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Water-cooling towers — Testing and rating of thermal performance

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National foreword

This British Standard is the UK implementation of ISO 16345:2014.

The UK participation in its preparation was entrusted to Technical Committee RHE/17, Testing of air conditioning units.

A list of organizations represented on this committee can be obtained on request to its secretary.

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ISBN 978 0 580 58177 9

ICS 27.080

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2014.

Amendments issued since publication

Date	Text affected
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INTERNATIONAL STANDARD

ISO
16345

First edition
2014-06-01

Water-cooling towers — Testing and rating of thermal performance

*Tours de refroidissement de l'eau — Essais et détermination des
caractéristiques de performance*



Reference number
ISO 16345:2014(E)
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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 86, *Refrigeration and air-conditioning*, Subcommittee SC 6, *Testing and rating of air-conditioners and heat pumps*.

Water-cooling towers — Testing and rating of thermal performance

1 Scope

This International Standard covers the measurement of the thermal performance and pumping head of open- and closed-circuit, mechanical draft, wet and wet/dry cooling towers and natural draft and fan-assisted natural draft, wet and wet/dry cooling towers. The standard rating boundaries for series mechanical draft, open- and closed-circuit cooling towers are specified.

This International Standard does not apply to the testing and rating of closed-circuit towers where the process fluid undergoes a change in phase as it passes through the heat exchanger or where the thermophysical properties of the process fluid are not available.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply. The symbols used to identify the terms contained in this International Standard are listed and defined in [Clause 3](#).

2.1

airflow rate

total amount of dry air and associated vapour water moving through the cooling tower

2.2

ambient air conditions

atmosphere adjacent to, but not affected by, the cooling tower

2.3

approach

difference between cold (re-cooled) water temperature and the inlet-air wet-bulb temperature

2.4

approach deviation

deviation between the guaranteed and adjusted test approach

2.5

atmospheric gradient (lapse rate)

average rate of change of dry-bulb temperature with change in altitude from cold water basin curb, or sill, level to around twice the height of the cooling tower

Note 1 to entry: The convention for use with this International Standard will be to use a negative value for decrease in temperature as height increases.

2.6

average wind direction

predominant direction of the wind over the duration of the test period

2.7

average wind speed

arithmetical average of wind speed measurements taken over the duration of the test period

2.8

barometric pressure

atmospheric pressure taken over the duration of each test period

2.9
basin

open structure located beneath the cooling tower for collecting the circulating water and directing it to the sump or suction line of the circulating pump

2.10
basin curb

top elevation of the tower basin

Note 1 to entry: Usually the datum from tower elevations is measured.

2.11
blowdown

water discharged from the system to control the concentration of salts or other impurities in the circulating water

2.12
capability

measured thermal capacity of a cooling tower, expressed as a percentage of the design water flow rate

2.13
cell

smallest subdivision of the tower, bounded by exterior walls and partition walls, which can function as an independent unit

Note 1 to entry: Each cell can have one or more fans or stacks and one or more distribution systems.

2.14
cell dimensions

dimensions that describe the size of a cooling tower cell

Note 1 to entry: The dimensions include

- a) dimension perpendicular to the tower longitudinal axis and usually at right angles to the air inlet faces,
- b) length: dimension parallel to the longitudinal axis and the plane where air inlets are usually located, and
- c) height: on induced draft towers, the distance from the basin curb to the top of the fan deck, but not including the fan stack.

Note 2 to entry: On forced and natural draft towers, the distance from the basin curb to the discharge plane of the tower.

2.15
closed-circuit cooling tower

cooling tower comprised of a water flow loop re-circulating over the outside of a closed-circuit heat exchanger containing the process fluid loop

Note 1 to entry: Air is drawn through the water passing over the outside of the closed-circuit heat exchanger, enabling cooling by evaporation. No direct contact occurs between the process fluid loop and the open evaporative cooling loop.

2.16
cold (re-cooled water temperature) water

in an open cooling tower, the average temperature of the water entering the tower basin

Note 1 to entry: The convention from here on will be to use the term "cold water" in ISO 16245.

Note 2 to entry: In the case where the measurement is downstream of the basin or the pump, corrections are needed for the effects of the pump and any other makeup water, blowdown, or heat sources entering the basin.

2.17

cooling range

difference between the hot and cold water or process fluid temperatures

Note 1 to entry: The term 'range' is also applied to this definition, but is regarded as a non-preferred term.

2.18

cooling tower

apparatus in which process fluid is cooled by evaporative heat exchange with ambient air

2.19

counter-flow

situation in which air and water flow in opposite direction within the cooling tower

2.20

cross-flow

situation in which air flows perpendicularly to the water flow within the cooling tower

2.21

discharge plume

discharge air stream of the cooling tower when made visible (wholly or in part) by the condensation of water vapour as the moist air stream is cooled to ambient temperature

2.22

distribution system

system for receiving the water entering the cooling tower and distributing it over the area where it contacts the atmospheric air

2.23

drift eliminator

assemblies downstream of the heat transfer media which serve to reduce the drift loss

2.24

drift loss

portion of the water flow rate lost from the tower in the form of fine droplets mechanically entrained in the discharge air stream, commonly expressed as mass per unit time or a percentage of the circulating water flow rate

Note 1 to entry: It is independent of water lost by evaporation.

2.25

dry-bulb temperature

temperature of an air-vapour mixture indicated by a thermometer with a clean, dry sensing element that is shielded from radiation effects

Note 1 to entry: Dry-bulb temperature can be further categorised as either

- a) ambient dry-bulb temperature: the dry-bulb temperature of air measured windward of the tower and free from the influence of the tower or
- b) entering dry-bulb temperature: the dry-bulb temperature of the air entering the tower, including the effect of any re-circulation and/or interference.

2.26

entering air conditions

average characteristics of the airflow entering the cooling tower

2.27

fan power

power consumed by the fan driver, which might or might not include the efficiency of the driver, depending on the contract

2.28

fill (pack)

devices placed in the cooling tower within the heat exchange section for the purpose of enhancing the surface area and/or the rate of heat transfer from the water stream to the air stream

2.29

final test result

average of the results from the minimum number of valid test periods

2.30

flow rate

quantity of hot process fluid to be cooled by the tower

2.31

fluid type

type of process fluid to be cooled by the tower

2.32

fouling factors

expression of reduction of heat transfer capability caused by internal and/or external contamination of the heat exchanger

2.33

heat exchanger pressure drop

pressure drop of the process fluid across the contractual inlet and outlet locations of the heat exchanger(s) of a closed-circuit or wet/dry cooling tower, adjusted for elevation and velocity

2.34

heat load

rate of heat removal from the process fluid within the tower

2.35

hot process fluid temperature

average temperature of the process fluid entering the heat exchanger in a closed-circuit tower

2.36

hot water temperature

average temperature of the inlet water in an open-circuit cooling tower

2.37

interference

thermal contamination of air entering the cooling tower by a source extraneous to the tower, generally another cooling tower

2.38

L/G

ratio of total mass flow rates of liquid (water) over gas (dry air) in an open-circuit cooling tower

2.39

makeup

water added to the system to replace the water lost by evaporation, drift, blowdown, and leakage

2.40

mechanical draft cooling tower

cooling tower where the air circulation is produced by a fan

Note 1 to entry: Mechanical draft cooling towers can be further categorised as either

- a) forced draft: the fan is located in the entering air stream or
- b) induced draft: the fan is located in the discharge air stream.

2.41

natural draft cooling tower

cooling tower wherein the air circulation is produced by a difference in density between the cooler air outside the cooling tower and the warmer, more humid air inside

Note 1 to entry: Natural draft towers can be fan assisted.

2.42

non-series type

design, generally site constructed, for which the performance is project dependent

2.43

open-circuit (wet) cooling tower

cooling tower wherein the process fluid is warm water which is cooled by the transfer of mass and heat through direct contact with atmospheric air

2.44

partition wall

vertical interior wall, either transverse, longitudinal, or radial, that subdivides a cooling tower into cells

2.45

process fluid

working fluid used to transport heat from heat source to the cooling tower

Note 1 to entry: It can be water or any chemical element, compound or mixture, liquid or gas, in single phase flow.

2.46

pump head

in an open-circuit tower, the sum of static head and dynamic head from the contractual inlet interface to the discharge of the distribution system to atmosphere

2.47

re-circulation

portion of the outlet air that re-enters the tower

2.48

relative humidity

ratio of the mole fraction of water vapour in a given air sample to the mole fraction of water vapour in a sample of saturated air at the same temperature and pressure, usually expressed as a percentage

2.49

series type

design which is fixed and described in the manufacturer's catalogue, generally factory assembled, and for which the performance data are pre-determined

2.50

spray water flow

quantity of water flowing over the outside of the heat exchanger in a closed-circuit tower

2.51

test agent

person or entity responsible for conducting the testing

2.52

test period

time duration where readings or recordings of every measurement have to be averaged and test period results can be calculated

2.53

test readings

individual sets of data recorded at regular intervals for each instrument or measurement point required

2.54

thermal lag

time interval before the temperature of the water leaving the influence of the cooling air is detected at the point of cold water temperature measurement

2.55

tolerance

numerical value defined in contract documents or by a certification program expressed in percentage points or degrees Celsius which can be applied to the test results when determining compliance with the pass/fail criteria

Note 1 to entry: Typically, a tolerance is agreed for taking test variability into account.

2.56

top of shell wind speed

for natural draft or fan-assisted natural draft towers, the wind speed at the elevation of the plane through the top of shell and within the defined distance from the tower

2.57

total dissolved solids

weight of inorganic and organic matter in true solution per unit volume of water

Note 1 to entry: Typically, over 90 % of all solids dissolved in water are present as six different ions. Calcium, magnesium, sodium, chlorides, sulphates, and carbonates are usually expressed as mg/l.

2.58

total suspended solids

weight of particulates, both organic and inorganic, suspended, but not dissolved, per unit of water

Note 1 to entry: Total suspended solids are usually expressed as mg/l.

2.59

uncertainty, random

estimate characterizing the range of values within which it is asserted with a given degree of confidence that the true value of the measure can be expected to lie

2.60

valid test period

test period where constancy and values of measured parameters are within the limits of this code

2.61

water flow rate

quantity of hot water flowing into an open cooling tower

2.62

water loading

water flow rate expressed as quantity per unit of fill plan area of the tower

2.63

wet-bulb temperature

temperature of air indicated by a thermometer, shielded from radiation, with the sensing element covered by a thoroughly wetted and adequately ventilated wick

Note 1 to entry: Properly measured, it closely approximates the temperature of an adiabatic saturation and can be further categorised as either

- a) ambient wet-bulb temperature: the wet-bulb temperature of air measured windward of the tower and free from the influence of the tower or
- b) entering wet-bulb temperature: the wet-bulb temperature of the air entering the tower, including the effect of any re-circulation and/or interference.

2.64

wet/dry cooling tower

cooling tower incorporating two concurrent modes of heat transfer: wet or evaporative and dry or sensible

Note 1 to entry: Wet/dry towers can be of open or closed type and are most often used to control or limit the discharge plume, but can also be used to reduce water consumption.

2.65

design

set of parameters defined by specification or contract as the basis against which the cooling tower performance is analyzed

3 Symbols and abbreviations

A_C	total internal area of hot water conduit at tower inlet, expressed in square metres, m^2
A_{FILL}	gross face area of fill, perpendicular to direction of airflow, expressed in square metres, m^2
a	area of transfer surface per unit of fill volume, expressed in square metres per cubic metres, m^2/m^3
C	heat transfer coefficient
C_{CAP}	tower capability, expressed as a percentage (%) of design flow
C_F	pressure loss coefficient, expressed as a dimensionless unit
c_p	specific heat of a fluid at constant pressure, expressed in $kJ/kg\ ^\circ C$
	NOTE Assumed to be $4,186\ kJ/kg\ ^\circ C$ for water.
D	diameter of pipe, expressed in metres, m
d	diameter of wet bulb and covering, expressed in millimetres, mm
ΔE	difference in elevation between the inlet and outlet nozzles of the heat exchanger of a closed-circuit tower, expressed in metres, m
G	mass flow rate of dry air through the cooling tower, expressed in kilograms of dry air per second, $kg\ dry\ air/s$
g_c	acceleration due to gravity, expressed in metres per square second, m/s^2
H	elevation difference between top of the shell of a natural draft tower and the midpoint of fill height, expressed in metres, m
H_P	tower pumping head of flowing fluid, expressed in metres, m
h	enthalpy, expressed in kilojoules per kilogram dry air, $kJ/kg\ dry\ air$
h	enthalpy difference, expressed in kilojoules per kilogram of dry air, $kJ/kg\ dry\ air$
h_A	enthalpy of air, expressed in kilojoules per kilogram dry air, $kJ/kg\ dry\ air$
h_{HA}	enthalpy of air-water vapour mixture at bulb air temperature, expressed in kilojoules per kilogram dry air, $kJ/kg\ dry\ air$
h_M	enthalpy of saturated air-water vapour mixture at bulb water temperature, expressed in kilojoules per kilogram of dry air, $kJ/kg\ dry\ air$
I_{CAP}	tolerance for instance for tests uncertainty on tower capability, expressed as a percentage, %

I_{TEMP}	tolerance for instance for tests uncertainty on tower approach deviation, expressed in degrees Celsius, °C
K	overall heat and mass transfer coefficient, expressed in kilograms per second, kg/s°m ²
KaV/L	tower characteristic, expressed in dimensionless units
kW_{FM}	input power to an electric fan motor, expressed in kilowatts, kW
kW_{PM}	input power to an electric pump motor, expressed in kilowatts, kW
$K_0; K_1$	constants in formulae, derived by combining known values of K_2
L	mass flow rate of water entering the cooling tower, expressed in kilograms per second, kg/s
L/G	ratio of mass flow rate of water to that of air, expressed in dimensionless units
n	an integer number, typically the n^{th} term in a series
P_B	barometric pressure, expressed in pascals, Pa
P_{HE}	pressure loss across the heat exchanger of a closed-circuit or wet/dry cooling tower, expressed in kilopascals, kPa
P_I	static pressure of the process fluid at the inlet nozzle to the heat exchanger of a closed-circuit tower, expressed in pascals, Pa
P_O	static pressure of the process fluid at the outlet nozzle to the heat exchanger of a closed-circuit tower, expressed in pascals, Pa
P_T	total pressure referred to atmospheric, expressed in pascals, Pa
P_{ST}	static pressure at the centreline of the tower hot water inlet conduit, expressed in metres of flowing fluid, m
P_V	velocity pressure (computed from $v^2/2g_c$) at the centreline of tower hot water inlet conduit, expressed in metres of flowing fluid, m
P_1	static pressure of water or process fluid at suction of main circulating pump, expressed in kilopascals, kPa
P_2	static pressure of water or process fluid at discharge of main circulating pump, expressed in kilopascals, kPa
Q_A	volumetric flow rate of air, expressed in cubic metres per second, m ³ /s
Q_{BD}	volumetric flow rate of blowdown water, expressed in mass flow rate of water per second, L/s
Q_{MU}	volumetric flow rate of makeup water, expressed in mass flow rate of water per second, L/s
Q_{PF}	volumetric flow rate of process fluid, expressed in mass flow rate of water per second, L/s
Q_{RW}	volumetric flow rate of water re-circulating over the external surface of the heat exchanger of a closed-circuit cooling tower, expressed in mass flow rate of water per second, L/s
Q_W	volumetric flow rate of circulating water in an open cooling tower, expressed in mass flow rate of water per second, L/s
q	heat transfer rate from water/process fluid to the ambient air, expressed in kilojoules per second, kJ/s
q_{DRY}	dry heat transfer rate for wet/dry cooling tower, expressed in kilojoules per second, kJ/s
q_{WET}	wet heat transfer rate for wet/dry cooling tower, expressed in kilojoules per second, kJ/s

q_{TOT}	total heat transfer rate for wet/dry cooling tower, expressed in kilojoules per second, kJ/s
R	cooling range, expressed in degrees Celsius, °C
RH	relative humidity, expressed as a percentage, %
S	thermal lag, expressed in seconds, s
T_{App}	approach deviation, expressed in degrees Celsius, °C
T_{BD}	temperature, blowdown water, expressed in degrees Celsius, °C
T_{CW}	temperature, cold water leaving the tower, expressed in degrees Celsius, °C
T_{CPF}	temperature, cold process fluid leaving the tower, expressed in degrees Celsius, °C
T_{DB}	temperature, air dry-bulb, expressed in degrees Celsius, °C
T_{HW}	temperature, hot water entering the cooling tower, expressed in degrees Celsius, °C
T_{HPF}	temperature, hot process fluid entering the tower, expressed in degrees Celsius, °C
T_{MU}	temperature, makeup water, expressed in degrees Celsius, °C
T_{RW}	temperature, re-circulating water of a closed-circuit cooling tower measured at the pump discharge, expressed in degrees Celsius, °C
T_{WB}	temperature, air wet-bulb, expressed in degrees Celsius, °C
T_{am}	ambient dry-bulb temperature, expressed in °C
T_{ent}	average entering dry-bulb temperature, expressed in °C
tex	linear mass density of fibres, expressed as mass in grams per 1 000 metres (1 tex = 10 ⁻⁶ kg/m)
V	effective cooling tower fill volume, expressed in cubic metres, m ³
V_A	velocity of air, expressed in metres per second, m/s
V_{avg}	average wind velocity
VFD	variable frequency drive
V_L	velocity of liquid, expressed in metres per second, m/s
V_W	velocity of wind, expressed in metres per second, m/s
v_A	specific volume of air, expressed in cubic metres of mixture per kilogram of dry air, m ³ mixture/kg dry air
W_{FM}	fan motor power output, expressed in kilowatts, kW
$X_{x, adj}$	designates the value has been adjusted, e.g. for fan power, makeup water temperature, etc.
$X_{x, amb}$	designates the value pertains to the ambient air surrounding the tower
$X_{x, 1}$	designates value pertains to air entering the tower inlet
$X_{x, 2}$	designates value pertains to air leaving the tower (discharge)
$X_{x, d}$	designates the value pertains to the design condition
$X_{x, dry}$	indicates the value pertains to the dry section of a wet/dry cooling tower

$X_{x,i}$	indicates the value is obtained from the intercept of two curves
$X_{x,(n)}$	number counter, e.g. the n^{th} term
$X_{x,PF}$	designates the value pertains to the process fluid circulating through the heat exchanger of a closed-circuit cooling tower
$X_{x,pred}$	designates a predicted value determined from the manufacturer's performance data
$X_{x,t}$	designates the value pertains to a measured test condition
$X_{x,w}$	designates the value pertains to the water circulating through an open cooling tower
$X_{x,wet}$	indicates the value pertains to the wet portion of a wet/dry
x	exponent applied to L/G ratio in the cooling tower operating formula, expressed in dimensionless units
	NOTE Typically on the order of $-0,6$.
y	exponent applied to ratio of design to test fan motor power to adjust dry capacity of wet/dry towers expressed in dimensionless units
Z_i	vertical distance from basin curb to centreline of tower piping inlet, expressed in metres, m
z	exponent applied to ratio of design to test fan motor power to adjust capacity of closed-circuit towers, expressed in dimensionless units
	NOTE Typically on the order of $0,2$.
γ	weighting coefficient, expressed in dimensionless units
ρ_W	density of water, expressed in kilograms per cubic metre, kg/m^3
Y	correction factor for crossflow towers, from Annex E , expressed in dimensionless units
η_{FM}	efficiency of fan motor, expressed as a percentage, %
η_P	efficiency of main circulating pump (not motor), expressed as a percentage, %
ρ	specific mass or density, expressed in kilograms per cubic metre, kg/m^3
ρ_A	density of air, expressed in kilograms per cubic metre, kg/m^3
ρ_{PF}	density of process fluid, expressed in kilograms per cubic metre, kg/m^3
τ_1	time at the start of the test period, expressed in hours and minutes, hr-min
τ_2	time at the end of the test period, expressed in hours and minutes, hr-min
φ_A	absolute humidity of air, expressed in kilograms of mixtures per kilograms of air, $\text{kg mixture}/\text{kg air}$

4 Performance tests — General

4.1 Application of standard

The performance test forming the subject of this International Standard can be carried out as a contractual acceptance test or as a qualification or re-verification test, as part of a certification programme. This International Standard can also be used as a guideline to monitor the performance of equipment during its operation. The method described in this International Standard for the verification of performance applies to all cooling towers described in the Scope.

4.2 Test schedule

Acceptance tests should be carried out within a period of one year after start up, preferably after commissioning. To achieve full thermal performance of open cooling towers with film fill, the cooling tower shall operate under heat load for a sufficient period to condition the fill. For this reason, a mutual agreement about the anticipated test schedule between owner/purchaser, testing agency, and manufacturer shall be reached.

For closed-circuit cooling towers, it is preferred to conduct the test as shortly as possible after the start up to avoid the influence of heat exchanger surface contamination. This can also apply to certain wet/dry configurations, where water is sprayed on the heat exchanger surface.

4.3 Pretest agreements

4.3.1 General

If the test is being performed to establish compliance with contractual obligations, it is recommended the parties to the contract agree to several aspects of the test, prior to the test.

4.3.2 Test tolerance and uncertainty

When testing is run according to this code, the results represent without correction for uncertainty the best available assessment of the actual performance of the equipment. The parties to a test should agree before starting a test and ideally before signing a contract on any tolerances that can be applied to measured final test results. Agreement should also be reached prior to testing as to whether, how, and by whom an uncertainty calculation shall be made to assess the quality of the testing conducted, including any criteria for rejection of testing based on uncertainty.

4.3.3 Fouling factors

On closed-circuit cooling towers where a fouling factor is included in the performance guarantee, the purchaser and the manufacturer should agree upon the degree of fouling assumed to be present at the time of the test and the method for adjusting the test results to the fouling allowance specified.

4.3.4 Additional or rescheduled tests

The parties to the test should agree to the allocation of additional expenses incurred if for some reason the test shall be halted and rescheduled at another time or if one or more parties request additional tests.

4.3.5 Scope of test and evaluation method

The parties of the test should agree on the scope of the test, i.e. the use of single or multiple valid test periods, engineering or survey grade, extended test method, and the test evaluation method, either by determination of the tower capability or by approach deviation. For wet/dry closed-circuit cooling towers, it needs to be determined whether the test shall also include verification of performance in the dry operating mode.

4.3.6 Documentation

Prior to the testing contract and preferably with the original tower proposal, the manufacturer shall submit performance documents setting out the guaranteed properties as function of the allowable influence parameters (see [5.3](#)).

4.4 Flexibility

It is recognized that the data limitations specified throughout this test procedure represent desired conditions which might not exist at the time the test is performed. In such cases, existing conditions

be used for performance test, if mutually agreed upon by authorized representatives of the manufacturer, the purchaser, and the agency conducting the test (if applicable). In such cases, the accuracy of the test is compromised (see [10.4](#)) and full compliance to this code can no longer be claimed.

5 Objective of tests

5.1 General

The objective of the testing is to verify the guaranteed thermal and hydraulic properties of the cooling tower supplied, including verifying the following items:

- a) determination of the tower capability or approach deviation at measured conditions;
- b) pump head, flow rates, and pressure losses.

5.2 Basis of guarantee

The cold water (process fluid) temperature is as a function of:

- a) water (process fluid) flow rate;
- b) wet-bulb temperature or relative humidity and dry bulb;
- c) cooling range, or hot water temperature, and where applicable, as a function of other parameters such as
 - dry-bulb temperature,
 - fan driver power consumption (as driver input or output as contractually agreed),
 - atmospheric pressure,
 - atmospheric vertical temperature gradient,
 - wind speed, and
 - wind direction;
- d) cooling tower pump head or the heat exchanger pressure drop applicable parameters, which are defined by tower type in [Table 1](#);
- e) other parameters can be guaranteed subject to the contract.

5.3 Form of the guarantee documents

5.3.1 General

The guarantee documents shall take the form of performance curves or characteristic curves and associated tabular data, or spread sheets, curves, formulas, computer programs, etc. A block of data shall be included on the curves containing the guaranteed parameters for the appropriate products as defined in [Table 1](#). If supplied as spread sheets, formulas, computer programs, etc., the information shall be equivalent in scope and detail to the requirements for curves in [5.3.2](#) through [5.3.6](#) and characteristic equations in [5.3.7](#).

5.3.2 Performance curves — Mechanical draft

The tower manufacturer shall submit tower performance data in the form of a family of performance curves consisting of a minimum of three sets of three curves each. One set shall apply to 90 %, one set to 100 %, and the other to 110 % of the design process fluid flow rate. Each set shall be presented as a plot

of wet-bulb temperature as the abscissa versus cold water temperature as the ordinate, with cooling range as a parameter. Curves shall be based on constant fan speed and pitch.

- a) In addition to the design cooling range curve, at least two bracketing curves at approximately 80 % and 120 % of the design cooling range shall be included as a minimum. The design point shall be clearly indicated on the appropriate curve.
- b) The curves shall fully cover (but not necessarily be limited to) allowable variations from design specified in [8.2.4.2](#).
- c) On closed-circuit towers, including wet/dry, where the process fluid is a mixture (e.g. an aqueous glycol solution), the performance curves shall be expanded to encompass solution concentration as a parameter with curves for at least three concentrations: design, five percentage points above design, and five percentage points below design (e.g. for a design concentration of 25 %, performance curves shall be submitted for 20 %, 25 %, and 30 % concentrations). These curves shall be interpolated to the measured concentration at the time of the test evaluation.
- d) For wet/dry closed-circuit cooling towers, the manufacturer shall specify the operating conditions and control settings of the tower required to yield full capacity in the wet/dry operating mode. If verification of performance in the dry operating mode is required, the manufacturer shall specify operating conditions and control settings in this mode and submit performance curves as specified above but with the dry-bulb temperature as abscissa.

5.3.3 Performance curves — Wet/dry and fan-assisted natural draft towers

The tower manufacturer shall submit a family of curves which relate the pertinent performance variables, including as a minimum, one set of curves for each of three process fluid flow rates, one at 90 % of design, one at 100 % of design, and one at 110 % of design. Each set shall consist of three or more cooling range curves and at least four relative humidity curves, arranged to show the effects of wet-bulb temperature, relative humidity, and cooling range on the cold process fluid temperature. Curves shall be based on constant fan speed and pitch.

NOTE In special cases where performance guarantees are limited for winds from specific directions, measurement of the wind direction would become mandatory.

Table 1 — Measured parameters for guarantee by tower types

	Series			Non-series			Natural drift	Natural drift fan assisted
	Open	Closed and Closed Wet/Dry	Open Wet/Dry	Open	Closed and Closed Wet/Dry	Open Wet/Dry		
Flow rate	M	M	M	M	M	M	M	M
Fluid type	M	M	M	M	M	M	M	M
Fan power	M	M ^c	M	M	M	M	—	M
Cold temp., or range and approach	M	M	M	M	M	M	M	M
Entering WBT or RH and DBT	M	M	M	M	M	M	M	M
Entering DBT	M	M	M	M	M	M	M	M
Hot temp., or range and approach	M	M	M	M	M	M	M	M
Barometric pressure	M	M	M	M	M	M	M	M
Average wind speed	M	M	M	M	M	M	M	M
Average wind direction	S ^d	S ^d	S ^d	S ^d	S ^d	S ^d	S ^d	S ^d
Top of shell wind speed	—	—	—	—	—	—	M ^b	M ^b
Ambient dry bulb	—	—	—	—	—	—	M	M
Atmospheric gradients	—	—	—	—	—	—	M	M
Liquid gas ratio (L/G)	O	O	O	O	O	O	—	O
Pump head	S	S	S	M	M	M	M	M
Heat exchange pressure drop	—	M	S ^a	—	M	S ^a	—	—
Spray pump power	—	M	—	—	M	—	—	—
Dissolved and suspended solids	M	M	M	M	M	M	M	M
Fouling factors	—	S	S	—	S	S	—	—
Fluid properties	—	M	—	—	M	—	—	—

NOTE 1 Parameters indicated with M are mandatory.

NOTE 2 Parameters indicated with O are required for induced draft towers, as it is needed for possible corrections of the fan power.

NOTE 3 Parameters indicated with S are not mandatory, but only suggested for information purposes.

^a Required for wet/dry cooling towers with dry heat exchangers on separate heat sources.

^b Mandatory but not practical to measure in most cases. This parameter should be evaluated through a visual criteria in the case of daytime basic tests, and is not relevant in the case of extended tests.

^c For wet/dry closed-circuit towers, the fan power requirement in dry operating mode should be indicated if verification of dry performance is included in the test.

^d In special cases where performance guarantees are limited for winds from specific directions, measurement of the wind direction would become mandatory.

In addition to the design cooling range curve, at least two bracketing curves at approximately 80 % and 120 % of the design cooling range shall be included as a minimum. The design point shall be clearly indicated on the appropriate curve.

The relative humidity curves shall be presented in approximately equally spaced curves and shall cover the extent of expected conditions (e.g. 20 %, 40 %, 60 %, and 100 % relative humidity or 60 %, 70 %, 80 %, and 100 % relative humidity). Each curve shall include the dry-bulb temperature expressed as a function of the wet-bulb temperature and relative humidity on which the curve is based.

The curves shall fully cover (but not necessarily be limited to) the allowable variations from design specified in [8.2.4.2](#).

In the case where multiple modes of air and/or water flow control are guaranteed, additional sets of curves shall be submitted.

5.3.4 Performance curves — Natural draft towers

The manufacturer shall submit a family of curves which relate the pertinent performance variables, including as a minimum, one set of curves for each of three process fluid flow rates, one at 90 % of design, one at 100 % of design, and one at 110 % of design. Each set shall consist of three or more cooling range curves and four or more relative humidity curves, arranged to show the effects of wet-bulb temperature, relative humidity, and cooling range on the cold process fluid temperature.

- a) In addition to the design cooling range curve, at least two bracketing curves at approximately 80 % and 120 % of the design cooling range shall be included as a minimum. The design point shall be clearly indicated on the appropriate curve.
- b) The relative humidity curves shall be presented in approximately equally spaced curves and shall cover the extent of expected conditions (e.g. 20 %, 40 %, 60 %, and 100 % relative humidity or 60 %, 70 %, 80 %, and 100 % relative humidity). Each curve shall include the dry-bulb temperature expressed as a function of the wet-bulb temperature and relative humidity on which the curve is based.
- c) The curves shall fully cover (but not necessarily be limited to) the allowable variations from design specified in [8.2.4.2](#).

5.3.5 Performance curves — Scale

Temperature scales comprising the ordinate and abscissa shall be based on increments no greater than 0,2 °C at a spacing no closer than 0,1 °C/mm, to enable reading precision.

5.3.6 Characteristic curves (mechanical draft for basic tests)

When the performance of an open-circuit cooling tower is to be evaluated by the characteristic curve method, the manufacturer shall submit tower performance data in the form of a curve or family of curves relating tower characteristic (KaV/L) to the water/air ratio (L/G), clearly indicating the design L/G to be used for the test evaluation. This relationship can be presented as a formula, with all constants listed, or as a curve or properly identified family of curves, expressing the effects of variables (such as hot water temperature and airflow rate) that can have a significant effect on the result. The data submitted shall cover a range of L/G values extending from 80 % or less of the design L/G to 120 % or more.

5.3.7 Characteristic curves — Scale

If the relationship is presented as a curve, the graphical scaling shall permit the determination of KaV/L to a minimum precision of three significant figures.

5.3.8 Characteristic equations (natural draft towers for extended tests)

When extended tests are conducted, performance curves are not practical for test evaluation. Instead, the performance of the tower is assumed to be described by Formula (1) (operating equation) and

Formula (2) (draft equation) and the manufacturer shall submit polynomials or values for the coefficients involved in these characteristic equations.

$$\frac{KaV}{L} = C \left(\frac{L}{G} \right)^X \quad (1)$$

$$\rho_{A,1} - \rho_{A,2} = (0,5) \frac{\rho_{A,1}}{g_c H} C_F v_A^2 \quad (2)$$

The heat transfer coefficient, C , and the pressure loss coefficient, C_F , are supplied by the manufacturer in the form of a function of the wind velocity at 10 m and of other parameters which affect the tower performance such as the average velocity of the air, V_A . The factors C , C_F , and h shall apply between 90 % and 110 % of the water flow rate, and between 80 % and 120 % of the design cooling range. The values of draft height, H , and gross fill plan area, A_{FILL} , are also supplied by the manufacturer. The average velocity of air through the fill, $\overline{V_A}$, is calculated by Formula (3).

$$\overline{V_A} = G \frac{(1 + \varphi_A)}{\rho_{A,1} A_{FILL}} \quad (3)$$

NOTE The tower thermal capacity obtained in solving the characteristic equations is an approximation of the actual thermal capacity, which performance curves show when drawn according to an exact method. However, this approximation is generally acceptable and is validated by this International Standard as long as the hot water temperature does not exceed 50 °C.

5.3.9 Tabular data

A table shall be included on or accompany the performance or characteristic curves listing the design point conditions of

- the type of process fluid and, if other than water, the composition,
- the process fluid flow rate,
- the temperature of the hot process fluid entering the tower,
- the temperature of the cold process fluid leaving the tower,
- the entering wet-bulb and dry-bulb temperatures,
- the design liquid-over-gas ratio (L/G),
- the design wind conditions and atmospheric gradient, if applicable, and
- the design barometric pressure or altitude.

And, additionally for mechanical draft towers:

- the design fan driver power (input or output as contractually agreed);
- the efficiency of the fan driver (if applicable);
- the density of the air entering the fan(s) at the design operating point;
- the exponent (EXP) to be used to determine the adjusted test flow rate on closed-circuit towers or, alternatively, a performance curve relating % capability to % design fan driver power encompassing, as a minimum, the range of 90 % to 110 % design fan power. In the case when no value is given for the exponent in the contract, 1/3 could be used, subject to mutual agreement;

- e) for induced, mechanical draft towers, the volumetric airflow rate entering the fan(s) at the design operating condition;
- f) for closed-circuit towers including wet/dry, the output power and motor efficiency of the external circuit re-circulating pump when the pump and piping are supplied by the manufacturer. Alternatively, when the pump and/or the piping is supplied by others, the manufacturer shall specify the flow rate of the re-circulating water and the static pressure required at the re-circulating water inlet connection(s) (or the static head of a gravitational system) to produce the design flow rate;
- g) in the specific case of separate fans serving dry and wet portions of a tower or separate towers, the manufacturer shall submit dry surface pressure drop and heat transfer exponents as required for use in evaluating the fan driver output power exponent (γ) in Formula (66);
- h) for wet/dry closed-circuit cooling towers, the manufacturer shall provide the fan power requirement in dry operating mode, if dry performance verification is included in the test.

6 Test preparation

6.1 Purpose

The purpose of this Clause is to set forth

- a) the responsibilities of the owner or site contractor and the testing agency in preparing a cooling tower for a field performance or acceptance test and
- b) the conditions that shall be present at the time of the test to ensure the test results accurately reflect the capability of the tower.

6.2 Test scheduling and site preparation

Proper preparation of the cooling tower and scheduling of the test will expedite the actual test, control test costs, and ensure the measured data accurately reflect the true capability of the cooling tower.

6.2.1 Responsibilities

The cooling tower owner or his representative is responsible for helping to arrange the test date with the parties to the test, for preparing the tower for test, and for providing free and safe access to the tower and all the instrument and control locations during the test. Execution of the test is contractually defined and preferably should be conducted by a suitable, independent third party test agency mutually agreeable to owner and manufacturer. The parties to an acceptance test are the owner's representative, the manufacturer's representative, and the test agent, if an independent third party agency.

6.2.2 Scheduling

The actual date for the test should be set only after ensuring:

- a) the tower is in good operating order;
- b) the necessary provisions for measuring all required test parameters have been installed (see [6.4](#));
- c) the operating personnel have been advised of the test and the tower is expected to be operating within the deviations from design conditions allowed by the test code (see [8.2.4](#) and [8.3.5](#));
- d) the closer the tower is to operating at design conditions during the actual test, the more likely the test results will reflect the actual capability of the tower. For this reason, the test codes require the tower be operating within specific, maximum allowable deviations from design. In towers comprised of multiple, identical cells, if agreeable to the parties to the test, the number of cells in operation can be adjusted prior to the test in order to bring the cells being tested within the allowable limits;

- e) all parties to the test, including the owner, purchaser, and manufacturer and test agent, shall have been notified of a proposed test date and can be present on site if they so desire;
- f) final confirmation of the test date should be made only after considering the local weather forecasts. For basic tests, conditions that should be avoided include winds above 4,5 m/s (unless otherwise contractually specified), continuous rain, thunderstorm activity, dry-bulb temperature below 5 °C, and high likelihood of a warm or cold front moving through the area.

In cases where it is not practical to measure the wind speed at the top of the shell, an indicator of the wind conditions at the top of the shell shall be the appearance of plume at the exit. For an acceptable test, visual observations of the plume shall indicate that the plume completely fills the shell outlet and rises vertically for a minimum distance of approximately one-half of the outlet diameter.

6.3 Tower physical condition

6.3.1 General

For the cooling tower to produce the rated capacity, all of the individual components shall be operating properly and be clear of any obstructions or blockages. The manufacturer shall be given an opportunity to conduct a detailed, pre-test inspection of the tower, prior to the scheduled test date.

6.3.2 Heat transfer media

The heat transfer media should be in a suitable operating condition.

6.3.2.1 Film-filled open-circuit towers

The fill surface shall be properly conditioned by operation for at least 500 h (for PVC) with hot water temperature of at least 32 °C. Other materials can require longer conditioning periods.

6.3.2.2 All open-circuit fill media

The fill shall be operating in an unobstructed manner, free of visible silt, algae, slime, or other accumulations which cause flow to channel. Such channeling sometimes leaves visible high and low water flow areas at the discharge of the fill, indicating a heavy fouling. In any case, the most effective way to detect an accumulation of any kind is to inspect an inside layer, if fill is layered, by removing the upper one.

6.3.2.3 Closed-circuit towers (including wet/dry)

The heat exchangers shall be operating without excessive internal fouling that would restrict heat transfer beyond the specified value. The external surfaces of the heat exchangers shall be operating, free of silt, algae, slime, scale, and other accumulations which impede heat transfer or retard or channel the normal flow of air and water.

6.3.3 Water distribution system

Design flow and unobstructed water distribution shall be provided over the heat transfer media (fill) if the tower is to produce rated capacity. Therefore, the following shall be verified before conducting a thermal performance or acceptance test.

- a) Distribution system is in good operating condition, free of algae, slime, or other obstructions to flow.
- b) All nozzles/orifices are properly installed, clean, and in good operating condition.
- c) Circulating water is essentially free of oil or other foreign materials.
- d) The flow rate to the tower (or cells to be tested) is within ± 10 % of design.

- e) The flow to all hot water basins/cells is balanced.

NOTE If balancing is necessary, open all balancing valves and check the water level in each hot water basin (crossflow towers) or the spray pressure at each inlet connection (counterflow towers). Then, at the basin/connection with the highest level/pressure, slowly reduce the flow until all levels/pressures are essentially equal. Serious imbalances can require more than one adjustment.

- f) All bypass valves are operating properly with no leakage across the valve when in the closed position. At the time of test, all bypass valves shall be locked in the closed position with no leakage.

6.3.4 Mechanical equipment

The mechanical equipment on each cell should be checked to verify

- a) the fans and drivers are in good working order, turning freely with no binding or interference,
- b) the fans rotate in the proper direction, and
- c) when operating within the deviations from design conditions allowed by the test code, the fan drivers shall be loaded to within $\pm 10\%$ of the design power consumption of the fan.

6.3.5 Drift eliminators

All drift eliminators shall be properly installed and in good operating condition, free of algae, slime, or other obstructions to airflow.

6.3.6 Air inlets

The air inlets to the tower shall be free of all obstructions or blockages which were not considered or accounted for in the tower selection and design. Louvers, if any, are all installed and in their proper position.

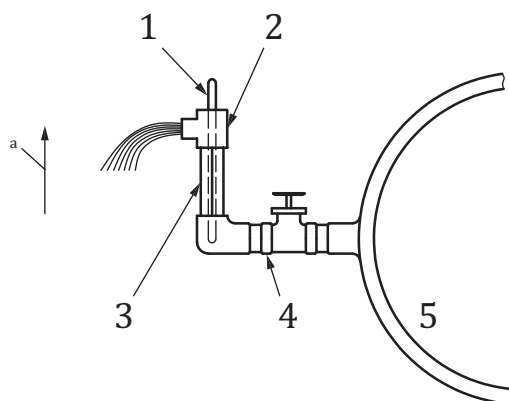
6.4 Provisions for instrumentation

6.4.1 Description

Unless otherwise specified in the contract documents or through prior agreement, the agency conducting the test will provide all the instrumentation required to properly conduct the test. However, it is typically the responsibility of the tower owner and/or site contractor to provide the temperature taps, thermowells, Pitot taps, power for instrumentation, other utilities, etc. necessary for the test, as detailed in [Clause 7](#).

6.4.2 Temperature measurements

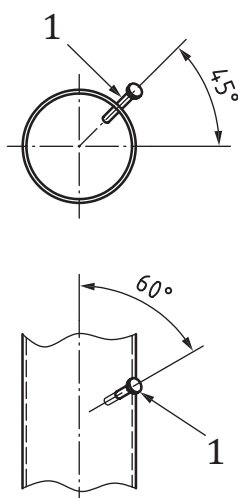
In closed conduits, temperature measurements can be made using a flowing tap in the line (see [Figure 1](#)) or with a temperature well (see [Figure 2](#)) filled with a heat conducting paste or fluid. The stations should be located at a point where the water is well mixed and, if taps are used, at a positive pressure.



Key

- 1 Thermometer
- 2 tee (optional)
- 3 nipple, 12,5 mm × 150 mm
- 4 gate valve, 12,5 mm
- 5 pipe
- a Vertical.

Figure 1 — Temperature tap



Key

- 1 temperature well

Figure 2 — Temperature well

NOTE Taps should not be used if the continuous bleeding of water from the tap over the duration of the test would present a system or environmental problem. In open channels, a grid structure can be required to support and locate temperature sensors. To power the psychrometers, furnish AC power to the tower site with sufficient extension cords to reach all inlet faces of the tower. Check with the testing agency for the preferred supply voltage.

6.4.3 Flow measurement

6.4.3.1 General

Accurate measurement of the cooling tower flow rate is essential to an accurate determination of the cooling tower capability and appropriate care shall be taken in selecting both the instrument(s) to be used and the point at which the measurement is made.

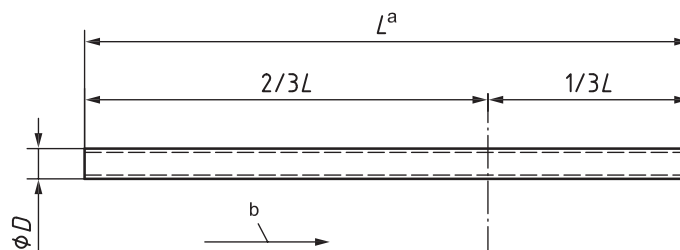
6.4.3.2 Measurement site

When the flow rate of the circulating water or process fluid is to be measured in a closed conduit, the measurement station can be situated in virtually any easily accessible line with a positive pressure, typically in the main hot water header or in the individual risers to each cell. If a main header is selected, make certain the flow being measured is only for the tower(s) under test and no other flow streams are added or removed between the measurement station and the tower inlet connection(s). Flow measurements at each individual riser require more time, but they ensure only the flow to the tower(s) being tested is measured and, where more than one riser is being used, they provide information on the balance of flow between cells.

6.4.3.3 Location

Most of the commonly used flow measurement devices require a fully developed velocity profile at the point of measurement. To ensure accurate measurement, the flow measurement station shall be situated in a section of straight pipe, free of any valves or fitting, extending 20 pipe diameters in length. The measurement station should be located with 2/3 the length of straight pipe upstream and 1/3 the length downstream (see [Figure 3](#)). Compromises in these criteria will adversely affect the accuracy of the flow measurement and the test result.

In addition to the considerations for accuracy, it is also imperative that the measurement site be safely accessible to test personnel during the test. The tower owner and/or site contractor shall provide the necessary ladders, scaffolding, and safety harnesses.



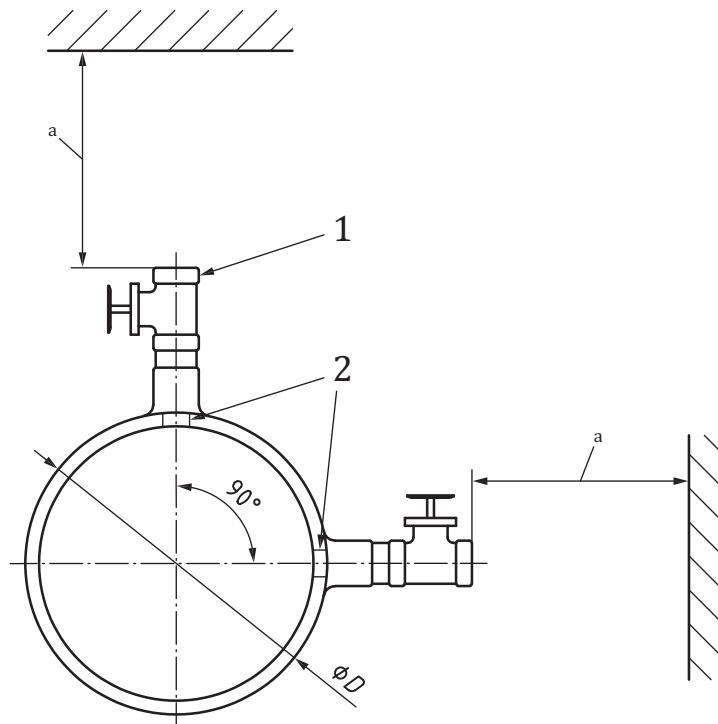
Key

- a ideally 20D, minimum 10D
- b flow

Figure 3 — Flow measurement site

6.4.3.4 Measurement by Pitot tube traverse

When the flow rate to the tower is to be measured by Pitot tube traverse of the conduit, install two taps at the point of measurement in the same transverse plane through the pipe, separated by 90°, and fit them with 30 mm or 40 mm, full ported gate valves as illustrated in [Figure 4](#). On large diameter pipes, a reinforced Pitot tube can be required and the size of the taps and valves increased accordingly. If there is any doubt to the size, coordinate with the testing agency. Additionally, ensure adequate clearance is available beyond each valve to accommodate the full length of the Pitot tube for insertion and withdrawal. As noted in [Figure 4](#), for conduits 600 mm or less in diameter, provide at least 1,3 m clearance. For conduits larger than 600 mm, provide a clearance equal to three times the conduit diameter.



Key

- 1 2 each of 30 mm or 40 mm full ported gate valves
- 2 2 each of 30-mm-diameter clean drilled holes, free of burrs
- a Minimum clearance: for $D \leq 600$ mm, use 1,3 m; for $D \geq 760$ mm, use $3D$

Figure 4 — Pitot tube taps and required clearance

6.4.3.5 Flow measurements by other methods

Instruments other than a Pitot tube can be used for flow measurement, some of which are not intrusive. In such cases, the tower owner and/or site contractor shall work with the test agent to ensure the proper provisions, as described in the appropriate International Standard, are made for the flow measurement, prior to the scheduled test date.

6.4.3.6 Makeup flow

Unless the makeup flow can be shut off for several hours for the duration of the test, a volume type meter or other suitable flow measuring device should be installed in the makeup line leading to the tower.

6.5 Fan driver input power

For electric motors, provide access at the disconnect switch or the starter for each fan motor to measure the power input with a portable, clamp-on power meter. If the fan motor voltage is over 600 v, the fan motor is equipped with a variable frequency drive (VFD), or if the fans are not driven by electric motors, the tower owner and/or site contractor shall work with the test agent to make such provisions as are necessary to correctly measure the power input to the fan(s).

6.6 Site conditions

6.6.1 General

Typically, cooling tower tests are tentatively scheduled by the test purchaser well in advance of the actual test date. This tentative date should be selected such that the likelihood is high that the required tower operating conditions and the weather conditions will comply with the test code requirements.

6.6.2 Tower operating conditions

The closer the tower is to operating at design conditions during the actual test, the more likely the test results will reflect the actual capability of the tower. For this reason, the test codes require the tower be operating within specific, maximum allowable deviations from design.

These allowable deviations are set forth in [8.2.4](#) and [8.3.5](#) of this International Standard and every effort should be made to comply with them at the time of the test.

NOTE In towers comprised of multiple, identical cells, if agreeable to the parties to the test, the number of cells in operation can be adjusted prior to the test in order to bring the cells being tested within the allowable limits.

6.6.3 Weather conditions

For basic test, final confirmation of the test date should be made only after considering the local weather forecasts. Conditions that should be avoided include

- a) winds above 4,5 m/s unless otherwise contractually specified,
- b) continuous rain,
- c) thunderstorm activity,
- d) dry-bulb temperature below 5 °C, and
- e) high likelihood of a warm or cold front moving through the area.

6.7 Miscellaneous

There are also several other aspects of preparing for a test which are not covered in this International Standard, but shall be addressed to ensure the test proceeds smoothly, on the appointed day. These include, but are not limited to:

- a) When power input measurements shall be made on electric fans or pump motors, arrange for an electrician to be on site on the day of the test to assist with these measurements.
- b) Similarly, have operators available on the day of the test should the need arise to adjust valves or make minor adjustments to the system or tower to facilitate the test.
- c) Arrange for security clearances and vehicle passes for test personnel and observers as well as any necessary plant safety orientations, special training, certificates of insurance, etc.
- d) Install all ladders, lifts, scaffolding, railings, and safety equipment necessary to ensure safe access to the tower and all measurement stations, particularly the flow measurement station, during the test.
- e) See checklist, [Annex M](#).

7 Instrumentation and test setup

7.1 Calibration

All instrumentation employed during the course of the test shall be calibrated prior to the test. Calibration shall be traceable to primary or secondary standards calibrated by a recognized authority, such as a national standards authority, or derived from accepted values of natural physical constants. Instruments shall be recalibrated on a regular schedule appropriate for the respective instrument and full calibration records shall be maintained. The minimum calibration frequencies shall be as shown in [A.1.1](#). An instrument shall also be calibrated whenever it is damaged or its accuracy is called into question for any other reason. Additionally, at the request and expense of the test purchaser, any and all instrumentation used on a test can be calibrated before and/or after a test.

7.2 Flow measurements

7.2.1 General

All tests require measurement of the main circulating water or process fluid flow rate. Measurement of the makeup water flow rate and the blowdown water flow rate might be necessary, depending upon the tower operating mode during the test.

The flow rates shall be measured using any of the methods specified in [A.2.2](#). The method employed, the location, and the number of measurements taken will depend upon the nature of the installation, the importance of the measurement, and the type of test.

7.2.2 Flow rate measurements

The flow rate of the water or process fluid shall be measured at a point where a well-developed velocity profile exists, preferably in the piping leading to the tower. The measurement location should be 20 diameters downstream and 10 diameters upstream of any obstructions or transitions in the piping. Measurement stations with insufficient upstream and downstream distances will have significant, adverse impact on the velocity profile and the accuracy of the measurement and should be resolutely avoided.

7.2.3 Inspections of measurement devices

Flow measurement devices, whether temporarily or permanently installed, shall be inspected prior to the test for dimensional conformity and functionality.

7.3 Temperature measurements

7.3.1 General

Temperature shall be measured using any of the methods specified in [Annex A](#). The temperature-sensitive elements shall be carefully located to ensure the measurement is representative of the true bulb temperature of the fluid at the point of measurement.

The indicator or recorder shall be graduated in increments of not more than 0,1 °C and be readable to $\pm 0,05$ °C. The temperature-sensitive element shall be accurate to $\pm 0,05$ °C.

7.3.2 On-site comparison

Prior to the test, an on-site comparison of all temperature sensors shall be conducted. In the case of electronic data acquisition systems, this shall be performed after all wiring connections are made. If in doubt, a temperature sensor will be compared to another similar sensor and replaced if it is questionable.

7.3.3 Water/process fluid temperatures

7.3.3.1 General

The temperatures of the water/process fluid shall be measured at full flowing bleeds, directly in the process stream or in thermometer wells installed at the point of measurement. Thermometer wells shall be filled with a thermal conducting liquid or paste to ensure the temperature-sensing device is exposed to a representative temperature.

7.3.3.2 Hot water or process fluid temperatures

The temperature of the hot water or process fluid entering the tower shall be measured in the tower riser(s) or at the discharge of the inlet riser(s) into the distribution system or, for a multi-cell tower, in the supply header just upstream of the first riser. For closed-circuit towers, including wet/dry, the temperature of the hot process fluid entering the tower shall be measured at the inlet to the heat exchanger or, for towers with multiple heat exchangers or cells, in the supply header just upstream of the inlet connection to the first heat exchanger. For either type of tower, if the source is a mixture of two or more streams at different temperatures, complete mixing shall be ensured at the point of measurement or sufficient flow rate and temperature measurements of the individual streams shall be made to ensure an accurate weighted average fluid temperature.

7.3.3.3 Cold water or process fluid temperatures

Although other locations can be used, the temperature of the cold water leaving the tower should preferably be measured at the circulating pump discharge for best mixing, and the average measured value corrected for heat added by the pump in accordance with 9.2.4. For closed-circuit towers, including wet/dry, the temperature of the cold process fluid leaving the tower shall be measured at the outlet of the heat exchanger or, for a tower with multiple heat exchangers or cells, in the header just downstream of the last outlet connection. For either type of tower, if the best available measurement is made at a location such as a water discharge flume where temperatures and velocities are not uniform over the stream cross section, sufficient flow rate measurements should and temperature measurements shall be made to ensure an accurate, weighted average fluid temperature.

7.3.3.4 Makeup water temperature

If the makeup system is running during the test, the temperature of the makeup water shall be measured at the point the makeup water enters the system.

7.3.3.5 Blowdown temperature

If the blowdown system is operative during the test, the temperature of the blowdown water shall be measured at the point the blowdown leaves the system.

7.3.4 Entering air temperatures

7.3.4.1 Required entering air temperature

Entering air wet-bulb temperature is required for all cooling-tower tests. Entering air dry-bulb temperature is required for forced draft and natural draft towers to determine the thermodynamic properties of the air entering or around the tower and for induced draft configurations to facilitate the determination of the psychometric properties of the air entering the fan(s) and/or when estimating the evaporation rate.

7.3.4.2 Measurement stations

Air temperature measurement stations shall be located 1,5 m from the cooling tower air intake(s). A sufficient number of measurement stations shall be employed to ensure the average of the test readings

yields an accurate representation of the true inlet wet-bulb temperature. Requirement for the minimum number and location of measurement stations is given in [Annex C](#).

7.3.4.3 Dry-bulb temperature

When the entering air dry-bulb temperature measurement is for the sole purpose of determining the physical properties of the entering air on a mechanical draft tower, this can be achieved, in most cases, by means of a single measurement station, or at most two stations.

7.3.5 Ambient air temperature

Ambient air dry-bulb temperature, T_{am} , is required for natural draft cooling towers. This measurement shall be placed at a fixed meteorological mast of 10 m height, located at least 300 m from the tower, and in an open and unobstructed location.

7.3.6 Atmospheric gradient for natural draft

The inlet dry-bulb temperature gradient is a critical measurement on natural draft towers since it is used to determine the inlet-air density which, in turn, is part of the driving force that makes the cooling tower perform. The following are the dry-bulb temperature measurement requirements for natural draft towers.

- a) For the direct measurement of natural draft cooling tower vertical ambient dry-bulb temperature gradient, the plan location of the instruments shall be neither downwind of nor within the influence of the cooling tower or any other site sources of turbulence or thermal gradients which might substantially affect the measured data. The vertical elevations shall be as specified in [Annex A](#). Instrumentation locations and techniques will be site-specific and shall be based upon mutual agreement prior to testing.
- b) As an indicator of the vertical dry-bulb temperature gradient on natural draft towers, two dry-bulb instruments shall be located at the same circumferential near or above the top of the air inlet. The instrument placed near or above the top of the air inlet can be located on a stairway at or above the elevation of the top of the air inlet if the location otherwise satisfies the criteria herein. The instruments shall not be placed downwind of the cooling tower. Every effort shall be made to place the instruments in locations not subject to radiation or to convective air heating effects due to solar heating of the shell. The placement of the gradient indicator instruments shall be mutually agreed upon by the parties to the test.
- c) As another indicator, we shall compare the ambient dry-bulb temperature, T_{am} (as defined in [7.3.5](#)), with the average entering dry-bulb temperature, T_{ent} , and only consider test periods such as:

$$-1 < T_{ent} - T_{am} < 0$$

7.4 Pressure measurements

7.4.1 General

Pressures shall be measured using any of the devices specified in [Annex A](#) as appropriate for the magnitude of the pressure to be measured.

7.4.2 Pressure taps

Tappings into conduits for pressure measurements shall be 3 mm or less and be free of burrs and other irregularities.

7.4.3 Heat exchanger pressure drop

Measurements for determining the pressure drop of the process fluid across the heat exchanger of a closed-circuit or wet/dry tower shall be made in accordance with [A.4](#). The stations shall be located as closely as possible to the contractual inlet and outlet locations of the heat exchanger(s). Corrections shall be made for fitting losses, changes in pipe size, etc. that produce pressure differences between the measuring stations and the contractual locations.

7.5 Fan/pump driver power

7.5.1 General

The power consumed by the fan/pump driver shall be measured. If the tower performance is based on driver output, the measured power input shall be adjusted for the efficiency of the driver using the efficiency provided by the driver manufacturer.

7.5.2 Electric motors

In the case of electric motors, power input shall be determined by direct measurement of the kilowatt input at a location such that the instrumentation can accurately measure the total power input to the device. A line loss correction shall be made, unless otherwise agreed by all parties.

7.5.3 Variable frequency drives

If the electric motor is equipped with a variable frequency drive (VFD) or other power altering device, appropriate actions (such as bypassing the device) shall be taken to ensure an accurate measurement and that no speed changes are made to the fan over the duration of the test.

7.6 Wind velocity (speed and direction)

7.6.1 General

Wind velocity shall be measured with any of the devices specified in [Annex A](#), preferably remote reading and recording. The number of measurement stations and their location is dependent upon the type of tower under test and the test type.

7.6.2 Mechanical draft towers

For mechanical draft towers, the wind velocity measurement shall be made in an open and unobstructed location, upwind of the tower and beyond the influence of the inlet-air approach velocity. Care shall be taken to ensure the recorded wind speed and direction are representative of wind conditions affecting the tower. Placement of the wind measurement device shall be subject to mutual agreement by all parties to the test. Wind direction shall be recorded in compass degrees with the reference north clearly indicated.

7.6.2.1 Tower heights less than or equal to 6 m

For cooling towers with an overall height of 6 m or less between the basin curb and discharge elevations, the wind velocity shall be measured 1,5 m above the elevation of the basin curb, at a point within 15 m to 30 m of the tower, if practical.

7.6.2.2 Tower heights greater than 6 m

Where the distance between basin curb and the discharge elevation exceeds 6 m, the wind velocity shall be measured at a height above the curb elevation that is approximately one-half the difference between the curb and discharge elevations and at a distance of at least 30 m from the tower, if practical.

7.6.3 Natural draft towers

7.6.3.1 Inlet

For natural draft towers, the wind velocity shall be measured at a height equal to one-half the inlet height and a distance from the cooling tower that is at least twice the air inlet height and no less than a quarter of the base diameter of the tower. When conducting extended tests, a fixed meteorological tower/mast, typically 10 m height, can be used if located at least 300 m from the tower and in an open and unobstructed location.

7.6.3.2 Discharge

For natural draft towers, the wind velocity shall be measured in a horizontal plane extending through the discharge opening at the top of the shell at a point within 45 m to 450 m from the edge of the shell, if practical. Situations where there is a strong wind at the discharge and little or no wind at the air inlet should be avoided.

An indicator of the wind conditions at the top of the shell shall be the appearance of plume at the exit. For an acceptable test, visual observations of the plume shall indicate that the plume completely fills the shell outlet and rises vertically for a minimum distance of approximately one-half of the outlet diameter.

In the case of extended tests, top of shell wind speed parameter is not relevant.

7.7 Tower pump head

Two measurements are required for determining tower pumping head:

- a) the gauge static pressure at the centreline of the water inlet connection;
- b) the measured, vertical distance between the top of the basin curb and the centreline of the hot water inlet connection.

7.8 Water or process fluid analysis

A sample of the circulating water and, where applicable, the process fluid shall be taken during the test if any parties to the test question water quality. The sample shall be analysed by a reputable testing laboratory to determine the composition of the fluid.

8 Execution of test

8.1 Requirements for testing type

Execution of two types of tests, basic and extended, is described in this Clause. The decision to run one type of test rather than the other depends on the type of tower (extended tests typically only apply on natural draft cooling towers) and on the contract (guarantee parameters involved). Basic tests take place over a short duration. Extended tests require longer duration and an unattended data acquisition is required.

8.2 Basic tests

Basic tests are appropriate for all types of cooling towers.

8.2.1 Duration of the test period

A test period (see definition in [Clause 3](#)) lasts 1 h plus any thermal lag time, if applicable.

A valid test period fulfils all requirements listed in [8.2.4](#).

Only valid test periods will be considered in an acceptable test.

8.2.2 Required number of valid test periods

The minimum number of valid test periods required for mechanical draft is one and for natural draft is six collected over 2 d. Test periods shall not overlap. The results of all valid test periods shall be taken into account in the acceptance test.

8.2.3 Test measurements

Tests can be categorised as either engineering grade or survey grade depending upon the method and frequency of acquiring the test readings.

8.2.3.1 Engineering grade

Engineering grade is the more rigorous and preferred method of acquiring test data. An automated, electronic data acquisition shall be employed to scan all measuring instruments at regular intervals no greater than 15 s in duration. Test readings shall be comprised of no less than four scans of each required instrument averaged over a 1 min period (see [Table 2](#)). Engineer grade tests are recommended for acceptance and certification testing.

8.2.3.2 Survey grade

In survey grade tests, readings shall be taken and recorded manually at regular intervals over the test period, as specified in [Table 2](#).

8.2.4 Validity conditions for basic acceptance tests

A test period shall be valid only if the requirements below are met.

8.2.4.1 Climatic condition requirements during the test period

- a) No rain, snow, or hail.
- b) No fog; the difference between dry-bulb and wet-bulb temperature shall be greater than 0,5 °C.
- c) The wet-bulb temperature of the ambient air shall be greater than or equal to 2 °C.
- d) If no other limits are specified in the contract, the average wind speed (see [7.6](#)) shall not exceed 3 m/s for natural draft and 4,5 m/s for mechanical draft. Gusts of more than 5 m/s for natural draft and 7 m/s for mechanical draft shall not occur more than 10 times within an hour.
- e) When testing natural draft towers, it is recommended that the following climatic conditions are also achieved during the hour preceding the start of any valid test period: the average vertical ambient dry-bulb temperature gradient G shall be within 0 °C/100 m of height and 1 °C decrease/100 m of height. Refer to [7.3.6](#).
- f) If the indicator defined in [7.3.6 c\)](#) is used, the validity condition shall be: $-1 < T_{\text{ent}} - T_{\text{am}} < 0$.

8.2.4.2 Variations from design

The test shall be conducted within the following limitations.

The following variations from design conditions shall not be exceeded:

- a) wet-bulb temperature: $\pm 8,5$ °C;
- b) dry-bulb temperature (if applicable): $\pm 14,0$ °C;
- c) range: ± 20 %;

- d) circulating water flow: ± 10 %;
- e) barometric pressure: $\pm 3,5$ kPa;
- f) fan driver power: ± 10 %.
- g) water/process fluid quality: The quality of the water/process fluid, or in the case of closed-circuit cooling towers, the re-circulating spray water, shall be as follows.
 - 1) Dissolved solids or suspended solids shall not exceed 5,000 mg/l, or where specified in the contract documents, 1,1 times the specified value.
 - 2) Content of oil, tar, or fatty substances, as determined by a recognized national standard, shall not exceed 10 mg/L for splash fills and 1 mg/L for film fills.
 - 3) For wet/dry towers, the limits for variation of design conditions during dry operation and for foreign substances in the circulating water shall be by prior mutual agreement between the purchaser and the manufacturer.

Table 2 — Basic test — Frequency of readings and units of measure

Measurement	Readings per hour, min.		Units	Record to nearest unit
	Engineering grade	Survey grade		
Entering wet-bulb temperature ^a	60	12	°C	0,05
Entering dry-bulb temperature	60	12	°C	0,05
Cold water temperature	60	12	°C	0,05
Hot water temperature	60	12	°C	0,05
Water flow rate ^b	1	1	m ³ /h	0,5 %
Tower pumping head	1	1	M	0,01
Fan driver power input ^c	1	1	kW	0,5 %
Wind velocity	60	cont.	m/s	0,5
Makeup temperature	60	2	°C	0,05
Makeup flow ^d	2	2	m ³ /h	0,5 %
Blowdown temperature	60	2	°C	0,05
Blowdown flow ^d	2	2	m ³ /hr	0,5 %
Barometric pressure	60	1	kPa	0,01
Atmospheric gradient ^e	1	1	°C/100 m	0,05
Wind speed at tower exit ^e	1	1	m/s	0,5
Spray water temperature ^f	60	12	°C	0,05
Heat exchanger pressure drop	3	3	kPa	0,01

^a Or relative humidity and dry bulb.

^b Three centre point readings per hour for comparison with full traverse reading (when measurement is made by Pitot tube traverse) to confirm variations in flow have not exceeded the allowable limit.

^c If applicable or required. For wet/dry closed-circuit cooling towers during dry operation, the same requirements as indicated in this table apply.

^d If makeup and/or blowdown can't be turned off during the test.

^e For natural draft or fan-assisted natural draft.

^f For closed circuit.

NOTE Depending on the fluid type, the chemical composition can be analysed. In case of glycol solutions with known glycol properties, it is sufficient to measure the glycol concentration.

Table 2 (continued)

Measurement	Readings per hour, min.		Units	Record to nearest unit
	Engineering grade	Survey grade		
Spray pump power	1	1	W	0,5 %
Fluid type	1	1	X	x
a Or relative humidity and dry bulb. b Three centre point readings per hour for comparison with full traverse reading (when measurement is made by Pitot tube traverse) to confirm variations in flow have not exceeded the allowable limit. c If applicable or required. For wet/dry closed-circuit cooling towers during dry operation, the same requirements as indicated in this table apply. d If makeup and/or blowdown can't be turned off during the test. e For natural draft or fan-assisted natural draft. f For closed circuit. NOTE Depending on the fluid type, the chemical composition can be analysed. In case of glycol solutions with known glycol properties, it is sufficient to measure the glycol concentration.				

8.2.4.3 Constancy of test conditions

Scatter is the maximum permissible variation of any observation. It represents the greatest permissible difference between the maximum and minimum instrument readings during the period.

When expressed as a percentage, the maximum allowable variation is the specified percentage of the arithmetical mean of the observations. For a valid period, variations shall not exceed the following limits.

- a) Circulating water flow rate shall not vary by more than $\pm 1,5$ % from the average period value.
- b) Heat load shall not vary by more than $\pm 2,5$ % from the average period value.
- c) Range shall not vary by more than $\pm 2,5$ % from the average period value.
- d) Further, an individual reading of the entering air temperature (e.g. the average of all the psychrometer readings at one time interval) shall not deviate from the overall average for the duration of the period by more than the following:
 - 1) wet-bulb temperature: $\pm 1,5$ °C;
 - 2) dry-bulb temperature: $\pm 4,5$ °C (if applicable, e.g. testing wet/dry tower in the dry mode);
 - 3) trends: The temperature of the entering air, as measured at individual psychrometers or determined at dry-bulb sensors and hygrometers, can fluctuate during the period, but the linear least squares trend in the reading average (average for all stations) for the test period shall not exceed the following:
 - i. Wet-bulb temperature: 1 °C per hour.
 - ii. Dry-bulb temperature: 3 °C per hour (if applicable, e.g. testing wet/dry tower in the dry mode).
 - iii. Cooling range: 1 °C per hour, or 10 % of the test range, whichever is less.
 - iv. It is important to limit the magnitude of these trends for the following reasons. A sufficiently large, gradual, downward trend in wet-bulb or dry-bulb (wet/dry, opened or closed, natural draft and fan-assisted natural draft) will tend to make the tower result look worse than the tower result would be at steady wet-bulb. Likewise, a sufficiently large, gradual, upward trend will tend to make the tower look better than at a steady wet-bulb temperature. Similarly, a sufficiently large, gradual, downward trend in cooling range will tend to make

the tower result look worse than at a steady cooling range. Conversely, a sufficiently large, gradual, upward trend in cooling range will tend to make the tower result look better than at a steady cooling range.

8.2.5 Data recording

Valid test periods can be consecutive, but not overlapping, as long as validity requirements are fulfilled.

When a measurement requires several probes, the data from each probe shall be recorded independently and the value of the parameter equals to the arithmetic average of all the readings. Then, the value of each parameter for the test period is an arithmetic average of the successive readings within the test period (see [Clause 9](#)).

8.3 Extended tests

8.3.1 General

Extended tests enable an actual verification of wind effect on tower performance. They are appropriate when the contract requires that the supplier guarantees the average cold water temperature (or approach) as a function of all main parameters, including wind speed.

8.3.2 Duration of the test period

A test period (see definition [Clause 3](#)) lasts 10 min.

8.3.3 Required number of valid test periods

A minimum of 300 valid test periods are required for an acceptance test. All valid test periods recorded shall be taken into account in the acceptance test.

8.3.4 Frequency of measurements in an extended test

Measurements shall be taken and recorded at regular intervals over a period (see [Table 3](#)). Recordings are required, due to the fact that extended tests take place over several weeks.

8.3.5 Validity conditions for extended tests

A test period shall be valid only if the requirements below are met.

8.3.5.1 Climatic condition requirements during the period

- a) No rain, snow, or hail.
- b) No fog; the difference between dry-bulb and wet-bulb temperature shall be greater than 0,5 °C.
- c) The wet-bulb temperature of the ambient air shall be greater than or equal to 2 °C.
- d) In the event of high obstacles (other cooling tower, turbine building) being in the vicinity of the cooling tower, only those test periods for which the wind does not come from the direction of these obstacles are taken into account.
- e) The standard deviation, s , of the average wind velocity (V_{avg}) in the period shall be less than a limit value: $s < (0,5 V_{avg} + 0,2 V_{avg})$.
- f) The average vertical ambient dry-bulb temperature gradient G shall lie within 0 °C/100 m of height and 1 °C decrease/100 m of height (see [7.3.6](#)); if the indicator defined in [7.3.6 b](#)) is used, the average dry-bulb temperature near the top of the air inlet shall not be higher than the average dry-bulb measured on the same circumferential 1,5 m above grade level.

g) Maintain constant basin level with makeup flow rate.

8.3.5.2 Variations from design

The following variations from design conditions shall not be exceeded in a test period:

- a) wet-bulb temperature: $\pm 8,5$ °C;
- b) dry-bulb temperature: ± 14 °C;
- c) circulating water flow rate: ± 10 %;
- d) range: ± 20 %;
- e) barometric pressure: $\pm 3,5$ kPa;
- f) water/process fluid quality: The quality of the water/process fluid, or in the case of closed-circuit cooling towers, the re-circulating spray water, shall be as follows.
 - 1) Dissolved solids or suspended solids shall not exceed 5,000 mg/l, or where specified in the contract documents, 1,1 times the specified value.
 - 2) Content of oil, tar, or fatty substances, as determined by a recognized national standard, shall not exceed 10 mg/L for splash fills and 1 mg/L for film fills.
 - 3) For wet/dry towers, the limits for foreign substances in the circulating water shall be by prior mutual agreement between the purchaser and the manufacturer.

Table 3 — Extended test — Minimum frequency of recordings and units of measure

Measurement	Minimum readings/ test period per station	Units	Record to nearest
Entering wet-bulb temperature	10	°C	0,05
Entering dry-bulb temperature	10	°C	0,05
Ambient dry-bulb temperature	10	°C	0,05
Cold water temperature	10	°C	0,05
Hot water temperature	10	°C	0,05
Water flow rate ^b	1	m ³ /hr	0,5 %
Tower pumping head	once/test	m	0,01
Wind velocity	60	m/s	0,5
Makeup temperature	10	°C	0,05
Makeup flow ^b	1	m ³ /hr	0,5 %
Blowdown temperature	10	°C	0,05
Blowdown flow ^b	1	m ³ /hr	0,5 %
Barometric pressure	10	kPa	0,01
Atmospheric gradient ^c	1	°C/100 m	0,05
Wind speed at tower exit ^c	1	m/s	0,5
^a Relative humidity and dry bulb. ^b In case of constant water flow rate (flow produced by pumps, without adjusting mechanism on the circuit). This flow rate should be measured only once for the whole acceptance test, preferably at the beginning of the test. ^c Direct measurement (if practical) or through indicator (see A.6.2).			

8.3.5.3 Constancy of test conditions

During the hour preceding the end of the test period:

- a) The difference between the maximum and minimum values of the cooling range on the tower shall not exceed 5 % of the average value.
- b) The difference between the maximum and minimum values of the temperature of the cold water shall not exceed 1 °C.
- c) During the test period, the variation from the maximum to the minimum in the average cold water temperature readings shall not exceed 0,2 °C.

8.3.6 Conducting an extended performance test

A test period shall last 10 min. Valid test periods can be consecutive, but not overlapping, as long as validity requirements are fulfilled.

When a measurement requires several probes, the value of the parameter equals the arithmetic average of all the readings. Then, the value of each parameter for the test period is an arithmetic average of the successive readings within the test period. See [Clause 9](#).

9 Evaluation of tests

9.1 General

The thermal performance of a cooling tower is its ability to produce guaranteed cold water temperatures under specified operating conditions and inlet-air conditions. This can be verified by a direct comparison between the test results and the manufacturer's performance curves or by reference of the test results to the design conditions using characteristic curve analysis. When extended tests are carried out, the guaranteed temperature is calculated as a function of the different measured parameters for each test period.

9.2 Computation of test period values from test reading values

9.2.1 Determination of measured test values

The individual, consecutive test readings for each parameter shall be arithmetically averaged over the duration of the test period to obtain the measured test value for that parameter. Test readings shall be corrected for instrument calibration.

9.2.2 Thermal lag

If the test duration extending from τ_1 to τ_2 includes an extension (S) for thermal lag, in accordance with [4.4](#), the following readings shall be averaged over the first time period extending from τ_1 to $(\tau_2 - S)$:

- a) hot water (process fluid) temperature (T_{HW});
- b) dry-bulb temperature (T_{DB});
- c) wet-bulb temperature (T_{WB}) or relative humidity (RH) and dry-bulb temperature (T_{DB});
- d) flow rate of circulating water (process fluid) (Q_W);
- e) flow rate and temperature of any water other than the circulating water entering the tower basin [e.g. makeup (Q_{MU} and T_{MU})];
- f) fan driver power (W_{FM}).

The remaining measurements shall be averaged over the latter period extending from $(\tau_1 + S)$ to τ_2 :

- a) temperature of cold water (process fluid) leaving the tower (T_{CW});
- b) flow rate and temperature of any flow stream leaving the tower basin [e.g. blowdown (Q_{BD} and T_{BD})].

9.2.3 Hot water (process fluid) temperature

The test hot water (process fluid) temperature (T_{HW}) used to evaluate the tower performance shall be the measured temperature readings of the entering flow stream, averaged over the duration of the test period. In the case of multiple streams, the mass flow weighted average temperature shall be used.

9.2.4 Cold water (process fluid) temperature

The test cold water (process fluid) temperature (T_{CW}) used to evaluate the tower performance shall be the measured temperature readings of the leaving flow stream, averaged over the duration of the test period. In the case of multiple streams, the mass flow weighted average temperature shall be used. Final results shall be corrected as necessary for the effects of the makeup, blowdown, and any other heat added or removed between the tower and the point of measurement.

- a) If the test cold water temperature was measured at a point between the outlet connection on the tower and the suction of the re-circulating pump, no adjustment to the measured temperature for pump energy is necessary.
- b) If the test cold water temperature was measured on the discharge side of the re-circulating pump using a flowing bleed stream open to the atmosphere, the measured temperature shall be adjusted for throttling process using Formula (4).

$$T_{CW, adj} = (T_{CW,t}) - 0,002\ 39 \left(\frac{P_2}{\eta_P} \right) \quad (4)$$

- c) If the test cold water temperature was measured on the discharge side of the re-circulating pump using a closed well, the measured temperature shall be adjusted for the heat added due to the inefficiency of the pump using Formula (5).

$$T_{CW, adj} = (T_{CW,t}) - 0,002\ 39 (P_2 - P_1) \left(\frac{1 - \eta_P}{\eta_P} \right) \quad (5)$$

9.2.5 Makeup and blowdown adjustments

For open-circuit cooling towers, if the makeup is injected and/or the blowdown is removed upstream the cold water measurement section, then the test cold water temperature shall be adjusted for the effect of makeup and/or blowdown, using Formula (6).

$$T_{CW} = \left[\frac{(Q_W)(T_{CW, adj}) + (Q_{BD})(T_{BD}) - (Q_{MU})(T_{MU})}{(Q_W) + (Q_{BD}) - (Q_{MU})} \right] \quad (6)$$

For closed-circuit cooling towers, the evaluation procedure calls for the flow rate of the process fluid to be adjusted to account for the effect of makeup and/or blowdown, using Formula (7).

$$Q_{PF, T, adj, 1} = (Q_{PF, t}) - \left[\frac{(T_{RW} - T_{MU}) (\rho_W) (C_{P, W})}{(T_{HPF} - T_{CPF}) (\rho_{PF}) (C_{P, PF})} \right] (Q_{MU}) \quad (7)$$

9.2.6 Entering air temperatures

The test values for the entering air wet-bulb temperature (T_{WB}) and, when required, the dry-bulb temperature (T_{DB}) shall be the arithmetic average of their respective readings taken over the duration of test to comply with the requirements of [8.2.4.3](#).

$$|T_{WB(n)} - \bar{T}_{WB}| \leq 1,5^\circ \quad (8)$$

and

$$|T_{DB(n)} - \bar{T}_{DB}| \leq 4,5^\circ \quad (9)$$

and the slope $\Delta T/\Delta t$ of a least square fit to the measured temperatures over the duration of the test period shall not exceed:

- a) $\pm 1^\circ \text{C}$ per hour for wet-bulb temperatures;
- b) $\pm 3^\circ \text{C}$ per hour for dry-bulb temperatures.

NOTE These conditions are not applicable for extended tests (see [9.3](#)).

9.2.7 Ambient air temperature

The test values for the ambient air wet-bulb and wet-bulb temperatures shall be the arithmetic average of the readings taken over the test period.

9.2.8 Fan driver output power

If applicable, the fan driver output power shall be computed using Formula (10):

$$W_{FM, t} = (kW_{FM, t}) (\eta_{FM}) \quad (10)$$

9.2.9 Validity of test

$$\left| \frac{q_{t,(n)}}{q_t} - 1 \right| \leq 0,025 \quad (11)$$

$$\left| \frac{R_{t,(n)}}{R_t} - 1 \right| \leq 0,025 \quad (12)$$

$$\left| \frac{W_{FM,t}}{W_{FM,d}} - 1 \right| \leq 0,1 W_{FM,d} \quad (13)$$

9.2.10 Wind velocity

9.2.10.1 The recorded values for wind speed and direction shall be reviewed for conformance to [8.2.4](#) or [8.3.4](#), as applicable.

9.2.10.2 The vertical dry-bulb temperature gradient, either by the actual or the indicator, shall be calculated as 100 times the higher elevation temperature (°C) minus the lower elevation temperature divided by the higher elevation (m) measured minus the lower elevation, expressed in metres. The result is expressed as °C/100 m.

9.2.11 Tower pumping head

When pressure readings are taken at multiple inlets, the measured test values shall be corrected to the centreline of the inlet connection, if necessary, and combined by averaging the readings arithmetically to a single value.

$$\overline{P_{ST}} = \left(\frac{1}{n} \right) \sum_{i=1}^n P_{ST(n)} \quad (14)$$

Then determine the test value of the velocity at the tower inlet connection(s) based on the measured test flow rate and the total area of the inlet connections.

$$v_{L,t} = \frac{1\,000 \times Q_{W,t}}{A_C} \quad (15)$$

Next, determine the velocity pressure of the re-circulating water at the inlet to the tower

$$P_{V,t} = \left(\frac{\rho_W \times v_{L,t}^2}{2 g_C} \right) \quad (16)$$

and determine the total measured tower pumping head at test flow as

$$H_{P,t} = P_{V,t} + P_{ST,t} + \gamma Z_i \quad (17)$$

The pumping head corrected to design flow is

$$H_{P,d} = \left[(P_{V,1} + P_{ST,1}) \left(\frac{Q_{W,d}}{Q_{W,t}} \right)^2 \right] + \gamma Z_i \quad (18)$$

9.2.12 Closed-circuit tower heat exchanger pressure drop

The static pressure at the inlet and outlet nozzles of the heat exchangers shall be measured in accordance with the provisions of [A.4](#).

$$\Delta P_{HE,adj} = \Delta P_{HE,t} \left(\frac{Q_{PF,d}}{Q_{PF,t}} \right)^{1,8} \quad (19)$$

9.3 Basic thermal performance test evaluation (for all tower types)

The performance of a cooling tower can be evaluated from the measured test data using either the performance curve method (preferred) or the characteristic curve method, as agreed by the parties to the test, prior to the test.

9.3.1 Methodologies, a discussion

The characteristic curve analysis typically includes some simplifying assumptions which increase the inaccuracy of the result as the deviations between the measured test conditions and the design conditions

increase. Additional inaccuracies are introduced when attempting to use this essentially counterflow methodology to evaluate crossflow cooling towers, although these can be partially mitigated through the use of adjustment factors. Therefore, the characteristic analysis is presented in this test code for open-circuit, mechanical draft cooling towers primarily as a means to evaluate the performance of an existing cooling tower for which the manufacturer's performance data are not available. It should not be used for acceptance or certification testing.

9.3.2 Psychrometrics

A single set of official psychrometric formulae has been adopted and is included in the code both in tabular form for ease of use and with source code for computer application. The purpose of including these data is not to endorse any one set of psychrometric formulae, but to adopt an easily available and computer friendly basis so that all persons calculating test results from this code will obtain the same answer from the same input data. This psychrometric information is included in [Annex D](#).

9.3.3 Open-circuit, mechanical draft towers — Performance curve method

The formats for the performance curves and data submitted by the manufacturer are described in [5.3.2](#), [5.3.5](#), and [5.3.9](#).

9.3.3.1 Evaluation by flow rate capability

The cooling tower performance can be evaluated in terms of flow capability where the measured performance is expressed as a percentage of the flow rate predicted by the manufacturer's data for the measured test conditions. An example of this methodology is given in [Annex F](#).

9.3.3.1.1 Determination of the predicted flow rate

The predicted flow rate for the measured test conditions shall be determined by crossplotting the manufacturer's performance curves. A suitable procedure consists of first entering the manufacturer's curves at the measured test wet-bulb temperature and determining the associated cold water temperature for each combination of range and flow rate. Using these data, prepare a crossplot relating cooling range to cold water temperature with the three water circulation rates as parameters. Enter this crossplot at the measured test range and determine the cold water temperature associated with each flow rate. Using these data, develop a second crossplot relating cold water temperature to water circulation rate. Enter this final curve at the corrected test cold water temperature and from the intersection with the curve, determine the predicted flow rate for the measured test conditions.

9.3.3.1.2 Determination of psychrometric properties of air at fans

Forced draft and induced draft tower configurations require different procedures for determining the properties of the air entering the fans.

9.3.3.1.2.1 Forced draft units

For forced draft towers, the fan inlet-air conditions are the same as the tower inlet-air conditions. Therefore the test density ($\rho_{A1,t}$) and the test specific volume ($v_{A1,t}$) are computed directly from the measured test wet-bulb temperature, dry-bulb temperature, and barometric pressure. The design conditions at the tower's air inlet shall be supplied by the manufacturer.

9.3.3.1.2.2 Induced draft units

For an induced draft tower, the condition of air at the inlet to the fan(s) is the tower discharge condition and both the design and test discharge air properties shall be determined by a heat balance calculation.

The heat balance formula states that the heat gain of the air as it moves through the cooling tower equals the heat loss of the water such that:

$$L \times (C_{P,W}) \times (T_{HW} - T_{OW}) = G \times (h_{A,2} - h_{A,1}) \quad (20)$$

Rearranging terms to isolate the value for exit air enthalpy, the heat balance formula becomes:

$$h_{A,2} = \left(\frac{L}{G} \right) \times (C_{P,W}) \times (T_{HW} - T_{OW}) + h_{A,1} \quad (21)$$

which can be solved directly for the enthalpy of the leaving air at design conditions, by submitting the data supplied by the manufacturer. The air leaving the tower and entering the fan(s) is assumed to be saturated at this enthalpy, and the remaining properties can be found using the thermodynamic properties for moist air from [Annex D](#).

The test discharge air properties are calculated by substituting all known values into Formula (21) and reducing terms to express the test $(L/G)_t$ as a function of discharge air density and specific volume. This expression of $(L/G)_t$ is then substituted into the heat balance Formula (20) along with the known values for specific heat, temperatures, and enthalpy of the entering air and combining terms to express the enthalpy of the leaving air as a function of the density $(\rho_{A2,t})$ and specific volume $(v_{A2,t})$ of the leaving air:

$$h_{A2,t} = (K_1) \times (v_{A2,t}) + K_2 \quad (22)$$

where K_1 and K_2 are constants derived by combining the known numerical values.

At this point, a leaving air temperature is assumed and the values of density $(\rho_{A2,t})$ and specific volume $(v_{A2,t})$ for saturated air at that temperature are used to solve the formula for enthalpy. The calculated value for enthalpy is then compared to the actual enthalpy of saturated air at the assumed temperature and the process repeated with a new assumed air temperature until the calculated value closely matches the actual value. Then, the psychrometric properties of saturated air at that temperature are used for the density and specific volume of the air entering the fan(s). A detailed example is given in [Annex F](#).

9.3.3.1.3 Determination of the adjusted test flow rate

The adjusted test flow rate is determined from Formula (23) below, using the procedure described above in [9.3.3.1.2](#) to determine the density of the air entering the fan(s).

$$Q_{W,t,adj} = Q_{W,t} \left(\frac{W_{FM,d}}{W_{FM,t}} \right)^{1/3} \left(\frac{\rho_{A,t}}{\rho_{A,d}} \right)^{1/3} \quad (23)$$

9.3.3.1.4 Determination of the tower capability

The capability, C_{CAP} , expressed in percent of design circulating flow, is then computed using Formula (24).

$$C_{CAP} = 100 \left(\frac{Q_{W,t,adj}}{Q_{W,pred}} \right) \quad (24)$$

9.3.3.1.5 Multiple valid test periods

Where there are multiple valid test period results to be averaged, Formula (25) shall apply.

$$\bar{C}_{CAP} = \left(\frac{1}{n} \right) \sum_{i=1}^n C_{CAP(n)} \quad (25)$$

9.3.3.1.6 Compliance

The tower shall have achieved the guaranteed condition if

$$C_{CAP} + I_{CAP} \geq 100\% \quad (26)$$

where $I_{CAP} = 0$, unless specified differently in the contract.

9.3.3.2 Evaluation by approach deviation

Alternatively, the cooling tower performance can be evaluated in terms of approach deviation, the difference between the corrected cold water temperature and the cold water temperature predicted by the manufacturer's data. This comparison can be done at the measured test conditions or at the design conditions. However, when a penalty is contractually specified as a function of degrees deviation, the evaluation shall be made at design conditions per [9.3.3.2.2](#) below.

9.3.3.2.1 Predicted cold water temperature at measured test conditions

Using the final crossplot developed in [9.3.3.1.1](#) relating cold water temperature to water circulation rate, enter the plot at the adjusted test flow, as determined in [9.3.3.1.3](#), and project a line vertically to intersect the curve. Read the value for the predicted cold flow temperature ($T_{CW, pred}$) at the point of intersection.

9.3.3.2.1.1 Comparison with measured cold water temperature

Compare the corrected test value for cold water temperature ($T_{CW, t}$) to the predicted cold water temperature ($T_{CW, pred}$) determined above such that the approach deviation (ΔT_{App}) equals:

$$\Delta T_{App} = (T_{OW, corr}) - (T_{ow, pred}) \quad (27)$$

9.3.3.2.2 Approach deviation at design conditions

To determine the approach deviation at design conditions, first determine the tower capability as described in [9.3.3.1](#). Then, using the manufacturer's performance curves, develop a plot of leaving water temperature as a function of tower capability for the design range and wet-bulb temperature. A suitable procedure consists of first entering the manufacturer's curves at the design wet-bulb temperature and determining the cold water temperature at design range for each flow rate. Using these data, prepare a crossplot relating cold water temperature to the reciprocal of the percentage water circulation rate, expressed as a decimal (e.g. 90 % flow equates to 111,11 % capability, 110 % flow equates to 90,91 % capability). Enter this crossplot at the tower capability as determined in [9.3.3.1.4](#) and project a line vertically to intersect the curve. At the intersection, read the predicted cold water temperature ($T_{CW, pred}$) for the tower at the test capability.