BRITISH STANDARD

BS 5141-2:
1977

Specification for

Air heating and cooling coils —

Part 2: Method of testing for rating of heating coils

UDC 697.97:697.978.001.4

Cooperating organizations

The Refrigeration, Heating and Air Conditioning Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

Association of Consulting Engineers*
Association of Manufacturers of Domestic Electrical Appliances
Boiler and Radiator Manufacturers' Association Ltd*
British Combustion Equipment Manufacturers' Association
British Gas Corporation
British Mechanical Engineering Confederation
British Refrigeration and Air Conditioning Association*
Building Services Research and Information Association*
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National Coal Board
Society of British Gas Industries
Water-tube Boilermakers' Association

The Government departments and scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

Department of the Environment — Building Research Establishment
Institute of Domestic Heating Engineers
Unit Heater Manufacturers' Association

This British Standard, having been prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee, was published under the authority of the Executive Board on 31 March 1977

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Contents

Foreword

This Part of this British Standard has been prepared under the authority of the Refrigeration, Heating and Air Conditioning Standards Committee in response to requests from industry.

It constitutes a revision of BS 2619 "*Method of test and rating for steam-heated air-heater batteries*" and BS 3208 "*Methods of test and rating for hot-water air-heater batteries*", which will both be withdrawn.

This Part is the second of a series concerned with air heating and cooling coils.

Where reference is made to British Standards for which no metric version is available, the appropriate British Standard in imperial units shall be used in conjunction with BS 350. Attention is also drawn to BS 3763.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 38, 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.

1 Scope

This Part of BS 5141 gives a method of testing for rating of duct-mounted air heating coils with hot water or dry saturated steam as the heating medium within the range of variables given in Table 1.

2 References

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

3 Object of the tests

The object of the tests is to provide a fundamental means of establishing the rating of coils operating in other than test conditions by applying test data obtained from a prototype coil (or coils).

4 Definitions

For the purposes of this British Standard the following definitions apply.

4.1
heating coil

a water-to-air or steam-to-air heat exchanger of the tubular type, through which air is passed by mechanical means over the external surface, such as is normally connected into a system of ventilation ductwork. The heat exchanger surface considered is of the extended surface, externally finned type

4.2
reference conditions

temperature 20 °C, absolute pressure 1.013 bar[1)], relative humidity 43 %, density 1.200 kg/m^3

4.3
rows

the number of banks of tubes in the direction of air flow (see Figure 1)

4.4
passes

the number of times the water or steam in any one circuit crosses the air flow (see Figure 2)

4.5
similar coils

a range of coils having the same

a) water/steam tube size, spacing, arrangement (in-line or staggered, see Figure 1) and internal construction;

b) water or steam flow geometry, the general method of combining rows and circuits (see Figure 2);

c) fin type, construction and spacing (see Figure 3).

4.6
turbulator

a device inside a tube to increase heat transfer

1) 1 bar = 10^5 N/m^2 = 100 kPa

5 Nomenclature

Symbol	Description	Units
A_{Di}	Surface area of ductwork between inlet samples and centre of coil	m^2
A_{Do}	Surface area of ductwork between outlet sampler and centre of coil	m^2
A_F	Coil face area	m^2
A_i	Coil internal surface area ($n_t \pi\ d_i\ l_t\ 10^{-3}$)	m^2
A_o	Coil external surface area ($A_P + A_s$)	m^2
A_P	Area of exposed tubes	m^2
A_s	Total surface area of coil fins (both sides); where fin collars are employed, the collar is taken as part of the exposed tube area	m^2
A_t	Cross-sectional area of coil tube (bore area)	m^2
B	Coil surface area ratio (A_o/A_i)	—
c_{pa}	Specific heat capacity of air	kJ/(kg K)
c_{pw}	Specific heat capacity of water	kJ/(kg K)
c_{pam}	Specific heat capacity of air at mean air temperature	kJ/(kg K)
c_{pwm}	Specific heat capacity of water at mean water temperature	kJ/(kg K)
d_i	Tube internal diameter	mm
d_o	Tube external diameter	mm
F	Factor for corrected logarithmic mean temperature	—
f_a	Air-side film transfer coefficient	$W/(m^2\ K)$
f_v	Steam-side film transfer coefficient	$W/(m^2\ K)$
f_w	Water-side film transfer coefficient	$W/(m^2\ K)$
f_{ws}	Water-side film transfer coefficient for smooth bore tubes	$W/(m^2\ K)$
f_{wt}	Water-side film transfer coefficient for tubes fitted with turbulators	$W/(m^2\ K)$
g	Acceleration due to gravity	m/s^2
K_i	Heat leakage coefficient for air inlet section	kW/K
K_o	Heat leakage coefficient for air outlet section	kW/K
K_w	Correction factor for hydraulic pressure drop	—
k	Thermal conductivity of insulating material	W/(m K)
k_t	Thermal conductivity of tube wall material	W/(m K)
k_f	Thermal conductivity of fin material	W/(m K)
l_c	Length of one complete water circuit	m
l_t	Length of each coil water tube	m
L	Latent heat of evaporation of steam at the test steam pressure	kJ/kg
m_a	Air mass flow rate	kg/s
m_v	Condensate mass flow rate	kg/s
m_w	Water mass flow rate	kg/s
n_c	Number of circuits	—
n_t	Number of tubes in coil	—
n	Number of rows in test coil	—
n'	Number of rows in coil under consideration	—
P_b	Barometric pressure	bar

Symbol	Description	Units
P_{vi}	Steam inlet pressure (gauge)	bar
Δp_c	Coil air pressure drop	Pa
Δp_r	Coil air pressure drop corrected to reference density	Pa
$\Delta p_{rn}'$	Coil air pressure drop corrected to reference density for coil of n' rows	Pa
Δp_w	Hydraulic pressure drop (measured)	Pa
Δp_{wc}	Hydraulic pressure drop corrected for heat differences between coil inlet and outlet	Pa
Δp_{wct}	Hydraulic pressure drop at reference temperature	Pa
Q	Mean heat transferred	kW
Q_a	Heat transferred on air side	kW
Q_v	Heat transferred on steam side	kW
Q_w	Heat transferred on water side	kW
R	Overall thermal resistance	m^2 K/W
R_a	Thermal resistance of air film	m^2 K/W
R_f	Fin thermal resistance	m^2 K/W
R_m	Metal thermal resistance	m^2 K/W
R_t	Tube wall thermal resistance	m^2 K/W
R_v	Thermal resistance of steam film (based on A_o)	m^2 K/W
R_w	Thermal resistance of water film (based on A_o)	m^2 K/W
t_a	Ambient temperature (dry bulb)	°C
t_{ai}	Inlet air temperature (dry bulb)	°C
t_{ao}	Outlet air temperature (dry bulb)	°C
t_{aic}, t_{aoc}	t_{ai} and t_{ao} corrected for heat losses or gains	°C
t'_{ai}	Inlet air temperature (wet bulb)	°C
t'_{ao}	Outlet air temperature (wet bulb)	°C
t_{vi}	Inlet steam temperature	°C
t_{vs}	Dry saturated steam temperature corresponding to steam inlet pressure P_{vi} (from steam tables)	°C
t_{wi}	Inlet water temperature	°C
t_{wo}	Outlet water temperature	°C
t_{wm}	Mean water temperature; $(t_{wi} + t_{wo})/2$	°C
Δt_m	Corrected logarithmic mean temperature difference between air and water	°C
v_r	Air velocity at coil face at reference condition	m/s
v_w	Mean water velocity	m/w
X_b	Inner radius of fin	mm
X_e	Outer radius or equivalent radius of fin	mm
Y_f	Fin thickness	mm
Y_i	Thickness of insulating material	mm

Greek symbols	Description	Units
γ, δ	Parameters defined in **14.1.1.2**	—
η	Surface effectiveness	—
ϕ	Fin efficiency	—
ρ	Density	kg/m^3
ρ_r	Reference air density (1.2 kg/m^3)	kg/m^3

Suffices

a	air
b	barometric; inner radius of fin
c	calculated; circuits; corrected
D	duct
e	outer radius of fin
F	face
f	fin
i	inlet; insulating; internal
m	mean; metal
o	external; outlet
p	exposed tubes; pressure
r	reference condition(s)
s	smooth; surface
t	reference temperature; tube(s); turbulator
T	total
v	steam
w	water

6 Instrumentation

6.1 Temperature measurement

6.1.1 The measurement of temperature shall comply with the requirements of BS 1041. If liquid-in-glass thermometers are used, they shall be graduated in intervals not exceeding 0.1 °C, and shall comply with the requirements of BS 593, partial immersion ranges. All temperature-measuring instruments shall be calibrated against an NPL calibrated thermometer to a precision of 0.1 °C.

6.1.2 Water and steam temperatures shall be measured by means of instruments inserted into oil-filled pockets similar to those in Figure 4.

6.1.3 For water temperature differences below 5 °C, it is necessary to take special care and the differential thermocouple system shown in Figure 5 is recommended, together with a separate measurement of inlet water temperature.

6.1.4 The inlet and outlet air temperatures shall be measured by means of the system given in BS 4194 (Appendix D). The measurement system shall be connected to sampling tubes similar to those shown in Figure 6.

6.2 Flow measurement

6.2.1 The measurement of water flow at temperatures up to 95 °C shall preferably be by means of direct weighing (although one of the methods described in BS 1042 may be used).

The measurement of water flow at temperatures over 95 °C shall be made by one of the methods described in BS 1042.

When direct weighing is used, the water leaving the test rig shall be collected in vessels of known weight and weighed to an accuracy of 0.1 % over the range of weights used in the test. The weight of each vessel used shall not exceed 50 % of its normal contents. The net weight of each charge shall be recorded by weighing the vessel both after emptying the previous charge and after filling. The vessels shall be covered to prevent loss by evaporation.

6.2.2 The measurement of steam flow shall be be weighing the condensate. The weighing apparatus shall be as described in **6.2.1**.

6.2.3 The measurement of air flow shall be as specified in BS 1042-1 or, alternatively, a flow meter shall be used calibrated in situ by the methods given in BS 1042-2.

6.3 Pressure measurement

6.3.1 Side wall tappings for measurement of hydraulic pressure drop shall be fitted adjacent to the coil. The tappings shall be as specified in Figure 7 and shall be connected to form a piezometric ring.

An inverted U-tube manometer, similar to that shown in Figure 7, shall be employed for the measurement of hydraulic pressure drop.

6.3.2 Steam pressure gauges shall comply with the requirements of clause 30 a) of BS 1780:1960. They shall be at least 150 mm in diameter and shall have a total scale range not more than three times the measured pressure.

For pressures below 0.3 bar (gauge), a liquid manometer is desirable.

6.3.3 Wall static air pressures shall be measured with static taps conforming to the specifications given in BS 1042-2. A minimum of four taps shall be symmetrically disposed about the duct walls and connected to form a piezometric ring.

6.3.4 Manometers shall have a total scale range of not more than three times the maximum measured pressure. Manometers shall have scale intervals not greater than 2 % of the total scale range, with the exception of pressures below 50 Pa, in which case the maximum intervals shall be 1 Pa.

The minimum differential pressures for flow measurement shall be 25 Pa for inclined U-tube manometers and micro-manometers and 500 Pa for vertical U-tube manometers.

7 Air flow leakage test

The heat transfer tests specified in this standard are to be carried out on coils that have been sealed against air flow leakage; this condition will not, however, always apply in practice and consequently it is necessary, following the procedure given in **7.1**, to carry out air flow leakage tests to indicate possible reduction of coil heat transfer performance.

7.1 Procedure. Connect a standard coil to an air supply system as shown in Figure 8.

NOTE If the air supply pressure is greater than that specified by the coil manufacturer, a pressure relief valve is to be fitted after the regulator.

Increase the air supply pressure to that desired for the test (but not higher than that recommended by the manufacturer), hold for a minimum period of 15 min, and then reduce to zero. Again increase the supply to the previous value and hold constant for a further 15 min, at the end of which read the flow rate and record this as the coil leakage flow at the test pressure.

NOTE If an integrating flow meter is employed, measurement may commence 10 min after the second pressurization.

8 Test apparatus

8.1 Air

8.1.1 The test coil shall be connected to an air supply and measuring system similar to that shown in Figure 9, the flow metering system being located downstream of the coil under test.

8.1.2 The air velocity, temperature and humidity profiles at the sampling tubes shall be uniform (to within 5 %) and to this end mixers, similar to either of the types shown in Figure 10, shall be employed, together with the honeycomb, gauze screens, and changes in section indicated in Figure 9.

NOTE It is recommended that the profiles at the inlet and outlet sampling tubes are checked during the assembly of the test rig as any large deviations from the mean may give rise to difficulty in obtaining a heat balance. The outlet conditions should also be checked before the flow metering system is connected.

8.1.3 The test coil and duct work between the inlet and outlet sampling tube shall be insulated with at least 50 mm thickness of insulating material having a thermal conductivity not exceeding 0.06 W/(m K). All ductwork between these stations shall be constructed from metal. The ductwork and test coil from the inlet sampling tube to the flow meter shall be sealed against air leaks. The test coil shall be sealed against air leakage.

8.2 Hot water

8.2.1 There shall be available a means for providing and controlling a continuous supply of water at any temperature and flow rate that is required for the test. Suitable arrangements of equipment are shown in Figure 11 and Figure 12.

8.2.2 The pipe work shall be arranged to give an unobstructed straight run at entry and exit from the coil under test, the pipe diameter being equal to that demanded by the unit connections and of a length equal to five pipe diameters. The "thermometer" pockets shall be positioned such that the water flow is towards the base of the pocket, as indicated by the arrows in Figure 4.

8.2.3 Side wall tappings for measuring the hydraulic pressure drop shall be fitted as specified in **6.3.1**.

8.2.4 The lengths of pipe between the temperature measurement positions, the coil connections and the coil casing shall be insulated with at least 40 mm thickness of insulating material having a thermal conductivity not exceeding 0.06 W/(m K).

8.3 Steam

8.3.1 The steam supply and consumption test equipment shall be similar to the arrangement shown in Figure 13.

8.3.2 The length of pipe between the steam pressure and temperature measurement positions and the coil shall not exceed 300 mm and shall be insulated with at least 40 mm thickness of insulating material having a thermal conductivity not exceeding 0.06 W/(m K).

8.3.3 The pipe conveying the condensate to the sight glass shall not exceed a total length of 1 m.

This pipe and the pipe from the sight glass to the collecting vessel shall be insulated with at least 40 mm thickness of insulating material having a thermal conductivity not exceeding 0.06 W/(m K).

8.3.4 An air cock, throttle valve, pressure gauge or manometer, a temperature measuring instrument and a separator with drain shall be fixed in the steam pipe close to the steam inlet of the unit, as means for controlling and indicating the steam pressure and temperature. The use of a superheater, preferably electrically heated, is also advisable.

8.3.5 An air cock, automatic or otherwise, a sight glass with water-level indicator and a throttle valve shall be fixed close to the coil condensate outlet.

8.3.6 The condensate shall be collected and weighed (see **6.2.2**) and means shall be employed to minimize loss by evaporation. An aftercooler should be fitted if required.

9 Requirements for rating tests

9.1 To establish ratings for similar coils (see **4.2**), having four or more rows, the test coil shall have a minimum of four rows.

If the ratings are required for 1-, 2- or 3-row coils, separate tests shall be carried out on similar coils (see **4.2**) with the appropriate number of rows.

All test coils shall have a minimum face area of 0.5 m^2.

9.2 The tests shall be carried out within the range of variables given in Table 1. For values of variables outside this range, further tests will be required. The values used on test shall be within the manufacturer's recommended limits.

9.3 For coils using hot water as the heating medium, separate tests are to be made to determine the ratings for the range 40 °C to 120 °C and 120 °C to 200 °C.

10 Tests required for establishing a rating

The following tests shall be made.

10.1 Heat transfer. Heat transfer tests shall be made at one water velocity or at one steam pressure and a minimum of four air flow rates spaced approximately at equal logarithmic intervals throughout the required flow range.

10.2 Air static pressure drop. The air static pressure drop shall be measured during each heat transfer test.

10.3 Hydraulic pressure drop. The hydraulic pressure drop shall be measured during each heat transfer test. An additional series of measurements shall be carried out on one coil at a minimum of four water velocities covering the manufacturer's recommended range of water velocities. These measurements may be carried out without a thermal load. The water temperatures shall be recorded.

10.4 Air flow leakage. For coils of one, two or three rows, separate air flow leakage tests shall be made. For similar coils of four or more rows, the test coil shall have a minimum of four rows. Tests shall be carried out at a minimum of four static pressures, spaced at equal logarithmic intervals, up to 1 500 Pa or the manufacturer's maximum recommended working pressure, whichever is the greater. The leakage flow rate shall be plotted against static pressure on logarithmic graph paper. It will be possible to obtain the approximate leakage flow for any coil in the range from this graph.

11 General test procedures

Before commencing the test carry out the procedures specified in **11.1** or **11.2** as appropriate.

11.1 Hot water. Select an inlet water temperature between 70 °C and 90 °C if the coil is to be rated in the range 40 °C to 120 °C or between 150 °C and 170 °C if the coil is to be rated in the range 120 °C to 200 °C. Select a water flow rate within the requirements of Table 1.

Vent the coil and water supply piping system to remove all air.

Set the required air flow rate, within the provisions of Table 1 and as required by **12.1**.

11.2 Steam. Adjust the steam to the required pressure and temperature within the provisions of Table 1; adjust the flow rate so that the level of condensate is visible in the gauge glass.

Vent the coil and steam supply system to remove all air.

Set the required air flow rate, within the provisions of Table 1.

Table 1 — Heat transfer variables for test purposes

Variable	Range (see note)
Inlet air temperature, dry bulb, t_{ai}	below 25 °C
Inlet water temperature, t_{wi}	as required by **11.1**
Water or steam Reynolds number	above 3 100
Steam condition	1.5 °C to 3 °C superheat
Air velocity at coil face	1 m/s to 10 m/s
NOTE The maximum values used on test shall be within the manufacturer's recommended limits.	

12 Test results

12.1 The test shall be carried out under steady-state conditions. These shall be said to exist when the measurements given in Table 2 do not vary by more than the specified amounts from their mean value over a period of 30 min; readings being taken at 10 min intervals or, alternatively, using a data logger.

Table 2 — Allowed variation from mean value of data

Inlet air temperature, dry bulb, t_{ai}	± 0.2 °C
Inlet air temperature, wet bulb, t'_{ai}	± 0.2 °C
Air mass flow rate, m_a	± 1 %
Inlet water temperature, t_{wi}	± 0.2 °C
Inlet steam temperature, t_{vi}	± 0.5 °C
Water mass flow rate, m_w	± 1 %
Condensate mass flow rate, m_v	± 2 %
Steam pressure, gauge, P_{vi}	± 1 %

12.2 The test shall occupy not less than 30 min, and complete sets of data shall be taken at intervals not exceeding 10 min with the exception of barometric pressure and ambient temperature, which shall be recorded at start and finish. During the test, the mean values shall not vary by more than those given in Table 2.

A complete set of data shall comprise:

Inlet air temperature (dry bulb)	t_{ai}	°C
Inlet air temperature (wet bulb)	t'_{ai}	°C
Outlet air temperature (dry bulb)	t_{ao}	°C
Outlet air temperature (wet bulb)	t'_{ao}	°C
Coil air-side pressure drop	Δp_c	Pa
Air mass flow rate	m_a	kg/s
Barometric pressure	P_b	bar
Ambient temperature	t_a	°C

with either:

Inlet water temperature	t_{wi}	°C
Outlet water temperature	t_{wo}	°C
Water mass flow rate	m_w	kg/s
Hydraulic pressure drop	Δp_w	Pa

or:

Steam inlet pressure (gauge)	p_{vi}	bar
Steam inlet temperature	t_{vi}	°C
Condensate mass flow rate	m_v	kg/s

12.3 The test measurements shall be averaged and the average values used in all calculations.

13 Basic calculations

13.1 Water side. The heat transferred from the water (Q_w) shall be computed in kilowatts from the equation

$$Q_w = m_w \, c_{pw} \, (t_{wi} - t_{wo})$$

where

m_w is the water mass flow rate obtained from direct weighing or from flow meter (kg/s)

c_{pw} is the specific heat capacity of water at $[t_{wi} + t_{wo})/2$ (kJ/(kg K)]

t_{wi} is the inlet water temperature (°C)

t_{wo} is the outlet water temperature (°C)

13.2 Steam side. The heat transferred from the steam (Q_v) shall be computed in kilowatts from the equation

$$Q_v = m_v L$$

where

m_v is the condensate mass flow rate (kg/s)

L is the latent heat of evaporation of steam at the test steam pressure (kJ/kg)

13.3 Air side

13.3.1 *Calculation of corrections to air inlet and outlet temperatures.* The heat leakage coefficients K_i and K_o for the sections between the inlet air temperature measuring station and the coil centre and between the coil centre and the outlet air temperature measuring station respectively shall be computed in kW/K from the equations:

Inlet section

$$K_i = A_{Di}\, k/Y_i$$

Outlet section

$$K_o = A_{Do}\, k/Y_i$$

where

- A_{Di} is the surface area of duct work between inlet sampler and centre of coil (m^2)
- A_{Do} is the surface area of duct work between outlet sampler and centre of coil (m^2)
- Y_i is the thickness of insulating material (mm)
- k is the thermal conductivity of insulating material [W/(m K)]

The following temperature corrections shall be made to allow for heat losses or gains to the air passing through the test coil.

Inlet air temperature (dry bulb) at coil in degrees Celsius

$$t_{aic} = t_{ai} + \frac{K_i(t_a - t_{ai})}{m_a c_{pa}}$$

Outlet air temperature (dry bulb) at coil in degrees Celsius

$$t_{aoc} = t_{ao} - \frac{K_o(t_a - t_{ao})}{m_a c_{pa}}$$

where

- t_{ai} is the inlet air temperature (dry bulb) (°C)
- t_{aic} is the inlet air temperature (dry bulb) corrected for heat losses or gains (°C)
- t_a is the ambient temperature (dry bulb) (°C)
- K_i is the air inlet section heat leakage coefficient (kW/K)
- m_a is the air mass flow rate (kg/s)
- c_{pa} is the specific heat capacity for air at either t_{ai} or t_{ao} as appropriate [kJ/(kg K)]
- t_{ao} is the outlet air temperature (dry bulb) (°C)
- t_{aoc} is the outlet air temperature (dry bulb) corrected for heat losses or gains (°C)
- K_o is the air inlet section heat leakage coefficient (kW/K)

If the total heat leakage is less than 1 % of the test coil capacity (Q_w), no temperature corrections are necessary.

13.3.2 *Air mass flow rate.* The air mass flow rate shall be calculated from the air volume flow rate, using the air density at the flow meter.

13.3.3 *Calculation of air side heat transferred.* The heat transferred to the air (Q_a) shall be computed in kilowatts from the equation:

$$Q_a = m_a c_{pa}\,(t_{aoc} - t_{aic})$$

where

- m_a is the air mass flow rate (kg/s)
- c_{pa} is the specific heat capacity for air at the mean air temperature [kJ/(kg K)]
- t_{aic} is the inlet air temperature (dry bulb) corrected for heat losses or gains (°C)
- t_{aoc} is the outlet air temperature (dry bulb) corrected for heat losses or gains (°C)

13.4 Mean heat transferred. The mean heat transferred (Q) shall be computed in kilowatts from the equation:

$Q = (Q_w + Q_a)/2$ or $Q = (Q_v + Q_a)/2$

The test shall be void if the ratio

Q_w/Q_a or Q_v/Q_a

is outside the limiting values 0.95 and 1.05

where

- Q_w is the heat transferred on the water side (kW)
- Q_a is the heat transferred on the air side (kW)
- Q_v is the heat transferred on the steam side (kW)

13.5 Hydraulic pressure drop. The hydraulic pressure drop shall be corrected for any height (static head) difference between measuring points and recorded at the test water flow rate and temperature.

13.6 Air pressure drop. The air pressure drop at reference condition shall be calculated from the equation

$\Delta p_r = \Delta p_c \rho_a / \rho_r = \Delta p_c \rho_a / 1.2$

where

- Δp_r is the air pressure drop corrected to reference air density (P_a)
- Δp_c is the coil air pressure drop (Pa)
- ρ_a is the mean air density $(\rho_{ai} + \rho_{ao})/2$ (kg/m^3)
- ρ_r is the reference air density (kg/m^3)

13.7 Air velocity. The coil face air velocity at reference condition shall be calculated from the equation

$V_r = m_a / \rho_r A_F = m_a / 1.2\ A_F$

where

- V_r is the air velocity at reference conditions (m/s)
- m_a is the air mass flow rate (kg/s)
- ρ_r is the reference air density (kg/m^3)
- A_F is the coil face area (m^2)

14 Heat transfer calculations

The heat transferred from a coil surface is related to the fluid and coil properties by the equation

$$Q = \frac{A_o\ \Delta t_m \times 10^{-3}}{R} = \frac{A_o \Delta t_m \times 10^{-3}}{R_a + R_m + R_w} \text{ or } \frac{A_o \Delta t_m \times 10^{-3}}{R_a + R_m + R_v}$$

where

- Q is the mean heat transferred (kW)
- A_o is the coil external surface area $(A_p + A_s)$ (m^2)
- R is the overall thermal resistance (m^2 K/W)
- R_a is the air film thermal resistance (m^2 K/W)
- R_m is the metal thermal resistance (m^2 K/W)
- R_v is the steam film thermal resistance (based on A_o) (m^2 K/W)
- R_w is the water film thermal resistance (based on A_o) (m^2 K/W)
- Δt_m is the corrected logarithmic mean temperature difference between air and water or between air and steam (see **14.3**) (°C)

In order to employ the equation, it is necessary to calculate the various thermal resistances. These shall be determined from theoretical and experimental data as described in the following clauses.
(See also Appendix A.)

14.1 Metal thermal resistance. The metal thermal resistance of the coil (R_m) may be expressed as the sum of the thermal resistance of the tube wall (R_t) and the thermal resistance of the fin (R_f). The thermal resistance of the fin is a function of the heat transfer coefficient for the air side.

14.1.1 ***Basic equations***

14.1.1.1 *Tube wall thermal resistance*

$$R_t = \frac{B(d_o - d_i)}{k_t(1 + d_o/d_i)} \times 10^{-3}$$

where

- R_t is the tube wall thermal resistance (m^2 K/W)
- k_t is the thermal conductivity of the tube wall material [W/(m K)]
- d_o is the tube external diameter (mm)
- d_i is the tube internal diameter (mm)
- B is the coil surface ratio (A_o/A_i)
- A_o is the coil external surface area ($A_p + A_s$) (m^2)
- A_i is the coil internal surface area ($n_t \pi d_i l_t \times 10^{-3}$) ($m^2$)
- A_p is the area of exposed tubes (m^2)
- A_s is the total surface area of coil fins (both sides) (m^2)
- n_t is the number of tubes in coil
- l_t is the length of each tube (m)

14.1.1.2 *Fin thermal resistance*

$$R_f = \frac{(1 - \eta)}{\eta f_a}$$

where

- R_f is the fin thermal resistance (m^2 K/W)
- η $= \dfrac{\phi A_s + A_p}{A_o}$ is the surface effectiveness
- f_a is the air side heat transfer coefficient [W/(m^2 K)]
- A_s is the total surface area of coil fins (both sides) (m^2)
- A_p is the area of exposed tubes (m^2)
- A_o is the coil external surface area ($A_p + A_s$) (m^2)
- ϕ is the fin efficiency obtained from Figure 14 and Figure 15. The parameters γ and δ in these figures are determined from the following equations:
- γ $= X_e/X_b$
- δ $= (X_e - X_b)\sqrt{(2f_a \times 10^{-3})/(k_f Y_f)}$
- k_f is the thermal conductivity of the fin material [W/(m K)]
- X_b $= d_o/2$, or $\{d_o/2 +$ (fin collar thickness)$\}$ when fin collars are used (mm)
- d_o is the tube external diameter (mm)

With circular fins of constant thickness (use Figure 14 for ϕ)

- X_e is the fin outside radius (mm)
- Y_f is the fin thickness (mm)

With spiral fins or fins of constant area for heat flow (use Figure 15 for ϕ)

- X_e is the fin tip radius (mm)
- Y_f is the fin root thickness (mm)

With rectangular fins (use Figure 14 for ϕ)

X_e = (length of fin × depth of fin × $1/\pi)^{0.5}$ (mm)

Y_f is the fin thickness (mm)

With continuous plate fins (use Figure 14 for ϕ)

X_e = (length of fin × depth of fin × $1/\pi \times 1/n_t)^{0.5}$ (mm)

n_t is the number of tubes in coil

Y_f is the fin thickness (mm)

14.1.2 *Rating data.* The calculations indicated by the equations given in **14.1.1** shall be carried out for a minimum of six assumed values of f_a. It will be necessary to assume values covering the expected range of coil performance.

R_a $(= 1/f_a)$ shall be plotted versus $(R_a + R_m)$ as shown in Figure 16.

R_m $(= R_f + R_t)$ shall be plotted versus f_a as shown in Figure 17.

14.2 Water film thermal resistance. For smooth bore tubes

$R_w = B/f_{ws}$

For tubes with turbulators

$R_w = B/f_{wt}$

where

R_w is the water film thermal resistance (m² K/W)

B is the coil surface area ratio (A_o/A_i)

f_{ws} is the water film heat transfer coefficient for smooth bore tubes [W/(m² K)]

f_{wt} is the water film heat transfer coefficient for tubes with turbulators [W/(m² K)]

14.2.1 ***For smooth bore tubes***

$$f_{ws} = \frac{5600\,(1 + 0.015\,t_{wm})\,v_m^{0.8}}{d_i^{0.2}}$$

for water temperatures between 40 °C and 120 °C

$$f_{ws} = \frac{9700\,(1 + 0.0038\,t_{wm})\,v_w^{0.8}}{d_i^{0.2}}$$

for water temperatures between 120 °C and 200 °C

where

t_{wm} is the mean water temperature $(t_{wi} + t_{wo})/2$ (°C)

v_w is the mean water velocity $(m_w/\rho_w n_c A_t)$ (m/s)

d_i is the tube internal diameter (mm)

m_w is the water mass flow rate (kg/s)

ρ_w is the water density at mean water temperature (kg/m³)

n_c is the number of circuits

A_t is the internal cross sectional area of coil tube (m²)

14.2.2 *For tubes with turbulators.* The following tests shall be carried out to determine the water-film heat transfer coefficient for tubes with internal fins or turbulators, since this cannot be determined by an empirical formula.

14.2.2.1 Heat transfer tests are carried out on two similar coils, each having identical heat transfer surfaces but one having smooth bore tubes and the other having turbulators.

14.2.2.2 The tests shall be carried out at a minimum of four water flow rates, spaced approximately at equal logarithmic intervals throughout the recommended water flow range. Water flow rates and inlet temperatures for the tests on the coil fitted with turbulators shall be to within 2 % of those employed for the tests on the coil with smooth bore tubes. The tests shall be carried out at one air flow rate, which shall not vary by more than 2 % from test to test. The heat transferred in each test shall be calculated as described in clause **13**.

14.2.2.3 The following additional calculations for each of the four flow rates shall be carried out to determine f_{wt}.

a) Compute the values of overall thermal resistance for each coil and for each water flow rate from

$$R = \frac{A_o \Delta t_m 10^{-3}}{Q}$$

where

R	is the overall thermal resistance (m^2 K/W)
A_o	is the coil external surface area (m^2)
Δt_m	is the corrected logarithmic mean temperature difference between air and water (°C)
Q	is the mean heat transferred

b) Subtract the overall thermal resistance at identical water flow rates for the coil with turbulators from that for the coil with smooth bore tubes.The difference in each case is equal to the change in thermal resistance due to the turbulators (ΔR).

c) Calculate the value of f_{ws} from the equation given in in **14.2.1**.

d) f_{wt} is then given by the equation:

$$f_{wt} = \left(\frac{1}{f_{ws}} - \frac{\Delta R}{B}\right)^{-1}$$

where

ΔR	is the change in thermal resistance due to the turbulators (m^2 K/W)
B	is the coil surface area ratio

14.2.2.4 For water temperatures between 40 °C and 120 °C, $f_{wt}/(1 + 0.015\, t_{wm})$ or for water temperatures between 120 °C and 200 °C, $f_{wt}/(1 + 0.0038\, t_{wm})$ shall then be plotted against v_w on logarithmic graph paper, and the best line drawn through the test points, as shown in Figure 18. This curve shall be used to determine f_{wt} in the analysis of the coil performance data.

14.3 Air-film thermal resistance for hot water coils (R_a)

14.3.1

$$R_a = \frac{A_o \Delta t_m \times 10^{-3}}{Q} - R_m - R_w$$

where

R_a	is the air film thermal resistance (m^2 K/W)
A_o	is the coil external surface area (m^2)
Q	is the mean heat transferred (kW)
R_m	is the metal thermal resistance (m^2 K/W)
R_w	is the water film thermal resistance (m^2 K/W)
Δt_m	is the corrected logarithmic mean temperature difference (°C)

a) For crossflow single pass coils

$$\Delta t_m = F \frac{(t_{wo} - t_{aic}) - (t_{wi} - t_{aoc})}{\log_e (t_{wo} - t_{aic}) - \log_e (t_{wi} - t_{aoc})}$$

F is obtained from Figure 19.

b) For counterflow coils (multipass)

$$\Delta t_m = \frac{(t_{wo} - t_{aic}) - (t_{wi} - t_{aoc})}{\log_e (t_{wo} - t_{aic}) - \log_e (t_{wi} - t_{aoc})}$$

c) For parallel flow coils (multipass)

$$\Delta t_m = \frac{(t_{wi} - t_{aic}) - (t_{wo} - t_{aoc})}{\log_e (t_{wi} - t_{aic}) - \log_e (t_{wo} - t_{aoc})}$$

where

t_{aic} is the inlet air temperature (dry bulb) corrected for heat losses or gains (°C)
t_{aoc} is the outlet air temperature (dry bulb) corrected for heat losses (°C)
t_{wi} is the inlet water temperature (°C)
t_{wo} is the outlet water temperature (°C)

14.3.2 The procedure for obtaining R_a is to calculate R_w, which is equal to B/f_w, and R, which is equal to $(A_o \Delta t_m \times 10^{-3})/Q$.

Subtracting R_w from $(A_o \Delta t_m \times 10^{-3})/Q$ will yield $(R_a + R_m)$; R_a can then be obtained from a curve plotted in accordance with **14.1.2** (see Figure 16). This procedure is demonstrated by the first example given in Appendix B.

The above calculation shall be repeated for each air velocity.

For each air velocity plot R_a against v_r on logarithmic graph paper as shown in Figure 20.

14.4 Steam film thermal resistance (R_v)

$R_v = B/f_v$

where

R_v is the steam film thermal resistance (m² K/W)
B is the coil surface area ratio
f_v is the steam film heat transfer coefficient (W/m² K)
f_v may be taken as 11 500 W/(m² K)

14.5 Air film thermal resistance for steam coils (R_a)

14.5.1

$$R_a = \frac{A_o \Delta t_m \times 10^{-3}}{Q} - R_m - R_v$$

where

R_a is the air-film thermal resistance (m² K/W)
A_o is the coil external surface area (m²)
Q is the mean heat transferred (kW)
R_m is the metal thermal resistance (m² K/W)
R_v is the steam-film thermal resistance (m² K/W)

Δt_m is the corrected logarithmic mean temperature difference for steam

$$\Delta t_m = \frac{(t_{aoc} - t_{aic})}{\log_e(t_{vs} - t_{aic}) - \log_e(t_{vs} - t_{aoc})}$$

t_{aic} is the inlet air temperature (dry bulb) corrected for heat losses or gains (°C)

t_{aoc} is the outlet air temperature (dry bulb) corrected for heat losses or gains (°C)

t_{vs} is the dry saturated steam temperature corresponding to steam inlet pressure p_{vi} (from steam tables) (°C)

14.5.2 The procedure for obtaining R_a is to calculate R_v, which is equal to B/f_v, and R, which is equal to $(A_o\, \Delta t_m \times 10^{-3})/Q$.

Subtracting R_v from $(A_o\, \Delta t_m \times 10^{-3})/Q$ will yield $(R_a + R_m)$; R_a can then be obtained from a curve plotted in accordance with **14.1.2** (see Figure 16).

This procedure is demonstrated by the second example given in Appendix B.

15 Pressure drop calculations

15.1 Air-side pressure drop corrected to reference density (Δp_r)

a) Plot Δp_r against v_r for each air velocity on logarithmic graph paper. This graph shall be used to obtain the pressure drop for all coils of the same number of rows as the test coil. For Δp_r see **13.7** and for v_r see **13.8**.

b) If the air-side pressure drop is required for coils with a greater number of rows (n') than those in the test range, it shall be calculated in pascals from the test coil with the greatest number of rows by means of the equation.

$\Delta p_{rn}' = \Delta p_r\, (n'/n)$ for each air velocity

where

Δ_{rn}' is the air pressure drop for the coil being considered (Pa)

Δp_r is the air side pressure drop corrected to reference density obtained from the graph drawn under a) (Pa)

n is the number of rows in the test coil

n' is the number of rows in the coil under consideration

15.2 Hydraulic pressure drop. The hydraulic pressure drop coefficient is a function of the water tube Reynolds number. The water density may be assumed constant for each of the ranges of water temperatures given in Table 1. The water viscosity, however, changes very rapidly with temperature in these ranges and it is therefore necessary to apply a viscosity correction. This correction is applied by converting all pressure drops to the equivalent pressure drop at a reference water temperature of 80 °C. The following calculations shall be carried out.

a) Correct the measured hydraulic pressure drop for any head difference between the coil inlet and outlet water tubes, by means of the equation:

$\Delta p_{wc} = \Delta p_w - g\, H\, \rho_w$

where

Δp_{wc} is the hydraulic pressure drop corrected for head differences between coil inlet and outlet (Pa)

Δp_w is the hydraulic pressure drop (measured) (Pa)

H is the height of inlet water supply tube minus the height of the outlet water supply tube (m)

ρ_w is the water density (kg/m^3)

g is the acceleration due to gravity (m/s^2)

b) Correct Δp_{wc}, to the hydraulic pressure drop at reference water temperature of 80 °C by means of the equation:

$$\Delta p_{wct} = K_w \, \Delta p_{wc}$$

where

Δp_{wct} is the hydraulic pressure drop at reference temperature (80 °C) (Pa)

K_w is the hydraulic pressure drop correction factor obtained from Figure 21 at the test mean water temperature.

c) Plot the hydraulic pressure drop per unit length of circuit ($\Delta p_{wct}/l_c$) against water velocity on logarithmic graph paper. The results for all test coils shall be plotted on one graph and the best line drawn through all test points. This line shall be used for the determination of the hydraulic pressure drop of any coil in the range.

16 Accuracy and extrapolation

The test results may not be extrapolated beyond the range of air velocities employed in the tests, or to conditions outside those given in Table 2.

The test data may be applied to all coils in the range, providing the full range of tests, described in clause **13**, have been carried out. The overall accuracy of calculations, at conditions other than those used in the rating tests, based on the test data is probably somewhat better than 10 % for all coils in the range and in the region of 5 % for the test coils.

Appendix A Procedure for heat transfer calculations

Summary of procedure described in clause **14** for preparing Figure 16, Figure 17 and Figure 20 from test data.

Step	Calculation	Reference
1.	Calculate R_t	**14.1.1.1**
2.	Assume six values of f_a	**14.1.2**
3.	Calculate six values of R_f from the assumed six values of f_a	**14.1.1.2**
4.	Add each of the six values of R_f to R_t and obtain six values of R_m	**14.1**
5.	Calculate six values of R_a from $Ra = 1/f_a$	**14.1.2**
6.	Add six values of R_m to corresponding six values of R_a to obtain six values of $(R_m + R_a)$ to obtain Figure 16	**14.1.2**
7.	Plot six values of R_a versus six values of $(R_m + R_a)$ to obtain Figure 16	**14.1.2**
8.	Plot six values of R_m versus six values of f_a to obtain Figure 17	**14.1.2**
9.	Calculate f_{ws} or find f_{wt} by experiment	**14.2.1** **14.2.2**
10.	Calculate R_w from $R_w = B/f_w$	**14.2**
11.	Calculate at least four values of $A_o\ \Delta t_m \times 10^{-3}/Q$ corresponding to four values of air velocity (see **12.1**)	**14.3**
12.	Subtract R_w from each of the four values of $A_o\ \Delta t_m \times 10^{-3}/Q$ to give four values of $(R_a + R_m)$	**14.3**
13.	Obtain corresponding values of R_a from Figure 16	**14.3**
14.	Plot the four values of R_a versus v_r to obtain Figure 20	**14.3**

Appendix B Examples of heat transfer test data calculations

NOTE For the purpose of these examples, it is assumed that the typical graphs (Figure 16 and Figure 18) represent the results of tests.

B.1 Example for a hot water coil

Data	Symbol	Values	Units
Basic data for a 2-row coil, fitted with turbulators — counter flow, 2 passes [as Figure 2(3)]	A_o	7.4	m^2
	A_F	0.141	m^2
	B	29	
	$A_t n_c$	0.00076	m^2
Test data (includes data established in typical graphs, Figure 16 and Figure 18)	t_{aic}	18.9	°C
	t_{aoc}	42.2	°C
	m_a	0.62	kg/s
	Q_a	14.58	kW
	t_{wi}	87.5	°C
	t_{wo}	70.2	°C
	m_w	0.205	kg/s
	Q_w	14.79	kW
	Q	14.69	kW

Step	Calculation	Symbol	Values	Units
1.	Mean water velocity $\frac{m_w}{\rho_w A_t n_c} = \frac{0.205}{972.6 \times 0.00076}$	v_w	0.277	m/s
2.	Water film heat transfer coefficient; determine from Figure 18, see **14.2.2.4** $\frac{f_{wt}}{(1 + 0.015\, t_{wm})} = 2060$ Therefore $f_{wt} = 2060 \times \left(1 + 0.015 \times \frac{70.2 + 87.5}{2}\right)$	f_{wt}	4 496	W/(m² K)
3.	Water film thermal resistances B/f_{wt}	R_w	0.00645	m² K/W
4.	Corrected logarithmic mean temperature difference between air and water for counter flow coil $\frac{(t_{wo} - t_{aic}) - (t_{wi} - t_{aoc})}{\log_e (t_{wo} - t_{aic}) - \log_e (t_{wi} - t_{aoc})}$ $= \frac{(70.2 - 18.9) - (87.5 - 42.2)}{\log_e 51.3 - \log_e 45.3.}$ $= \frac{6}{2.3\,(1.7101 - 1.6561)}$	Δt_m	48.31	°C
5.	Overall thermal resistance $= (A_o\, \Delta t_m \times 10^{-3})/Q$	R	0.0243	m² K/W
6.	Air film thermal resistance plus metal thermal resistance $= R - R_w$	$R_a + R_m$	0.0179	m² K/W
7.	Air film thermal resistance from Figure 16	R_a	0.0138	m² K/W

B.2 Example for a steam coil

Data	Symbol	Values	Units
Basic data for 2-row coil, smooth bore tubes — crossflow, single passes [as Figure 2(4)]	A_o	7.4	m²
	A_F	0.141	m²
	B	29	
	$A_t n_c$	0.00152	m²
Test data (Includes data established in typical graphs, Figure 16 and Figure 18)	t_{aic}	17.8	°C
	t_{aoc}	68.4	°C
	m_a	0.62	kg/s
	Q_a	31.65	kW
	P_{vi}	2.0	bar (gauge)
	t_v	135.5	°C
	m_v	0.015	kg/s
	Q_v	32.46	kW
	Q	32.06	kW

Step	Calculation	Symbol	Values	Units
1.	Steam film heat transfer coefficient from **14.4**	f_v	11 500	W/(m² K)
2.	Steam film thermal resistance B/f_v	R_v	0.00252	m² K/W
3.	Determine from tables temperature of saturation for steam at test pressure P_{vi} (note t_v must exceed t_{vs} by 1.5 °C to 3 °C)	t_{vs}	133.54	°C
4.	Corrected logarithmic mean temperature difference between air and saturated steam temperatures	Δt_m	88.14	°C
5.	$\frac{t_{aoc} - t_{aic}}{\log_e (t_{vs} - t_{aic}) - \log_e (t_{vs} - t_{aoc})}$ Overall thermal resistance $= (A_o \, \Delta t_m \times 10^{-3})/Q$	R	0.0203	m² K/W
6.	Air film thermal resistance plus metal thermal resistances $= R - R_w$	$R_a + R_m$	0.0178	m² K/W
7.	Air film thermal resistance from Figure 16	R_a	0.0138	m² K/W

Appendix C Examples of heating duty calculations

NOTE For the purpose of these examples, it is assumed that the typical graphs represent the results of tests.

C.1 Performance calculation for hot water coil

It is required to calculate whether a 4-row coil is capable of the specified performance as follows:

Performance requirements:

m_a = 0.86 kg/s
t_{ai} = 4.5 °C
t_{ao} = 46.1 °C
t_{wi} = 85 °C
v_w = 0.30 m/s
m_w = 0.54 kg/s

Coil data:

A_F = 0.141 m²
A_o = 13 m²
B = 25
n = 4

Step	Calculation	Symbol	Value	Units
1.	Mean face air velocity = $m_a / 1.2 A_F$	v_r	5.08	m/s
2.	Air film thermal resistance (from Figure 20)	R_a	0.0085	m^2 K/W
3.	Air film thermal resistance plus metal thermal resistance (from Figure 16)	$R_a + R_m$	0.0125	m^2 K/W
4.	Heat given to air = $m_a c_{pa} \cdot (t_{ai} - t_{ao})$	Q_a	36.0	kW
5.	Water outlet temperature = $t_{wi} + Q_a / c_{pw} m_w$	t_{wo}	69.1	°C
6.	Water film thermal resistance = B/f_w (from Figure 18 at t_{wm} = 77.0 °C and v_w = 0.30 m/s)	R_w	0.0053	m^2 K/W
7.	Overall thermal resistance $R_a + R_m + R_w$	R	0.0178	m^2 K/W
8.	Corrected logarithmic mean temperature difference	Δt_m	50.6	°C
9.	Calculated heat transferred $= \dfrac{A_o \, \Delta t_m}{R \, 10^3}$	Q	37.0	kW

Since the available rate of heat transfer given in step 9 exceeds the required heat transfer from step 4, the coil is capable of the specified performance.

C.2 Performance calculation for a steam coil

It is required to calculate whether a 1-row coil is capable of the specified performance as follows:

Performance requirements:

m_a = 1.73 kg/s

t_{ai} = – 1 °C

t_{ao} = 30 °C

P_{vi} = 4.0 bar

Coil data:

A_F = 0.3 m^2

A_o = 6.915 m^2

B = 25

n = 1

Step	Calculation	Symbol	Value	Units
1.	Mean face air velocity = $m_a/1.2 \, A_F$	v_r	4.806	m/s
2.	Air film thermal resistance (from Figure 20)	R_a	0.0085	m^2 K/W
3.	Air film thermal resistance plus metal thermal resistance (from Figure 16)	$R_a + R_m$	0.015	m^2 K/W
4.	Heat given to air = $m_a \, c_{pa}(t_{ao} - t_{ai})$	Q_a	54.0	kW
5.	Steam film thermal resistance = B/f_v where f_v = 11 500 W/(m^2 K)	R_v	0.00217	m^2 K/W
6.	Overall thermal resistance $R_a + R_m + R_v$	R	0.01717	m^2 K/W
7.	Corrected logarithmic mean temperature difference	Δt_m	137.25	°C
8.	Calculated heat transfer $A_o \, \Delta t_m / R.10^3$	Q	55.2	kW

Since the available rate of heat transfer given in step 8 exceeds the required heat transfer from step 4, the coil is capable of the specified performance.

Appendix D Typical values of thermal conductivity

Material	ISO designation	Nearest BS designation	Thermal conductivity W/(mK)		
			At 20 °C	At 100 °C	At other temperatures
Aluminium	Al 99.5 Al 99.0 Al Mnl	IB IC N3	— — —	— — —	227 – 230 (0 °C) 227 (0 °C) 151 – 176 (0 °C)
Copper					
Electrolytic tough-pitch	Cu-ETP	C.101	393	386	—
Fire defined tough-pitch high conductivity	Cu-FRHC	C.102	393	386	—
Phosphorous-de-oxidized copper (high residual phosphorous)	Cu-DHP	C.106	292 – 365	—	—
Brass					
70/30 brass, (deep drawing brass)	Cu Zn 30	CZ 105 and CZ 106	121	—	147 (200 °C)
Aluminium brass	Cu Zn 20 Al 2	CZ 110	100	—	126 (200 °C)
Admiralty brass (inhibited brass)	Cu Zn 28 Sn 1	CZ 111	109	—	138 (200 °C)
Cupro-nickel					
90/10 Cupro-nickel	Cu Ni 10 Fe 1 Mn	CN 101	—	—	45 (temperature unspecified)
70/30 Cupro-nickel	Cu Ni 30	CN 107	—	—	29
70/30 Cupro-nickel	Cu Ni 30	CN 107	—	—	(temperature unspecified)
Stainless steel		302 304 316 321 347	— — — — —	15.9 14.2 15.9 15.9 15.9	— — — — —
Carbon steel	Ts 2 Ts 3 Ts 9H	320 360 410	56.6 56.6 49.5	55.4 55.4 48.4	— — —

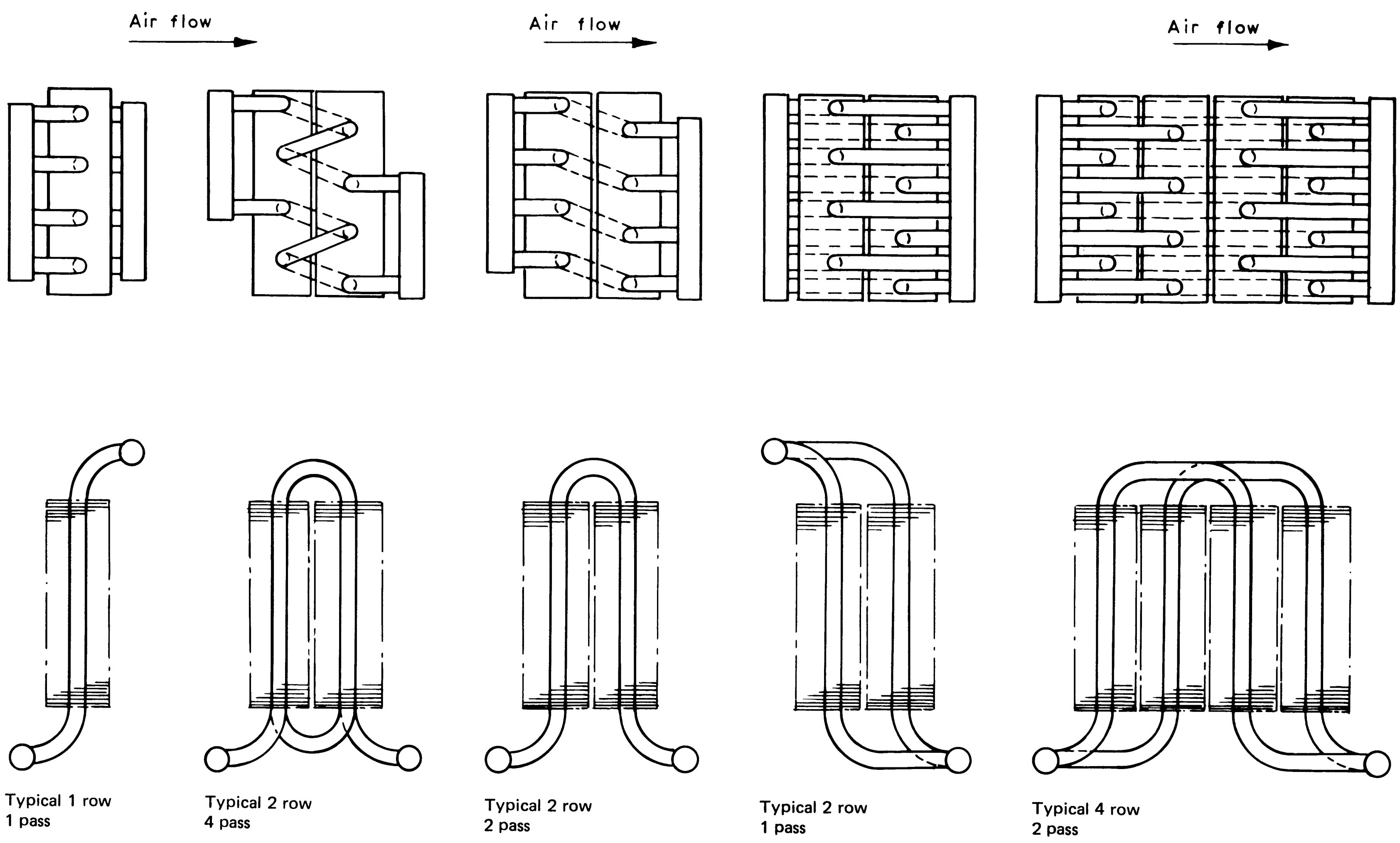


Figure 1 — Typical arrangement of passes

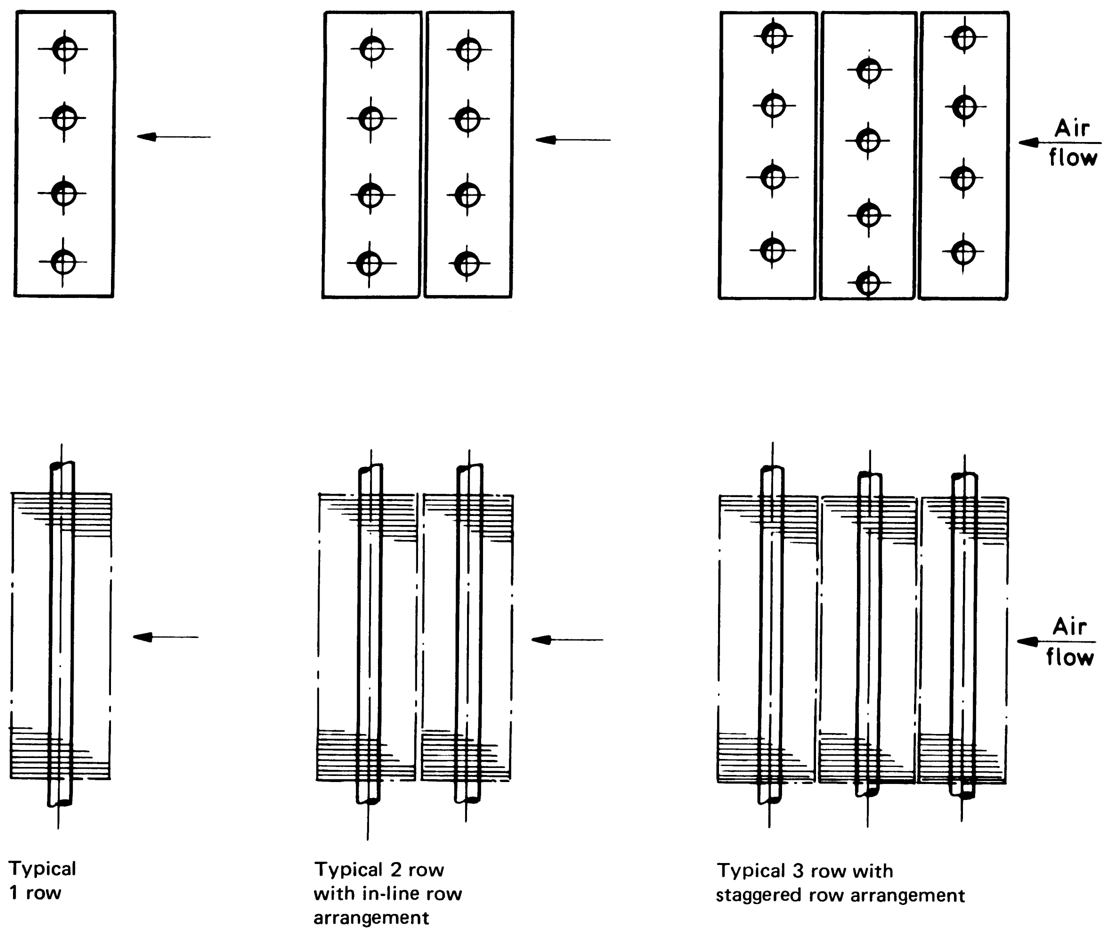


Figure 2 — Typical arrangement of rows

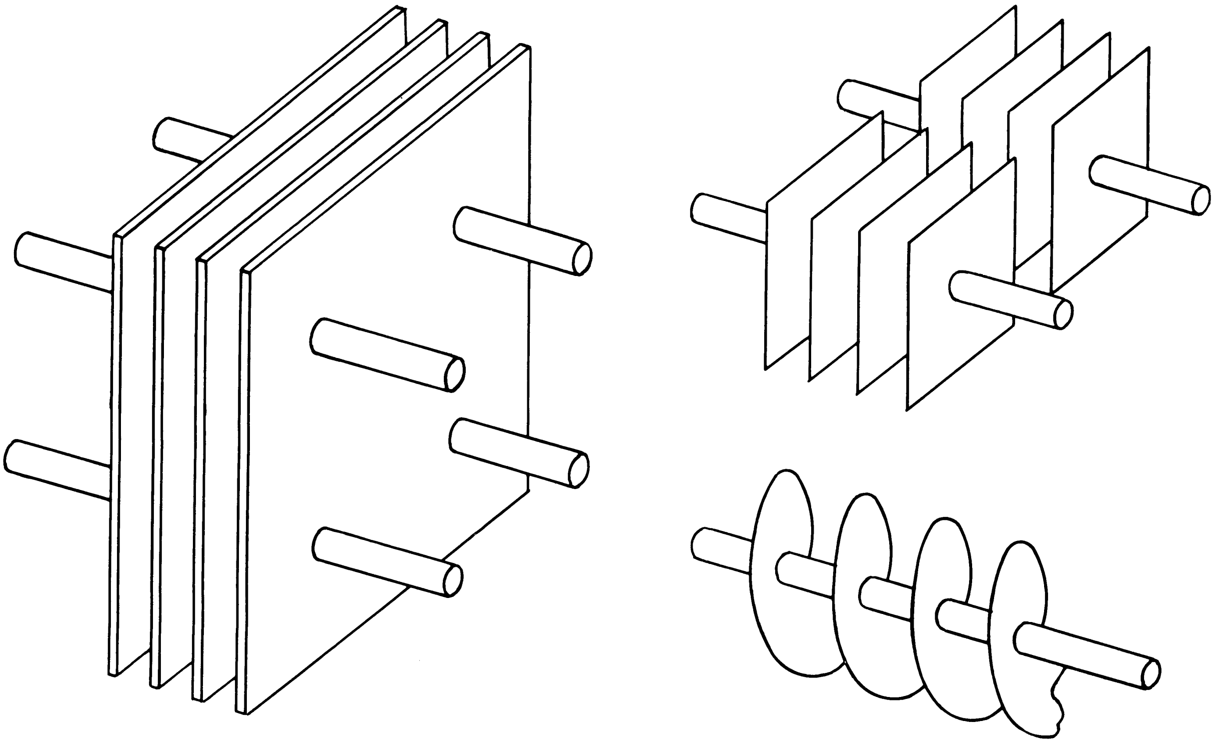
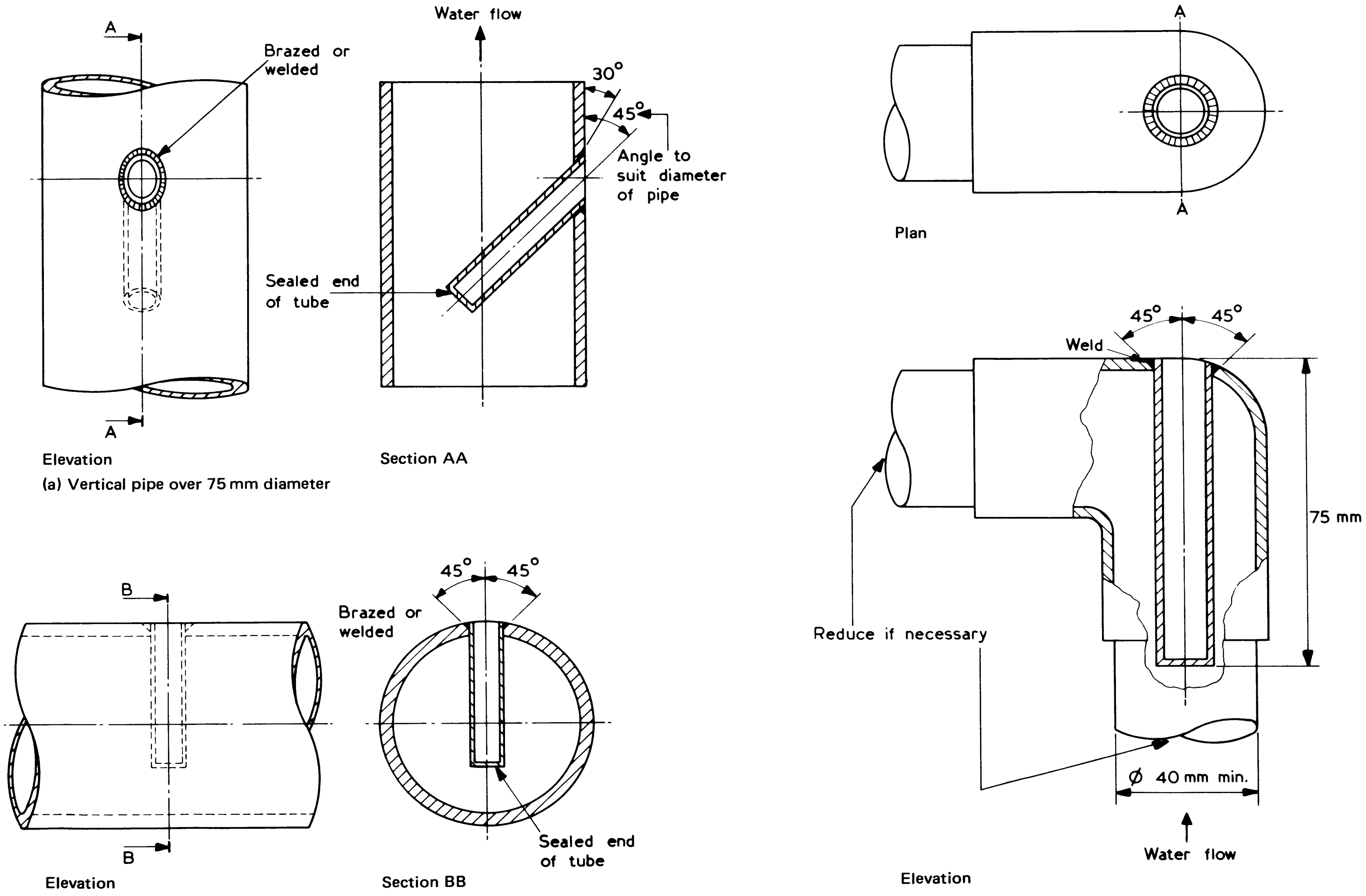


Figure 3 — Types of fins



NOTE (a) and (b) min. tube length 100 mm
Pockets from 20 swg tube i.d. approx 10 mm

(c) Pipe less than 75 mm dia.

Figure 4 — Thermometer pockets

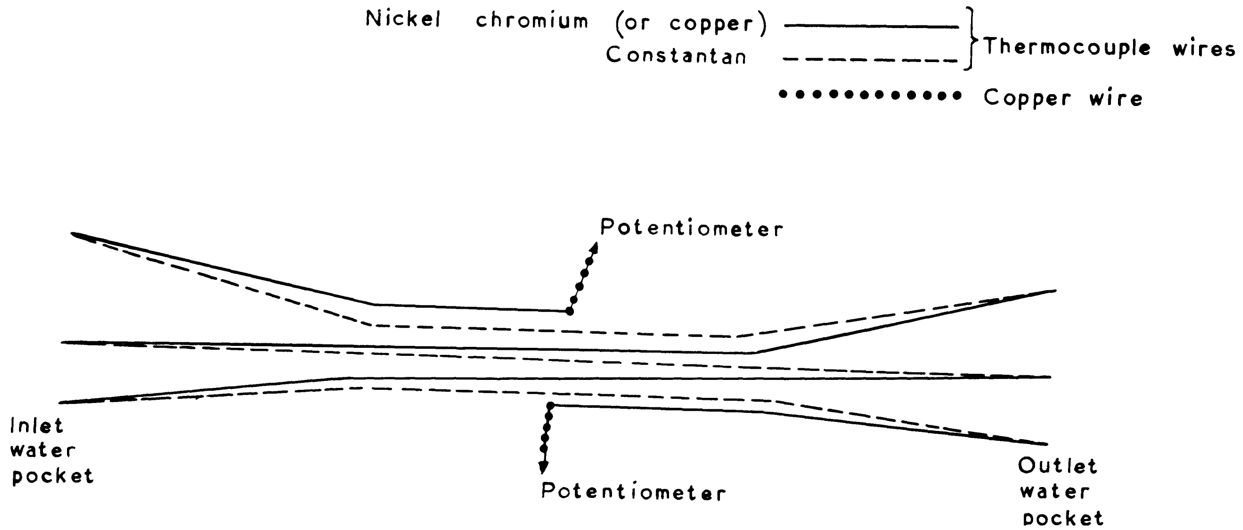
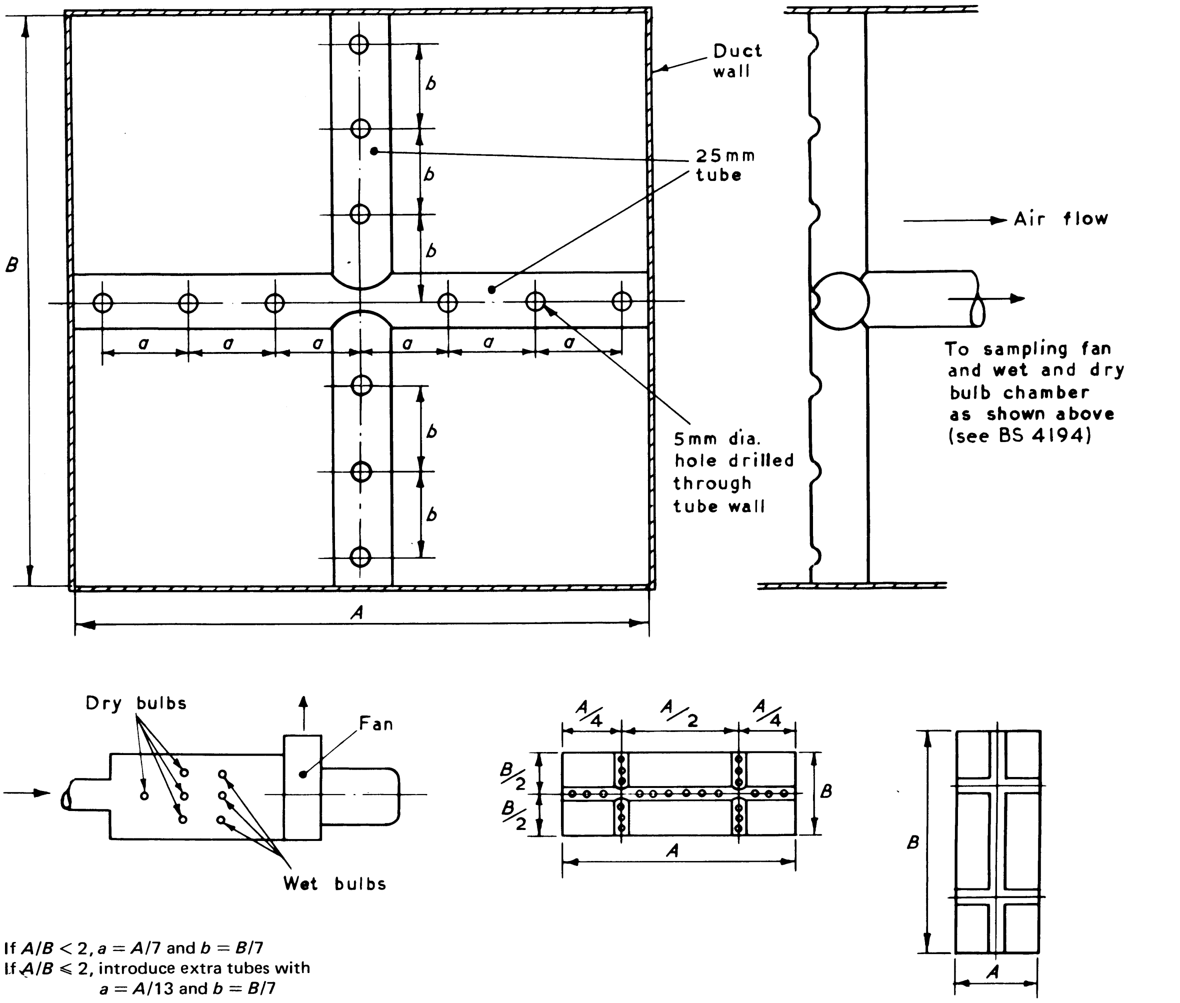
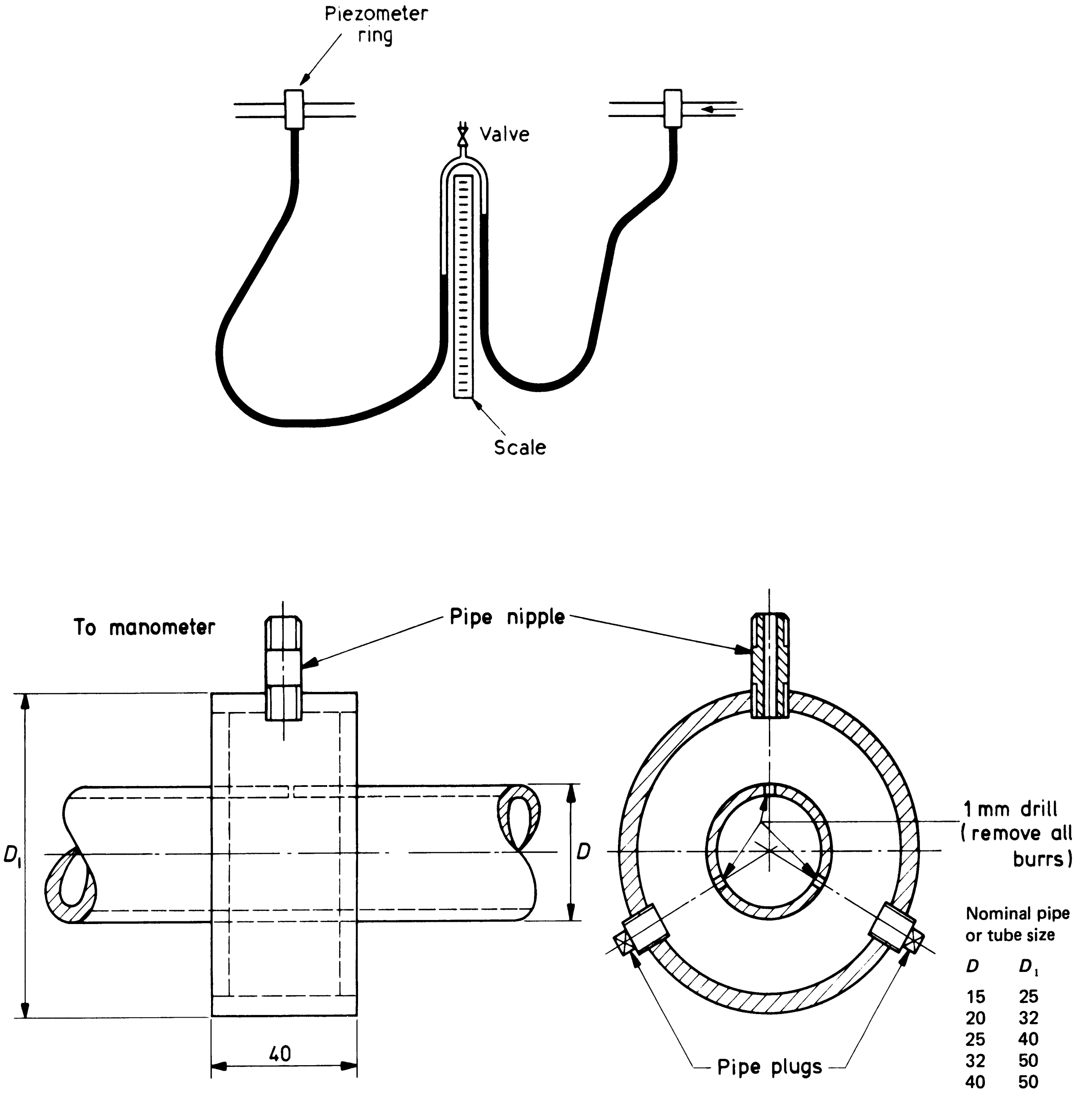


Figure 5 — Multijunction differential thermocouple



If $A/B < 2$, $a = A/7$ and $b = B/7$
If $A/B \leqslant 2$, introduce extra tubes with $a = A/13$ and $b = B/7$

Figure 6 — Air sampling tubes



Nominal pipe or tube size

D	D_1
15	25
20	32
25	40
32	50
40	50

Figure 7 — Inverted tube pattern manometer and piezometer ring

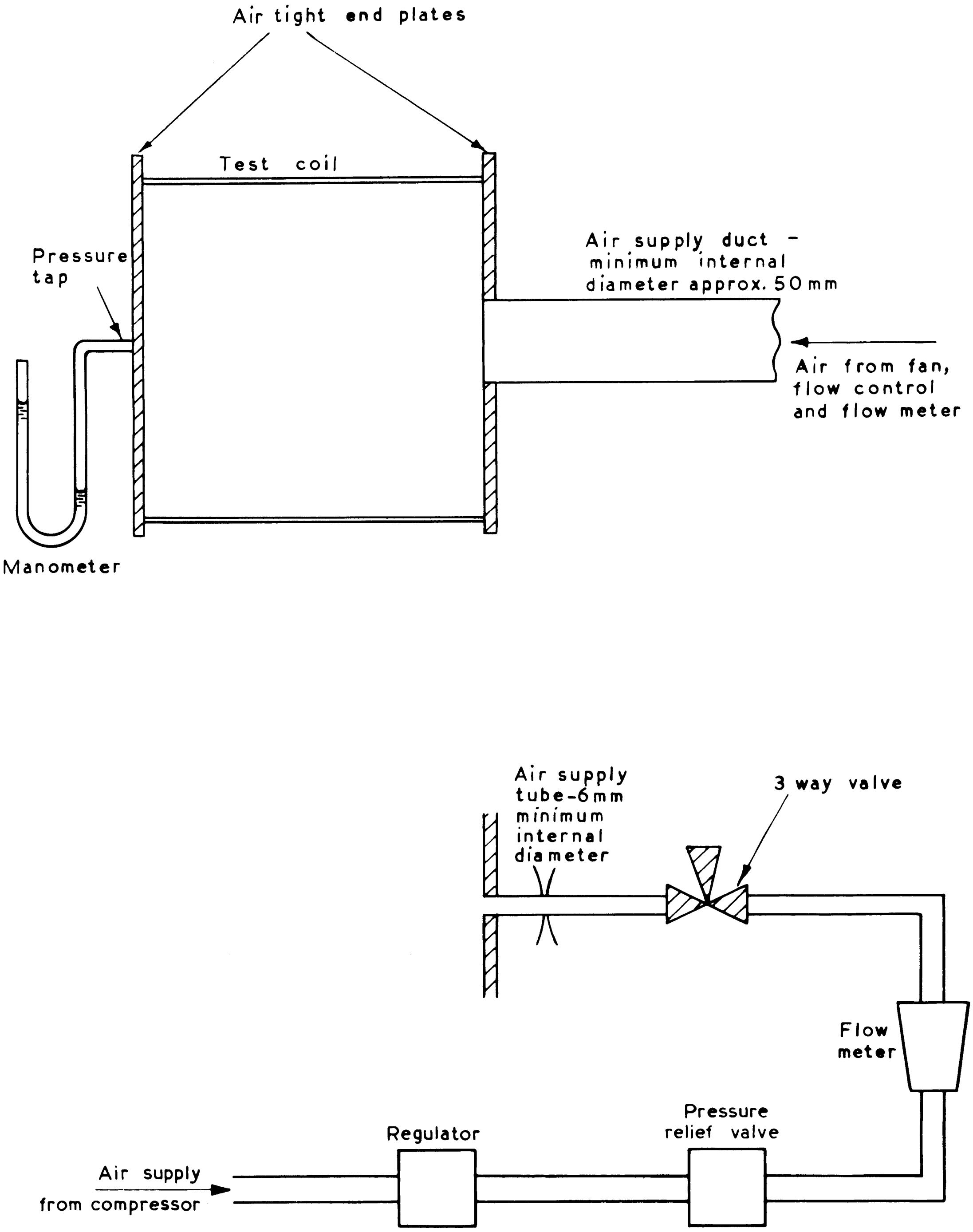


Figure 8 — Apparatus for air flow leakage test (showing alternative air supply systems)

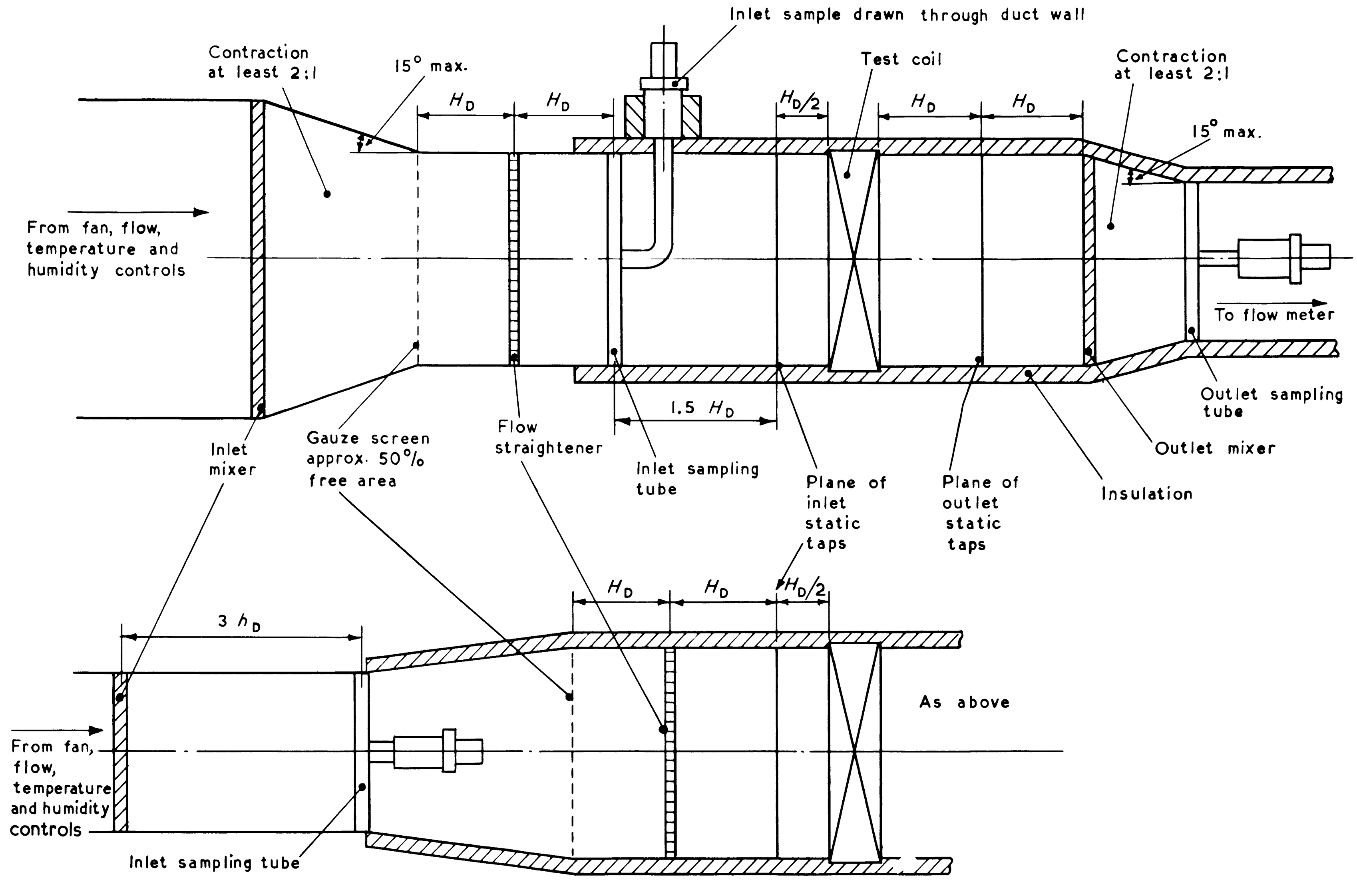


Figure 9 — Typical test duct arrangements

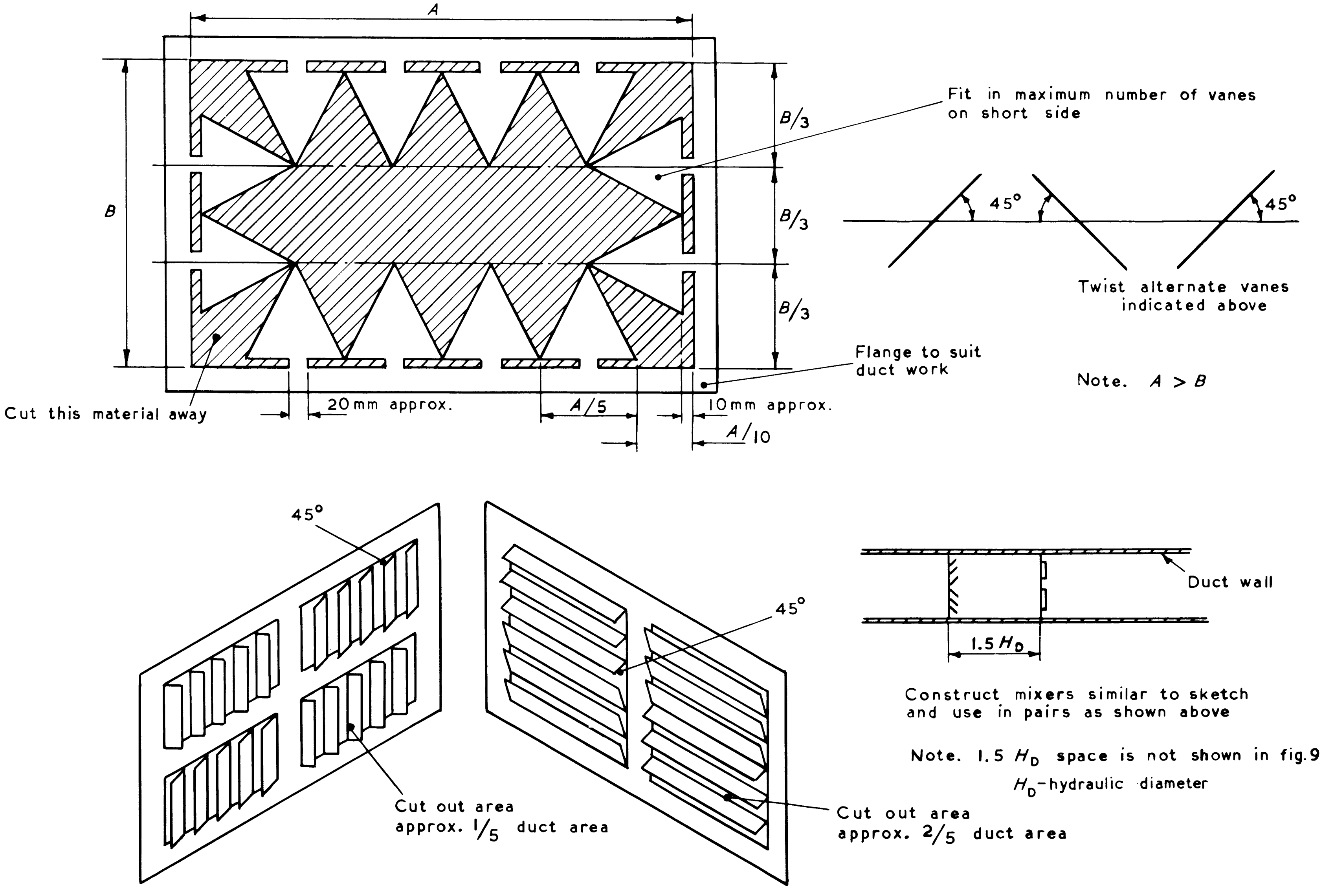


Figure 10 — Air flow mixers

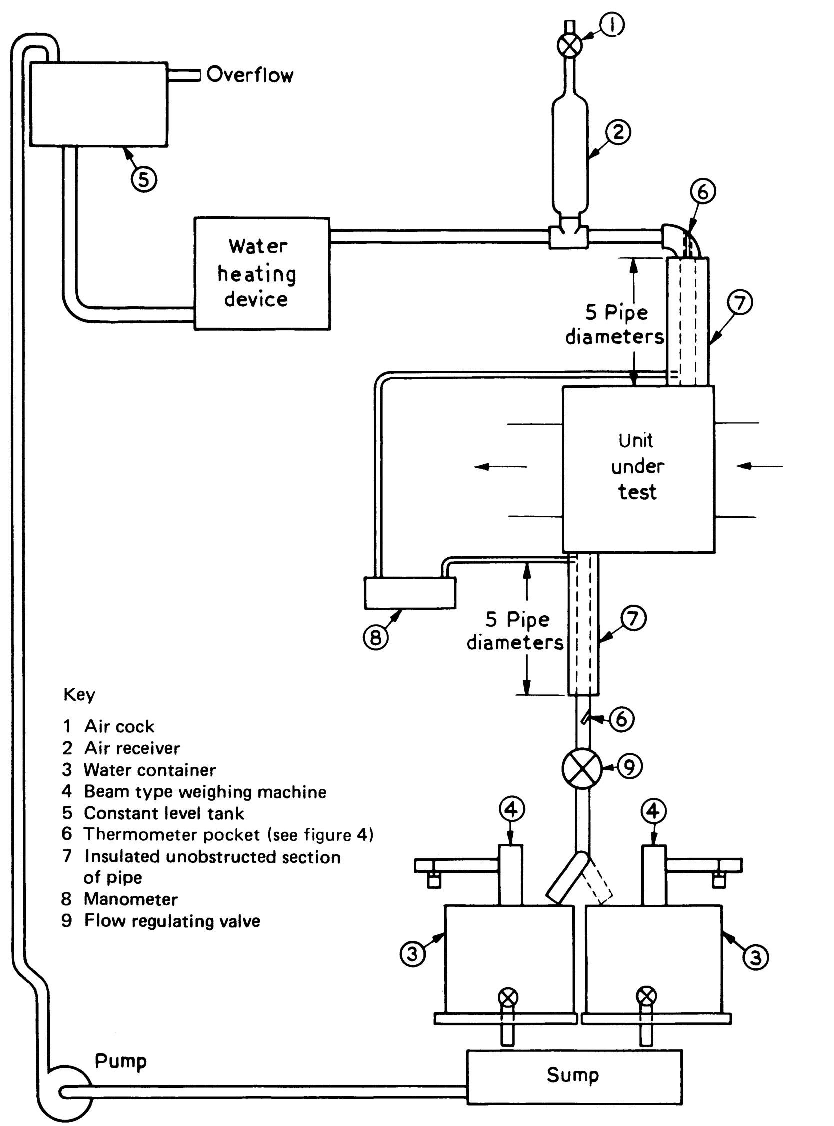


Figure 11 — Open-circuit water system

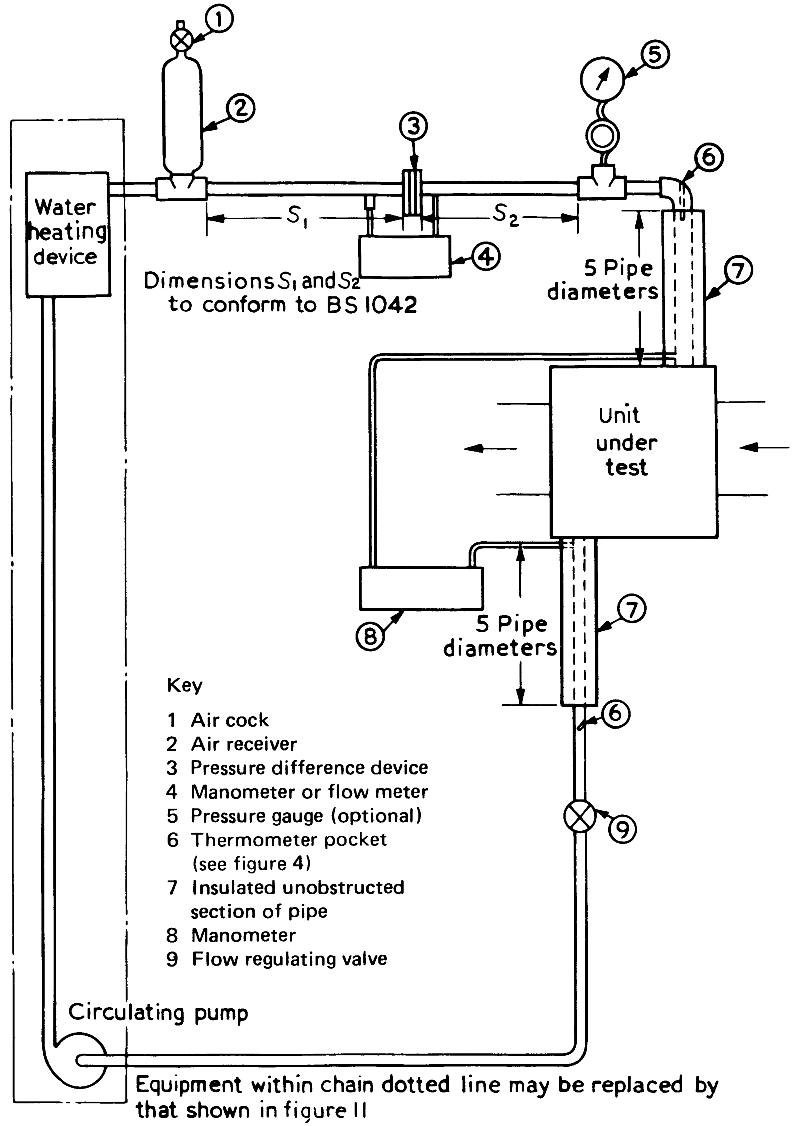
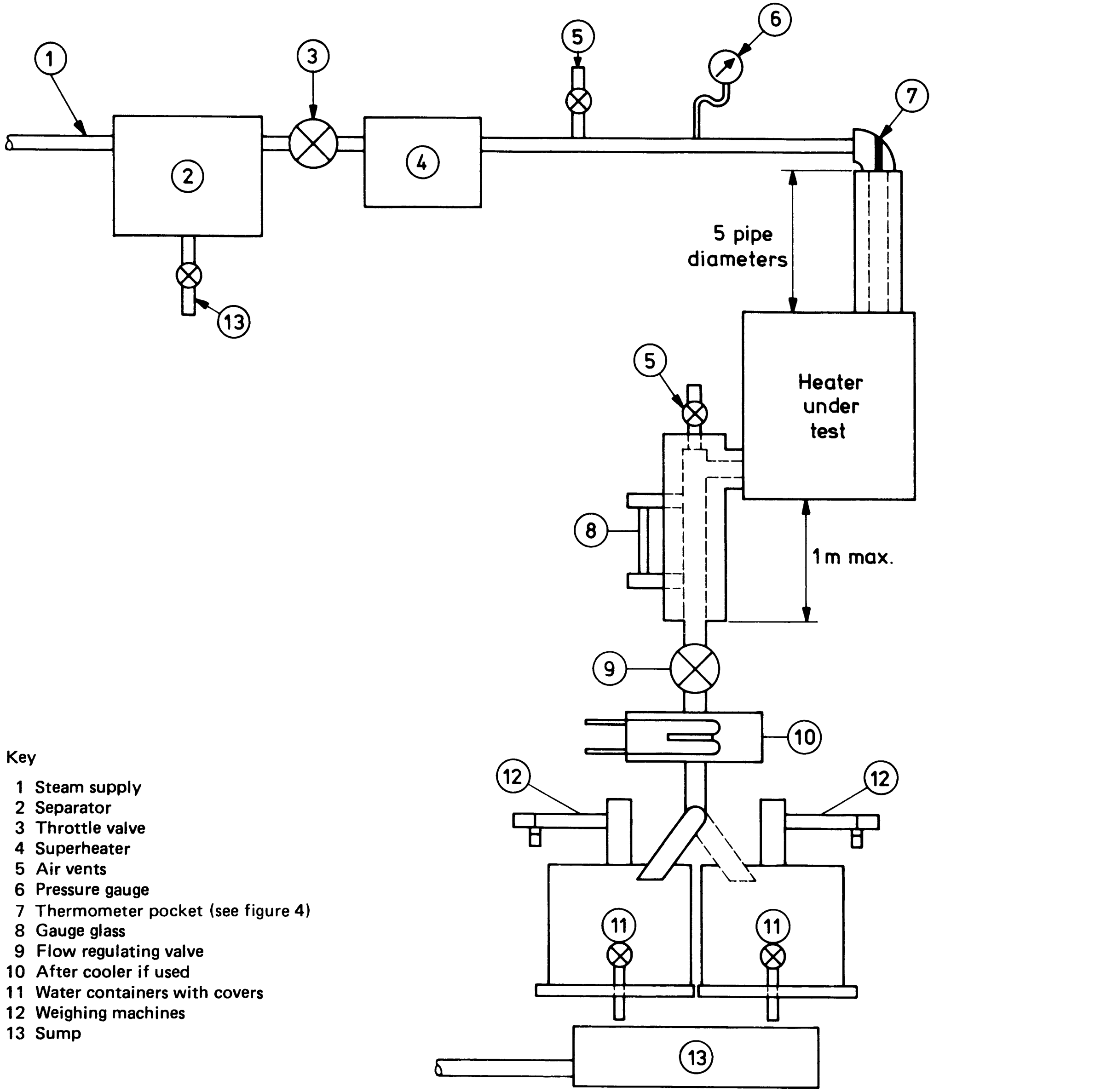


Figure 12 — Closed-circuit water system



Key

1 Steam supply
2 Separator
3 Throttle valve
4 Superheater
5 Air vents
6 Pressure gauge
7 Thermometer pocket (see figure 4)
8 Gauge glass
9 Flow regulating valve
10 After cooler if used
11 Water containers with covers
12 Weighing machines
13 Sump

Figure 13 — Steam system

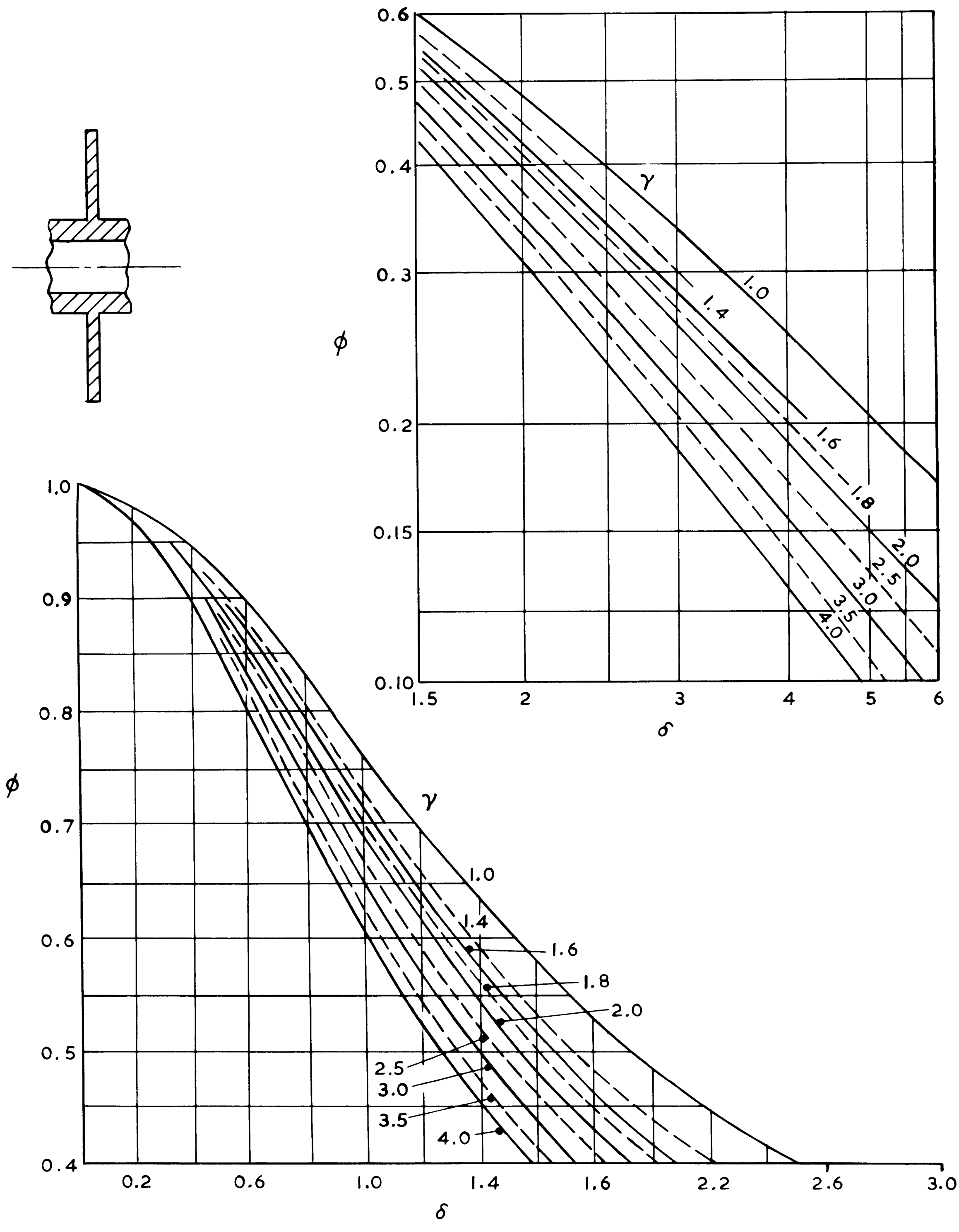


Figure 14 — Efficiency of fins of constant thickness

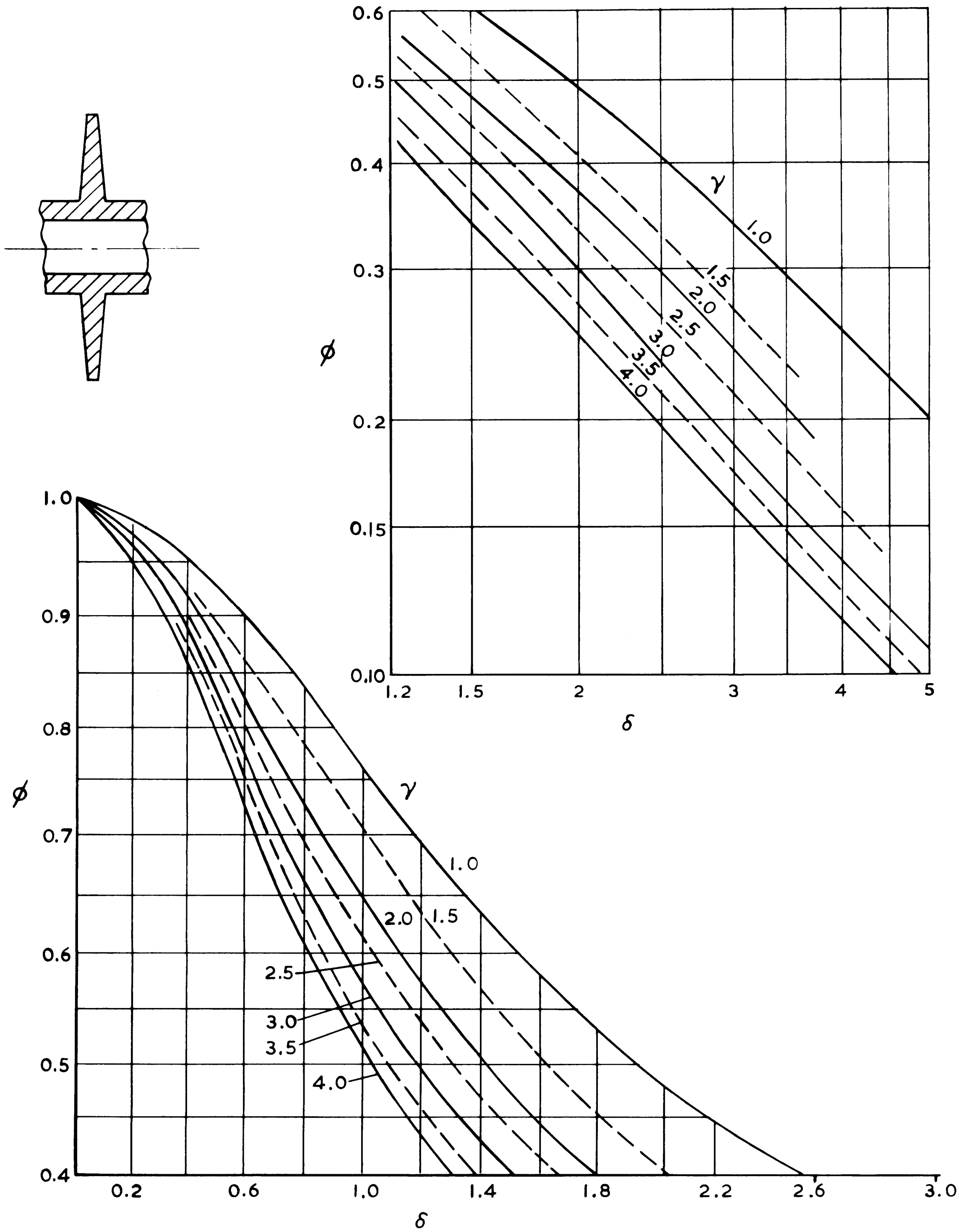


Figure 15 — Efficiency of fins of constant area for heat flow and spiral fins

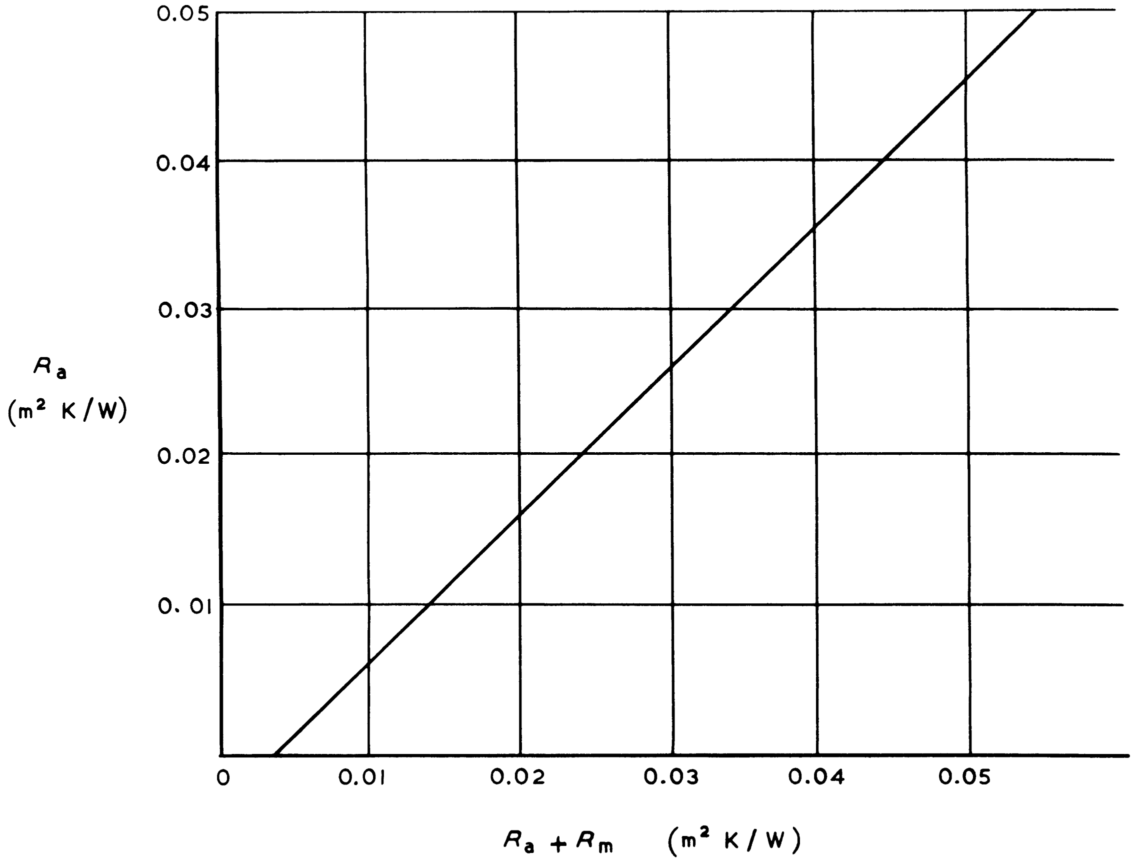


Figure 16 — Example of graph of R_a versus (R_a + R_m) prepared from test data

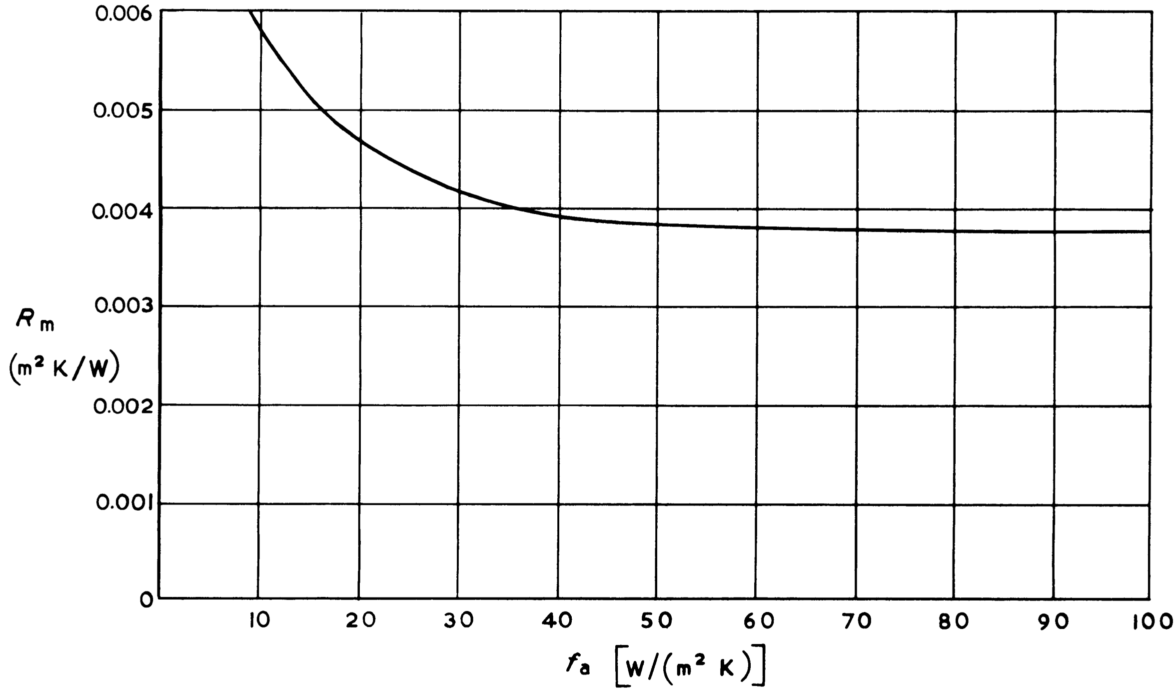


Figure 17 — Example of graph of R_m versus f_a

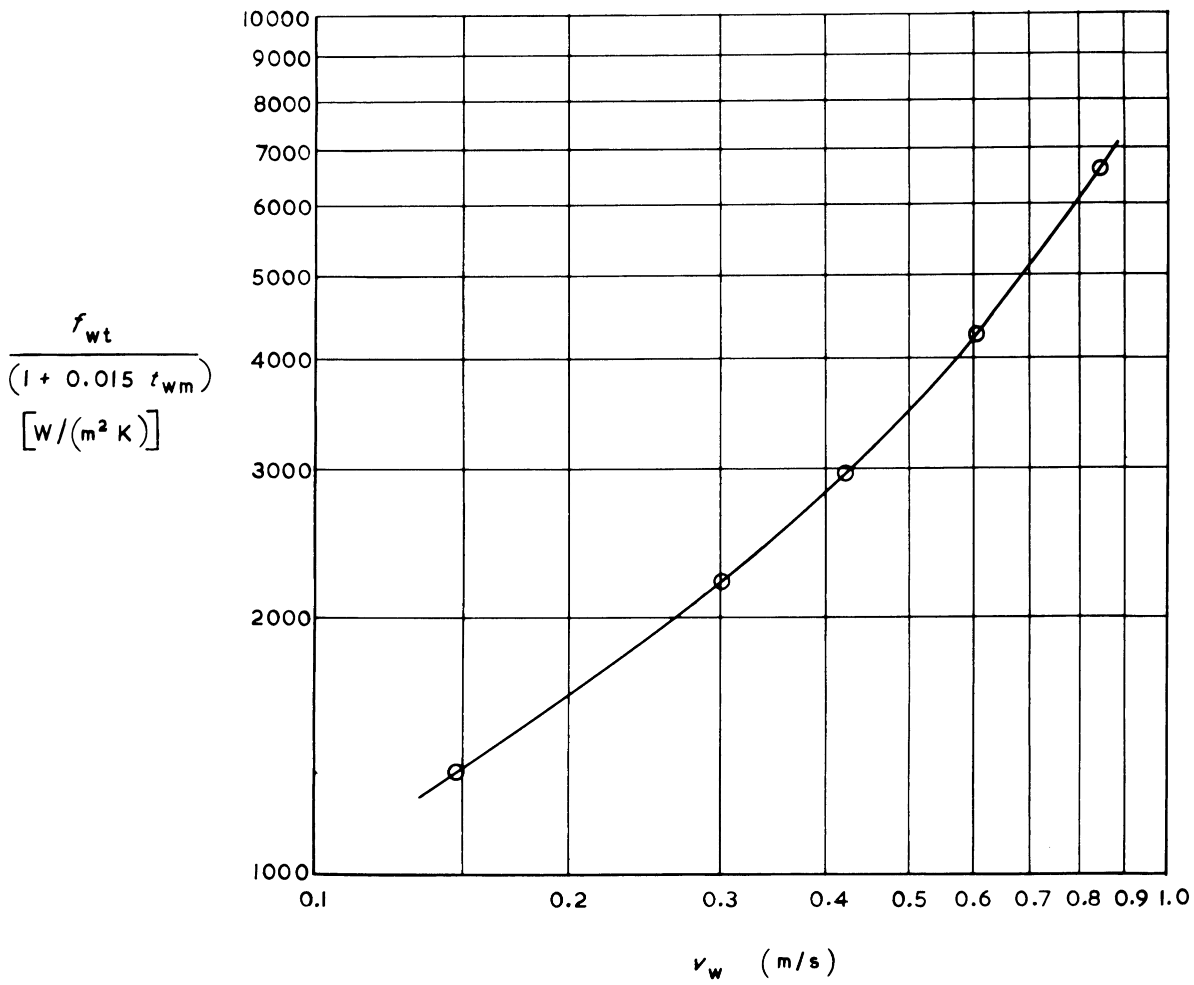


Figure 18 — Example of water-film heat transfer coefficient for tube with turbulators for inlet water temperatures between 40 °C and 120 °C

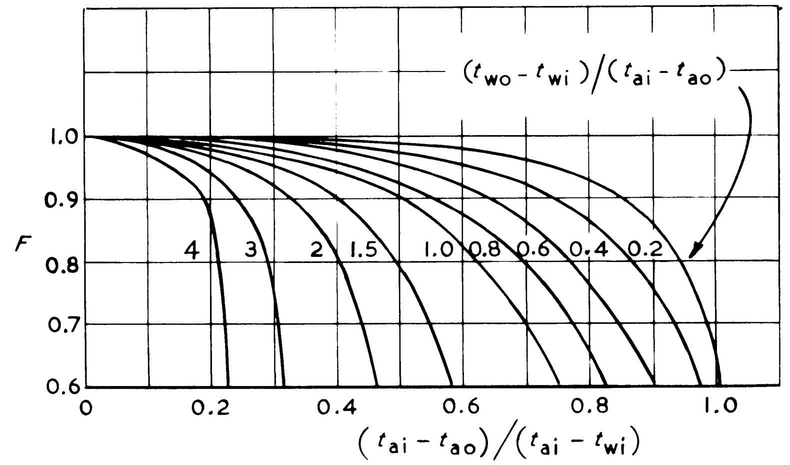


Figure 19 — Graph of factor F for corrected logarithmic mean temperature for cross-flow single-pass coils

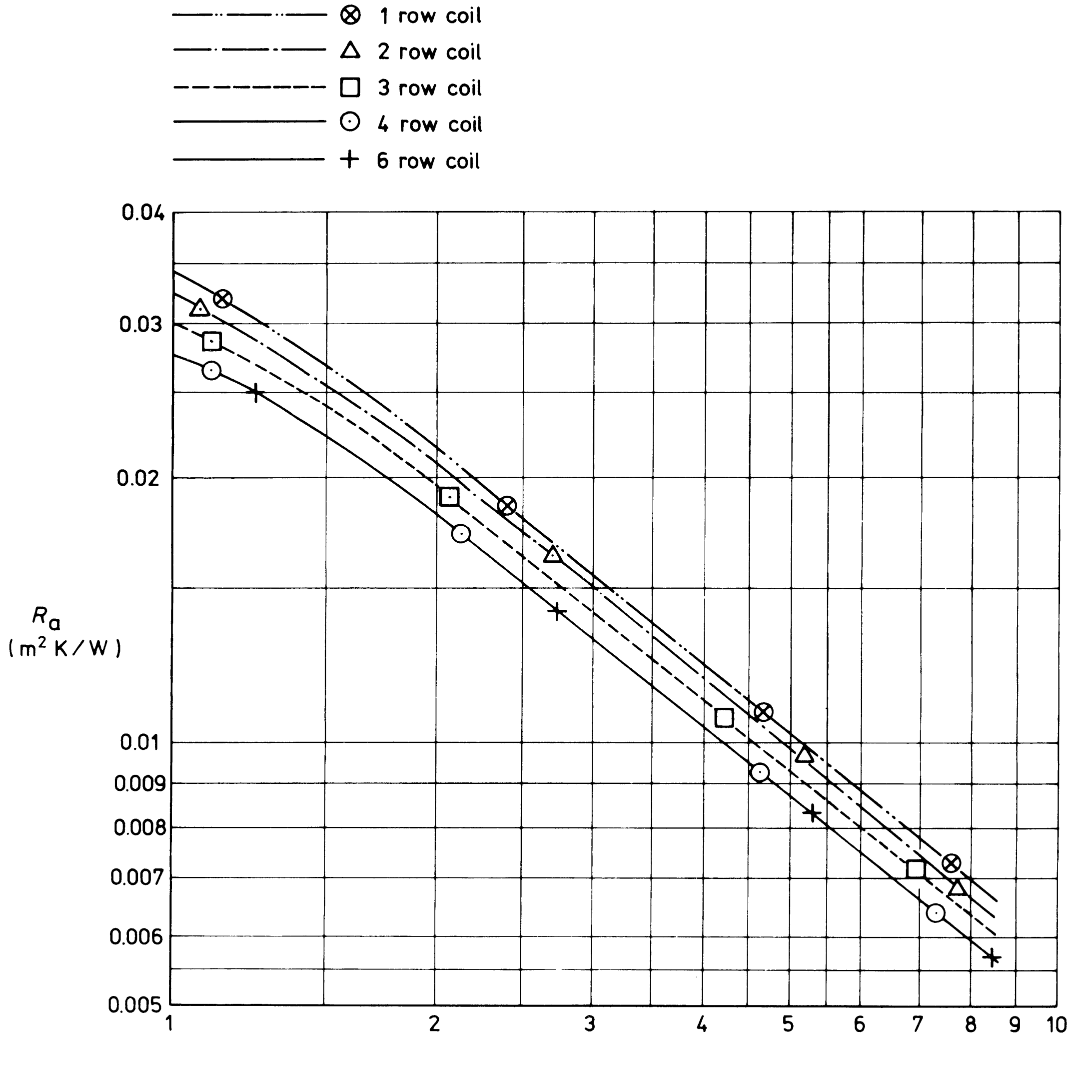


Figure 20 — Example of graph of R_a as a function of velocity v_r

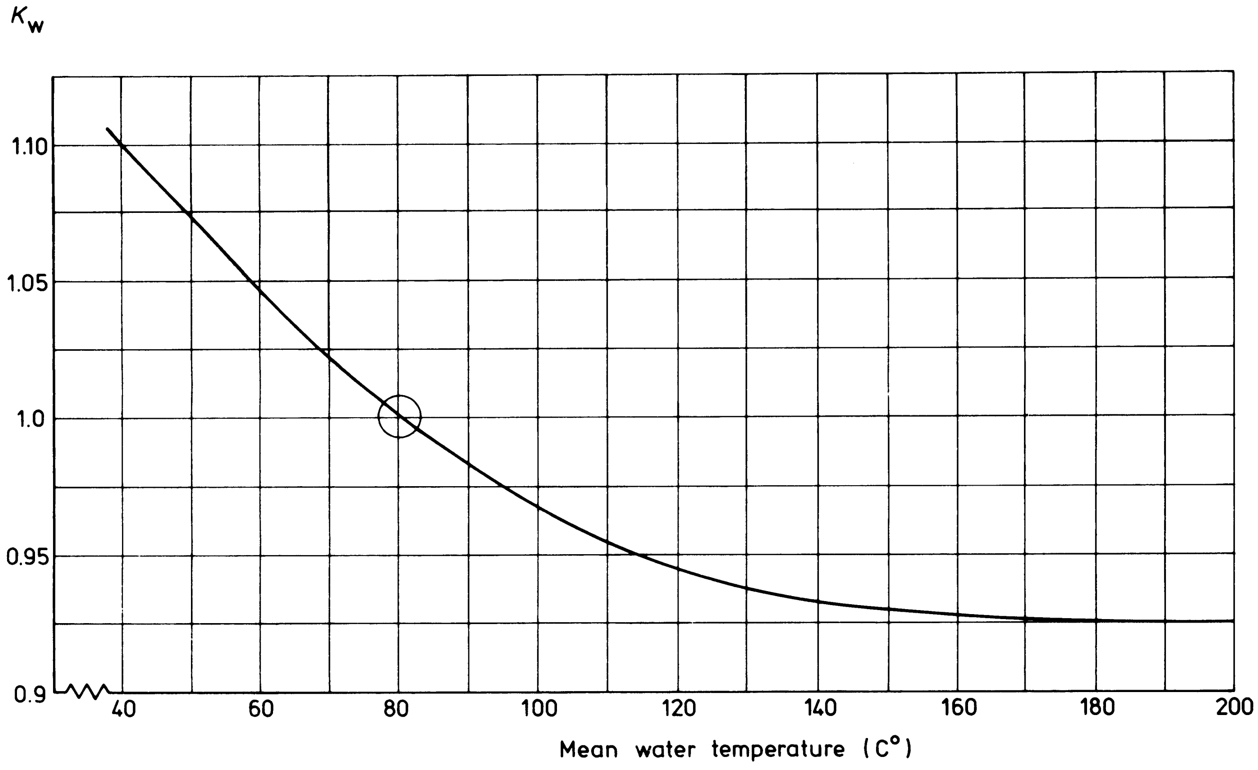


Figure 21 — Correction factor K_w for hydraulic pressure drop

Publications referred to

BS 350, *Conversion factors and tables.*
BS 593, *Laboratory thermometers.*
BS 1041, *Code for temperature measurement.*
BS 1042, *Methods for the measurement of fluid flow in pipes.*
BS 1780, *Bourbon tube pressure and vacuum gauges.*
BS 3763, *The International System of Units (SI).*
BS 4194, *Design requirements and testing of controlled-atmosphere laboratories.*

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