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British Standard

Water cooling towers

Part 2. Methods for performance testing

Tours de refroidissement par l'eau
Partie 2. Méthodes d'essai de fonctionnement

Wasserkühltürme
Teil 2. Funktionsprüfung

British Standards

Foreword

This Part of BS 4485, which has been prepared under the direction of the Civil Engineering and Building Structures Standards Committee, deals with the performance testing of industrial mechanical draught and natural draught water cooling towers. This Part of BS 4485 is a revision of BS 4485 : Part 2 : 1969 which is withdrawn.

The principal difference between this Part of BS 4485 and the 1969 edition is the introduction of the option of using a computer to do the calculation of thermal performance capability rather than carrying it out manually.

The performance of a cooling tower is dependent upon a number of factors, such as conditions of the atmosphere, conditions of the cooling water flow, conditions of equipment and conditions of the site, and the object of this Part of BS 4485 is to describe methods for the accurate determination of thermal performance. In addition, methods are described for the functional testing of equipment necessary for the satisfactory operation of a cooling tower.

This Part of BS 4485 also includes a description for the performance test procedure, the computation and evaluation of results, and the appendices provide worked examples for establishing the L/G ratio for natural draught cooling towers, and also the cooling tower characteristic KaV/L.

The other Parts of BS 4485 are as follows.

Part 1 Glossary of terms
Part 3 Code of practice for thermal and functional design
Part 4 Code of practice for the 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in the revisions of BS 4485 : Parts 2, 3 and 4 so that when they have all been published BS 4485 : Part 1 can be withdrawn.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.

Contents

Methods

1 Scope

This Part of BS 4485 describes methods for the determination of the performance of industrial mechanical draught and natural draught water cooling towers.

This Part of BS 4485 can also be applied to other forms of cooling towers.

NOTE 1. The matters to be agreed between purchaser and supplier are listed in appendix A.

NOTE 2. The titles of the publications referred to in this standard are listed on page 33.

2 Definitions

For the purposes of this Part of BS 4485 the following definitions apply.

2.1 air flow. Total quantity of air, including associated water vapour flowing through the tower.

2.2 ambient wet (dry) bulb temperature. Wet (dry) bulb temperature of air measured windward of the tower and free from the influence of the tower.

2.3 approach. Difference between recooled water temperature and nominal inlet air wet bulb temperature.

2.4 inlet water flow. Quantity of hot water flowing into the tower.

2.5 cold water basin. Device underlying the tower to receive the cold water from the tower and direct its flow to the suction line or sump.

2.6 cooling range. Difference between the hot water temperature and the recooled water temperature.

NOTE. The term 'range' is also applied to this definition, but is regarded as a non-preferred term.

2.7 drift loss. Water lost from the tower as liquid droplets entrained in the outlet air.

2.8 heat load. Rate of heat removal from the water within the tower.

2.9 hot water temperature. Temperature of inlet water.

2.10 inlet air wet (dry) bulb temperatures. Average wet (dry) bulb temperatures of the inlet air; including any recirculation effect.

NOTE. This is an essential concept for purposes of design, but is difficult to measure.

2.11 make up. Water added to the circulating water system to replace water loss from the system by evaporation, drift, purge and leakage.

2.12 nominal inlet air wet (dry) bulb temperatures. Arithmetical average of the measurements taken within 1.5 m of the air inlets and between 1.5 m and 2.0 m above the basin kerb elevation on both sides of the cooling tower.

NOTE. See **5.2.2**.

2.13 purge. Water discharged from the system to control concentration of salts or other impurities in the circulating water.

2.14 recooled water temperature. Average temperature of the water at the cold water basin discharge excluding the effect of any make-up entering the basin.

2.15 recirculation. Portion of the outlet air that re-enters the tower.

2.16 fan drive assembly. Components for driving the fan, normally comprising driver, drive shaft and transmission unit, and primary supporting members.

2.17 fan power. Power input to the fan drive assembly, excluding power losses in the driver.

2.18 tower pumping head. Total head of water required at the inlet to the tower, measured above the basin kerb, to deliver the inlet water through the distribution system.

2.19 water loading. Inlet water flow expressed in quantity per unit of plan packing area of the tower.

2.20 wet (dry) bulb temperature. The temperature indicated by an adequately ventilated and wetted (non-wetted) thermometer in the shade and (where applicable) protected from strong ground radiation.

3 Symbols and units

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

4 Conditions of validity of tests

4.1 General

In determining the performance and thermal efficiency of mechanical and natural draught cooling towers, the conditions of validity specified in **4.2** to **4.5** shall be fulfilled.

NOTE. These conditions may also form the basis for contractual agreement between the purchaser and the supplier.

4.2 Conditions of site

Any variations in the conditions of the site from those of the design shall be recorded.

4.3 Conditions of equipment

At the time of test all equipment and systems shall be in proper operating condition, and the following checks shall be made.

(a) The water distribution system shall be clear and free from foreign materials which may clog or impede the normal water flow.

(b) Mechanical equipment shall be in good working order and set for the design duty (see **6.1**).

(c) Drift eliminators shall be clear and free from algae and other deposits which may impede normal air flow.

(d) Packing shall be free from foreign material, such as oil, tar, scale or algae, and shall have been in use for such a period (as recommended by the supplier) to ensure adequate wetting.

(e) The water level in the cold water basin shall be at normal operating elevation immediately prior to the test.

NOTE. Wherever possible the make-up and purge should be shut off during the test in the interest of simplicity and accuracy.

In the event of the equipment not being in a satisfactory operating condition, such adjustment or changes as may be required to place it in proper operating condition shall be made. However, no adjustments shall be made which are not practical in continuous commercial operation, other than the initial setting.

Table 1. Symbols and units

Symbol	Quantity	Units
a	Area of effective transfer surface per unit of tower packed volume	m^2/m^3
c	Specific heat capacity of water	kJ/(kg·K)
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_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
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	$kg/(m^2 \cdot s)$
n	(Constant)	—
Q_I	Inlet water flow	m^3/s
Q_M	Make-up water flow	m^3/s
Q_P	Purge water flow	m^3/s
t_{DB}	Dry bulb temperature	°C
t_E	Temperature of mixture of recooled water and make-up leaving cold water basin	°C
t_M	Make-up water temperature	°C
t_P	Purge water temperature	°C
t_{WB}	Wet bulb temperature	°C
t_1	Hot water temperature	°C
t_2	Recooled water temperature	°C
V	Effective packed volume per unit area of packing	m^3/m^2
V_B	Average water volume in cold water basin during the test	m^3
W_h	Fan horsepower	W
λ	(Constant)	—
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
KaV/L	Tower characteristic	—
L/G	Water/air ratio	—
Subscripts		
d	design	—
t	test	—

*The quantity defined for G applies to counterflow; for crossflow see appendix C.

†All enthalpies relate to 1 kg of dry air.

4.4 Conditions of atmosphere

The tests shall be carried out during stable weather conditions and within the following limitations.

(a) Wind velocity readings averaged over the test period shall not exceed 5.0 m/s, with readings averaged over 1 min not exceeding 7.0 m/s, when measured at a height of 1.5 m to 2.0 m above local ground level.

(b) The inlet wet bulb temperature shall be within ± 5 K of the design wet bulb temperature, but shall not fall below 3 °C.

Readings may fluctuate but the rate of change in average wet bulb temperature shall not exceed 1 K/h.

(c) In the case of natural draught towers, the relative humidity shall not fall below 40 %.

(d) Natural draught towers shall not be tested under conditions of atmospheric inversion. Where doubt exists as to the presence of a normal 'lapse rate', additional readings of air temperature shall be taken at a height of 8 m to 10 m to confirm a positive lapse (see **5.2**).

The tests shall be carried out during daylight hours for reasons of safety and accuracy of measurements except that under certain circumstances it may be necessary to carry out noise tests at night.

4.5 Conditions of inlet water

The total dissolved solids in the inlet water shall be within 500 mg/L of the design value and oil, tar or other fatty substances shall not exceed 10 mg/L.

4.6 Variation from design conditions

The following variations of average test readings from design conditions are permissible.

(a) Inlet water flow not more than 10 % below or 10 % above the design value.

(b) Cooling range not more than 20 % below or 20 % above the design value.

(c) Heat load not more than 20 % below or 20 % above the design value.

During the hour selected in accordance with **7.3.1** as being representative of the test conditions, the difference between maximum and minimum readings of the inlet water flow, cooling range and heat load, shall not exceed 5 %.

5 Instruments and methods of measurement

5.1 Measurement of wind velocity

Instruments shall be calibrated before use. Measurement shall be made in an open and unobstructed location to the windward of the equipment at a horizontal distance sufficient to eliminate the influence of the upstream effects of the equipment, and, where possible, a vertical distance of 1.5 m to 2.0 m above local ground level.

NOTE 1. The instrument recommended for the measurement of wind velocity is either the rotating cup or rotating vane anemometer.

NOTE 2. If such a location is inaccessible, a suitable location for wind measurement should be agreed between the test personnel (see appendix A).

NOTE 3. The frequency of readings taken should increase with wind speed and gust effect, in order to arrive at a representative average result.

5.2 Measurement of air temperature

5.2.1 *General.* The number of stations at which measurements are to be taken depends upon the size of the cooling tower and the existence of neighbouring influences. In the case of multi-cell mechanical draught and natural draught cooling towers, a minimum of three stations shall be used, whereas one station may suffice for a single-cell cooling tower.

5.2.2 *Measurement of nominal inlet air temperatures.* The nominal inlet wet bulb and dry bulb temperature shall be determined as the arithmetical average of the measurements taken within 1.5 m of the air inlets and between 1.5 m and 2.0 m above the basin kerb elevation on both sides of the cooling tower so as to bracket substantially the air flow to the tower.

In the case of natural draught towers, it is likely that the ambient and nominal inlet air temperatures will be identical, in which case the tests can be carried out using the ambient temperature measurements only in accordance with **5.2.3.**

5.2.3 *Measurement of ambient temperatures.* The ambient wet bulb and dry bulb temperatures shall be determined as the arithmetic average of measurements taken, where possible, approximately 1.5 m to 2 m above ground level, and not less than 15 m or more than 100 m to windward of the equipment, and equally spread along a line substantially bracketing the flow of air to the equipment.

NOTE. If such a location is inaccessible, or the area surrounding the equipment contains elements which can affect the ambient wet bulb and dry bulb temperatures, a suitable location for these measurements should be mutually agreed (see appendix A).

5.2.4 *Measurement of wet bulb and dry bulb temperatures.* The instrument for the measurement of the wet bulb and dry bulb temperature shall be a mechanically aspirated psychrometer complying with the following.

(a) The temperature-sensitive element shall be in accordance with **5.3.1**.

(b) Temperature-sensitive elements shall be shielded from the direct rays of the sun or from any other sources of radiant heat. Shielding devices shall be substantially at the dry bulb temperature.

(c) The wick covering the bulb of the wet bulb thermometer shall be kept clean at all times and maintained in a saturated condition. It shall be a snug fit over the bulb and at least 25 mm in length.

(d) The temperature of the distilled water used to wet the wick shall be at approximately the wet bulb temperature to be measured.

NOTE 1. This can be obtained in practice by allowing adequate ventilated wick between the water supply and the temperature-sensitive element.

(e) The air velocity over the temperature-sensitive elements shall be between 3.0 m/s and 6.0 m/s.

At least three successive readings, separated by 10 s, shall be taken at any given location and averaged after the psychrometer has reached equilibrium.

NOTE 2. The instrument will usually reach equilibrium in 2 min.

5.3 Measurement of water temperature

5.3.1 *General.* The method used to measure water temperature shall be accurate to $\pm$ 0.05 °C.

NOTE. The instrument preferred for water temperature measurement is the mercury in glass thermometer with divisions etched on the glass at intervals not greater than 0.1 °C. Other officially calibrated instruments may be used by mutual agreement (see appendix A).

The instrument used for the test shall have been checked against a reference thermometer calibrated by an approved calibrating authority prior to the test, but not more than 6 months before the test in the case of a first calibration of the same instrument. Certificates of examination shall be made available for inspection.

The locations of the temperature measuring instruments shall be such that the average temperature of the hot and the recooled water flows are determined. Where various streams of different temperatures combine, the point of measurement shall be located to ensure complete mixing without stratification.

If stratification is evident, the weighted average water temperature shall be determined by a survey of a selected section using simultaneous temperature and water flow measurements at each point.

5.3.2 *Hot water temperature.* A suitable location for the measuring instrument for hot water temperature is the common supply conduit to the tower.

5.3.3 *Recooled water temperature.* The recooled water temperature can be measured directly at the point where the water is discharged from the basin, the average cold water temperature being determined by simultaneous test readings, where possible, across the selected section.

Where stratification is evident, a suitable point of measurement is at the outlet of the circulating water pump. Allowance shall also be made for the rise in temperature due to energy losses in the pump (see **8.4**).

When the temperature of the circulating water in the basin is the mixed temperature of both circulating water and make-up water, the recooled water temperature shall be determined indirectly by heat balance calculation taking into account the temperature and quantity of make-up and purge and other heat added or removed between the tower and the point of measurement (see **8.4**).

5.3.4 *Make-up water and purge temperatures.* Temperature readings shall be taken at the spill over weir or in the piping immediately adjacent to the cooling tower.

5.4 Measurement of water flow

5.4.1 *Measurement*

5.4.1.1 *Inlet water flow.* Measurements shall be made either:

(a) in the piping leading to the cooling tower, and care shall be taken to ensure that during the test water is neither fed into nor taken away from the pipe system between the measuring points and the cooling tower; or

(b) where it is not possible or practicable to measure the flow at the inlet to the cooling tower, a different location shall be selected and the necessary correction shall be applied to determine the actual flow into the cooling tower.

5.4.1.2 *Make-up water flow.* Measurement of make-up water flow shall be made in the make-up piping leading to the cooling tower or the system.

5.4.1.3 *Purge water flow.* Measurement of the purge water flow shall be made in the piping leading from the cooling tower or the system.

5.4.2 *Methods*

5.4.2.1 *General.* The method to be employed for the measurement of inlet water flow will be dependent upon the layout of the pipe system, and shall be selected from those methods listed in (a) to (h) and detailed in **5.4.2.2** to **5.4.2.9**.

(a) Pitot-static tubes.

(b) Orifice plates and nozzles.

(c) Venturi tubes.

(d) Notches, weirs and flumes.

(e) Current meters.

(f) Dilution methods (including the use of radioisotope techniques).

(g) Heat balance.

(h) Magnetic or sonar devices.

NOTE. The method to be employed should be agreed between the purchaser and the supplier.

5.4.2.2 *Pitot-static tubes.* The design and use of pitot-static tubes shall be as specified in BS 1042 : Section 2.1.

NOTE. This device is suited to a closed circuit where no permanent flow measuring device is installed.

5.4.2.3 *Orifice plates and nozzles.* The design and use of orifice plates and nozzles shall be as specified in BS 1042 : Part 1.

NOTE. These devices are suited to closed circular conduits running full. They are normally permanently installed and their inherent energy loss usually limits the use to small diameter pipelines.

5.4.2.4 *Venturi tubes.* The design and use of venturi tubes shall be as specified in BS 1042 : Part 1.

NOTE. The conditions for the measurement of water flow are the same as those for an orifice plate or nozzle but with the advantage that this type of device results in a lower permanent head loss.

5.4.2.5 *Notches, weirs and flumes.* The construction and installation of notches, weirs and flumes shall be as specified in BS 3680 : Part 4A.

NOTE. This method is suitable only when a system is designed to accommodate a notch, weir or flume as a permanent structure.

5.4.2.6 *Current meters.* Current meters shall be as specified in BS 3680 : Part 8A and their use shall be as specified in BS 3680 : Part 3A.

NOTE. This method is suitable for flow in channels having a free water surface.

5.4.2.7 *Dilution methods.* Flow measurement by chemical dilution shall be as specified in BS 3680 : Part 2A and by radioactive tracer dilution as specified in BS 3680 : Part 2C.

NOTE 1. This method is equally applicable to flow in open channels with free water surface and to conduits running full.

NOTE 2. It is important that the appropriate water authority and river authority are consulted.

NOTE 3. The requirements specified in **7.3.2** do not apply with the use of this method.

5.4.2.8 *Heat balance.* Application of this method shall be as specified in BS 752.

NOTE. This method can be employed in the case of power station cooling towers.

5.4.2.9 *Magnetic or sonar devices.* Several proprietary devices are available and have the potential for high accuracy.

5.5 Water analysis

When it is required to determine the concentration of dissolved solids, oil, tar and other fatty substances (see **4.5**) samples of water shall be taken at the cooling tower inlet, and tests carried out in accordance with BS 2690 : Part 9 or Part 11, as appropriate.

5.6 Measurement of tower pumping head

The following measurements shall be taken in order that the pumping head may be evaluated.

(a) Static pressure above atmosphere measured at the centreline of the water inlet to the tower and immediately adjacent to the termination of supply.

NOTE 1. This may be a connecting flange or another termination of supply agreed between the purchaser and supplier.

(b) The height above basin kerb level of the point at which the above static pressure is measured.

(c) The cross section of the inlet conduit at which the above static pressure is measured.

NOTE 2. This may be most conveniently taken from the design drawings and an observation taken to confirm that the size and shape of the inlet corresponds to the design.

5.7 Measurement of power input to the fan driver

The electrical power input of three-phase a.c. electric motors shall be determined from measurements of voltage and current in each phase in conjunction with the power factor quoted by the motor manufacturer.

When voltage measurements cannot be made at the motor terminals, due allowance shall be made for voltage drop in the cable between the points of measurement and the motor terminals.

5.8 Measurement of drift loss

The assessment of the nuisance created by drift loss from a cooling tower shall be obtained by the method described in appendix B.

NOTE. The amount of drift loss can be estimated by taking the difference between the quantity of make-up water flow and the sum of the purge flow and evaporation loss. The accuracy of the measurement of the various quantities concerned should be taken into account. This measurement should preferably be carried out under conditions of no-heat-load.

5.9 Measurement of tower noise

When it is necessary to measure the free-field sound level of a cooling tower, the instrument used shall be an industrial grade sound level meter, complying with BS 5969, fitted with an 'A' weighting network and capable of measurements at least over the range 30 dBA to 90 dBA.

The instrument shall have its acoustic calibration checked immediately before and after the test.

The microphone of the sound level meter shall be located out of doors, at least 1.5 m above local ground level.

NOTE 1. The microphone positions should be agreed between the purchaser and the supplier.

The values recorded shall correspond to the free-field noise of the cooling tower (water and fans) and exclude noise due to wind, electrical interference and other sources of noise.

The total noise inclusive of the tower under full water and fan load shall be measured and also the background noise measured immediately before the test and exclusive of fan and water noise.

Measurements shall be made under conditions representative of the guaranteed conditions.

NOTE 2. Evaluation of the results obtained is covered by appendix B of BS 4485 : Part 3 : 1988.

6 Test checks and readings

6.1 Functional test

6.1.1 *General.* In order to establish that the cooling tower is fully operational and that the mechanical equipment is functioning in accordance with the design requirements, check the equipment in accordance with **6.1.2** to **6.1.4.**

6.1.2 *Fans.* Check the following:

(a) that the fan blades are set to the correct pitch for design duty;

(b) that the fan is centralized in the fan casing to ensure uniform tip clearance within the specified tolerances;

(c) that the fan rotates in the correct plane;

(d) that the direction of rotation of the fan is correct at all speeds.

6.1.3 *Fan drive assembly.* Check the following:

(a) that the fan drive is aligned within the specified tolerances;

(b) that the lubrication is in accordance with the manufacturer's recommendations;

(c) that the fan power observed under no-heat-load conditions is within the capacity of the driver;

(d) that there is no excessive mechanical noise or vibration.

6.1.4 *Water distribution system.* Check the following:

(a) that all valves are operating freely;

(b) that the system is regulated for even distribution;

(c) that the water levels are correct with sufficient freeboard;

(d) that on an approximate assessment, the inlet water flow is in accordance with **4.6**(a).

6.2 Performance test

6.2.1 *General.* For the performance test take the readings detailed in **6.2.2** and make the check detailed in **6.2.3.**

6.2.2 *Thermal performance test.* To conduct a full thermal performance test, take readings of the following quantities:

(a) wet bulb temperature;

(b) dry bulb temperature;

(c) hot water temperature;

(d) recooled water temperature;

(e) inlet water flow;

(f) make-up water flow and temperature;

(g) purge water flow and temperature;

(h) fan power;

(i) wind velocity.

The number and frequency of the readings to be taken shall be in accordance with **7.3.2.**

Water samples shall be taken when there is reason to believe that the water does not comply with **4.5.**

6.2.3 *Pumping head.* Check that the total head at each tower inlet is correct for design conditions.

6.2.4 *Amenities.* If tests on tower noise and drift nuisance are required, they shall be carried out in accordance with **5.9** and appendix B respectively.

7 Performance test procedure

NOTE. Recommendations for the test personnel are given in appendix A.

7.1 Preparation for test

7.1.1 *Programme.* The programme for the test shall include particulars of the following items:

(a) number of cooling towers to be tested;

(b) number of cells per cooling tower to be tested;

(c) extent and duration of the test;

(d) methods of measurement and measuring equipment;

(e) personnel required;

(f) communications, transport and signals;

(g) temporary power and water supplies, and other facilities;

(h) preparation and circulation of test records.

7.1.2 *Inspection.* Inspect the cooling tower before the tests to ascertain that the conditions of the equipment have not changed since the functional tests carried out in accordance with **6.1.**

7.1.3 *Measurements.* Prepare test record sheets, in advance, clearly indicating the items to be recorded at the various observation points for the observers.

The test record sheets shall record the following:

(a) the serial number of each cooling tower, and of the instruments and any other essential information to identify the instruments and measuring points;

(b) all readings made at each observation point and the exact time at which each was taken, together with any circumstances deserving attention;

(c) the name of the particular observer(s) and the date of test.

7.1.4 *Instruments.* Prior to the test, arrange for a recognized authority to calibrate instruments used in this test over a range covering the test conditions.

Ensure that all necessary instrument corrections and calibration curves are available, so that adequate preliminary calculations can be made and all errors eliminated or accounted for before the tests are terminated, and the test instruments removed.

If any doubt arises about the accuracy or reliability of an instrument, replace it and/or check it by a recalibration as soon as practicable.

7.2 Preliminary tests

It is permissible to run preliminary tests in order to determine whether the equipment and measuring instruments are in suitable condition for the conduct of a performance test, to acquaint the personnel with the test procedure and to determine whether any adjustments or modifications are required.

NOTE 1. The supplier should be allowed to make preliminary tests and to carry out any adjustments or modifications that may be necessary. The supplier should be limited, by written agreement, as to the time to be taken for these preliminary test adjustments and modifications, so that the acceptance tests are not unduly delayed.

NOTE 2. A preliminary test may, if mutually agreed, be considered as an acceptance test, provided it has complied with all the requirements for an acceptance test.

7.3 Test procedure

7.3.1 *Duration of test.* Ensure that the duration of the test is such as to enable steady state conditions to be achieved within the limits specified in **4.6**. Take the readings (at the intervals specified in **7.3.2**) during the hour in which conditions are steadiest, as the test readings.

Increase the period of 1 h by a period equivalent to the thermal lag of the system, as specified in **8.6**, provided this exceeds 15 min.

If the test run is undertaken with the make-up water and purge shut off, the water level in the basin will drop and the concentration of dissolved solids in the circulating water will increase. Therefore, limit the duration of the test run so that the corresponding rise in pumping head will not decrease the inlet water flow by more than 5 % and the increase in the concentration of dissolved solids does not exceed the concentration specified.

7.3.2 *Frequency of readings* (see note 3 to **5.4.2.7**). Take readings:

(a) at regular intervals over the same period of time, at each measuring point;

(b) accurately, even for preliminary tests, so as to be repeatable and to serve as a reliable basis for calculating the test results;

(c) at the frequencies given in table 2.

7.3.3 *Test records.* Prepare complete test record sheets in accordance with **7.1.3**.

NOTE. The test records should be signed by the Chief of Test (see appendix A) and by representatives of both the purchaser and the supplier.

7.3.4 *Preliminary results.* Work out a preliminary assessment of results during the test in order to investigate irregularities, to eliminate detectable faults and errors, and to ensure that the test points are suitable in number and position for determining the final results.

8 Computation of results

8.1 Reduction of test readings

In general, use the arithmetic mean of the quantities during the test period to derive the average values necessary for the final evaluation of the results. However, when conditions of stratification are known to exist compute the mean values of water temperatures in accordance with **8.2** to **8.7**.

8.2 Computation of inlet water temperature

Derive the mean value of the inlet water temperature from the arithmetic mean of the individual readings at each measuring point weighted by the corresponding water velocities at these points to give average hot water temperatures.

8.3 Computation of recooled water temperature with make-up and purge flows shut off

8.3.1 Derive the mean value of the recooled water temperature from the arithmetic mean of the individual readings at each measuring point weighted by the corresponding water velocities at these points to give the average recooled water temperature.

Table 2. Frequency of readings

Quantity	Unit	Recommended number of readings each hour
Wind velocity	m/s	3 to 12 (see **5.1**)
Wet bulb temperature	°C	12
Dry bulb temperature (for natural draught cooling tower)	°C	12
Hot water temperature	°C	12
Recooled water temperature	°C	12
Make-up water temperature	°C	2
Purge water temperature	°C	2
Inlet water flow	m^3/s	12 (see **5.4.2**)
Make-up water flow	m^3/s	2
Purge water flow	m^3/s	2
Tower pumping head	m	2
Fan power	W	1

8.3.2 When the point of measurement for the recooled water temperature is taken at the discharge of the circulating water pump, determine the true recooled water temperature by subtracting the temperature rise of the water across the pump from the measured value.

8.4 Computation of recooled water temperature with make-up and purge flows operating

Where make-up and purge flows exist up-stream of the point of temperature measurement, this point being taken before the circulating water pump, determine the true recooled water temperature readings by heat balance calculation as follows:

$$t_2 = \frac{Q_I t_E + Q_P t_P - Q_M t_M}{Q_I + Q_P - Q_M}$$

NOTE. This equation is based on the assumption that during the test there is no leakage and the make-up water only replaces the evaporation and purge loss (drift losses being neglected).

When the point of measurement for recooled water temperature is taken at the discharge of the circulating water pump, the value of t_E in the equation shall be reduced by the calculated temperature rise across the pump.

8.5 Computation of tower pumping head

Compute the pumping head, which represents the total energy at the cooling tower inlet related to basin kerb level, as the sum of the measurements taken in accordance with **5.6**(a) and (b) and add to this the velocity head, calculated on the basis of the measured water flow and the conduit cross section measured in accordance with **5.6**(c).

8.6 Computation of thermal lag

Calculate the thermal lag of the cooling tower as:

$$\frac{V_B}{Q_I + Q_P}$$

Where the thermal lag exceeds 15 min assume that the period of the recooled water temperature readings lags an equivalent time behind the period of the other readings.

8.7 Computation of fan power

Compute the fan power from measurements of electrical power input to the motor, together with the efficiency quoted by the motor manufacturer.

9 Evaluation of thermal performance

The measure of the thermal performance of a cooling tower is its ability to fulfil guaranteed conditions in terms of fan power, water flow, range, approach and inlet air conditions.

This can be achieved by a direct comparison between the test results and the manufacturer's performance curves, or by reference of the test results to design conditions as described in appendix C.

The effect of measurement errors shall be taken into account when interpreting the results.

NOTE. The reproducibility of this evaluation is ± 5 %. Therefore, the tower should be deemed acceptable if the evaluated result from the test equals or exceeds 95 % of the design capability.

Appendices

Appendix A. Matters to be agreed between purchaser and supplier

A.1 General

The object of the test procedure is to determine the overall operating characteristics of mechanical draught and natural draught cooling towers, and to verify the technical guarantees. To this end the matters listed in **A.2** to **A.6** should be agreed between the purchaser and supplier.

A.2 Technical guarantees

The functional and thermal performance guarantees within the validity specified in clause **4** should be agreed.

The guaranteed thermal performance of the cooling tower should be related to the nominal inlet air conditions at a specified reference position, given in **5.2.2**, which is intended to provide a compromise between measurement of ambient and inlet air conditions.

NOTE. This measurement may detect gross recirculation and in arriving at a specified nominal condition, due allowance should have been made by the purchaser in consultation with the supplier.

A.3 Performance curves

Manufacturer's performance curves should be obtained to show the recooled water temperature at conditions other than the design operating conditions. Charts should be provided to include the variations in nominal inlet wet bulb temperature, inlet water flow and range, specified in **4.4**(b) and **4.6**(a) and (b). In the case of natural draught towers, these curves should also include variations in relative humidity, within the limits specified in **4.4**(c).

The guarantee zone should be clearly marked on all curves.

NOTE. Recirculation effects may be calculated in accordance with BS 4485 : Part 3.

A.4 Date of test

Tests should be carried out within a period of 1 year following the completion of the cooling tower installation, unless otherwise agreed between the purchaser and the supplier.

A.5 Test personnel

A.5.1 Responsibility for tests

Unless otherwise provided in the contract, the purchaser and the supplier should have equal rights in settling all details of test methods, instruments, procedure and in the selection of test personnel. Subject to their agreement, the responsibility for carrying out tests may be assigned to either the purchaser or the supplier, or to an independent authority acceptable to both. All necessary information concerning guarantees and conditions of operation which are required for the acceptance tests should be made available to all parties.

A.5.2 Chief of Test

The test should be controlled and coordinated by one person acceptable to all parties, designated 'Chief of Test'. He should exercise authority over all observers, and be responsible for all measurements. He should conduct and supervise that test, at the conclusion of which he should submit a report to all parties on the operating conditions of the test, and any factors which in his opinion have a bearing on the accuracy of the results.

A.5.3 Competence of personnel

Personnel should include engineers experienced in the measurement of the quantities concerned as detailed in **6.2**.

A.6 Test conditions

The following matters related to the test should be agreed between the purchaser and supplier:

(a) the conditions of validity (see **4.1**);

(b) the location of measurements (see clause **5**);

(c) the instrument used for the measurement of water temperature (see **5.3.1**);

(d) the method of measurement of inlet water flow (see **5.4.2.1**);

(e) the use of preliminary tests (see **7.2**);

(f) the signing of test reports (see **7.3.3**).

Appendix B. Guidance on precipitation rates and determination of droplet size for the evaluation of drift nuisance

B.1 Evaluation of precipitation rate

To ascertain the rate of precipitation from the cooling tower, place a treated cotton cellulose medium fast general purpose filter paper* on the ground in the area subjected to drift nuisance.

Then accurately measure the diameter of the blots registered on the paper and make a detailed count of the numbers of blots according to diameter.

Determine the droplet diameter (in micrometres) for each blot diameter from the curve given in figure 1.

Table 3 lists for each droplet size, within the range 100 μm to 2000 μm, the number of droplets for an exposure time of 1 min which will result in 0.01 mm precipitation per hour over an area 100 mm x 100 mm.

Using table 3, determine in each droplet size bracket the percentage count in relation to the figures in table 3 (correcting for time and area). Then determine the approximate total precipitation by addition of the individual percentages.

B.2 Precipitation rates

Table 4 provides guidance on the effect of drift nuisance in terms of the rate of precipitation measured in millimetres per hour.

The chief source of inaccuracy arises from the problem of exact measurement of the blot diameter, further errors may arise in original positioning of the test papers and moisture falling from trees.

*A Whatman No. 1 filter paper has been found suitable. The Whatman filter paper may be prepared by dusting with powdered potassium permanganate Lisamine Green or Erio Green or be dipped in a 10 g/L solution of potassium ferricyanide. After drying the dipped paper and immediately prior to use, dust liberally with powdered ferrous ammonium sulphate.

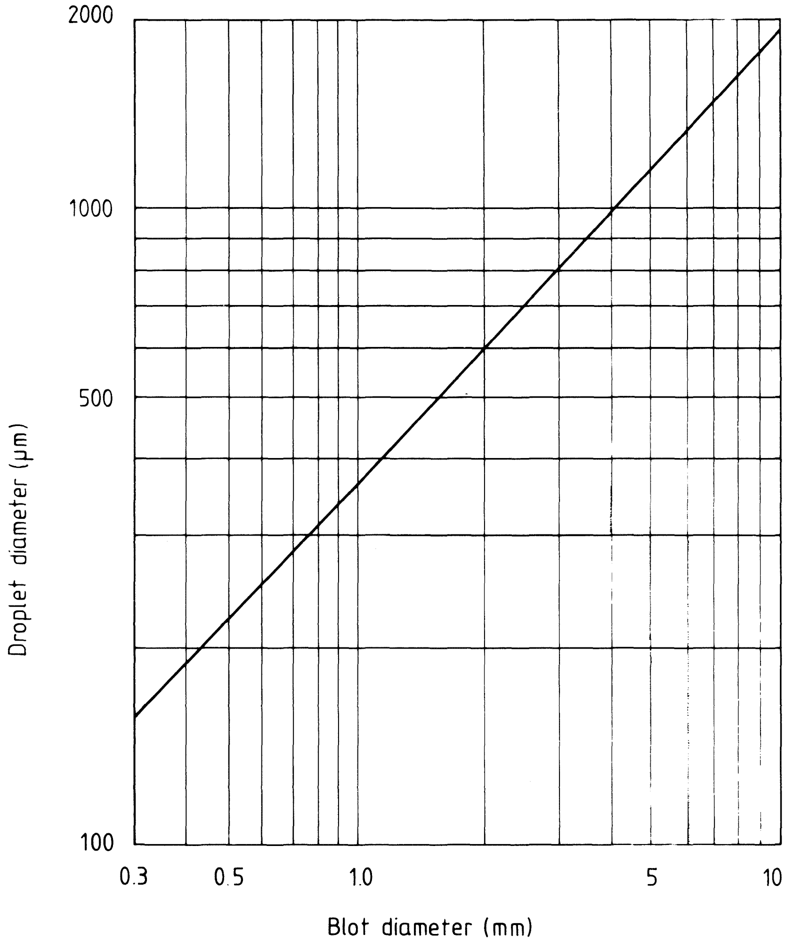

Figure 1. Determination of droplet diameter

Table 3. Precipitation rates for droplet diameters 100 µm to 2000 µm

Droplet diameter	Number of droplets/min per 100 mm × 160 mm per 0.01 mm precipitation	Droplet diameter	Number of droplets/min per 100 mm × 100 mm per 0.01 mm precipitation
µm		µm	
100	3183.0	900	4.4
150	943.0	1000	3.18
200	398.0	1100	2.39
250	204.0	1200	1.84
300	118.0	1300	1.45
350	74.0	1400	1.16
400	50.0	1500	0.94
450	35.0	1600	0.78
500	25.5	1700	0.65
600	14.7	1800	0.54
700	9.3	1900	0.46
800	6.2	2000	0.40

Table 4. Guide to nuisance effects for precipitation rates of 0.05 mm/h to 0.0005 mm/h

Precipitation rate		Effects
mm/h		
Over 0.05	Highly objectionable	Wets ground and may cause puddles of water
0.025 to 0.05	Definitely a nuisance	Wets ground if humidity is high
0.012 to 0.025	Noticeable, opinions are divided on nuisance	Stains parked cars, windows and spectacles
0.005 to 0.012	Easily detected but not obtrusive	Produces a slight tingling sensation on the face
0.0005 to 0.005	Would normally pass unnoticed	Readily detected with sensitized papers
Less than 0.0005	Unnoticeable to the senses	Difficult to detect with sensitized papers

Appendix C. Methods for evaluating test results

C.1 General

This appendix provides a method for evaluating the test results when related to design conditions for counterflow towers.

Although not theoretically correct, it may be used with acceptable accuracy as an empirical method for the evaluation of crossflow towers providing that the ratio L/G is taken to be the ratio of the total mass flows of water and dry air to the tower or cell under test.

The information given in **C.2** to **C.6** relates to a manual method of calculation but the results may be more conveniently achieved by use of a computer program (see appendix D for one in Microsoft Basic).

C.2 Manufacturer's data

The supplier should submit a tower characteristic curve in the form of a plot of tower characteristic, KaV/L, versus water to air flow ratio, L/G. The plot should fit an equation of the form:

$$KaV/L = \lambda(L/G)^n$$

where λ and n are constants for a particular design of packing.

On the same plot, a curve representing design approach, cooling range and wet bulb temperature should be shown and the intersection of the two curves will indicate the design value of L/G.

The plot should cover a range of L/G values from 10 % above to 10 % below design value.

C.3 Determination of test value of *L/G* for mechanical draught

Calculate the test value of L/G from the average water flow rate and fan horsepower during the test using the following equation:

$$(L/G)_t = \frac{\text{Test water loading}}{\text{Design water loading}} \times \left(\frac{W_{hd}}{W_{ht}}\right)^{1/3} \times (L/G)_d$$

C.4 Determination of test value of *L/G* for natural draught

A method for the determination of the test value of L/G for natural draught towers is described in appendix E.

C.5 Determination of test value of *KaV/L*

Calculate the test value of KaV/L from average test values of hot water, recooled water and wet bulb temperatures and the test value of L/G using the following equation:

$$\frac{KaV}{L} = \int_{t_2}^{t_1} \frac{c\mathrm{d}t}{(h_L - h_G)}$$

An example of a numerical method for determining this integral (the Tchebycheff method) is described in appendix F.

NOTE. The Tchebycheff method for numerically evaluating the integral $\int_a^b y\,\mathrm{d}x$ uses values of y at predetermined values of x within the interval a to b, so selected that the sum of these values of y multiplied by a constant times the interval $(b - a)$ gives the desired values of the integral. In its four point form the approximate formula becomes:

$$\int_a^b y\,\mathrm{d}x = \frac{(b - a)}{4}(y_1 + y_2 + y_3 + y_4)$$

where

y_1 are values of y at $x = a + 0.1\ (b - a)$;

y_2 are values of y at $x = a + 0.4\ (b - a)$;

y_3 are values of y at $x = b - 0.4\ (b - a)$;

y_4 are values of y at $x = b - 0.1\ (b - a)$.

Hence for the evaluation of KaV/L,

$$\frac{KaV}{L} = \int_{t_2}^{t_1} \frac{c\mathrm{d}t}{(h_L - h_G)}$$

$$= \frac{t_1 - t_2}{4} \times \left\{ \frac{1}{(h_L - h_G)_1} + \frac{1}{(h_L - h_G)_2} + \frac{1}{(h_L - h_G)_3} + \frac{1}{(h_L - h_G)_4} \right\} \times c$$

Enthalpy values to be used in this calculation are tabulated in table 5 for an atmospheric pressure of 101.325 kPa. This data may be used for locations up to 300 m above sea level without correction for altitude.

C.6 Determination of tower performance

Locate the point representing values calculated in **C.3** or **C.4** and in **C.5** on the manufacturer's plot described in **C.2**. Through this point draw a curve parallel to the tower characteristic curve. The intersection of the line so drawn with the design approach curve determines the value of L/G at which the tower will produce a design approach at design range and wet bulb temperature.

The ratio of this value of L/G to the design value of L/G multiplied by 100 represents the percentage of the design circulating flow which can be cooled at design range, approach and inlet air conditions.

An example of an evaluation for a natural draught tower calculated by this method is given in appendices E and F.
The evaluation for a mechanical draught tower involves the calculations illustrated in appendix F following correction of L/G in accordance with **C.3**.

Table 5. Enthalpy of saturated air

Temperature	Interval (°C)										Temperature
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	
	Enthalpy (kJ/kg dry air)										
°C											°C
0	9.44	9.61	9.78	9.95	10.12	10.30	10.47	10.64	10.82	10.99	0
1	11.16	11.34	11.52	11.69	11.87	12.05	12.22	12.40	12.58	12.76	1
2	12.94	13.12	13.30	13.48	13.66	13.85	14.03	14.21	14.40	14.58	2
3	14.77	14.95	15.14	15.32	15.51	15.70	15.89	16.08	16.27	16.46	3
4	16.65	16.84	17.03	17.22	17.42	17.61	17.80	18.00	18.19	18.39	4
5	18.59	18.78	18.98	19.18	19.38	19.58	19.78	19.98	20.18	20.38	5
6	20.59	20.79	21.00	21.20	21.41	21.61	21.82	22.03	22.23	22.44	6
7	22.65	22.86	23.07	23.29	23.50	23.71	23.92	24.14	24.35	24.57	7
8	24.79	25.00	25.22	25.44	25.66	25.88	26.10	26.32	26.55	26.77	8
9	26.99	27.22	27.44	27.67	27.90	28.13	28.35	28.58	28.81	29.05	9
10	29.28	29.51	29.74	29.98	30.21	30.45	30.69	30.92	31.16	31.40	10
11	31.64	31.88	32.13	32.37	32.61	32.86	33.10	33.35	33.59	33.84	11
12	34.09	34.34	34.59	34.84	35.10	35.35	35.61	35.86	36.12	36.37	12
13	36.63	36.89	37.15	37.41	37.67	37.94	38.20	38.47	38.73	39.00	13
14	39.27	39.54	39.81	40.08	40.35	40.62	40.90	41.17	41.45	41.73	14
15	42.00	42.28	42.56	42.85	43.13	43.41	43.70	43.98	44.27	44.56	15
16	44.85	45.14	45.43	45.72	46.02	46.31	46.61	46.90	47.20	47.50	16
17	47.80	48.10	48.41	48.71	49.02	49.32	49.63	49.94	50.25	50.56	17
18	50.87	51.19	51.50	51.82	52.14	52.46	52.78	53.10	53.42	53.75	18
19	54.07	54.40	54.73	55.06	55.39	55.72	56.05	56.39	56.72	57.06	19
20	57.40	57.74	58.08	58.43	58.77	59.12	59.46	59.81	60.16	60.51	20
21	60.87	61.22	61.58	61.94	62.29	62.66	63.02	63.38	63.75	64.11	21
22	64.48	64.85	65.22	65.59	65.97	66.34	66.72	67.10	67.48	67.86	22
23	68.25	68.63	69.02	69.41	69.80	70.19	70.59	70.98	71.38	71.78	23
24	72.18	72.58	72.98	73.39	73.80	74.21	74.62	75.03	75.44	75.86	24
25	76.28	76.70	77.12	77.54	77.97	78.39	78.82	79.25	79.69	80.12	25
26	80.56	81.00	81.44	81.88	82.32	82.77	83.22	83.67	84.12	84.57	26
27	85.03	85.49	85.95	86.41	86.87	87.34	87.81	88.28	88.75	89.22	27
28	89.70	90.18	90.66	91.14	91.63	92.11	92.60	93.09	93.59	94.08	28
29	94.58	95.08	95.58	96.09	96.60	97.11	97.62	98.13	98.65	99.17	29
30	99.69	100.21	100.74	101.26	101.79	102.33	102.86	103.40	103.94	104.48	30
31	105.03	105.57	106.12	106.68	107.23	107.79	108.35	108.91	109.48	110.04	31
32	110.61	111.19	111.76	112.34	112.92	113.50	114.09	114.68	115.27	115.86	32
33	116.46	117.06	117.66	118.27	118.88	119.49	120.10	120.72	121.34	121.96	33
34	122.59	123.21	123.84	124.48	125.11	125.75	126.40	127.04	127.69	128.34	34
35	129.00	129.66	130.32	130.98	131.65	132.32	132.99	133.67	134.35	135.03	35
36	135.72	136.41	137.10	137.80	138.50	139.20	139.91	140.62	141.33	142.05	36
37	142.77	143.49	144.21	144.94	145.68	146.41	147.16	147.90	148.65	149.40	37
38	150.15	150.91	151.67	152.44	153.21	153.98	154.76	155.54	156.32	157.11	38
39	157.90	158.70	159.50	160.30	161.11	161.92	162.73	163.55	164.37	165.20	39
40	166.03	166.87	167.71	168.55	169.40	170.25	171.10	171.96	172.83	173.69	40
41	174.57	175.44	176.32	177.21	178.10	178.99	179.89	180.79	181.70	182.61	41
42	183.53	184.45	185.37	186.30	187.24	188.18	189.12	190.07	191.02	191.98	42
43	192.94	193.91	194.88	195.86	196.84	197.83	198.82	199.82	200.82	201.82	43
44	202.84	203.85	204.87	205.90	206.93	207.97	209.01	210.06	211.11	212.17	44
45	213.24	214.31	215.38	216.46	217.55	218.64	219.73	220.84	221.94	223.06	45
46	224.18	225.30	226.43	227.57	228.71	229.86	231.01	232.17	233.34	234.51	46
47	235.69	236.87	238.06	239.26	240.46	241.67	242.88	244.10	245.33	246.56	47
48	247.80	249.05	250.30	251.56	252.83	254.10	255.38	256.67	257.96	259.26	48
49	260.57	261.88	263.20	264.53	265.86	267.20	268.55	269.90	271.27	272.64	49

Table 5 *(concluded)*

Temperature	Interval (°C) 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Temperature
	Enthalpy (kJ/kg dry air)										
°C											°C
50	274.01	275.40	276.79	278.19	279.59	281.01	282.43	283.86	285.29	286.74	50
51	288.19	289.65	291.12	292.59	294.08	295.57	297.07	298.57	300.09	301.61	51
52	303.15	304.69	306.24	307.79	309.36	310.93	312.51	314.11	315.71	317.31	52
53	318.93	320.56	322.19	323.84	325.49	327.15	328.82	330.51	332.19	333.89	53
54	335.60	337.32	339.05	340.79	342.53	344.29	346.06	347.83	349.62	351.42	54
55	353.22	355.04	356.87	358.70	360.55	362.41	364.28	366.15	368.04	369.94	55
56	371.86	373.78	375.71	377.65	379.61	381.57	383.55	385.54	387.54	389.55	56
57	391.57	393.61	395.66	397.71	399.78	401.87	403.96	406.07	408.19	410.32	57
58	412.46	414.62	416.79	418.97	421.16	423.37	425.59	427.82	430.07	432.33	58
59	434.60	436.89	439.19	441.50	443.83	446.17	448.53	450.90	453.28	455.68	59
60	458.09	460.52	462.96	465.42	467.89	470.38	472.88	475.39	477.93	480.47	60
61	483.04	485.62	488.21	490.82	493.45	496.09	498.75	501.43	504.12	506.83	61
62	509.56	512.30	515.06	517.84	520.63	523.44	526.27	529.12	531.99	534.87	62
63	537.77	540.70	543.64	546.59	549.57	552.57	555.58	558.62	561.67	564.74	63
64	567.84	570.95	574.09	577.24	580.41	583.61	586.83	590.07	593.32	596.60	64
65	599.91	603.23	606.58	609.94	613.33	616.75	620.18	623.64	627.12	630.63	65
66	634.16	637.71	641.28	644.89	648.51	652.16	655.83	659.53	663.26	667.01	66
67	670.79	674.59	678.42	682.27	686.16	690.06	694.00	697.97	701.96	705.98	67
68	710.02	714.10	718.21	722.34	726.51	730.70	734.92	739.18	743.46	747.78	68
69	752.12	756.50	760.91	765.35	769.83	774.33	778.87	783.45	788.05	792.69	69
70	797.37	802.08	806.82	811.60	816.42	821.27	826.16	831.09	836.05	841.05	70
71	846.09	851.17	856.28	861.43	866.63	871.86	877.14	882.45	887.81	893.21	71
72	898.65	904.13	909.66	915.24	920.85	926.51	932.21	937.96	943.76	949.60	72
73	955.49	961.43	967.41	973.45	979.53	985.66	991.85	998.08	1004.37	1010.70	73
74	1017.10	1023.54	1030.04	1036.59	1043.20	1049.86	1056.58	1063.36	1070.20	1077.09	74
75	1084.04	1091.06	1098.13	1105.27	1112.46	1119.73	1127.05	1134.44	1141.89	1149.41	75
76	1157.00	1164.65	1172.38	1180.17	1188.03	1195.97	1203.98	1212.06	1220.21	1228.44	76
77	1236.74	1245.13	1253.59	1262.13	1270.75	1279.45	1288.23	1297.10	1306.05	1315.08	77
78	1324.21	1333.42	1342.72	1352.11	1361.59	1371.17	1380.84	1390.61	1400.47	1410.43	78
79	1420.49	1430.65	1440.92	1451.29	1461.76	1472.34	1483.03	1493.84	1504.75	1515.77	79
80	1526.92	1538.18	1549.55	1561.06	1572.67	1584.42	1596.29	1608.29	1620.43	1632.69	80
81	1645.09	1657.62	1670.30	1683.11	1696.06	1709.17	1722.43	1735.82	1749.38	1763.09	81
82	1776.96	1790.98	1805.18	1819.53	1834.06	1848.76	1863.63	1878.68	1893.92	1909.33	82
83	1924.94	1940.74	1956.72	1972.91	1989.30	2005.89	2022.69	2039.71	2056.94	2074.38	83
84	2092.05	2109.96	2128.10	2146.47	2165.09	2183.95	2203.07	2222.43	2242.07	2261.97	84
85	2282.14	2302.59	2323.32	2344.35	2365.66	2387.27	2409.20	2431.44	2454.00	2476.88	85
86	2500.10	2523.66	2547.57	2571.84	2596.47	2621.47	2646.85	2672.63	2698.80	2725.38	86
87	2752.37	2779.80	2807.65	2835.96	2864.71	2893.94	2923.66	2953.86	2984.57	3015.78	87
88	3047.53	3079.82	3112.67	3146.09	3180.09	3214.69	3249.90	3285.76	3322.26	3359.41	88
89	3397.27	3435.82	3475.11	3515.12	3555.90	3597.49	3639.85	3683.07	3727.15	3772.09	89

Appendix D. Computer program for calculating performance capability

A program in Microsoft Basic for calculating performance capability is as follows.

NOTE. In this appendix the references to BS 4485 : Part 2 : 1987 should be read as 'BS 4485 : Part 2 : 1988'.

```
10  REM  ********  Program P4485   Rev. 6  Date: 30 January 1987  ********
12  M$='        EVALUATION OF THERMAL PERFORMANCE: WATER COOLING TOWER'
14  L$=' ****************************************************************'
16  N$='                  TEST METHOD TO BS 4485: PART 2:1987'
18  Q$='                    INPUT FROM VDU. OUTPUT TO VDU'
20  PRINT L$
22  PRINT M$
24  PRINT N$
26  PRINT Q$
28  PRINT L$
30  PRINT
32  PRINT ' ********************** INPUT DESIGN DATA *********************'
34  PRINT
36  PRINT ' IS IT A MECHANICAL OR A NATURAL DRAUGHT TOWER ? (Input M or N)'
38  INPUT LINE I$
40  IF SUB(I$,1)='M' THEN 46
42  IF SUB(I$,1)='N' THEN 46
44  GOTO 36
46  D$=SUB(I$,1)
48  PRINT ' DESIGN INLET WATER FLOW  (m3/s)  ?'
50  INPUT Q1
52  PRINT ' DESIGN HOT WATER TEMPERATURE  (C)  ?'
54  INPUT T1
56  PRINT ' DESIGN RECOOLED WATER TEMPERATURE  (C)  ?'
58  INPUT T2
60  IF D$='M' THEN 66
62  PRINT ' DESIGN DRY BULB TEMPERATURE OF INLET AIR  (C)  ?'
64  INPUT D1
66  PRINT ' DESIGN WET BULB TEMPERATURE OF INLET AIR  (C)  ?'
68  INPUT W1
70  IF D$='N' THEN 76
72  PRINT ' DESIGN FAN POWER  (kW)  ?'
74  INPUT P3
76  PRINT ' IS THE DESIGN BASED ON ATMOS. PRESSURE, OR ALTITUDE? (Input P or A)'
78  INPUT LINE P$
80  IF P$='P' THEN 86
82  IF P$='A' THEN 92
84  GOTO 76
86  PRINT ' DESIGN ATMOSPHERIC PRESSURE  (kPa)  ?'
88  INPUT P1
90  GOTO 96
92  PRINT ' DESIGN ALTITUDE  (m  above sea level)  ?'
94  INPUT A1
96  PRINT ' DESIGN AIR/WATER RATIO L/G  ?'
98  INPUT J1
100 PRINT ' "n" VALUE FOR TOWER CHARACTERISTIC CURVE KaV/L=C*(L/G)^n  ?'
102 INPUT N1
104 N1=-ABS(N1)
106 PRINT
108 PRINT ' ********************** INPUT TEST DATA **********************'
110 PRINT
112 PRINT ' TEST INLET WATER FLOW  (m3/s)  ?'
114 INPUT Q2
116 PRINT ' TEST HOT WATER TEMPERATURE  (C)  ?'
118 INPUT T5
120 PRINT ' TEST RECOOLED WATER TEMPERATURE  (C)  ?'
122 INPUT T6
124 IF D$='M' THEN 130
126 PRINT ' TEST DRY BULB TEMPERATURE OF INLET AIR  (C)  ?'
128 INPUT D2
130 PRINT ' TEST WET BULB TEMPERATURE OF INLET AIR  (C)  ?'
132 INPUT W2
134 IF D$='N' THEN 140
136 PRINT ' TEST FAN POWER  (kW)  ?'
```

```
 138   INPUT P4
 140   PRINT ' Calculating ...
 142   REM      SET LOOP TOLERANCES FOR KaV/L, L/G (TEST), ENTHALPY BALANCE
 144   REM      AND EXPECTED WATER TEMPERATURE ( Ref. Line 7016 - 7018 )
 146   Y1=1.E-05
 148   Y2=2.E-05
 150   Y3=.0015
 152   Y4=.0001
 154   REM      **************** READ DATA, DEFINE FUNCTIONS ****************
 156   READ A,B,C,D,E,F,G,T0,T9,M1,M2,C1,C2,C3,L0,R0,P9,B1,B2
 158   DIM N(4),W(4),A(4),D(4),T(6),E(2)
 160   READ N(1),N(2),N(3),N(4),C0
 162   GOSUB 3020
 164   REM      ************************ CALCULATIONS ***********************
 166   IF D$='M' THEN  GOSUB 1010
 168   IF D$='N' THEN  GOSUB 2010
 170   IF F0+F1+F2+F3+F6+F7+F8=0 THEN  GOSUB 2852
 172   REM      ********* PRINT OUTPUT (AND WARNINGS - IF APPLICABLE) ********
 174   GOSUB 4006
 176   GOSUB 4306
 178   END
1000   REM      ***********************************************************
1002   REM       SUBROUTINE: CALCULATION OF TOWER CAPABILITY - MECH. DRAUGHT
1004   REM      ***********************************************************
1006   REM      ********************* CHECK DATA INPUT *********************
1008   REM      *** SET ERROR FLAG F7 (INPUT DATA ERROR)
1010   F7=0
1012   REM      *** SET ERROR FLAG F3 (NO CONVERGENCE)
1014   F3=0
1016   IF W1<3 THEN  F7=1
1018   IF W2<3 THEN  F7=1
1020   IF T2<=W1 THEN  F7=1
1022   IF T6<=W2 THEN  F7=1
1024   IF T1<=T2 THEN  F7=1
1026   IF T5<=T6 THEN  F7=1
1028   IF T1>90 THEN  F7=1
1030   IF T5>90 THEN  F7=1
1032   IF P$='A' THEN  P1=FNP(A1)
1034   REM * TEST ATMOSPHERIC PRESSURE IS ASSUMED EQUAL TO THE DESIGN VALUE *
1036   REM SEA LEVEL PRESSURE IS USED FOR ALTITUDES UP TO 300 m (BS4485: Pt 3)
1038   IF P1>=FNP(300) THEN  IF P1<FNP(0) THEN  P1=FNP(0)
1040   IF P1<70 THEN  F7=1
1042   R1=T1-T2
1044   IF F7=1 THEN 1198
1046   REM      ******************* CALCULATE DESIGN KaV/L ******************
1048   P0=P1
1050   D0=W1
1052   W0=W1
1054   V0=FNV(W0)
1056   E(1)=FNE(D0)
1058   REM      *** SET ERROR FLAG F8 (NEGATIVE ENTHALPY DRIVING FORCE)
1060   F8=0
1062   FOR I=1,4
1064   T=T2+N(I)*R1
1066   D0=T
1068   W0=T
1070   V0=FNV(W0)
1072   W(I)=FNE(D0)
1074   A(I)=E(1)+N(I)*R1*J1*C0
1076   IF W(I)<A(I) THEN  F8=1
1078   D(I)=1/(W(I)-A(I))
1080   NEXT I
1082   IF F8=1 THEN 1198
1084   K1=R1/4*(D(1)+D(2)+D(3)+D(4))*C0
1086   REM      ************* CALCULATE TEST L/G AND TEST KaV/L *************
1088   J2=J1*Q2/Q1*(P3/P4)^(1/3)
1090   R2=T5-T6
1092   P2=P1
1094   P0=P2
1096   D0=W2
1098   W0=W2
1100   V0=FNV(W0)
```

```
1102  E(2)=FNE(DO)
1104  REM      *** SET ERROR FLAG F8 (NEGATIVE ENTHALPY DRIVING FORCE)
1106  F8=0
1108  FOR I=1,4
1110  T=T6+N(I)*R2
1112  DO=T
1114  WO=T
1116  VO=FNV(WO)
1118  W(I)=FNE(DO)
1120  A(I)=E(2)+N(I)*R2*J2*CO
1122  IF W(I)<A(I) THEN  F8=1
1124  D(I)=1/(W(I)-A(I))
1126  NEXT I
1128  IF F8=1 THEN 1198
1130  K2=R2/4*(D(1)+D(2)+D(3)+D(4))*CO
1132  REM  * SOLVE FOR L/G: TEST TOWER CHARACTERISTICS & DESIGN DEMAND CURVE
1134  REM      *** SET ERROR FLAG F8 (NEGATIVE ENTHALPY DRIVING FORCE)
1136  F8=0
1138  I3=1
1140  I8=1
1142  J3=J2
1144  D8=SGN(K3-K4)
1146  K3=K2*(J3/J2)^N1
1148  FOR I=1,4
1150  T=T2+N(I)*R1
1152  DO=T
1154  WO=T
1156  VO=FNV(WO)
1158  W(I)=FNE(DO)
1160  A(I)=E(1)+N(I)*R1*J3*CO
1162  IF W(I)<A(I) THEN  F8=1
1164  D(I)=1/(W(I)-A(I))
1166  NEXT I
1168  IF F8=0 THEN 1176
1170  F8=0
1172  J3=J3-.1
1174  GOTO 1144
1176  K4=R1/4*(D(1)+D(2)+D(3)+D(4))*CO
1178  IF ABS(K3-K4)<Y1 THEN 1196
1180  IF I3=50 THEN  F3=1
1182  IF I3=50 THEN 1198
1184  IF D8<>0 THEN  IF D8<>SGN(K3-K4) THEN  I8=.5*I8
1186  J3=J3+SGN(K3-K4)*I8
1188  IF J3<0 THEN  J3=.01
1190  I3=I3+1
1192  GOTO 1144
1194  REM      *********** CALCULATE PERCENTAGE TOWER CAPABILITY ************
1196  E5=100*J3/J1
1198  RETURN
2000  REM      ************************************************************
2002  REM       SUBROUTINE: CALCULATION OF TOWER CAPABILITY - NATURAL DRAUGHT
2004  REM      ************************************************************
2006  REM      ********************* CHECK DATA INPUT *********************
2008  REM      *** SET ERROR FLAG F7 (INPUT DATA ERROR)
2010  F7=0
2012  REM      *** SET ERROR FLAGS F0, F1, F2, F3 (NO CONVERGENCE)
2014  F0=0
2016  F1=0
2018  F2=0
2020  F3=0
2022  IF W1<3 THEN  F7=1
2024  IF W2<3 THEN  F7=1
2026  IF T2<=W1 THEN  F7=1
2028  IF T6<=W2 THEN  F7=1
2030  IF T1<=T2 THEN  F7=1
2032  IF T5<=T6 THEN  F7=1
2034  IF T1>90 THEN  F7=1
2036  IF T5>90 THEN  F7=1
2038  IF D1<W1 THEN  F7=1
2040  IF D2<W2 THEN  F7=1
```

```
2042  IF P$='A' THEN  P1=FNP(A1)
2044  REM * TEST ATMOSPHERIC PRESSURE IS ASSUMED EQUAL TO THE DESIGN VALUE *
2046  REM SEA LEVEL PRESSURE IS USED FOR ALTITUDES UP TO 300 m (BS4485: Pt 3)
2048  IF P1>=FNP(300) THEN  IF P1<FNP(0) THEN  P1=FNP(0)
2050  IF P1<70 THEN  F7=1
2052  R1=T1-T2
2054  REM     ******** PROPERTIES OF INLET AIR AT DESIGN CONDITIONS ********
2056  P0=P1
2058  D0=D1
2060  W0=W1
2062  V0=FNV(W0)
2064  U1=FNR(W0)
2066  IF U1<40 THEN  F7=1
2068  IF F7=1 THEN 2346
2070  E1=FNE(D0)
2072  X1=FND(V0)
2074  E6=E1+R1*J1*C0
2076  REM    PROPERTIES OF EXIT AIR AT DESIGN CONDITIONS (ASSUME SATURATION)
2078  I0=1
2080  I7=10
2082  T7=40
2084  E7=E6
2086  D7=SGN(E6-E7)
2088  D0=T7
2090  W0=T7
2092  V0=FNV(W0)
2094  E7=FNE(D0)
2096  IF ABS(E6-E7)<Y3 THEN 2110
2098  IF I0=50 THEN  F0=1
2100  IF I0=50 THEN 2346
2102  IF D7<>0 THEN  IF D7<>SGN(E6-E7) THEN  I7=.5*I7
2104  T7=T7+SGN(E6-E7)*I7
2106  I0=I0+1
2108  GOTO 2086
2110  X2=FND(V0)
2112  REM     ****************** CALCULATE DESIGN KaV/L ******************
2114  REM     *** SET ERROR FLAG F8 (NEGATIVE ENTHALPY DRIVING FORCE)
2116  F8=0
2118  D0=W1
2120  W0=W1
2122  V0=FNV(W0)
2124  E(1)=FNE(D0)
2126  FOR I=1,4
2128  T=T2+N(I)*R1
2130  D0=T
2132  W0=T
2134  V0=FNV(W0)
2136  W(I)=FNE(D0)
2138  A(I)=E(1)+N(I)*R1*J1*C0
2140  IF W(I)<A(I) THEN  F8=1
2142  D(I)=1/(W(I)-A(I))
2144  NEXT I
2146  IF F8=1 THEN 2346
2148  K1=R1/4*(D(1)+D(2)+D(3)+D(4))*C0
2150  REM     ********* PROPERTIES OF INLET AIR AT TEST CONDITIONS *********
2152  R2=T5-T6
2154  P2=P1
2156  P0=P2
2158  D0=D2
2160  W0=W2
2162  V0=FNV(W0)
2164  U2=FNR(W0)
2166  IF U2<40 THEN  F7=1
2168  IF F7=1 THEN 2346
2170  E2=FNE(D0)
2172  X3=FND(V0)
2174  REM     ******************** CALCULATE TEST L/G ********************
2176  J4=J1
2178  I2=1
2180  E8=E2+R2*J4*C0
2182  REM     PROPERTIES OF EXIT AIR AT TEST CONDITIONS (ASSUME SATURATION)
2184  I1=1
2186  I8=10
```

```
2332  IF D8<>0 THEN  IF D8<>SGN(K3-K4) THEN  I8=.5*I8
2334  J3=J3+SGN(K3-K4)*I8
2336  IF J3<0 THEN  J3=.01
2338  I3=I3+1
2340  GOTO 2292
2342  REM     *********** CALCULATE PERCENTAGE TOWER CAPABILITY ************
2344  E5=100*J3/J1
2346  RETURN
2800  REM     ************************************************************
2802  REM       SUBROUTINE: ALTERNATIVE PRESENTATION OF CAPABILITY
2804  REM         OF WATER COOLING TOWER IN TERMS OF TEMPERATURE
2806  REM     ************************************************************
2808  REM     It may be desirable to express the capability of a water
2810  REM     cooling tower as the difference in recooled water temperature
2812  REM     between that obtained on the actual cooling tower under test
2814  REM     and that expected from the designed cooling tower when
2816  REM     operating at test conditions of water flow rate,
2818  REM     cooling range, fan power, wet and dry bulb temperatures.
2820  REM
2822  REM     METHOD OF SOLUTION: An inherent feature of this method
2824  REM     of evaluation is that the water/air ratio remains constant and
2826  REM     equal to the test value of L/G. The first step is to calculate
2828  REM     the theoretical value of KaV/L for a 100 % efficient tower
2830  REM     from the design tower characteristics at test value of L/G.
2832  REM     Then, the corresponding value of theoretical recooled water
2834  REM     temperature is obtained by iteration to match the above
2836  REM     theoretical KaV/L. This calculation uses test conditions
2838  REM     of water flow, cooling range, fan power, wet & dry bulb air
2840  REM     temperatures. Finally, the theoretical and test values of
2842  REM     recooled water temperature are compared in order to assess
2844  REM     the capability of the cooling tower under test in terms
2846  REM     of temperature.
2848  REM
2850  REM     *** SET ERROR FLAG F4  (NO CONVERGENCE)
2852  F4=0
2854  REM     *** SET ERROR FLAG F8 (NEGATIVE ENTHALPY DRIVING FORCE)
2856  F8=0
2858  I4=1
2860  I9=1
2862  IF T6-W2<3 THEN  I9=.2
2864  IF ABS(E5-100)<20 THEN  I9=.2
2866  R2=T5-T6
2868  T(6)=T6+.05*(E5-100)
2870  IF T(6)<W2+3*I9 THEN  T(6)=W2+3*I9
2872  D9=SGN(K5-K7)
2874  K5=K1*(J2/J1)^N1
2876  FOR I=1,4
2878  T=T(6)+N(I)*R2
2880  D0=T
2882  W0=T
2884  V0=FNV(W0)
2886  W(I)=FNE(D0)
2888  A(I)=E(2)+N(I)*R2*J2*C0
2890  IF W(I)<A(I) THEN  F8=1
2892  D(I)=1/(W(I)-A(I))
2894  NEXT I
2896  IF F8=1 THEN 2916
2898  K7=R2/4*(D(1)+D(2)+D(3)+D(4))*C0
2900  IF ABS(K5-K7)<Y4 THEN 2914
2902  IF I4=50 THEN  F4=1
2904  IF I4=50 THEN 2916
2906  IF D9<>0 THEN  IF D9<>SGN(K5-K7) THEN  I9=.5*I9
2908  T(6)=T(6)-SGN(K5-K7)*I9
2910  I4=I4+1
2912  GOTO 2872
2914  D5=T(6)-T6
2916  RETURN
3000  REM     *************************************************************
3002  REM                     SUBROUTINE: PSYCHROMETRY (S.I. Units)
```

```
3004  REM      Reference (1): BS 2520: 1983, Barometer conventions and tables
3006  REM      Reference (2):  C.E.R.L. Report RD/L/M 198, June 1968
3008  REM                      Psychrometric data for moist air (in S.I. units)
3010  REM      Source for Ref.(2): 1963, Proceedings, International Symposium
3012  REM                          on Humidity and Moisture (various authors)
3014  REM      **************************************************************
3016  REM
3018  REM      ********** SATURATION VAPOUR PRESSURE OF WATER (Pa) **********
3020  DEF FNV(WO)=10^(A/(WO+TO)+B*LOG(WO+TO)+C*10^(D*(WO-.01))+E*10^(F*(1-T9/(WO+TO)))+G)
3022  REM      ****** SPECIFIC HUMIDITY (kg water vapour / kg dry air) ******
3024  DEF FNW(VO)=M1/M2*(VO-1000*PO*C1*(DO-WO))/(1000*PO-VO+1000*PO*C1*(DO-WO))
3026  REM      ** SPECIFIC ENTHALPY (kJ/kg dry air+associated water vapour **
3028  DEF FNE(DO)=C2*DO+FNW(VO)*(LO+C3*DO)
3030  REM      *SPECIFIC VOLUME OF MOIST AIR (m3 air+water vapour/kg dry air)
3032  DEF FNS(WO)=RO*(DO+TO)/(M2*(1000*PO-VO+1000*PO*C1*(DO-WO)))*1000
3034  REM      **************** DENSITY OF MOIST AIR (kg/m3) ****************
3036  DEF FND(VO)=(1+FNW(VO))/FNS(WO)
3038  REM      **************** PERCENTAGE RELATIVE HUMIDITY ****************
3040  DEF FNR(WO)=100*(FNV(WO)-1000*PO*C1*(DO-WO))/FNV(DO)
3042  REM      ** STANDARD ATMOSPHERIC PRESSURE (kPa) vs. ALTITUDE ( m asl) *
3044  DEF FNP(X)=P9+B1*X+B2*X*X
3046  REM      *********************** OUTPUT FORMAT **********************
3048  DEF FNA(X)=INT(100*X+.5)/100
3050  DEF FNB(X)=INT(1000*X+.5)/1000
3052  RETURN
4000  REM      **************************************************************
4002  REM            SUBROUTINE: OUTPUT TO VDU DESIGN DATA & TEST RESULTS
4004  REM      **************************************************************
4006  PRINT L$
4008  PRINT M$
4010  T$='MECHANICAL'
4012  IF D$='N' THEN  T$='NATURAL'
4014  PRINT '                          TYPE: ':T$:'DRAUGHT'
4016  PRINT N$
4018  PRINT L$
4020  PRINT
4022  PRINT ' ',' ','DESIGN','TEST':'  LIMITS OF VALIDITY'
4024  PRINT ' ',' ','DATA','DATA':'        OF TEST'
4026  PRINT
4028  PRINT ' Water flow        (m3/s)',Q1,Q2,FNA(.9*Q1):'-':FNA(1.1*Q1)
4030  PRINT ' Hot water temp.        (C)',T1,T5
4032  PRINT ' Recooled water temp.  (C)',T2,T6
4034  PRINT ' Cooling range          (K)',FNA(R1),FNA(R2),FNA(.8*R1):'-':FNA(1.2*R1)
4036  H1=INT(1000*Q1*R1)
4038  H2=INT(1000*Q2*R2)
4040  PRINT ' Heat load         (kcal/s)',H1,H2,INT(.8*H1+.5):'-':INT(1.2*H1+.5)
4042  IF D$='N' THEN  PRINT ' Inlet dry bulb temp. (C)',D1,D2
4044  L1=W1-5
4046  IF L1<3 THEN  L1=3
4048  PRINT ' Inlet wet bulb temp. (C)',W1,W2,L1:'-':L1+10
4050  IF D$='N' THEN  PRINT ' Inlet rel. humidity  (%)',FNA(U1),FNA(U2),'40 - 100 '
4052  IF D$='M' THEN  PRINT ' Fan power            (kW)',P3,P4
4054  R$=''
4056  IF A1>0 THEN  IF P1=FNP(0) THEN  R$='See NOTE (1)'
4058  PRINT ' Atmos. pressure    (kPa)',FNB(P1),'Design value',R$
4060  IF P$='A' THEN  PRINT ' Altitude          (m asl) ',A1,'-'
4062  PRINT ' L/G water/air ratio',J1,FNB(J2)
4064  PRINT ' "n" for KaV/L=C*(L/G)^n',N1,'Design value'
4066  PRINT ' Tower KaV/L          ',FNB(K1),FNB(K2)
4068  PRINT
4070  PRINT ' TOWER CAPABILITY      (%)','100',FNA(E5)
4072  IF F0+F1+F2+F3+F4+F6+F7+F8>0 THEN 4082
4074  PRINT ' EXPECTED RECOOLED WATER TEMPERATURE (C)',FNA(T6+D5)
4076  IF FNA(D5)<0 THEN  PRINT ' WORSE THAN DESIGN BY':FNA(ABS(D5)):'(K)'
4078  IF FNA(D5)>0 THEN  PRINT ' BETTER THAN DESIGN BY':FNA(D5):'(K)'
4080  IF FNA(D5)=0 THEN  PRINT ' EQUAL TO DESIGN'
4082  PRINT
4084  IF R$='' THEN 4092
4086  PRINT ' NOTE (1): For altitudes 0-300 m above sea level, the test data'
4088  PRINT ' is evaluated at mean sea level pressure (BS 4485: Pt 3)'
4090  PRINT
4092  RETURN
```

```
4300  REM      ***********************************************************
4302  REM       SUBROUTINE: PRINT WARNINGS IF APPLICABLE
4304  REM      ***********************************************************
4306  IF F0=1 THEN  PRINT ' *** WARNING:  NO CONVERGENCE (DESIGN EXIT AIR TEMP.)'
4308  IF F1=1 THEN  PRINT ' *** WARNING:  NO CONVERGENCE (TEST EXIT AIR TEMP.)'
4310  IF F2=1 THEN  PRINT ' *** WARNING:  NO CONVERGENCE (TEST L/G)'
4312  IF F3=1 THEN  PRINT ' *** WARNING:  NO CONVERGENCE (L/G FOR TOWER CAPABILITY)'
4314  IF F4=1 THEN  PRINT ' *** WARNING:  NO CONVERGENCE (EXPECTED COLD WATER TEMP.)'
4316  IF F6=1 THEN  PRINT ' *** WARNING:  NEGATIVE DRAUGHT'
4318  IF F7=1 THEN  PRINT ' *** WARNING:  INPUT DATA ERROR'
4320  IF F8=1 THEN  PRINT ' *** WARNING:  NEGATIVE ENTHALPY DRIVING FORCE'
4322  RETURN
5000  REM      *********** DATA FOR FNV(X): A,B,C,D,E,F,G,T0,T9 *************
5002  DATA -2948.997118,-2.1836674,-.000150474,-.0303738468,.00042873
5004  DATA 4.76955,25.83220018,273.15,273.16
5006  REM      ****************** DATA FOR FNW(WO): M1,M2,C1 ****************
5008  DATA 18.01534,28.9645,.000666
5010  REM      ***************** DATA FOR FNE(DO): C2,C3,L0 *****************
5012  DATA 1.00568,1.84598,2500.84
5014  REM      ******************** DATA FOR FNS(WO): R0 *******************
5016  DATA 8.31432
5018  REM      ***************** DATA FOR FNP(X): P9,B1,B2 *****************
5020  DATA 101.325,-.0118917,4.94444E-07
5022  REM      ***** DATA FOR N(4): INTERVALS FOR NUMERICAL INTEGRATION *****
5024  DATA .1,.4,.6,.9
5026  REM      ********** SPECIFIC HEAT OF WATER (Reference 2): C0 **********
5028  DATA 4.18684
7000  REM      *********** Program P4485: Rev. 6: GENERAL NOTES *************
7002  REM
7004  REM  (A) The program uses constants of up to 10 digits for water vapour
7006  REM  pressure correlation vs. temperature. This version of the program
7008  REM  is also suitable for single precision BASIC with data storage
7010  REM  limited to six digits, but such limitation may affect the results
7012  REM  slightly to an extent which is normally negligible.
7014  REM
7016  REM  (B) The tolerances for iteration loops were tested and are set
7018  REM  wide to ensure convergence when using six-digit data storage.
7020  REM
7022  REM  (C) The input data contains usual information for the design
7024  REM  conditions and the averaged test results, as listed in lines
7026  REM  36-138. The 'n' value for the fill characteristics also needs
7028  REM  to be input: KaV/L=C*(L/G)^n.
7030  REM
7032  REM  (D) For altitudes from 0 to 300 m above sea level the program
7034  REM  evaluates results at ambient pressure equal to that at sea level,
7036  REM  in accordance with BS 4485: Part 3. For altitudes over 300 m
7038  REM  above sea level the calculations are made at reduced ambient
7040  REM  air pressure corresponding to the design altitude.
7042  REM  (Reference: BS 2520, Barometer conventions and tables).
7044  REM
7046  REM  (E) Four examples of output are appended for information.
7048  REM
7050  REM  (F) An error condition occurs if the limits of this BS Test
7052  REM  Code are exceeded, or if there is no convergence after 50
7054  REM  iterations. In such cases the flow of calculations stops and
7056  REM  partial output is printed, which contains input data and
7058  REM  results calculated prior to the occurence of this error.
7060  REM  Noughts are displayed for the remaining data. This may help
7062  REM  to trace the problem. Several diagnostic messages may appear
7064  REM  in the output to warn the user of possible input data errors,
7066  REM  or some unspecified abnormality which prevents the completion
7068  REM  of calculations.
7070  REM
7072  REM  (G) The program may need adjustments to suit user's operating
7074  REM  system, or the type of BASIC in use. An output file may be
7076  REM  written by simple modification of the subroutine 4000.
7078  REM
7080  REM  ****** End of program P4485  Rev. 6  Date: 30 January 1987 ******
```

EXAMPLES OF OUTPUT: Program P4485 REV. 6 Date: 30 January 1987

****

EVALUATION OF THERMAL PERFORMANCE: WATER COOLING TOWER
TYPE: NATURAL DRAUGHT
TEST METHOD TO BS 4485: PART 2: 1987

****

	DESIGN DATA	TEST DATA	LIMITS OF VALIDITY OF TEST
Water flow (m3/s)	20	18	18 - 22
Hot water temp. (C)	34	29.8	
Recooled water temp. (C)	25	21.8	
Cooling range (K)	9	8	7.2 - 10.8
Heat load (kcal/s)	180000	144000	144000 - 216000
Inlet dry bulb temp. (C)	18.4	12.9	
Inlet wet bulb temp. (C)	15	12	10 - 20
Inlet rel. humidity (%)	69.72	90.17	40 - 100
Atmos. pressure (kPa)	101.325	Design value	See NOTE (1)
Altitude (m asl)	50	-	
L/G water/air ratio	1.2	1.041	
"n" for KaV/L=C*(L/G)^n	-.6	Design value	
Tower KaV/L	1.133	1.169	

TOWER CAPABILITY (%)	100	95.74
EXPECTED RECOOLED WATER TEMPERATURE (C)		21.45

WORSE THAN DESIGN BY .35 (K)

NOTE (1): For altitudes 0-300 m above sea level, the test data is evaluated at mean sea level pressure (BS 4485: Pt 3)

****

EVALUATION OF THERMAL PERFORMANCE: WATER COOLING TOWER
TYPE: NATURAL DRAUGHT
TEST METHOD TO BS 4485: PART 2: 1987

****

	DESIGN DATA	TEST DATA	LIMITS OF VALIDITY OF TEST
Water flow (m3/s)	20	18	18 - 22
Hot water temp. (C)	34	29.8	
Recooled water temp. (C)	25	21.8	
Cooling range (K)	9	8	7.2 - 10.8
Heat load (kcal/s)	180000	144000	144000 - 216000
Inlet dry bulb temp. (C)	18.4	12.9	
Inlet wet bulb temp. (C)	15	12	10 - 20
Inlet rel. humidity (%)	70.1	90.32	40 - 100
Atmos. pressure (kPa)	97.79	Design value	
Altitude (m asl)	301	-	
L/G water/air ratio	1.2	1.04	
"n" for KaV/L=C*(L/G)^n	-.6	Design value	
Tower KaV/L	1.082	1.121	

TOWER CAPABILITY (%)	100	95.86
EXPECTED RECOOLED WATER TEMPERATURE (C)		21.47

WORSE THAN DESIGN BY .33 (K)

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EXAMPLES OF OUTPUT:  Program P4485  REV. 6   Date: 30 January 1987

*****************************************************************
      EVALUATION OF THERMAL PERFORMANCE: WATER COOLING TOWER
                     TYPE: MECHANICAL DRAUGHT
                TEST METHOD TO BS 4485: PART 2:1987
*****************************************************************

                           DESIGN        TEST   LIMITS OF VALIDITY
                           DATA          DATA        OF TEST

Water flow        (m3/s)   10            9.23          9 - 11
Hot water temp.      (C)   46            44.2
Recooled water temp. (C)   23            22.5
Cooling range        (K)   23            21.7          18.4 - 27.6
Heat load       (kcal/s)   230000        200290        184000 - 276000
Inlet wet bulb temp. (C)   18.3          17.7          13.3 - 23.3
Fan power           (kW)   240           208
Atmos. pressure    (kPa)   101.325       Design value  See NOTE (1)
Altitude         (m asl)   50            -
L/G water/air ratio        .75           .726
"n" for KaV/L=C*(L/G)^n    -.6           Design value
Tower KaV/L                2.89          2.837

TOWER CAPABILITY     (%)   100           97.04
EXPECTED RECOOLED WATER TEMPERATURE (C)  22.3
WORSE THAN DESIGN BY .2 (K)

NOTE (1): For altitudes 0-300 m above sea level, the test data
is evaluated at mean sea level pressure (BS 4485: Pt 3)


*****************************************************************
      EVALUATION OF THERMAL PERFORMANCE: WATER COOLING TOWER
                     TYPE: MECHANICAL DRAUGHT
                TEST METHOD TO BS 4485: PART 2:1987
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Water flow        (m3/s)   10            9.23          9 - 11
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Cooling range        (K)   23            21.7          18.4 - 27.6
Heat load       (kcal/s)   230000        200290        184000 - 276000
Inlet wet bulb temp. (C)   18.3          17.7          13.3 - 23.3
Fan power           (kW)   240           208
Atmos. pressure    (kPa)   97.79         Design value
Altitude         (m asl)   301           -
L/G water/air ratio        .75           .726
"n" for KaV/L=C*(L/G)^n    -.6           Design value
Tower KaV/L                2.753         2.706

TOWER CAPABILITY     (%)   100           97.04
EXPECTED RECOOLED WATER TEMPERATURE (C)  22.31
WORSE THAN DESIGN BY .19 (K)
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Appendix E. Determination of test value of *L/G* for natural draught towers

E.1 General

Whereas it can be assumed that for a mechanical draught tower the air flow produced by the fan(s) remains constant within the limitations detailed in **4.4** and **4.6**, such is not the case with a natural draught tower.

The natural draught induced by the shell is proportional to the differences in density between the ambient air and the air–water vapour mixture leaving the packing. The operating air flow can only be determined by equating the tower draught to the tower resistance at any one set of conditions.

E.2 Determination of density difference of design conditions

Calculate the increase in total heat of air from inlet to exit of packing from the following equation.

$\Delta h = (L/G)_d \times (\Delta t)_d \times c$

In figure 2, locate point (1 d) representing inlet air wet bulb temperature and relative humidity. The intersection (2 d) of a vertical line through this point with the total heat curve gives the enthalpy value of the air inlet conditions.

Find the point (3 d) on the total heat curve representing an increase in total heat equal to the calculated value of Δh. The intersection (4 d) of a vertical line through (3 d) with the saturated air line gives the point representing the exit air conditions. Subtraction of the densities at (1 d) and (4 d) gives the required density difference $(\Delta \rho)_d$.

E.3 Determination of test value of *G*

To a convenient scale commence a plot of $\Delta \rho$ versus G/G_d taking unity at the design value of G. Locate design $(\Delta \rho)_d$ (point (1) on figure 3) and through this point draw a section of the square law curve: $\Delta \rho = (\Delta \rho)_d \times (G/G_d)^2$. This represents the variation with G of the overall tower resistance.

Obtain values for draught curve using figure 2, test conditions and trial values of G. The intersection of draught and resistance curves gives the test value of G and hence the test value of L/G.

Example

Parameter	Design conditions	Test conditions
Wet bulb temperature	15 °C	12 °C
Dry bulb temperature	18.4 °C	12.9 °C
Relative humidity	70 %	90 %
Cooling range	9 K	8 K
Approach	10 K	9.8 K
Design *L/G*	1.2	—
Water loading	—	90 %

(a) *Determine density difference at design conditions.*

Increase in air enthalpy:

$$\Delta h = L/G \times \Delta t \times c$$
$$= 1.2 \times 9 \times 4.1868 \text{ kJ/kg}$$
$$= 45.217 \text{ kJ/kg}$$

From figure 2.

Inlet air density (point 1d) = 1.2040 kg/m³

Exit air density (point 4d) = 1.1580 kg/m³

Thus $(\Delta \rho)_d$ = 0.0460 kg/m³ (figure 3 point (1))

(b) *Determine test value of G*

$L_t = 0.9 \times L_d$ Cooling range = 8 K

Say $G = 1 \times G_d$:

$$\text{Then test } (L/G)_t = \frac{0.9}{1} \times (L/G)_d = 0.9 \times 1.2 = \underline{1.08}$$

Increase in air enthalpy:

$$\Delta h = (L/G)_t \times \Delta t \times c = 1.08 \times 8 \times 4.1868 \text{ kJ/kg} = \underline{36.174 \text{ kJ/kg}}$$

From figure 2.

Inlet air density (point 1t) = 1.2275 kg/m^3

Exit air density (point 4t) = 1.1772 kg/m^3

Thus $(\Delta \rho)_t$ = 0.0503 kg/m^3 (figure 3 point (2))

Now say $G = 1.1 \times G_d$:

$$\text{Then } (L/G)_t = \frac{0.9}{1.1} \times (L/G)_d$$

$$= \frac{0.9}{1.1} \times 1.2 = 0.98$$

Increase in air enthalpy:

$$\Delta h = (L/G)_t \times \Delta t \times c = 0.98 \times 8 \times 4.1868 \text{ kJ/kg} = \underline{32.824 \text{ kJ/kg}}$$

From figure 2 Exit ρ = 1.1813 kg/m^3

$(\Delta \rho)_t$ = 0.0462 kg/m^3 (figure 3 point (3))

Draw draught line through points (2) and (3)

Draught and resistance curves intersect at

$1.0305 \times G_d$ (figure 3 point (4))

$$(L/G)_t = \frac{0.9}{1.0305} \times 1.2 = 1.048$$

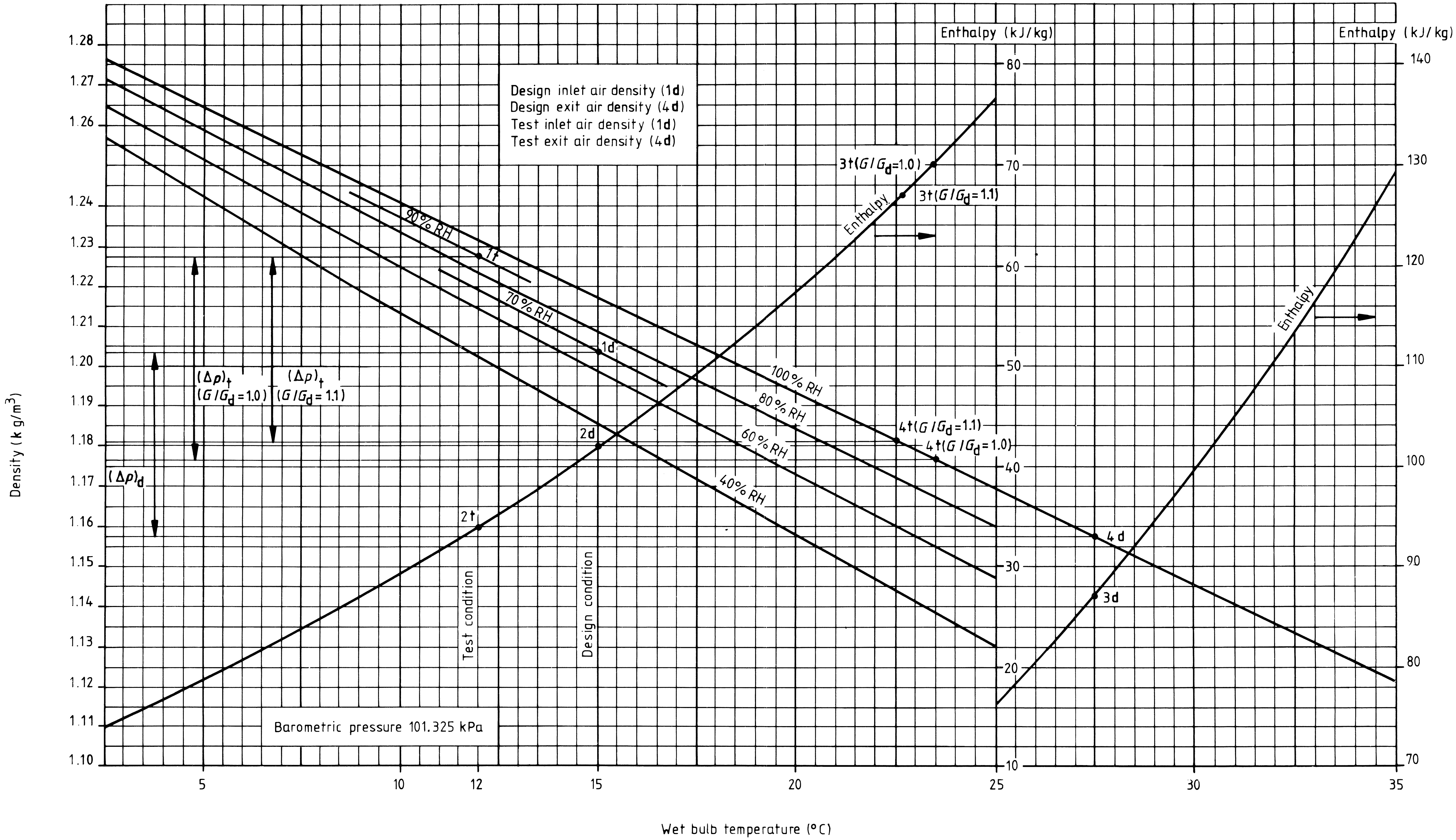

Figure 2. Graph for determination of density difference at design conditions

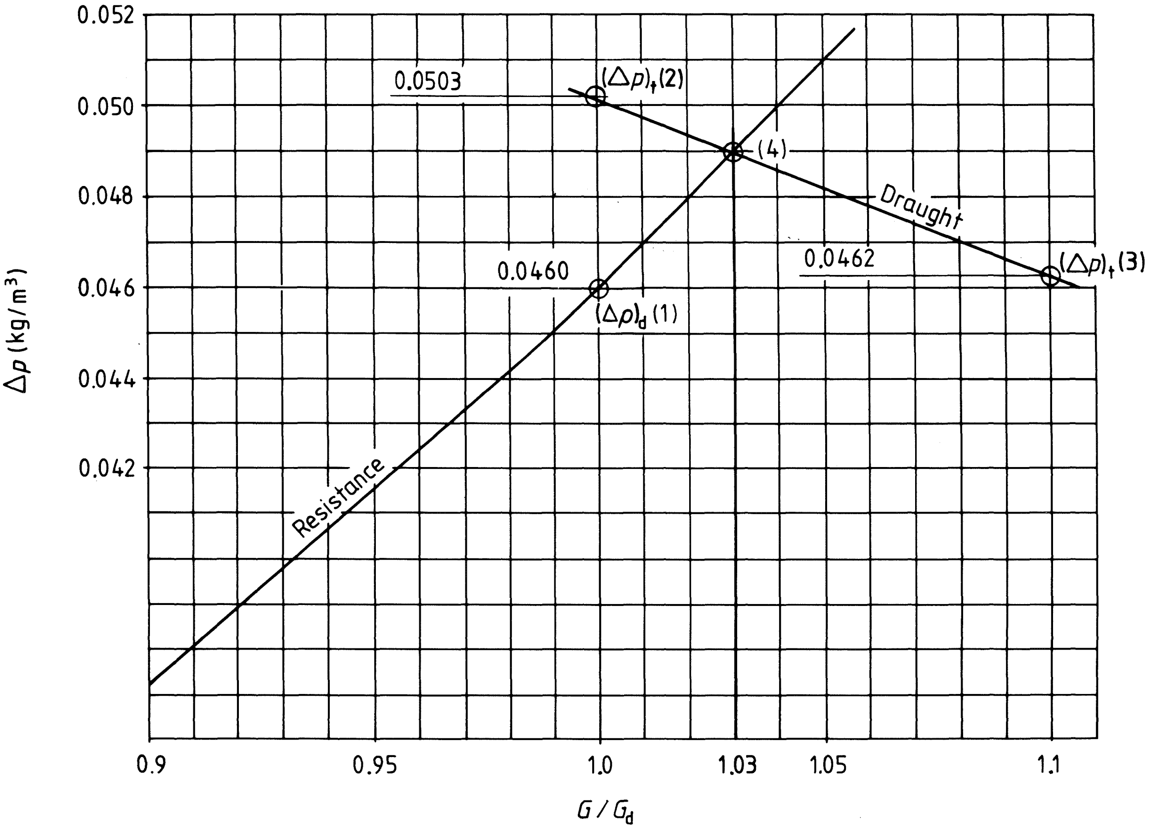

Figure 3. Determination of relation between G_d and G_t for natural draught cooling towers

Appendix F. Example of determination of cooling tower capability from calculation of *KaV/L* value

Using the L/G value obtained in the example given in appendix E, the value of KaV/L is determined as follows:

given $t_1 = 29.8\ ^\circ\text{C}$

$t_2 = 21.8\ ^\circ\text{C}$

$t_{WB} = 12\ ^\circ\text{C}$

$L/G = 1.048$

From enthalpy table at t_{WB} 12 °C:

h_1 = 34.1 kJ/kg (inlet air h_1)

$h_2 = h_1 + L/G\ (t_1 - t_2)\ c$

= 34.1 + 1.048 (29.8 − 21.8) x 4.1868 kJ/kg

= 69.2 kJ/kg

Using the method given in **C.5** and the data listed in table 5 the following is obtained:

t °C		h_L	h_G		$h_L - h_G$	$\frac{1}{h_L - h_G}$
t_2	= 21.8		h_1	= 34.1		
$t_2 + 0.1\ (t_1 - t_2)$	= 22.6	66.7	$h_1 + 0.1c\ L/G\ (t_1 - t_2)$	= 37.6	29.1	0.0344
$t_2 + 0.4\ (t_1 - t_2)$	= 25.0	76.3	$h_1 + 0.4c\ L/G\ (t_1 - t_2)$	= 48.1	28.2	0.0355
$t_1 - 0.4\ (t_1 - t_2)$	= 26.6	83.2	$h_2 - 0.4c\ L/G\ (t_1 - t_2)$	= 55.2	28.0	0.0357
$t_1 - 0.1\ (t_1 - t_2)$	= 29.0	94.6	$h_2 - 0.1c\ L/G\ (t_1 - t_2)$	= 65.7	28.9	0.0346
t_1	= 29.8		h_2	= 69.2		

Thus KaV/L is obtained by substituting these values in the formula:

$$KaV/L = \left\{ \frac{t_1 - t_2}{4} \times \left(\frac{1}{(h_L - h_G)_1} + \frac{1}{(h_L - h_G)_2} + \frac{1}{(h_L - h_G)_3} + \frac{1}{(h_L - h_G)_4} \right) \right\} \times c$$

$$KaV/L = \frac{(29.8 - 21.8)}{4} \times (0.0344 + 0.0355 + 0.0357 + 0.0346) \times 4.1868$$

$$= 1.17$$

From figure 4: a curve drawn through the point KaV/L = 1.17 at L/G = 1.048 parallel to manufacturer's characteristic curve intersects the 10 K approach curve at an L/G of 1.155.

The tower capability is therefore:

$$\frac{1.155}{1.2} \times 100 = 96.25\ \%$$

i.e. the tower is capable of cooling 96.25 % of the design inlet flow at design approach, range and inlet air conditions. The accuracy of the various test observations should be taken into account in the interpretation of this value.

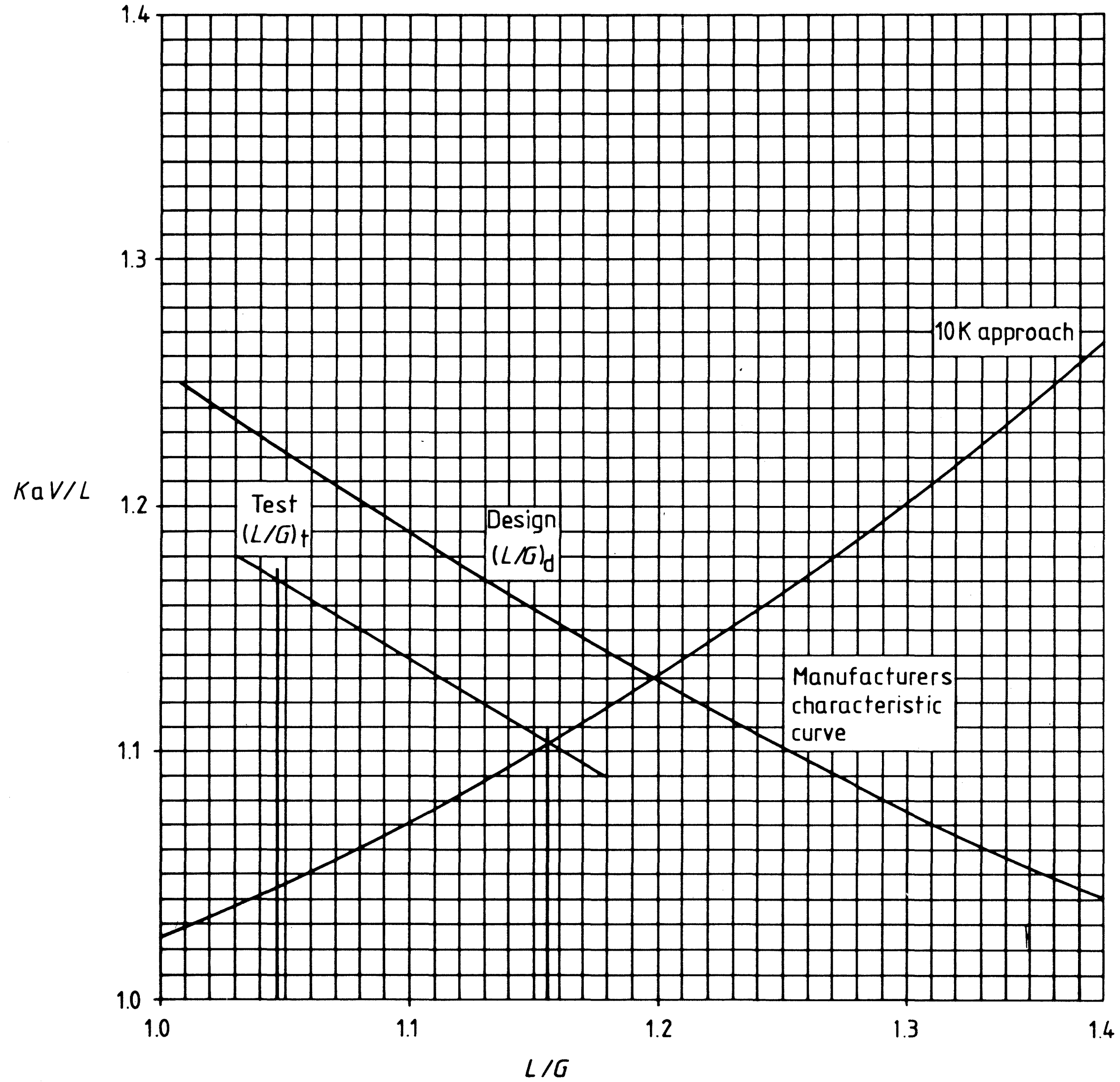

Figure 4. Determination of cooling tower capability

Publications referred to

BS 752 Test code for acceptance of steam turbines
BS 1042 Measurement of fluid flow in closed conduits
Part 1 Pressure differential devices
Section 1.1 Specification for square-edged orifice plates, nozzles and venturi tubes inserted in circular cross section conduits running full
Section 1.2 Specification for square-edged orifice plates and nozzles (with drain holes, in pipes below 50 mm diameter, as inlet and outlet devices) and other orifice plates and Borda inlets
Section 1.4 Guide to the use of devices specified in Sections 1.1 and 1.2
Part 2 Velocity area methods
Section 2.1 Method using Pitot static tubes
BS 2690 Methods of testing water used in industry
Part 9 Appearance (colour and turbidity), odour, suspended and dissolved solids and electrical conductivity
Part 11 Anionic, cationic and non-ionic detergents and oil
BS 3680 Measurement of liquid flow in open channels
Part 2A Constant rate injection
Part 2C Methods of measurement using radioactive tracers
Part 3A Velocity-area methods
Part 4A Method using thin-plate weirs
Part 8A Current meters incorporating a rotating element
BS 4485 Water cooling towers
*Part 1 Glossary of terms
Part 3 Code of practice for thermal and functional design
*Part 4 Structural design of cooling towers
BS 5969 Specification for sound level meters

*Referred to in the foreword only.

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