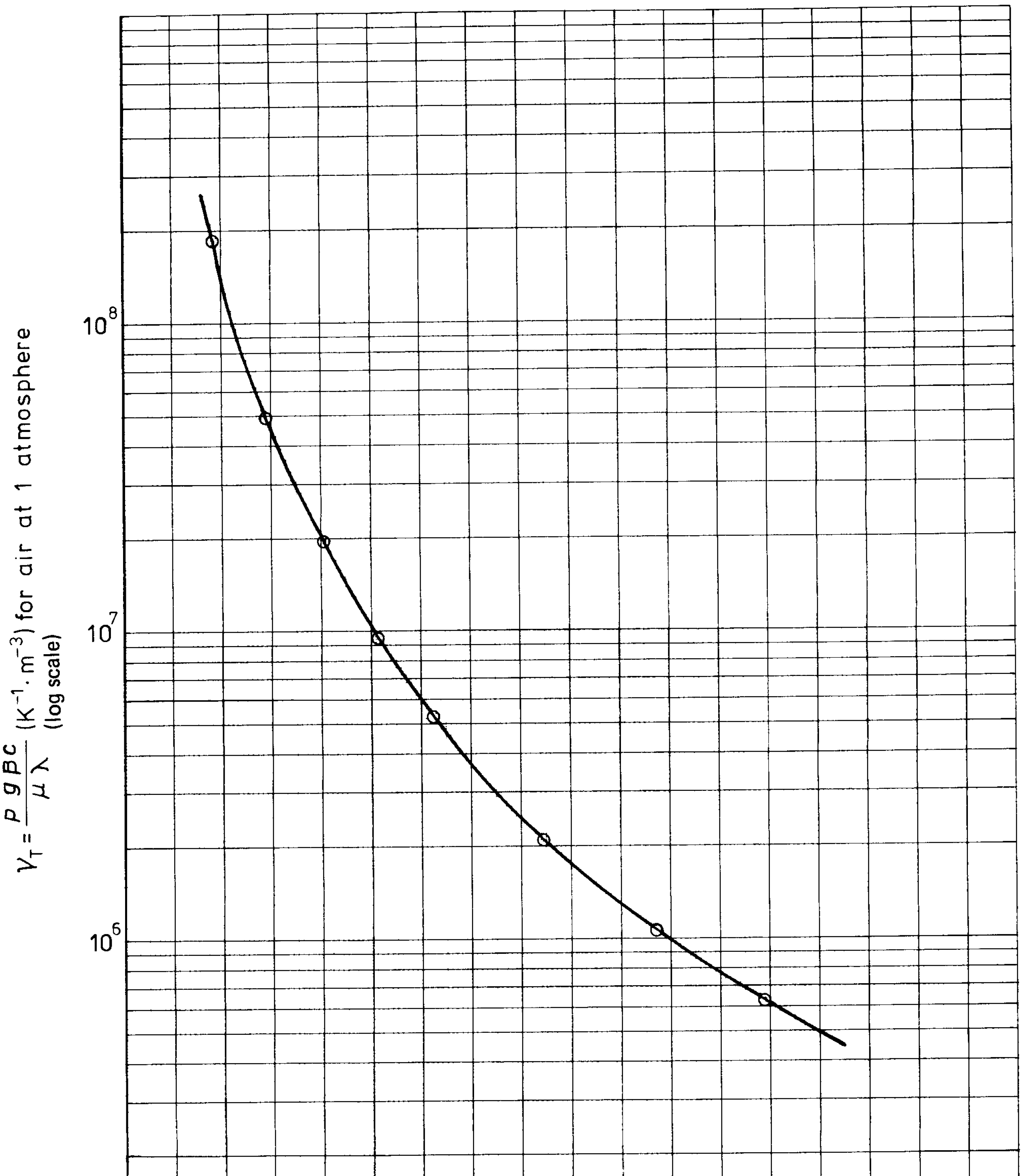

Figure 1 — Graph for use in calculating cladding surface temperature

Appendix E Meteorological data

E.1 United Kingdom

Location	Hourly mean wind speed (see note 1)	Annual minimum temperature (see note 2)	Mean annual minimum temperature (see note 3)	Mean daily temperature (see note 4)	Percentage of time (see note 5)
	m/s	°C	°C	°C	%
Belfast	16	– 12	– 8	9.0	2.5
Birmingham	14	– 18	– 10	10.0	5
Bournemouth	15	– 12	– 8	10.5	5
Brighton	15	– 10	– 8	10.5	5
Bristol	16	– 14	– 8	10.5	6
Cardiff	17	– 12	– 8	10.5	20
Carlisle	17	– 14	– 10	9.0	15
Coventry	15	– 14	– 8	10.0	5
Doncaster	16	– 14	– 8	9.5	5
Dover	15	– 12	– 8	10.5	5
Edinburgh	17	– 12	– 8	8.5	5
Exeter	16	– 10	– 4	10.5	10
Fishguard	19	– 8	– 4	10.5	20
Glasgow	17	– 12	– 8	9.0	2.5
Gloucester	15	– 12	– 8	10.0	5
Holyhead	20	– 12	– 6	10.0	20
Hull	17	– 14	– 6	9.5	2.5
Leeds	16	– 14	– 8	9.5	2.5
Liverpool	17	– 12	– 8	10.0	2.5
London	15	– 12	– 6	10.5	5
Maidstone	15	– 16	– 8	10.5	5
Manchester	16	– 14	– 8	10.0	2.5
Newcastle	18	– 10	– 8	9.0	2.5
Norwich	15	– 14	– 6	9.5	2.5
Nottingham	14	– 16	– 8	9.5	5
Oxford	15	– 16	– 8	10.0	5
Penzance	19	– 8	– 4	11.0	10
Perth	16	– 18	– 10	8.5	5
Plymouth	17	– 10	– 4	10.5	10
Portsmouth	15	– 10	– 6	10.5	5
Southampton	15	– 10	– 6	10.5	5
Stirling	17	– 18	– 8	8.5	5
Swansea	17	– 10	– 6	10.5	20

NOTE 1 Hourly mean wind speed (in m/s) exceeded for 0.1 % of the time during the years 1965 to 1973. Valid for a height of 10 m above open level terrain (gust ratio 1.60) and for altitudes between 0 and 70 m above mean sea level.

NOTE 2 Annual minimum temperature (in °C) likely to occur once in 50 years based on data for 1941 to 1970. Reduced to mean sea level 0.5 °C/100 m.

NOTE 3 Mean annual minimum temperature (in °C), 1941 to 1970. Reduced to mean sea level 0.5 °C/100 m.

NOTE 4 Mean daily temperature (in °C), 1941 to 1970. Reduced to mean sea level 0.5 °C/100 m.

NOTE 5 Percentage of time with relative humidity 99 %, 1961 to 1970.

E.2 World

Location	**Mean annual minimum temperature** (see note 1)	**Absolute minimum temperature** (see note 2)	**Mean annual temperature** (see note 3)	**Maximum average monthly precipitation** (see note 4)
Europe	°C	°C	°C	mm
Arkhangel'sk	– 36.3	– 41.2	0.4	63
Athens	– 1.2	– 5.7	18.3	71
Basle	– 14.5	– 24.1	10.1	94
Belfast	– 8.2	– 12.8	9.1	94
Belgrade	– 14.7	– 24.5	12.1	96
Berlin	– 15.3	– 22.0	9.1	73
Brussels	– 10.2	– 16.8	10.1	95
Bucuresti	– 20.4	– 32.2	10.9	121
Budapest	– 14.1	– 22.5	11.1	72
Cardiff	– 6.0	– 16.7	10.3	116
Copenhagen	– 10.4	– 24.2	8.5	71
Den Helder	– 8.3	– 18.5	0.7	89
Dublin	– 5.7	– 10.9	9.5	80
Edinburgh	– 5.6	– 9.4	8.7	83
Helsinki	– 23.7	– 33.2	4.8	73
Istanbul	– 5.0	– 8.9	14.0	119
Lisbon	1.7	– 1.2	17.5	111
London	– 5.7	– 9.5	11.6	64
Luxembourg	– 12.0	– 19.6	9.3	84
Madrid	– 5.8	– 10.1	13.9	48
Moscow	– 29.9	– 31.0	4.5	88
Oslo	– 18.1	– 26.0	6.1	95
Paris	– 7.8	– 14.7	11.5	64
Prague	– 15.8	– 27.8	—	68
Reykjavik	– 12.9	– 17.1	5.0	89
Rome	2.3	– 6.0	16.1	129
Sofia	– 16.2	– 21.0	11.1	87
Stockholm	– 16.1	– 28.2	6.7	76
Vienna	– 13.6	– 22.6	9.7	84
Warszawa	– 19.3	– 29.1	8.3	96
Africa				
Accra	18.3	15.0	26.7	178
Algiers	3.3	0	18.3	137
Bulawayo	1.7	– 2.2	19.4	142
Cairo	3.9	1.1	21.7	5
Capetown	0	2.2	16.7	89
Casablanca	2.2	– 0.6	17.2	71
Dakar	14.4	11.7	25.0	25
Djibouti	20.0	17.2	30.0	23
Johannesburg	– 4.4	– 7.2	16.1	124
Kano	8.9	6.1	26.7	310
Lagos	19.4	15.6	27.2	460
Las Palmas	10.6	7.8	20.6	53
Kinshasa	15.0	14.4	25.0	221
Libreville	18.3	16.7	26.1	373
Lusaka	5.6	3.9	20.6	231
Maputo	8.9	7.2	22.8	130

Location	**Mean annual minimum temperature** (see note 1)	**Absolute minimum temperature** (see note 2)	**Mean annual temperature** (see note 3)	**Maximum average monthly precipitation** (see note 4)
Africa (continued)	°C	°C	°C	mm
Marrakesh	0.6	– 2.8	19.4	33
Mombasa	19.4	16.1	28.9	320
Monrovia	17.2	12.8	25.6	996
Port Said	6.1	0	21.7	18
Harare	1.7	0	18.3	196
Tangier	2.2	– 2.2	16.7	147
Timbuktu	6.7	5.0	28.9	81
Tripoli	3.9	0.6	19.4	94
Tunis	1.7	– 1.1	18.3	63
Australasia				
Adelaide	2.2	0	17.2	76
Brisbane	3.9	2.2	20.6	163
Christchurch	– 3.9	– 6.1	11.7	69
Hobart	– 0.6	– 2.2	12.8	61
Melbourne	– 0.6	– 2.8	17.2	66
Perth	3.3	1.1	17.8	180
Port Darwin	15.6	13.3	28.3	386
Port Moresby	20.6	17.8	27.2	193
Sydney	3.9	2.2	17.2	135
Wellington	0	– 1.7	12.8	137
Asia				
Bahrain	8.3	5.0	22.8	18
Beirut	4.4	– 1.1	17.2	190
Bombay	16.7	11.7	27.2	617
Calcutta	9.4	6.7	26.0	328
Madras	16.1	13.9	28.5	356
New Delhi	1.7	– 0.6	25.0	180
Hong Kong	6.1	0	22.8	394
Irkutak	– 42.2	– 50.0	– 1.7	79
Kuwait	3.3	0.6	25.0	28
Muscat	15.0	10.6	26.1	28
Pusan	– 10.0	– 13.9	13.9	295
Rangoon	15.0	12.8	27.2	256
Singapore	20.6	18.9	27.2	256
Tokyo	– 6.1	– 8.3	14.4	234
Vladivostok	– 26.1	– 30.0	4.4	119
Canada				
Edmonton	– 41.0	– 48.0	2.8	84
Montreal	– 28.3	– 33.9	6.1	94
Prince Rupert	– 11.7	– 19.5	7.8	312
St Johns	– 20.6	– 30.0	4.5	150
Winnipeg	– 38.9	– 47.8	1.7	79

Location	**Mean annual minimum temperature** (see note 1)	**Absolute minimum temperature** (see note 2)	**Mean annual temperature** (see note 3)	**Maximum average monthly precipitation** (see note 4)
Greenland	°C	°C	°C	mm
Angmagssalik	– 25.6	– 32.2	– 11.1	119
Thule	– 37.8	– 41.0	– 14.4	13
USA				
Anchorage	– 35.6	– 37.8	1.7	66
Chicago	– 23.3	– 30.6	9.6	89
Dallas	– 10.6	– 19.4	18.3	114
Los Angeles	1.7	– 2.2	17.2	79
Miami	3.9	– 2.8	13.9	233
Minneapolis	– 29.4	– 36.7	7.2	112
New York	– 16.7	– 25.6	7.7	109
Phoenix	– 1.7	– 8.9	21.1	25
San Francisco	2.8	– 2.8	13.9	119
Seattle	– 6.1	– 16.1	11.1	142
Washington	– 15.6	– 26.1	13.3	112
Yellowstone Park	– 31.7	– 40.5	3.6	51
South America				
Asuncion	1.7	– 1.7	23.3	157
Bogota	5.6	4.4	14.4	160
Buenos Aires	– 2.8	– 5.6	16.1	109
Caracas	9.4	7.2	20.6	109
Concepcion	3.9	2.2	22.8	206
Cristobal	21.7	18.9	27.2	566
Georgetown	21.1	20.0	26.7	302
Guatemala City	7.2	5.0	20.0	274
Guayaquil	16.1	13.9	25.6	277
Lima	10.6	9.4	20.0	8
Montevideo	2.2	– 3.9	16.1	99
Nassau	11.7	5.0	25.0	175
Rio de Janeiro	13.3	10.0	22.8	137
San Jose	10.6	9.4	20.6	305
San Salvador	10.6	7.2	25.0	328
Santiago	– 2.8	– 4.4	15.0	84

NOTE 1 The mean annual minimum temperature column gives the mean, over the period for which observations have been made, of the lowest temperature recorded in each year. It is recommended that this figure is used for design calculations as the minimum ambient temperature.

NOTE 2 The absolute minimum temperature column shows the lowest temperature ever recorded. Comparison of this with the first column gives a crude idea of the spread of minimum temperature readings.

NOTE 3 The mean annual temperature may be used, in conjunction with the design maintenance temperature, to estimate the annual energy consumption of a surface heating system.

NOTE 4 The precipitation data in the last column are the average figures, in terms of equivalent rainfall, for the month of greatest precipitation.

E.3 References. Further data may be found in the following reference works compiled by the Meteorological Office, from which the data presented in **E.1** and **E.2** here were extracted.

Meteorological Office. Met. 0.617. *Tables of temperature, relative humidity and precipitation for the world:*

- — *Part 1: North America, Greenland and the North Pacific Ocean;*
- — *Part 2: Central and South America, the West Indies and Bermuda;*
- — Part 4: *Africa, the Atlantic Ocean south of 35°N, and the Indian Ocean;*
- — Part 5: *Asia;*
- — Part 6: *Australasia and the South Pacific Ocean.*

Meteorological Office. Met. 0.856. *Tables of temperature, relative humidity, precipitation and sunshine for the world:*

Part 3: — *Europe and the Azores*

Meteorological Office. Climatological Memorandum 73.

Maps of mean and extreme temperature over the United Kingdom 1941 – 1970.

Meteorological Office. Climatological Memorandum 75.

Maps of mean vapour pressure and of frequencies of high relative humidity over the United Kingdom.

Meteorological Office. Climatological Memorandum 79.

Maps of hourly mean wind speed over the United Kingdom 1965 – 1973.

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Publications referred to

BS 476, *Fire tests on building materials and structures.*

BS 476-4, *Non-combustibility test for materials.*

BS 476-5, *Method of test for ignitability.*

BS 5345, *Code of practice for the selection, installation and maintenance of electrical apparatus for use in potentially explosive atmospheres (other than mining applications or explosive processing and manufacture).*

BS 5345-1, *Basic requirements for all parts of the code.*

BS 5422, *Specification for the use of thermal insulating materials.*

BS 5970, *Code of practice for thermal insulation of pipework and equipment (in the temperature range of – 100 °C to 870 °C).*

BS 6351, *Electric surface heating.*

BS 6351-1, *Specification for electric surface heating devices.*

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