
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

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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Part of BS 4485 is a revision of BS 4485 : Part 3 : 1977, together with its Addendum No. 1 (1978) both of which are withdrawn.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in the revisions of BS 4485 : Parts 2, 3 and 4 so that when they have all been published BS 4485 : Part 1 can be withdrawn.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.

* 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	$\text{kJ}/(\text{kg}\cdot\text{K})$
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	$\text{kg}/(\text{m}^2\cdot\text{s})$
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	$\text{kg}/[\text{m}^2\cdot\text{s}\cdot(\text{kg}/\text{kg})]$
L	Mass water flow per unit plan area of packing	$\text{kg}/(\text{m}^2\cdot\text{s})$
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_s	Sound pressure	N/m^2
P_0	Sound pressure reference datum	N/m^2
Q_1	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.

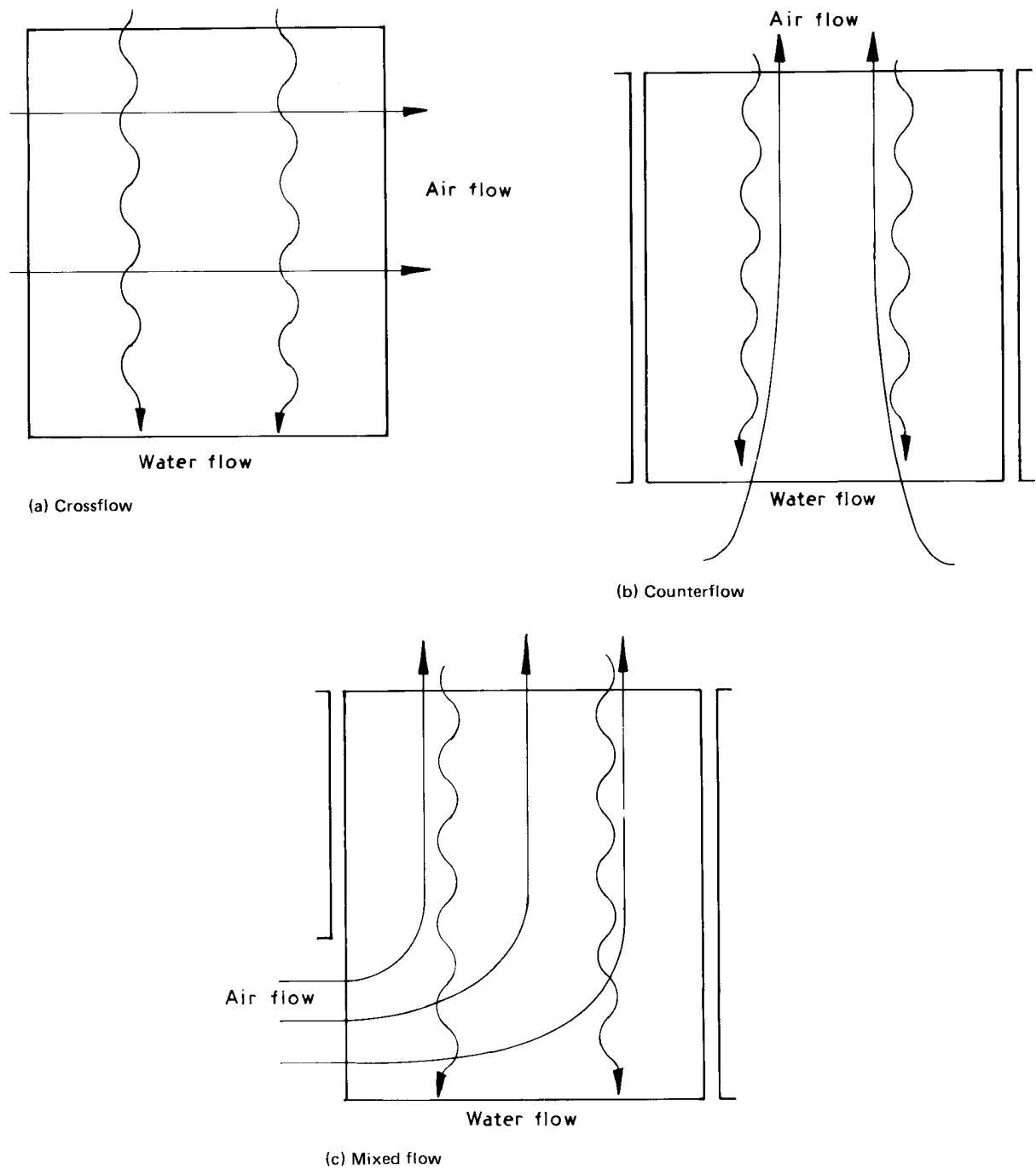


Figure 1. Air-water flow paths in crossflow, counterflow and mixed flow towers

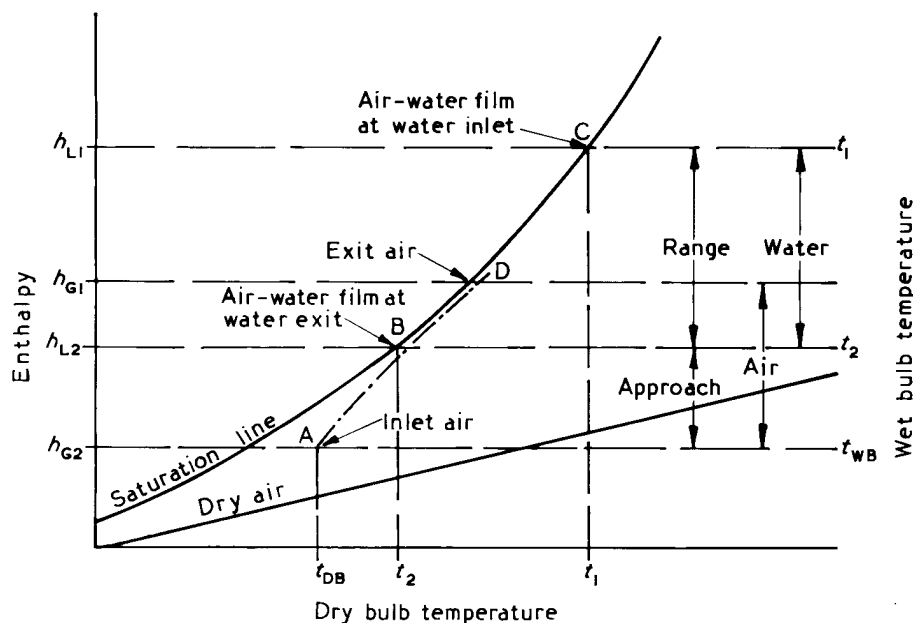


Figure 2. Conditions of air and water in a cooling tower

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

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

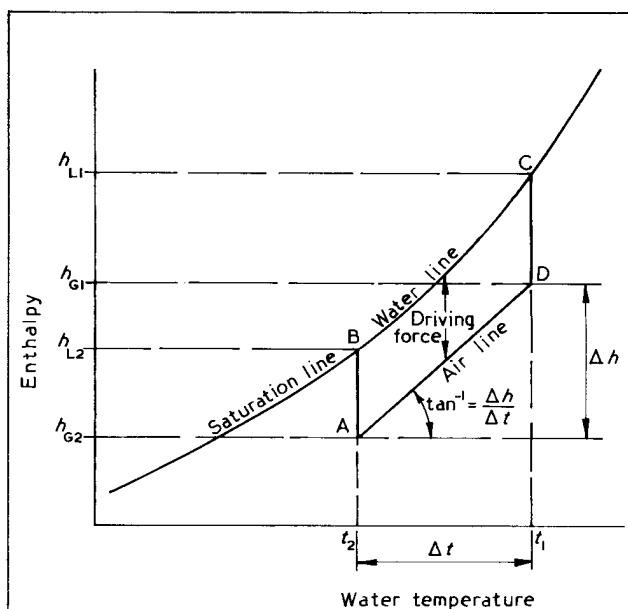


Figure 3. Heat transfer diagram

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

(1) In figure 2, therefore, the inlet and exit air temperatures are joined by a line having a slope equal to c_p/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 $\text{kg}/[\text{m}^2 \cdot \text{s} \cdot (\text{kg}/\text{kg})]$.

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

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

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

$$cL\Delta t = Ka \times V \times h_m = G\Delta h \quad (3)$$

From equation (3) may be derived the relationship:

$$\frac{KaV}{L} = \frac{c\Delta t}{h_m}$$

or

$$\frac{KaV}{L} = \int_{t_2}^{t_1} \frac{cdt}{h_L - h_G} \quad (4)$$

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 $c\Delta t/h_m$ (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 ($t_2 - t_{WB}$) that could form a cooling specification, there will be an infinite variety of demand curves*.

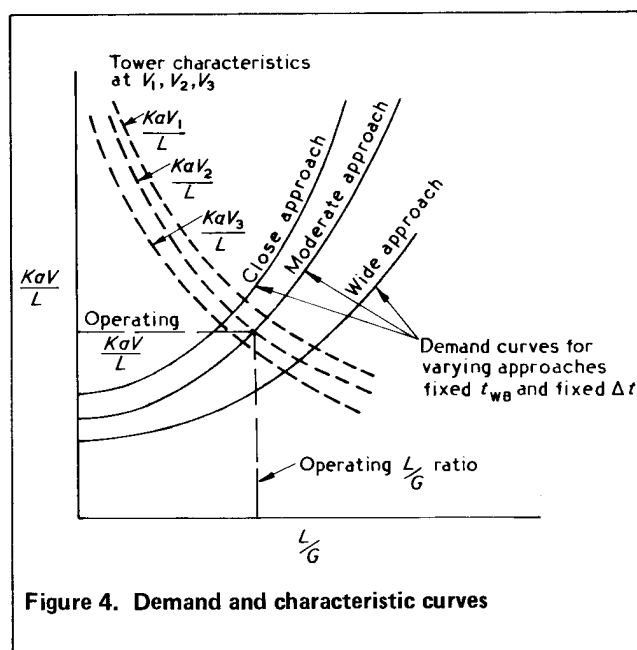


Figure 4. Demand and characteristic curves

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.

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

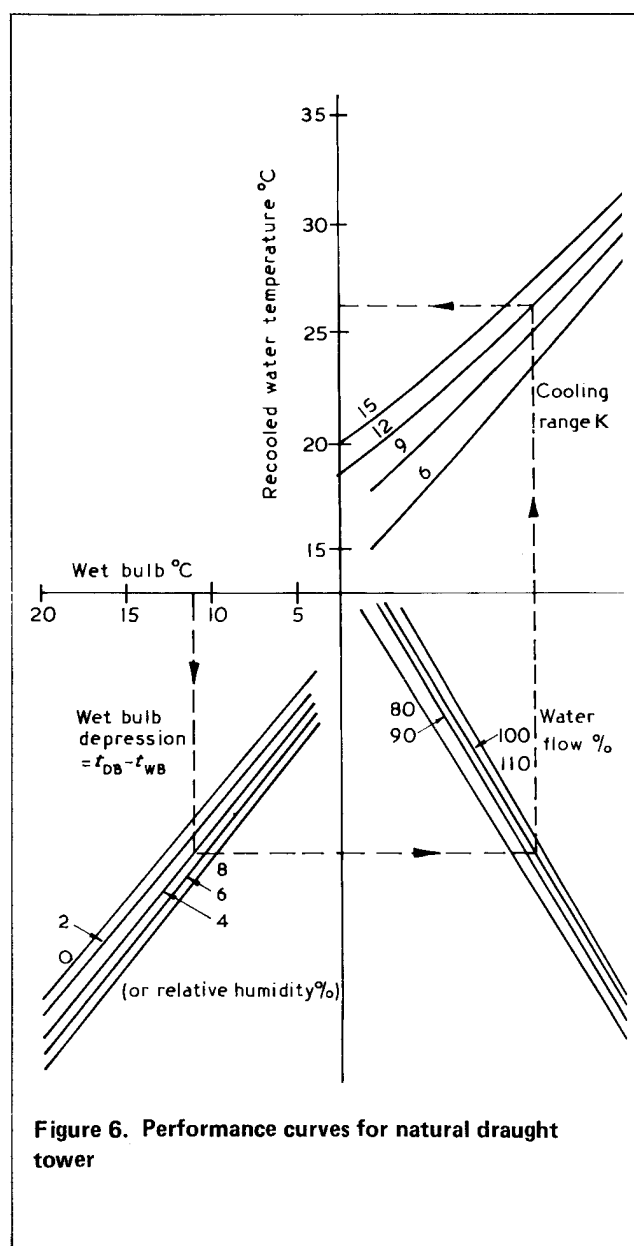
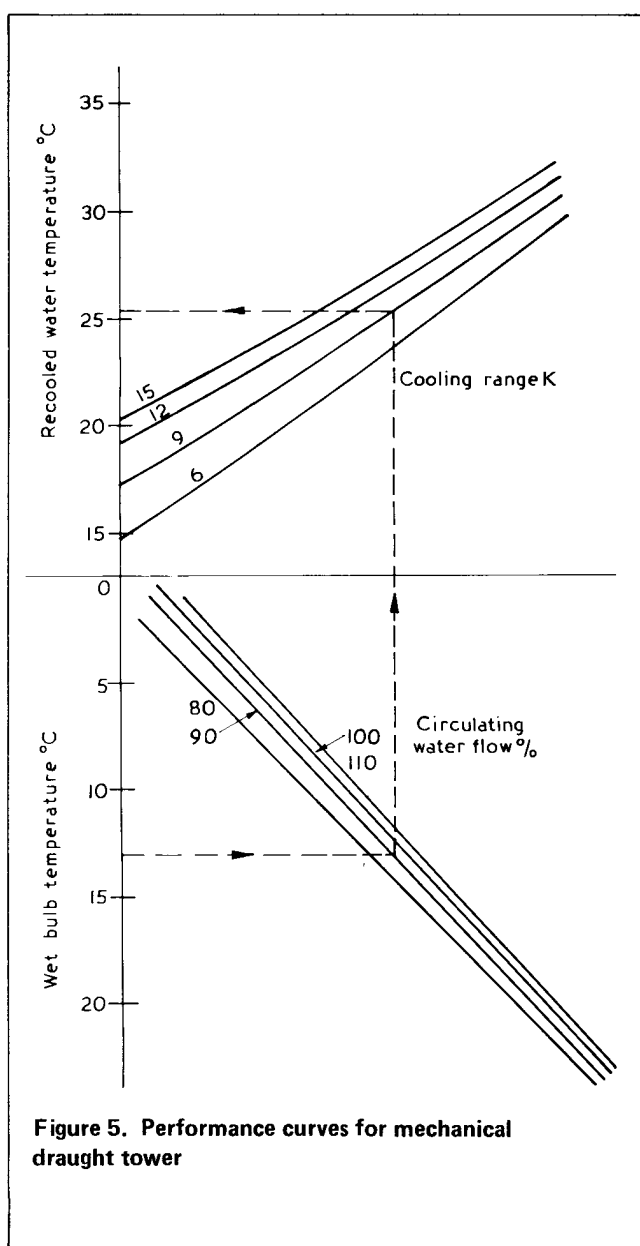
Except for small density changes affecting fan output, for mechanical draught towers G is independent of atmospheric conditions and at constant L the value of L/G remains constant for all atmospheric changes. For the design flow L , the curves of demand may therefore be converted into curves of performance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



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

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

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

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.

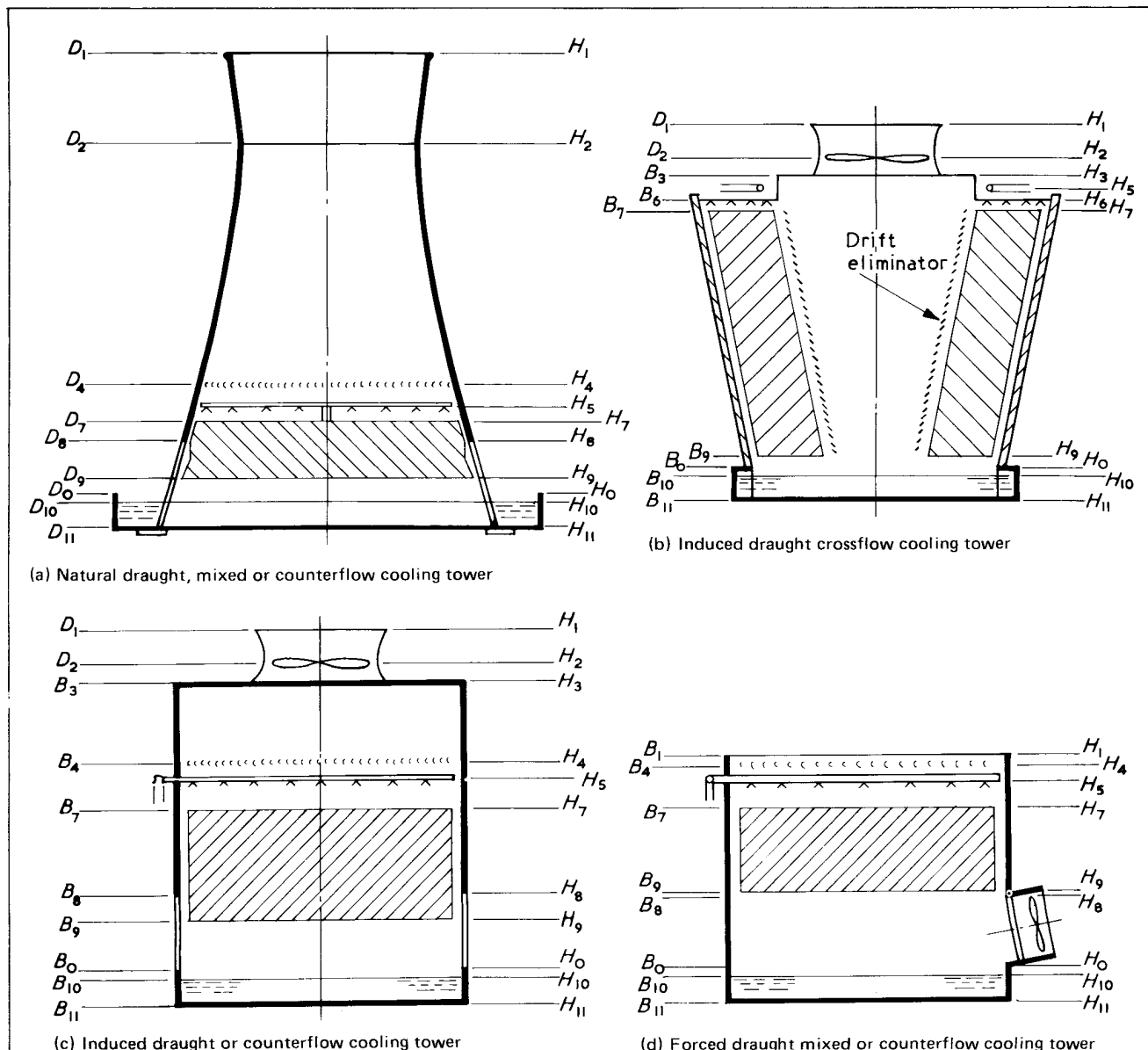
Relaxation of the duty permits higher water loadings on all packing. In the case of film packing, this means either a thicker water film without increase in the transfer area or the use of the plastics plate extended surface area type giving a larger area per unit volume without necessarily increasing 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 $1.25 \text{ m}^3/\text{s}$ 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.



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	$D_{10} \ H_{10}$	$B_{10} \ H_{10}$	$B_{10} \ H_{10}$	$B_{10} \ H_{10}$
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).

* 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 m³/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.

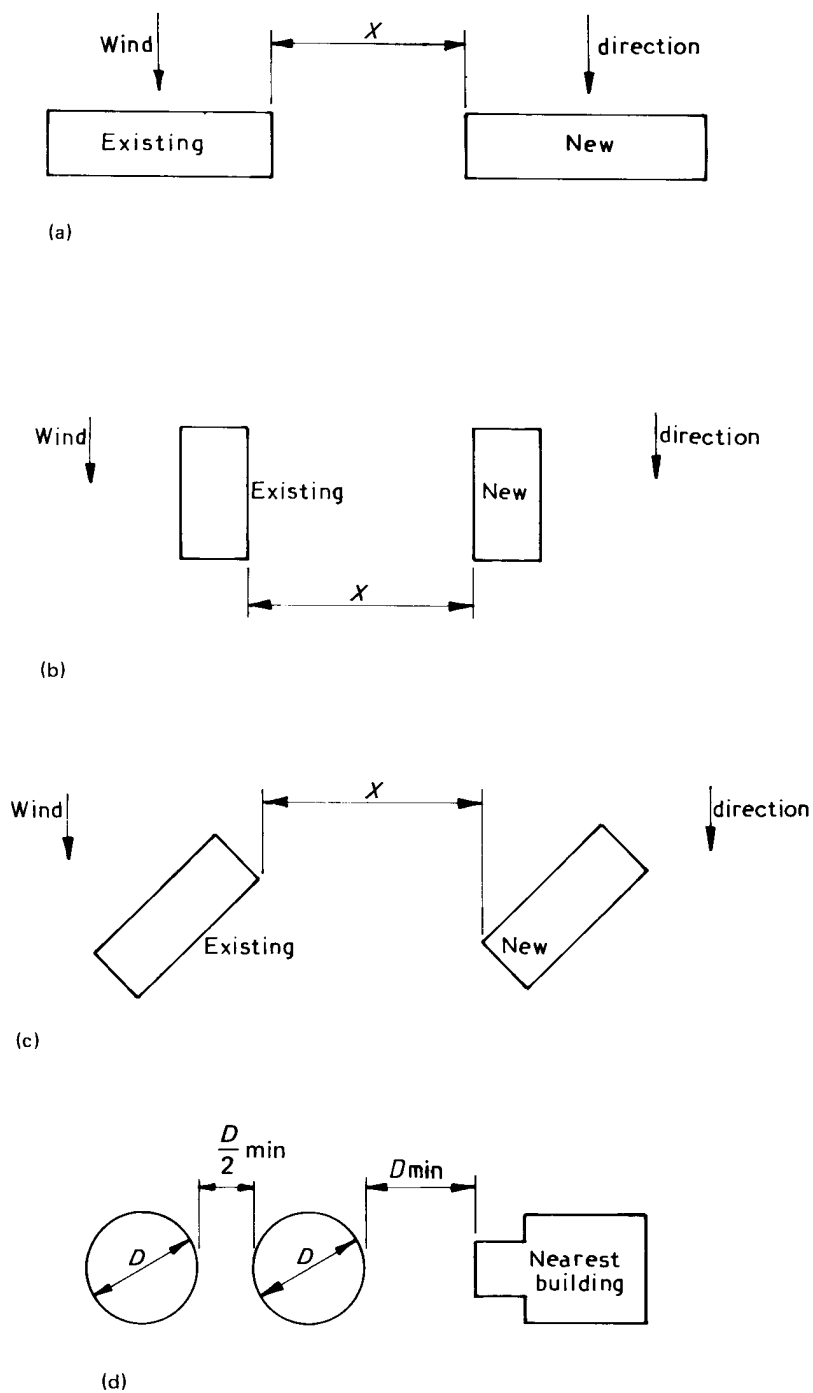


Figure 8. Spacing