BS 4485 : Part 3 : 1988
UDC 66.045.53/.54

British Standard

Water cooling towers

Part 3. Code of practice for thermal and functional design

Tours de refroidissement par l'eau
Partie 3. Conception thermique et fonctionnelle — Code de bonne pratique

Wasserkühltürme
Teil 3. Leitfaden für die Bemessung unter thermischen und funktionalen Gesichtspunkten

British Standards Institution

Foreword

This Part of BS 4485, which has been prepared under the direction of the Civil Engineering and Building Standards Committee, deals with the thermal and functional design of natural draught, mechanical draught and factory prefabricated cooling towers. This Part of BS 4485 is a revision of BS 4485 : Part 3 : 1977, together with its Addendum No. 1 (1978) both of which are withdrawn.

In this revision the following principal changes have been made.

(a) The guidelines on water treatment have been expanded as these were not considered sufficient for good operating practice.

(b) Reference has been made to the potential health hazard arising from the bacterial population of cooling towers, as it relates to the design of the towers. However, operational techniques for control in this area are outside the scope of this Part of BS 4485.

(c) Factory prefabricated cooling towers previously dealt with in Addendum No. 1 to BS 4485 : Part 3 : 1977 have been covered by suitable modification of the main text of this Part of BS 4485.

(d) Information to be supplied by the purchaser and the manufacturer, which was included in Addendum No. 1 to BS 4485 : Part 3 : 1977, now appears as appendix A in this Part of BS 4485 as it is considered relevant to all types of cooling towers.

(e) Materials of construction have been omitted as these are dealt with in BS 4485 : Part 4*.

(f) A new clause on maintenance has been added which was in Addendum No. 1 to BS 4485 : Part 3 : 1977.

This Part of BS 4485 provides information on design principles, siting and spacing. Guidance is given on specific thermal and hydraulic requirements, on mechanical equipment and on environmental aspects such as discharge into rivers and cooling tower noise.

The other Parts of BS 4485 are as follows.

Part 1 Glossary of terms

Part 2 Methods for performance testing

Part 4 Structural design of cooling towers

Where necessary, definitions have been included in the revisions of BS 4485 : Parts 2, 3 and 4 so that when they have all been published BS 4485 : Part 1 can be withdrawn.

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

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* Under revision.

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Code of practice

1 Scope

This Part of BS 4485 gives recommendations for the thermal and functional design of industrial and natural draught water cooling towers and factory prefabricated cooling towers.

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

2 Symbols and units

For the purposes of this Part of BS 4485, the symbols and units given in table 1 apply.

Table 1. Symbols and units

Symbol	Quantity	Unit
a	Area of effective transfer surface per unit of tower packing volume	m^2/m^3
A_s	Area of sound propagation	m^2
A_p	Total packing area normal to air flow	m^2
B	Width or length dimensions perpendicular to tower axis	m
c	Specific heat capacity of water	kJ/(kg·K)
C	Concentration factor at equilibrium	
C_T	Concentration factor at time T	
C_1	Original make-up concentration of impurities	%
C_2	Stable state concentration of impurities in circulating system under continuous purge	%
D	Diameter	m
g	Acceleration due to gravity	
G	Mass flow of dry air per unit plan area of packing	$kg/(m^2 \cdot s)$
h	Enthalpy* of air-water vapour mixture	kJ/kg
h_m	Mean driving force	kJ/kg
h_G	Enthalpy* of air-water vapour mixture passing through the packing	kJ/kg
h_L	Enthalpy* of saturated air film in contact with and at the temperature of the water passing through the packing	kJ/kg
H	Height (vertical distance above or below basin kerb level)	m
H_e	Effective height of shell, normally taken as height from middle of packing to top of shell	m
K	Coefficient of mass transfer defined in terms of difference in absolute humidity	$kg/[m^2 \cdot s \cdot (kg/kg)]$
L	Mass water flow per unit plan area of packing	$kg/(m^2 \cdot s)$
m_1	Mass of solute	kg
m_2	Mass of solvent	kg
M_1	Relative molecular mass of solute	
M_2	Relative molecular mass of solvent	
n	Mole fraction of solvent	
N	Number of velocity heads representing the system resistance	
p	Total pressure	Pa
p_2	Vapour pressure of pure solvent	Pa
p_3	Vapour pressure of solution	Pa
P_5	Sound pressure	N/m^2
P_0	Sound pressure reference datum	N/m^2
Q_l	Circulating water flow	m^3/s
R	Surface radius from sound source	m

* All enthalpies relate to 1 kg dry air and associated water vapour.

Table 1 *(concluded)*

Symbol	Quantity	Unit
S_w	Sound power level reading at a point source	dB
S_p	Sound pressure level reading some specified distance away from the source	dB
T	Time	h
t_b	Temperature of water with which boundary vapour is associated	°C
t_m	Mean water temperature	°C
t_DB	Dry bulb temperature	°C
t_E	Temperature of mixture of recooled water and make-up leaving cold water basin	°C
t_WB	Wet bulb temperature	°C
t_1	Hot water temperature at inlet	°C
t_2	Recooled water temperature	°C
V	Effective packing volume per unit area of packing	m^3/m^2
V_b	Volume in cold water basin	m^3
v_e	Evaporation rate	m^3/h
v_p	Purge rate	m^3/h
V_s	Volume in system excluding pond	m^3
w_1	Atmospheric moisture content of ambient air condition	kg/kg
w_2	Atmospheric moisture content at mean water temperature saturated conditions	kg/kg
W_d	Fan driver power	kW
W_o	Sound power threshold	W
W_s	Sound power	W
x	Pond surface area	m^2
X	Spacing	m
ρ	Density of air	kg/m^3
Δh	Change in air enthalpy	kJ/kg
Δt	Cooling range	K
$\Delta \rho$	Change in air density	kg/m^3
	Approach	K
	Power	W
KaV/L	Tower characteristic	
L/G	Water/air ratio	

3 Thermal design principles

3.1 Cooling process

A water cooling tower is a heat exchanger in which warm water falls gravitationally through a cooler current of air. Heat is transferred from the water to the air in two ways:

(a) by evaporation as latent heat of water vapour;

(b) by sensible heat in warming the air current in its passage through the tower.

As a general measure, about 80 % of the cooling occurs by evaporation and about 20 % by sensible heat transfer.

The transfer of heat is effected from the water through the boundary film of saturated air in contact with the water surface. This air is saturated at the water temperature. From this saturated air film, heat transfer occurs to the general mass of air flowing through the tower.

In the interests of efficiency, it is essential that both the area of water surface in contact with the air and the time of contact be as great as possible. This may be achieved either by forming a large number of water droplets as repetitive splash effects in one basic kind of tower packing, or by leading the water in a thin film over lengthy surfaces.

Air flow is achieved either by reliance on wind effects, by thermal draught or by mechanical means. The direction of air travel may be opposed to the direction of water flow giving counterflow conditions, or may be at right angles to the flow of water giving crossflow conditions. Although the methods of analysis may be different for counterflow and crossflow conditions, the fundamental heat transfer process is the same in both cases. In some designs mixed flow conditions exist. These patterns of flow are illustrated in figure 1.

Present cooling tower technology relies on the fact that, with acceptable error, the effects of evaporative and sensible heat transfer can be combined into one dependent on enthalpy difference. The difference concerned is that between the enthalpy of the film of air surrounding the water surface (taken to be at water temperature) and the enthalpy of the general mass of air flowing through the tower. This enthalpy difference varies according to the point of measurement in the tower, but at all points it provides the enthalpy potential or driving force for the heat transfer.

The so-called combined transfer theory depends upon certain approximations, which are reasonable at normal cooling water temperatures and particularly when the characteristics of the packing have been determined in accordance with the theory. However, the approximations become progressively less valid with increasing water temperature and a more exact analysis should be adopted in applications where the mean water temperature exceeds 35 °C.

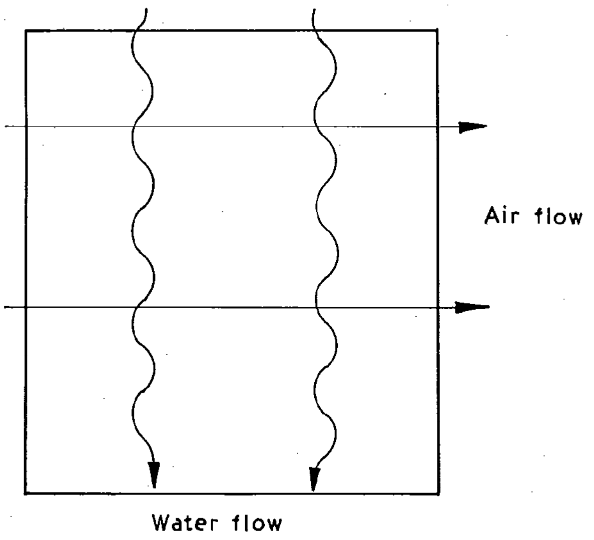
The air and air-water film conditions, in passage through the tower, may be illustrated on a psychrometric chart as shown in figure 2. The cooling range of the tower corresponds to the difference in temperature of the air-water film between entry to and exit from the tower.

Air enters the tower having wet and dry bulb characteristics dependent on the ambient conditions. It is generally in an unsaturated state and achieves near-saturation in passing through the tower. It may be considered saturated at exit in all but very dry climates.

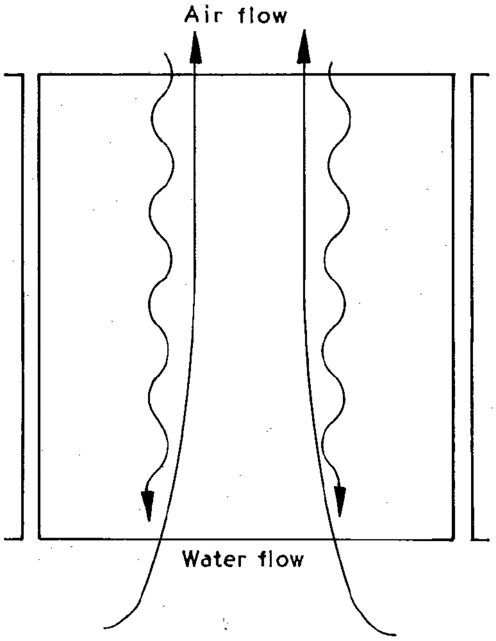
The enthalpy of the entering air is considered, with acceptable error, to be equivalent to the enthalpy of air saturated at the wet bulb temperature. For the purposes of enthalpy differences in heat transfer, only the wet bulb temperature of the ambient air is therefore of significance.

The dry bulb temperature has, however, to be considered for draught assessment purposes in those towers whose air flow relies on thermally created draught. The thermal draught is defined by the change of density of the air between entry to and exit from the cooling tower multiplied by the effective shell height, and the dry bulb temperature as well as the wet bulb temperature is of significance in determining the density of ambient air.

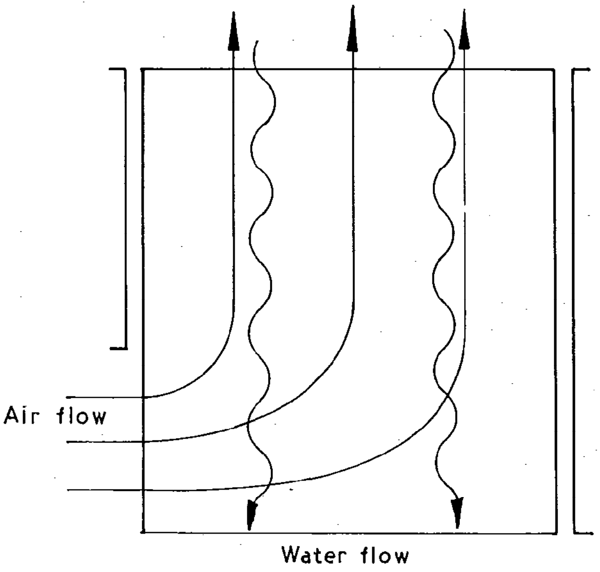
The theoretical limit to which the water may be cooled is that of the ambient wet bulb temperature. This could only be achieved with an infinitely large tower and, in practice, the terminal or recooled water temperature has some approach to the wet bulb temperature. This approach may vary from about 3 K in rigorous chemical plant cooling to 10 K or above in easier conditions. The approach is fixed only at design air conditions and increases or decreases as ambient conditions vary from cold to warm, respectively, about the design point.



(a) Crossflow



(b) Counterflow



(c) Mixed flow

Figure 1. Air-water flow paths in crossflow, counterflow and mixed flow towers

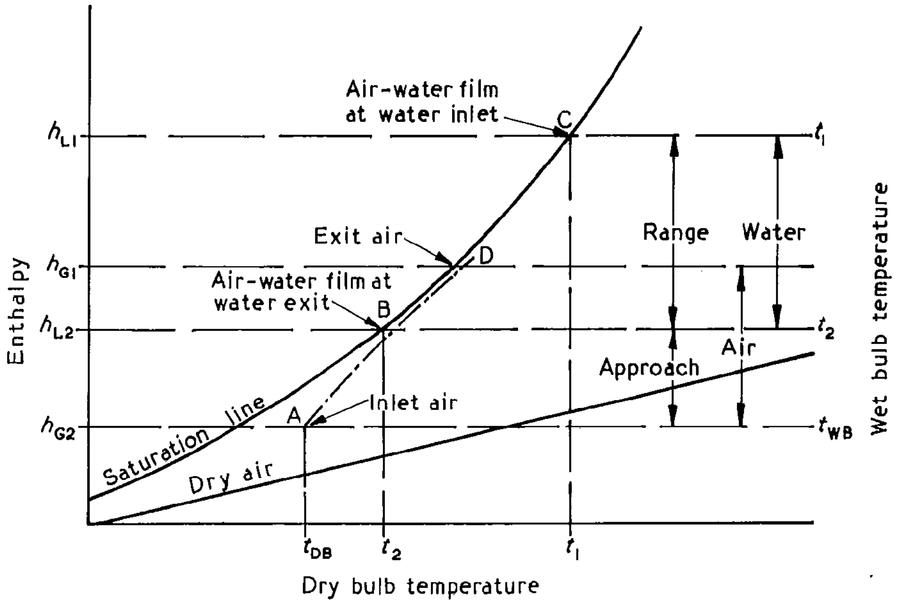


Figure 2. Conditions of air and water in a cooling tower

3.2 Heat transfer diagram for counterflow conditions

Figure 2 establishes the relative changes occurring in a counterflow tower on a base of air temperatures. To convert this figure to a heat transfer diagram, the initial and final enthalpies of the air flow through the tower may be transferred across to meet the ordinates through the recooled and inlet water film temperatures respectively. This is shown in figure 3.

It is important to note that the base of the diagram in figure 3 has now to be considered to be that of water temperature. The diagram, although valid in terms of air enthalpy, cannot be used as a measure of air temperatures.

Enthalpy differences between air and water may now be measured directly. The relevant part of the saturation line is referred to as the 'water line' and the joining initial and final values of air enthalpy as the 'air line'. Ordinate differences between these two lines give a measure of the driving force at the water temperature concerned, and the mean value of all such ordinate differences in the diagram is referred to as the mean driving force, h_m.

In any design the ambient air condition in which a cooling tower is to operate is known, which effectively fixes point A on the heat transfer diagram (see figure 3). Points B and C are known from specified conditions of the water requirement at the plant being cooled. Point D remains as an unknown quantity dependent on the heat balance in the cooling tower:

heat gained by air = heat lost by water per unit area of packing

$$G\Delta h = cL\,\Delta t \qquad (1)$$

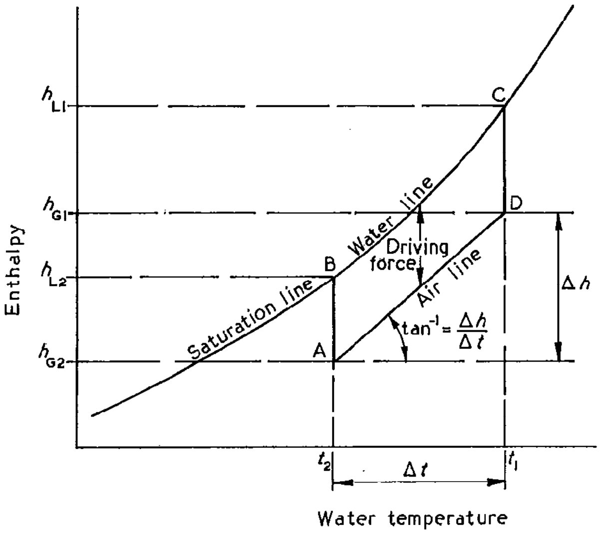


Figure 3. Heat transfer diagram

from which $$\frac{\Delta h}{\Delta t} = \frac{cL}{G} \qquad (2)$$

In figure 2, therefore, the inlet and exit air temperatures are joined by a line having a slope equal to cL/G.

A selected value of L/G is therefore necessary before the heat transfer diagram can be completed. In essence, since the total heat to be dissipated in the tower is known from plant cooling duty requirements, L and Δt are obtained from the specified duty, leaving G as a variable quantity to be selected for any tower design.

In the case of air flow promoted by mechanical means, the value of G may be selected and can be considered to remain constant for all conditions of inlet air. Where G is dependent on thermal draught, however, it varies as atmospheric changes occur and is a selected value only at the specified design air condition.

The vehicle of heat transfer in the cooling tower is the packing. This packing will have a transfer coefficient which, due to the impossibility of measuring the air-water interface produced by the packing, is an overall coefficient Ka. This combines a coefficient of K of mass transfer with the area a of transfer surface per unit of tower packing volume, giving units of Ka as $\text{kg}/[\text{m}^2\cdot\text{s}\cdot(\text{kg/kg})]$.

The heat transfer capacity per unit area of packing and per unit time is therefore defined by:

$$\text{overall transfer coefficient, } Ka \times \text{packing volume, } V \times \text{mean driving force, } h_\text{m}$$

In sequence, for the whole heat transfer operation, therefore:

$$\text{heat lost by water} = \text{heat transferred by packing} = \text{heat gained by air}$$

or

$$cL\Delta t = Ka \times V \times h_\text{m} = G\Delta h \qquad (3)$$

From equation (3) may be derived the relationship:

$$\frac{KaV}{L} = \frac{c\Delta t}{h_\text{m}}$$

or

$$\frac{KaV}{L} = \int_{t_2}^{t_1} \frac{c\mathrm{d}t}{h_\text{L} - h_\text{G}} \qquad (4)$$

The right-hand side of equation (4) is seen to be a function, for any value of L/G defining the air line, dependent only on the specification demanded of the cooling tower in terms of inlet water temperature range Δt, and inlet air conditions.

The left-hand side of equation (4) is a function only of the capability of any tower design, by virtue of its packing characteristics, to meet the specified duty.

These two functions KaV/L (representing packing configuration) and $c\Delta t/h_\text{m}$ (representing specified conditions when plotted on a common base of L/G) (see figure 4) form two curves known as the characteristic curve and the demand curve, respectively. The intersection of these curves corresponds to the value of L/G at which that particular packing arrangement would produce heat transfer equal to that specified by that particular demand curve.

Because there is an infinite variety of values of Δt, t_WB and approach ($t_2 - t_\text{WB}$) that could form a cooling specification, there will be an infinite variety of demand curves*.

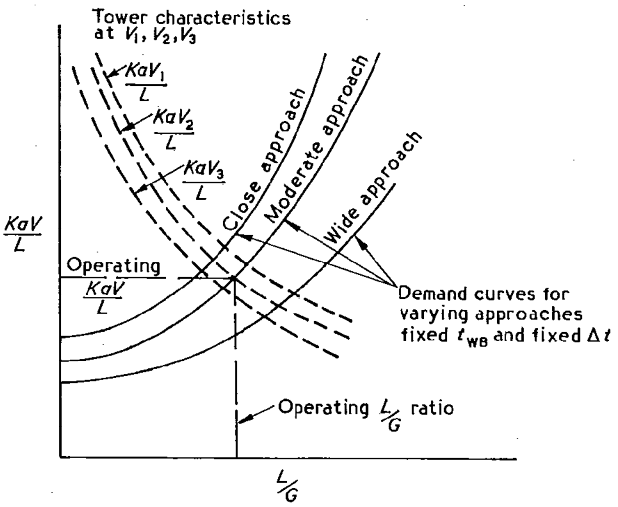


Figure 4. Demand and characteristic curves

Each point on the demand curve requires solution of equation (4) in order to produce h_m for a value of L/G. This process is repeated for various significant values of L/G to produce the relevant section of demand curve.

In the absence of availability of prepared standard curves, the integration process may be carried out with acceptable accuracy for any specified condition and L/G by using the Tchebycheff numerical approximation (see BS 4485 : Part 2) or other methods of suitable accuracy.

These demand curves plotted with KaV/L as ordinate and L/G as abscissa give the values of KaV/L required for any particular specified duty in conjunction with any suitable value of water/air ratio.

Since the selection of a suitable water/air ratio is normally the prerogative of the tower supplier it is not normally necessary in specifying the duties of a cooling tower for a demand curve to be provided with the specification.

The characteristic curve of a particular cooling tower design is the result of experimental evaluation, in the absence of any accurate means of calculating K and a separately from an individual design prior to testing.

There is evidence that the characteristic curve is to some extent dependent on the value of G, but with acceptable error it may be assumed that for fixed values of V and L a single characteristic curve is tenable for all variation of demand and of air flow. In determining the final parameters of a design, the specified demand curve should be compared with a known tested packing characteristic and a suitable choice made of the L/G ratio satisfying both curves. In the case of mechanical draught towers, a value of G should then be chosen and the resistance of the packing estimated at that particular L/G ratio. A suitable fan should then be chosen to overcome the packing resistance and other resistances in the tower, and the design parameters are then complete.

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* Curves for certain selected design parameters have been made commercially available by the Cooling Tower Institute of USA.

Except for small density changes affecting fan output, for mechanical draught towers G is independent of atmospheric conditions and at constant L the value of L/G remains constant for all atmospheric changes. For the design flow L, the curves of demand may therefore be converted into curves of performance for the particular tower design, on ordinates and abscissae more meaningful to the tower user.

The user in general wishes to know what performance, in terms of recooled water temperature, may be expected of the tower with varying wet bulb temperature and water load; this information should be given in the form shown in figures 5 and 6.

The curves shown in figures 5 and 6 are typical and cover water flow variations between 80 % and 110 %. From these curves, the values of approach and inlet water temperatures should be determined. The guaranteed area of these curves should be tested in accordance with BS 4485 : Part 2. Operation of the tower outside these water loads should always be referred back to the supplier to ensure that the distribution and packing design are suitable for the anticipated variation in operating conditions.

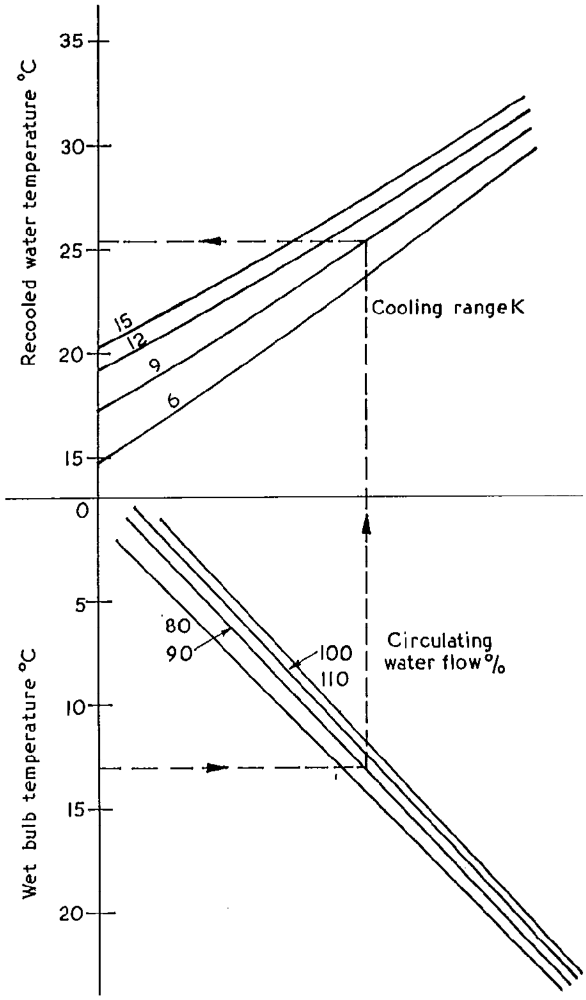


Figure 5. Performance curves for mechanical draught tower

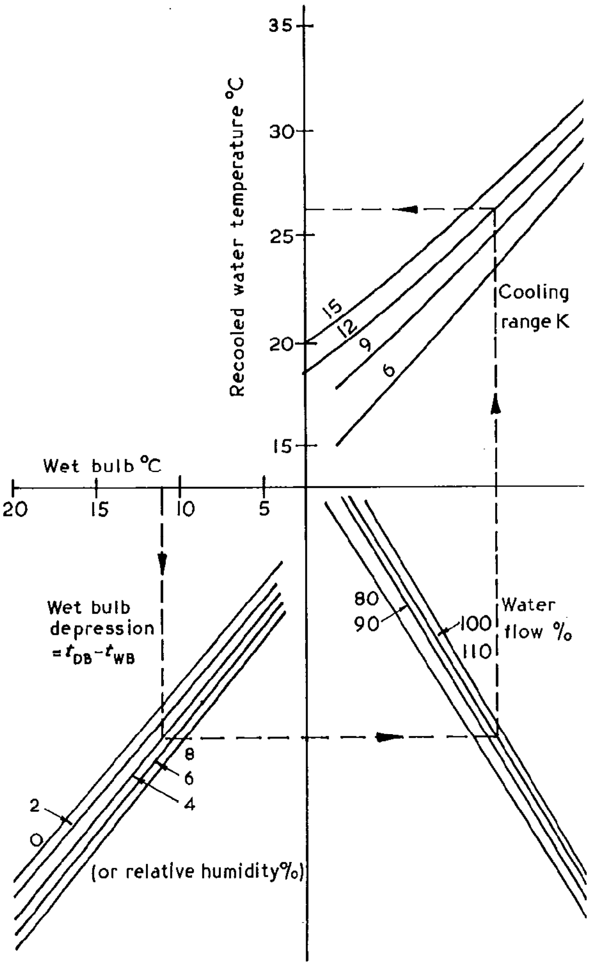


Figure 6. Performance curves for natural draught tower

3.3 Crossflow tower calculation

The heat transfer equation (3) applies to each unit plan area of a counterflow cooling tower. Where the air flows horizontally across the falling water flow, the problem becomes two-dimensional and the calculation should take into account the changes of water and air conditions that take place in both the horizontal and the vertical directions.

Equation (3) remains valid for an elemental volume at any location within the packing, but the solution for the complete packing volume involves a step-by-step computation commencing at the top of the air inlet and extending by increments of horizontal and vertical elements to a completion at the lower and opposite corner of the packing cross section. Such a calculation is only feasible by computer, particularly when a number of trial solutions may be required to optimize a design.

It is fortuitous, however, that the demand curves, described in **4.2** as a representation of relative cooling difficulty, appear to be reasonably valid also for crossflow cooling provided that the L/G ratio is taken as the overall ratio of mass flows of water and air through the tower. Within limitations they can therefore be used to determine the effect of small changes of operating conditions such as may be required in an analytical evaluation of performance test results. The facility is recognized and incorporated within the provisions of BS 4485 : Part 2.

3.4 Natural draught tower calculations

The operating air flow of a natural draught tower is determined by the equating of the draught induced by the air density change in conjunction with the height of the shell to the total resistance to airflow of the combination of shell, packing, water, etc., thus:

tower draught = total resistance to air flow

or

$$H_e \Delta\rho = \frac{NG^2}{2g\rho} \qquad (5)$$

$$G^2 \propto \rho\Delta\rho$$

or

$$G \propto \sqrt{\rho\Delta\rho}$$

Under conditions of constant water load and cooling range, the values of ρ and $\Delta\rho$ vary with ambient temperature, both increasing with reduction in ambient temperature and vice versa, with consequent variations in the values of G and L/G.

The variation in performance of a natural draught tower with ambient conditions is therefore different from that of mechanical draught tower, as it gives a closer approach at ambient temperatures below design and a wider approach above. This feature is important in the evaluation of the two alternatives where performance at all temperatures over the year is being considered.

The procedure for arriving at the design of a natural draught tower is similar to that for mechanical draught in that the operating L/G ratio is obtained by the intersection of the appropriate demand curve and packing characteristic. Equation (5) enables the shell height to be calculated for a trial value of G and successive calculations are made in order to arrive at satisfactory height and diameter proportions for the tower.

This may be expedited by the use of the expression $A_p\sqrt{H_e}$ (which is constant). This relationship for a given duty and tower configuration can be derived from equation (5).

The sizing of large natural draught towers is subjected to empirical factors that take into account the combination of crossflow and counterflow conditions that occur in the traditional design.

Performance curves for a natural draught tower have to include dry bulb as an extra parameter. This is most conveniently shown as wet bulb depression ($t_{DB} - t_{WB}$). A comprehensive presentation of performance covering normal variations of all parameters may be shown in a family of curves as suggested in figure 6.

4 Types of cooling tower and their relative merits

4.1 General

There are many types of tower used in evaporative cooling, but generally they tend to be divided into two groups depending upon the method used for moving air through the tower:

(a) natural draught;

(b) mechanical draught.

Either of these may be associated with counterflow or crossflow arrangements (see figures 1 and 7).

A combination of natural draught and mechanical draught can be used with advantage with large installations requiring difficult cooling duties. It overcomes performance limitation of natural draught towers and the fogging and recirculation problems of conventional mechanical draught towers.

The performance of a given cooling packing is determined by the relative mass flows of water and air, i.e. the ratio L/G. The smaller this ratio becomes, the more heat is extracted from the water or, alternatively, the nearer the recooled temperature approaches the wet bulb temperature. The degree of difficulty of cooling duty may be considered as being determined largely by the combination of cooling range and approach, a wide cooling range and close approach constituting a difficult duty and, conversely, a narrow cooling range and wide approach an easy duty.

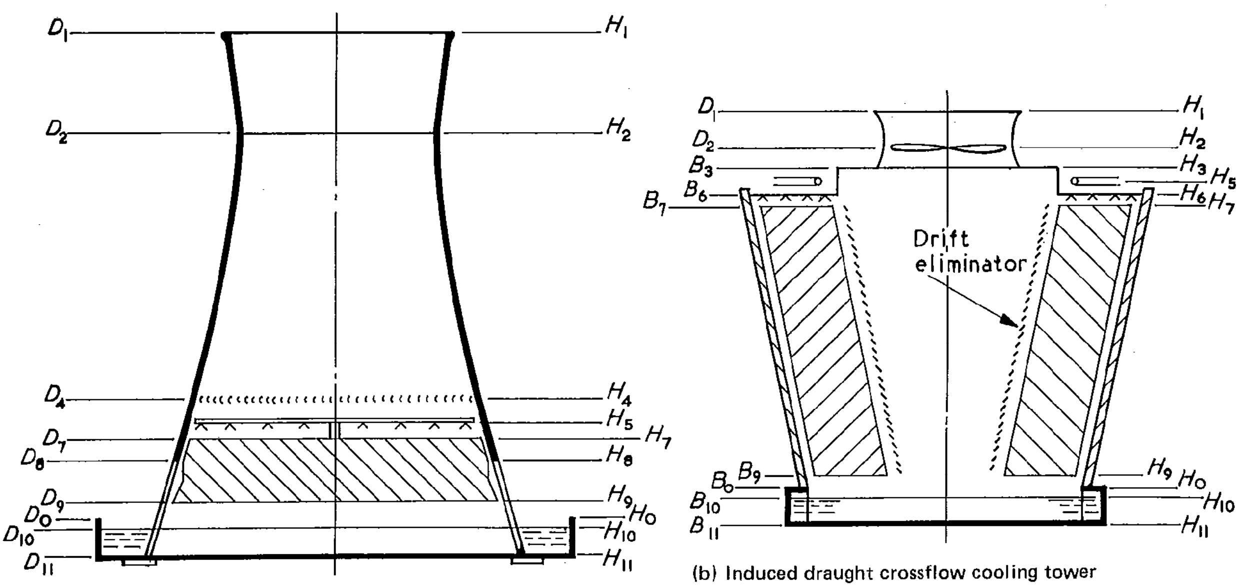
The low L/G ratios associated with difficult cooling duties involve light water loadings and high air flows for which an arrangement of film packing is particularly advantageous. Here the water flows in a thin film over the surface in the packing, allowing the air to flow through the free apertures with low resistance. Alternatively, the same cooling can be achieved with closely spaced splash packings and with lower air flows in combination with increased packing heights, although this results in higher resistance.

Relaxation of the duty permits higher water loadings on all packing. In the case of film packing, this means either a thicker water film without increase in the transfer area or the use of the plastics plate extended surface area type giving a larger area per unit volume without necessarily increasing the resistance.

Further relaxation of duty moves the advantage towards the crossflow arrangement where the relatively less efficient cooling process becomes offset by the economy of construction and the low resistance to air flow even under extremely high water loadings.

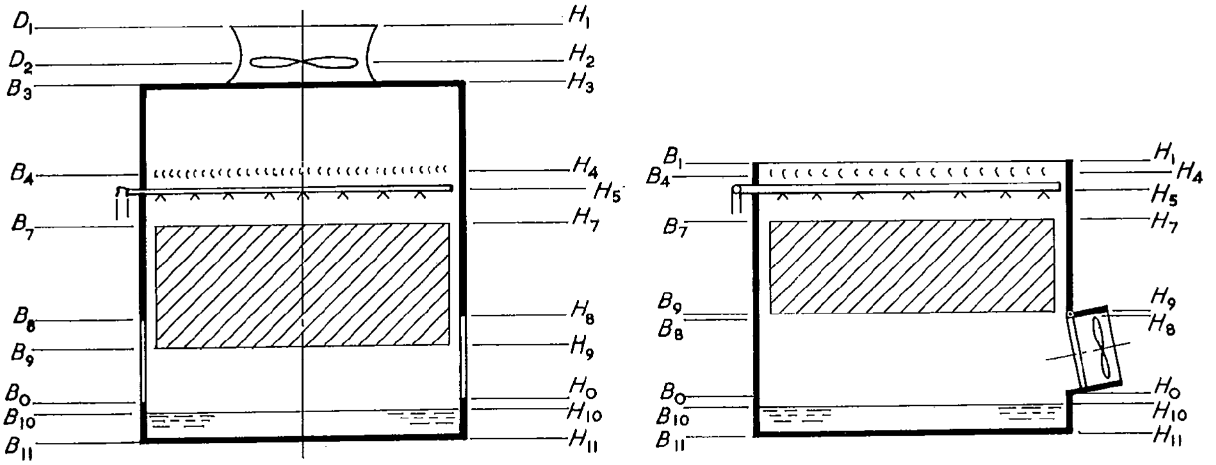
The use of natural draught is also dependent on the required *L*/*G* ratio and hence the degree of cooling difficulty. The high air flows associated with difficult cooling duties involve the discharge of air with insufficient buoyancy to take advantage of the chimney effect of a natural draught tower. A satisfactory thermal force can therefore be obtained only with the easier duties. The economics of natural draught are also subject to scale effect, the air flow and therefore the performance of each unit of packing area increasing with tower size due to the corresponding increase in chimney height. For this reason it is not expected that natural draught would be found economical for quantities appreciably less than 1.25 m^3/s circulating rate and then only for moderate to easy cooling duties.

The air rate through a natural draught tower varies inversely with ambient temperature, in contrast to a mechanical draught tower which operates at virtually constant air rate. This results in differing performance characteristics.



(a) Natural draught, mixed or counterflow cooling tower

(b) Induced draught crossflow cooling tower



(c) Induced draught or counterflow cooling tower

(d) Forced draught mixed or counterflow cooling tower

NOTE. A standard reference sheet for physical dimensions is given in table 2.

Figure 7. Illustrations of basic types of cooling tower

Table 2. Standard reference sheet for physical dimensions (see figure 7)

Item	Natural draught (figure 7(a))	Crossflow (figure 7(b))	Induced draught (figure 7(c))	Forced draught (figure 7(d))
Top of air outlet	D_1 H_1	D_1 H_1	D_1 H_1	B_1 H_1
Throat	D_2 H_2	D_2 H_2	D_2 H_2	— —
Fan deck	— —	B_3 H_3	B_3 H_3	— —
Eliminator screen	D_4 H_4	— —	B_4 H_4	B_4 H_4
Distribution pipes	— H_5	— H_5	— H_5	— H_5
Distribution basins	— —	B_6 H_6	— —	— —
Top of packing	D_7 H_7	B_7 H_7	B_7 H_7	B_7 H_7
Top of air inlet	D_8 H_8	B_8 H_8	B_8 H_8	B_8 H_8
Bottom of packing	D_9 H_9	B_9 H_9	B_9 H_9	B_9 H_9
Cold water basin	D_0 H_0	B_0 H_0	B_0 H_0	B_0 H_0
Water level	D_{10} H_{10}	B_{10} H_{10}	B_{10} H_{10}	B_{10} H_{10}
Bottom of cold water basin	D_{11} H_{11}	B_{11} H_{11}	B_{11} H_{11}	B_{11} H_{11}

4.2 Natural draught towers

4.2.1 *Atmospheric tower*

4.2.1.1 *General.* Air movement through the tower is almost entirely dependent upon natural wind forces. Water falls in a vertical path through a packing while the air moves in a horizontal path, resulting in a crossflow arrangement to achieve a cooling effect. Wind speed is a critical factor in the thermal design and should always be specified. This type of tower is infrequently used in practice.

4.2.1.2 *Advantage.* The advantage is that there is no mechanical or electrical maintenance.

4.2.1.3 *Disadvantages.* The disadvantages are as follows.

(a) Narrow construction results in considerable length of tower.

(b) There is high capital cost due to low thermal capacity.

(c) Unobstructed location broadside on to prevailing wind is required.

(d) The recooled water temperature varies widely with changes in the wind speed and direction.

(e) The drift loss may be substantial under high wind conditions.

4.2.2 *Hyperboloidal tower**† (see figures 1 and 7(a))

4.2.2.1 *General.* Air flow is affected by the reduction in density of the column of warm saturated air within the tower shell. Secondary effects of wind velocity may influence air flow but are not normally taken into consideration in tower design. The choice of counterflow, mixed flow or crossflow arrangements is dictated primarily by site and economic considerations.

4.2.2.2 *Advantages.* The advantages are as follows.

(a) It is suited to large water flow rates.

(b) High-level emission of plume virtually eliminates fogging at ground level and recirculation.

(c) It occupies less ground space than multiple mechanical draught towers for large thermal duty.

(d) It is independent of wind speed and direction when compared with atmospheric towers.

(e) There is no fan noise.

(f) There is no mechanical or electrical maintenance.

4.2.2.3 *Disadvantages.* The disadvantages are as follows.

(a) The chimney effect of the shell diminishes as the humidity decreases and this may be a disadvantage in hot dry climates.

(b) Close approach is not economical.

(c) The considerable height of shell frequently arranged in multiple installations presents an amenity disadvantage.

4.3 Mechanical draught towers (see figures 1 and 7(b), (c) and (d))

4.3.1 *General.* Fans are used to produce air movement through the tower. This enables the air flow to be determined independently of other process conditions. Correct quantities and velocities of air may be selected to satisfy various design demands.

Several alternative ways of locating the fans in relation to tower structure are used to obtain specific advantages; also there are two basic flow arrangements for air-water flow, the counterflow and the crossflow (see figure 1).

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* See BS 4485 : Part 4 for shell geometry.

† Commonly known as hyperbolic tower.

4.3.2 *Advantages.* The advantages are as follows.

(a) There is positive control of the air supply.

(b) Minimum capital costs makes it appropriate for low load factor applications.

(c) High water loadings can be maintained regardless of the size of tower.

(d) Difficult duties (long range combined with close approach) are more easily attainable than in natural draught.

(e) It has a low height structure.

4.3.3 *Disadvantages.* The disadvantages are as follows.

(a) Power is required to operate the fans.

(b) It requires mechanical and electrical maintenance.

(c) Warm, moist discharge air may recirculate into the air intakes.

(d) For large multi-tower installations, the total ground area required is greater than for natural draught hyperboloidal towers for equivalent duty. This is due to the spacing of towers to minimize recirculation.

(e) Fogging and drift may create problems at low levels.

(f) Fan noise may be a nuisance.

4.3.4 *Forced draught tower* (see figures 1 and 7(d))

4.3.4.1 *General.* A forced draught tower is a mechanical draught tower having one or more fans located in the air intake, normally limited to capacities of up to 0.3 m^3/s.

4.3.4.2 *Advantages.* The advantages are as follows.

(a) There is low vibration due to rotating components being located near the base of the tower.

(b) Fan units are placed in a comparatively dry air stream; this reduces the problem of moisture condensing in the motor or gearbox.

(c) Fan units located at the base of the tower facilitate inspection and maintenance.

(d) Fans moving ambient air will absorb less power than in induced draught towers (but see **4.3.5.2**(b)).

(e) See also **4.3.2**.

4.3.4.3 *Disadvantages.* The disadvantages are as follows.

(a) It may be more subject to recirculation than induced draught towers for equivalent duties.

(b) Ice may form on fan inlets during operation in winter. This can be minimized by arranging the fan ducts at a slight angle for draining any water back into the storage basin.

(c) See also **4.3.3**.

4.3.5 *Induced draught tower* (see figures 1 and 7(b) and (c))

4.3.5.1 *General.* An induced draught tower is a mechanical draught tower having one or more fans at the air discharge.

4.3.5.2 *Advantages.* The advantages are as follows.

(a) It has the ability to handle large water flow rates (but see **4.2.2**).

(b) It is suitable for larger cell sizes and fan sizes as compared with forced draught. Larger fan sizes may result in greater efficiency and consequently lower power and sound levels.

(c) It uses a more compact ground area than a forced draught tower of equivalent capacity due to the absence of fans on one side.

(d) Fan equipment in warm exhaust air is less liable to icing up in winter operation.

(e) See also **4.3.2**.

4.3.5.3 *Disadvantages.* The disadvantages are as follows.

(a) Protection is required for mechanical equipment against corrosion and internal condensation.

(b) Inspection and maintenance of mechanical equipment is relatively difficult due to fans being located 5 m to 20 m above the base.

(c) See also **4.3.3**.

4.3.6 *Counterflow tower* (see figures 1 and 7(c) and (d))

4.3.6.1 *General.* A counterflow tower is a mechanical draught tower in which air and water flow in opposite, mainly vertical, directions.

4.3.6.2 *Advantages.* The advantages are as follows.

(a) Normally it is an economical choice for difficult duties (long range combined with close approach).

(b) It is less prone to icing than crossflow towers (see **8.5.1**).

(c) See also **4.3.2**.

4.3.6.3 *Disadvantages.* The disadvantages are as follows.

(a) With induced draught arrangement the water distribution system (generally piping or troughs with spray nozzles) cannot be easily inspected and cleaned unless the tower is shut down.

(b) See also **4.3.3**.

4.3.7 *Crossflow tower* (see figures 1 and 7(b))

4.3.7.1 *General.* A crossflow tower is a mechanical draught tower in which air flow is normally horizontal, in contact with falling water drops. It is normally associated with an induced draught arrangement.

4.3.7.2 *Advantages.* The advantages are as follows.

(a) It may be an economical choice for large water flows.

(b) The plan area at basin level and the total power for fans and pumps can be less than for other mechanical draught towers.

(c) The water distribution system of the open pan type is easy to clean without shut-down.

(d) It may be designed to suit low-silhouette applications for small duties.

(e) See also **4.3.2**.

4.3.7.3 *Disadvantages.* The disadvantages are as follows.

(a) Prevention of icing during extreme weather conditions generally demands more care from the operator.

(b) The exposure of water distribution basins to sunlight promotes growth of algae (see **8.4.4**, **8.4.10** and **8.4.11**).

(c) See also **4.3.3**.

5 Siting, spacing and environmental considerations

5.1 General

The siting and spacing of a cooling tower installation should be considered from economic, thermal and environmental aspects.

5.2 Siting

5.2.1 *Tower levels.* The cooling tower may be located at a suitable site either below or above the heat source, but due consideration should be given to the question of drainback from the system resulting in loss of water and flooding.

5.2.2 *Air restrictions.* On small industrial tower installations, due to aesthetic reasons or sound attenuation requirements, enclosures or barriers are sometimes built to shield the towers. These barriers or enclosures should be spaced and designed to achieve the minimum of air restriction with the maximum maintenance working area. The exclusion of birds and bird droppings may also necessitate the provision of barriers which should be subject to the same considerations.

The total flow area in the barrier or enclosure should be a minimum of twice the area of the tower inlet openings on that side.

5.2.3 *Recirculation.* On large mechanical draught industrial towers, the most usual problems encountered are recirculation and extraneous influences that affect the inlet air wet bulb temperature.

Recirculation is an entrainment in the inlet air of a proportion of the exit air from the cooling tower. On large natural draught towers this does not normally occur due to the height of the tower.

Extraneous influences may modify the inlet air conditions by interference from adjacent towers or other heat sources.

The extent of recirculation depends mainly upon wind direction and its velocity, tower length and atmospheric conditions. Further factors that may exert some influence are spacing, topography or geographical situations with respect to downdraught, exit air speed, tower height and the density difference between exit air and ambient temperatures.

5.2.4 *Orientation of cooling towers.* The orientation of cooling towers should be as follows.

(a) Towers with air inlets on one side should be oriented so that the air inlets face the prevailing wind.

(b) Towers with air inlets on opposite faces of the cooling tower should be oriented so that the air inlets face at 90° to the prevailing wind.

(c) Large mechanical draught towers should preferably be divided into banks, each of which should have a length-to-width ratio of about 5 to 1.

(d) The wind loading on any tower within a group will be affected by the grouping and spacing and should be considered in their structural design (see BS 4485 : Part 4).

NOTE. The prevailing wind direction, determined by the local topography, should be taken as that obtained during periods of maximum duty.

5.3 Spacing

5.3.1 The spacing of cooling towers or cooling tower banks should be based upon the recommendations in **5.3.2** to **5.3.5**.

5.3.2 When the long axis of one bank is perpendicular to the prevailing wind direction (see figure 8(a)), the influence on another bank will be minimized when the distance, *X*, between the banks is greater than their average length. The long axes of the tower banks should be in line.

5.3.3 When the long axis of the existing tower is parallel to the wind direction (see figure 8(b)), the influence of the existing tower on the new will be minimized if the distance, *X*, is greater than their average length.

5.3.4 When the long axis of the existing tower is at 45° to the wind direction (see figure 8(c)), the influence of the existing tower on the new will be minimized if the distance, *X*, between the towers measured normal to the wind direction is greater than their average length.

5.3.5 Spacing of large natural draught cooling towers is considered to be adequate if adjacent cooling towers are spaced so that the distance between the towers is equal to or greater than half the base diameter of the large tower (see figure 8(d)). Should a tower be sited in close proximity to large buildings such as the turbine and boiler houses, the nearest point of the tower relative to the buildings should be at least one tower diameter away (see figure 8(d)).

5.4 Environmental considerations

5.4.1 *General.* The effects of drift, blow-out, fogging and noise are further contributing factors that may need consideration when siting a tower installation.

5.4.2 *Drift.* When towers are sited adjacent to high-voltage electrical equipment, drift may cause flashover and icing problems. Drift can also constitute a hazard, particularly under icing conditions, on public footpaths and roadways and may also create a nuisance in adjacent residential areas.

Drift may also create a health hazard by virtue of its bacterial population and towers should be sited so as to avoid drift into open windows and re-entrainment of cooling water droplets in the intake air to ventilation equipment.

Effective eliminators at the tower discharge should be capable of reducing the drift to an acceptable level (see **8.4.4** and also table 4 of BS 4485 : Part 2 : 1988).

5.4.3 *Blow-out.* Blow-out is water blown out from the air inlet and occurs to a greater extent on natural draught towers of counterflow design than on mechanical induced draught towers. It can produce a nuisance factor with similar detrimental effects to drift, although the radius of area affected would be smaller.

Where blow-out creates a nuisance, it may be reduced by the following means:

(a) diagonal partitions or a central division situated so that the prevailing winds are prevented from blowing across the tower basin;

(b) inclined louvre boards positioned around the air opening at the base of the tower, sections of which may be removable to permit access.

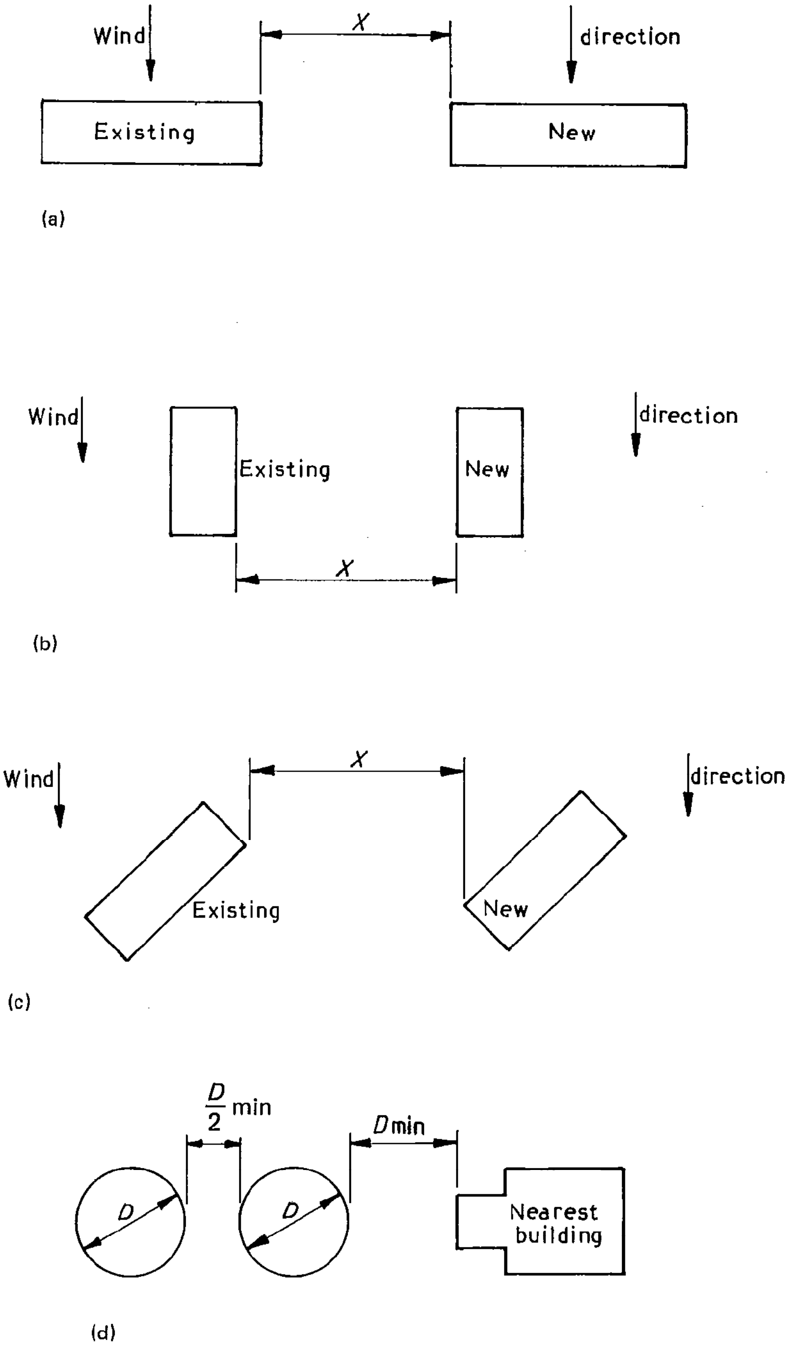

Figure 8. Spacing

5.4.4 *Fogging.* Fogging arises from the mixing of the warm moist air discharged from the tower with cooler ambient air, which lacks the capacity for absorbing all the moisture as vapour. This mixing results in the excess moisture condensing as fog.

When fogging exists, it is a nuisance factor that could create visibility and icing hazards. It is an intrinsic feature of any evaporative cooling tower and is worst during periods of low ambient temperatures and high relative humidity.

The dissipation of fog, where it occurs, depends mostly on the characteristics of the prevailing atmosphere.

Measures may be taken to reduce fogging, but these add substantially to the capital and operating costs of the tower. For example, heating the moist air discharge reduces the fog as does an increase in the volume of air through the tower.

Fan stacks discharging warm vapours at a high elevation can be a partial solution, although this may be expensive depending on the stack diameter and the height required to derive some benefit. This problem is solved far more easily if the tower installation is sited where the least possible nuisance may be caused. The high-level discharge of the vapour plume from a natural draught tower generally prevents this from being a hazard.

5.4.5 *Abstraction from water sources.* The concentration of impurities in a recirculating water system using evaporative cooling is maintained at the desired level by abstracting more than the evaporative loss of water from a convenient water source (e.g. river, lake or treated sewage) and discharging the excess water as purge back to the same or some other source. Water used in this manner may be subject to a charge by the water supplier*. Where the circulating water intakes for the make-up water are situated on waterways, special precautions may be necessary to exclude fish from intake works. It may not be possible to abstract make-up water at all times (e.g. low water flows or heavy silt burden at certain tides) and some storage provision should then be made for operation without make-up.

5.4.6 *Discharge of cooling water.* Discharge of cooling tower purge directly to the environment will be subject to water supplier* consent as an industrial effluent. This consent will be conditional mainly on the temperature, volume and composition of the effluent and the extent to which it will be diluted by the receiving water. Discharge temperature restrictions and the elimination of navigation hazards may necessitate auxiliary cooling or pre-dilution of the discharge by further abstracted water. The conditions of consent will almost certainly place limitations on the type of water treatment which may be used. Chromates are now almost universally banned and restrictions on the use of a range of other inhibitors and biocides are becoming increasingly widespread. Discharge to sewers may also entail consent subject to conditions. These conditions should also be observed when draining the system for maintenance.

5.4.7 *Noise*

5.4.7.1 *General.* The likely noise level from fans and falling water in a cooling tower installation should be considered in the context of the existing noise level at the proposed site.

It is necessary that the noise aspect be given early prominence in that to effect a significant reduction in noise may need a design of tower quite different from and possibly less economical than that which may have been suitable in a position of no noise restriction.

Various corrective measures are discussed in **5.4.7.4** and **5.4.7.7**.

5.4.7.2 *Noise level.* The noise level can vary greatly depending on the application and type of tower used. The necessity to limit noise can be a major factor in deciding tower type and position. In certain circumstances because of fans, size limitations, etc., it is not always possible to design a tower for quiet running; in such cases it should be sited as far away as possible from noise-sensitive areas, or be fitted with silencers at increased capital and operating costs.

The noise generated by the fan is related to the fan power, static pressure and tip speed. Fan static pressure is equal to the pressure drop through the tower; fan power is directly proportional to air flow. It follows, therefore that increasing air flow through the tower increases both fan power and static pressure and, consequently, noise power.

Water noise is created by the impact of water droplets on packing surfaces and on the water surfaces in the pond. In certain cases water noise can predominate but, owing to its noise structure and freedom from discrete frequencies, may not be as offensive as that arising from the fans.

Noise and vibration from fans, falling water, pumps and other ancillary equipment can be transmitted through the tower structure into the base upon which the tower stands and hence into a building if so sited. In certain instances, therefore, it may be necessary to ensure that this transmission is reduced to acceptable levels in the areas concerned.

Failure to obtain information on the noise level of a proposed cooling tower by a purchaser or failure to realize the significance of data on noise levels given by the supplier sometimes results in a cooling tower installation creating a considerable nuisance.

5.4.7.3 *Low noise level cooling towers.* Occasionally site requirements are such that the noise level of the towers normally offered by suppliers is totally unacceptable. In such cases the supplier will, if possible, offer a low noise level tower. These towers will probably incorporate such features as centrifugal fans or acoustic attenuators. The air speed through the packing may be reduced below the normal level, or the packing rearranged to reduce air pressure drop.

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* The term water supplier covers any water supply organization, including Water Authorities, Regional and Islands Councils, and Water Companies.

5.4.7.4 *Reducing noise level after installation.* If, after a tower has been installed, changed conditions require a reduction in noise level, this can be achieved usually at considerable expense. If spare cooling capacity exists, the noise can be reduced by changing the fan speed. If there is no reserve of capacity, it may be possible to improve matters by changing the fan from an axial flow to a centrifugal type.

As a last resort, acoustic baffles can be built around the tower or silencers fitted on the air inlets and/or outlets. In these cases care should be taken to ensure correct air flow into the tower, both in quantity and in flow pattern; a new fan may be required to overcome the additional resistance.

The degree of basic noise level may be such that:

(a) the noise from the cooling tower may cause a nuisance in adjacent quiet buildings within the user's own property;

(b) it may increase the noise level outside the owner's property to such a level as to be objectionable to the neighbours, and lead into legal difficulties.

Methods of rating industrial noise affecting mixed residential and industrial areas are given in BS 4142.

Appendix B describes a method of calculating the expected noise level of a cooling tower at a particular distance.

5.4.7.5 *Fan equipment noise.* The noise spectrum and sound power level, S_W, of a fan may normally be obtained in accordance with BS 848 : Part 2 from the fan manufacturer. There is evidence to show that the resulting fan noise at a cooling tower is given by:

$$S_W = 96.25 + 10 \log_{10} (\text{driver kW}) \qquad (6)$$

given with reference to 10^{-12} W.

Care should be taken that the installation conditions of the fan, such as the nature of supports, do not introduce beats which may be obtrusive.

Electrical noises may arise during switching to energize the fan or to change fan speed. Such noises may also be obtrusive particularly at night, since they tend to be both intermittent and at discrete frequencies.

5.4.7.6 *Water noise.* Water noise from a large tower with splash packing, or film packing with large free drop distances below the packing, may be as much as, or greater than, the noise attributed to fans. It is, however, of a less objectionable nature, being of broad band without discrete frequencies.

Small towers on the roofs of buildings may cause water noise to be transmitted through the water basin into the structure.

5.4.7.7 *Noise abatement summary.* If noise is to be a minimum at any point of sensitivity, the following recommendations are made.

(a) The basic noise level should be as low as possible. Fan power should be low and the water noise reduced to a minimum.

(b) The towers should be sited the maximum distance from the point of sensitivity.

(c) If a multi-cell mechanical draught unit is to be installed, the fans should be in line with the point of sensitivity and the air inlets in the broadside on position.

(d) Motors should be located behind the fan flares when viewed from the sensitive point.

(e) In forced draught towers the fan axis should be away from the sensitive point.

(f) It may be possible to analyse the sound spectrum, locate and abate discrete frequencies and thereby reduce the general noise level.

(g) Antivibration mounting may be necessary to minimize the transfer of vibration from a tower to a supporting building. In certain cases the fan and driver may be independently supported on antivibration mountings and flexibly connected to the tower which may then be rigidly mounted. This has the advantage of eliminating the need for flexible circulating water connections, make-up lines and drains.

(h) Silencers on fan intakes or discharge stacks are possible aids in the reduction of noise, but may introduce prohibitive additional air resistance.

(i) The use of multi-speed drives for the fan provides for a reduction in noise level when operated at reduced speed.

(j) Employment of centrifugal fans in the case of forced draught cooling towers may contribute to a reduction in noise level.

(k) As fan noise is roughly proportional to fan driver power, the air flow directly influences the degree of noise. Towers that operate at high L/G ratio may therefore be less noisy than their most economical equivalent where there is a noise problem to be solved.

(l) If fan noise is to be reduced on an existing tower, it may be possible to reduce the fan capacity and therefore fan power by operating at an increased water flow and a different heat balance. If the tower is small and of the forced draught kind, then a change from axial to centrifugal fans may be possible.

6 Guidance on specified operational requirements

6.1 Selection of design conditions (including probability curves)

6.1.1 *General.* The parameters involved in the design of a cooling tower are:

(a) ambient wet bulb temperature;

(b) approach;

(c) cooling range;

(d) circulating water flow;

(e) altitude (considered if more than 300 m above sea level).

An additional parameter in the case of natural draught towers is ambient dry bulb temperature or, alternatively, ambient relative humidity.

6.1.2 *Ambient air temperatures.* The successful design of water cooling towers is dependent on an adequate knowledge of atmospheric conditions prevailing in the chosen area in order to make a realistic prediction of the conditions likely to be encountered during the operating life of a cooling tower. In general, reliable hourly or daily weather information is available from meteorological stations situated at strategic points, and this information is usually taken over a considerable period of time.

It is important that the correct design ambient conditions are chosen with care, since to design the cooling equipment to cater for an extreme condition of temperature involves unnecessary expense when the tower would operate for a much greater period of time under ambient conditions less than the extreme. Conversely, if the design conditions are chosen too low, the tower will be undersized for a large period of its operating life with adverse effects on its allied components in the system. Hence, in general, the designer has to cater for the tower to produce its given output during a given percentage of its operating life.

In certain industrial processes this percentage can be very high, as the cold water temperature has to be maintained at a certain level for the greater part of the operating time. In this case the approach of the cold water temperature to the ambient wet bulb temperature is comparatively close, necessitating a larger installation than if the approach value were relaxed to allow for the design cold water temperature to be exceeded for a greater percentage of time. In this instance the manner in which the information on the atmospheric conditions is presented is important, as this will enable the cooling tower designer to select optimum design values.

Generally the hottest period of the year is selected as the critical area to be studied. For UK climatic conditions the atmospheric information covering the four-month period June to September inclusive is analysed and presented in the form of wet and dry bulb temperature isotherm maps for the different localities. Figure 9 shows screen dry bulb and wet bulb isotherms for the UK.

From these maps the designer is able to select a value of the particular wet bulb temperature suitable for a given percentage of the total hours of this four-month period. Hence, a 1 % isotherm line of 19 °C wet bulb temperature (i.e. a high design wet bulb temperature) is exceeded for only 30 h per year of the total hours for this period. Similarly, a 5 % isotherm of 17 °C wet bulb temperature (i.e. a moderate design wet bulb temperature) will allow the design ambient wet bulb temperature to be exceeded for 150 h per year.

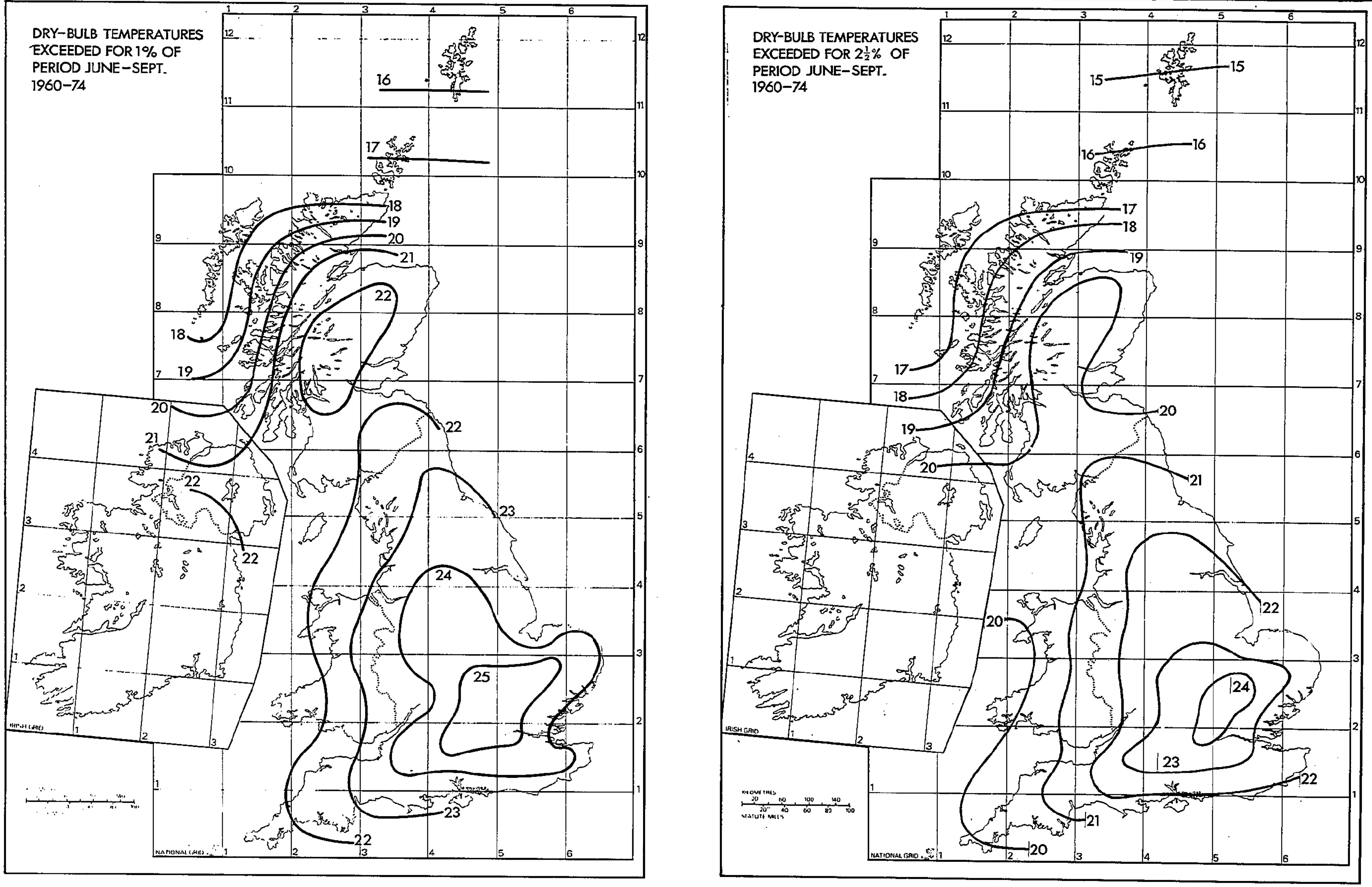
NOTE. Detailed information for a specific locality may be obtained from the Meteorological Office.

Hence, a cooling tower design based on a high design wet bulb temperature necessitates a larger and more costly cooling tower than one designed on a moderate design wet bulb temperature.

Normally in power station practice it is important that full output from the turbo-generator sets is available in the winter months and not so important during the summer period when the machines can be off-loaded or shut down for maintenance. In certain countries, however, this trend may be reversed where, for example, air conditioning plant may take a greater part of the load in the hotter months. It is therefore necessary to specify the design and the conditions with a bias to the heavier load requirements of the system. Owing to difficulty in predicting the load requirements for any particular period of time, in general it is sufficient for monthly load factors to be used together with average monthly ambient conditions in order to produce a weighed average annual ambient condition. So for the case of the higher winter load factor, the cold water temperature can be expected to be better than desired in winter conditions and worse for the summer period.

6.1.3 *Approach.* Approach is a very sensitive design parameter. Closer approaches are limited by practical difficulties such as minimum water loading on the packing. The cooling tower supplier should be consulted before consideration is given to approaches closer than 3 K for mechanical draught towers or 7 K for natural towers. At these levels an increase of 1 K in approach may result in a reduction of 20 % in tower size and is therefore of considerable economic significance.

6.1.4 *Cooling range and water quantity.* Cooling range and water quantity variations are usually considered in relation to a fixed heat load and are selected in conjunction with other plant conditions.



(a) Dry bulb temperatures exceeded for 1 % of hours.

(b) Dry bulb temperatures exceeded for 2½ % of hours.

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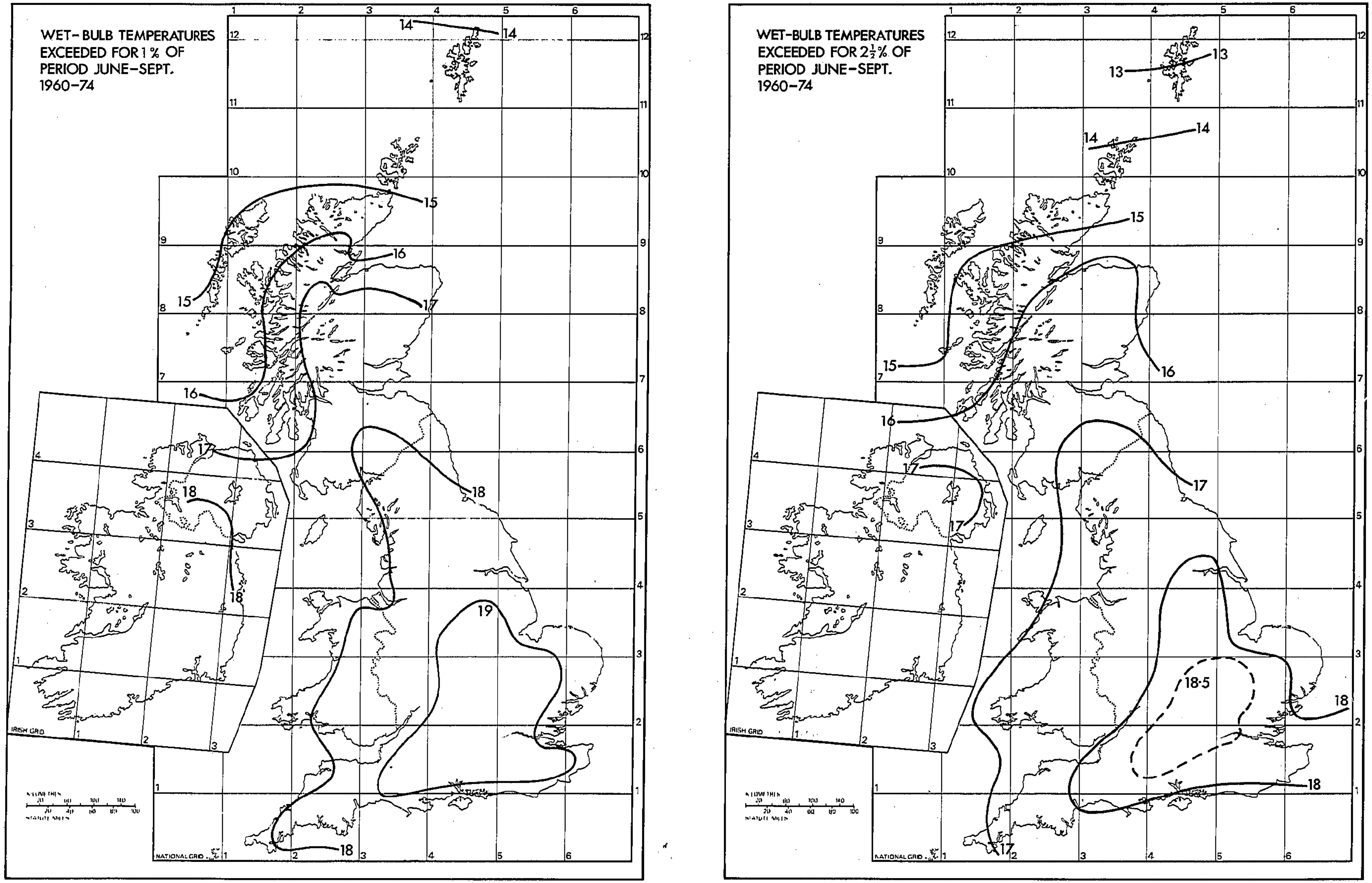
Figure 9. Screen dry bulb and wet bulb isotherms for the UK for temperatures exceeded for the stated percentage of hours during June to September: period 1964-1970



(c) Wet bulb temperatures exceeded for 1 % of hours.

(d) Wet bulb temperatures exceeded for 2½ % of hours.

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Figure 9 *(concluded)*

6.2 Guidance on the effect of variations of parameters

6.2.1 *General.* In arriving at the best selection of design parameters, it is useful to carry out a first order assessment of the effect on tower size and cost of a variation in the parameters relating to cooling range, approach and wet bulb temperature.

6.2.2 *Mechanical draught cooling towers.* Mechanical draught cooling towers are generally designed for an economical air flow, and different operating temperatures can be achieved by varying the water loading, the packing depth and the type of packing, and also by varying the flow arrangement from counterflow to crossflow.

Figure 10 illustrates as a first order approximation the effect that variations in cooling range, approach and wet bulb temperature have on the relative plan area of a mechanical draught counterflow cooling tower. Conditions of 12 K cooling range, 5 K approach, and 17 °C wet bulb temperature have been selected as average temperatures for mechanical draught cooling towers in the UK. A typical water loading for these conditions is 2.3 kg/(m^2·s). Changes in packing type and depth can vary this value by ± 20 %.

Any variation from these temperature conditions can then be read from figure 10 as a relative plan area factor which can be directly related to the changing cost. An overall plan area factor is derived from a multiplication of the individual factors. The following example illustrates the method.

Example

A cooling tower is required to cool 0.625 m^3/s water flow from 33 °C to 23 °C at 16.5 °C wet bulb temperature. The relative plan area factor for range, approach and wet bulb temperature obtained from figure 10 is derived as follows.

Conditions	Relative plan area factor
Cooling range 10 K	0.90
Approach 6.5 K	0.79
Wet bulb temperature 16.5 °C	1.03

Overall relative plan area factor = 0.90 x 0.79 x 1.03 = 0.73.

For the conditions of 12 K cooling range, 5 K approach and 17 °C wet bulb temperature, the relative plan area factor is unity and the water loading typically 2.3 kg/(m^2·s). Hence, for the specified conditions the expected plan area for a counterflow tower would be (0.625 x 1000)/2.3x x 0.73 = 199 m^2.

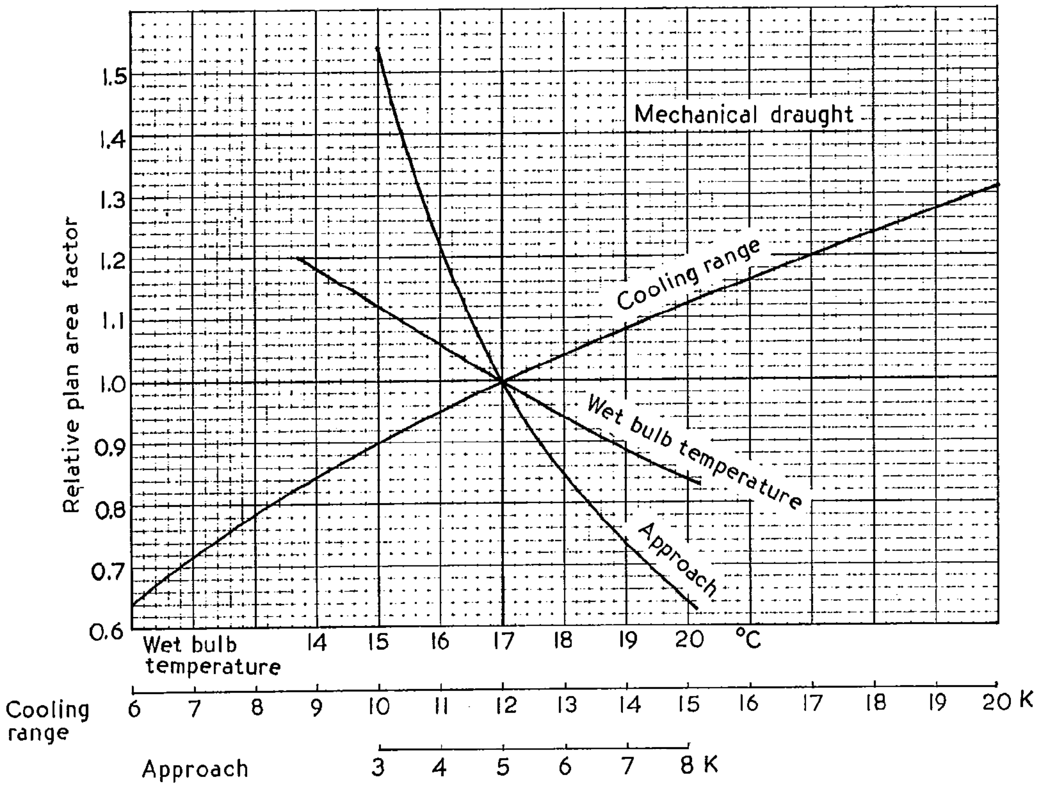


Figure 10. Mechanical draught counterflow tower: variation of tower size with cooling range, approach and wet bulb temperature

6.2.3 *Natural draught cooling towers.* In the case of natural draught cooling towers, it can be shown that for given thermal conditions there is a constant relationship between plan area of packing and the square root of the chimney height; this can lead to an infinite number of combinations of height and diameter for any cooling problem. In general, towers are currently being constructed with a height-to base diameter ratio of 1.25, and figures 11 and 12 have been derived using this relationship and a mixed flow splash type of packing.

The procedure for determining the variation in size and cost of a natural draught cooling tower is similar to that used for a mechanical draught type. Figure 11 shows the variation of duty factor with cooling range, approach and wet bulb temperature, the conditions selected for a duty factor of unity being 12 K range, 10 K approach and 10 °C wet bulb temperature. Thus an overall duty factor can then be derived from these individual factors for changing design conditions. From figure 12, a tower base diameter can be determined from the duty factor and the water flow over the tower. This may then be compared with the base diameter of a natural draught cooling tower operating at the duty factor of unity. It is sufficiently accurate for small variations in operating temperatures to take the variation in tower costs as being directly proportional to the square of the tower diameters. The following example illustrates the method.

Example

A cooling tower is required to cool 3.75 m^3/s of water from 33 K to 20 K at 11 °C wet bulb temperature.

Conditions	Duty factor
Cooling range 13 K	1.05
Approach 9 K	1.20
Wet bulb temperature 11 °C	0.945

Overall duty factor = 1.05 x 1.2 x 0.945 = 1.19.

Circulating water flow times the duty factor = 3.75 x 1.19 = 4.46, hence from figure 12 the tower base diameter is 80.5 m.

For a duty factor of unity and circulating water flow of 3.75 m^3/s, the base diameter as derived from figure 12 is 75 m. Hence, the order of increase in cost is represented by the ratio:

$$\left(\frac{80.5}{75}\right)^2$$

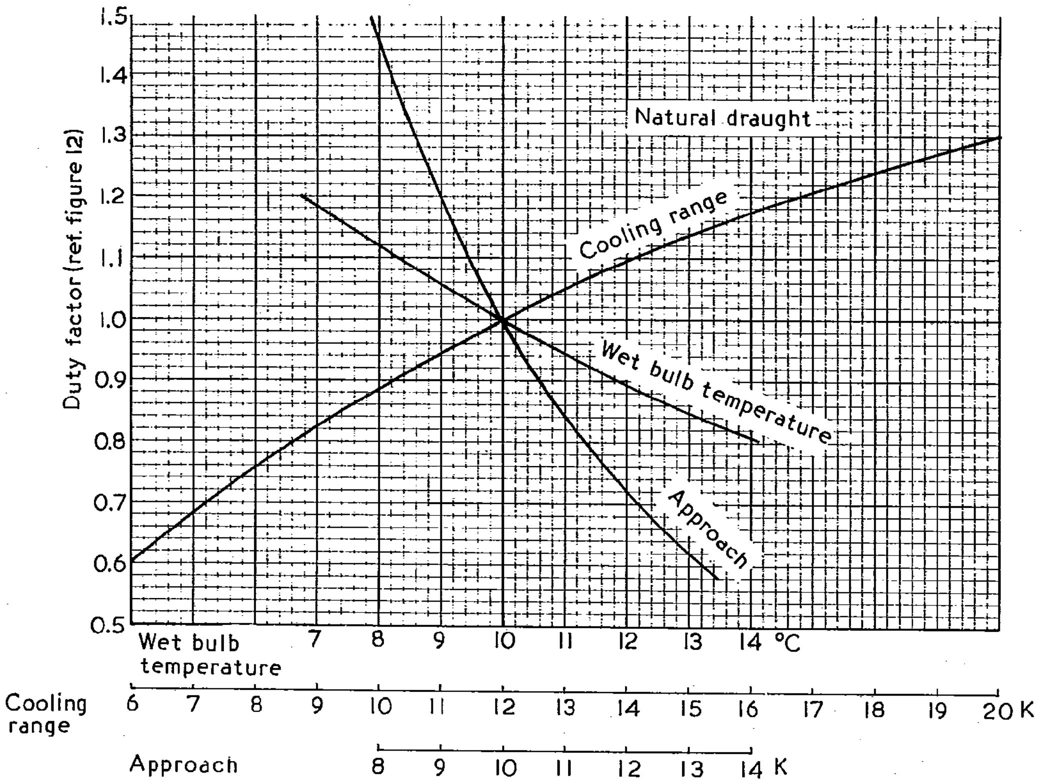


Figure 11. Natural draught tower: variation of duty factor with cooling range, approach and wet bulb temperature (at constant 70 % r.h.)

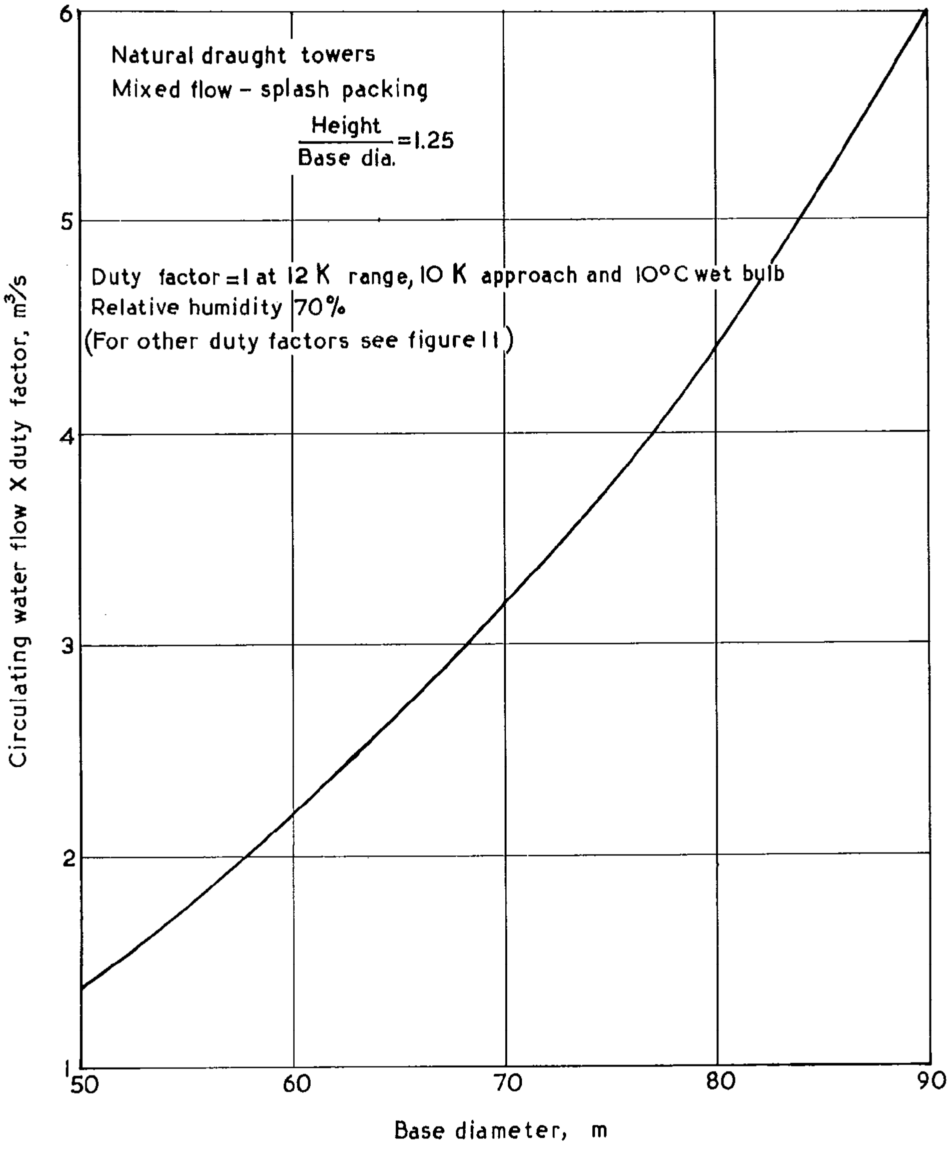


Figure 12. Natural draught tower: variation of base diameter with circulating water flow corrected for duty factor

7 General thermal design

7.1 Packings

7.1.1 *Function.* As mentioned previously (see **3.1**) the function of a packing in a cooling tower is:

(a) to increase the duration of contact between the air and the water;

(b) to cause fresh surfaces of water to be formed, thus increasing the rate of heat transfer per unit volume.

7.1.2 *Types*

7.1.2.1 *General.* Packing may be of the two types described in **7.1.2.2** and **7.1.2.3**.

7.1.2.2 *Splash packings.* Splash packings are those in which the thermal performance of packing depends on the heat transfer from the surface of the water droplets in the packing area plus the heat transfer from the wetted surfaces of laths. In general the most commonly used material is timber in the form of small-section laths specifically treated to resist rot and fungus infection (see BS 4485 : Part 4). The laths may be placed in the tower individually or in the form of prefabricated trays.

Other materials used in splash packings are prestressed concrete and plastics.

7.1.2.3 *Film packings.* Film packings differ from splash packings in that they are primarily designed to provide a large surface area of material in the packing area over which the water is caused to film, thereby exposing a large surface area to the air flow. They include what are otherwise termed extended surfaces or sheet packings.

7.1.2.4 *Selection of packing.* The intended situation of a tower should be considered in deciding on a particular type of packing. In general, the film packings will be more susceptible to fouling by suspended solids, fats and oils, biological growth or other process contamination. Where fouling may become a problem, the spacing and configuration of the packing elements should be considered regarding the potential for cleaning.

7.1.3 *Water loadings.* The minimum water loading varies for different configurations and types of packing. It is dictated, particularly on the film and extended surface packings, by the possibility that channelling may occur at very low loadings. This may cause areas of the packing to dry out with consequent loss of performance.

The maximum water loading on a packing is determined largely by the increase in resistance to air flow and by the risk of excessive drift.

Somewhat higher water loadings can in general be used in a crossflow cooling tower irrespective of the type of packing.

Cooling tower water loadings do not approach the level at which flooding takes place. The only problem with high water loadings is in obtaining adequate air flow and crossflow towers will often therefore be found advantageous.

7.1.4 *Height of packing.* The height of cooling tower packing will vary considerably even within the various types of packing according to the design economics relating to any specified requirements. In general, however, it can be stated that for equivalent duties and fan power requirements the film or extended surface packings will be of lower height than the splash bar type of packing.

7.2 Drift eliminators

Spray distribution systems and splash packings produce a spectrum of droplet sizes the lighter of which are carried downstream in the discharge of air. This situation does not arise in those systems where an arrangement of troughs and gutters allows the water to trickle on to a film packing, although malfunction of such systems due to fouling or other defects can create splashing and drift loss. It is usual therefore to install a drift eliminator in the air flow, downstream of the packing and distribution system, to reduce the quantity of drift loss to an extent acceptable to the particular environment (see appendix B of BS 4485 : Part 2 : 1988).

The function of a drift eliminator is to provide surfaces on which the droplets are caused to impinge. In the case of a horizontal eliminator they coalesce to a size at which they are large enough to fall back to the packing, and in the case of a vertical or near vertical eliminator they form a film of water that drains to appropriate collection points from which it can be removed without causing further drift.

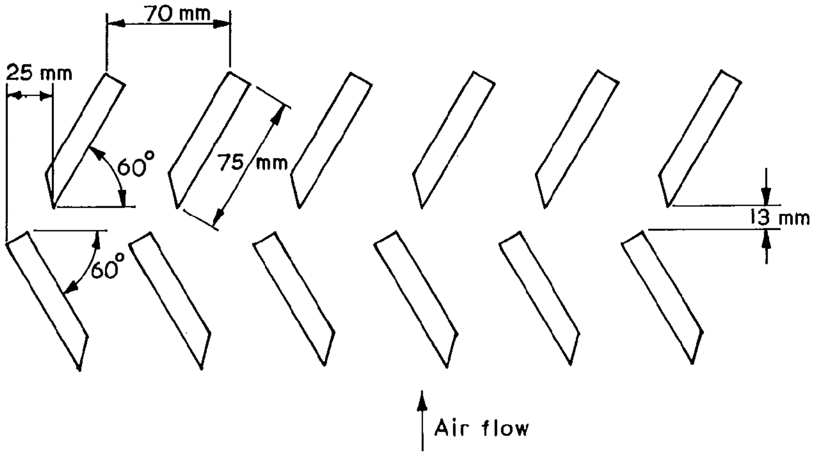
The usual arrangement of an eliminator consists of a grid of parallel elements in one or several layers with surfaces inclined to the normal direction of air flow. As the air turns between these elements the inertia of the water droplets causes them to impinge on the surfaces. The success of such a system depends on limiting the air velocity to a level at which the droplets can remain and coalesce without being stripped off the downstream edges of the elements.

For a given droplet size spectrum, which is determined by the design of distribution and packing systems, the amount of drift is largely related to the air velocity. However, a compensating factor is the increase in effectiveness of eliminators with velocity providing that the limit is not reached at which stripping occurs.

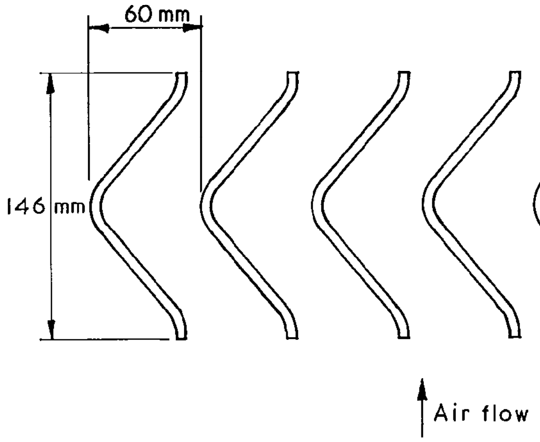
The design of an eliminator is based upon a compromise between effectiveness and resistance to air flow. The spacing of the elements and their inclination to the normal direction of air flow are important, as are the relative position and angle of successive layers of elements. Widely used eliminators are shown in figure 13. Figure 13(a) illustrates an eliminator consisting of two layers of timber louvres and figure 13(b) one consisting of a single layer of single corrugations cut from a suitably profiled plastics sheet. Either of these arrangements should be capable of complying with the normally accepted requirements of a precipitation rate not exceeding 0.025 mm/h as defined in table 4 of BS 4485 : Part 2 : 1988 provided that they are installed in a continuous manner with suitable flashings or overlaps and positioned so that the air flow is normal to the plane of the eliminator.

The effectiveness of an eliminator can be increased, at the expense of increase in air flow resistance, by reduction in blade spacing or alternatively by the installation of further layers of elements.

Eliminators may also be constructed from formed plastics sections, wire or plastics mesh or angled honeycomb material.



(a) Two layers of timber louvres



(b) Single layer of single corrugations

Figure 13. Drift eliminators

7.3 Recirculation

The percentage of air recirculating on the leeward side of the cooling tower can vary between 3 % and 20 %. However, the higher figure is normally associated with installations of one or more large multi-cell mechanical draught cooling towers.

In general, therefore, recirculation of the warmed air discharged from the cooling towers is relatively insignificant in mechanical draught cooling towers under 0.5 m^3/s capacity, the recommended allowance (60 % factor) on wet bulb temperature for the example in **6.2.2** amounting to 0.24 °C.

The maximum extent of recirculation on a large multi-cell tower has been found to occur with winds generally in the range 2 m/s to 5 m/s and blowing at an angle of 20° to 70° to the tower longitudinal centreline. Therefore, provided that the tower is correctly oriented to the wind prevailing during peak demand periods (see **5.2.4**), it may be assumed that maximum recirculation, as in the case of maximum wet bulb temperature, will occur for only a proportion of the total operating time. When an allowance for recirculation is made, this should be taken as approximately 60 % of the maximum anticipated recirculation. Figures 14 and 15 indicate both the maximum and the design recommendations for recirculation with correction factors that can be used to adjust the recirculation allowance according to the actual cooling range and anticipated approach.

The recirculation allowance determined from figure 14 is based on 17 °C wet bulb temperature. For other wet bulb temperatures the recirculation allowance should be increased by 4 % for each degree reduction in wet bulb temperature or vice versa.

If the cooling tower that is the subject of the wet bulb investigation is to be installed either as an extension of an existing tower or in proximity to other towers (see **5.3**), the recirculation allowance should be based on the *total* flow of the nearest existing tower plus the new tower. Should the cooling range and approach differ from those of the existing tower(s), the recirculation allowance should be checked using both sets of figures and the combination giving the maximum value for the recirculation allowance should be chosen.

Example

A cooling tower is required to handle a water flow of 3.33 m^3/s when cooling from 38 °C to 22 °C with an ambient wet bulb temperature of 15 °C.

The 60 % curve in figure 14 gives a recommended allowance of 0.69 °C which requires a further correction for cooling range and approach from figure 15. The intersection of 16 K cooling range and 7 K approach gives the value 1.64. Correcting for a reduction of 2 °C in wet bulb temperature, this becomes 1.64 × 0.69 × 1.08 = 1.22 °C, i.e. the design inlet air wet bulb temperature should be equal to 16.22 °C as compared with the ambient wet bulb temperature originally specified at 15 °C. This represents a 20 % increase in the size of the tower.

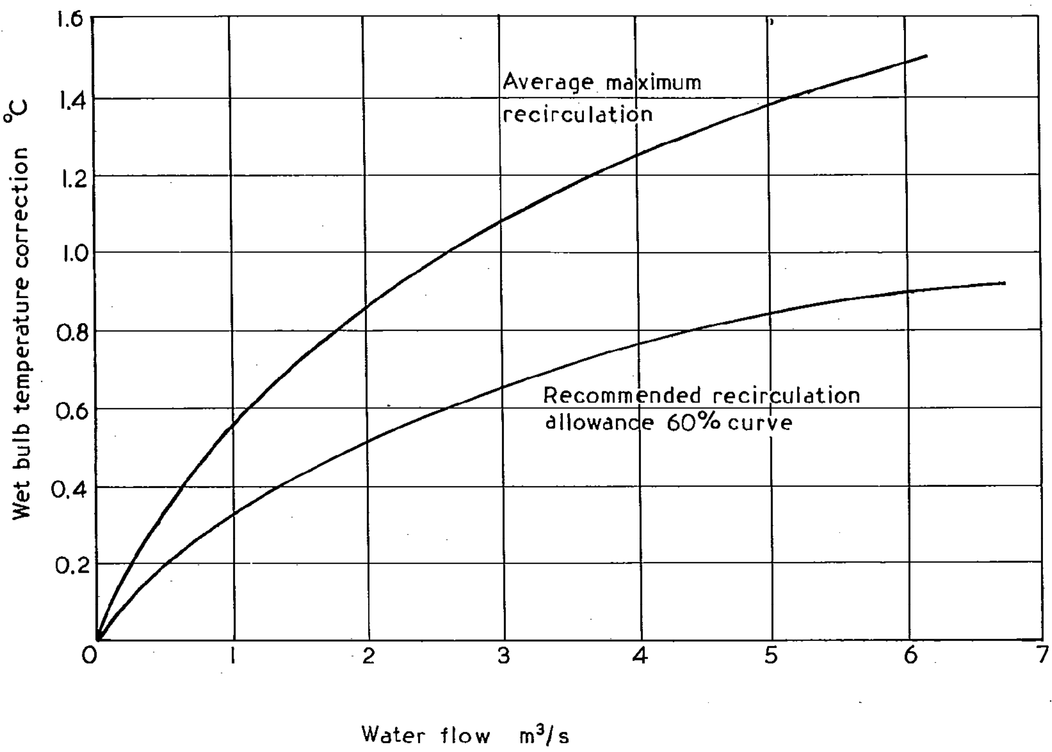


Figure 14. Basic recirculation allowance

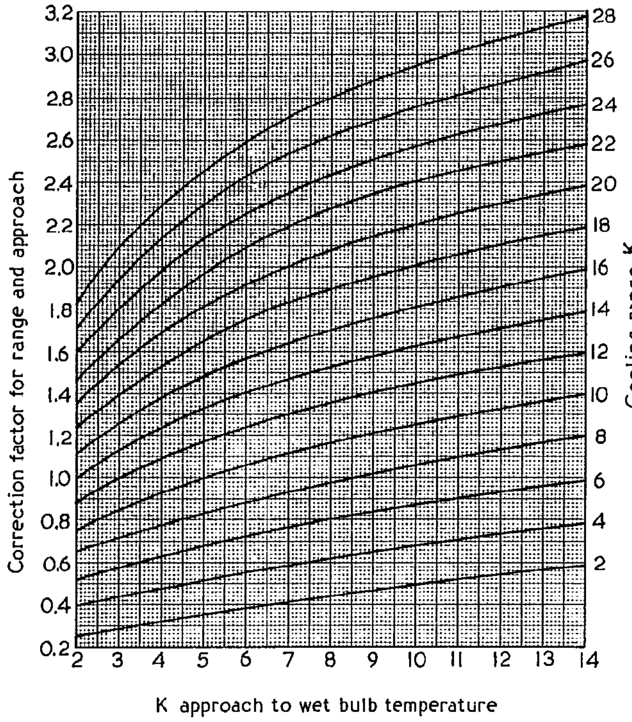


Figure 15. Correction for cooling range and approach at 17 °C wet bulb temperature

7.4 Effect of altitude

Cooling tower calculations involve the use of published tables of psychrometric data that are generally based on a barometric pressure of 1000 mbar*. Barometric pressure falls at a rate of approximately 1 mbar for each 10 m increase in altitude and, although this may be ignored for locations up to 300 m above sea level, appropriate corrections should be applied when designing for sites at higher altitudes.

Reduced pressure results in increased moisture content and hence enthalpy value of saturated air, and reflects in an alteration to the heat transfer diagram. This is illustrated in figure 16 which shows an increase in enthalpy value for all points in the diagram in the case of high altitude. However, the enthalpy corrections are progressive with increasing temperature and invariably the average lift on the water line will be greater than that for the air line, the result being an increase in mean driving force with altitude.

In the case of mechanical draught towers, the increase in mean driving force results in a reduction in tower size provided that the fans are rated to maintain the mass air flow at the reduced barometric pressure. In the case of natural draught towers, however, the draught available from a given height of chimney reduces at high altitude; this is a counteracting effect to the benefit arising from increased mean driving force, making it probable that there will be no significant variation in tower size.

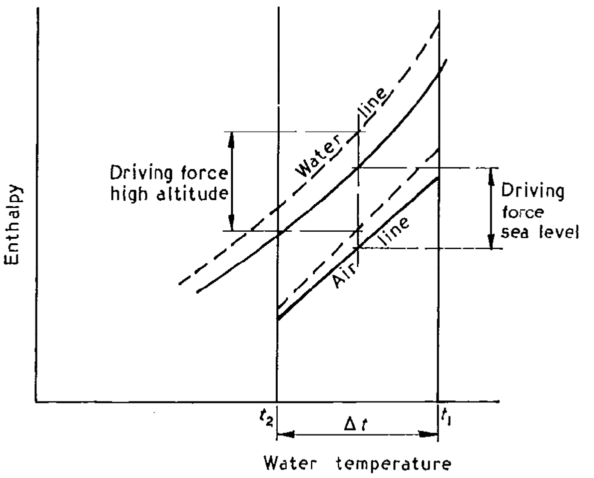


Figure 16. Effect of altitude on heat transfer diagram

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* 1 mbar = 100 N/m² = 100 Pa.

8 Hydraulic requirements of cooling towers

8.1 Water distribution

8.1.1 The intention of any distribution system is to achieve an even spread of water over the packing in a manner that produces an optimum heat transfer for the packing concerned.

In the case of a splash packing, the water is presented by a system of sprayers or splash plates and is subsequently redistributed in the upper part of the packing by successive impacts with the splash bars.

Distribution to a film packing may be achieved by an intricate system of troughs aimed to achieve full film flow and consequent freedom from drift. However, the efficiency of such systems is marred if the quality of the water circulated is such as to lead to fouling, and the intricate nature of such a distribution system may in itself form a considerable resistance to air flow. For practical reasons, the distribution will normally be in the form of a spray as in a splash packing, true film flow being achieved in the upper part of the packing.

8.1.2 The main feeder arrangement to a distribution system may in the case of natural draught towers be by pipework or open troughs:

(a) running radially from the centre to the periphery (see figure 17(a));

(b) at 90° to a diametral feed heater (see figure 17(b));

(c) running radially from the periphery to the centre (see figure 17(c)).

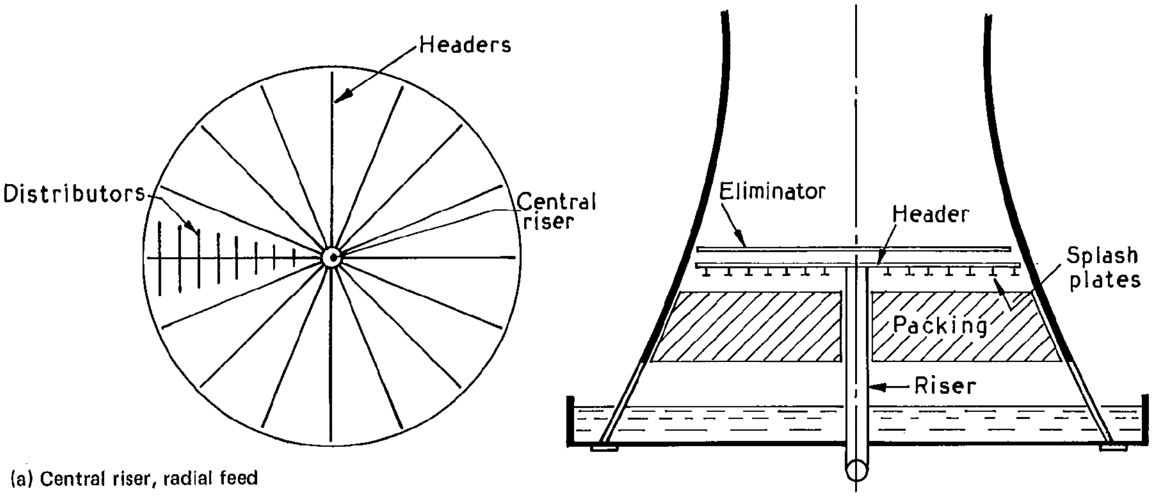
The method shown in figure 17(c) may take the form of a header pipe inside or outside the tower shell or an open channel formed in the concrete work integral with the shell of the tower.

Mechanical draught towers of the crossflow type have external header pipes above the distribution basin; those of the counterflow variety have internal distribution systems supplied from an external header or from individual rise pipes to each cell. (See figure 18(a) and (b).)

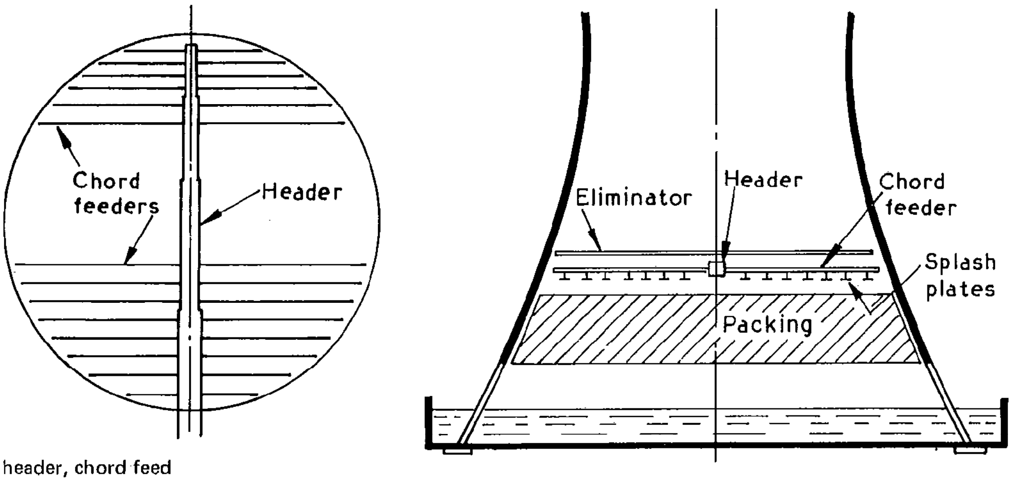
8.1.3 It is preferable that a tower be easily divisible into maintenance areas. In the case of multi-cell towers, each cell water system is usually separately controlled.

In the case of natural draught towers, maintenance may be based on one-half of a tower being taken out of commission by permanent dividing walls and valving of the distribution system. The cold water basin should be similarly divided. It should be noted that with half a tower out of commission, the cooling will be inefficient compared with the full tower due to air bypassing the wetted packing.

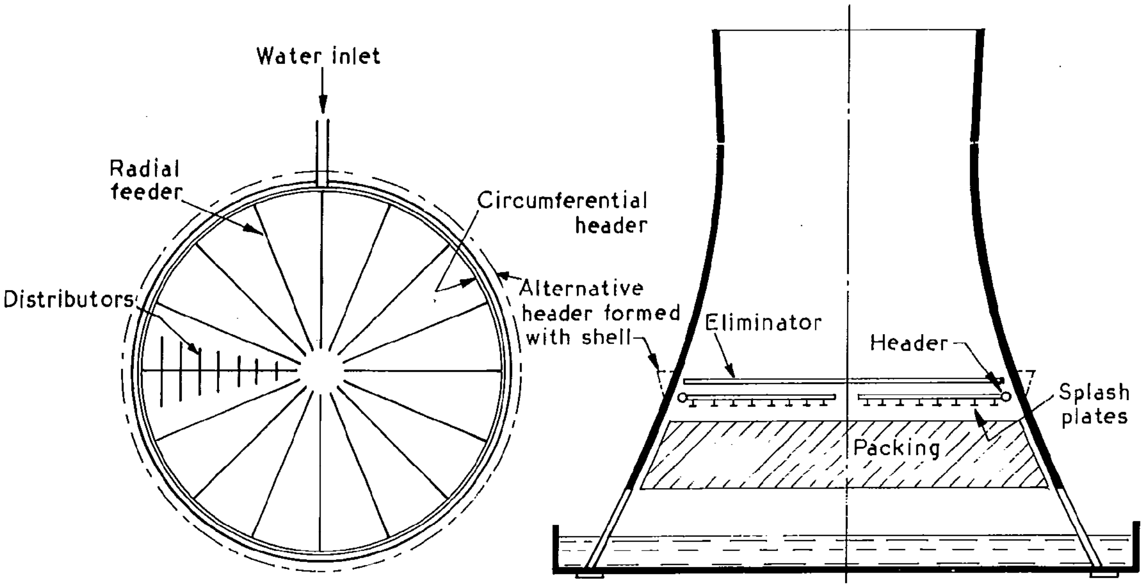
8.1.4 Where control of recooled water temperature is to be maintained within close limits, such control may be devised by bypass lines from the input to the tower to the recooled water exit channel or basin. Such a system reduces the flow into the tower by the amount bypassed and the mix achieved will be at a temperature higher than the recooled water temperature that would have resulted, unmixed, at the ambient temperatures concerned. Other methods, such as fan speed control or air dampers, may be used for less critical applications.



(a) Central riser, radial feed

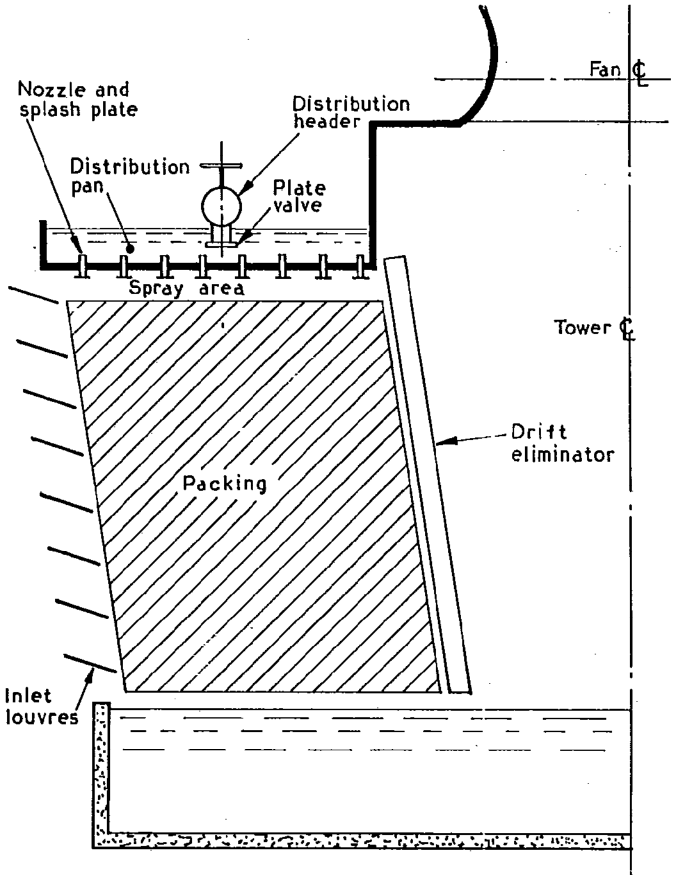


(b) Diametric header, chord feed

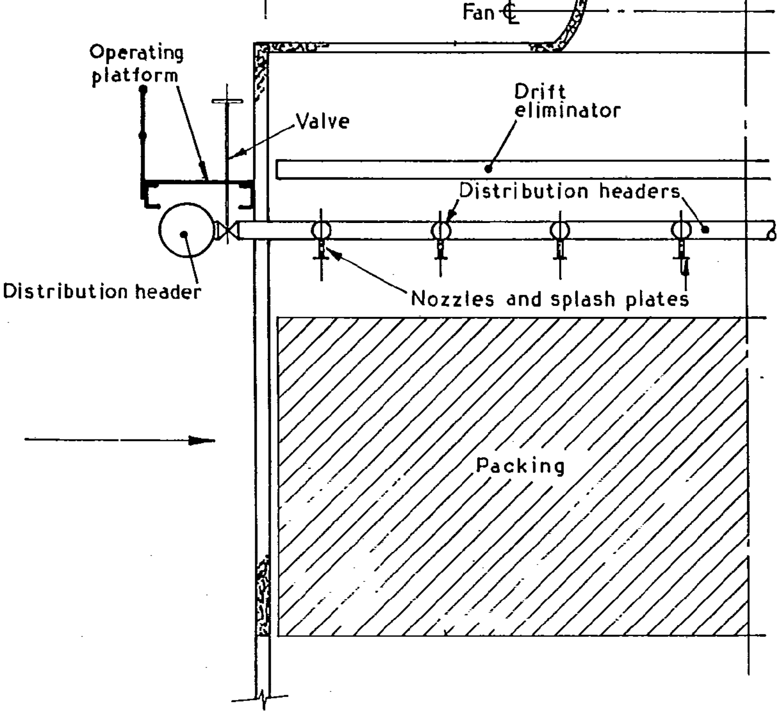


(c) Circumferential header, radial feed

Figure 17. Natural draught tower: water distribution



(a) Crossflow tower



(b) Counterflow tower

Figure 18. Mechanical draught tower: water distribution

8.2 Water losses

8.2.1 *General.* Water losses from a cooling system consist of evaporation losses from the cooling process, purge to prevent excessive build-up of impurities, and losses in the form of either blow-out from the tower air inlet or air-entrained drift through the tower air exit. Such blow-out and drift losses form an irreducible minimum purge since the water lost by them is of the same quality as that normally bled from the system in the process of purging.

8.2.2 *Evaporation losses.* To evaluate an evaporation loss at any ambient air condition, it is necessary to know the inlet and exit air state and the quantity, G, of air throughput. The difference in moisture content at inlet and exit gives a direct indication of the amount of water evaporated in passage through the tower.

However, when the need for towers is first considered accurate information on the exit air state is rarely available, and it is sufficiently accurate in assessing water needs to assume that the air leaving the tower is saturated at the mean water temperature, t_m. This enables the enthalpy of the exit air to be found, and consequently the enthalpy difference between exit and inlet air, from which L/G may be estimated as $h/\Delta t$.

The value of t_m is determined from:

$$t_m = \frac{t_1 + t_2}{2} \qquad (7)$$

The estimated loss from the system, (in m^3/s), is given by:

$$(w_2 - w_1)\ \frac{Q_l}{L/G}$$

For estimation of evaporative loss in UK conditions, an average figure is about 1 % of the circulation rate per 7 K temperature drop in the tower. The minimum rate of loss occurs in winter, the maximum in summer, varying between 1 % per 8 K and 1 % per 5 K, respectively. Probable losses are shown in figure 19.

8.2.3 *Drift and blow-out losses.* The degree to which drift and blow-out losses occur depends on the following factors:

(a) the air flow through the tower, a high air rate being likely to cause higher drift loss;

(b) the wind strength, speed and direction relative to the orientation of the tower, and the area of air inlet.

Measures taken to offset these losses are discussed in **5.4.2**, **5.4.3** and **7.2**. For the purpose of assessing water requirements, these losses will be adequately covered by an allowance of 0.1 % of the circulating water flow.

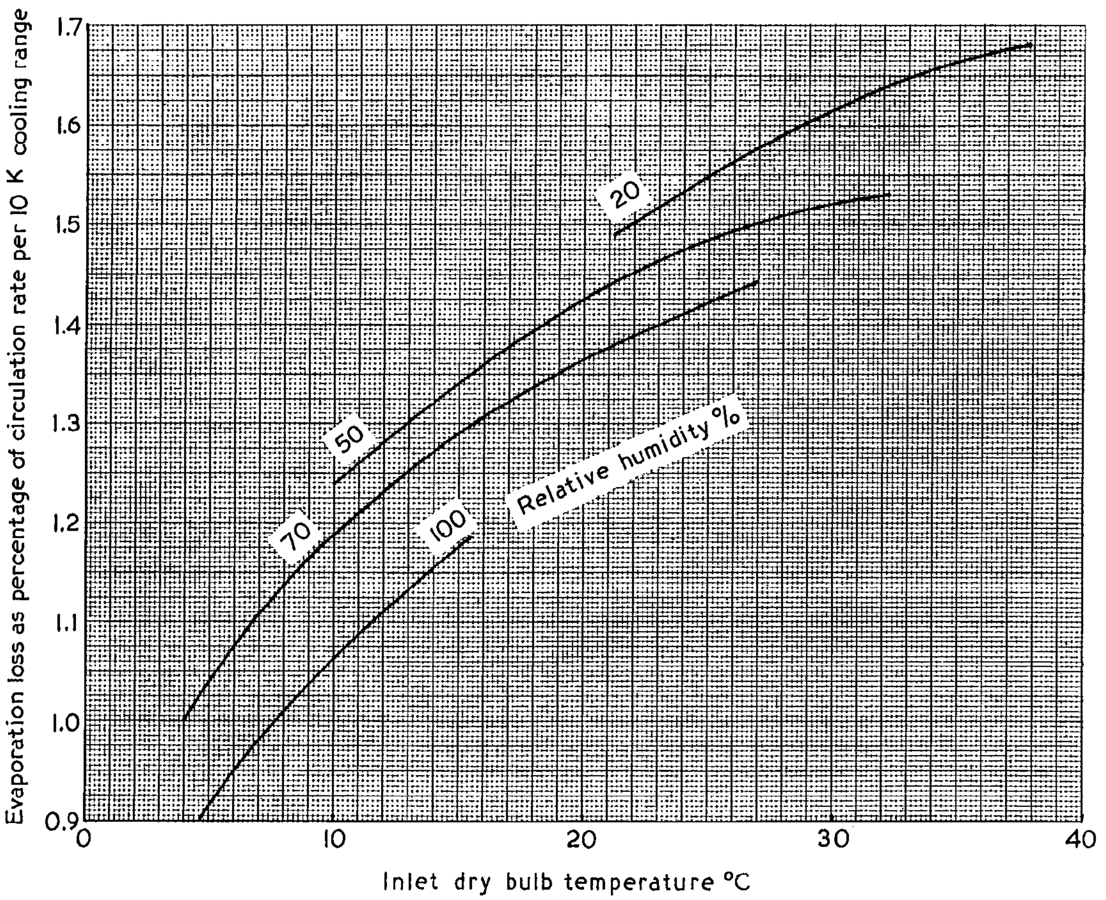


Figure 19. Variation in evaporation losses with ambient conditions

8.2.4 *Purge losses.* Purge is essential in an evaporating system to limit the resulting concentration of dissolved solids in the water which would otherwise eventually reach saturation and give rise to excessive scale and deposition. Such purging may be continuous or intermittent, continuous purging being preferable in establishing more stable conditions and being more economical in sizing discharge drainage facilities.

The conditions of chemical stability of the water in a cooling system are shown in figure 20. The make-up rate is the sum of the evaporation rate, V_e, and the purge rate, V_p.

If the original make-up concentration of impurities (in terms of a stable, easily measured characteristic such as chloride) is C_1 % and the stable state in the circulating system under a continuous purge is C_2 %, then

$$\frac{C_2}{C_1} = \frac{V_p + V_e}{V_p} = \frac{\text{total make-up}}{\text{purge}} \qquad (8)$$

The ratio C_2/C_1 is the concentration factor C. It is clear that the concentration factor varies with the other parameters so that

$$V_p = \frac{V_e}{(C - 1)} \qquad (9)$$

i.e. for a concentration factor of 4, the purge is equal to one third of the evaporation rate, etc.

Graphical presentation of this relationship (see figure 21) shows that at high concentrations the system tends to become unstable for a very little saving in water and, conversely, at low concentrations a large amount of make-up is required for very small differences in concentration. The cost and availability of water supply would normally mean that chemical control of deposition and corrosion is more economical than control by very low concentration factors.

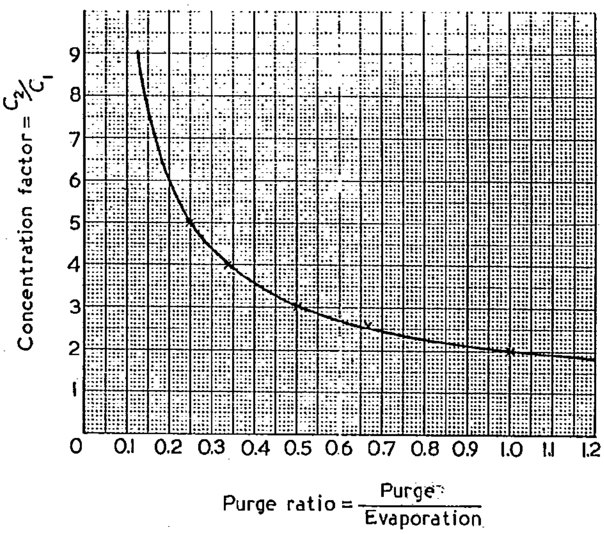


Figure 21. Relation between purge ratio and concentration factor

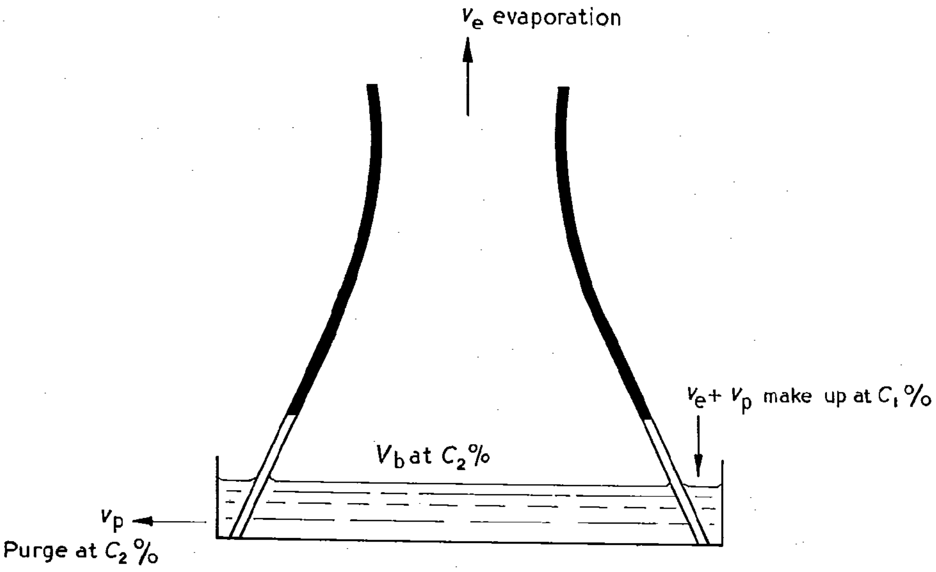


Figure 20. Purge, make-up and evaporation quantity balance

8.3 Cold water basin design

8.3.1 *Location, geometry and division.* Cooling tower basins are usually located immediately under the packing area of the tower, variation in capacity being usually achieved by depth variations in the interest of ground area occupied by the structure. They normally follow the plan shape of the tower structure, circular for natural draught towers and rectangular for mechanical draught units. The foundations of the tower are therefore found under or integral with the basin structure. In the case of natural draught towers, the basins are therefore normally considered part of the tower contract; but in the case of mechanical draught towers, which may be timber-framed, separate contractual arrangements are frequently considered. In such circumstances close attention should be paid to accuracy of holding-down bolts, foundation sockets, etc. to ensure that the superimposed tower structure is properly married into the basin framework beneath.

Cold water basin floors should be channelled or finished to fall, which enables silt deposits to be easily cleared or washed away, and overflow facilities should be provided since the rate of evaporation and make-up can rarely be exactly matched. It is usual for at least 225 mm of freeboard to be allowed for the outside walls above the overflow sill, and in operation a correct setting of the water level in the basins should be such that there is sufficient freeboard to the overflow sill to absorb the quantity of water normally in suspension in and under the packing. A useful allowance for this is 75 mm to 150 mm. The actual operational values can be easily determined by starting the system with the water level at the overflow sill and observing the drop of water level as the water is taken into circulation.

Purge drainage and facilities for completely draining down the basin are usually arranged to discharge into the same channel but, in circumstances of heavy silting, separate drain-down arrangements through silt beds may be necessary. Eventual discharge from the system may be combined for overflow, purge and drain-down facilities.

In the case of single towers, division of the basin area into suitable maintenance areas may be advisable particularly where aggressive waters or silts are likely. It is necessary also where the towers themselves are divided into maintenance areas, since from a safety point of view the basin under a tower should be drained when packing maintenance is undertaken.

Where a basin is subdivided, it should be connected to the main cold water flow channel through a penstock or other means of isolation of adequate dimensions and with suitable design adjustment for the hydraulic losses through the device.

8.3.2 *Capacity.* The required capacity of the cooling tower basin may be determined by considering the time during which the make-up water supply to the system could be cut off due to accident or maintenance. During such a period the water content of the system depletes through evaporation and other losses, and it is necessary to determine the rate of loss and the effects of this loss on the concentration of impurities in the system.

For a system at equilibrium having a concentration factor, C, in which the purge and make-up are discontinued for a time, T, the concentration factor at time T is given by:

$$C_T = C \frac{V_b + V_s}{V_b + V_s - v_e T} \tag{10}$$

Ultimately with all the water in the basin evaporated, i.e. $V_b = v_e T$ then:

$$C_T = C \frac{V_b + V_s}{V_s} \tag{11}$$

From equation (11) a basin characteristic can be drawn of the type shown in figure 22 indicating the increase in concentration factor generated by a given rate of evaporation in a pond of specified depth and surface area. It should be noted that lines of equal concentration meet at a point below the zero depth axis by an amount equal to the storage in the pipework, etc., expressed as an equivalent basin volume.

The error in neglecting drift and blow-out loss effect in this calculation is negligible.

The amount of allowable increase in concentration depends on the rate at which deposits are likely to occur in condenser tubes and elsewhere.

NOTE. Close control of alkalinity may be necessary. During a draw-down period it may therefore be advisable to modify chemical dosing, such as an acid feed to neutralize the increased alkalinity of the system.

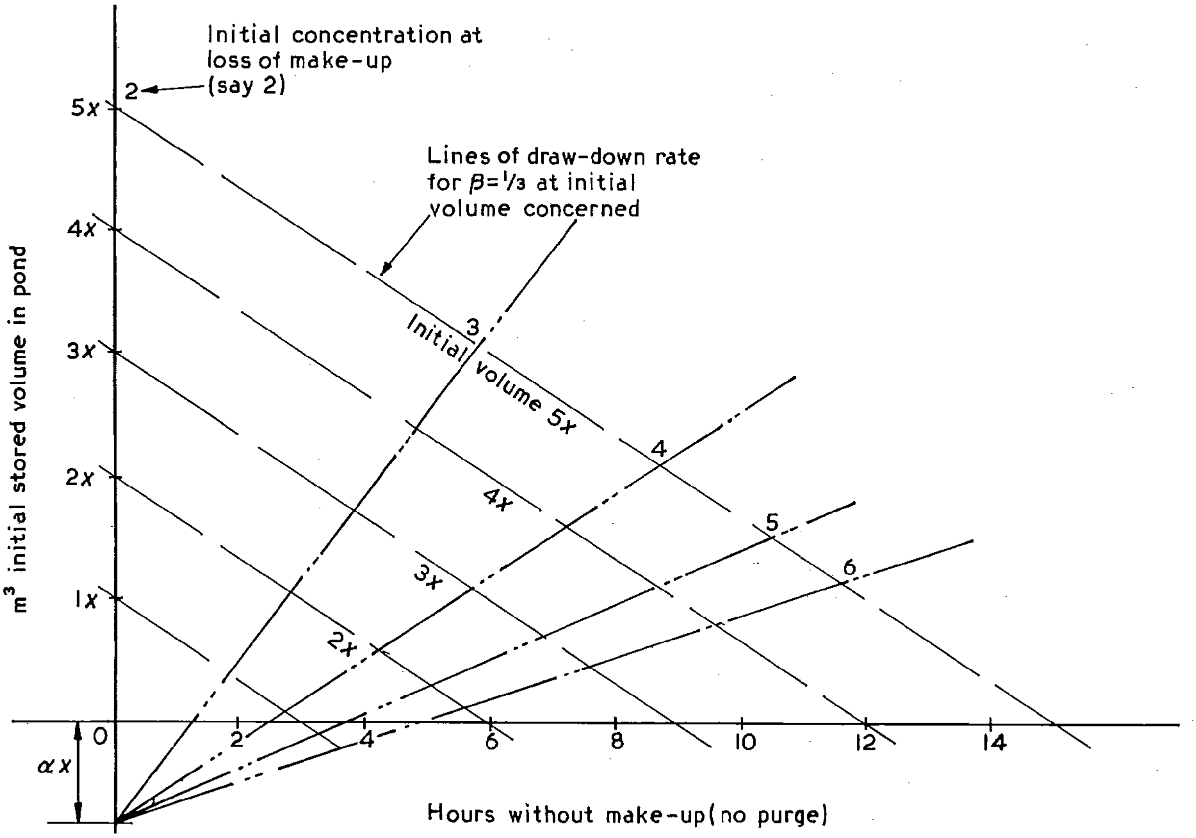
8.3.3 *Pump suction effects and entry channels.* It should be ensured that no pump suction condition limits the amount by which the cold water basin level may be drawn down. For instance, the position of the impeller should always be lower than the lowest draw-down level by an amount sufficient to ensure adequate cover of the impeller against cavitation and vortices. It may be necessary to have 'unused' capacity in the basin if a great deal of sludge deposit is anticipated.

The cross section of conduit and screen leading from the cold water basin to the pump house inlet should be adequate for the normal circulation rate at the reduced water level (and hence reduced hydraulic cross section) and adequate allowance should be made for hydraulic losses.

8.3.4 *Integral basins.* Integral basins should be adequately braced or reinforced to support the full mass of water stored. The suction outlet from the cold water basin should be fitted with a mesh screen to act as a filter. The free area of the screen should be not less than that of the outlet pipe, otherwise high pressure losses will result at the suction outlet causing a reduction in water level between thescreen and the mouth of the outlet pipe. This will ultimately result in air entrainment causing air locks elsewhere in the system.

The minimum depth of water should be sufficient to avoid air entrainment. Special anti-vortex devices, which may incorporate strainer screens, functioning with a reduced depth of water above the suction outlet, may be fitted.

For screens in perforated or woven metal, the average hole size should be 6 mm. If the holes are smaller, repeated blockage of the strainer will necessitate frequent cleaning and maintenance. If the hole sizes are larger, other components of the system will become blocked.



NOTE.

x = Pond surface area (m²)

αx = Volume in system other than in the ponds (i.e. pipes, etc.)

βx = Draw-down rate due to evaporation

Example. With initial volume of $4x$ and a draw-down rate of $^1/_3x$ per hour (i.e. $\beta = {}^1/_3$), the concentration factors shown are developed after the times shown without make-up.

Figure 22. Pond characteristic

In some instances, it may be necessary to fit a non-return valve to prevent drain-back of water from the system when this is above the level of the water in the basin.

In order to obtain maximum benefits from the water treatment involved and to assist in general cleanliness and satisfactory operating conditions, the following features should be incorporated in the cold water basin.

(a) A sludge barrier should be provided where the bottom of the water outlet connection is less than 50 mm from the floor of the basin. It should be not less than 100 mm high and 450 mm to 600 mm from the outlet connection so as to act as a baffle for mobile deposits. The drain connection should be positioned on the sludge side of the barrier, and there should be no other projection on the floor of the basin which would prevent the removal of sludge.

(b) An inspection panel or panels should be placed on the side of the tower to allow rapid access so that the maintenance washout can be carried out with the minimum waste of time and the maximum efficiency.

It is preferable to have a large bore drain fitted in the basin both to make it a simple procedure to empty the basin quickly and also to enable the sediment and debris to be carried away. The drain from the basin should be provided with an air break when discharging into a drainage system. In no circumstances should a direct connection be made, with or without a trap.

A bleed-off should be provided, preferably controlled by a lock-shield valve, to limit the build-up of solids in the system.

Where it is required to limit the bleed-off to the operating period of the plant, the bleed-point may be arranged on the inlet pipe to the cooling tower at a point higher than the level held by the water when the pump is inactive.

The make-up water should enter the storage basin beneath the cooling tower via a level-control valve, which should be firmly mounted to the edge of the basin or on to a support within the surrounding basin sides. The level-control valve should be isolated to a position in the basin which avoids disturbance of the float from the suction outlet and from air turbulence. It is sometimes desirable to have a quick-fill by-pass connection fitted complete with its own isolating hand valve. An overflow connection should be positioned between the water operating level and the level of the make-up valve.

There should be adequate vertical distance between the overflow and the water level maintained by the level-control valve to accommodate all water which may return to the tank when the pumps stop. This should include all water in pipework above the tank and contained within the operating distribution system and packing.

8.4 Water quality

8.4.1 *General.* A full mineral and biological examination of the make-up supply is essential and if wide seasonal variations, e.g. in agricultural run-off, are anticipated then an appropriate series of samples should be examined.

The nature of the circulating water under the proposed operating conditions may then be estimated and any aspects potentially detrimental to the performance or structure of the tower given due consideration.

8.4.2 *pH, alkalinity and hardness.* Together, pH, alkalinity and hardness will usually exert the controlling influences on whether problems of corrosion or scale deposition are likely. A useful guide is the saturation index (Langelier or Ryznar) which may be calculated for the make-up water and extrapolated to the temperature and concentration factors expected in the working tower. These considerations will indicate any limits on concentration factor and if pH control will be needed, as well as being a guide to selection of chemical additive requirements for scale or corrosion control.

8.4.3 *Temperature.* In addition to its effect on corrosion and deposition, the operating temperature may restrict the use of certain plastics and above 20 °C progressively reduces the permissible stressing of timber structures. (See also BS 4485 : Part 4.)

8.4.4 *Biological activity.* Cooling towers offer favourable environments for a wide range of microorganisms which, if uncontrolled, can give rise to health hazards and fouling of the tower packing and of associated heat exchange equipment with consequent loss of performance. Structural damage may result from overloading of tower packing with biomass. A health hazard may also arise from the development and distribution of pathogenic organisms by cooling water systems (see **8.4.11**).

8.4.5 *Entrainment of gases.* Circulating cooling water absorbs oxygen and other gases from the atmosphere. This absorption may affect the pH value of the water and the oxygen content, increasing the corrosion potential.

8.4.6 *Entrainment of solids.* A cooling tower will efficiently scrub particulate solids from the air flow. These will add to any suspended solids already present through deposition of hardness salts or corrosion processes. Fouling of heat exchangers as well as erosive damage to pumps and interference with corrosion inhibitor performance can result. In the larger systems the solid matter may settle and be removed by purge from the tower basin but increasingly the use of sidestream or even full flow filtration is found necessary.

8.4.7 *Oils, grease and fats.* The presence of immiscible organic matter such as oils, grease and fats in excess of 10 g/L may directly reduce evaporation and hence performance. It may also lead to fouling of packing and heat exchange surfaces, either directly or by its nutrient value to the biological population.

8.4.8 *Sulphate content.* If a high sulphate content is indicated, a sulphate-resisting concrete may have to be used in the water contact areas of the tower.

8.4.9 *Dissolved solids.* The effect of dissolved solids on the vapour pressure of water is dependent on their concentration and nature (see **8.3.2**, figure 22 and also BS 4485 : Part 2). It is suggested that if the projected total dissolved solids in the tower will exceed 5000 mg/L then the effect on the vapour pressure may be sufficient to significantly reduce evaporation and its influence on tower performance should be checked.

8.4.10 *Chlorination.* Chlorine is widely used to control the growth of algae in cooling systems. Over-chlorination should be avoided since leaching of the timber may result, with damage to the timber strength. It is customary to ensure that the dose of chlorine and contact time are such that the free chlorine resulting at the tower inlet is sufficient to inhibit growth of algae but insufficient to cause timber damage.

8.4.11 *Other additives.* The control of corrosion, scale formation, deposition of suspended solids and bio-fouling may require the addition of chemicals to the system. These can be selected from a wide range of materials including the following:

(a) polymers of high relative molecular mass used as clarifiers to aid suspended solids removal by flocculation;

(b) polymers of low relative molecular mass, organophosphorus compounds or polyphosphates used as threshold anti-precipitants for scale prevention;

(c) polymers, natural and synthetic sulphonates used to disperse suspended solids;

(d) inorganic and organic phosphorus compounds, molybdates, silicates, zinc salts, chromates, nitrites, etc. used in corrosion inhibitor formulations;

(e) chlorine, bromine, organohalogen compounds, quaternary ammonium salts, amines, imidazolines, etc. used for the control of biological growth.

Whilst such additives will be prescribed for the overall benefit of the system, side effects such as the detrimental effect of chlorination on corrosion and on wood, the contribution of phosphorus compounds to bio-fouling or general restrictions on disposal of purge (see **5.4.6**) should be considered.

8.4.12 *Pre-treatment of make-up to cooling towers.* Pre-treatment for larger systems is usually limited to suspended solids removal by sedimentation and possibly flocculation. In the case of smaller systems, however, instances arise where base exchange softening of the make-up is economically favourable by virtue of enabling operation at a higher concentration factor with consequent savings in water charges and chemical treatment costs.

8.4.13 *Control of water conditions.* Regular testing is essential to keeping proper control of the water conditions in any cooling system. Modern automatic dosing, pH and purge control systems are not totally infallible. pH value, concentration factor and scale/corrosion inhibitor level should be checked weekly or even daily if operating conditions justify it. General biological activity may be easily monitored on a weekly basis with the aid of simple dip slides.

8.5 Design for winter operation

8.5.1 *General.* The necessity for anti-icing devices to be incorporated in the tower design should be considered at the pre-tender stage, and the means to be employed preferably discussed between the purchaser and the prospective suppliers.

The methods available for providing anti-icing facilities, and the need for such facilities, depend largely on the following factors.

(a) The severity of weather conditions at the cooling tower site.

(b) The thermal design conditions. For example, a close approach tower will mean a relatively higher air flow and a greater tendency to icing conditions in the air inlet.

(c) The type of cooling tower used. A counterflow tower will normally have the packing protected by the tower shell, with a lesser tendency to icing on the packing than a mixed flow tower when part of the packing may be exposed. On the face of a crossflow tower the low temperature areas of the water will be at the lower face area of the packing, and the possibility of freezing in any stagnant areas of the top water distribution trays should be borne in mind.

When the tower is designed to be drained down in winter the system and tower should be designed so that no water pockets remain. In these circumstances anti-icing devices are unnecessary.

For removal of ice already formed:

(a) in the case of mechanical draught towers, fans should be switched off for adequate defrosting periods;

(b) in the case of forced draught towers, a sparge pipe may be fitted in the fan casing upstream of the fan to clear ice build-up on the fan blades and casing.

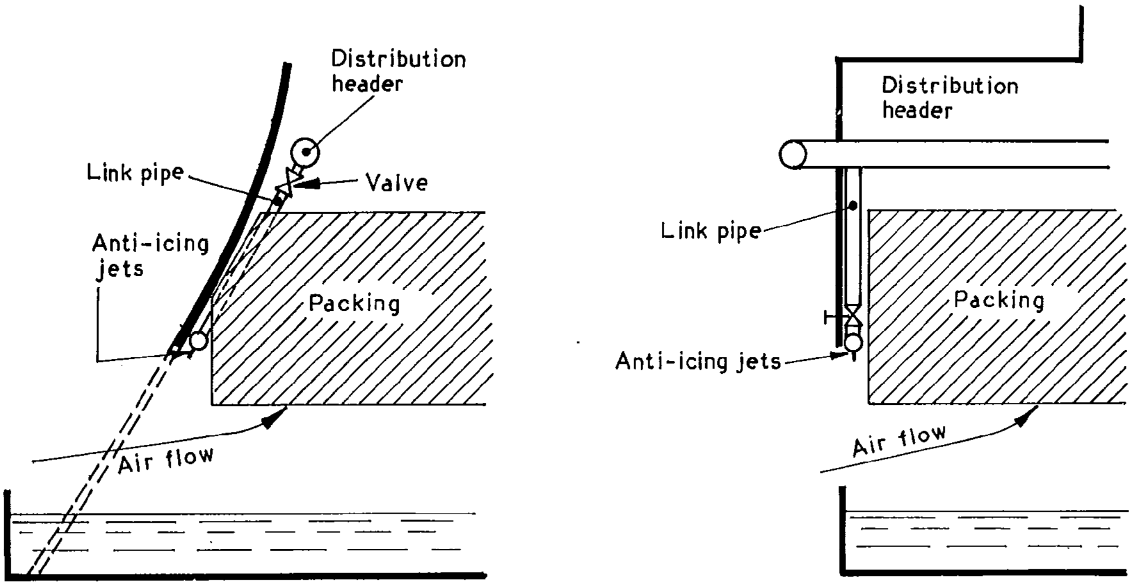
8.5.2 *Avoidance of icing by air control.* As the air temperature drops, so does the recooled water temperature. It is often the case that below a certain temperature no further economic benefit occurs. In such circumstances, in a mechanical draught tower, some fans may be stopped allowing the water temperature to rise sufficiently to keep the tower free of ice. A further refinement would be reducing fan speed in suitable circumstances, particularly where the saving in power has significant economic effect. In extreme conditions (about −20 °C and most unlikely to be needed in the UK) it may be desirable to provide for reversed air flow as an effective means of clearing air inlets partially blocked by ice. In crossflow towers, anti-icing may be brought about by reducing the fan speed so that a curtain of warm water is formed in front of the packing, falling from louvre to louvre down the face of the tower.

8.5.3 *Avoidance of icing by control of water load.* The most commonly used device is a bypass of the tower producing a warm water curtain outside the exposed packing face. For efficient operation it is important that such a curtain should consist of jets of water rather than small particles which might themselves become frozen. Generally the bypass should operate under a pressure head of not less than 2.0 m (having allowed for friction losses), the nozzles should be of a diameter not less than 12 mm, and the total bypass flow should be about 25 % of the circulating water flow. Figure 23 shows typical bypass pipe locations.

It is helpful, when combating a tendency to form ice, to reduce the number of cells working, which will increase the water loading and the temperatures of the water on the remaining cells.

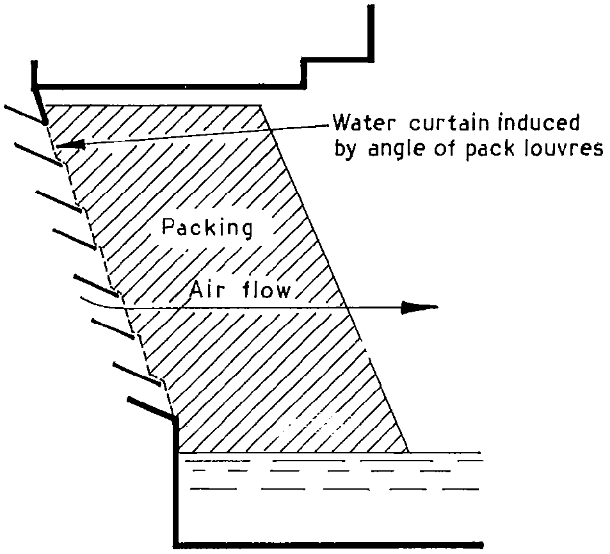
It should be noted that complete isolation has to be attained as the persistence of minor water leaks on to the packing can lead to a major ice build-up. Precautions should also be taken to avoid any static water in sections of pipework.

8.5.4 *Effects of anti-icing flow on tower capacity.* When the anti-icing pipe is in use, the effect on tower capacity is the equivalent of a bypass equal to the anti-icing flow as the cooling effect on the bypass flow will not be substantial. At the time of the year when such a system is in use, unless the towers serve generating plant, the maximum capacity of the tower is not usually required and no disadvantage is to be expected from the use of an anti-icing facility.



(a) Natural draught mixed flow

(b) Mechanical draught mixed flow



(c) Mechanical draught crossflow showing induced water curtain

Figure 23. Anti-icing arrangements

8.6 Use of saline water

8.6.1 *General.* For the proper use of water resources, the consumption of high quality fresh water in an industrial cooling context should be discouraged, particularly if the quantities concerned are large as is usually the case in power plants. Any installation should use the lowest quality water suitable for the process concerned, and this coupled with the quantities needed may lead to the increasing use of sea water in cooling water circuits.

8.6.2 *Problems particular to saline water and recommended protective measures*

8.6.2.1 Owing to the higher quantities of dissolved impurities in sea water than normally found in fresh water, the concentration ratio which it is possible to use in a saline system is normally less than that which could be used in a fresh water system. (See also **8.4**.)

8.6.2.2 The high sulphate content of sea water makes it essential to use sulphate-resisting cements in all the water contact areas of the tower and cold water basin, with consequent added capital cost. (See also BS 4485 : Part 4.)

8.6.2.3 Sea water may contain marine wood-boring organisms which are more aggressive to timber than those found in fresh water, requiring a greater preservative content in the timber. (See BS 4485 : Part 4.) Precautions against algal fouling are similar to those taken in a fresh water system.

8.6.2.4 Corrosion effects may be pronounced unless protected or resistant metals are used. It should be noted that the saline water in circulation is elevated in temperature, concentrated and fully aerated. Protective coatings are also recommended for metals not in direct contact with the water, such as handrails and the external surfaces of valve bodies and general ironmongery. (See also BS 5493 and BS 4485 : Part 4.)

8.6.2.5 Drift loss and blow-out may affect vegetation in the immediate area and cause salt encrustation on adjacent buildings. Siting is therefore additionally important when considering a salt water system, but the presence of the cooling tower may not materially affect buildings in a plant complex that is in any case exposed to severe coastal conditions. Blow-out from the sides of a large natural draught tower may affect buildings up to 100 m distant. If mechanical draught towers are to be used, drift losses may have significant local effect and should be countered by careful attention to the eliminator design and its associated air flow. (See also **7.2**.)

8.6.2.6 Fouling of the make-up water system by Crustacea or sediment may become pronounced. Crustaceous growth at the intake is encouraged by the more abundant food supply due to the increased flow rate, and an unstable sea bed at the intake may give rise to high levels of suspended solids which could be deposited in those parts of the system where the speed of flow is low.

8.7 Effect of salinity on heat transfer

8.7.1 *General.* Where the total impurities in the circulating water amount to less than 5000 mg/L, no correction in the heat transfer calculation need be made (see BS 4485 : Part 2). Sea water make-up, however, contains impurities in excess of this amount and varies in salinity between 30 % and 100 %. In this context 100 % salinity is 31 g sodium chloride (NaCl) per litre, i.e. 31 000 mg/L. Sea water in circulation will be more concentrated than the sea water make-up and may therefore contain up to, for example, 60 000 mg/L of salts. The presence of these salts in solution alters the vapour pressure, the density and the specific heat capacity of the solution when compared with pure water or, in practice, fresh water of relatively low salt content.

8.7.2 *Changes of density and specific heat capacity.* In practice the change in density (which is increased) is offset by the change in specific heat capacity (which is lowered), so that on balance there is no change from this effect in the equation (1), i.e.:

$$G\Delta h = cL\Delta t$$

This volume of water in circulation has therefore the same heat-absorbing capacity at source, and since Δt will not have altered there is no change in the water/air ratio and consequently no change in the air line slope on the heat transfer diagram.

8.7.3 *Changes in vapour pressure.* When a solute is added to a solvent to form a weak solution, the vapour pressure of the solution, p_3, is lowered relative to that of the pure solvent, p_2, so that:

$$\frac{p_3}{p_2} = \frac{m_2 M_1}{m_1 M_2 + m_2 M_1} = n \tag{12}$$

The vapour pressure of the solution is therefore:

$$p_3 = n\,p_2 \tag{13}$$

and is the reduced value (relative to fresh water) to be used in the enthalpy equation governing the boundary conditions of saturated vapour through which heat transfer is effected:

$$h = 1.00568 t_b + 0.622 \frac{p_3}{(p - p_3)} (1.846 t_{DB} + 2501) \tag{14}$$

Figure 24 shows the resulting reduction in mean driving force available if the same water temperatures were expected. For proper heat balance the heat transfer operation should therefore be carried out at higher operating temperatures, and consequently a greater approach for the same range when compared with fresh water.

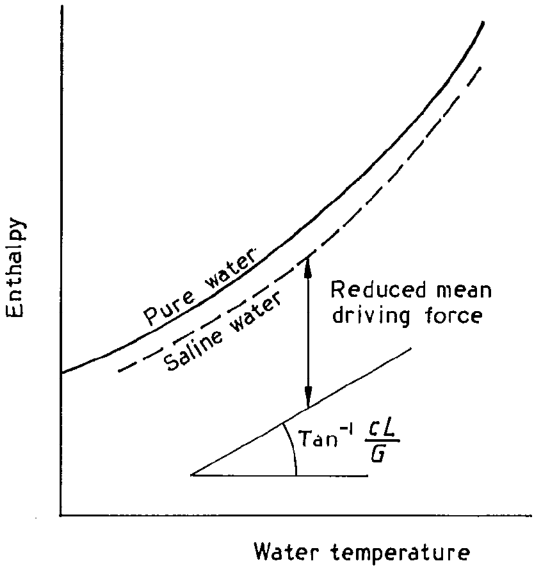


Figure 24. Effect of salinity on heat transfer diagram

Typically for a 60 000 mg/L sodium chloride salt solution, the mole fraction

$$n = \frac{94 \times 58.5}{94 \times 58.5 + 6.0 \times 18} = 0.981$$

$$p_3 = 0.981 p_2$$

For a water inlet temperature of 30 °C and outlet temperature of 18 °C the water side enthalpies are reduced from 99.49 kJ/kg to 98.13 kJ/kg and from 50.81 kJ/kg to 50.18 kJ/kg, respectively.

9 Mechanical equipment

9.1 Fans

9.1.1 *General.* The low static pressure characteristic of a cooling tower favours the use of axial flow fans. Where it is desirable to obtain extreme quietness of operation, centrifugal fans may become necessary. It should be noted, however, that due to the increase in the size and mass for equivalent duties, their use is limited primarily to small forced draught cooling towers in a quiet environment.

The use of any fan, whether for forced or induced draught application, that is required to operate at two or more speeds (e.g. with a two-speed or a variable speed driver) should be checked with the fan manufacturer to ensure that it is not operated close to a critical speed.

All blades of a fan should be set to the same pitch to avoid unbalanced aerodynamic forces.

Cooling tower fans should be statically balanced and have blades numbered or otherwise marked for correct assembly.

9.1.2 *Direct drive fans.* In sizes up to about 2 m diameter, fans are usually either directly coupled to a medium or slow speed electric motor or driven by means of V-belts from an externally mounted motor. These smaller fans are usually set in the factory to the correct pitch, and adjustment of the fan pitch on site is not normally undertaken. Direct drive fan units are generally manufactured with a rigid steel casing and integral support structure for the fan and driver.

9.1.3 *Indirect drive fans.* On fans greater than 2 m diameter, the drive usually employs a centrally mounted, right-angled reduction gearbox with a drive shaft and externally mounted electric motor (see figure 25). Fans of 2 m diameter and larger are usually of the manually adjustable pitch pattern.

9.1.4 *Induced draught fans.* Induced draught fans on a cooling tower are required to operate in conditions of warmth and high humidity (approaching 100 %) and are liable to be wetted by drift. They should thus be of a material, or have a protective finish, that will resist any corrosive effects arising from circulating water contacting the blade and hub surfaces. Protective finishes should be capable of withstanding the erosive effect of impacting water droplets.

9.1.5 *Forced draught fans.* Forced draught fans handle ambient air and may be affected by dust or debris. The choice of protective finish should therefore allow for any such risk of damage, but does not normally need to allow for corrosive effects that may arise from continuous direct contact with circulating water.

Forced draught fans should be mounted so that any water entering the fan casing drains back into the cold water basin.

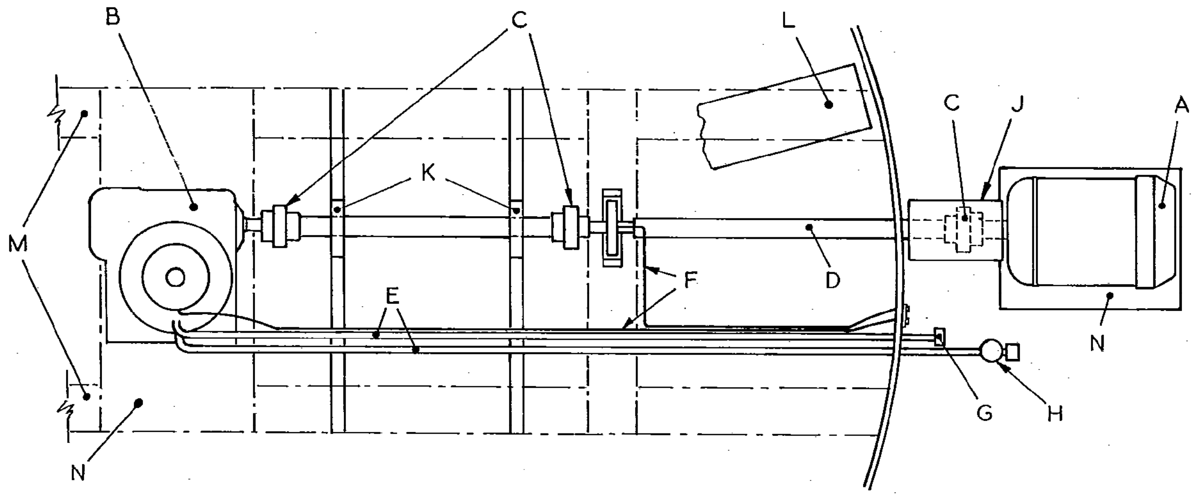
9.2 Gearboxes

9.2.1 Gearboxes should be rated for 1.75 times the fan power at design conditions or the installed motor power, whichever is the greater, and on the basis of the 12 h day working rating of the gearbox.

The output shaft bearings should have an L10 life of 100 000 h as defined in BS 5512 : Part 1. As this produces reversing radial loads on the bearings, special consideration should be given to the relationship between bearing clearances, fan bearing span and diameter.

The elevated temperature of the surrounding air during normal operation should be taken into account and, when located in a very cold climate, consideration should be given to the problems of a cold start.

9.2.2 Double oil seals are a preferred feature to minimize the risk of oil leakage or ingress of moisture. Gearboxes mounted in the induced draught position, i.e. in areas of near 100 % humidity, should be provided with a remote vent carried to the outside of the fan stack to minimize the risk of condensation from breathing moisture-laden air. Lubrication, grease pipes and oil-level indicators should be taken to the outside of the fan to facilitate servicing.



		Reference subclause			Reference subclause
A	Fan driver	9.4	G	Anti-vibration cut-out switch	9.6
B	Right-angled reduction gearbox	9.2	H	Oil level dipstick, also fill and drain pipes	9.2.2
C	Shaft couplings	9.3	J	Coupling retaining straps	10.2
D	Single or two-part shaft	9.3	K	Shaft guards	10.2
E	Gearbox oil fill-level and breather pipes	9.2.2	L	Fan blade	
F	Grease lines to all bearings positioned within fan casing	9.2.2, 9.3	M	Gearbox supports	9.5
			N	Gearbox and motor mounts	9.5

Figure 25. Typical arrangement for induced draught fan drive assembly

9.3 Drive shafts and couplings

Drive shafts are commonly of 'floating' pattern supported and located by the couplings or universal joints at the ends. Such drive shaft arrangements can be designed to accommodate the unavoidable misalignments and end float requirements. The drive shafts are generally tubular to minimize the mass and can be up to 4.5 m in length. Single shafts longer than 3 m should be dynamically balanced.

When 'non-floating' pattern drive shafts are employed, the supporting bearings should be of the self-aligning sealed type designed to allow grease replenishment whilst running. With this arrangement it is more difficult to accommodate misalignment, and the coupled units (e.g. an electric motor and a gearbox) should be mounted in a rigid manner relative to each other.

Good balance of drive shafts and couplings is essential. With good detail design to ensure symmetry about the rotational axis and good quality control in manufacture, the need for dynamic balancing can generally be avoided especially if the couplings are statically balanced. Hollow rotating components should be sealed to prevent water ingress or be effectively drained to prevent accumulated water impairing the balance.

For guidance in the selection of flexible couplings, reference should be made to BS 3170. If guarding to ensure the safety of personnel needs to be considered, reference should be made to BS 5304.

All components should be effectively protected against corrosion, having due regard to the situation in which they will be operating. For rotating components it is essential, in the interests of maintaining the inherent balance, that the control of thickness of protective coatings be of a very high order. Reference should be made to BS 5493 for guidance in the protection of steel components from corrosion.

9.4 Fan drivers

9.4.1 *Electric motors*

9.4.1.1 Electric motors should comply with BS 4999 and BS 5000.

9.4.1.2 Electric motors are required to operate under full exposure to all weather conditions and should therefore be fully weatherproofed to withstand the exposure conditions. Before operation, when the motor is in its final position, the drain plugs (if any) in the lowest positions should be removed.

9.4.1.3 Electric motors should be selected, having regard to the required frequency of starting and to the starting system used, to give an adequate accelerating torque for the fan and its drive over the expected range of climatic conditions. Particular attention should be given to any requirement for a cold weather start on a dry tower.

9.4.1.4 Motor bearings should be designed to carry any extra loads imposed by the mass of an extended drive shaft or, in the case of direct mounted fans, the mass thrust and unbalanced forces of the fan itself.

9.4.1.5 When the motor is required to stand for some hours in conditions that may give rise to excessive condensation, it may be desirable to incorporate heaters within the motor frame to reduce this risk. If heaters are installed, they should be interlocked with the starter to ensure that they are inoperative whilst the motor is running.

9.4.1.6 If required for use in the tropics, a shield should be installed over the motor to avoid heat gain from solar radiation.

9.4.2 *Other drivers.* When it is intended to use other forms of driver (e.g. steam turbines, internal combustion engines or hydraulic motors), due consideration should be given to the mass and possible vibration effects.

9.4.3 *Isolators.* All forms of driver, whether electric or otherwise, should be provided with local isolation for use when servicing the equipment.

9.5 Supports for mechanical equipment

Supports for mechanical equipment may be constructed in reinforced concrete, steel or a composite construction using timber interconnecting members and steel base plates. They serve to minimize possible movement between the associated elements of the fan drive assembly, e.g. motor, drive shaft and gearbox. The design should take into account possible corrosive conditions, the vibratory loads from the fan unit and the possibility of excess forces arising from possible damage to any part of the complete fan and drive assembly. (See also BS 4485 : Part 4.)

9.6 Vibration cut-out switches

Vibration cut-out switches should be capable of disconnecting the energy supply to the driver in the event of any abnormal vibration of mechanical equipment. This may occur in case of mechanical failure or severe out-of-balance condition on rotating parts due to:

(a) accumulation of water or debris in hollow fan blades or shafts;

(b) icing-up of fan equipment;

(c) physical damage;

(d) incorrect assembly.

Switches should be of the manual reset pattern to be reset before the driver can be started after clearing the fault, and should incorporate a means for adjusting the response level to allow for the normal slight vibration that usually occurs during the starting and stopping of the fan.

9.7 Keys and keyways

Keys and keyways should comply with BS 4235 : Part 1.

10 Safety precautions

10.1 General

The risks in mechanical draught towers are predominantly those associated with rotating machinery and its power supply. Natural draught towers and some very large mechanical draught towers may give rise to dangers of large water basins of considerable depth, of access and of the possibility of trapping personnel in the extremely humid conditions inside the towers.

Large mechanical draught towers may in particular create environmental hazards outside the tower due to fogging or the freezing of drift on adjacent roads. Blow-out from either mechanical or natural draught towers may cause a similar icing problem.

In many instances proper operational procedures may in themselves prove adequate safety precautions. Attention should nevertheless be paid to the aspects detailed in **10.2** to **10.5** at the design stage.

10.2 Mechanical plant

Rotating parts in accessible positions should be adequately guarded (see BS 5304).

Shafts should be prevented from major displacement by suitable retaining straps situated just clear of the shafts (see figure 25, item K).

Fan stacks intended to serve as barriers to access should be of adequate height and internal depth. The following dimensions have been found acceptable: height, not less than 1.5 m above local deck level; internal depth, not less than 0.8 m to any internal rotating parts.

10.3 Electrical plant

Emergency locked control switches should be installed adjacent to all motors.

All electrical plant and installations should comply with the relevant electrical safety regulations and be suitable for the operating conditions.

10.4 Access

All doors providing access into a cooling tower should be so designed as to be easily opened from the inside of the tower and should open outwards. Bolts, locks, etc. on such access doors should be such that they cannot accidentally become fastened.

Means of access for all towers should be suitably designed to comply with all applicable regulations and should be adequately lit and guarded.

Water exit points from ponds and waterways should be adequately guarded.

Where fitted in water basins, emergency escape ladders should extend to the floor.

10.5 Fire precautions

Where combustible areas are not maintained in a wet condition, it may be necessary to provide a sprinkler or other system.

Where a tower is large enough to merit such consideration, more than one access point to high level should be provided.

11 Maintenance

Design of the cooling tower should incorporate easy, adequate and safe access to all components requiring periodic maintenance.

Any special tools or accessories necessary for maintaining the cooling tower should be supplied by the vendor.

The necessary copies of operating and comprehensive maintenance instructions should be provided by the manufacturer/supplier.

Appendices

Appendix A. Enquiry and suggested tender information for cooling towers

A.1 Information to be provided by the purchaser

A.1.1 General

The information in **A.1.2** to **A.1.12** can be given by the client for tendering purposes or in the form of a questionnaire supplied by the manufacturer to the purchaser.

A.1.2 Location of site . . . .

(a) National grid ref. or equivalent . . . .

(b) Height above ground level. . . . . m

(c) Height above sea level . . . . .m

(d) Maximum expected wind speed . . . . m/s

A.1.3 Site details*

(a) Available area: length . . m; width . . . . .m

(b) Height limit: min . . . .m; max. . . . . m

(c) Any other restrictions . . . .

(d) Sketch of tower location giving direction of prevailing wind

A.1.4 Type of tower required†

. . . .

A.1.5 Restrictions on unit size*

(a) No. of towers . . . . each of . . . . cell(s) . . .

(b) Max. lifting mass‡ . . . . kg

(c) Max. operating mass . . . . kg

(d) Max. permissible size of largest section: length . . . m
width . . . m
height. . . m

(e) Required with/without basins (delete as necessary)

A.1.6 Duty of each tower . . . . . . L/s
of water from . . . . °C to . . . . . . °C

A.1.7 Ambient air conditions

(a) Dry bulb temperature max.. . . . . °C min. . . °C

(b) Wet bulb temperature . . . . °C

(c) Relative humidity . . . % at dry bulb temperature

A.1.8 Electricity supply . . . . . V . . . . . phase
. . . . . Hz . . . . . wire

A.1.9 Noise level

A design requirement of noise rating . . . . . .
is being sought at the points indicated on the sketch required by **A.1.3**(d).

A.1.10 Extras required

A.1.11 Details of water

(a) Type . . . .

(b) Analysis if known. . . . .

(c) Water supplier. . . . .

(d) Details of intended water treatment if known. . .
. . . .

(e) Recommended purge rate. . . . . L/s

(f) Mains pressure available for make-up . . . .
. . . . kPa

(g) Head pressure available at tower inlet . . . . kPa

(h) Expected contamination . . . .

A.1.12 Additional information (including legislative and regulatory requirements at site)

---

* Any restrictions, particular to the site, should be made clear. Particular attention is drawn to the following:
(a) restricted access for delivery vehicles;
(b) restricted access for cooling towers into building;
(c) building design restrictions to air movement;
(d) details of adjacent chimneys, discharge ventilation fans or process discharges.

† If a particular type of tower, i.e. forced draught, induced draught, etc., is required by the purchaser, it should be indicated to minimize pointless alternative selections being made by the supplier.

‡ See **6.1.2**. Consideration should be given to possible environmental heat gain which may increase the wet bulb temperature of the air at the intake of the cooling tower.

A.2 Information to be provided by the supplier

A.2.1 General. The information in **A.2.2** to **A.2.4** is required for the assessment of compliance with the purchaser's requirements and to accommodate provisions required in structural design.

A.2.2 Specification . . . .

(a) Type of tower* . . . .

(b) No. of towers . . . . each of . . . . . cells(s).

(c) Max. lifting mass. . . . . kg

(d) Max. operating mass . . . . kg

(e) Dry mass. . . . . kg

(f) A mass distribution diagram is enclosed YES/NO (delete as necessary)

(g) Maximum size of largest section:
length . . . . . m; width . . . . . m;
height . . . . m

(h) With/without basin (delete as necessary)

A.2.3 Duty of each tower . . . . L/s

of water from . . . . . . °C to . . . . °C

at ambient air wet bulb temperature of . . . . . . °C

A.2.4 Tower packing

(a) Type. . . . .

(b) Material . . . .

A.2.5 Casing

(a) Materials . . . .

(b) Protective treatment(s)† . . . .

A.2.6 Basin

(a) Materials . . . .

(b) Water quantity held (i) at operating level. . . . . m^3
(ii) at overflow level . . . . . m^3

A.2.7 Fans

(a) Type . . . .

(b) Air flow per tower . . . . m^3/s

(c) Fan static pressure . . . . kPa

(d) No. of fans (i) per drive shaft . . . .
(ii) per motor . . . .

(e) Fan speed . . . . r/min

(f) Handling wet or ambient air . . . .

A.2.8 Motors

(a) No. per unit . . . .

(b) Absorbed power. . . . . kW per motor

(c) Rated power . . . . kW per motor

(d) Speed(s) . . . . r/min

(e) Electricity supply . . . . . V . . . . phase
. . . . Hz . . . . wire

(f) Frame size . . . .

(g) Enclosure . . . .

(h) Manufacturer . . . .

(i) Inside wet airstream/outside wet airstream (Delete as necessary)

A.2.9 Drive details . . . .

A.2.10 Distribution system

(a) Type . . . .

(b) Minimum pressure tower inlet . . . . kPa

A.2.11 Eliminators

(a) Materials . . . .

(b) Expected drift loss . . . . %

A.2.12 Make-up. This includes recommended purge/excluding purge (delete as necessary).

. . . .

A.2.13 Noise level. Noise level complies/does not comply with **A.1.9.**

A.2.14 Additional information. . . . .
. . . .
. . . .

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* The type of tower being proposed by the supplier, i.e. forced draught, counterflow, induced draught crossflow, etc., should be stated.

† Any particular treatments should be as recommended in BS 4485 : Part 4.

Appendix B. Evaluation of noise in cooling towers

B.1 Noise assessment data

Data on the noise level of a tower may appear either:

(a) as sound power level readings (S_W) at a point source; or

(b) as sound pressure level reading (S_p) some specified distance away from the source.

Each is measured by comparison with a threshold base level which is now generally accepted in the case of power and pressure respectively as:

$W_0 = 10^{-12}$ W (power threshold)

$P_0 = 2 \times 10^{-5}$ N/m^2 (pressure reference datum)

giving the measure, in decibels, for S_W and S_p as:

$$S_W = 10 \log \frac{W_s}{W_0} \tag{15}$$

$$S_p = 10 \log \left(\frac{P_s}{P_0}\right)^2 = 20 \log \frac{P_s}{P_0} \tag{16}$$

S_W and S_p are related in terms of the area A_s of sound propagation by:

$$S_p = S_W - 10 \log A_s \tag{17}$$

so that for the hemispherical sound propagation over an assumed flat ground surface radius R from the source:

$$\begin{aligned} S_p &= S_W - 10 \log 2\pi R^2 \\ &= S_W - 20 \log R - 8 \end{aligned} \tag{18}$$

Normally one is interested in this value of S_p at a distance R away from the known or estimated level S_W and S_W has two components: fan noise and water noise. The fan noise component is generally evaluated empirically, reference 10^{-12} W, as:

$$\begin{aligned} S_W &= 96.25 + 10 \log W_d \text{ (for axial fan) or} \\ S_W &= 85.25 + 10 \log W_d \text{ (for centrifugal fan)} \end{aligned} \tag{19}$$

The water noise component varies considerably from tower to tower and should be estimated from known values of similar towers. The chosen water noise spectrum decibel values should then be added at each octave and bank centre-frequency (at the appropriate stage of circulation) to the computed fan spectrum.

The addition of decibel values should be done on the basis given in table 3.

B.2 Frequency measurement and attenuation

The acceptable noise level will usually be specified at a certain distance from the source as:

(a) being a certain number of decibels when the noise spectrum as a whole is measured on the weighted A scale; or

(b) falling within a limiting curve when the spectrum is analysed at the geometric mid-frequencies of the octave bands given below, and plotted on the British Standard equal loudness curves or similar.

In each case the measurement should be made on an instrument complying with BS 5969.

The octave band centre-frequencies (in Hz) at which measurement should be made are:

62.5, 125, 250, 500, 1000, 2000, 4000, 8000.

Table 3. Addition of decibels

Difference between the two values being added (dB)	0	1	2	3	4	5	6	7	8	9	10
Amount added to the larger for combined level (dB)	3	2.5	2	1.8	1.5	1.2	1.0	0.8	0.7	0.6	0.5

NOTE. Values below 0.5 dB are generally of little interest in this field.

B.3 Typical calculation method

The assessment of noise can only be approximate in that it is seldom possible to account accurately for the effects of wind, local buildings, etc. Within reasonable limits, however, the noise level may be estimated by the following procedure.

(a) Calculate the sound power level of the source and apply the resulting value over the whole spectrum octave centre band.

(b) Correct these values by attenuation or accentuation from the fan spectrum analysis given in table 4.

(c) Add for the fan discrete frequency.

(d) Correct these net values for the number of fans.

(e) Correct further for any special condition of use.

(f) Add the spectrum values estimated for water noise correction.

(g) Correct the net values for distance to the point of measurement (see figure 26).

(h) Correct the net values for directivity of sound (see figure 27).

(i) Compare the spectrum so obtained with the specified loudness curve or, after weighting, with the dBA value required.

For example, the calculation for a tower with two axial six-bladed fans of 50 kW rotating at 325 r/min where the noise value is required 200 m away is given in table 5. The fan discrete frequency is (325 × 6)/60 = 32.5, 5 dB being added to 31.5 centre-frequency band to allow for this.

Unless other evidence is available, directivity of water noise should be taken as 90° from the air intake at ground level.

If measurements made on one tower are used as a basis of calculation for another, care should be taken that the values concerned result from measurements taken from a similar position in plan area for the case concerned.

Table 4. Typical corrections to obtain octave band spectra for various fan types*

Fan type	Correction to overall sound power level for octave band centre-frequency (Hz) of							
	62.5	125	250	500	1000	2000	4000	8000
	dB	dB	dB	dB	dB	dB	dB	dB
Centrifugal:								
backward curved blades	-4	-6	-9	-11	-13	-16	-19	-22
forward curved blades	-2	-6	-13	-18	-19	-22	-25	-30
radial blades	-3	-5	-11	-12	-15	-20	-23	-26
Axial	-7	-9	-7	-7	-8	-11	-16	-18
Mixed flow	0	-3	-6	-6	-10	-15	-21	-27

* Specific data for particular fans may vary to some degree.

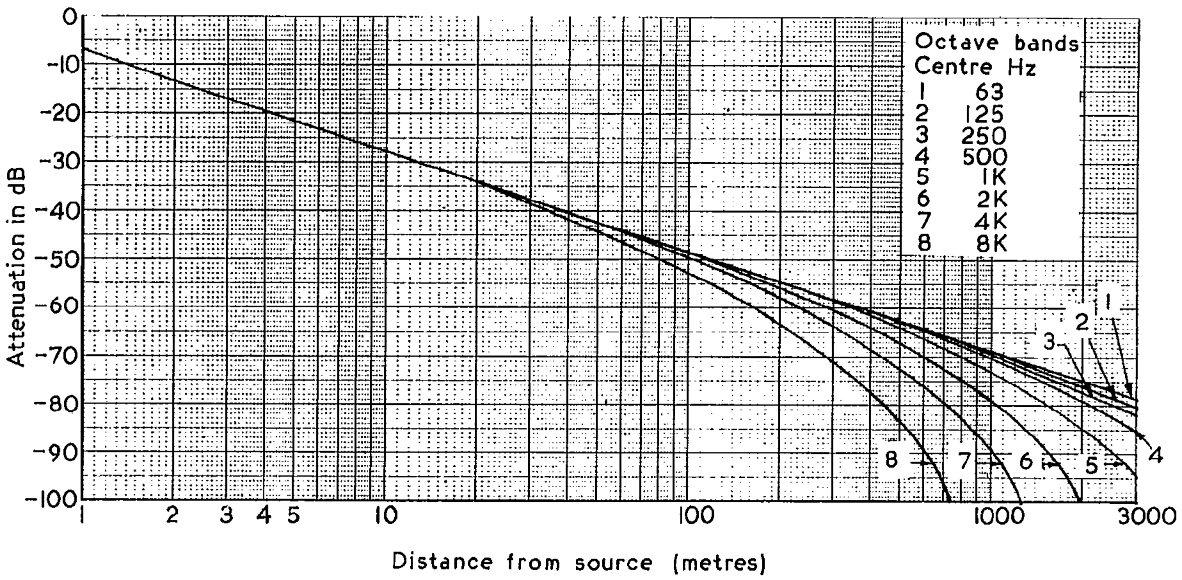
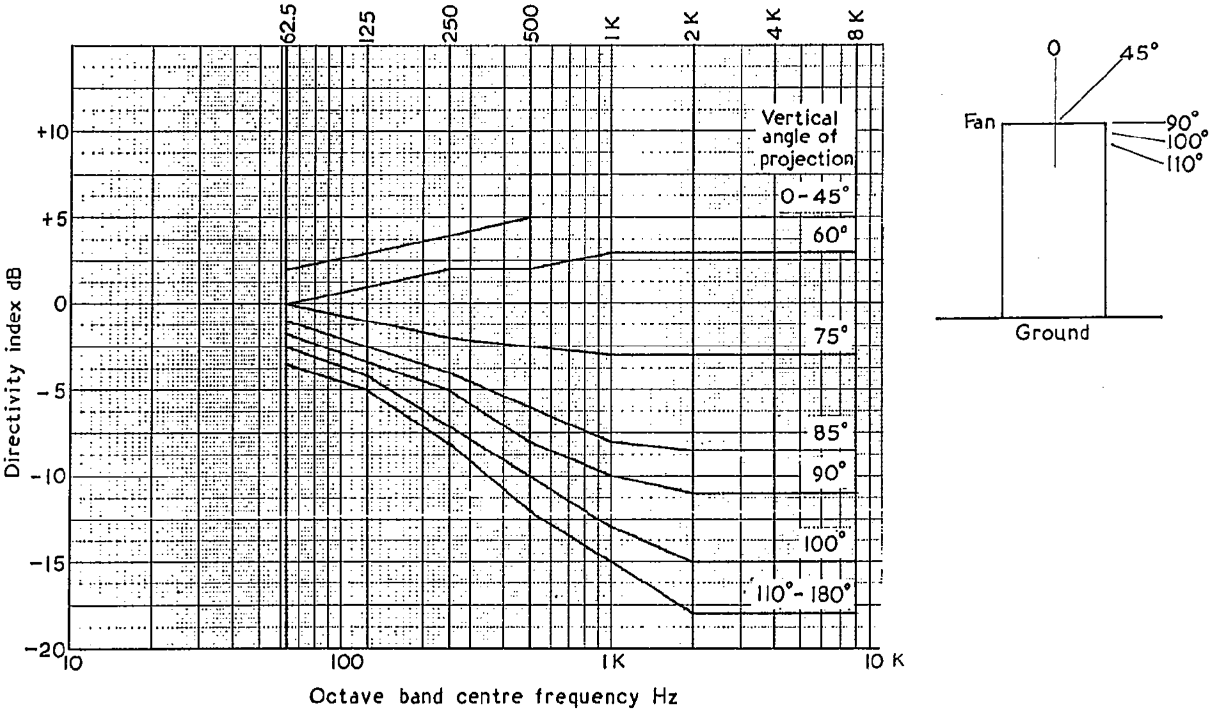

For hemispherical propagation and source sound power level re 10^{-12} W and sound pressure level re 2×10^{-5} N/m²

Figure 26. Attenuation for distance from source



NOTE. For stack heights less than 10 m, use 90°.

Figure 27. Directivity correction

Table 5. Tower noise calculation

Serial	Description	Noise level at octave band centre-frequency (Hz) of								
		31.5	62.5	125	250	500	1000	2000	4000	8000
		dB	dB	dB	dB	dB	dB	dB	dB	dB
1	S_W	113	113	113	113	113	113	113	113	113
2	Octave band correction	−7	−7	−9	−7	−7	−8	−11	−16	−18
3	Add discrete frequency	5	—	—	—	—	—	—	—	—
4	Net	111	106	104	106	106	105	102	97	95
5	Add for second fan	3	3	3	3	3	3	3	3	3
6	Net	114	109	107	109	109	108	105	100	98
7	Estimated water noise	108	108	104	104	108	110	104	100	80
8	Difference between serials 6 and 7	6	1	3	5	1	2	1	0	18
9	Using table 3, value to be added to larger of serials 6 and 7	1	2.5	1.8	1.2	2.5	2	2.5	3	0
10	Net, to the nearest whole number	115	111	109	110	111	112	107	103	98
11	Distance correction	−55	−55	−55	−55	−55	−55	−56	−58	−63
12	Net	60	56	54	55	56	57	51	45	35
13	Directivity correction assumed at 90°	−1	−2	−3	−5	−8	−10	−11	−11	−11
14	Final spectrum	59	54	51	50	48	47	40	34	24

Publications referred to

BS 848	Fans for general purposes
	Part 2 Methods of noise testing
BS 3170	Specification for flexible couplings for power transmission
BS 4142	Method of rating industrial noise affecting mixed residential and industrial areas
BS 4235	Specification for metric keys and keyways
	Part 1 Parallel and taper keys
BS 4485	Water cooling towers
	*Part 1 Glossary of terms
	Part 2 Methods for performance testing
	Part 4 Structural design of cooling towers
BS 4999	Specification for general requirements for rotating electrical machines
BS 5000	Specification for rotating electrical machines of particular types or for particular applications
BS 5304	Code of practice. Safeguarding of machinery
BS 5493	Code of practice for protective coating of iron and steel structures against corrosion
BS 5512	Specification for rolling bearings — dynamic load ratings and rating life
	Part 1 Calculation methods
BS 5969	Specification for sound level meters

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*Referred to in the foreword only.

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