

COOLING TECHNOLOGY INSTITUTE

CTI CODE TOWER Standard Specifications

Acceptance Test Code for Water Cooling Towers



Revised February 2000

CTI Code ATC-105 (00)

FOREWORD

This Cooling Technology Institute (CTI) publication is published as an aid to cooling tower purchasers and designers. It may be used by anyone desiring to do so, and efforts have been made by CTI to assure the accuracy and reliability of the data contained herein. However, CTI makes **NO WARRANTY OF FITNESS FOR PARTICULAR PURPOSE OR MERCHANTABILITY** nor any other warranty expressed, implied or statutory. In no event shall CTI be liable or responsible for **INCIDENTAL, CONSEQUENTIAL OR COMMERCIAL** losses or damage of any kind resulting from this publication's use; or violation of any federal, state, or municipal regulation with which this publication may conflict or for the infringement of any patent resulting from the use of this publication.

All CTI codes and standards are copyrighted with all rights reserved to CTI. The reproduction of any part of this or any other CTI code or standard is a violation of Federal Law. One must recognize and appreciate commitment by a number of volunteer members who donate their time to develop and update CTI codes and standards. The monies spent for code development, administrative staff support and publication are essential and constitute a substantial drain on CTI. The purchase price of these documents helps to offset these costs. Reproduction and distribution by others, in addition to being unethical, undermines this system and constitutes a further financial drain on CTI. When copies are needed, you are requested to call or write the Cooling Technology Institute, P.O. Box 73383, Houston, Texas 77273, (281) 583-4087. Please request that your associates buy the required codes and standards rather than copy them. Your cooperation in this matter is greatly appreciated.

Nothing contained herein is to be construed as granting any right for the manufacture, sale or use in connection with any method, apparatus, or product covered by letters patent, nor as insuring anyone against liability for infringement of letters patent.

This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers.

Approved by the CTI Executive Board.



This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2005.

Approved by the
CTI Executive Board

Copyright 2000
by Cooling Technology Institute
Printed in U.S.A.

CTI - Code
ATC-105(00)

Acceptance Test Code for Water Cooling Towers

Contents

	Page		Page
I. Test Procedure			
1. Scope and Purpose	1	7. Natural-Draft Cooling Towers - Performance Curve Method	11
1.1 Scope	1	7.1 Scope and Purpose	11
1.2 Purpose	1	7.2 Manufacturer's Data	11
1.3 Flexibility	1	7.3 Determination of Tower Capability	11
1.4 Other Uses	1	8. Natural-Draft Cooling Towers with Fan-Assist - Performance Curve Method	12
1.5 Impartial Testing Service	1	8.1 Scope and Purpose	12
1.6 System of Units	1	8.2 Manufacturer's Data	12
1.7 Uncertainty Analysis	1	8.3 Determination of Tower Capability	12
1.8 Nomenclature	1	9. Wet/Dry Mechanical-Draft Cooling Towers - Performance Curve Method	12
2. Conditions of Test	3	9.1 Scope and Purpose	12
2.1 Conduct of Test	3	9.2 Manufacturer's Data	12
2.2 Condition of Equipment	3	9.3 Determination of Tower Capability	13
2.3 Operating Conditions	3		
2.4 Constancy of Test Conditions	4	III. Appendices	
2.5 Duration of Test	4	A. SI Example Mechanical-Draft Cooling Tower Characteristic Curve Method	14
2.6 Frequency of Readings	4	B. IP Example Mechanical-Draft Cooling Tower - Characteristic Curve Method	17
2.7 Test Uncertainty	5	C. SI Example Mechanical-Draft Cooling Tower - Performance Curve Method	20
3. Instruments and Measurements	5	D. IP Example Mechanical-Draft Cooling Tower - Performance Curve Method	25
3.1 Water Flow Measurements	5	E. SI Example Natural-Draft Cooling Tower - Performance Curve Method	30
3.2 Water Temperature Measurements	5	F. IP Example Natural-Draft Cooling Tower - Performance Curve Method	38
3.3 Inlet Air temperature Measurements	6	G. Number and Location of Wet-Bulb Temperature Measurement Stations	46
3.4 Wind Velocity (Speed and Direction)	7	H. Psychrometrics	48
3.5 Tower Pumping Head	7	I. Correcting Cold Water Temperature for Heat Added by Pump	64
3.6 Fan Driver Power	8	J. Adjusting Measured Data for Thermal Lag	66
3.7 Water Analysis	8	K. References	67
4. Report of Results	8	L. Determining Wind Velocity on Natural Draft Cooling Towers	68
4.1 Scope	8	M. Expressing Tower Capability as a Function of Deviation from Design Cold Water Temperature	69
4.2 Test forms	8	N. Sample Test Forms	71
4.3 Distribution	8		
4.4 Security	8		
4.5 Limitations	8		
4.6 Tower Capability	9		
II. Evaluation of Results			
5. Mechanical-Draft Cooling Towers - , Characteristic Curve Method	10		
5.1 Scope and Purpose	10		
5.2 Manufacturer's Data	10		
5.3 Determination of Test L/G Value	10		
5.4 Determination of Test KAV/L Value	10		
5.5 Determination of Tower Capability	10		
6. Mechanical-Draft Cooling Towers - Performance Curve Method	11		
6.1 Scope and Purpose	11		
6.2 Manufacturer's Data	11		
6.3 Determination of Tower Capability	11		

Part I

Test Procedure

1. SCOPE AND PURPOSE

1.1 Scope. This Code covers the determination of the thermal capability of water cooling towers.

1.2 Purpose. The purpose of this Code is to describe instrumentation and procedures for the testing and performance evaluation of water cooling towers.

1.3 Flexibility. It is recognized that the data limitations specified throughout this test procedure represent desired conditions which may not exist at the time the test is performed. In such cases, existing conditions may be used if mutually agreed upon prior to the test by authorized representatives of the manufacturer, the purchaser, and the CTI.

1.4 Other Uses. Although intended primarily for thermal acceptance testing, all or parts of this Code may be used for other purposes, such as the determination of any of the individual measurements described. It may be used for the certification of tower product lines in accordance with CTI Bulletin STD-201, in which case references to the purchaser are not applicable. Portions of this code and/or other codes, such as "ASME PTC-30 Air Cooled Heat Exchangers", may be used as applicable as a basis for water conservation and plume abatement tests by prior mutual agreement of purchaser and manufacturer.

1.5 Impartial Testing Service. It is the intention of the Cooling Technology Institute to provide independent third-party thermal performance tests. This means that any situation in which the testing agency has a material or any other interest in the outcome of the test must be avoided. The CTI-licensed Test Agency referred to in this code shall have no connection with the manufacturer, the purchaser, or the Cooling Tower Institute, other than a contractual agreement with the latter. For the purposes of this code the CTI-licensed Test Agency is hereinafter referred to as the CTI.

1.5.1 Certain categories of business interests or activities may compromise the objectivity of an agency and are considered by CTI as inappropriate for an organization licensed to provide impartial testing services. When any portion of the revenues of a testing agency or any of its corporate parents or subsidiaries is derived from these interests or activities this will preclude that organization from consideration. The following is a non-exclusive listing of examples of these categories of business interests or activities:

a) The manufacture, repair, replacement, or upgrade of cooling towers or cooling tower components.

b) Operation or ownership of cooling towers related to primary income generating processes.

1.5.2 Further, any specific situation in which the testing agency can be said to have an interest in the outcome of a particular test is considered a conflict of interest and is to be avoided. The following is a non-exclusive listing of examples of such situations:

a) Performing cooling tower design, engineering, construction, or related consultation services, such as bid evaluation, for a party to a particular test (for the purposes of this paragraph, operation and maintenance recommendations do not constitute "related consultation services").

b) Engaging in a contractual or business relationship with the cooling tower manufacturer, constructor, or supplier of components or equipment on a particular tower to be tested. (A conflict of interest shall not exist if the testing agency has conducted independent testing of other cooling towers for cooling tower owners, manufacturers, constructors, or suppliers of components and equipment).

1.6 System of Units. This standard is written in Primary Rational SI (International System of Units) units with secondary I-P (Inch-Pound) units. For full details on appropriate conversions between I-P and SI units refer to CTI Bulletin STD-145.

1.7 Uncertainty Analysis. If an uncertainty analysis is desired, it should be agreed to by both parties prior to the test since this analysis requires recording of certain additional data.

1.8 Nomenclature. The symbols used in this Code are identified in the following tabulation (some additional symbols are listed independently in the Appendices).

Symbol	Description	Units
a	Area of transfer surface per unit of fill volume	m ² /m ³ (ft ² /ft ³)
C	Tower capability	% of design flow
c _{pw}	Specific heat of water at constant pressure	kJ/kg °C (BTU/lb _m °F)
g	Acceleration due to gravity	m/s ² (ft/s ²)
G	Mass flow rate of dry air through the cooling tower	kg dry air/s (lb _m dry air/hr)
G _d	Mass flow rate of dry air through the cooling tower at design conditions	kg dry air/s (lb _m dry air/hr)

Symbol	Description	Units	Symbol	Description	Units
G_t	Mass flow rate of dry air through the cooling tower at test conditions	kg dry air/s (lb _m dry air/hr)	$\dot{q}_{tot}$	Total heat load for wet/dry cooling tower	kJ/s (BTU/hr)
h	Enthalpy	kJ/kg dry air (BTU/lb _m dry air)	Q_a	Airflow rate	L/s (CFM)
h_a	Enthalpy of air	kJ/kg dry air (BTU/lb _m dry air)	Q_{bd}	Blowdown water flow rate	L/s (gpm)
h_i	Enthalpy of inlet air	kJ/kg dry air (BTU/lb _m dry air)	Q_{mu}	Make-up water flow rate	L/s (gpm)
h_o	Enthalpy of outlet, or exit air	kJ/kg dry air (BTU/lb _m dry air)	Q_w	Circulating water flow rate	L/s (gpm)
h_w	Enthalpy of water at saturated wet-bulb temperature	kJ/kg dry air (BTU/lb _m dry air)	$Q_{w\ pred}$	Circulating water flow rate, predicted for test conditions	L/s (gpm)
H_{pc}	Computed pumping head at design fluid flow rate, predicted from test measurements	m (ft) of flowing fluid	Q_{wd}	Circulating water flow rate, design	L/s (gpm)
H_{pt}	Test (measured) pumping head	m (ft) of flowing fluid	Q_{wt}	Circulating water flow rate, test	L/s (gpm)
h_w	Enthalpy of air-water vapor mixture at bulk water temperature	kJ/kg dry air (BTU/lb _m dry air)	$Q_{wt\ adj}$	Circulating water flow rate, test adjusted to design fan driver power	L/s (gpm)
K	Overall heat and mass transfer coefficient	kg/s m ² (lb _m /hr ft ²)	R	Cooling range	°C (°F)
KaV/L	Tower characteristic	dimensionless	T_a	Temperature air wet-bulb	°C (°F)
L	Mass flow rate of water entering the cooling tower	kg/s (lb _m /hr)	T_{bd}	Temperature of blowdown water	°C (°F)
L_d	Mass flow rate of water entering the cooling tower at design conditions	kg/s (lb _m /hr)	T_{cw}	Temperature of cold water leaving the tower	°C (°F)
L_t	Mass flow rate of water entering the cooling tower at test conditions	kg/s (lb _m /hr)	T_{db}	Temperature of air dry-bulb entering the cooling tower	°C (°F)
L_1	Mass flow rate of water adjusted to design fan power	kg/s (lb _m /hr)	T_{hw}	Temperature of hot water entering the cooling tower	°C (°F)
L_2	Tower capability expressed as mass flow rate of water at design fan power and design temperature conditions	kg/s (lb _m /hr)	T_{mu}	Temperature of makeup water	°C (°F)
$(L/G)_d$	Ratio of mass flow rate of water to that of air at design conditions	dimensionless	T_w	Temperature of water	°C (°F)
$(L/G)_t$	Ratio of mass flow rate of water to that of air at test conditions	dimensionless	T_{wb}	Temperature of air wet-bulb entering the tower	°C (°F)
$(L/G)_i$	L/G ratio at the intersection of the test characteristic curve and the design approach curve	dimensionless	v	Velocity	m/s (ft/s)
P_t	Total pressure referred to atmospheric	Pa (inches of water)	V	Effective cooling tower fill volume	m ³ (ft ³)
P_{st}	Test static pressure, measured at (or referred to) the centerline of the tower piping inlet	m (ft) of flowing fluid	$\dot{W}$	Fan driver output power	kW (bhp)
P_{vt}	Test velocity pressure (computed from $v^2/2g$) at the centerline of tower piping inlet	m (ft) of flowing fluid	y	Exponent for fan driver output power for the dry section of wet/dry cooling tower	dimensionless
$\dot{q}_{dry}$	Dry heat load for wet/dry cooling tower	kJ/s (BTU/hr)	Z_i	Vertical distance from basin curb to centerline of tower piping inlet	m (ft)
$\dot{q}_{wet}$	Wet heat load for wet/dry cooling tower	kJ/s (BTU/hr)	Z_s	Effective stack height	m (ft)
			$\Delta\rho$	Air density difference	kg mixture/m ³ (lb _m mixture/ft ³)
			$\Delta\rho_d$	Air density difference at design	kg mixture/m ³ (lb _m mixture/ft ³)
			$\Delta\rho_{dr}$	Air density difference driving force	kg mixture/m ³ (lb _m mixture/ft ³)
			$\Delta\rho_r$	Resistance to air flow	kg mixture/m ³ (lb _m mixture/ft ³)
			$\Delta\rho_t$	Air density difference at test	kg mixture/m ³ (lb _m mixture/ft ³)
			Δh	Enthalpy difference	kJ/kg dry air (BTU/lb _m dry air)
			ΔP_n	Total pressure differential at test velocity	Pa (inches of water)
			ΔP_t	Total pressure differential	Pa (inches of water)
			ΔP_{td}	Total pressure differential at design	Pa (inches of water)

Symbol	Description	Units
v	Specific volume of air	m^3 mixture/kg dry air (ft^3 mixture/ lb_m dry air)
v_1	Specific volume of inlet air	m^3 mixture/kg dry air (ft^3 mixture/ lb_m dry air)
v_2	Specific volume of exit air	m^3 mixture/kg dry air (ft^3 mixture/ lb_m dry air)
ρ	Air density	kg mixture/ m^3 (lb_m mixture/ ft^3)
ρ_d	Average air density at design	kg mixture/ m^3 (lb_m mixture/ ft^3)
ρ_t	Average air density at test	kg mixture/ m^3 (lb_m mixture/ ft^3)

2. CONDITIONS OF TEST

2.1 Conduct of Test. The tower shall be prepared for testing in accordance with CTI Document FSP-156, *Preparation and Procedures for An Official CTI Thermal Performance Test*. The test shall be conducted by CTI in the presence of authorized representatives of the purchaser and the manufacturer, if they desire to be present. For acceptance testing, these representatives shall be given adequate notice prior to the test. The manufacturer shall be given permission and adequate notice to inspect the tower and prepare it for the test. In no case shall any directly involved party be barred from the test site. Acceptance test(s) shall be conducted within 12 months after structural completion of the tower, unless otherwise stipulated by contractual agreement of purchaser and manufacturer.

2.2 Condition of Equipment. At the time of the test the tower shall be in good operating condition.

- Water distribution system shall be essentially clear and free of foreign materials which may impede the normal water flow.
- Mechanical equipment, if involved, shall be in good working order. Fans shall be rotating in the correct direction, with proper orientation of leading and trailing edges. Fan blades shall be at a uniform angle that will yield within ± 10 percent of the specified fan driver output power loading. In addition, centrifugal fans shall be free of foreign material and properly secured to the shafts.
- Drift eliminators shall be essentially clear and free of algae and other deposits which may impede normal air flow.
- Fill shall be essentially free of foreign materials such as oil, tar, scale, or algae.
- Water level in the cold water basin shall be at normal operating elevation and shall be maintained substantially constant during the test in order to provide proper air flow to the fill.

f) Make-up and/or blow-down streams may be stopped prior to testing if other test condition requirements are not adversely affected.

g) Air-cooled portions shall be essentially free of foreign materials, both inside and outside. Representatives of purchaser and manufacturer shall agree prior to commencement of testing that the cleanliness of the equipment is within the tolerance specified by the manufacturer. Prior establishment of cleanliness criteria is recommended.

2.3 Operating Conditions. The test shall be conducted within the following limitations:

2.3.1 The wet-bulb and dry-bulb temperatures shall be the inlet values, measured in accordance with Paragraph 3.3 of this test procedure.

2.3.2 The wind velocity shall be measured in accordance with Paragraph 3.4 of this test procedure, and shall not exceed the following:

2.3.2.1 For mechanical-draft towers:

- average wind velocity....4.5 m/s (10 miles per hour)
- one-minute duration.....7.0 m/s (15 miles per hour)

2.3.2.2 For natural-draft towers, the average wind velocity and peak wind velocity at the top of the tower and at the middle of the air inlet height shall lie within the design limits specified in the cooling tower purchase contract. If no limits were specified in that contract, an average wind velocity of 4.5 m/s (10 mph) and a peak one-minute velocity of 7.0 m/s (15 mph) at both locations, tower discharge and one-half air inlet height, shall be used as the limitation.

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.

2.3.2.3 If the wind velocity is specified in the contract, a wind speed correction curve may be supplied to correct for the actual wind speed measured at a given location.

2.3.3 The following variations from design conditions shall not be exceeded:

- 2.3.3.1** Wet-bulb temperature $\pm 8.5^\circ\text{C}$ (15°F)
- 2.3.3.2** Dry-bulb temperature $\pm 14.0^\circ\text{C}$ (25°F)
- 2.3.3.3** Range $\pm 20\%$
- 2.3.3.4** Circulating water flow $\pm 10\%$
- 2.3.3.5** Barometric pressure ± 3.5 kPa (1" Hg)
- 2.3.3.6** Fan driver output power. $\pm 10\%$

* If applicable

2.3.4 The water shall be distributed to all operating cells and/or parts of the tower as recommended by the manufacturer. For multi-cell towers, one or more cells may be shut down, providing the circulating water flow to each operating cell is within the allowable limits. (For the purposes of this Code, a "cell" is defined as the smallest subdivision of the tower, bounded by exterior walls and partition walls, which can function as an independent unit. Each cell may have one or more fans or stacks and one or more distribution systems).

2.3.5 The total dissolved solids in the circulating water shall be limited as follows:

2.3.5.1 For all towers except wet/dry towers, the dissolved solids shall not exceed the greater of the following:

- a) 5,000 ppm
- b) 1.1 times the design concentration

The circulating water shall contain not more than 10 ppm oil, tar, or fatty substances as determined by the procedure outlined in "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes", published by the American Public Health Association.

2.3.5.2 For wet/dry towers, the limits for foreign substances in the circulating water shall be by prior mutual agreement between the purchaser and manufacturer.

2.3.6 For natural-draft towers, there should not be rain during or at least two hours before the test.

2.3.7 For natural-draft towers, an additional criteria for defining acceptable test periods is the vertical ambient dry-bulb temperature gradient. Where it is practical to measure this parameter directly, the following criteria may be used for an acceptable test period:

The average cooling tower vertical ambient dry-bulb temperature gradient between the elevation of the center of the air inlet and twice the height of the top of the tower shell, assessed in 60 m (200 ft) maximum increments, shall everywhere lie within the design limits specified in the cooling tower purchase contract. If no limits were specified in that contract, an average gradient of at least a 0.65°C/100 m (3.5°F/1000 ft) decrease of height (U.S. Standard Lapse Rate) shall be used as a guideline.

An indicator of the cooling tower vertical ambient dry-bulb temperature gradient shall be the difference in dry-bulb temperatures between ground level and the top of the air inlet. For an

acceptable test, the average dry-bulb temperature at or near the top of the air inlet shall be at least 0.15°C (0.25°F) less than the average dry-bulb temperature measured 1.5 m (5 ft) above grade level.

2.4 Constancy of Test Conditions. For a valid test, variations in test conditions shall be within the following limits:

2.4.1 Circulating water flow shall not vary by more than 2 percent.

2.4.2 Heat load shall not vary by more than 5 percent.

2.4.3 Range shall not vary by more than 5 percent.

2.4.4 Individual psychrometer air temperature readings may fluctuate during the test, but the linear least squares trend in the reading average (average for all stations) for the test period shall not exceed the following:

2.4.4.1

Wet-bulb temperature ... 1°C (2°F) per hour

2.4.4.2

Dry-bulb temperature* ... 3°C (5°F) per hour
*If applicable

Secondly, the maximum deviation of a reading average (e.g. the average of all wet-bulb psychrometer readings at one time interval) may not exceed the overall test period average by more than the following:

2.4.4.3

Wet-bulb temperature ±1.5°C (3°F)

2.4.4.4

Dry-bulb temperature* ±4.5°C (7.5°F)
*If applicable

2.5 Duration of Test. After reaching steady state conditions, the requirements for test duration shall be as follows:

2.5.1 For mechanical-draft towers, the duration of the test run shall be not less than one hour. If thermal lag time is greater than five minutes, the timed test period shall be at least one hour plus thermal lag time; refer to Appendix J for additional information.

2.5.2 For natural-draft towers, it is recommended that the test duration include a minimum of six one-hour periods of test data where the operating conditions are within the limitations stated in Paragraph 2.3 and that they be collected over at least a 2-day period.

2.6 Frequency of Readings. Readings shall be taken at regular intervals and recorded in the units and to the number of digits shown in the following tabulation:

Measurement	Minimum Number Each Hour Per Station	Unit	Record to Nearest
Wet-bulb temperature ¹	12	°C (°F)	0.05 (0.1)
Dry-bulb temperature ¹	12	°C (°F)	0.05 (0.1)
Cold water temperature ¹	12	°C (°F)	0.05 (0.1)
Hot water temperature ¹	12	°C (°F)	0.05 (0.1)
Circulating water flow ²	3	L/s (gpm)	0.5%
Tower pumping head	1	m (ft)	0.01 (0.1)
Fan driver power input ³	1	kW (hp)	0.5%
Wind velocity	continuous	m/s (mph)	0.5 (1)
Make-up temperature	2	°C (°F)	0.05 (0.1)
Make-up flow ⁴	2	L/s (gpm)	0.5%
Blow-down temperature	2	°C (°F)	0.05 (0.1)
Blow-down flow ⁴	2	L/s (gpm)	0.5%
Barometric Pressure	1	kPa (In of Hg)	0.01

¹ Or recording

² Single center point readings for comparison with full traverse reading (when measurement is made by pitot tube) to verify that the flow has not changed by the allowable limit

³ If applicable or required

⁴ Or totaled values per test

2.7 Test Uncertainty. The overall test uncertainty depends on the type and number of instruments used for the various measurements, and on the stability of the test conditions. Details on the recommended method for evaluation of overall test uncertainty are presented in ASME PTC-19.1 "Measurement Uncertainty" and in Appendix K.

3. INSTRUMENT AND MEASUREMENTS

All instruments used on a test must be calibrated and approved by CTI prior to the test. Calibration must be traceable to the U.S. National Institute of Standards Technology (NIST), other national measurement laboratories, or derived from accepted values of natural physical constants. The minimum calibration frequencies will be as follows:

Instrument	Minimum Calibration Frequency
Temperature sensors	Within 3 months prior to use
Water flow measurement devices	Three years if undamaged
Electric power meters	Yearly
Wind speed and direction devices	Yearly

Calibrations shall be performed whenever an instrument is damaged or it's accuracy is called into question for any other reason. Sufficient on-site comparisons of temperature sensors, after all wiring connections are made, is required before testing. If in doubt, a temperature sensor will be compared to another similar sensor and replaced if it is outside the accuracy specified

for the appropriate measurement. In addition, at the request and expense of the test purchaser, any and all instrumentation used on a test can be calibrated before and after a test. The test agency shall have a written procedure for calibration of each instrument. The test agency shall maintain records showing the calibration history for each instrument and make them available upon request.

The test report shall include the individual identification and location for each instrument used on the test so that calibration date and history can be traced.

3.1 Water Flow Measurements.

3.1.1 The following water quantities shall be measured:

- Circulating water flow to the tower
- Make-up water flow*
- Blow-down flow*

* if not stopped prior to test

3.1.2 Circulating water flow measurements may be made by any of CTI-approved methods specified in CTI Bulletin STD-146, namely a Pitot tube or other flow measurement devices that have a calibration accuracy of ± 1.0 percent or better. CTI Bulletin STD-146 covers in detail the pitot tube including all the associated equations, piping requirements, table of equal annular mid-point factors for traverse point locations, and properties of water and manometer fluids. For the alternative flow measurement devices, sections are presented on operating principle, installation, and accuracy. The selection of the method and location of measurement will be dependent upon the nature of the installation to be tested and may decrease the actual installed accuracy.

3.1.3 If the circulating water flow to the tower is measured by pitot tube traverse, an air-over-water (inverted type) manometer shall be used unless otherwise agreed by the parties to the test. One full traverse (along two axes at 90° to each other) shall be made either immediately preceding the test or during the test. A minimum of two center-points readings shall be taken during the test to monitor for changes in flow, possibly requiring another pitot traverse.

3.2 Water Temperature Measurements. Water temperature measurements shall be made by any of the instruments (such as resistance thermometers or mercury-in-glass thermometers) and methods prescribed in ASME PTC-19.3 "Temperature Measurement". Temperature measurement devices should meet the following requirements:

- The indicator or recorder shall be graduated in increments of not more than 0.1°C (0.2°F).

b) The temperature-sensitive element shall be accurate to $\pm 0.05^{\circ}\text{C}$ (0.1°F).

c) The temperature-sensitive elements shall be carefully located where the water will be thoroughly mixed.

3.2.1 Hot circulating water temperature measurement shall be made in the tower riser(s) or at the discharge of the inlet riser(s) into the flume or distribution system or, for a multi-cell tower, in the supply header just upstream of the first riser. If the source is a mixture of two or more streams of different temperatures, complete mixing must be assured at the point of measurement or sufficient flow rate and temperature measurements shall be made to ensure an accurate weighted average water temperature.

3.2.2 Cold circulating water temperature measurements should preferably be made in a full-flowing bleed stream at the circulating pump discharge, and the average corrected for heat added by the pump (see Appendix I). If the measurement is made at a location where temperatures and velocities are not uniform over the stream cross-section, sufficient flow rate and temperature measurements shall be made to ensure an accurate weighted average water temperature.

3.2.3 Make-up water temperature measurement, if applicable, shall be made at the point the make-up water enters the system.

3.2.4 Blow-down temperature measurement, if applicable, shall be made at the point the blow-down leaves the system.

3.3 Inlet Air Temperature Measurements. The measurement of inlet wet-bulb temperature is required for the testing of all types of cooling towers covered by this Code. The measurement of inlet dry-bulb temperature is required for natural-draft, fan-assisted, and wet/dry cooling towers. The measurement of inlet dry-bulb temperature is also required for mechanical-draft cooling towers of the forced draft design, in order to determine the fan inlet air density. It is recommended that the dry-bulb temperature also be recorded for mechanical-draft towers of the induced draft design to allow accurate calculation of inlet air psychrometric properties and/or estimating evaporation.

3.3.1 Inlet Wet-bulb Temperature. The inlet wet-bulb temperature shall be measured with mechanically aspirated psychrometers, each meeting the following requirements:

a) The indicator or recorder shall be graduated in increments of not more than 0.1°C (0.2°F).

b) The temperature-sensitive element shall be accurate to $\pm 0.05^{\circ}\text{C}$ (0.1°F).

c) The temperature-sensitive element shall be shielded from direct sunlight or from other significant sources of radiant heat. The shielding device shall be within 1°C (2°F) of the surrounding dry-bulb temperature.

d) The temperature-sensitive element shall be covered with a wick that is continuously fed from a reservoir of distilled water.

e) The temperature of the distilled water used to wet the wick shall be at approximately the wet-bulb temperature being measured. This may be obtained in practice by allowing adequate ventilated wick between the water supply and the temperature-sensitive element.

f) The wick shall fit snugly over the temperature-sensitive element and extend at least 2 cm (0.75 in) past the element over the stem. It shall be kept clean while in use.

g) The air velocity over the temperature-sensitive element shall be maintained between 4.5 and 5.5 m/s (950 and 1050 ft/min).

3.3.1.1 For measurement of inlet wet-bulb temperature, the instruments shall be located within 1.5 m (5 ft) of the air intake(s). A sufficient number of measurement stations shall be designated to ensure that the test average is an accurate representation of the true average inlet wet-bulb temperature. Guidance on the location of measurement stations is given in Appendix G.

3.3.1.2 For manually recorded data, the average of 3 successive readings taken at 10-second intervals at each station shall be considered the wet-bulb temperature at that time at that instrument station. The station averages shall be averaged to obtain the effective wet-bulb temperature for that run. Such runs shall be made every 5 minutes during the test period, and the arithmetic average of these runs shall be considered the inlet wet-bulb temperature and shall be used for the evaluation of results.

3.3.1.3 For computer data acquisition systems, the number of readings taken must be at least equal to that of the manually recorded system, a minimum of 36 readings per hour. The number recorded must also be at least equal to the manually recorded system, a minimum of 12 per hour.

3.3.2 Inlet Dry-bulb Temperature. The inlet dry-bulb temperature, where applicable, shall be measured with mechanically aspirated wickless psychrometers each meeting the following requirements:

a) The indicator or recorder shall be graduated in increments of not more than 0.1°C (0.2°F).

b) The temperature-sensitive element shall be accurate to $\pm 0.05^{\circ}\text{C}$ (0.1°F).

c) The temperature-sensitive element shall be shielded from direct sunlight or from other significant sources of radiant heat. The shielding device shall be within 1°C (2°F) of the surrounding dry-bulb temperature.

d) When inlet dry-bulb temperature is measured for a mechanical-draft cooling tower, either forced or induced draft design, a measurement accuracy of 1°C to 3°C (2°F to 5°F) for the average inlet dry-bulb temperature is usually acceptable. In most cases this can be achieved by means of a single psychrometer of the type described above.

e) The air velocity over the temperature-sensitive element should be at least 2 m/s (400 FPM) and preferably the same as the wet-bulb psychrometer.

3.3.2.1 For the measurement of inlet dry-bulb temperature, instrument location, the number of stations, the frequency of readings, and the reading and averaging procedures shall be as described in Paragraphs 3.3.1.1, 3.3.1.2, and 3.3.1.3 for wet-bulb temperature measurement.

3.3.2.2 For natural-draft cooling towers, the inlet dry-bulb gradient temperature is very important since it affects the inlet air density which 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 neither be down-wind of nor within the influence of the cooling tower nor any other site sources of turbulence or thermal gradients which might substantially affect the data. The vertical elevations shall be as specified in Paragraph 2.3.7. 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 cir-

cumferential position around the tower, one at 1.5 m (5 ft) above grade level, and the other near or above the top of the air inlet. The instrument placed near or above the top of the air inlet may 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. Attempt 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.

3.4 Wind Velocity (Speed and Direction). Wind velocity shall be measured with a meteorological type anemometer and wind vane, preferably remote reading and recording. Rotating cup anemometers with separate wind direction vane or combination self-aligning propeller and direction vane devices are readily available and acceptable. Measurements 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 assure 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 tower orientation and reference North clearly indicated.

3.4.1 For mechanical-draft towers with an overall height of 6 m (20 ft) or less, wind velocity shall be measured 1.5 m (5 ft) above curb elevation, at a point within 15 to 30 m (50 to 100 ft) of the tower, if practical. For mechanical-draft towers where the distance between curb and discharge elevations exceeds 6 m (20 ft), the wind velocity shall be measured at an elevation above the curb elevation that is approximately one-half the difference between the curb and discharge elevations and at a point at least 30 m (100 ft) from the tower, if practical.

3.4.2 For natural-draft towers, the wind shall be measured at the top of the shell at a point within 45 to 450 m (150 to 1500 ft) from the curb of the tower, if practical. In addition, the wind velocity shall be measured at a height of one-half the inlet height and at a distance greater than twice the air inlet height and at least a quarter of the base diameter from the cooling tower. Section 2.3.2.2 gives the wind speed limitations.

3.5 Tower Pumping Head. Tower pumping head

shall be the sum of:

- a) The total pressure above atmospheric expressed in m (ft) of water at the centerline of the tower piping inlet, and
- b) The vertical distance measured in m (ft) of the centerline of the piping inlet above the basin curb.

Test pumping head is given by:

$$H_{pt} = P_{st} + P_{vt} + Z_t \quad (3.2)$$

where:

- H_{pt} = Test pumping head
 P_{st} = Test static pressure at the centerline of the tower piping inlet
 P_{vt} = Test velocity pressure at the centerline of the tower piping inlet
 Z_t = Vertical distance from basin curb to centerline tower piping inlet

Corrected pumping head is given by:

$$H_{pc} = \left[(P_{st} + P_{vt}) \left(\frac{L_d}{L_t} \right)^2 \right] + Z_t \quad (3.3)$$

where:

- H_{pc} = Corrected pump head at design flow rate
 L_d = Mass flow rate of water at design conditions
 L_t = Mass flow rate of water at test conditions

3.6 Fan Driver Output Power. For mechanical-draft and fan-assist towers, power shall be determined as power input to the motor or driver. In the case of electric motors, power input shall be determined by direct measurement of the kilowatt input, or by measurement of the voltage, current, and power factor per ASME PTC-19.6 "Electrical Measurement in Power Circuits". If motor input power is not directly measured at the motor, then a line loss correction shall be made, unless agreed upon by all parties. If a tower is equipped with a Variable Frequency Drive (VFD) the fan speed and power measurement can be affected, therefore, the VFD should be bypassed during the test. If a performance guarantee is based on driver output, efficiencies stated by the manufacturer of the driver may be used.

3.7 Water Analysis. A sample of the circulating water shall be taken during the test. If there are any questions concerning the condition of the circulating water, the sample shall be analyzed by a reputable testing laboratory to determine conformance with Paragraph 2.3.5 of this test procedure.

4. REPORT OF RESULTS

4.1 Scope. The report of the results of the test shall include, the data required by this test procedure, the manufacturer's data, a description of the cooling tower with its orientation and principal dimensions, and a sketch of the installation showing the location of points where water flow, temperatures, and other required measurements were taken. Notation shall be made of any buildings, obstructions, or other equipment in the immediate vicinity of the tower tested. Notation shall also be made of other equipment or facilities discharging heat or vapor in the immediate vicinity.

4.2 Test Forms. The test observations shall be entered on CTI Form ATC-106 (or equal), which shall constitute original log sheets to be authenticated by the signatures of CTI, the representatives of the manufacturer and the purchaser if they elected to be present.

4.3 Distribution. Upon completion of the test, one copy of Form ATC-106 becomes the property of the purchaser, one copy becomes the property of the manufacturer, and the original becomes the property of the CTI Representative.

A single summary sheet listing all important data and tower performance shall be prepared by the CTI Representative, who shall mail copies to the purchaser and the manufacturer within 10 days following the test.

4.4 Security. Information on any test will be available only to the purchaser, the manufacturer, and the CTI Representative. Any site or manufacturer identifiable information will not be released by CTI.

4.5 Limitations. Adherence to the limits of wet-bulb temperature, dry-bulb temperature, cooling range, and circulating water flow imposed by this Code will yield results with accuracy commensurate with the stability of the test conditions and the accuracy of the instruments specified for measurements.

When used for test conditions outside the limits described, errors may result due to the following considerations:

4.5.1 The effects of wide deviations from design in the following variables may not be adequately described by the equations and/or graphs used for adjustment of the test data:

- a) Water circulation rate
- b) Water temperatures
- c) Air flow rate
- d) Air wet-bulb temperature
- e) Air dry-bulb temperature

4.5.2 Strong and/or gusting winds are likely to result in cooling tower malperformance.

4.5.3 Poor air and/or water distribution will re-

sult in malperformance.

4.5.4 For evaluation by the characteristic curve method, the accuracy of the result will depend on the accuracy of the characteristic curve.

4.5.5 For evaluation by the performance curve method, the accuracy of the result will depend on the accuracy of the performance curves.

4.6 Tower Capability. Tower Capability is the thermal performance result calculated for a test conducted in accordance with this Code. Tower Capability is defined as the ratio of the adjusted water flow rate (or L/G) to the predicted water flow rate (or L/G) at the test conditions, expressed as a percent. The calculation procedures required to calculate the adjusted water flow rate and predicted water flow rate at the test conditions is dependent on the type of tower tested and is defined in Part II of this code.

Part II

Evaluation of Results

5. MECHANICAL-DRAFT COOLING TOWERS - CHARACTERISTIC CURVE METHOD

5.1 Scope and Purpose

This part of the Code outlines a method for evaluation of the performance of mechanical-draft cooling towers from test data using characteristic curves. The results are expressed in terms of water cooling capability.

5.2 Manufacturer's Data

The manufacturer shall submit tower performance data relating tower characteristic, KaV/L , and water/air ratio, L/G , indicating the design L/G to be used for the test evaluation. This relationship may be presented as an equation 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 air velocity) that may have a significant effect on the result, and shall cover a range of L/G values of at least ± 20 percent from design L/G . If the relationship is presented as a curve, the graphical scaling must permit the determination of KaV/L to a minimum precision equal to that provided by the **CTI Cooling Tower Performance Curves** (CTI Blue Book).

The design L/G value shall be identified, as well as a listing of the design point conditions of hot water temperature, cold water temperature, inlet-wet-bulb temperature, inlet dry-bulb temperature (forced draft tower), fan drive power (motor output power, unless otherwise stated), fan motor efficiency (if available at the time of quote), and either design barometric pressure or design basis elevation.

5.3 Determination of Test L/G Value

From the average water flow rate and fan driver output power at time of test, the test value of L/G_t shall be calculated from:

$$(L/G)_t = (L/G)_d \left(\frac{Q_{wt}}{Q_{wd}} \right) \left(\frac{\dot{W}_d}{\dot{W}_t} \right)^{1/3} \left(\frac{\rho_t}{\rho_d} \right)^{1/3} \left(\frac{v_t}{v_d} \right) \quad (5.1)$$

where:

$(L/G)_d$ = Ratio of mass flow rate of water to air from the manufacturer's design data

v = Specific volume of air, either test(_t) or design(_d)

ρ = Density of air, either test(_t) or design(_d)

$\dot{W}$ = Fan driver output power, either test(_t) or design(_d)

Q_w = Circulating water flow rate, either test(_t) or design(_d)

The design and test values of air specific volume (v) and density (ρ) are evaluated at:

- (a) the tower inlet conditions for a forced draft tower, or
- (b) the tower exit conditions for an induced draft tower (by heat balance).

Where the test was conducted with one or more cells of the tower shut down, in accordance with Paragraph 2.3.4, design water rate and fan driver output power shall be taken as the design values for the cells in operation.

5.4 Determination of Test KaV/L Value

Using average test values of hot water, cold water and wet-bulb temperatures, and test value of L/G , the test value of KaV/L shall be calculated from:

$$KaV/L = c_{pw} \int_{T_{cw}}^{T_{hw}} \frac{dT}{h_w - h_a} \quad (5.2)$$

where:

c_{pw} = Specific heat of water

T_{hw} = Temperature of the hot water

T_{cw} = Temperature of cold water

h_w = Enthalpy of the water

h_a = Enthalpy of air

Values for the enthalpies, h_w and h_a , can be taken from the tables, or calculated with the formulas in the Appendix H for the specific barometric pressure, or site elevation. The use of the integration method given in the Appendix is recommended. CTI Form ATP-127 or the CTI Bluebook software may be used for the computation.

5.5 Determination of Tower Capability

The point representing calculated values of L/G and KaV/L from the test data shall be located on the manufacturer's tower characteristic graph. Through this test point a curve shall be drawn parallel and using the same form as the manufacturer's tower characteristic curves. Points on this curve may be calculated by using CTI Form ATP-127 or the CTI Bluebook software. The intersection of the line so drawn with the design approach curve determines the value of L/G at which the tower would produce design cold water temperature when operating at design conditions. The tower capability in percent of design water flow is the ratio of the L/G so determined to design L/G , multiplied by 100. If multiple characteristic curves have been submitted, this design L/G shall be adjusted to the applicable characteristic curve for the test conditions.

An example evaluation is given in Section III, the Appendices.

6. MECHANICAL-DRAFT COOLING TOWER - PERFORMANCE CURVE METHOD

6.1 Scope and Purpose

This part of the Code outlines a method for evaluation of the performance of mechanical-draft cooling towers from test data using performance curves. The results are expressed in terms of water cooling capability.

6.2 Manufacturer's Data

The manufacturer shall submit a family of performance curves consisting of a minimum of 3 sets of 3 curves each. One set shall apply to 90%, one to 100%, and the other to 110% of the design water circulation rate. Each set shall be presented as a plot of wet-bulb temperature as abscissa versus cold water temperature as ordinate, with cooling range as parameter. Graphical scaling shall be incremented so as to provide a minimum of 0.2°C (0.5°F) increments and no more than 0.1°C/mm (5°F/inch) for both wet-bulb and cold water temperatures. **Curves shall be based on constant fan pitch angle.** In addition to the design range curve, bracketing range curves of approximately 80% and 120% of design to the nearest 0.5°C (1°F) shall be shown, at a minimum. The curves shall fully cover (but not necessarily be limited to) the range of variables specified in Paragraph 2.3. The design point shall be shown on the appropriate curve, as well as a listing of the design point conditions of hot water temperature, cold water temperature, inlet wet-bulb temperature, inlet dry-bulb temperature (forced draft tower), design L/G (induced draft only), fan drive output power (fan motor output power, unless otherwise designated), fan motor efficiency (if available a time of quote), and either design barometric pressure or design basis elevation.

6.3 Determination of Tower Capability

The manufacturer's performance curves shall be cross plotted at test conditions to determine capability. A suitable procedure consists of first preparing a set of 3 curves, based on test wet-bulb temperature, relating cooling range, cold water temperature, and water circulation rate. From this set of curves, a single curve is then prepared, based on test cooling range, relating cold water temperature to water circulation rate. The determination of performance capability consists of comparing the predicted water flow rate $Q_{w\text{ pred}}$ from this curve with the adjusted test water flow rate $Q_{wt\text{ adj}}$ using equations (6.1) and (6.2) following:

$$Q_{wt\text{ adj}} = Q_{wt} \left(\frac{\dot{W}_d}{\dot{W}_t} \right)^{1/3} \left(\frac{\rho_t}{\rho_d} \right)^{1/3} \quad (6.1)$$

where:

Q_{wt} = Circulating water flow rate, test

ρ = Density of air, either test(_t) or design(_d)

$\dot{W}$ = Fan driver output power, either test(_t) or design(_d)

The capability, C, expressed in percent of design circulating flow is computed using Equation (6.2):

$$C = \frac{Q_{wt\text{ adj}}}{Q_{wt\text{ pred}}} \times 100 \quad (6.2)$$

where:

$Q_{w\text{ pred}}$ = Circulating water flow rate, predicted for the test conditions

An example evaluation is given in Section III, the Appendices.

7. NATURAL-DRAFT COOLING TOWERS - PERFORMANCE CURVE METHOD

7.1 Scope and Purpose

This part of the Code outlines a method for evaluation of the performance of natural-draft cooling towers from test data using performance curves. The results are expressed in terms of water cooling capability.

7.2 Manufacturer's Data

The manufacturer shall submit a family of curves which correctly relate the pertinent performance variables.

Performance curves applicable to 90%, 100%, and 110% of the design water flow rate shall be furnished. Each set shall consist of three or more **cooling range** curves and three or more **relative humidity** curves, arranged to show the effects of wet-bulb temperature, relative humidity, and cooling range on outlet water temperature. The range curves shall be presented in uniform increments of 0.5°C (1°F), with sufficient scope to cover approximately $\pm 20\%$ of design range. The relative humidity curves shall be presented in uniform increments of % RH, with sufficient scope to cover approximately $\pm 40\%$ of the design value with maximum increments of 20% RH. The design point shall be shown on the appropriate curve, as well as a listing of the design point conditions of hot water temperature, cold water temperature, inlet wet-bulb temperature, inlet dry-bulb temperature, design L/G, and either design barometric pressure or design basis elevation.

7.3 Determination of Tower Capability

The manufacturer's performance curves shall be cross plotted at test conditions to determine capability.

From the test wet-bulb temperature, relative humidity, and cooling range, a cross-plot relating **outlet water temperature** and **predicted circulation rate** will be prepared. From this graph the predicted water circulation rate capability at the test outlet water tem-

perature is determined. Performance is then computed from Equation (7.1):

$$C = \frac{Q_{wt}}{Q_{w_{pred}}} \times 100 \quad (7.1)$$

where:

Q_{wt} = Circulating water flow rate, test

$Q_{w_{pred}}$ = Circulating water flow rate, predicted for test conditions

An example evaluation is given in Section III, the Appendices.

8. NATURAL-DRAFT COOLING TOWERS WITH FAN-ASSIST - PERFORMANCE CURVE METHOD

8.1 Scope and Purpose

This part of the Code outlines a method for evaluation of the performance of fan-assist cooling towers from test data using performance curves. The results are expressed in terms of water cooling capability.

8.2 Manufacturer's Data

The manufacturer shall submit a family of curves which correctly relate the pertinent performance variables.

Performance curves applicable to 90%, 100%, and 110% of the design water flow rate shall be furnished. Each set shall consist of three or more **cooling range** curves and three or more **relative humidity** curves, arranged to show the effects of wet-bulb temperature, relative humidity, and cooling range on outlet water temperature. The range curves shall be presented in uniform increments of 0.5°C (1°F), with sufficient scope to cover approximately ± 20% of design range. The relative humidity curves shall be presented in uniform increments of % RH, with sufficient scope to cover approximately ± 40% of the design value with maximum increments of 20% RH. The design point shall be shown on the appropriate curve, as well as a listing of the design point conditions of hot water temperature, cold water temperature, inlet wet-bulb temperature, inlet dry-bulb temperature, design L/G, and either design barometric pressure or design basis elevation.

Additional data must be furnished, however, to cover the effect of fan power. This may be accomplished in any one of several different ways,

- a) Three sets of curves shall be furnished, as for the pure natural-draft type, but with the addition of a nomograph extension covering the effects of fan power.
- b) Nine sets of curves shall be furnished, as for the pure natural-draft type; three of these applicable to design fan power and three each applicable to 80% and 120% of design fan power.

- c) Three sets of curves shall be furnished, as for the pure natural-draft type, plus the following additional design data to enable adjustment of test data to design fan power:

- 1) Design L/G ratio
- 2) Effective stack height
- 3) Design fan power.

8.3 Determination of Tower Capability

The manufacturer's performance curves shall be cross plotted at test conditions to determine capability.

The procedure is similar to that described for the pure natural-draft tower (Paragraph 7.3), but must include the additional variable **fan driver output power**.

If the manufacturer's curves include fan driver output power as a parameter, as described in Paragraph 8.2 (a), the evaluation procedure is essentially the same as for the pure natural-draft type, requiring a single cross plot.

When the manufacturer's curves include fan driver output power as a curve identification as mentioned in Paragraph 8.2 (b), the procedure requires an additional cross plot. A graph is first prepared relating **outlet water temperature** and **predicted circulation rate**. This graph will consist of three curves, one each for 80%, 100%, and 120% of design fan power. A second cross plot is then prepared, relating **fan power** and **predicted circulation rate** at test outlet water temperature. From this curve the predicted water circulation rate capability at the test fan power is determined, and percent capability computed as before.

If fan power is not included in the manufacturer's curves, the additional data listed in Paragraph 8.2 (c) shall be used to compute the effects of variations in fan power. A trial-and-error or graphical procedure is required to determine the solution.

An example evaluation is given in Section III, the Appendices.

9. WET/DRY MECHANICAL-DRAFT COOLING TOWERS - PERFORMANCE CURVE METHOD

9.1 Scope and Purpose

This part of the Code outlines a method for evaluation of the performance of mechanical-draft wet/dry cooling towers from test data using performance curves. The results are expressed in terms of water cooling capability. "Wet" and "Dry" refer to separate evaporative and non-evaporative heat exchanger elements incorporated into a cooling tower.

9.2 Manufacturer's Data

The manufacturer shall submit a family of curves which correctly relates the pertinent performance variables.

Performance curves applicable to 90, 100, and 110% of the design water flow rate shall be furnished. 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 outlet water temperature. The range curves shall be presented in uniform increments of 0.5°C (1°F), with sufficient scope to cover approximately $\pm 20\%$ of design range. The relative humidity curves shall be presented to cover the extent of expected conditions such as 5, 20, 40, 60, and 100% relative humidity. The design conditions shall be indicated on the set applicable to design water flow rate. The curve associated dry-bulb temperature to the wet-bulb on each fixed relative humidity graph shall be included. Note that for the case where the airflow dampers to the dry section are fully closed, then the tower can be evaluated by the standard mechanical draft cooling tower method, Paragraph 6.3.

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 in Equation (9.2).

9.3 Determination of Tower Capability

The manufacturer's performance curves shall be cross plotted at test conditions to determine capability.

From the test wet-bulb temperature, relative humidity, and cooling range, a cross-plot relating outlet water temperature and predicted circulation rate will be prepared, requiring an intermediate step to cross-plot relative humidity at constant wet-bulb temperature and range. From this graph the predicted water circulation rate capability at the test outlet water temperature is determined. The determination of performance capability consists of comparing the predicted water

flow rate from this curve with the adjusted water flow rate using equation (9.1) or (9.2) and equation (9.3).

For single fans for both wet and dry sections, the following equation (9.1) would apply:

$$Q_{wt,adj} = Q_{wt} \left(\frac{\dot{W}_d}{\dot{W}_t} \right)^{1/3} \left(\frac{\rho_t}{\rho_d} \right)^{1/3} \quad (9.1)$$

For the special case with separate fans moving air through the wet and dry portions of a single tower, or through separate wet and dry towers, the following version of equation (9.1), namely equation (9.2) would apply:

$$Q_{wt,adj} = Q_{wt} \left[\left(\frac{q_{wet}}{q_{tot}} \right) \left(\frac{\dot{W}_{d,wet}}{\dot{W}_{t,wet}} \right)^{1/3} \left(\frac{\rho_{t,wet}}{\rho_{d,wet}} \right)^{1/3} + \left(\frac{q_{dry}}{q_{tot}} \right) \left(\frac{\dot{W}_{d,dry}}{\dot{W}_{t,dry}} \right)^{1/3} \left(\frac{\rho_{t,dry}}{\rho_{d,dry}} \right)^{1/3} \right] \quad (9.2)$$

where:

$\dot{q}_{wet}$ = Wet heat load ($c_{pw} * L_t * (T_{on} - T_{off})$) for the wet section, or tower

$\dot{q}_{dry}$ = Dry heat load ($c_{pw} * L_t * (T_{on} - T_{off})$) for the dry section, or tower

$\dot{q}_{tot}$ = Total heat load ($\dot{q}_{wet} + \dot{q}_{dry}$)

$\dot{W}$ = Fan driver output power, for either wet(_{wet}) or dry(_{dry}) at either test(_t) or design(_d) conditions

y = $1 / [(1 + \text{dry surface air speed exponent for pressure drop})(\text{dry surface air speed exponent for heat transfer})]$

The capability is then given by Equation (9.3):

$$C = \frac{Q_{wt,adj}}{Q_{w,pred}} \times 100 \quad (9.3)$$

PART III — APPENDIX A

SI EXAMPLE EVALUATION OF MECHANICAL-DRAFT COOLING TOWER TEST
USING THE CHARACTERISTIC CURVE METHOD

Section A1. General

The purpose of this appendix is to describe and illustrate the characteristic curve methodology for evaluating a thermal performance test on a mechanical draft cooling tower, as described in Section 5 of the standard.

Section A2. Design and Test Conditions

Design and Test conditions for the mechanical draft cooling tower are summarized in the following table:

**Table A-1. Mechanical Draft Cooling Tower,
Design and Test Data**

	Design	Test
Water flow rate (Q_w)	220 L/s	209 L/s
Hot Water Temp. (T_{hw})	36°C	33.4°C
Cold Water Temp. (T_{cw})	30°C	27.1°C
Inlet Wet Bulb Temp. (T_{wb})	25°C	21.1°C
Inlet Dry Bulb Temp. (T_{db})	31°C	30.6°C
Total Fan Driver Power ($\dot{W}$)	60 kW	57.6 kW
Barometric Pressure (P_{bp})	101.325 kPa	101.325 kPa
Liquid to Gas Ratio (L/G)	1.700	

In accordance with Paragraph 5.2 of this standard, the manufacturer has submitted the Characteristic Curve shown in Figure A-1 (See page 20).

Section A3. Evaluation Procedure

Step 1 - Determine the Test L/G .

The test value of L/G is computed using the test values of hot water temperature, cold water temperature, entering dry-bulb and wet-bulb temperatures, barometric pressure, test flow and test total fan driver power.

To comply with this standard, the design and test values for density (ρ), specific volume (v), and enthalpy (h) of air must be determined using either the psychrometric tables in Appendix H of this standard, the psychrometric tables in *ASHRAE Handbook - Fundamentals (SI)*, or computed using the formulae of Appendix H which implements the ASHRAE calculations for moist air properties. For this example, the computer program of Appendix H was used to generate all psychrometric properties.

Since the evaluation is based upon the psychrometric properties of air at the fan inlet, different procedures must be employed to compute the L/G for forced draft and induced draft towers.

a. Forced Draft Tower

For a forced draft tower, the fan inlet air conditions are the same as the tower inlet air conditions. Therefore the test density (ρ_t) and

the test specific volume (v_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.

Given the Design and Test values for wet-bulb and dry-bulb temperatures and the barometric pressure, determine the density and specific volume of the inlet air.

At Design values of 25°C wet-bulb, 31°C dry-bulb, 101.325 kPa barometric pressure:

$$\rho_d = 1.1485 \text{ kg/m}^3$$

$$v_d = 0.88609 \text{ m}^3/\text{kg}$$

$$h = 76.274 \text{ kJ/kg}$$

At Test values of 21.1°C wet-bulb, 30.6°C dry-bulb, 101.325 kPa barometric pressure:

$$\rho_t = 1.1539 \text{ kg/m}^3$$

$$v_t = 0.87694 \text{ m}^3/\text{kg}$$

$$h = 61.102 \text{ kJ/kg}$$

Using these data, calculate the Test L/G from Equation (A-1).

$$(L/G)_t = (L/G)_d \left(\frac{Q_{wt}}{Q_{wd}} \right) \left(\frac{\dot{W}_d}{\dot{W}_t} \right)^{1/3} \left(\frac{\rho_t}{\rho_d} \right)^{1/3} \left(\frac{v_t}{v_d} \right) \quad (\text{A-1})$$

where:

$(L/G)_d$ = Ratio of mass flow rate of water to the mass flow rate air from the manufacturer's design data.

v = Specific volume of air, either test($_t$) or design($_d$)

ρ = Density of air, either test($_t$) or design($_d$)

$\dot{W}$ = Fan driver power, either test($_t$) or design($_d$)

Q_w = Circulating water flow rate, either test($_t$) or design($_d$)

Substituting values:

$$(L/G)_t = (1.70) \left(\frac{209}{220} \right) \left(\frac{60.0}{57.6} \right)^{1/3} \left(\frac{1.1539}{1.1485} \right)^{1/3} \left(\frac{0.87694}{0.88609} \right)$$

$$(L/G)_t = 1.623$$

b. Induced Draft Tower

For an induced draft tower, the conditions at the inlet of the fan are the tower's discharge conditions. The code requires that both the design and test, discharge air properties be determined by a heat balance calculation. Calculating *design* discharge air properties is a straightforward procedure while calculating *test* discharge air properties requires combining the heat balance

Equation (A-2) with Equation (A-1) and iterating for a solution.

The heat balance equation below simply states that the heat gain of the air equals the heat loss of the water:

$$Lc_{pw} \cdot (T_{hw} - T_{cw}) = G \cdot (h_o - h_i) \quad (A-2)$$

where:

L = Circulating water mass flow rate, kg/s

c_{pw} = Specific heat of water = 4.186 kJ/kg·°C

T_{hw} = Hot water temperature, °C

T_{cw} = Cold water temperature, °C

G = Mass flow rate of dry air through the tower, kg dry air/hr

h_o = Enthalpy of air leaving the tower, kJ/kg

h_i = Enthalpy of air entering the tower, kJ/kg.

Rearranging to separate the exit air enthalpy, the heat balance equation becomes:

$$h_o = (L/G) \cdot c_{pw} \cdot (T_{hw} - T_{cw}) + h_i \quad (A-3)$$

Determine the enthalpy of the entering air at design conditions as:

$$h_{id} = 76.274 \text{ kJ/kg}$$

Then, substituting all design values into Equation (A-3), calculate h_{od} .

$$h_{od} = (1.70) \cdot 4.186 \cdot (36 - 30) + 76.274 \text{ or}$$

$$h_{od} = 118.971 \text{ kJ/kg}$$

Assuming the discharge air is saturated at this enthalpy, determine the design discharge air temperature, density (ρ_d) and specific volume (v_d) as:

$$T_d = 33.35^\circ\text{C}$$

$$\rho_d = 1.1295 \text{ kg/m}^3$$

$$v_d = 0.91488 \text{ m}^3/\text{kg}$$

Next calculate the test L/G by substituting all known values into Eq. (B-1).

$$(L/G)_t = (1.70) \left(\frac{209}{220} \right) \left(\frac{60.0}{57.6} \right)^{1/3} \left(\frac{\rho_t}{1.1295} \right)^{1/3} \left(\frac{v_t}{0.91488} \right)$$

$$(L/G)_t = 1.7183 \cdot (\rho_t)^{1/3} \cdot v_t$$

Next, using the measured test conditions, the enthalpy of the entering air is determined as:

$$h_{it} = 61.102 \text{ kJ/kg}$$

This value along with the (L/G)_t just computed and the measured water temperatures are now substituted into the heat balance equation (A-3):

$$h_{ot} = (1.7183 \cdot (\rho_t)^{1/3} \cdot v_t) \cdot 4.186 \cdot (33.4 - 27.1) + 61.102$$

which then reduces to:

$$h_{ot} = 45.3147 \cdot (\rho_t)^{1/3} \cdot v_t + 61.102. \quad (A-4)$$

At this point, one must guess a discharge air temperature and, assuming the leaving air is saturated, determine h , ρ and v at

that temperature. Then substitute these values into Equation (A-4) and solve for h_{ot} . Compare this calculated enthalpy, h_{ot} , to the actual enthalpy, h , of the discharge air at the assumed temperature. Continue iterating the discharge air temperature until a suitable temperature is selected that satisfies the heat balance expression.

For a first iteration, use the average of the test T_{hw} and T_{cw} as the leaving air temperature. Typical iteration values are given below.

T_a	ρ_t	v_t	h_{ot} actual	h_{ot} computed	Error
30.0	1.1459	0.89656	100.005	103.616	+3.60%
31.0	1.1410	0.90185	105.368	103.806	-1.48%
30.7	1.1425	0.90025	103.733	103.749	+0.015%

A leaving air temperature of 30.7°C is sufficiently accurate. Now, determine the Test L/G by substituting the psychrometric values for saturated air at 30.7°C into Equation (A-1) and solve:

$$(L/G)_t = 1.7183 \cdot (1.1425)^{1/3} \cdot 0.90025$$

$$(L/G)_t = 1.617$$

Step 2 - Calculate KaV/L at the test L/G

Once the Test L/G is determined, the procedure for calculating KaV/L is identical for forced draft and induced draft towers. The calculation is readily performed using CTI form ATP-127, the significant portion of which is reproduced below. The KaV/L calculation is computed using the saturated enthalpy values at the wet bulb temperatures. Continuing with the induced draft tower example, the value KaV/L is computed in the following manner:

$$\text{For: } T_{hw} = \underline{33.4} \text{ and } T_{cw} = \underline{27.1}$$

$$\text{Then: } \frac{(T_{hw} - T_{cw})}{(33.4 - 27.1)} = \underline{6.3}$$

$$\begin{aligned} h_2 &= h_1 + c_{pw}(T_{hw} - T_{cw})(L/G) = 61.395 + 4.186 \times 6.3 \times 1.617 = \underline{104.038} \\ &= 0.1 c_{pw}(T_{hw} - T_{cw})(L/G) = 0.1 \times 4.186 \times 6.3 \times 1.617 = \underline{4.264} \\ &= 0.4 c_{pw}(T_{hw} - T_{cw})(L/G) = 0.4 \times 4.186 \times 6.3 \times 1.617 = \underline{17.057} \\ &= 0.1(T_{hw} - T_{cw}) = 0.1 \times \underline{6.3} = \underline{0.63} \\ &= 0.4(T_{hw} - T_{cw}) = 0.4 \times \underline{6.3} = \underline{2.52} \end{aligned}$$

T_a , °C for h_a	h_a
$T_{cw} = \underline{27.1}$	
$T_{cw} + 0.1(T_{hw} - T_{cw}) = \underline{27.73}$	<u>88.690</u>
$T_{cw} + 0.4(T_{hw} - T_{cw}) = \underline{29.62}$	<u>98.030</u>
$T_{hw} - 0.4(T_{hw} - T_{cw}) = \underline{30.88}$	<u>104.711</u>
$T_{hw} - 0.1(T_{hw} - T_{cw}) = \underline{32.77}$	<u>115.479</u>
$T_{hw} = \underline{33.4}$	

h_a	$h_w - h_a$	$1/\Delta h$
$h_i = 61.102$		
$h_i + 0.1 c_{pw}(T_{hw} - T_{cw})(L/G) = 65.659$	$\Delta h_1 = 23.031$	0.04342
$h_i + 0.4 c_{pw}(T_{hw} - T_{cw})(L/G) = 78.452$	$\Delta h_2 = 19.578$	0.05108
$h_o - 0.4 c_{pw}(T_{hw} - T_{cw})(L/G) = 86.981$	$\Delta h_3 = 17.731$	0.05640
$h_o - 0.1 c_{pw}(T_{hw} - T_{cw})(L/G) = 99.774$	$\Delta h_4 = 15.705$	0.06367
$h_o = 104.038$		
	$\Sigma 1/\Delta h = 0.21457$	

$$\frac{KaV}{L} = c_{pw} \cdot \frac{T_{hw} - T_{cw}}{4} \cdot \Sigma \frac{1}{\Delta h} = 4.186 \times \frac{6.3}{4} \times 0.21457 = 1.415$$

Step 3 - Determine the Intersect $(L/G)_i$

At the $(L/G)_i$ calculated from Step 1 (1.617) and the KaV/L calculated from Step 2 (1.415), plot the test performance point on the manufacturer's characteristic curve, as shown in Figure A-2, below. A curve is drawn through this point parallel to the tower characteristic curve. This parallel curve intersects the 5°C design approach curve at $(L/G)_p = 1.72$. This is the predicted L/G , which is the L/G that the tower would produce if operating at design conditions.

Step 4 - Calculate the Tower Capability.

As set forth in paragraph 5.5, the tower capability, C , is the ratio of the predicted L/G to the design L/G .

$$C = \{(L/G)_i / (L/G)_d\} \cdot 100 \quad (A-5)$$

$$C = (1.728 / 1.70) \cdot 100 = 101.6\%$$

Based on the test performed, the tower is capable of cooling 223.6 l/s from 36°C to 30°C at design wet-bulb temperature 25°C and design total fan driver power of 60 kW.

Figure A-1

Manufacturer's Characteristic Curve
with Design Point.

Cooling Tower Institute



25.00 WET BULB (°C)
6.00 RANGE (K)
0.00 ALTITUDE (m)
101.325 PRESSURE (kPa)

$$KaV/L = 2.0988 \cdot (L/G)^{-0.8950}$$

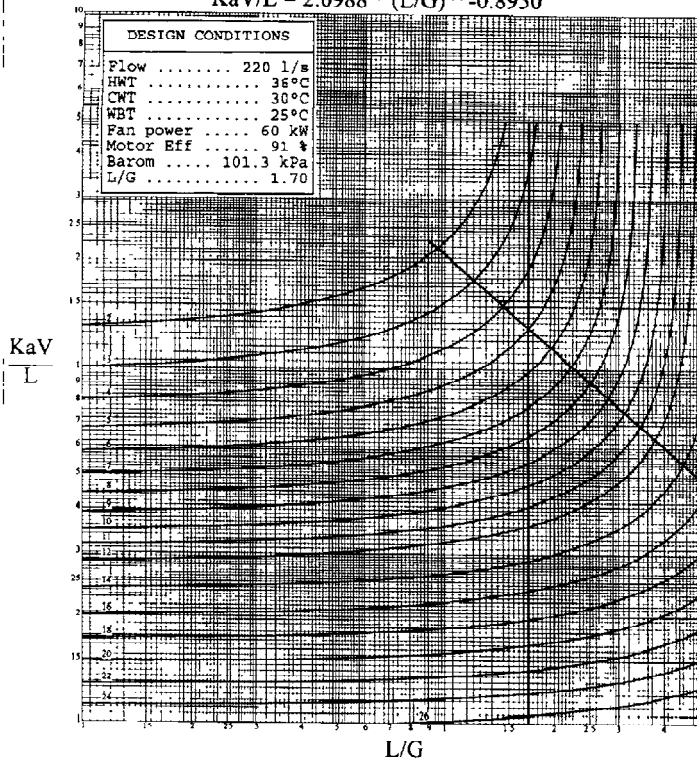
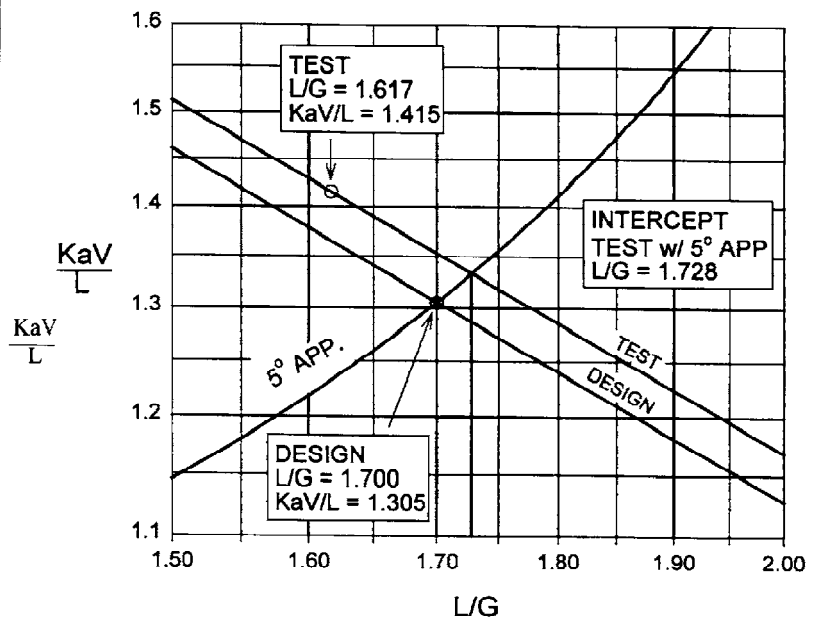


Figure A-2

Manufacturer's Characteristic Curve
with Design Point and Test Point



PART III — APPENDIX B

IP EXAMPLE EVALUATION OF MECHANICAL-DRAFT COOLING TOWER TEST USING THE CHARACTERISTIC CURVE METHOD

Section B1. General

The purpose of this appendix is to describe and illustrate the characteristic curve methodology for evaluating a thermal performance test on a mechanical draft cooling tower, as described in Section 5 of the standard.

Section B2. Design and Test Conditions

Design and Test conditions for the mechanical draft cooling tower are summarized in the following table:

**Table B-1. Mechanical Draft Cooling Tower,
Design and Test Data**

	Design	Test
Water flow rate (Q_w)	9500 gpm	9150 gpm
Hot Water Temp. (T_{hw})	115°F	104.7°F
Cold Water Temp. (T_{cw})	85°F	79.3°F
Inlet Wet Bulb Temp. (T_{wb})	80°F	73.1°F
Inlet Dry Bulb Temp. (T_{db})	90°F	85.2°F
Total Fan Driver Power ($\dot{W}$)	240 bhp	216 bhp
Barometric Pressure (P_{bp})	29.921"Hg	29.921"Hg
Liquid to Gas Ratio (L/G)	0.810	

In accordance with Paragraph 5.2 of this standard, the manufacturer has submitted the Characteristic Curve shown in Figure B-1 (See page 23).

Section B3. Evaluation Procedure

Step 1 — Determine the Test L/G .

The test value of L/G is computed using the test values of hot water temperature, cold water temperature, entering wet-bulb, entering dry-bulb, barometric pressure, test flow and test total fan driver power.

To comply with this standard, the design and test values for density (ρ), specific volume (v), and enthalpy (h) of air must be determined using either the psychrometric tables in Appendix H of this standard, the psychrometric tables in *ASHRAE Handbook - Fundamentals (IP)*, or computed using the formulas of Appendix H which implements the ASHRAE calculations for moist air properties. For this example, the computer program of Appendix H was used to generate all psychrometric properties.

Since the evaluation is based upon the psychrometric properties of air at the fan inlet, different procedures must be employed to compute the L/G for forced draft and induced draft towers.

a. Forced Draft Tower

For a forced draft tower, the fan inlet air conditions are the same as the tower inlet air conditions. Therefore the test den-

sity (ρ_t) and the test specific volume (v_t) are computed directly from the measured test values of wet-bulb temperature, dry-bulb temperature and barometric pressure. The design conditions at the tower's air inlet shall be supplied by the manufacturer.

Given the Design and Test values for wet-bulb and dry-bulb temperatures and the barometric pressure, determine the density and specific volume of the inlet air.

At Design values of 80°F wet-bulb, 90°F dry-bulb, and 29.921"Hg barometric pressure.:

$$\rho_d = 0.07131 \text{ lbm/ft}^3$$

$$v_d = 14.3025 \text{ ft}^3/\text{lbm}$$

$$h = 43.580 \text{ Btu/lbm}$$

At Test values of 73.1°F wet-bulb, 85.2°F dry-bulb, and 29.921"Hg barometric pressure:

$$\rho_t = 0.07216 \text{ lb/ft}^3$$

$$v_t = 14.0636 \text{ ft}^3/\text{lbm}$$

$$h = 36.711 \text{ Btu/lbm}$$

Using these data, calculate the Test L/G from Equation (B-1).

$$(L/G)_t = (L/G)_d \left(\frac{Q_{wt}}{Q_{wd}} \right) \left(\frac{\dot{W}_d}{\dot{W}_t} \right)^{1/3} \left(\frac{\rho_t}{\rho_d} \right)^{1/3} \left(\frac{v_t}{v_d} \right) \quad (\text{B-1})$$

where:

$(L/G)_d$ = Ratio of mass flow rate of water to the mass flow rate of air from the manufacturer's design data.

v = Specific volume of air, either test($_t$) or design($_d$)

ρ = Density of air, either test($_t$) or design($_d$)

$\dot{W}$ = Fan driver output power, either test($_t$) or design($_d$)

Q_w = Circulating water flow rate, either test($_t$) or design($_d$)

Substituting values:

$$(L/G)_t = (0.81) \left(\frac{9150}{9500} \right) \left(\frac{240}{216} \right)^{1/3} \left(\frac{.07216}{.07131} \right)^{1/3} \left(\frac{14.0636}{14.3025} \right)$$

$$(L/G)_t = 0.7977$$

b. Induced Draft Tower

For an induced draft tower, the conditions at the inlet of the fan are the tower's discharge conditions. The code requires that both the design and test, discharge air properties be determined by a heat balance calculation. Calculating *design* discharge air

properties is a straightforward procedure while calculating test discharge air properties requires combining the heat balance Equation (B-2) with Equation (B-1) and iterating for a solution.

The heat balance equation below simply states that the heat gain of the air equals the heat loss of the water:

$$L \cdot c_{pw} \cdot (T_{hw} - T_{cw}) = G \cdot (h_o - h_i) \quad (B-2)$$

where:

- L = Circulating water mass flow rate, lbm/hr
- c_{pw} = Specific heat of water = 1.0 Btu/lbm • °F
- T_{hw} = Hot Water Temperature, °F
- T_{cw} = Cold Water Temperature, °F
- G = Mass flow rate of dry air through the tower, lbm dry air/hr
- h_o = Enthalpy of air leaving the tower, Btu/lbm
- h_i = Enthalpy of air entering the tower, Btu/lbm.

Rearranging to separate the exit air enthalpy, the heat balance equation becomes:

$$h_o = (L/G) \cdot c_{pw} \cdot (T_{hw} - T_{cw}) + h_i \quad (B-3)$$

Determine the enthalpy of the entering air at design conditions as:

$$h_{id} = 43.580 \text{ Btu/lbm}$$

Then, substituting all design values into Equation (B-3), calculate h_{od} .

$$h_{od} = (0.81) \cdot 1.0 \cdot (115 - 85) + 43.580 \text{ or } h_{od} = 67.880 \text{ Btu/lbm.}$$

Assuming the discharge air is saturated at this enthalpy and barometric pressure, determine the design discharge air temperature, density (ρ_d) and specific volume (v_d) as:

$$\begin{aligned} T_d &= 97.77^\circ\text{F} \\ \rho_d &= 0.06952 \text{ lbm/ft}^3 \\ v_d &= 14.9624 \text{ ft}^3/\text{lbm} \end{aligned}$$

Next calculate the test L/G by substituting all known values into Eq. (B-1).

$$\begin{aligned} (L/G)_t &= (0.81) \left(\frac{9150}{9500} \right) \left(\frac{240}{216} \right)^{1/3} \left(\frac{\rho_t}{0.06952} \right)^{1/3} \left(\frac{v_t}{14.9624} \right) \\ (L/G)_t &= 0.13134 \cdot (\rho_t)^{1/3} \cdot v_t \end{aligned}$$

Next, using the measured test conditions, the enthalpy of the entering air is determined as:

$$h_{it} = 36.711 \text{ Btu/lbm}$$

This value along with the $(L/G)_t$ just computed and the measured water temperatures are now substituted into the heat balance equation (B-3):

$$h_{ot} = (0.13134 \cdot (\rho_t)^{1/3} \cdot v_t) \cdot 1.0 \cdot (104.7 - 79.3) + 36.711$$

which then reduces to:

$$h_{ot} = 3.3360 \cdot (\rho_t)^{1/3} \cdot v_t + 36.711 \text{ Btu/lbm} \quad (B-4)$$

At this point, one must guess a discharge air temperature and, assuming the leaving air is saturated, determine h , ρ and v at that temperature. Then substitute these values into Equation (B-4) and solve for h_o . Compare this calculated enthalpy, h_o , to the actual enthalpy, h , of the discharge air at the assumed temperature. Continue iterating the discharge air temperature until a suitable temperature is selected that satisfies the heat balance expression.

For a first iteration, use the average of the test T_{hw} and T_{cw} as the leaving air temperature. Typical iteration values are given below.

T_d	ρ_t	v_t	h_{ot} actual	h_{ot} computed	Error
92.0	.07052	14.6532	58.794	56.907	-3.21%
90.0	.07086	14.5528	55.950	56.801	+1.52%
90.6	.07076	14.5826	56.788	56.832	+0.07%

A leaving air temperature of 90.6°F is sufficiently accurate. Now, determine the Test L/G by substituting the psychrometric values for saturated air at 90.6°F into Equation (B-1) and solve:

$$(L/G)_t = 0.13134 \cdot (0.07076)^{1/3} \cdot 14.5826$$

$$(L/G)_t = 0.7922$$

Step 2 - Calculate KaV/L at the Test L/G

Once the Test L/G is determined, the procedure for calculating KaV/L is identical for forced draft and induced draft towers. The calculation is readily performed using CTI form ATP-127, the significant portion of which is reproduced below. The KaV/L calculation is computed using the saturated enthalpy values at the wet bulb temperatures. Continuing with the induced draft tower example, the value KaV/L is computed in the following manner:

$$\begin{aligned} \text{For: } T_{hw} &= 104.7 \text{ and } T_{cw} = 79.3 \\ \text{Then: } (T_{hw} - T_{cw}) &= (104.7 - 79.3) = 25.4 \end{aligned}$$

$$\begin{aligned} h_2 &= h_i + c_{pw}(T_{hw} - T_{cw})(L/G) = 36.827 + 1.00 \times 25.4 \times 0.7922 = 56.949 \\ &= 0.1 c_{pw}(T_{hw} - T_{cw})(L/G) = 0.1 \times 1.00 \times 25.4 \times 0.7922 = 2.012 \\ &= 0.4 c_{pw}(T_{hw} - T_{cw})(L/G) = 0.4 \times 1.00 \times 25.4 \times 0.7922 = 8.049 \\ &= 0.1(T_{hw} - T_{cw}) = 0.1 \times 25.4 = 2.54 \\ &= 0.4(T_{hw} - T_{cw}) = 0.4 \times 25.4 = 10.16 \end{aligned}$$

$T, ^\circ\text{F}$ for h_w	h_w
$T_{cw} = 79.3$	
$T_{cw} + 0.1(T_{hw} - T_{cw}) = 81.84$	45.727
$T_{cw} + 0.4(T_{hw} - T_{cw}) = 89.46$	55.207
$T_{hw} - 0.4(T_{hw} - T_{cw}) = 94.54$	62.624
$T_{hw} - 0.1(T_{hw} - T_{cw}) = 102.16$	75.768
$T_{hw} = 104.7$	

h_d	$h_w - h_d$	$1/\Delta h$
$h_i = 36.827$		
$h_i + 0.1 c_{pw}(T_{hw} - T_{cw})(L/G) = 38.840$	$\Delta h_1 = 6.887$	0.14519
$h_i + 0.4 c_{pw}(T_{hw} - T_{cw})(L/G) = 44.876$	$\Delta h_2 = 10.330$	0.09680
$h_o - 0.4 c_{pw}(T_{hw} - T_{cw})(L/G) = 48.901$	$\Delta h_3 = 13.724$	0.07287
$h_o - 0.1 c_{pw}(T_{hw} - T_{cw})(L/G) = 54.937$	$\Delta h_4 = 20.831$	0.04880
$h_i = 56.949$		
		$\Sigma 1/\Delta h = 0.36287$

$$\frac{KaV}{L} = c_{pw} \cdot \frac{T_{hw} - T_{cw}}{4} \cdot \sum \frac{1}{\Delta h} = 1.00 \times \frac{25.4}{4} \times 0.36287 = 2.304$$

Step 3 - Determine Intersect (L/G)_i

At the (L/G)_i calculated from Step 1 (0.792) and the KaV/L calculated from Step 2 (2.304), plot the test performance point on the manufacturer's characteristic curve, as shown in Figure B-2, page 23. A line is drawn through this point parallel to the tower characteristic curve. This parallel line intersects the 5°F design approach curve at (L/G)_i = 0.8184. This is the predicted L/G, which is the L/G that the tower would produce if operating at design conditions.

Step 4 - Calculate the Tower Capability.

As set forth in Paragraph 5.5, the tower capability, C, is the ratio of the predicted L/G to the design L/G.

$$C = \{(L/G)_i / (L/G)_d\} \cdot 100 \quad (B-5)$$

$$C = (0.8184 / 0.81) \cdot 100 = 101.0\%$$

Based on the test performed, the tower is capable of cooling 101.0% of design flow or 9594 gpm from 115°F to 85°F at design wet-bulb temperature 80°F at the design total fan driver power of 240 bhp.

Figure B-1

Manufacturer's Characteristic

Curve with Design Point.

Cooling Tower Institute



80.00 WET BULB (°F)
30.00 RANGE (°F)
0.00 ALTITUDE (ft)
29.921 PRESSURE ("Hg)

$$KaV/L = 2.0114 \cdot (L/G)^{-0.5350}$$

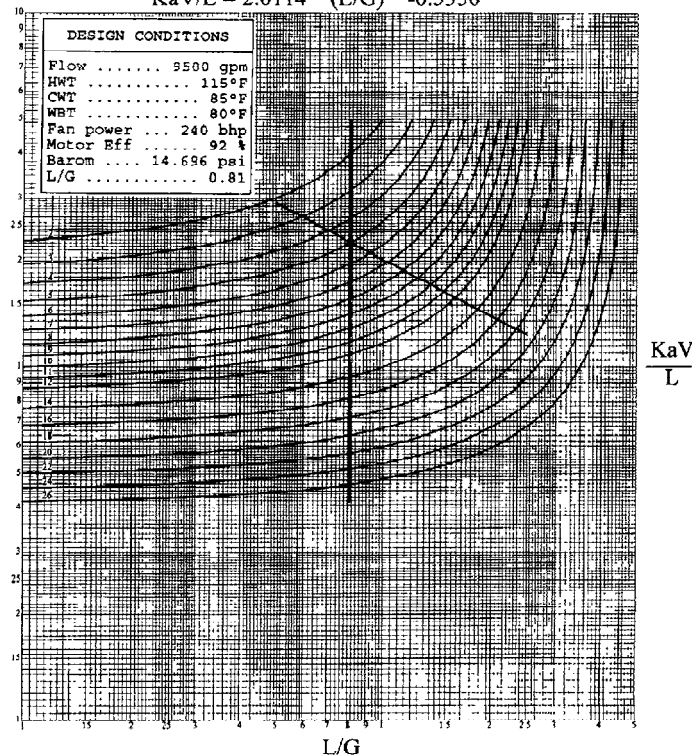
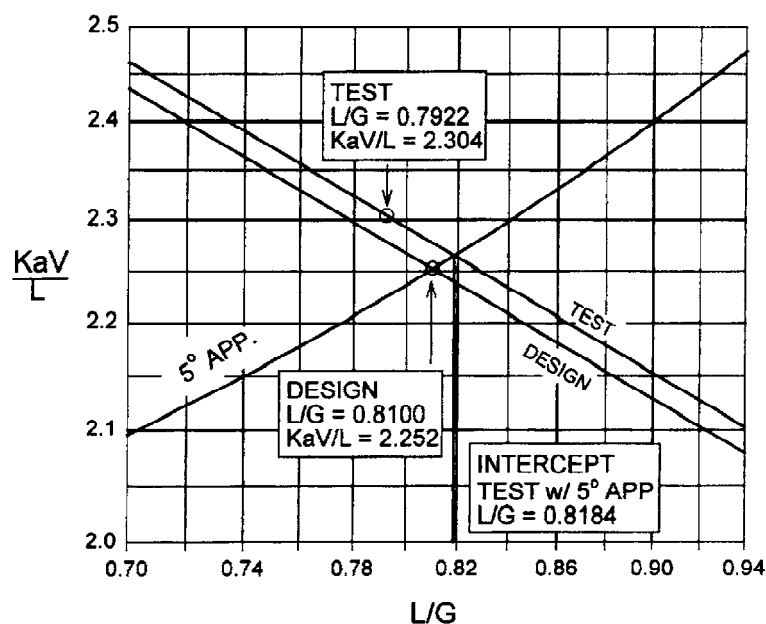


Figure B-2

Manufacturer's Characteristic Curve with Design Point and Test Point.



PART III — APPENDIX C

SI EXAMPLE EVALUATION OF MECHANICAL-DRAFT COOLING TOWER TEST
USING THE PERFORMANCE CURVE METHOD

Section C1. General

The purpose of this appendix is to describe and illustrate the performance curve methodology for evaluating a thermal performance test on a mechanical draft cooling tower, as described in Section 6 of the standard.

Section C2. Design and Test Conditions

Design and test conditions for the mechanical induced draft cooling tower are summarized in the following table.

Table C-1. Cooling Tower, Design and Test Data

Parameter	Design	Test
Water Flow Rate (Q_w)	3583 l/s	3623 l/s
Hot Water Temp. (T_{hw})	49.40 °C	46.50 °C
Cold Water Temp. (T_{cw})	30.60 °C	29.04 °C
Cooling Range (R)	18.80 °C	17.46 °C
Inlet Wet Bulb Temp. (T_{wb})	26.00 °C	24.53 °C
Inlet Dry Bulb Temp. (T_{db})	30.20 °C	25.52 °C
Fan Driver Power ($\dot{W}$)	107.00 kW	113.00 kW
Barometric Pressure (P_{bp})	101.325 kPa	98.80 kPa
Liquid to Gas Ratio (L/G)	1.300	

In accordance with paragraph 6.2 of this standard, the manufacturer has submitted Performance Curves with Cold Water presented as a function of Wet Bulb Temperature with Range and Water Flow Rate as parameters (see Figures C-1, C-2, and C-3).

Section C3. Evaluation Procedure

The steps to be followed in evaluating the test are as follows:

Step 1. Determine the Predicted Cold Water Temperatures

Scribe the submitted performance curves vertically at the test wet bulb temperature (24.53°C) to determine the predicted Cold Water Temperatures associated with the test Wet Bulb at each of the three Range and three Flow Rate conditions included on the performance curves.

Table C-2. Curve Points for Cold Water Temperature
vs Range at 24.53°C Test Wet Bulb

Range	90% Flow	100% Flow	110% Flow
17.0°C	28.61	29.40	30.22
18.8°C	28.84	29.63	30.48
21.0°C	29.07	29.86	30.73

Values of these predicted Cold Water Temperatures are tabulated in Table C-2.

Step 2. First Crossplot.

These values of Cold Water Temperature are plotted against Ranges using Flow Rate as a parameter (see Figure C-4).

Scribe Figure C-4 vertically at the Test Range (17.46°C) to deter-

mine the predicted Cold Water Temperatures at each of the three circulating Flow Rates. Values of these predicted Cold Water Temperatures are tabulated on Table C-3 below.

Table C-3. Curve Points for Cold Water Temperature vs
Water Flow at 24.53°C Test Wet Bulb and 17.46°C Test Range

90% Flow	100% Flow	110% Flow
28.67	29.46	30.29

Step 3. Second Crossplot

Using the values of Cold Water Temperature in Table C-2, plot the temperature as a function of the three Flow Rate percentages (see Figure C-5).

Step 4. Determination of Predicted Flow Rate

On Figure C-5 scribe a horizontal line at the test Cold Water Temperature to intersect the curve. At the intersection, project a line vertically downward to find the predicted circulating water Flow Rate associated with the test Wet Bulb, Range, and Cold Water Temperature.

$$Q_{w\text{pred}} = 94.70\% \text{ Design Flow} = 3393 \text{ L/s}$$

Step 5. Calculate the Adjusted Test Water Flow Rate

The adjusted test circulating Water Flow Rate is computed from equation 6.1, using the values for air density at the fan inlet and the fan driver output power, at both test and design conditions.

To comply with this standard, the design and test values for density (ρ), specific volume (v), and enthalpy (h) of air must be determined using either the psychrometric tables in Appendix H of this standard or the psychrometric tables in *ASHRAE Handbook - Fundamentals (SI)*, or computed using the formulae of Appendix H which implements the ASHRAE calculations for moist air properties. For this example, the computer program of Appendix H was used to generate all psychrometric properties.

Since the evaluation is based upon the psychrometric properties of air at the fan inlet, different procedures must be employed for forced draft and induced draft towers.

a. Forced Draft Tower

For a forced draft tower, the fan inlet air conditions are the same as the tower inlet air conditions. Therefore the test density (ρ_t) and the test specific volume (v_t) are computed directly from the measured test values of wet-bulb, dry-bulb and barometric pressure. In accordance with paragraph 6.2, the manufacturer shall supply the design conditions at the tower's air inlet.

Table C-4. Design and Test Values for Air Characteristics

Parameter	Design	Test
Barometric Pressure (P)	101.325 kPa	98.80 kPa
Wet Bulb Temp (T_{wb})	26.00 °C	24.53 °C
Dry Bulb Temp (T_{db})	30.20 °C	25.52 °C
Humidity Ratio (HR)	0.01966 kg/kg	0.01969 kg/kg
Specific Volume (v)	0.88656 m ³ /kg	0.89523 m ³ /kg
Enthalpy (h)	80.6307 kJ/kg	75.8211 kJ/kg
Density (kg/m ³)	1.15013	1.13902
Relative Humidity(RH)	71.98 (%)	92.36 (%)

b. Induced Draft Tower

For the induced draft tower, the fan air conditions are the tower discharge conditions.

The code requires that both the design and test, discharge air properties be determined by a heat balance calculation. Calculating **design** discharge air properties is a straightforward procedure while calculating **test** discharge air properties requires combining the heat balance Equation (C-2) with Equation (C-1) and iterating for a solution.

The heat balance equation states that the heat gain by the air equals the heat loss of the water. The formula follows

$$L \cdot C_{pw} \cdot (T_{hw} - T_{cw}) = G \cdot (h_o - h_i) \quad (C-1)$$

Where:

- L = Water mass flow rate, kg / hr
- C_{pw} = Specific Heat of Water = 4.186 kJ/kg °C
- T_{hw} = Hot Water Temperature, °C
- T_{cw} = Cold Water Temperature, °C
- G = Mass flow rate of dry air through the tower, kg / hr
- h_o = Enthalpy of air leaving the tower, kJ/kg
- h_i = Enthalpy of air entering the tower, kJ/kg

Rearranging to isolate the exit air enthalpy, the heat balance equation becomes:

$$h_o = (L/G) \cdot C_{pw} \cdot (T_{hw} - T_{cw}) + h_i \quad (C-2)$$

Determine the enthalpy of the entering air at design conditions as:

$$h_{id} = 80.631 \text{ kJ/kg}$$

Then, substituting all design values into Equation (C-2), calculate h_{od}

$$h_{od} = (1.30) \cdot 4.186 \cdot (49.4 - 30.6) + 80.631 \text{ or}$$

$$h_{od} = 182.936 \text{ kJ/kg}$$

Assuming the discharge air is saturated at this enthalpy, determine the design discharge air temperature, density (ρ_d) and specific volume (v_d) as :

$$T_a = 41.85 \text{ °C}$$

$$\rho_d = 1.08634 \text{ kg/m}^3$$

$$v_d = 0.97084 \text{ m}^3/\text{kg}$$

Next we need to calculate the discharge air characteristics at **test** conditions. First calculate the test L/G by substituting all known values into equation (5.1):

$$\left(\frac{L}{G}\right) = 1.300 \cdot \left(\frac{3623}{3583}\right) \cdot \left(\frac{\rho_i}{1.08634}\right)^{1/3} \cdot \left(\frac{107.0}{113.0}\right)^{1/3} \cdot \left(\frac{v_i}{0.97084}\right)$$

$$\left(\frac{L}{G}\right)_i = 1.2934 \cdot (\rho_i)^{1/3} \cdot v_i$$

Substitute this L/G expression into equation (C-2) to calculate the test exit air enthalpy, h_{ot}

$$h_{ot} = 1.2934 \cdot (\rho_i)^{1/3} \cdot (v_i) \cdot 4.168 \cdot (46.50 - 29.04) + 75.8211$$

$$= 94.1250 (\rho_i)^{1/3} \cdot (v_i) + 75.8211$$

At this point, guess at a discharge air temperature, and, assuming saturation, determine ρ and v at that temperature. Then, substituting these values of ρ and v into the final heat balance expression, calculate an h_{ot} .

Compare this calculated value for h_{ot} to the actual value for enthalpy at the assumed temperature and continue iterating discharge air temperature until a suitable temperature is selected for which the calculated value of h_{ot} matches the actual value.

For the first estimate of leaving air temperature, use the average of T_{hw} and T_{cw} at test conditions. Typical iteration values for this example are given in Table C-5 for Barometric pressure of 98.80 kPa.

Table C-5 Iteration for Enthalpy of Leaving Air

T_a	ρ_i	v_i	h_{ot} actual	h_{ot} computed	Error %
38.00	1.07797	0.96938	153.79	169.78	+10.40%
40.00	1.06791	0.98369	170.16	170.87	+0.416%
41.00	1.06281	0.99122	178.97	171.44	-4.20%
40.09	1.06745	0.98436	170.94	170.92	-0.009%

Substituting the psychrometric values at 40.90 °C, the adjusted flow rate is now calculated from equation 6.1.

$$Q_{wt_{adj}} = 3623 \cdot \left(\frac{107.0}{113.0}\right)^{1/3} \cdot \left(\frac{1.06745}{1.08634}\right)^{1/3} = 3537 \text{ L/s}$$

The tower capacity is then computed from equation 6.2.

$$C = \left(\frac{3537}{3393}\right) \cdot 100 = 104.2\%$$

Figure C-1. Water Flow Rate = 3225 L/s (90%)

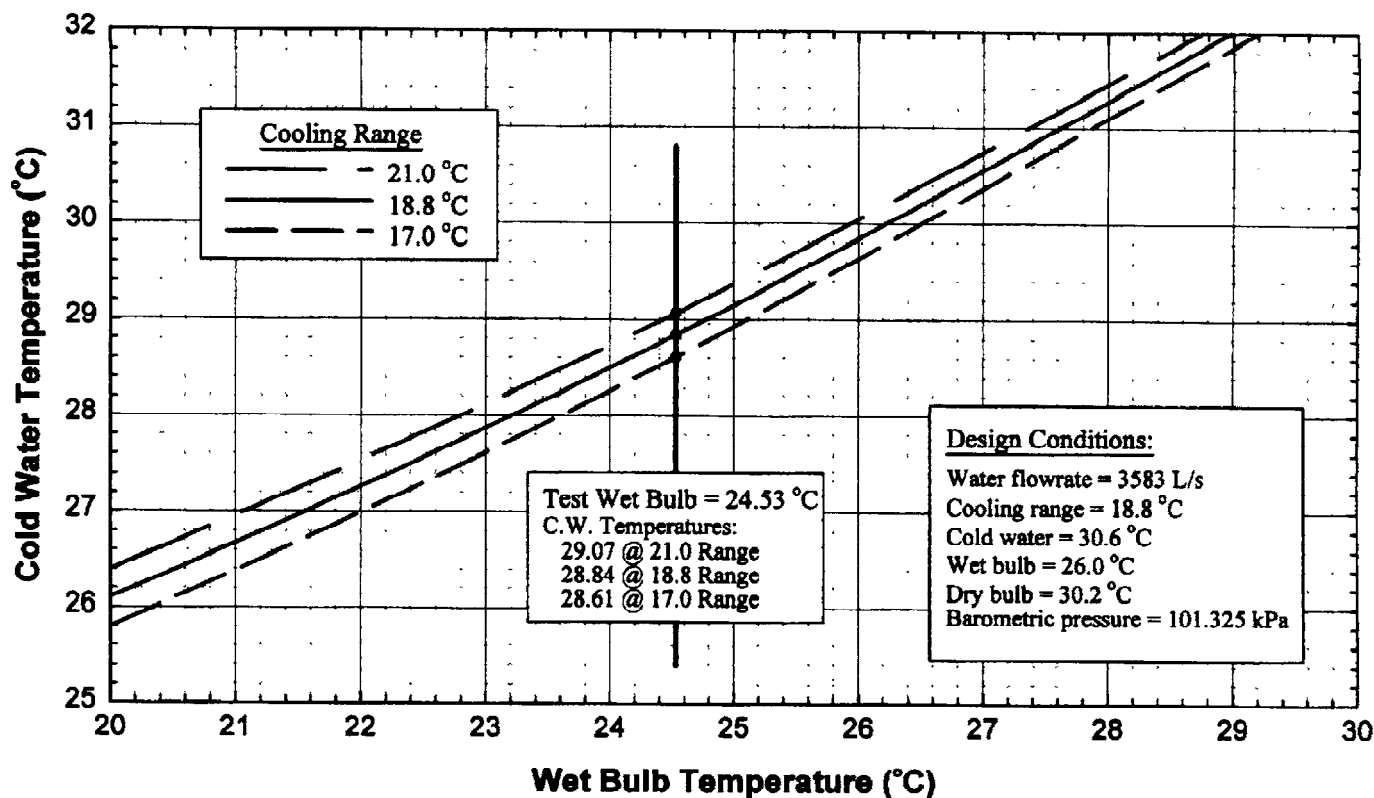


Figure C-2. Water Flow Rate = 3583 L/s (100%)

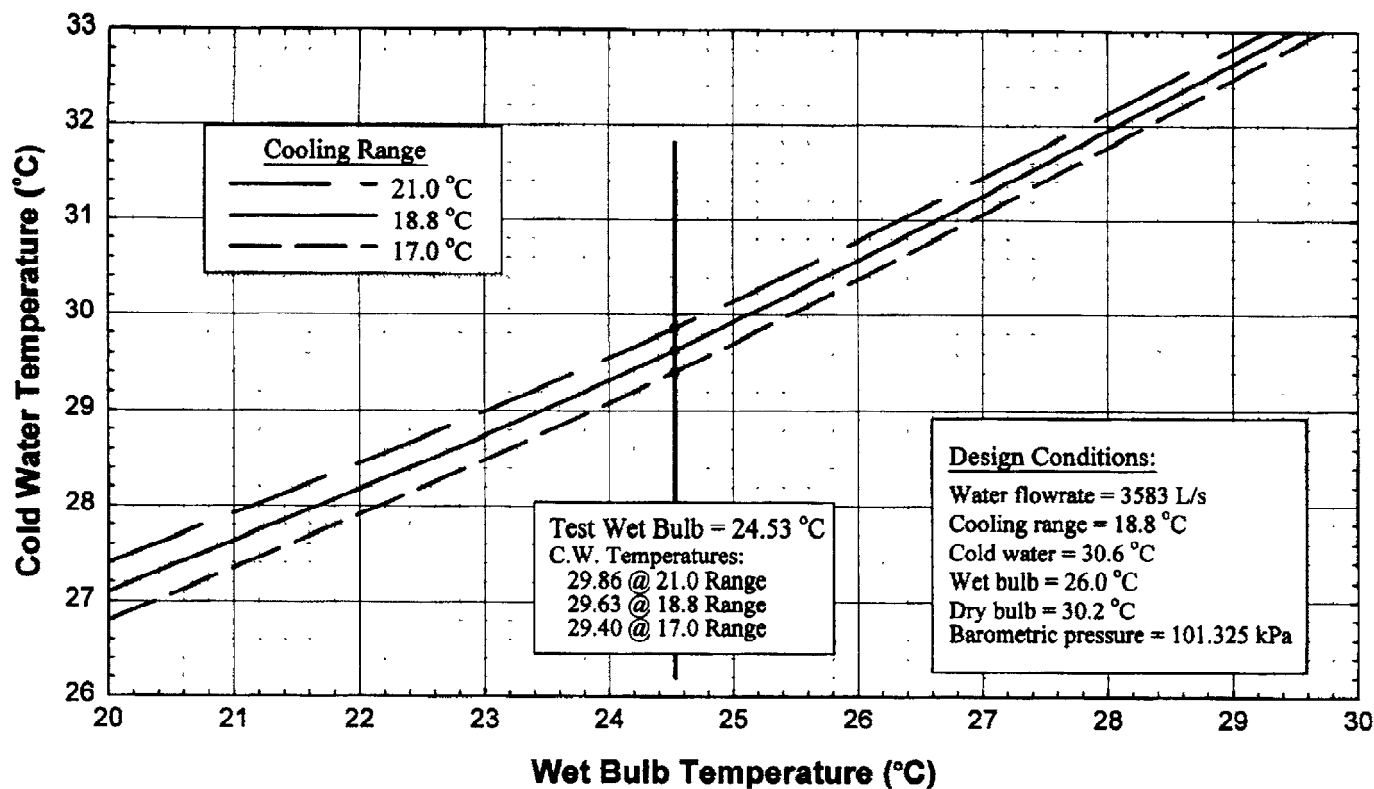
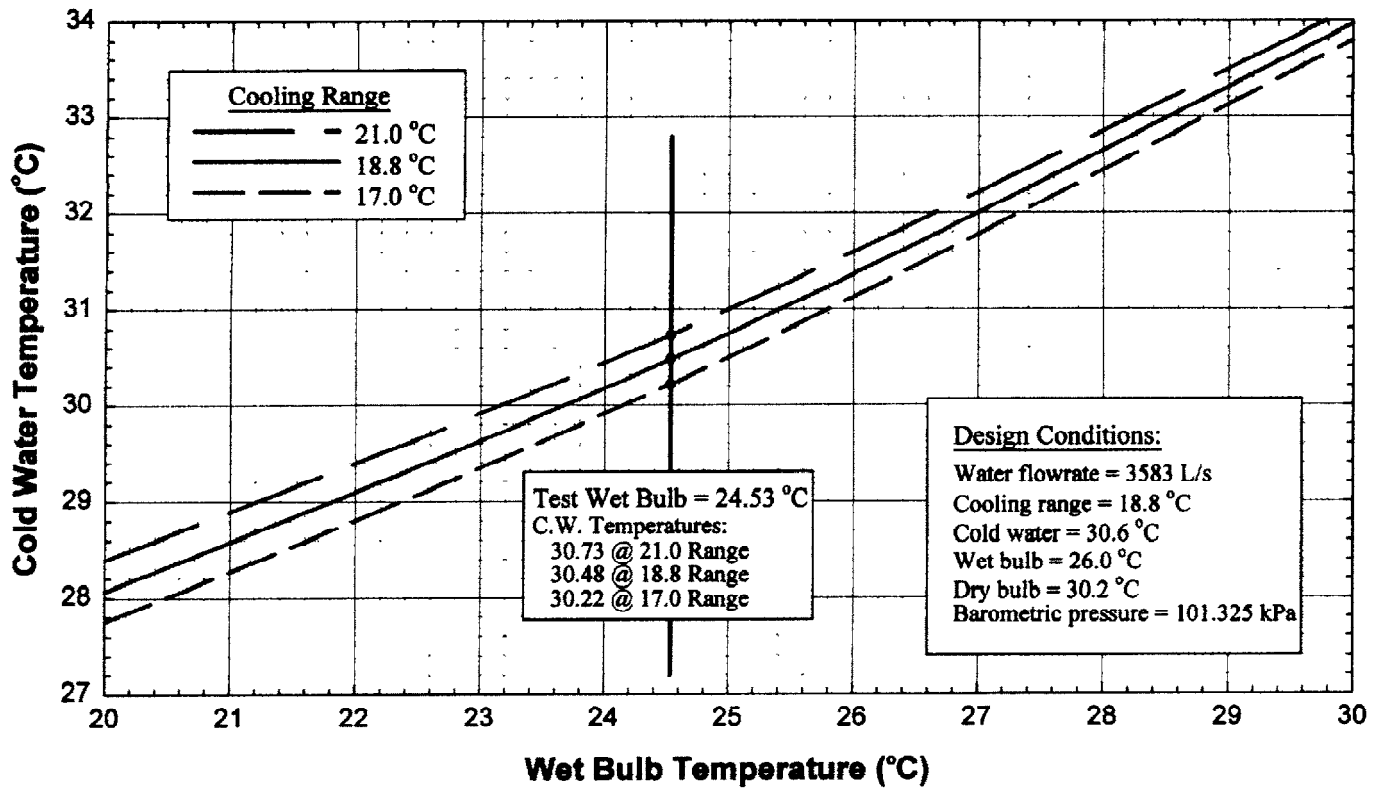


Figure C-3. Water Flow Rate = 3942 L/s (110%)



**Figure C-4. Crossplot 1.
Wet Bulb = 24.53 °C**

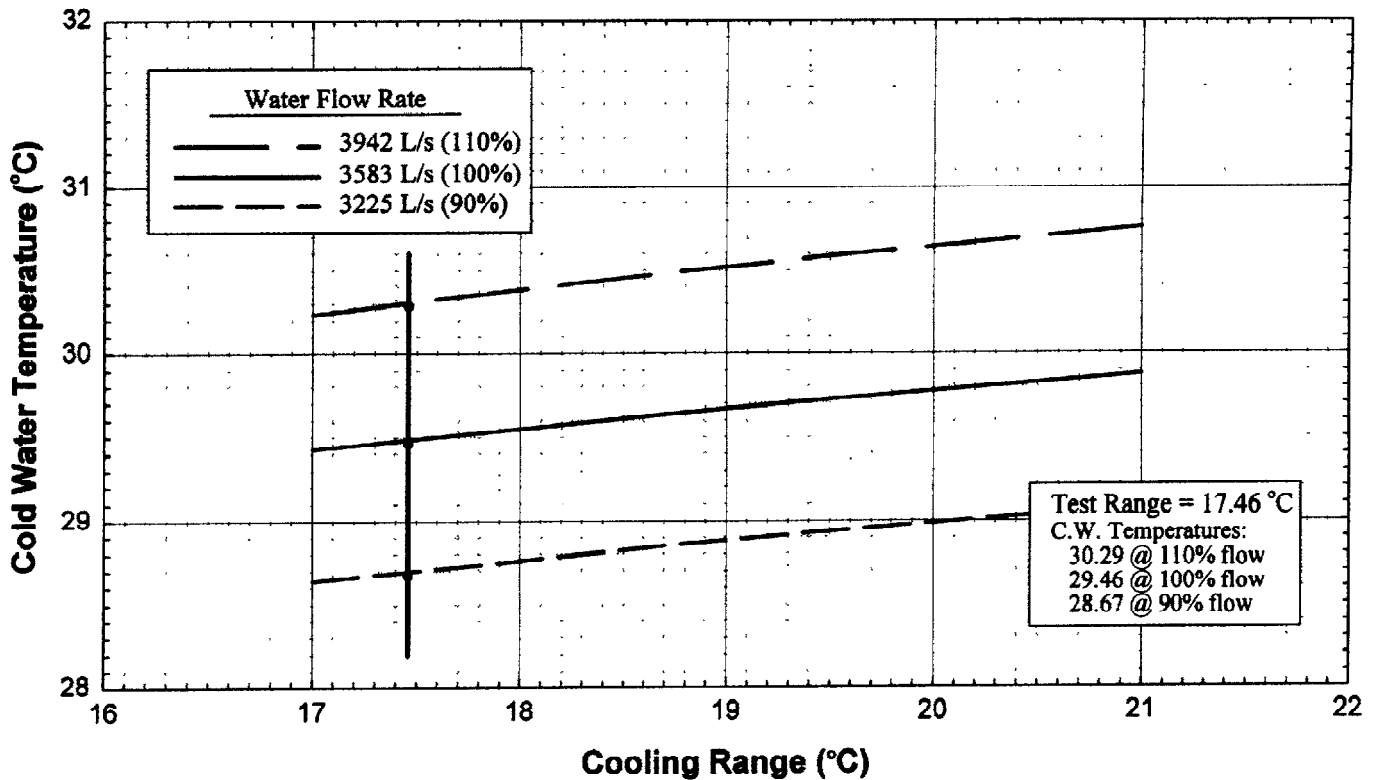
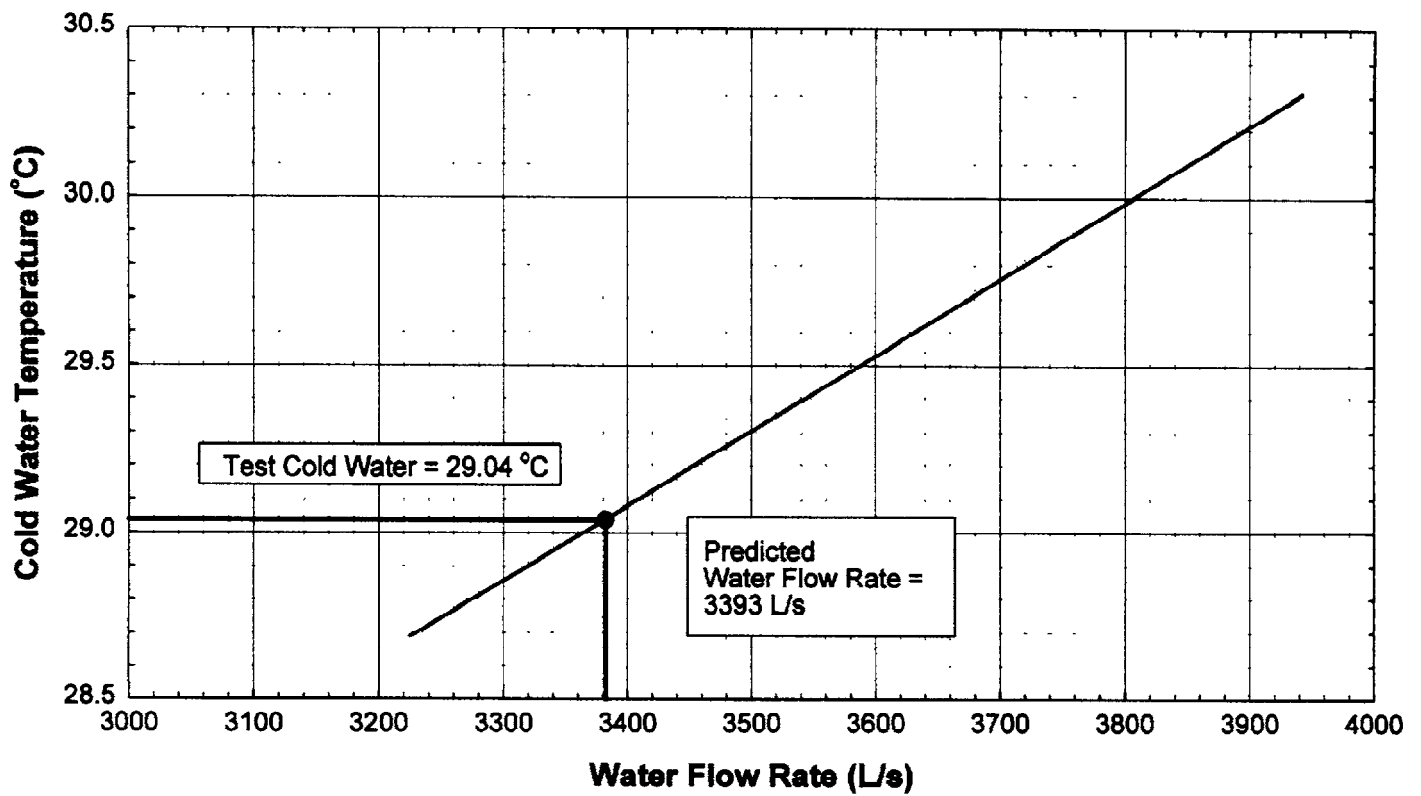


Figure C-5. Crossplot 2.
Wet Bulb = 24.53 °C Range = 17.46 °C



PART III — APPENDIX D

IP EXAMPLE EVALUATION OF MECHANICAL-DRAFT COOLING TOWER TEST
USING THE PERFORMANCE CURVE METHOD

Section D1. General

The purpose of this appendix is to describe and illustrate the performance curve methodology for evaluating a thermal performance test on a mechanical draft cooling tower, as described in Section 6 of the standard.

Section D2. Design and Test Conditions

Design and test conditions for a given mechanical induced draft cooling tower are summarized in the following table.

Table D-1. Cooling Tower Design and Test Data

Parameter	Design	Test
Water Flow Rate (Q_{wt})	56,792 gpm	57,426 gpm
Hot Water Temp. (T_{hw})	120.92°F	115.70°F
Cold Water Temp. (T_{cw})	87.08°F	84.27°F
Inlet Wet Bulb Temp. (T_{wb})	78.80°F	76.18°F
Inlet Dry Bulb Temp. (T_{db})	86.36°F	77.94°F
Fan Driver Power ($\dot{W}$)	143.40 bhp	151.50 bhp
Barometric Pressure (P_{bp})	29.921 in Hg	29.18 in Hg
Liquid to Gas Ratio	1.300	

In accordance with paragraph 6.2 of this standard, the manufacturer has submitted Performance Curves with Cold Water presented as a function of Wet Bulb Temperature with Range and Water Flow Rate as parameters (see Figures D-1, D-2, and D-3).

Section D3. Evaluation Procedure

The steps to be followed in evaluating the test are as follows:

Step 1. Determine the Predicted Cold Water Temperatures

Scribe the submitted performance curves vertically at the test wet bulb temperature (76.18°F) to determine the predicted Cold Water Temperatures associated with the test Wet Bulb Temperature at each of the three Range and three water Flow Rate conditions included on the performance curves.

Table D-2. Curve Points for Cold Water Temperature
vs Range at 76.18°F Test Wet Bulb

Range	90% Flow	100% Flow	110% Flow
27.0°F	82.88	84.14	85.81
33.84°F	83.91	85.37	87.23
40.61°F	84.87	86.49	88.53

Values of these predicted Cold Water Temperatures are tabulated in Table D-2.

Step 2. First Crossplot.

These values of Cold Water Temperature are plotted against Ranges using Flow Rate as a parameter (see Figure D-4).

Scribe Figure D-4 vertically at the test cooling Range (31.43°F) to determine the predicted Cold Water Temperatures at each of the three circulating Flow Rates. The values of these predicted Cold Water Temperatures are tabulated in Table D-3 below.

Table D-3. Curve Points for Cold Water Temperature vs
Water Flow at 76.18°F Test Wet Bulb and 31.43°F Test Range

90% Flow	100% Flow	110% Flow
83.55	84.94	86.73

Step 3. Second Crossplot

Using the values of Cold Water Temperature in Table D-2, plot these temperatures as a function of the three flow rate percentages (see Figure D-5)

Step 4. Determine the Predicted Flow Rate.

On Figure D-5 scribe an horizontal line at the test Cold Water Temperature to intersect the curve. At the intersection, project a line vertically downward to find the predicted circulating water Flow Rate associated with the test Wet Bulb, Range, and Cold Water Temperature.

$$Q_{w, \text{pred}} = 95.35\% \text{ Design Flow} = 54,152 \text{ gpm}$$

Step 5. Calculating the Adjusted Test Water Flow Rate

The adjusted test circulating water flow rate is computed from equation 6.1, using the values for air density at the fan inlet and the fan driver output power, at both the test and design conditions.

To comply with this standard, the design and test values for density (ρ), specific volume (v), and enthalpy (h) of air must be determined using either the psychrometric tables in Appendix H of this standard or the psychrometric tables in *ASHRAE Handbook - Fundamentals (IP)*, or computed using the formulae of Appendix H which implements the ASHRAE calculations for moist air properties. For this example, the computer program of Appendix H was used to generate all psychrometric properties.

Since the evaluation is based upon the psychrometric properties of air at the fan inlet, different procedures must be employed for forced draft and induced draft towers.

a. Forced Draft Tower

For a forced draft tower, the fan inlet air conditions are the same as the tower inlet air conditions. Therefore the test density (ρ) and the test specific volume (v) are computed directly from the measured test values of wet-bulb, dry-bulb and barometric pressure. In accordance with paragraph 6.2, the manufacturer shall supply the design conditions at the tower's air inlet.

Table D-4. Design and Test Values for Air Characteristics

Parameter	Design	Test
Barometric Pressure (P_{bp})	29.921 inHg	29.18 inHg
Wet Bulb Temp. (T_{wb})	78.80°F	76.18°F
Dry Bulb Temp. (T_{db})	86.36°F	77.94°F
Humidity Ratio (HR)	0.01971 lb/lb	0.01971 lb/lb
Specific Volume (v)	14.2009 ft ³ /lb	14.3382 ft ³ /lb
Enthalpy (h_i)	42.3329 BTU/lb	40.2958 BTU/lb
Density (ρ)	0.07180 lb/ft ³	0.07112 lb/ft ³
Relative Humidity (RH)	71.95%	92.44%

b. Induced Draft Tower

For the induced draft tower, the fan air conditions are the tower discharge conditions. The code requires that both the design and test, discharge air properties be determined by a heat balance calculation. Calculating **design** discharge air properties is a straightforward procedure while calculating **test** discharge air properties requires combining the heat balance Equation (D-2) with Equation (5.1) and iterating for a solution.

The heat balance equation states that the heat gain by the air equals the heat loss of the water. The formula follows

$$L \cdot C_{pw} \cdot (T_{hw} - T_{cw}) = G \cdot (h_o - h_i) \quad (D-1)$$

Where:

- L = Water mass flow rate, lb_m / hr
- C_{pw} = Specific Heat of Water = 1.0 BTU / lb_m • °F
- T_{hw} = Hot Water Temperature, °F
- T_{cw} = Cold Water Temperature, °F
- G = Mass flow rate of dry air through the tower, lb_m / hr
- h_o = Enthalpy of air leaving the tower, BTU/lb_m
- h_i = Enthalpy of air entering the tower, BTU/lb_m

Rearranging to separate the exit air enthalpy, the heat balance equation becomes:

$$h_o = (L/G) \cdot C_{pw} \cdot (T_{hw} - T_{cw}) + h_i \quad (D-2)$$

Determine the enthalpy of the entering air at design conditions as:

$$h_{id} = 42.333 \text{ Btu/lbm}$$

Then, substituting all design values into Equation (D-2), calculate h_{od} .

$$h_{od} = (1.300) 1.0 (120.91 - 87.07) + 42.333 \text{ or}$$

$$h_{od} = 86.325 \text{ Btu/lbm.}$$

Assuming the discharge air is saturated at this enthalpy and barometric pressure, determine the design discharge air temperature, density (ρ_d) and specific volume (v_d) as:

$$T_a = 107.323 \text{ °F}$$

$$\rho_d = 0.06782 \text{ lbm/ft}^3$$

$$v_d = 15.5500 \text{ ft}^3/\text{lbm}$$

Next we need to calculate the discharge air characteristics at test conditions. First calculate the test L/G by substituting all known values into equation (5.1):

$$\left(\frac{L}{G}\right) = 1.300 * \left(\frac{57,426}{56,792}\right) * \left(\frac{\rho_i}{0.06782}\right)^{1/3} * \left(\frac{143.4}{151.5}\right)^{1/3} * \left(\frac{v_i}{15.550}\right)$$

$$\left(\frac{L}{G}\right) = 0.20353 * (\rho_i)^{1/3} * v_i$$

Substitute this L/G expression into equation (D-2) to calculate the test exit air enthalpy, h_{ot} .

$$h_{ot} = 0.20353 * (\rho_i)^{1/3} * (v_i) * 1.0 * (115.70 - 84.27) + 40.2958$$

$$= 6.3969 (\rho_i)^{1/3} * (v_i) + 40.2958$$

At this point, guess at a discharge air temperature and, assuming saturation, determine ρ , and v at that temperature. Then, substituting these values for ρ and v into the final heat balance expression, calculate an h_{ot} .

Compare the calculated value for h_{ot} to the actual value of enthalpy at the assumed temperature and continue iterating discharge air temperature until a suitable temperature is selected for which the calculated value of h_{ot} matches the actual value.

For the first estimate of leaving air temperature, use the average of T_{hw} and T_{cw} at test conditions. Typical iteration values for this example are given in Table D-5 for Barometric pressure of 29.18 in Hg.

Table D-5 Iteration for Enthalpy of Leaving Air

T_a	ρ_i	v_i	h_{ot} actual	h_{ot} computed	Error %
100	0.06738	15.5006	73.0653	80.6437	+10.37%
105	0.06650	15.8207	82.9340	81.2980	-1.97%
104.00	0.06668	15.7542	80.8517	81.1617	+0.383%
104.16	0.06665	15.7648	81.1810	81.1833	+0.003%

Step 6 - Determine Cooling Tower Capability

Substituting the psychrometric values at 104.16°F, the adjusted flow rate is now calculated from equation 6.1.

$$Q_{wt_{adj}} = 57,426 * \left(\frac{143.4}{151.5}\right)^{1/3} * \left(\frac{0.06665}{0.06782}\right)^{1/3} = 56,057 \text{ gpm}$$

The tower capacity is then computed from equation 6.2.

$$C = \left(\frac{56,057}{54,152}\right) * 100 = 103.5\%$$

Figure D-1. Water Flow Rate = 51,113 gpm (90%)

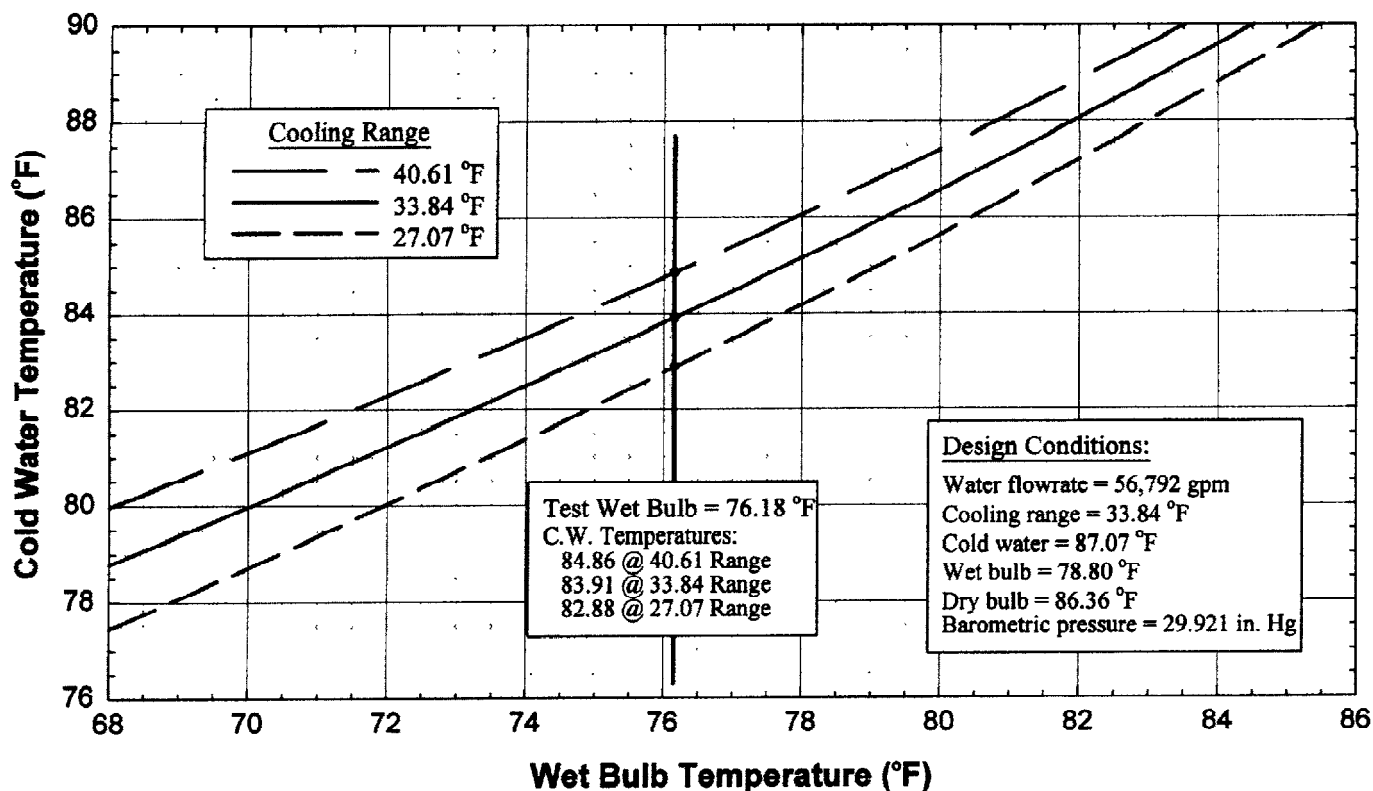


Figure D-2. Water Flow Rate = 56,792 gpm (100%)

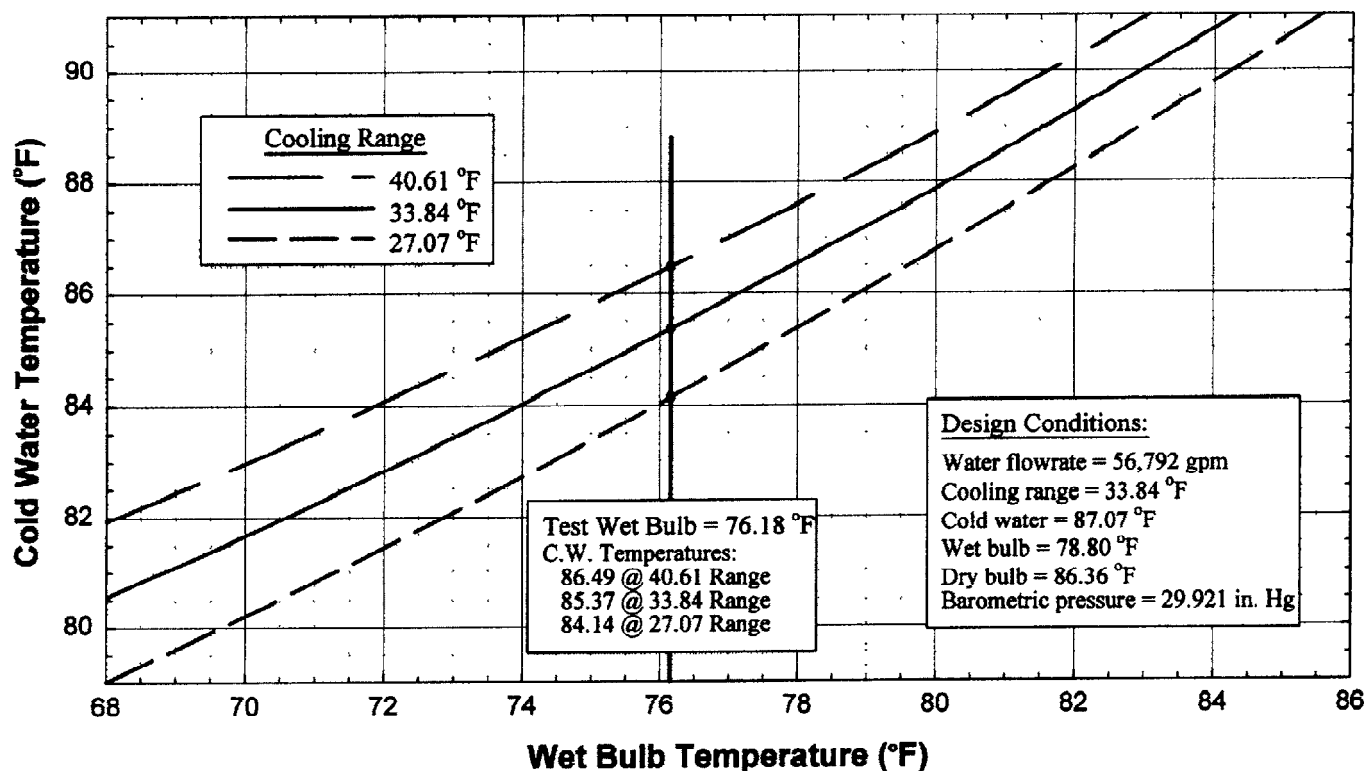
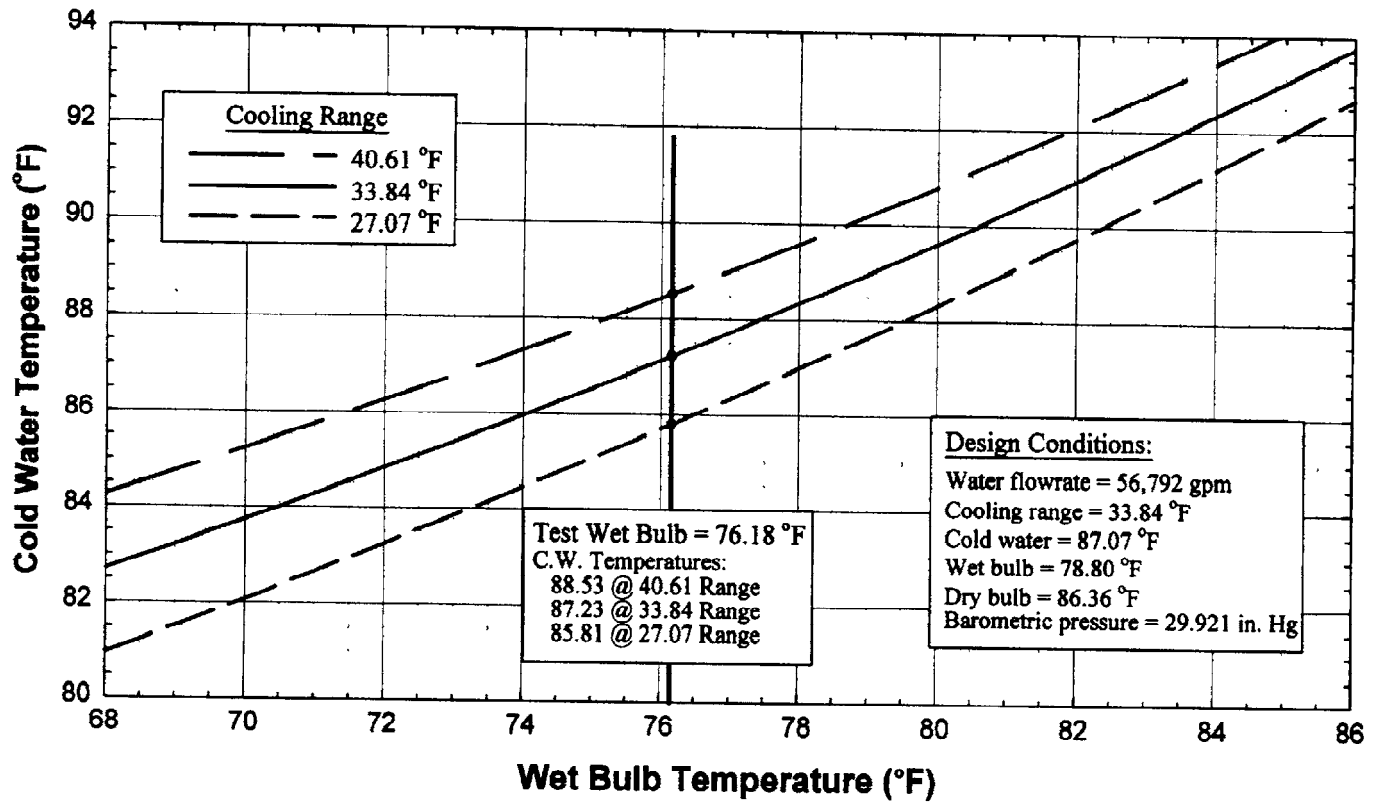


Figure D-3. Water Flow Rate = 62,471 gpm (110%)



**Figure D-4. Crossplot 1.
Wet Bulb = 76.18 °F**

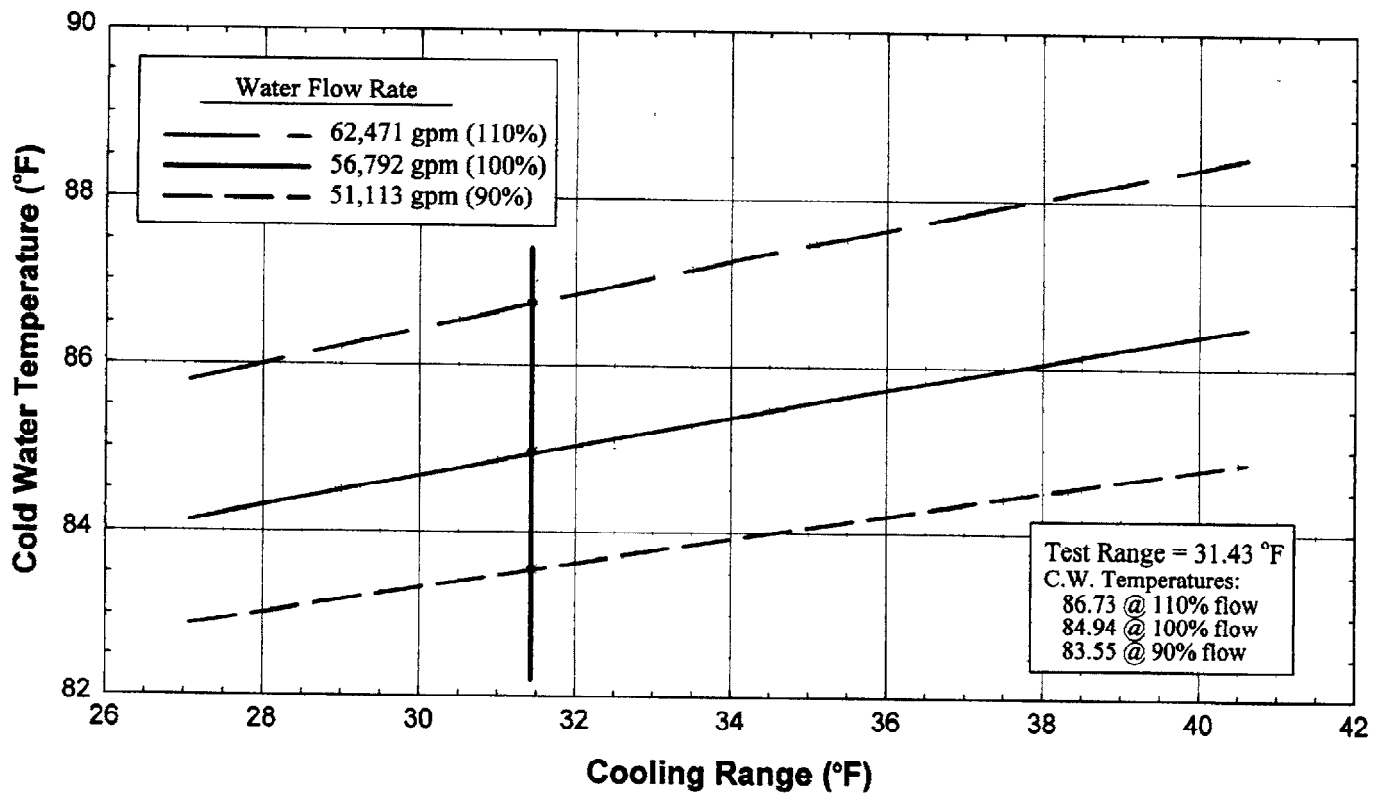
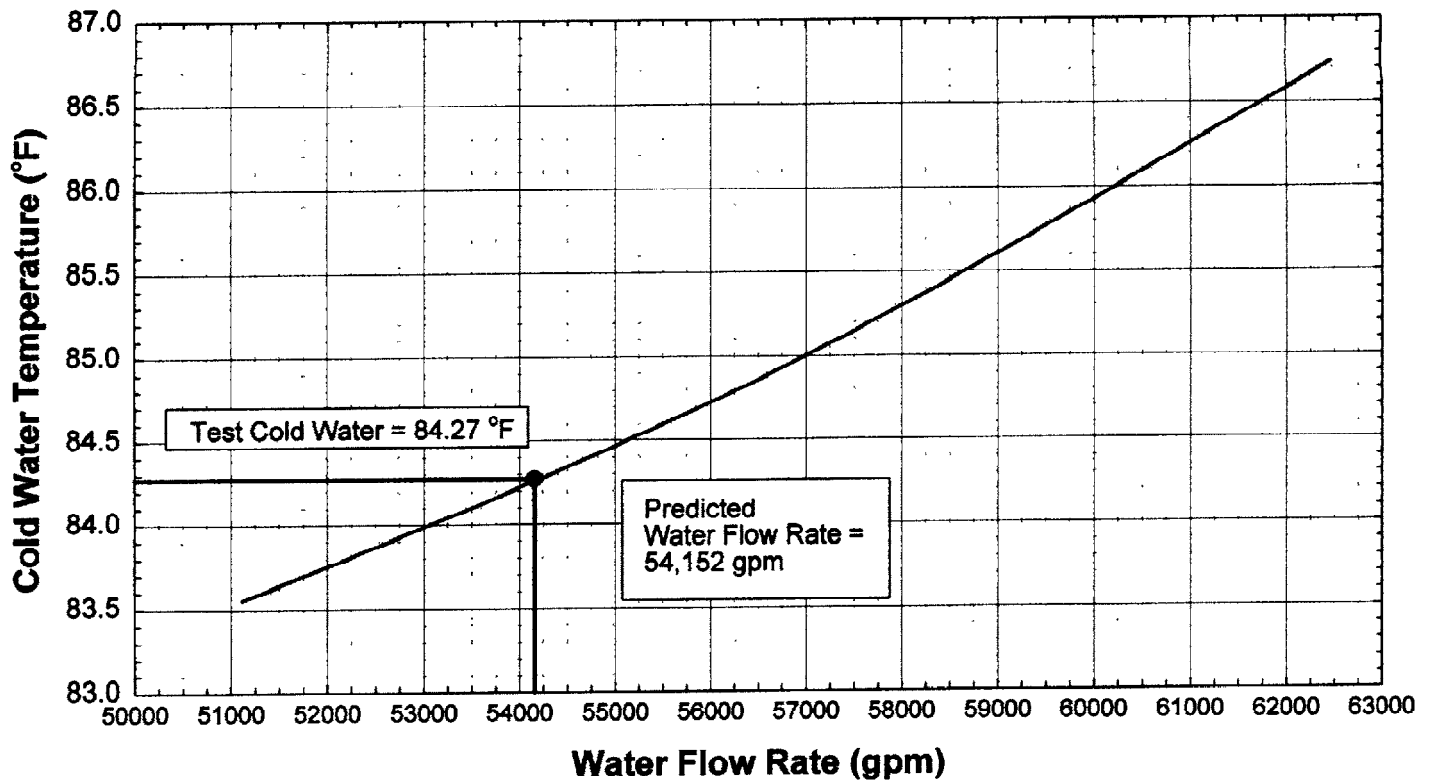


Figure D-5. Crossplot 2.
Wet Bulb = 76.18 °F Range = 31.43 °F



PART III — APPENDIX E

SI EXAMPLE EVALUATION OF NATURAL-DRAFT COOLING TOWER TEST USING THE PERFORMANCE CURVE METHOD

Section E1. General

The purpose of this appendix is to describe and illustrate the performance curve methodology for evaluating a thermal performance test on a natural draft cooling tower, as described in Section 7 of the standard.

Section E2. Design and Test Conditions

Design and test conditions for the natural draft cooling tower are summarized in the Table E-1 below:

Table E-1. Natural Draft Cooling Tower Design and Test Data

	Design	Test
Water Flow Rate (W)	23 889 L/s	22 299 L/s
Hot Water Temp (T_{hw})	32.80 °C	27.80 °C
Cold Water Temp (T_{cw})	25.40 °C	20.50 °C
Cooling Range (R)	7.40 °C	7.30 °C
Wet Bulb Temp (T_{wh})	16.00 °C	9.50 °C
Dry Bulb Temp (T_{dh})	18.20 °C	13.40 °C
Barometric Pressure (P_{bp})	101.325 kPa	103.70 kPa
Relative humidity (RH)	80.17%	60.42%

In accordance with Paragraph 7.2 of this standard, the manufacturer has submitted Performance Curves presenting Cold Water Temperature as a function of the air Dry Bulb Temperature with the Relative Humidity of the air as a parameter (see Figures E-1 through E-9).

E-1 to E-3 for 90 % of design water circulation rate ;

E-4 to E-6 for 100 % of design water circulation rate ;

E-7 to E-9 for 110 % of design water circulation rate.

Section E3. Evaluation Procedure

The five steps to be followed in evaluating the tower performance capability are as follows.

Step 1 - Determine the Predicted Cold Water Temperatures

Using the nine Performance Curves, three for each of the three water circulation rates, enter the curves at the test Dry Bulb Temperature (13.40°C) and determine the Cold Water Temperature for 60%, 80%, and 100% Relative Humidity at each Flow Rate and Range.

Table E-2. Predicted Cold Water Temperatures at 13.4°C Entering Dry Bulb Temperature.

Flow	Range	60% RH	80% RH	100% RH
90%	6.7°C	20.24	21.10	21.95
	7.4°C	20.46	21.31	22.16
	8.1°C	20.59	21.44	22.30
100%	6.7°C	21.11	21.94	22.78
	7.4°C	21.38	22.20	23.03
	8.1°C	21.56	22.39	23.23
110%	6.7°C	21.94	22.78	23.63
	7.4°C	22.17	23.02	23.86
	8.1°C	22.41	23.24	24.06

Step 2 - First Crossplot

Then for each Flow Rate, prepare a crossplot of Cold Water Temperature as a function of the Relative Humidity, with the cooling Range as a parameter (see figures E-10 through E-12).

Step 3 - Second Crossplot

Using these new curves, enter each at the Test Relative Humidity (60.42%) and determine the Cold Water Temperature for each Flow Rate and Range.

Table E-3. Predicted Cold Water Temperatures at 13.4°C Entering Dry Bulb Temperature and 60.42% RH

Range	90% Flow	100% Flow	110% Flow
6.7°C	20.26	21.13	21.95
7.4°C	20.48	21.39	22.19
8.1°C	20.61	21.58	22.43

Then, for each Flow Rate, develop a crossplot of the Cold Water Temperature as a function of the cooling Range, (see Figure E-13).

Step 4 - Third Crossplot

Enter Figure E-13 at the Test Range (7.30°C) and determine the Cold Water Temperature for each of the three Flow Rates.

Table E-4. Predicted Cold Water Temperatures at 13.4°C Entering Dry Bulb Temperature, 60.42% RH, and 7.3°C Range.

90% Flow	100% Flow	110% Flow
20.45	21.36	22.16

Then crossplot the water Flow Rate as a function of the Cold Water Temperature (see Figure E-14).

Step 5 - Determine Predicted Flow Rate

Enter Fig E-14 at the Measured Cold Water Temperature (20.50°C) and from the intersection with the curve, determine the Predicted

Water Flow Rate at the Test Cold Water Temperature as 21 639 L/s.

$$\% \text{Capability} = \left(\frac{22299 \text{ L/s}}{21639 \text{ L/s}} \right) \cdot (100) = 103.1\%$$

Step 6 - Determine Cooling Tower Capability

Using Equation 7.1, find the cooling tower Thermal Performance Capability as:

Figure E-1. Water Flow Rate = 21 500 L/s (90%) Range = 6.7 °C

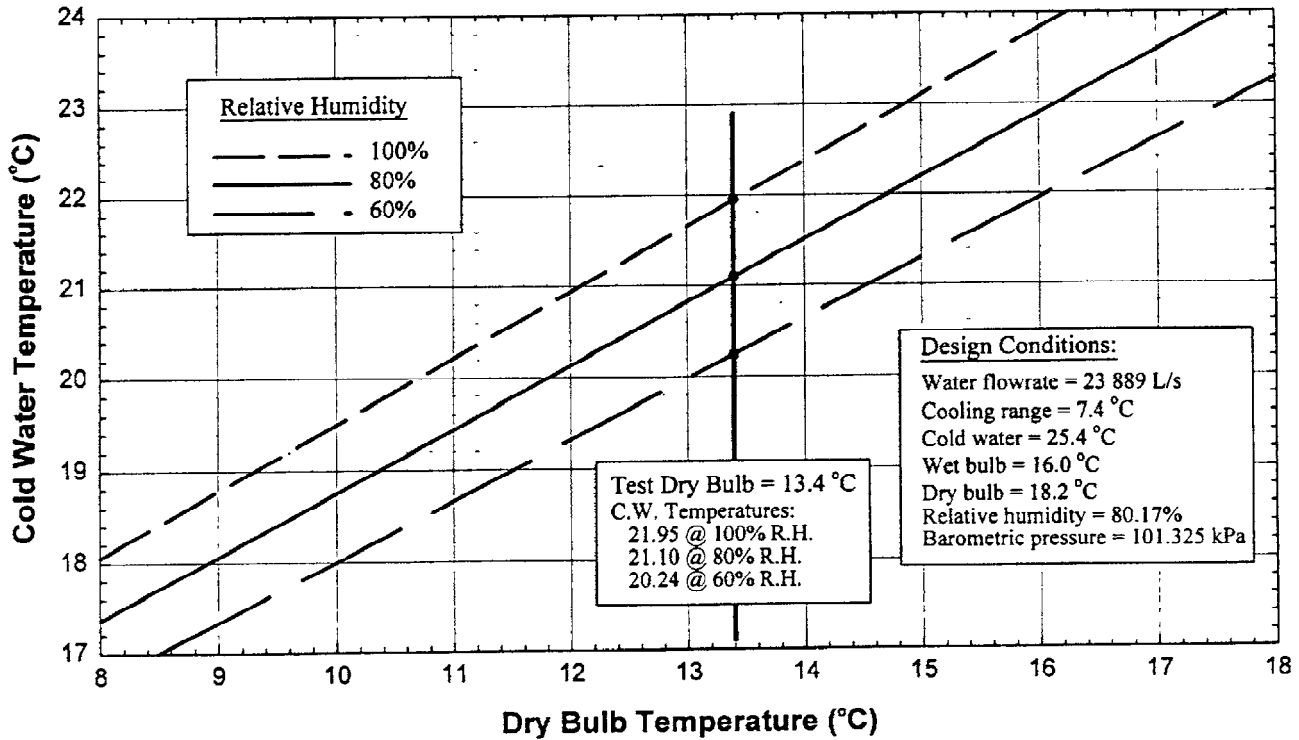


Figure E-2. Water Flow Rate = 21 500 L/s (90%) Range = 7.4 °C

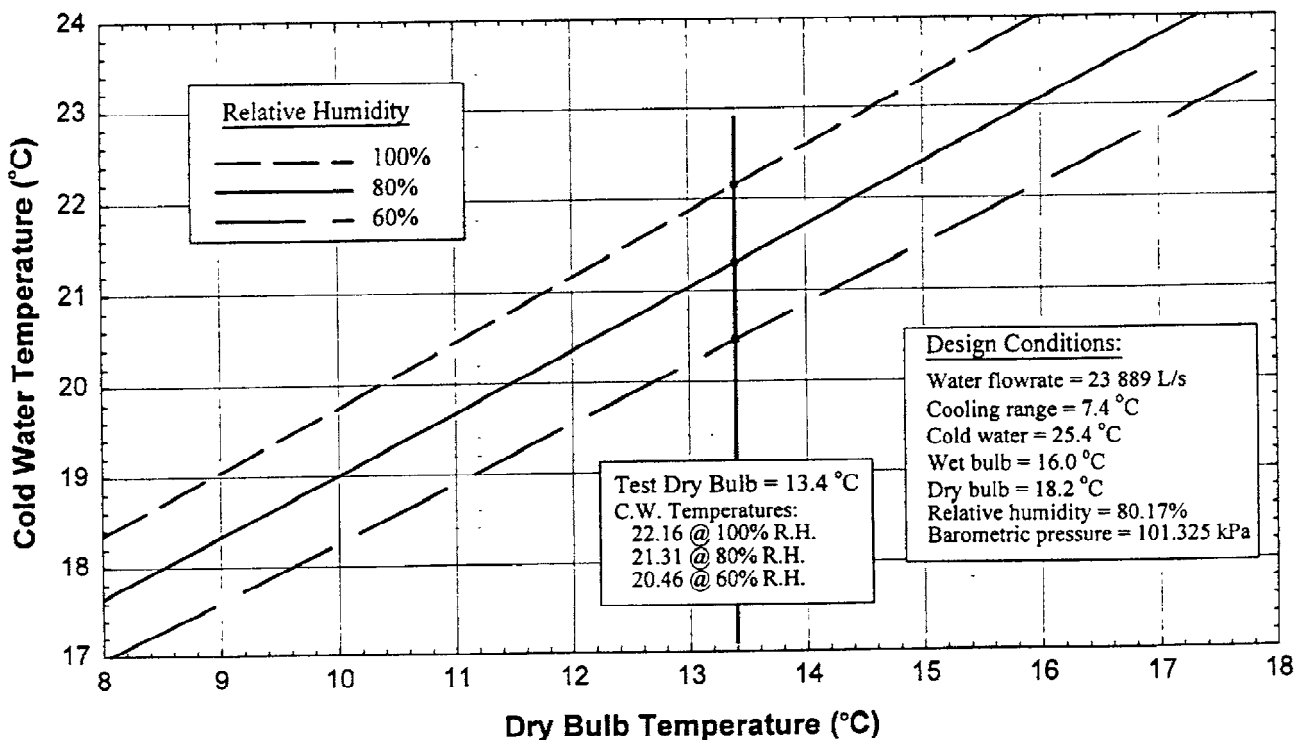


Figure E-3. Water Flow Rate = 21 500 L/s (90%) Range = 8.1 °C

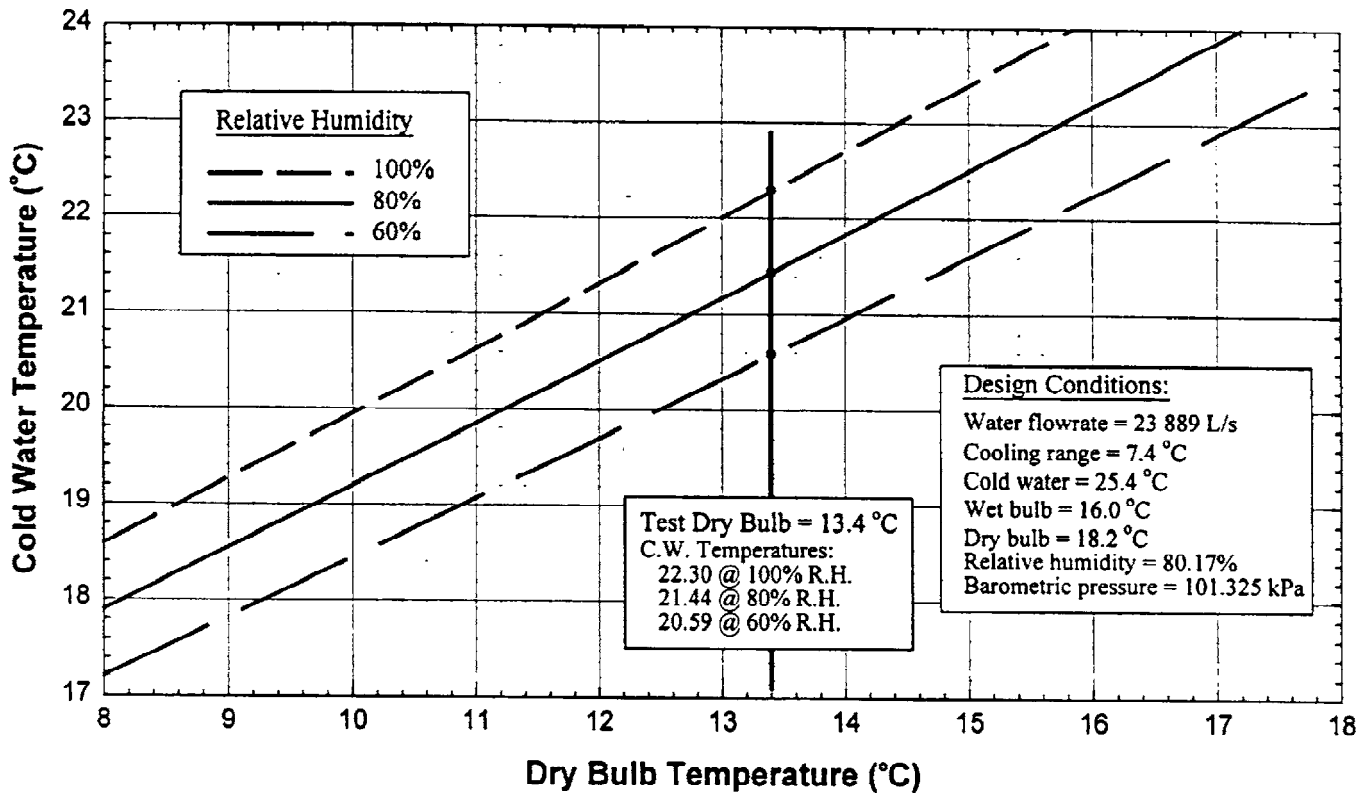


Figure E-4. Water Flow Rate = 23 889 L/s (100%) Range = 6.7 °C

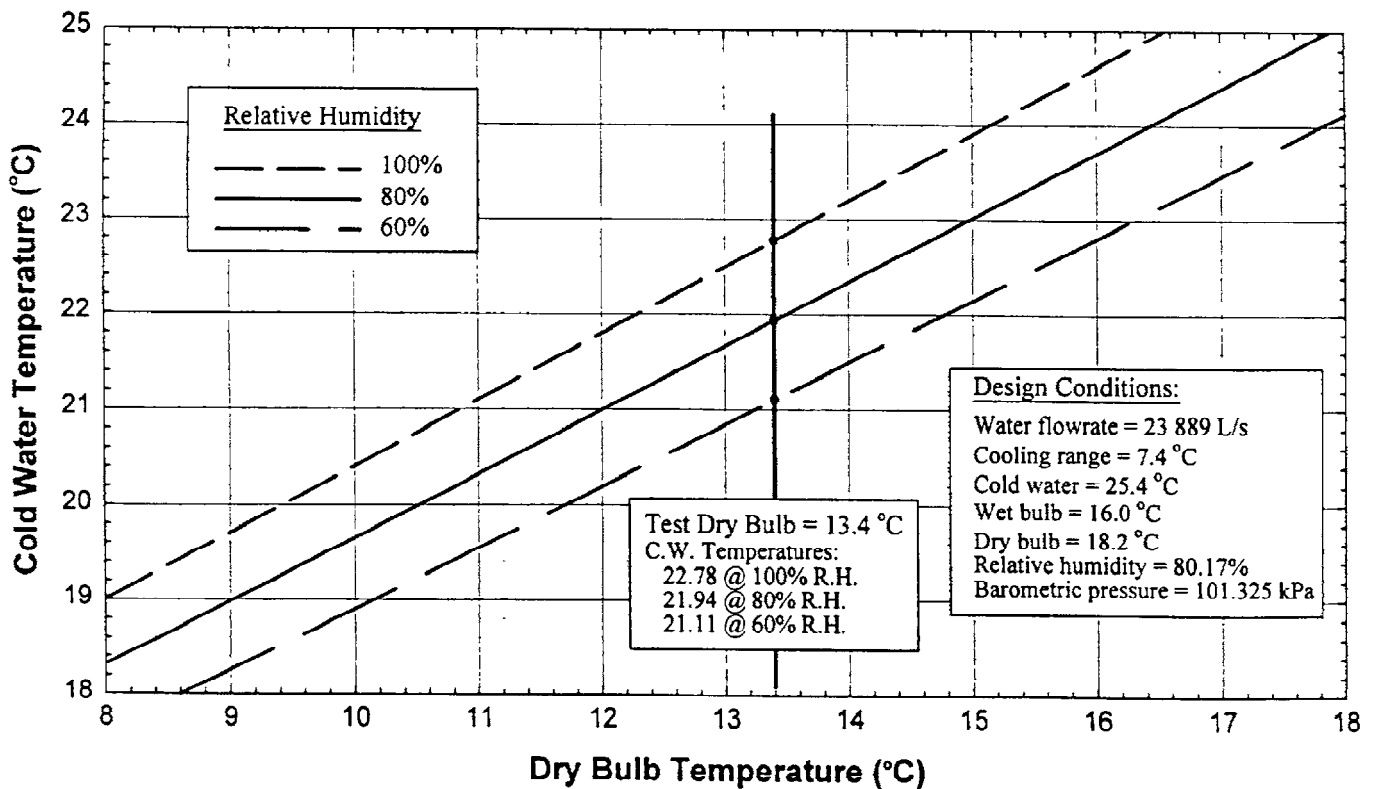


Figure E-5. Water Flow Rate = 23 889 L/s (100%) Range = 7.4 °C

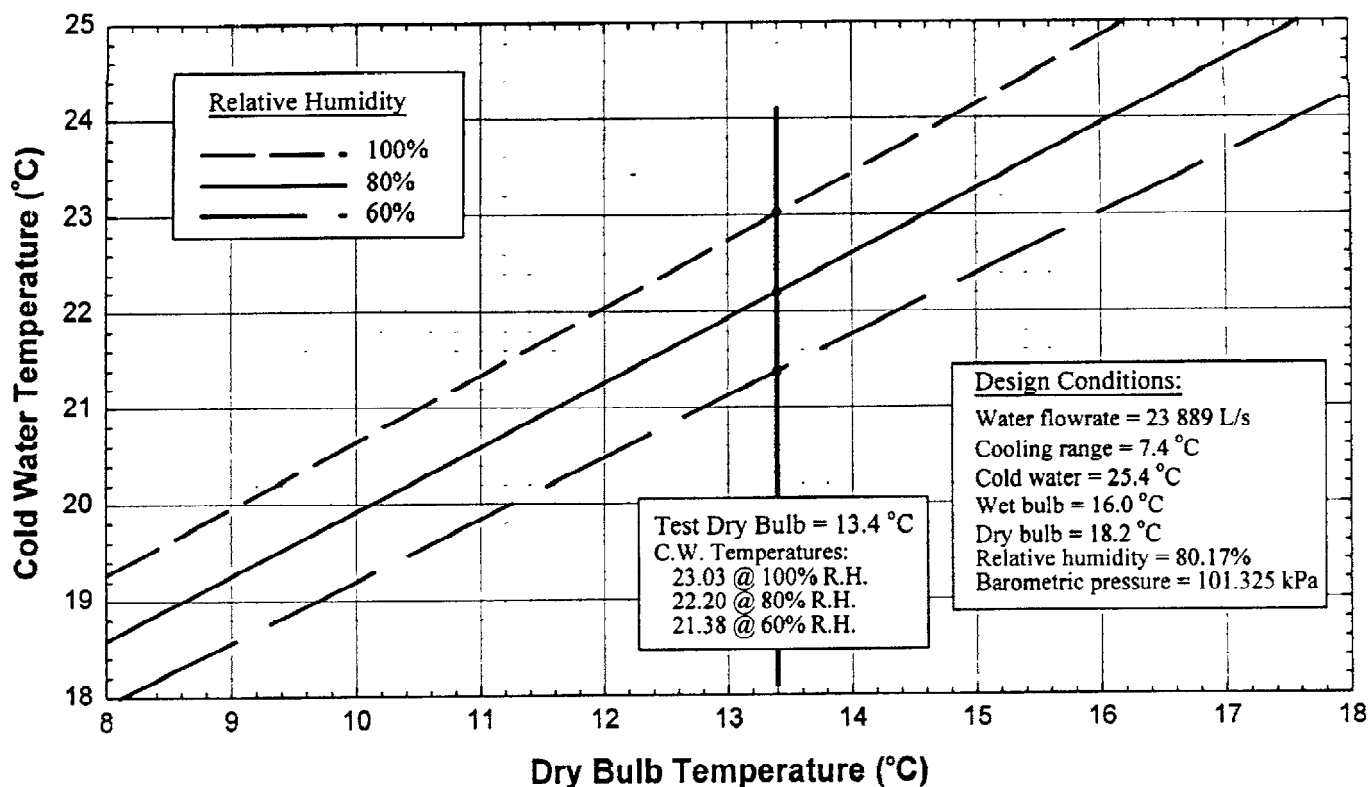


Figure E-6. Water Flow Rate = 23 889 L/s (100%) Range = 8.1 °C

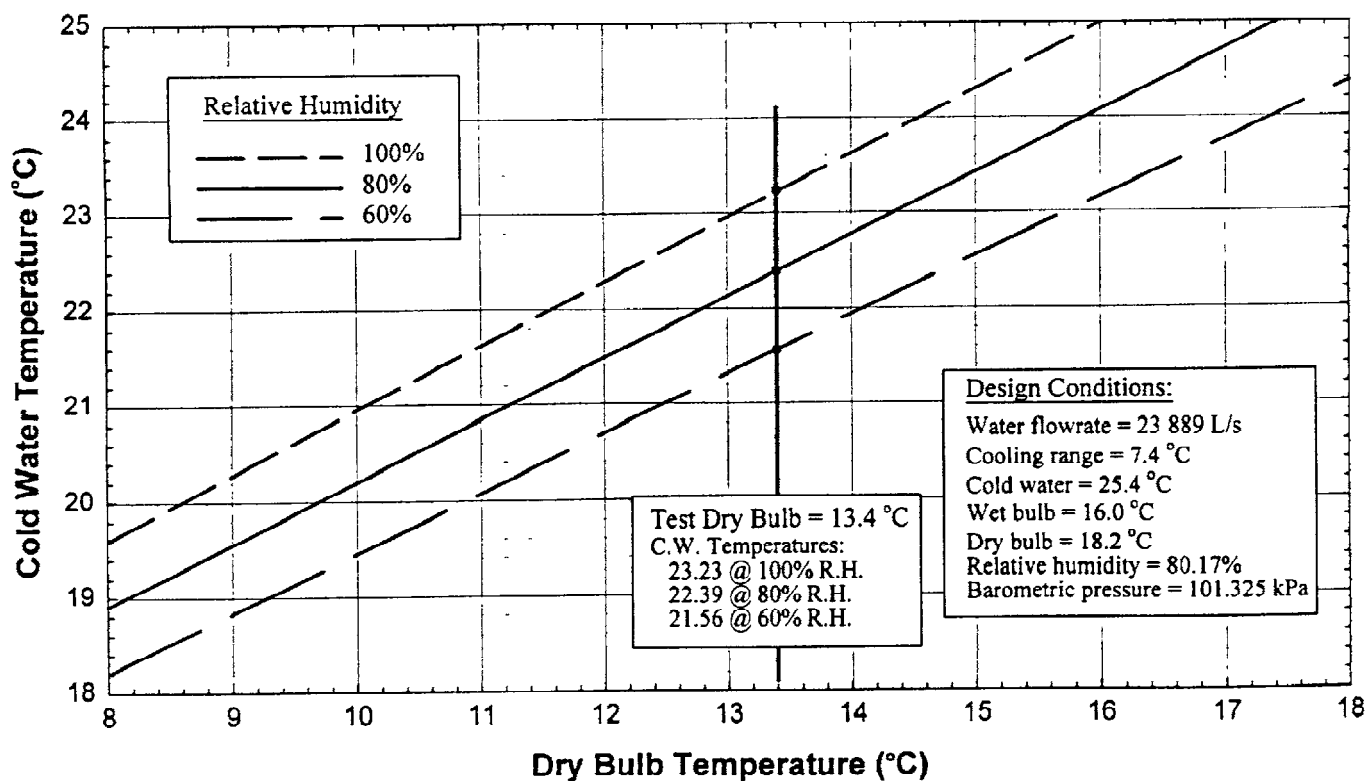


Figure E-7. Water Flow Rate = 26 278 L/s (110%) Range = 6.7 °C

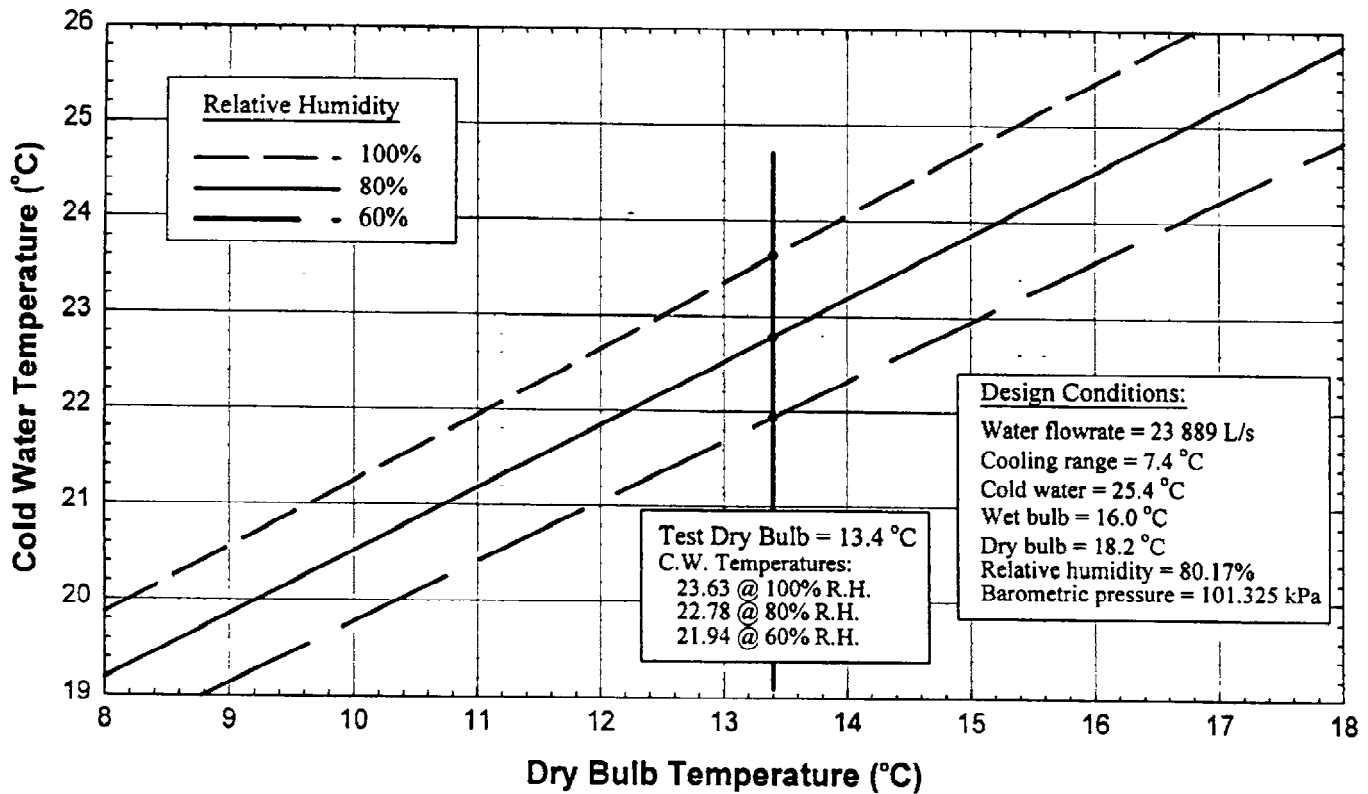


Figure E-8. Water Flow Rate = 26 278 L/s (110%) Range = 7.4 °C

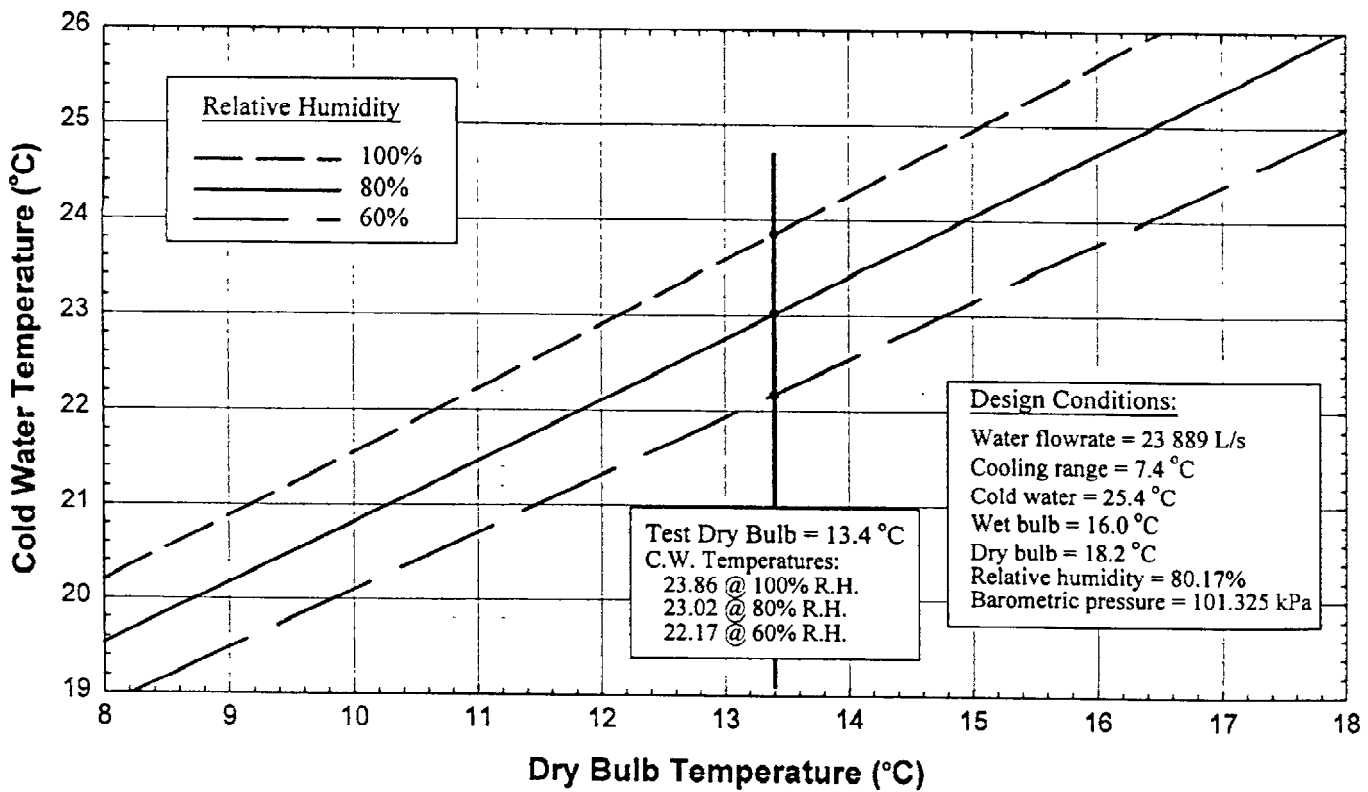


Figure E-9. Water Flow Rate = 26 278 L/s (110%) Range = 8.1 °C

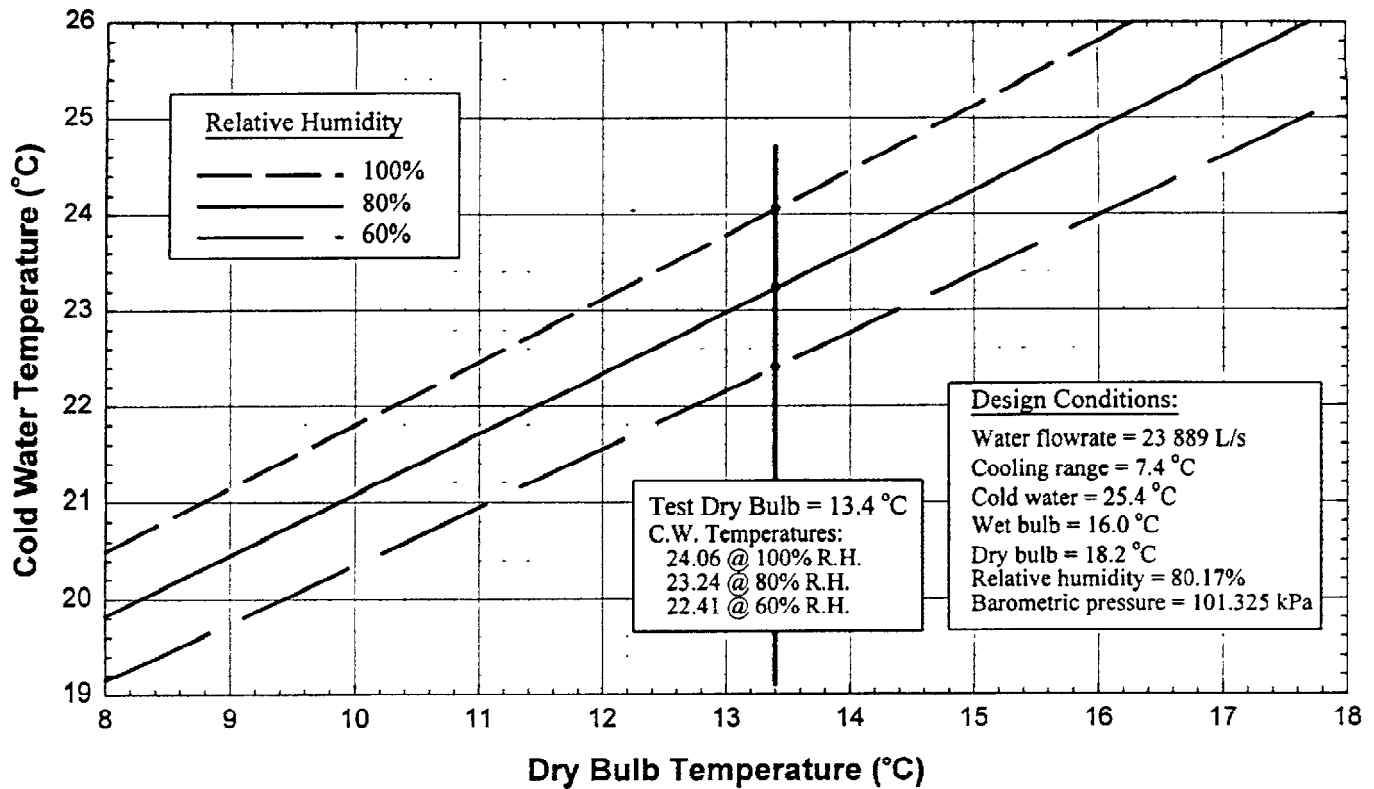


Figure E-10. Crossplot 1a.

Dry Bulb = 13.4 °C Water Flow Rate = 21 500 L/s (90%)

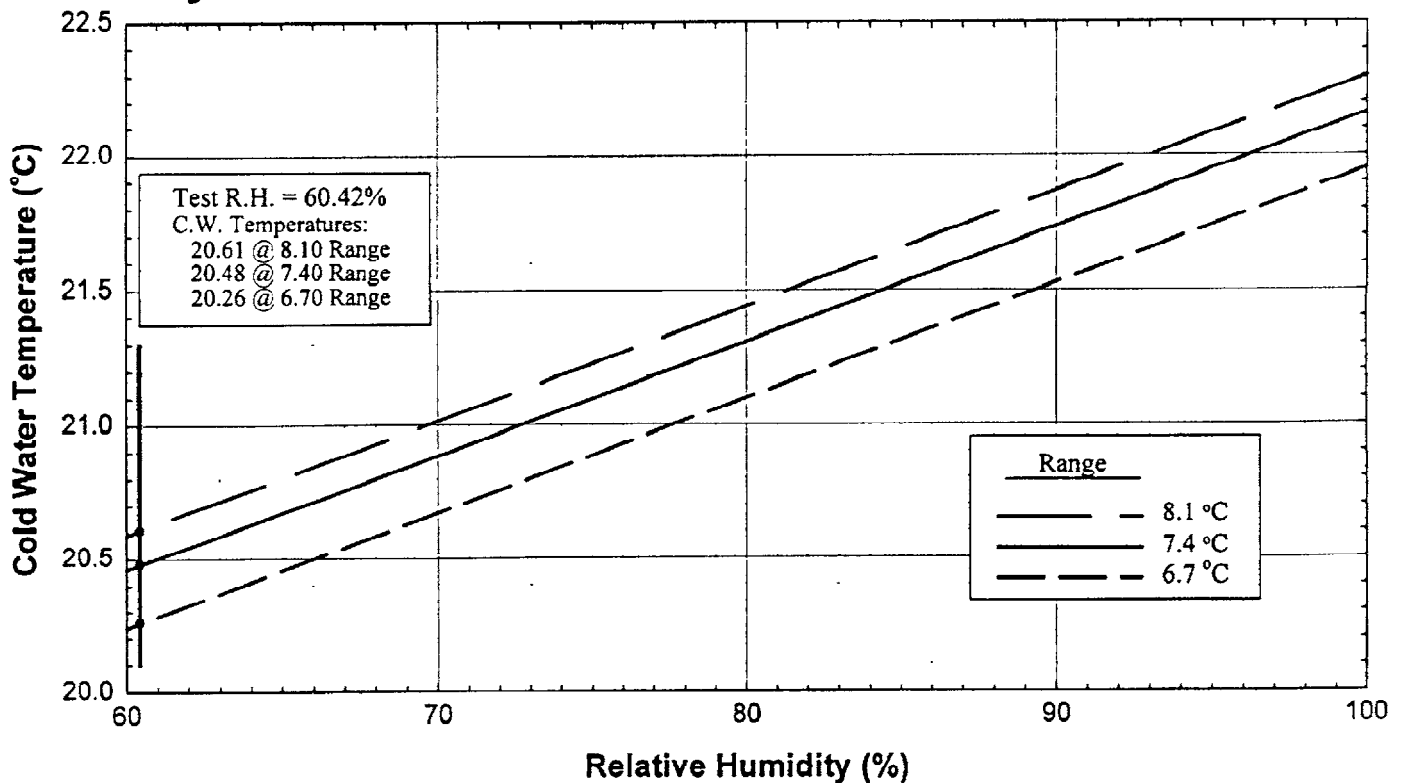


Figure E-11. Crossplot 1b.

Dry Bulb = 13.4 °C Water Flow Rate = 23 889 L/s (100%)

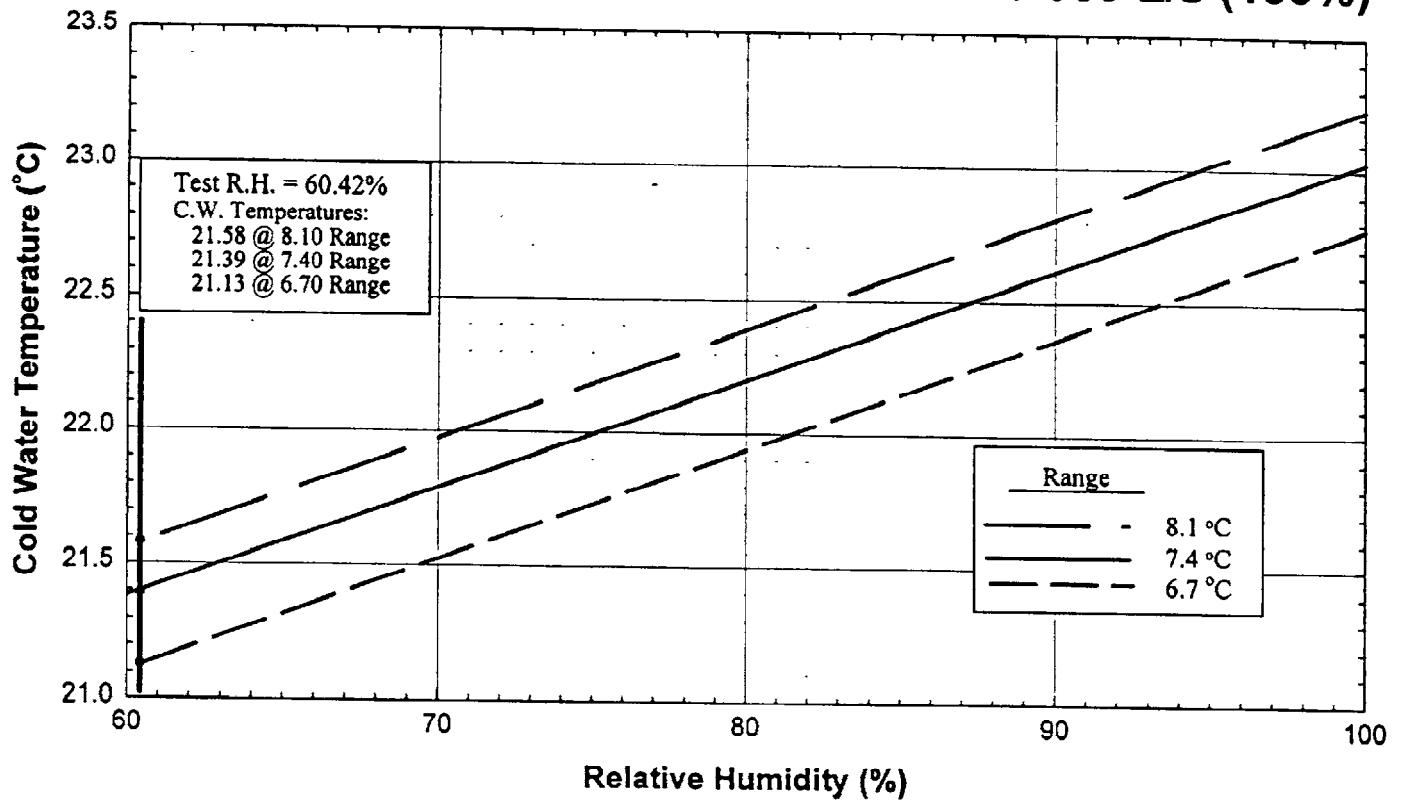


Figure E-12. Crossplot 1c.

Dry Bulb = 13.4 °C Water Flow Rate = 26 278 L/s (110%)

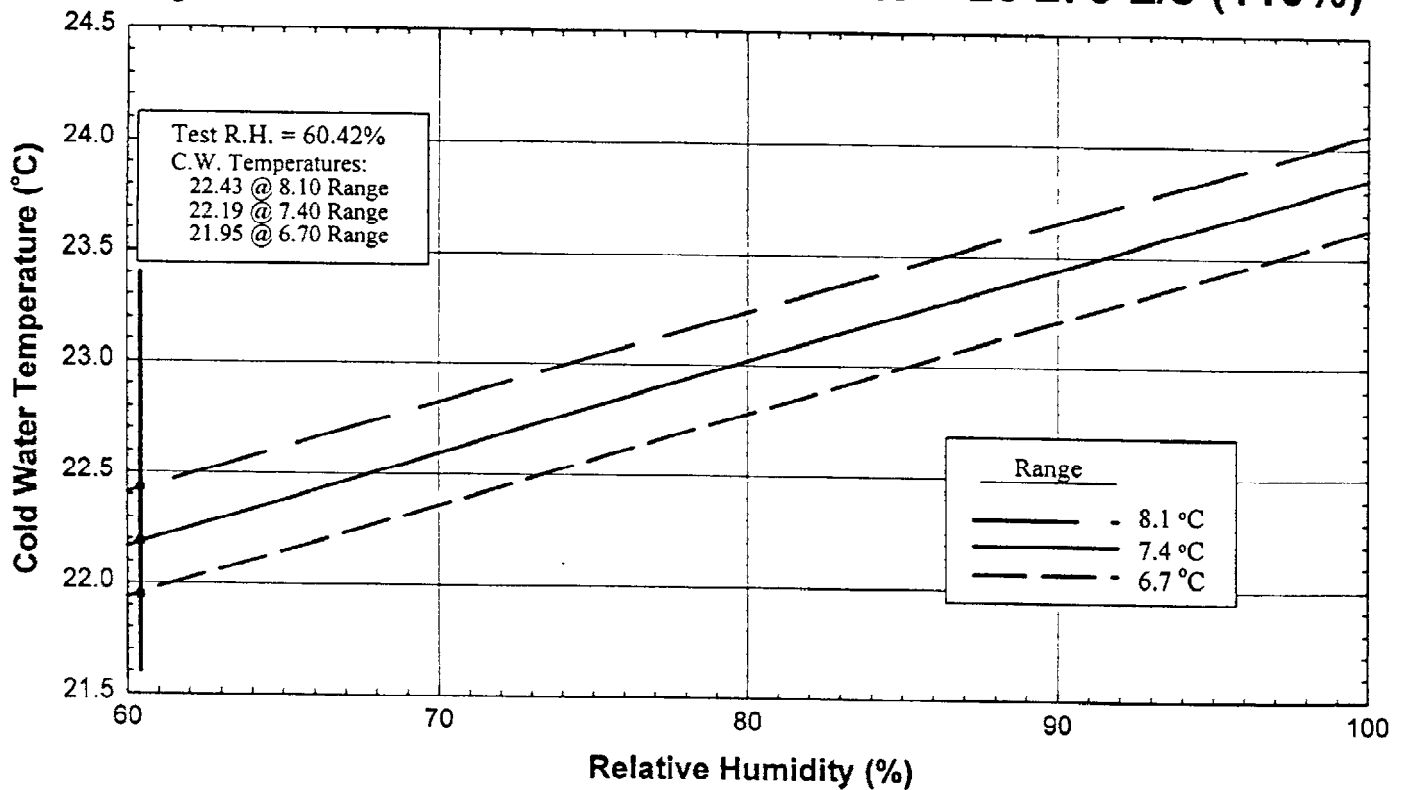


Figure E-13. Crossplot 2.
Dry Bulb = 13.4 °C Relative Humidity = 60.42%

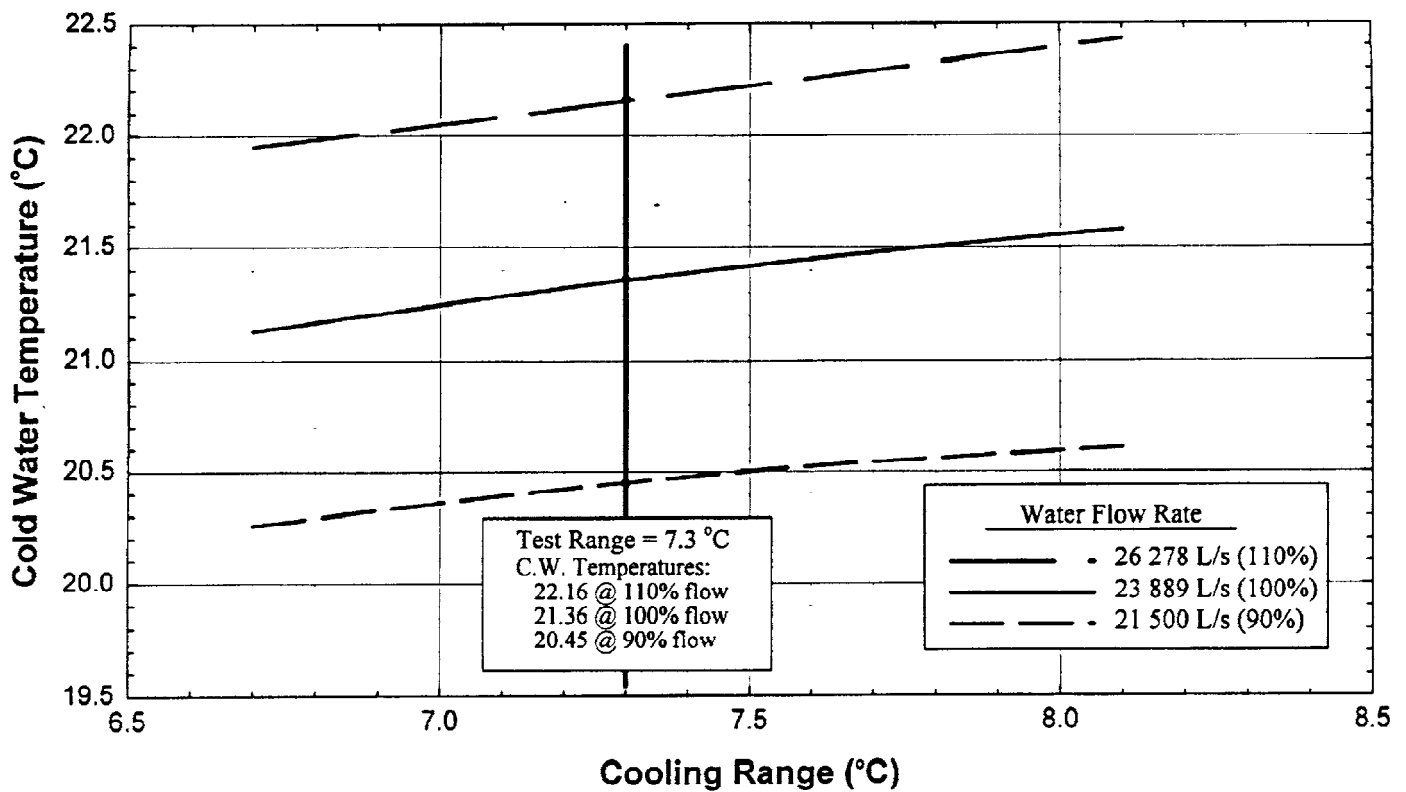
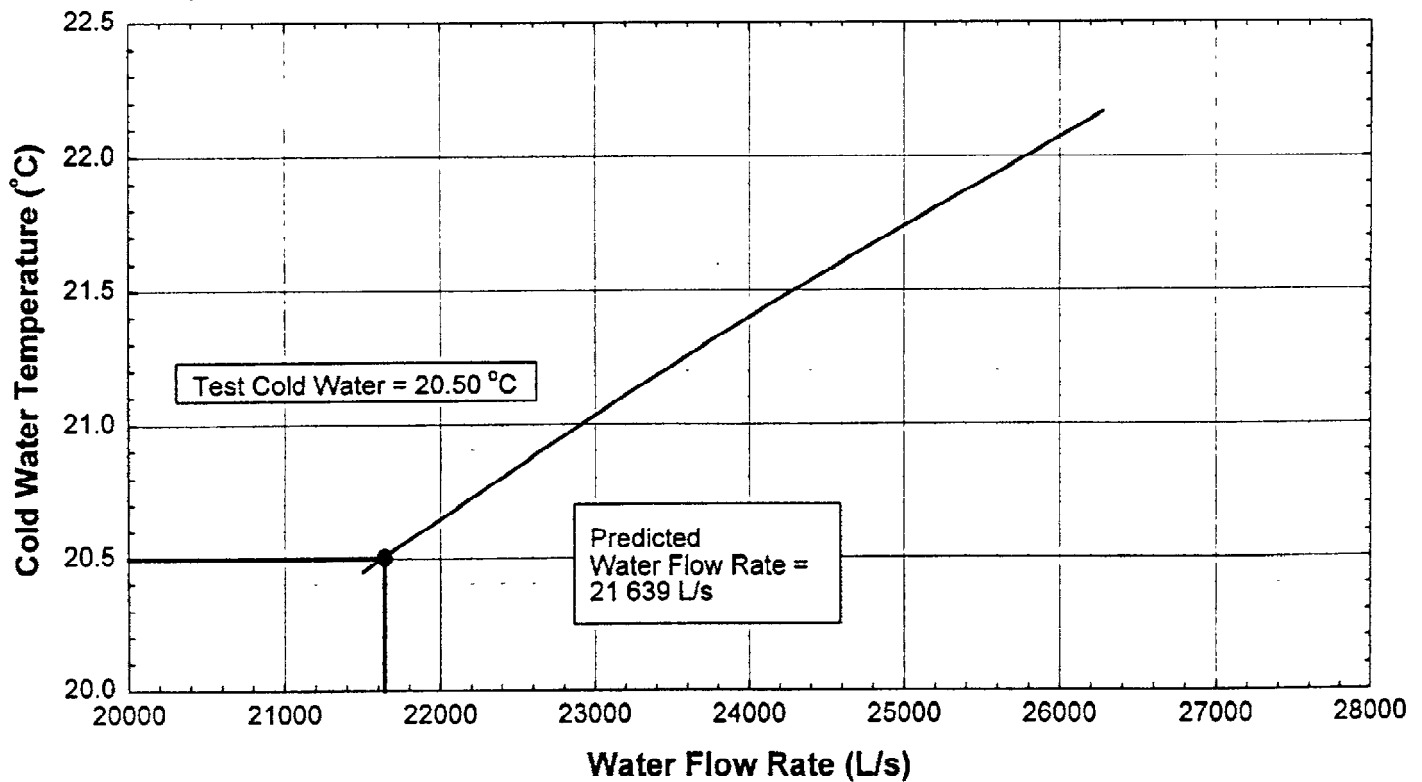


Figure E-14. Crossplot 3.
Dry Bulb = 13.4 °C Humidity = 60.42% Range = 7.3 °C



PART III — APPENDIX F

IP EXAMPLE EVALUATION OF NATURAL-DRAFT COOLING TOWER TEST
USING THE PERFORMANCE CURVE METHOD

Section F1. General

The purpose of this appendix is to describe and illustrate the performance curve methodology for evaluating a thermal performance test on a natural draft cooling tower, as described in Section 7 of the standard.

Section F2. Design and Test Conditions

The Design and measured Test Conditions for the natural draft cooling tower are summarized in Table F-1 below:

Table F-1. Natural Draft Cooling Tower Design and Test Data

	Design	Test
Water Flow Rate (W)	378,000 gpm	353,430 gpm
Hot Water Temp (Thw)	91.0 °F	82.04 °F
Cold Water Temp (Tcw)	77.7 °F	68.90 °F
Cooling Range (R)	13.3 °F	13.14 °F
Wet Bulb Temp (Twb)	60.8 °F	49.11 °F
Dry Bulb Temp (Tdb)	64.8 °F	56.12 °F
Barometric Pressure (Pbp)	29.921 inHg	30.570 inHg
Relative Humidity (RH)	79.955%	60.425%

In accordance with Paragraph 7.2 of this standard, the manufacturer has submitted Performance Curves presenting Cold Water Temperature as a function of the air Dry Bulb Temperature with the Relative Humidity of the air as a parameter (see Figures F-1 through F-9).

- F-1 to F-3 correspond to 90% of design water circulating rate;
- F-4 to F-6 correspond to 100% of design water circulating rate;
- F-7 to F-9 correspond to 110% of design water circulating rate.

Section F3. Evaluation Procedure

The five steps to be followed in evaluating the tower performance capability are as follows:

Step 1 - Determine the Predicted Cold Water Temperatures

Using the nine Performance Curves, three for each of the three water circulation rates, enter the curves at the test Dry Bulb Temperature (56.12°F) and determine the Cold Water Temperature for 60%, 80%, and 100% Relative Humidity at each Flow Rate and Range.

Table F-2. Predicted Cold Water Temperatures at 56.12°F
Entering Dry Bulb Temperature.

Flow	Range	60% RH	80% RH	100% RH
90%	12.0°F	68.44	69.97	71.51
	13.3°F	68.83	70.36	71.90
	14.6°F	69.07	70.60	72.13
100%	12.0°F	70.00	71.49	73.00
	13.3°F	70.48	71.97	73.45
	14.6°F	70.80	72.30	73.81
110%	12.0°F	71.48	73.01	74.53
	13.3°F	71.91	73.43	74.95
	14.6°F	72.34	73.82	75.32

Step 2 - First Crossplot

Then for each Flow Rate, prepare a crossplot of Cold Water Temperature as a function of the Relative Humidity, with the cooling Range as a parameter. (see figures F-10 through F-12).

Step 3 - Second Crossplot

Using these new curves, enter each at the Test Relative Humidity (60.42%) and determine the Cold Water Temperature for each Flow Rate and Range.

Table F-3. Predicted Cold Water Temperatures at 56.12°F
Entering Dry Bulb Temperature and 60.42% RH

Range	90% Flow	100% Flow	110% Flow
12.0°F	68.47	70.03	71.52
13.3°F	68.86	70.51	71.95
14.6°F	69.10	70.84	72.37

Then, for each Flow Rate, develop a crossplot of the Cold Water Temperature as a function of the cooling Range, (see Figure F-13).

Step 4 - Third Crossplot

Enter Figure F-13 at the Test Range (13.14°F) and determine the Cold Water Temperature for each of the three Flow Rates.

Table F-4. Predicted Cold Water Temperatures at 56.12°F
Entering Dry Bulb Temperature, 60.42% RH,
and 13.14°F Range.

90% Flow	100% Flow	110% Flow
68.81	70.45	71.89

Then crossplot the water Flow Rate as a function of the Cold Water Temperature (see Figure F-14).

Step 5 - Determine Predicted Flow Rate

Enter Fig F-14 at the Measured Cold Water Temperature (68.90°F) and from the intersection with the curve, determine the Predicted Water Flow Rate at the Test Cold Water Temperature as 342,224 gpm.

Step 6 - Determine Cooling Tower Capability

Using Equation 7.1, find the cooling tower Thermal Performance Capability as:

$$\% \text{Capability} = \left(\frac{353,430 \text{ gpm}}{342,224 \text{ gpm}} \right) \cdot (100) = 103.3\%$$

Figure F-1. Water Flow Rate = 340,200 gpm (90%) Range = 12.0 °F

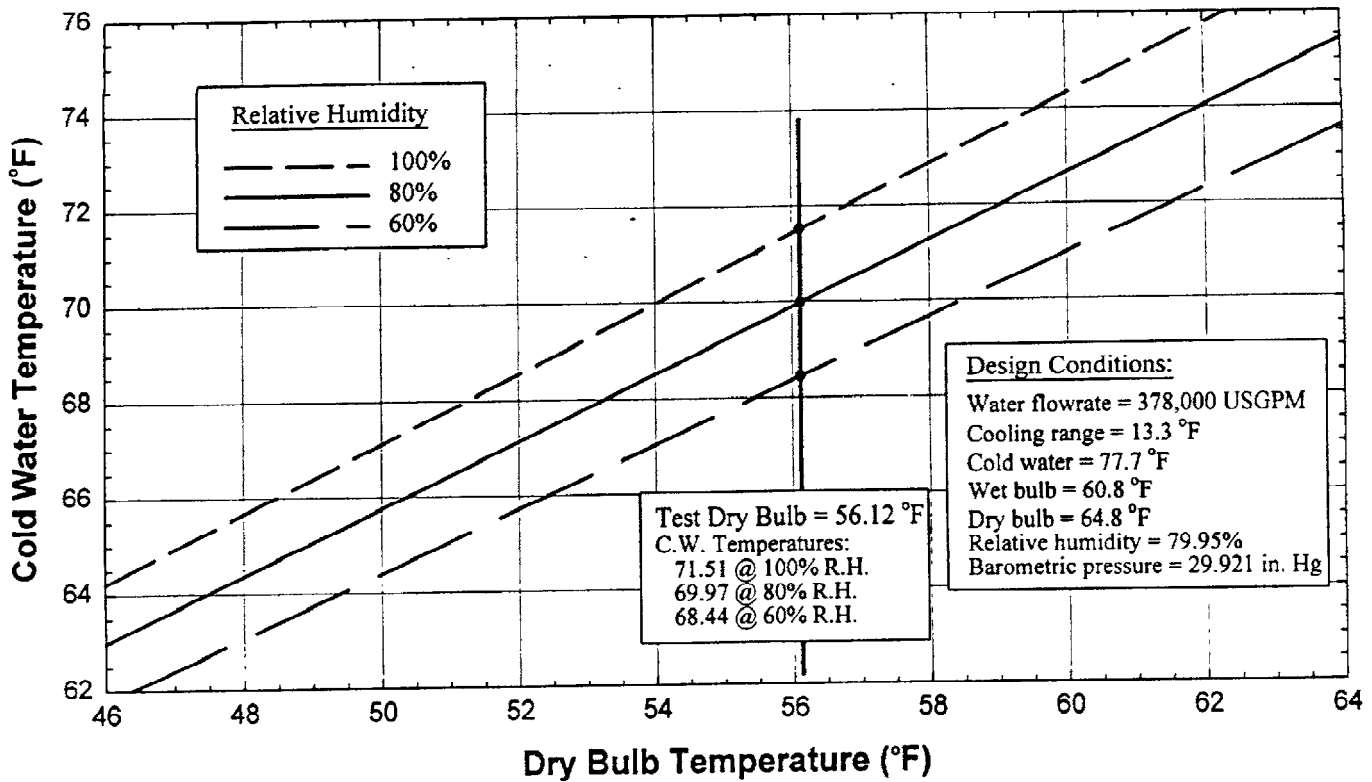


Figure F-2. Water Flow Rate = 340,200 gpm (90%) Range = 13.3 °F

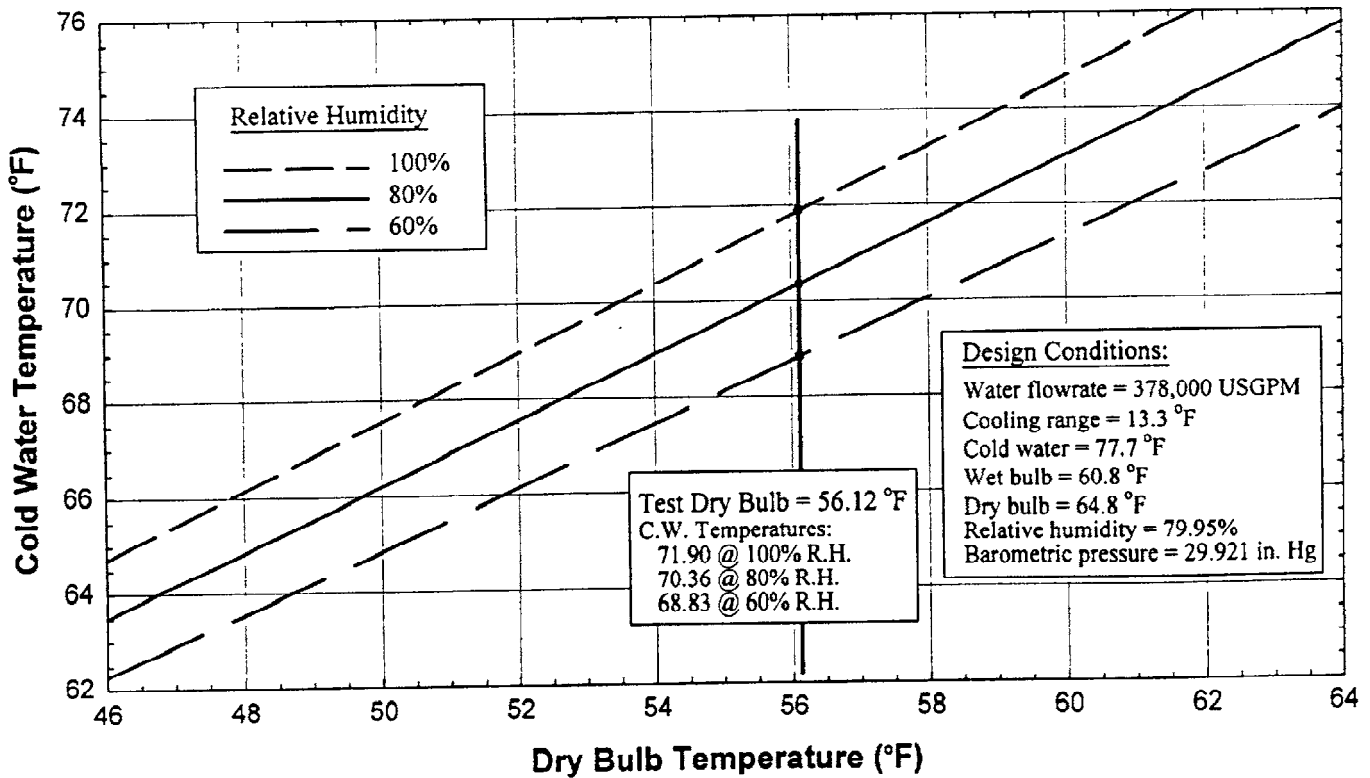


Figure F-3. Water Flow Rate = 340,200 gpm (90%) Range = 14.6 °F

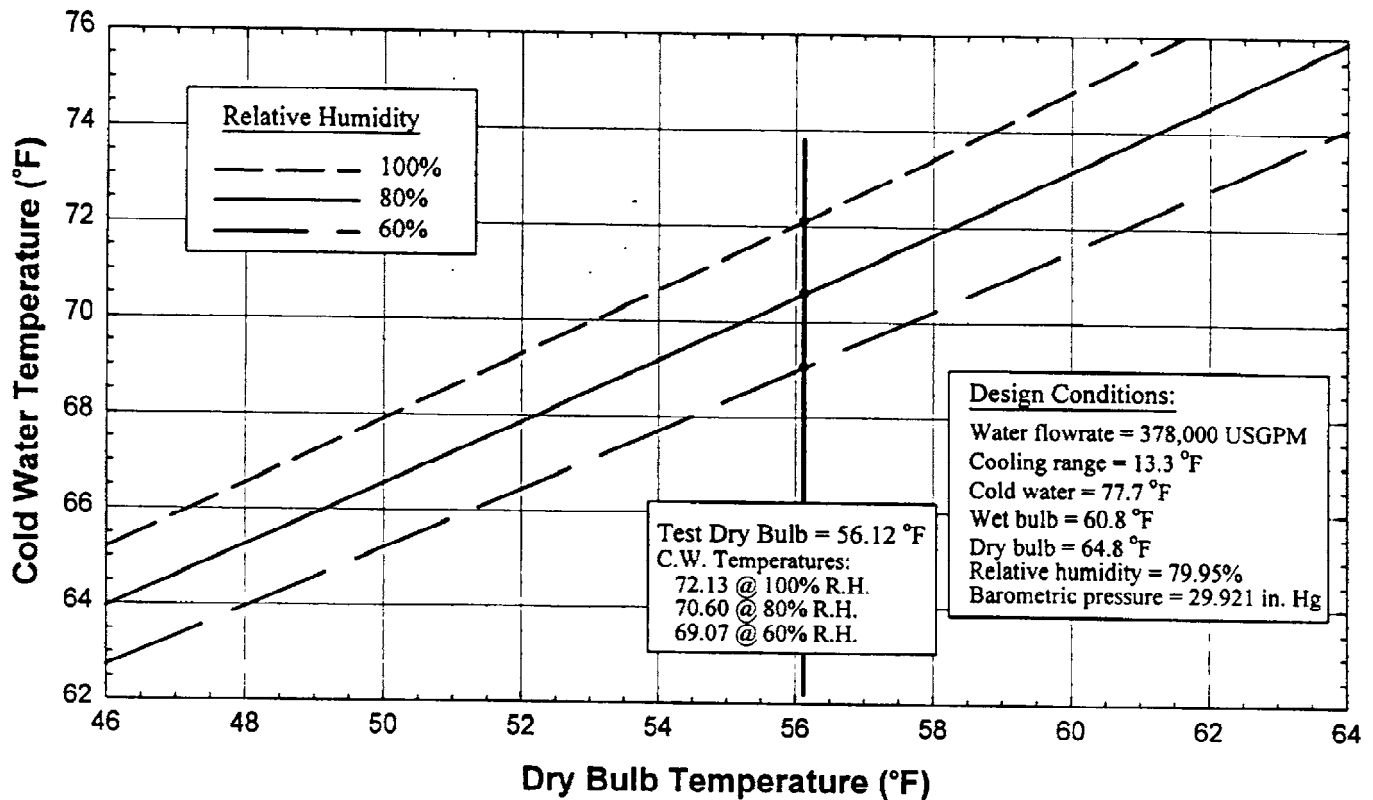


Figure F-4. Water Flow Rate = 378,000 gpm (100%) Range = 12.0 °F

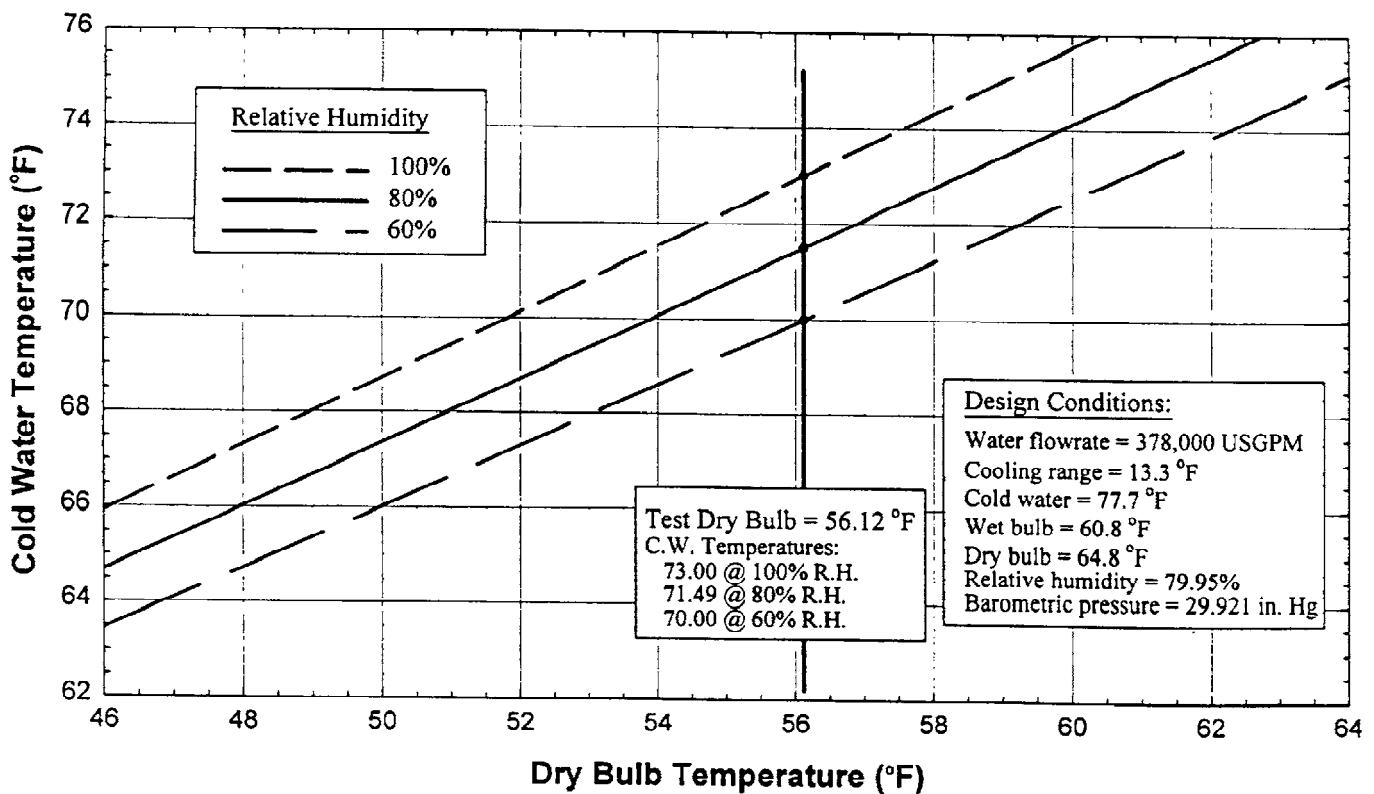


Figure F-5. Water Flow Rate = 378,000 gpm (100%) Range = 13.3 °F

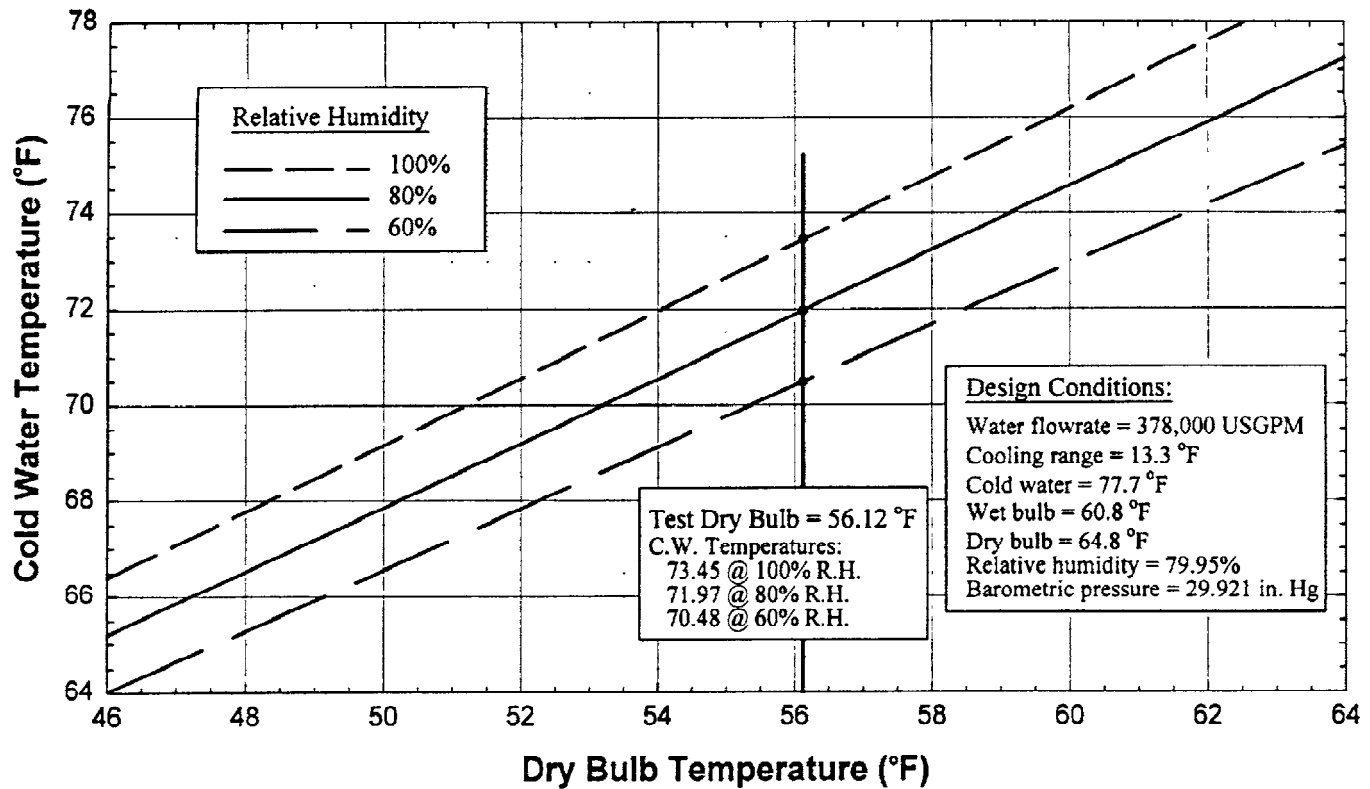


Figure F-6. Water Flow Rate = 378,000 gpm (100%) Range = 14.6 °F

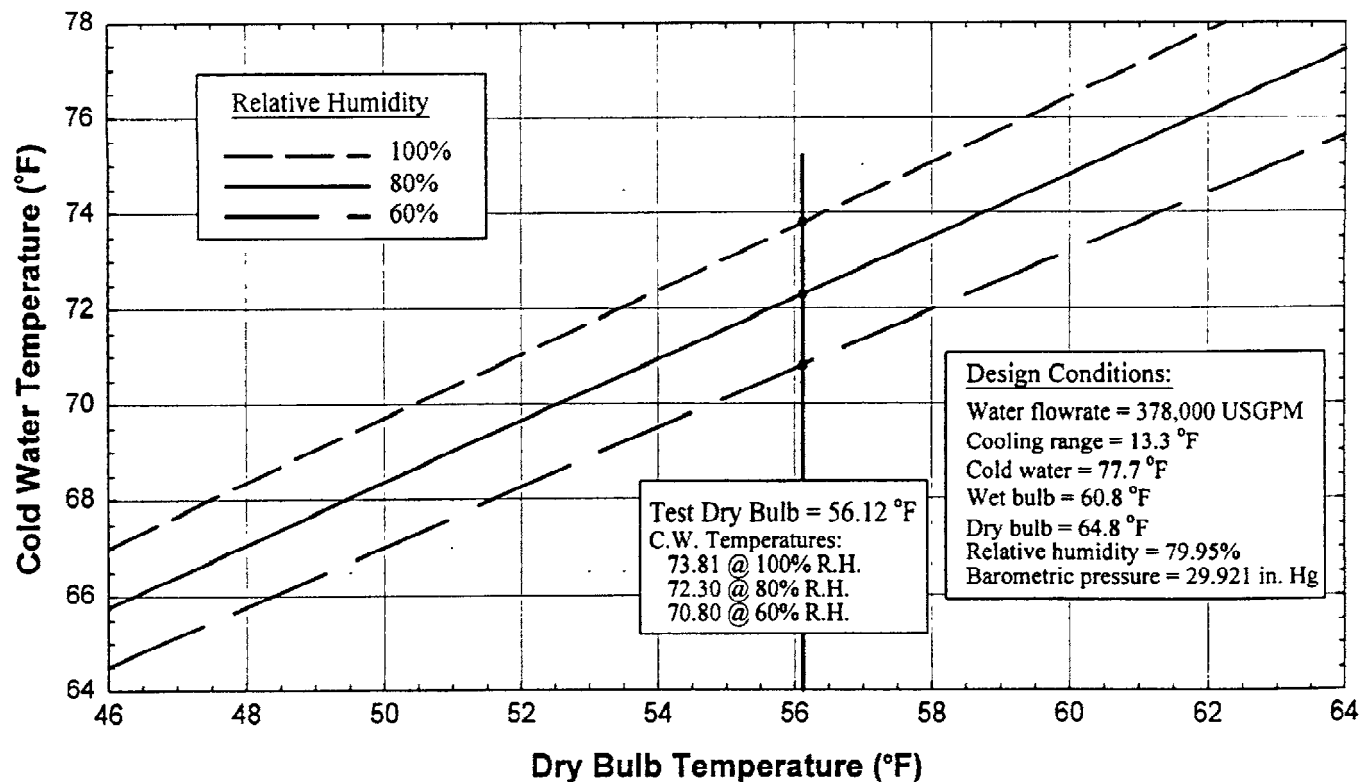


Figure F-7. Water Flow Rate = 415,800 gpm (110%) Range = 12.0 °F

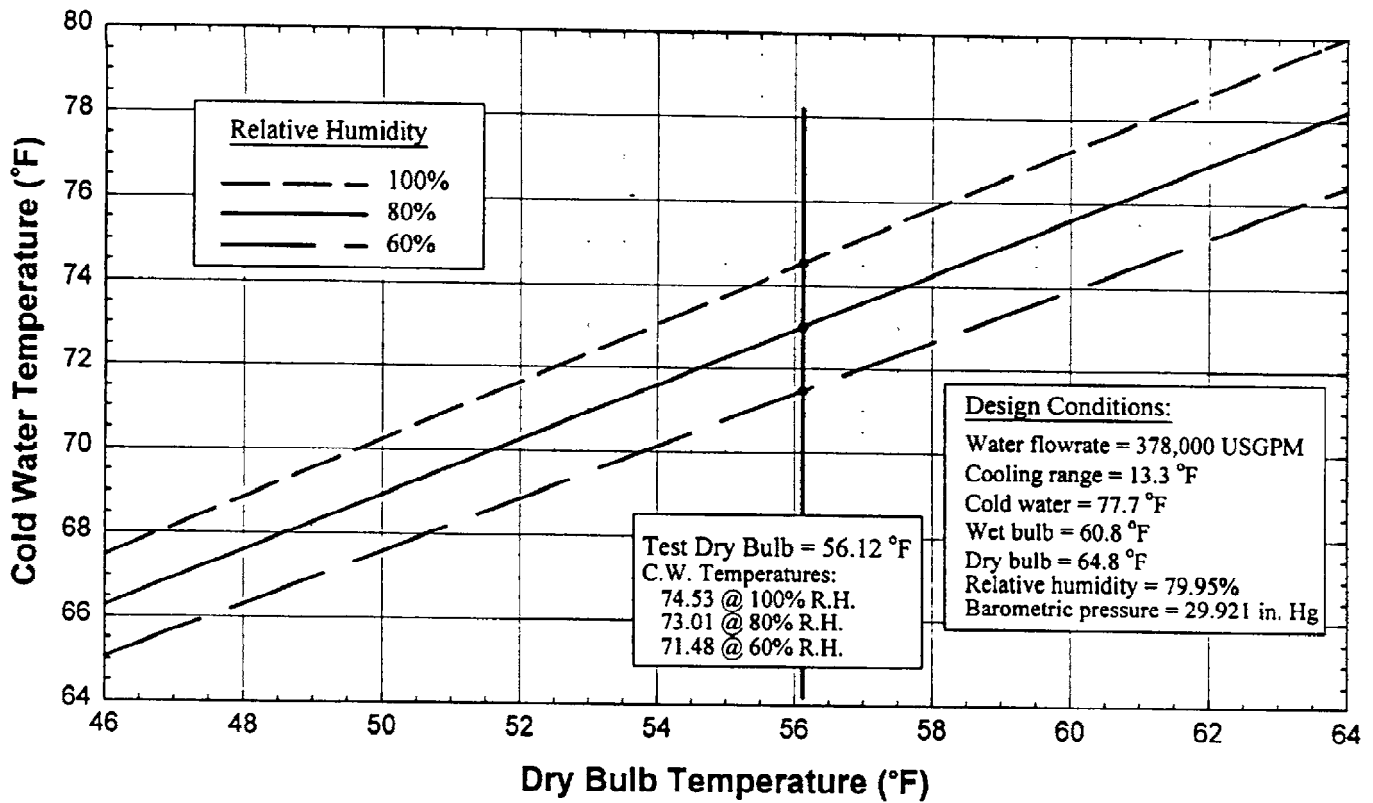


Figure F-8. Water Flow Rate = 415,800 gpm (110%) Range = 13.3 °F

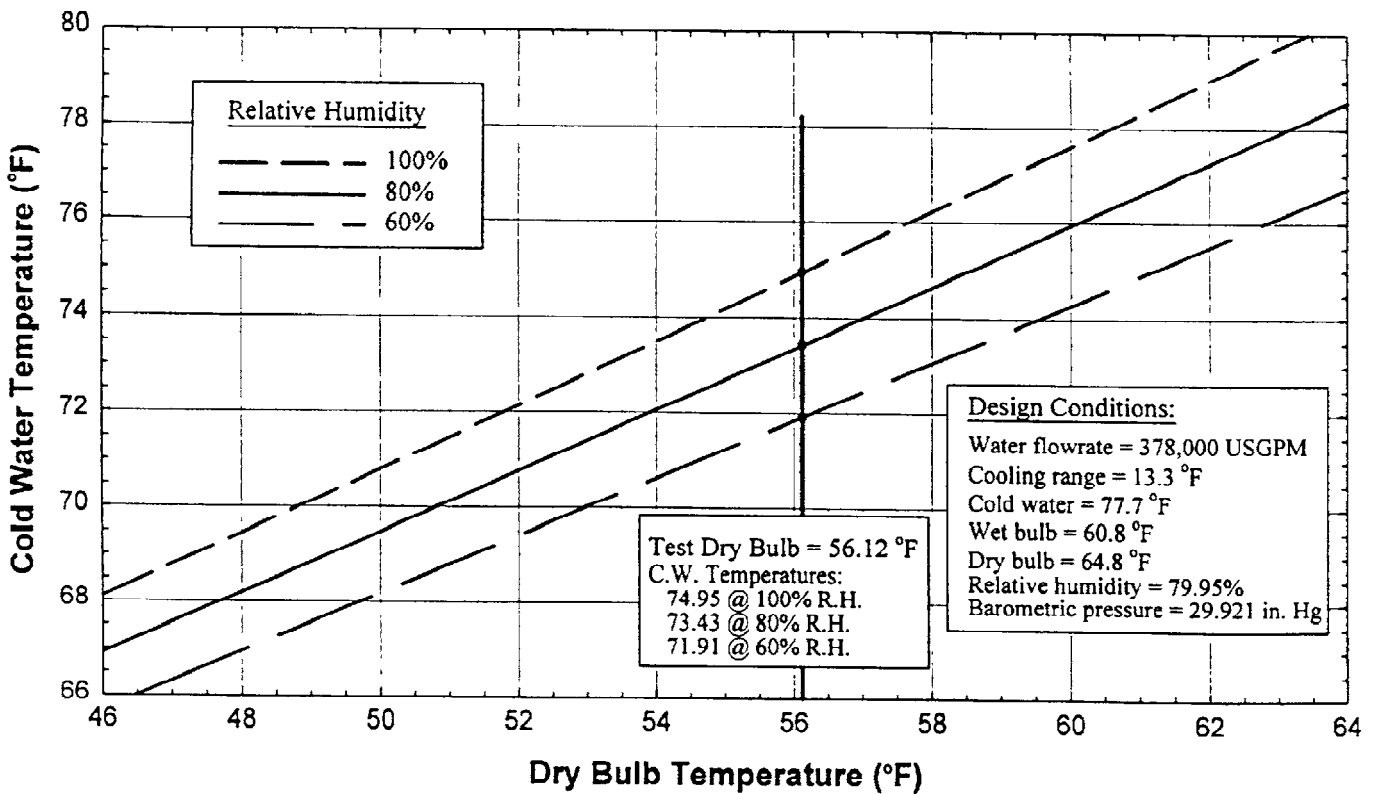


Figure F-9. Water Flow Rate = 415,800 gpm (110%) Range = 14.6 °F

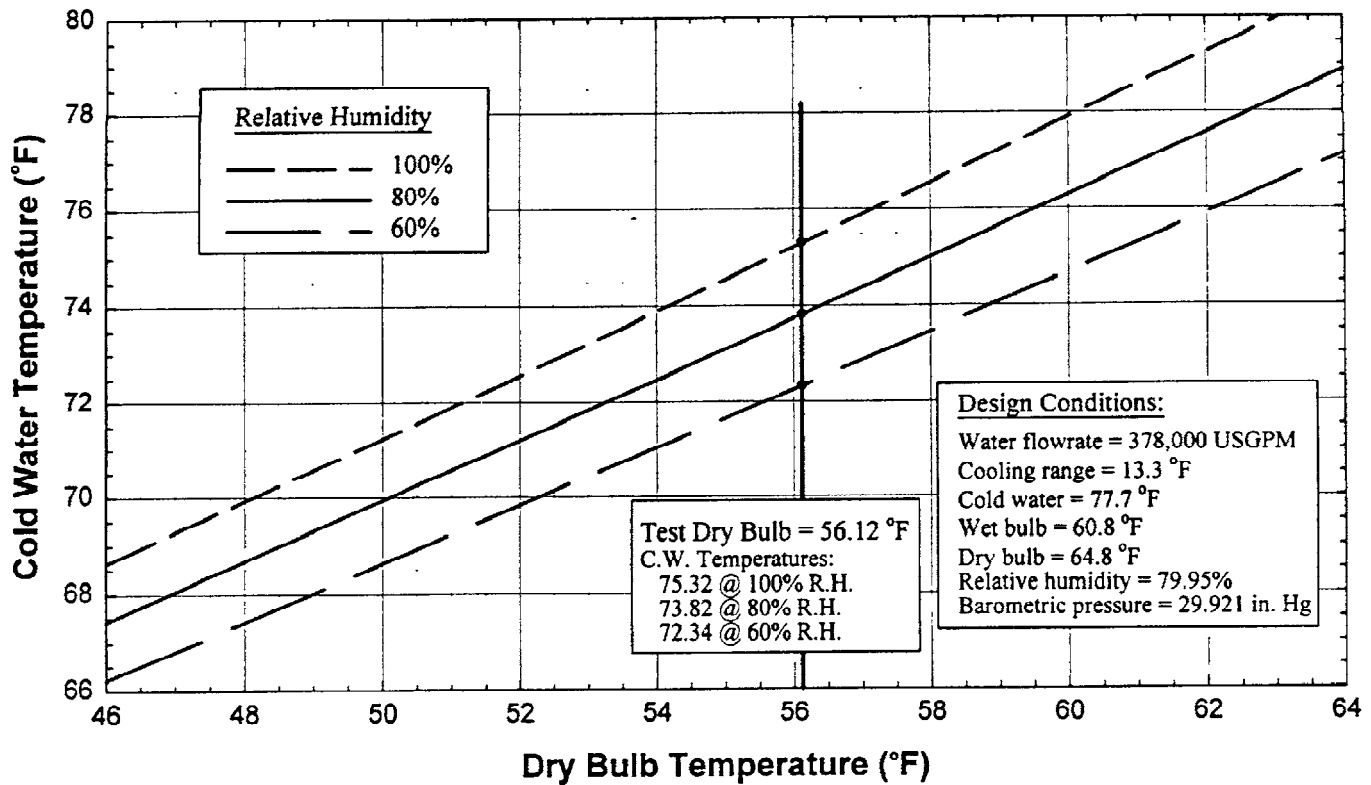


Figure F-10. Crossplot 1a.

Dry Bulb = 56.12 °F Water Flow Rate = 340,200 gpm (90%)

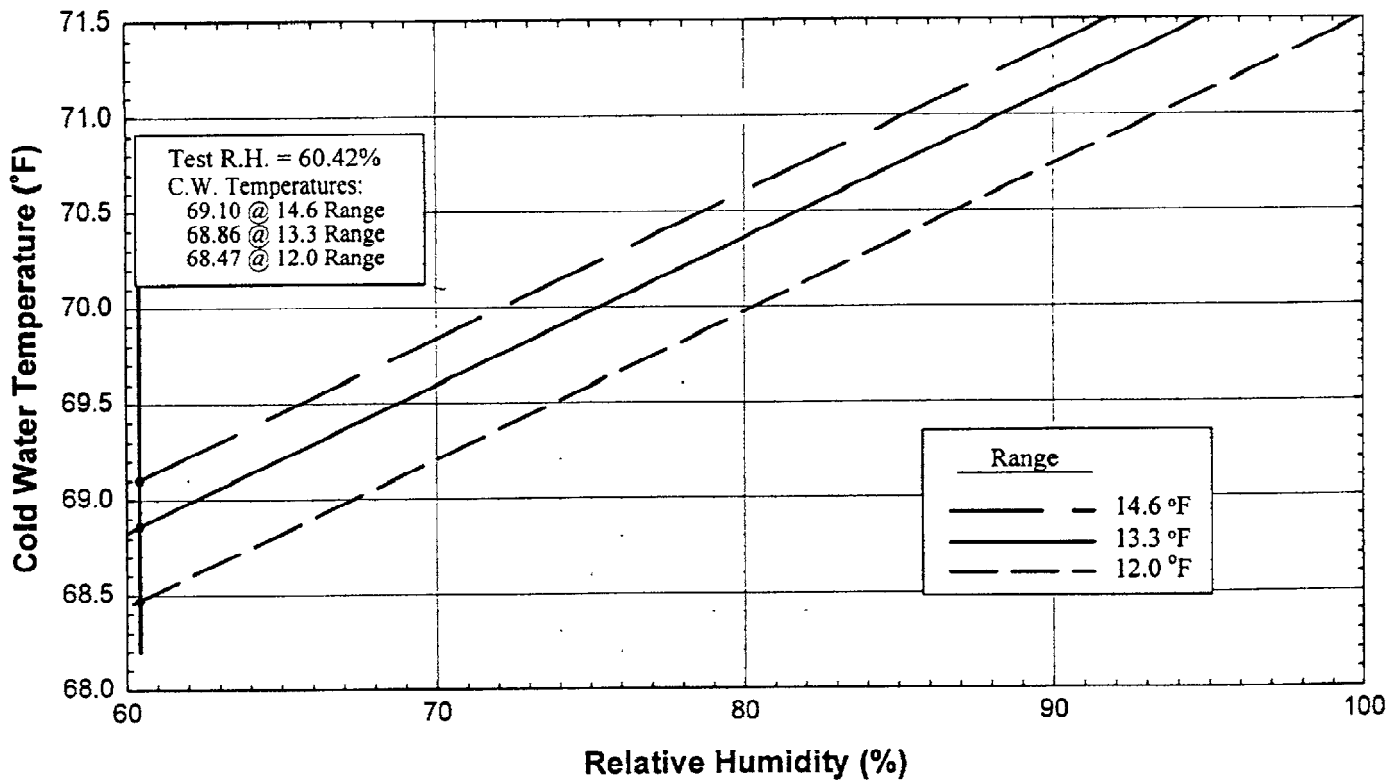


Figure F-11. Crossplot 1b.

Dry Bulb = 56.12 °F Water Flow Rate = 378,000 gpm (100%)

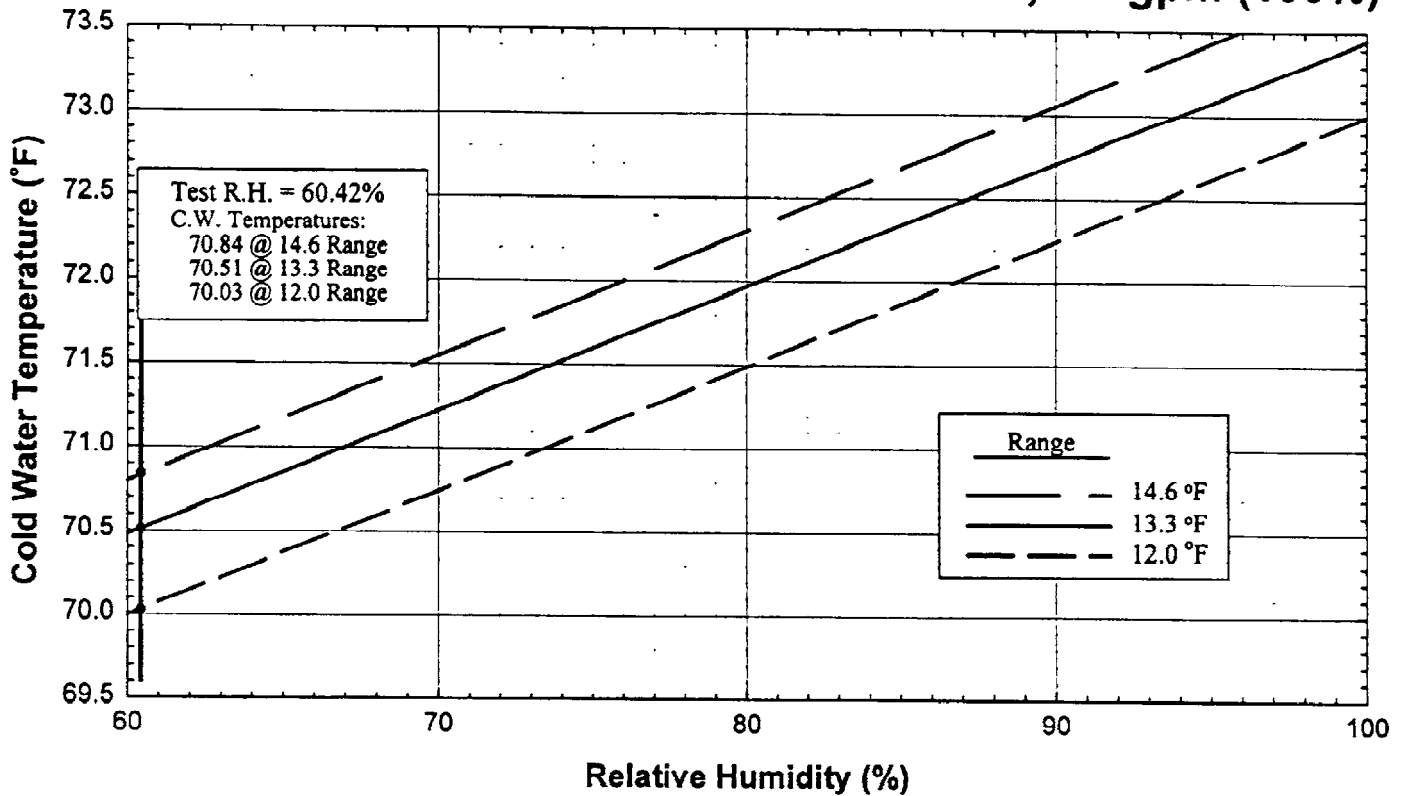


Figure F-12. Crossplot 1c.

Dry Bulb = 56.12°F Water Flow Rate = 415,800 gpm (110%)

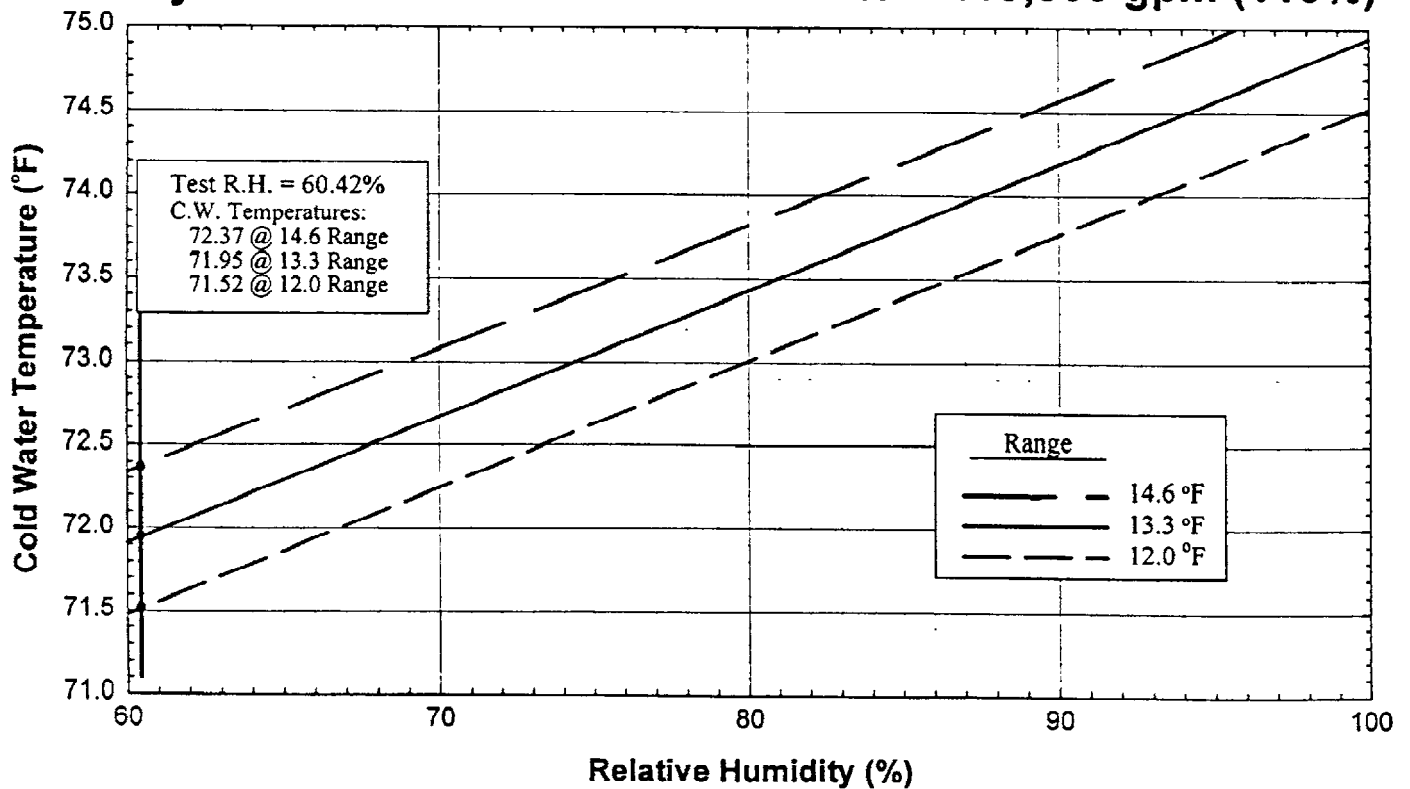


Figure F-13. Crossplot 2.
Dry Bulb = 56.12 °F Relative Humidity = 60.42%

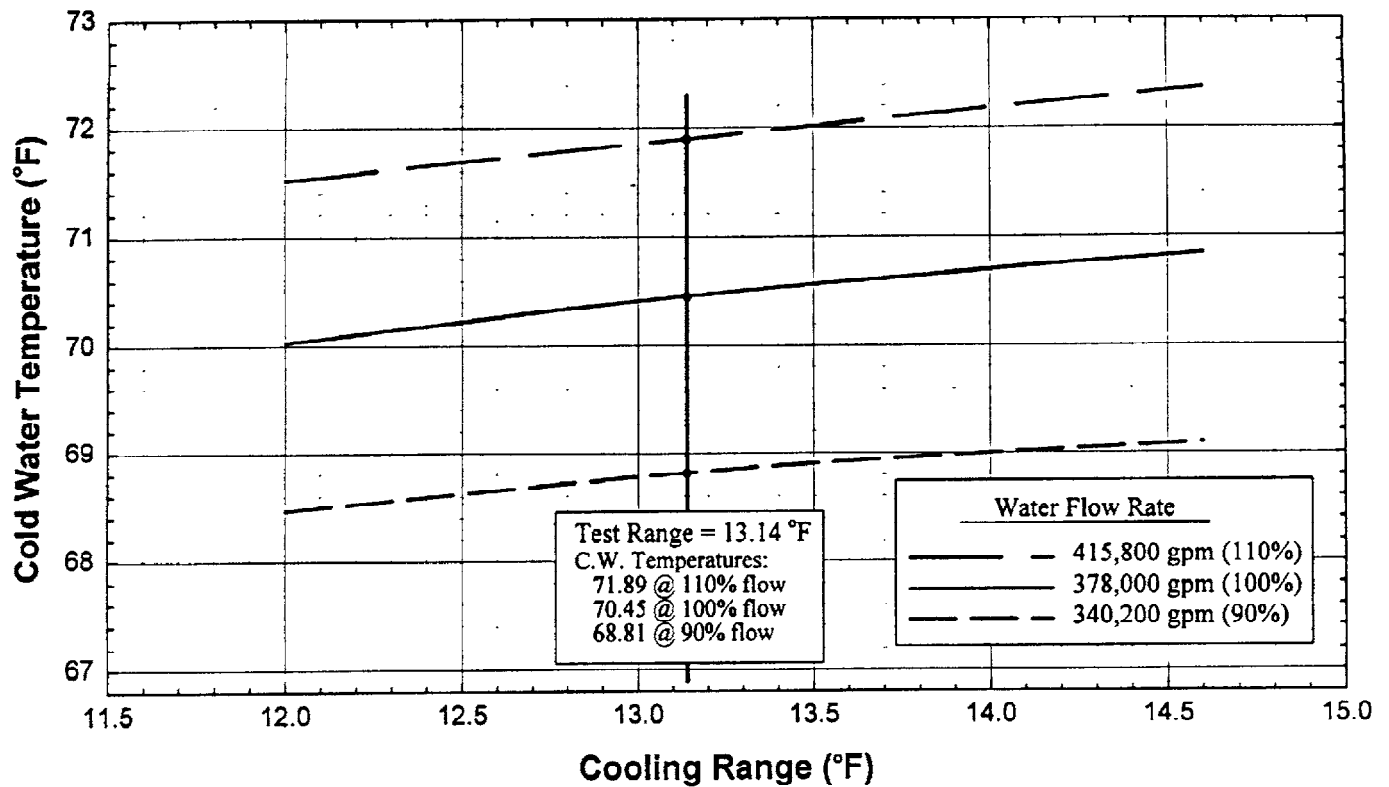
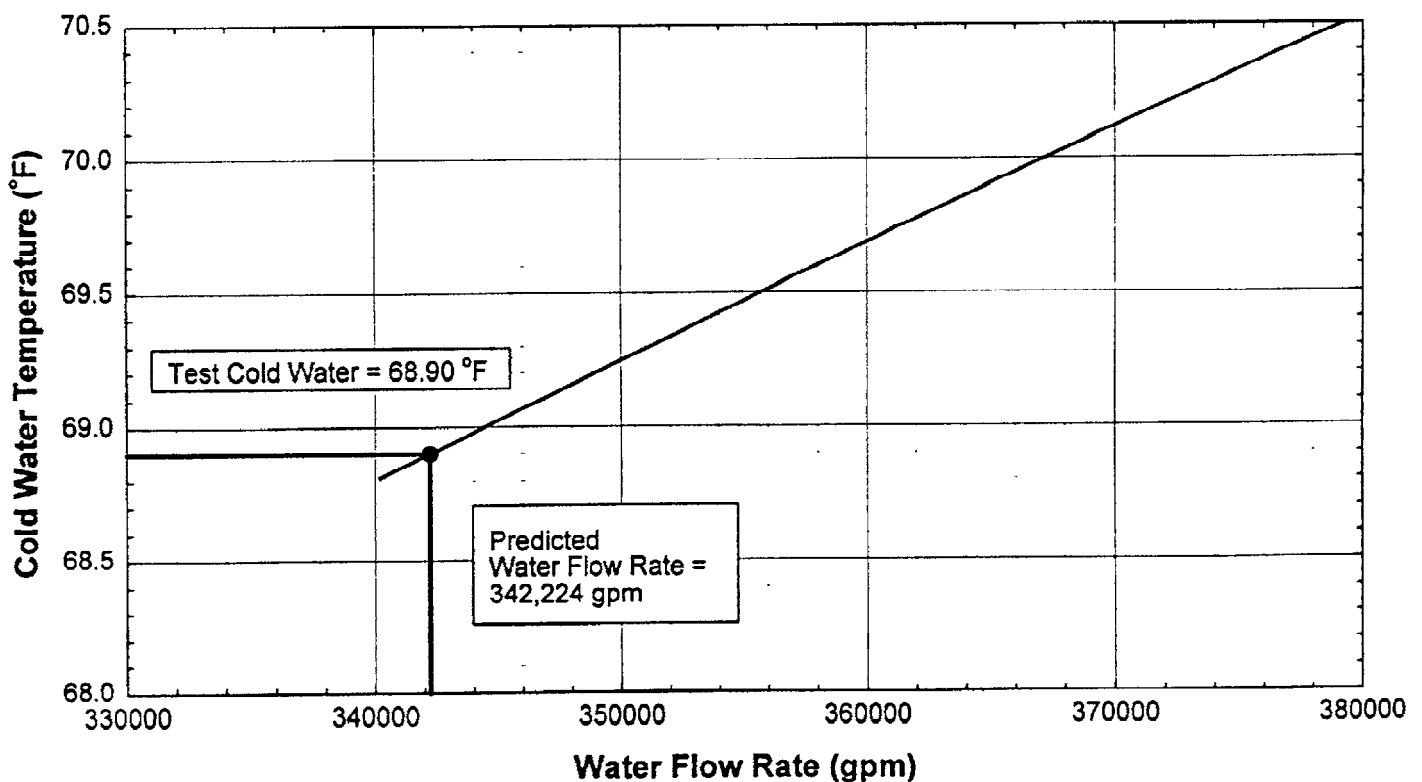


Figure F-14. Crossplot 3.
Dry Bulb = 56.12 °F Humidity = 60.42% Range = 13.14 °F



PART III — APPENDIX G

NUMBER AND LOCATION OF WET-BULB TEMPERATURE MEASUREMENT STATIONS

Section G1. General.

The purpose of this appendix is to prescribe the minimum number and location of wet bulb temperature measurement stations that will produce an acceptable, average inlet wet-bulb temperature for the test period.

Section G2. Recommended Number of Stations.

The minimum number of wet bulb temperature measurement stations are shown on Figures G-1 (SI) and G-2 (IP) which plot the number of stations as a function of the size of the air inlet area of concern.

Alternatively, the minimum number of stations may be calculated using the equation below and rounding all answers to the next higher whole number (e.g. if $n = 3.1$, use 4):

$$n = (K) (A)^{0.4}$$

Where:

n = the minimum number of stations

K = a constant to adjust for units of measure equal to 0.52 for SI and 0.20 for IP.

A = the inlet area of concern, m^2 (ft^2)

NOTE: The "inlet area of concern" applies to each *individual* area, rather than the total area. Thus when determining the number of stations for an induced-draft cooling tower having louvered inlet faces 4 m high by 35 m long on both longitudinal sides, the area "A" of each "area of concern" would be $4 \times 35 = 140 m^2$ and the recommended minimum number of stations per side would be 4 (8 total for the tower).

Both the graph and the equation assume both the air velocity and the temperatures are distributed uniformly (or nearly so) over the "inlet area of concern." A pre-test survey shall be conducted by the CTI Test Agency to confirm this assumption or detect any unusual conditions (see Paragraph G3).

Section G3. Location of Stations.

The area of concern shall be divided into equal area rectangles with measurement stations located at the geometric center of each rectangle, unless the pre-test survey reveals an unusual condition suggesting some other arrangement. In such instances, the Purchaser and the Manufacturer in consultation with the CTI Test Agency shall agree on the alternative locations.

The concentration of any recirculating air is normally greater at the top of the air intakes than at the bottom, particularly for crossflow or other tower types in which the distance between the exhaust plane and the top of the air inlet is relatively short. To ensure detection and measurement of such gradients, multiple vertical stations should be employed.

Section G4. Air Velocity Effects.

If either **air velocity** or **wet-bulb temperature** is uniform throughout the inlet area of consideration, it will not be necessary to weight

the wet-bulb temperatures.

In extreme cases, however, both **air velocity** and **wet-bulb temperature** may exhibit unacceptable variations for an extended period of time. If contractual agreement or other reasons prevent postponement of the test, sufficient measurements of the air velocity at each measurement station should be made and the measured test values of wet bulb temperature weighted in proportion the velocity distribution to obtain an acceptable average inlet wet-bulb temperature.

Section G5. Example Situations.

G5.1 Examples in SI Units

G5.1.1 Example #1 The tower to be tested is a counterflow type, with louvered air intakes measuring 2 m high by 60 m long along each side. The area of concern for each intake is $2m \times 60m = 120 m^2$. From Figure G-1 determine the recommended minimum number of stations per intake is four.

Alternatively, using the equation yields the same number:

$$n = 0.52 (120)^{0.4} = 3.5, \therefore \text{use } 4$$

Therefore, each intake should be divided into four imaginary rectangles, each measuring 2 m high by 15 m long with one wet-bulb measurement station located at the center-point of each rectangle.

G5.1.2 Example #2 The tower to be tested is a double flow crossflow type, with louvered intakes measuring 12 m high by 30 m long along the two side opposing sides. The area of each intake is $12m \times 30m = 360 m^2$. From the graph or equation, the recommended minimum number of stations per intake side is six.

These six stations/face could be arranged into six equal area rectangles measuring 6 m high by 10 m long. However, the preferred arrangement would be six rectangles measuring 3 m high by 15 m long to better monitor for a possible vertical temperature gradient.

G5.2 Examples in IP Units.

G5.2.1 Example #1 The tower to be tested is an induced draft, counterflow tower having louvered air inlets on both longitudinal sides measuring 12 feet high by 120 feet long. The area A_{ft^2} would be $12 ft. \times 120 ft. = 1,440$ square feet per individual area. Referring to Figure G-2, the recommended minimum number of stations per side would be 4 (8 total for the tower). Alternatively, using the equation:

$$n = 0.20 (1,440)^{0.4} = 3.7, \therefore \text{use } 4$$

G5.2.2 Example #2 Assume the tower to be tested is a counterflow type, with louvered air intakes along each side, each measuring 8 feet high by 180 feet long. The area of each intake is 1,440 square feet. From Figure G-2, the recommended minimum number of stations per intake is four. The equation

would yield approximately the same number:

$$n = 0.2 (1,440)^{0.4} = 3.7$$

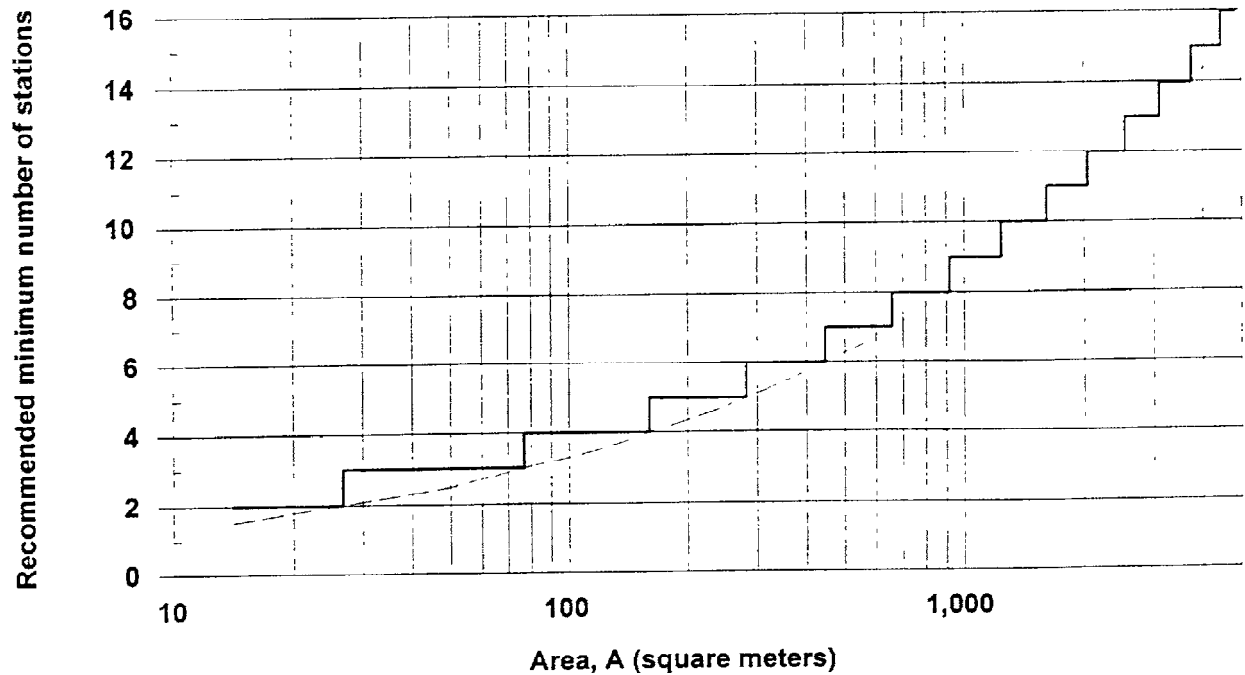
Therefore, each intake should be divided into four imaginary rectangles, each measuring 8 feet high by 45 feet long, and one wet-bulb measurement station located at the mid-point of each rectangle.

G5.2.3 Example #3 Assume the tower to be tested is a double flow crossflow type, with louvered intakes along the two op-

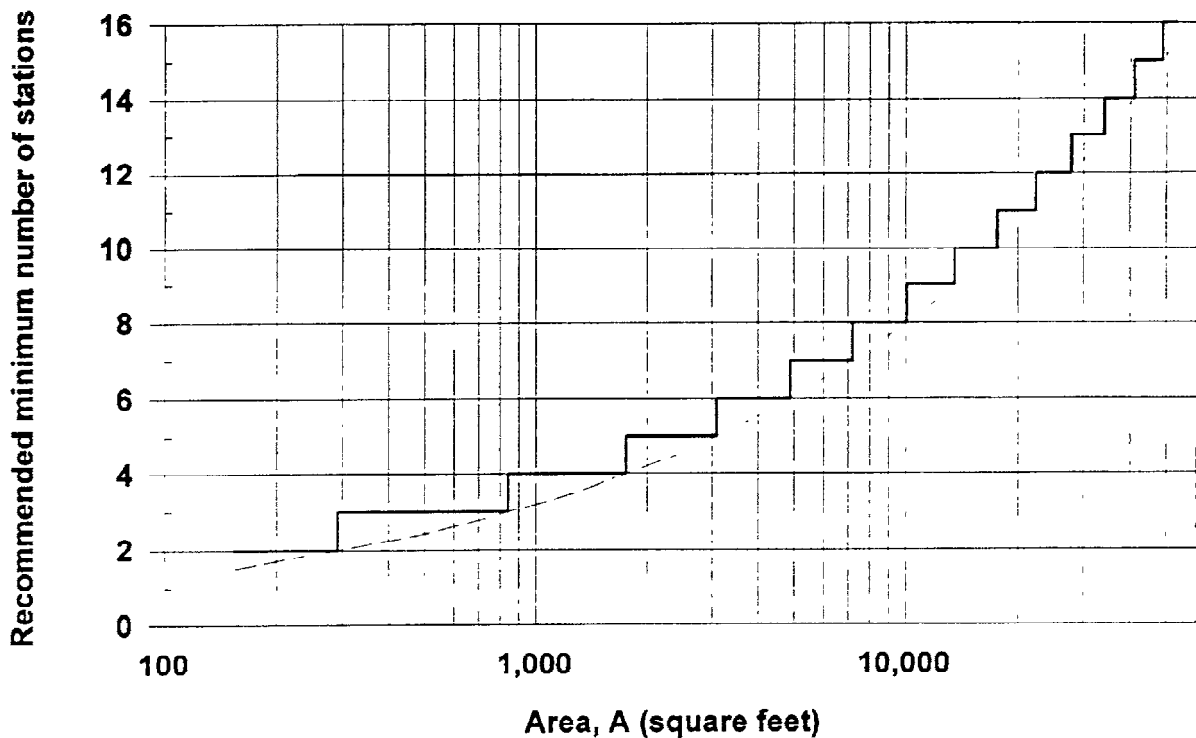
posing sides, each measuring 36 feet high by 96 feet long. The area of each intake is 3,456 square feet. From the graph or equation, the recommended minimum number of stations per intake is six.

Each inlet face could be divided into six rectangles, each measuring 18 ft high by 32 ft long. However, the preferred arrangement would be six rectangles, each measuring 12 ft high by 48 ft long to better monitor for a possible vertical temperature gradient.

G-1 NUMBER OF WET-BULB TEMPERATURE MEASUREMENT STATIONS



G-2 NUMBER OF WET-BULB TEMPERATURE MEASUREMENT STATIONS



PART III — APPENDIX H

PSYCHROMETRICS

This appendix is provided as a service to the users of ATC-105 to provide reliable psychrometric data, fully consistent with ASHRAE data, for use in evaluating the performance of Cooling Towers. The data are provided in two forms, the computer program listing in "BASIC" (below) and tabular values.

```
'
      CTIPSYCH program v3.5      RSB 1/30/97
' This is CTI implementation of ATC-105 psychrometrics
' The program follows ASHRAE 1989 Fundamentals
' Implementation of the psychrometric properties of moist air. It assumes
' ideal gas laws modified by experimental factor Fs. The Fs table has
' an improved curve fit from Hyland-Wexler values by RHH (1-97).
' Major modifications to separate SI property functions and calculate
' all SI properties explicitly according to 1993 ASHRAE equations.
' SI formulation still uses RHH Fs fit (IP units). All other values
' strictly ASHRAE 1993 SI.
```

DEF FNFs (t, P)

```
' NEW IMPROVED FS Enhancement Factor 0-200 deg F - RHH 1-19-97
C1 = 1.000119
C2 = 9.184907E-06
C3 = 1.286098E-11
C4 = -1.593274E-13
C5 = 2.872637E-04
C6 = -1.618048E-06
C7 = 1.467535E-08
C8 = 2.41896E-12
C9 = -1.371762E-10
C10 = -8.565893E-10
C11 = 1.229524E-10
C12 = -2.336628E-11
FS1# = C1 + C2 * t + C3 * t ^ 4 + C4 * t ^ 5 + C5 * P + C6 * P * t
FS1# = FS1# + C7 * P * t ^ 2 + C8 * P * t ^ 4 + C9 * t * P ^ 4
FNFs = FS1# + C10 * t ^ 2 * P ^ 2 + C11 * t ^ 2 * P ^ 3 + C12 * P ^ 2 * t ^ 3
END DEF
```

**** Function calculates IP Vapor pressure of Water Vapor (-148° to 392°) ****

DEF FNIPPws (tair!)

'Calculate saturation pressure at t!

IF tair! >= 32 THEN

C8 = -10440.39708#

C9 = -11.2946496#

C10 = -.027022355#

C11 = .00001289036#

C12 = -.000000002478068#

C13 = 6.5459673#

t = tair! + 459.67

LnPws = C8 / t + C9 + C10 * t + C11 * t * t + C12 * t * t * t + C13 * LOG(t)

FNIPPws = EXP(LnPws) 'ASHRAE Eq.(4)

ELSE

C1 = -10214.16462#

C2 = -4.89350301#

C3 = -.00537657944#

C4 = .000000192023769#

C5 = 3.55758316D-10

```

C6 = -9.03446883D-14
C7 = 4.1635019#
t = tair! + 459.67
LnPws = C1 / t + C2 + C3 * t + C4 * t * t + C5 * t * t * t + C6 * t * t * t * t + C7 *
LOG(t)
FNIPPws = EXP(LnPws) 'ASHRAE Eq.(3)
END IF
END DEF

```

*** Function calculates SI Vapor pressure of Water Vapor (-100° to 200°) *****

```

DEF FNSIPws (tair!)
'Calculate saturation pressure at t!
IF tair! >= 0 THEN
  C8 = -5800.2206#
  C9 = -5.516256#
  C10 = -.048640239#
  C11 = .000041764768#
  C12 = -.000000014452093#
  C13 = 6.5459673#
  t = tair! + 273.15
LnPws = C8 / t + C9 + C10 * t + C11 * t * t + C12 * t * t * t + C13 * LOG(t)
FNSIPws = EXP(LnPws) 'ASHRAE Eq.(4)
ELSE
  C1 = -5674.5359#
  C2 = -.51523058#
  C3 = -.009677843#
  C4 = .00000062215701#
  C5 = .0000000020747825#
  C6 = -9.4840240000000001D-13
  C7 = 4.1635019#
  t = tair! + 273.15
LnPws = C1 / t + C2 + C3 * t + C4 * t * t + C5 * t * t * t + C6 * t * t * t * t + C7 * LOG(t)
FNSIPws = EXP(LnPws) 'ASHRAE Eq.(3)
END IF
END DEF
DIM UNIT$(8)
UNIT$(1) = "BTU/lbm dry air": UNIT$(2) = "kJ/kg dry air"
UNIT$(3) = "lb mix/ft^3": UNIT$(4) = "kg mix/m^3"
UNIT$(5) = "ft^3/lb dry air": UNIT$(6) = "m^3/kg dry air"
UNIT$(7) = "lb water/lb dry air": UNIT$(8) = "kg water/kg dry air"
COLOR 15, 1, 1
main:
CLS : PRINT : PRINT
  INPUT "IP or SI Units (I or S)", UNIT$

```

```

IF UCASE$(UNIT$) = "S" THEN
  I% = 2

```

```

  INPUT "Barometric Pressure (kPa), Wet Bulb (C), Dry Bulb (C)= "; P!, wbC, dbC
  GOTO SICalc

```

```

ELSE

```

```

  I% = 1
  INPUT "Barometric Pressure (in Hg), Wet Bulb (F), Dry Bulb (F) "; inHg, wbF, dbF
  Psi = 14.696 * inHg / 29.921
  GOTO IPCalc
END IF

```

*****Given WB & DB Calculate IP psychrometric properties routine *****

```

IPCalc:
P! = Psi: twb! = wbF: tdb! = dbF

```

'Calculate vapor pressure and Fs factor at wb & db temperature

$$Pws.db = FNIPPws(tdb!)$$

$$Pws.wb = FNIPPws(twb!)$$

$$Fs.db = FNFs(tdb!, P!)$$

$$Fs.wb = FNFs(twb!, P!)$$

'Calculate saturated humidity ratio at twb using saturation pressure (Pws) at twb,
'and Fs correction factor at twb

$$Ws.wb = .62198 * Pws.wb * Fs.wb / (P! - Pws.wb * Fs.wb) \text{ 'ASHRAE Eq.(21a)}$$

'Calculate humidity ratio of the mixture

$$HUMIDRATIO = ((1093 - .556 * twb!) * Ws.wb - .24 * (tdb! - twb!)) / (1093 + .444 * tdb! - twb!) \text{ 'ASHRAE Eq.(33)}$$

IF HUMIDRATIO < 0! THEN PRINT "HumidRatio < 0 INVALID CONDITIONS": GOTO CHOICE

'Calculate saturated humidity ratio at tdb using saturation pressure(Pws) at
'tdb and correction factor Fs at tdb

$$Ws.db = .62198 * Pws.db * Fs.db / (P! - Pws.db * Fs.db) \text{ 'ASHRAE Eq.(21a)}$$

'Calculate degree of saturation

$$\text{DegofSat} = HUMIDRATIO / Ws.db \text{ 'ASHRAE Eq.(10)}$$

'Calculate relative humidity

$$\text{RelHumid} = \text{DegofSat} / (1 - (1 - \text{DegofSat}) * (Fs.db * Pws.db / P!)) \text{ 'ASHRAE Eq.(23a)}$$

'Calculate specific volume

$$Ra = 53.352 / 144 \text{ ' to change gas constant to psi per foot}$$

$$\text{SpVolume} = Ra * (tdb! + 459.67) * (1 + 1.6078 * HUMIDRATIO) / P! \text{ 'ASHRAE Eq. (26)}$$

'Calculate density

$$\text{Density} = (1 + HUMIDRATIO) / \text{SpVolume}$$

'Calculate enthalpy

$$\text{Enthalpy} = .24 * tdb! + HUMIDRATIO * (1061 + .444 * tdb!) \text{ 'ASHRAE Eq.(30)}$$

GOTO PRINTVAL

*****Given WB & DB Calculate SI psycrometric properties routine *****

SI Calc:

$$twb! = wbC; tdb! = dbC$$

'Calculate vapor pressure and Fs factor at wb & db temperature

$$Pws.db = FNSIPws(tdb!)$$

$$Pws.wb = FNSIPws(twb!)$$

$$tF! = tdb! * 1.8 + 32$$

$$Ppsi! = 14.696 * P! / 101.325$$

$$Fs.db = FNFs(tF!, Ppsi!)$$

$$tF! = twb! * 1.8 + 32$$

$$Fs.wb = FNFs(tF!, Ppsi!)$$

'Calculate saturated humidity ratio at twb using saturation pressure (Pws) at twb,
'and Fs correction factor at twb

$$Ws.wb = .62198 * Pws.wb * Fs.wb / (P! - Pws.wb * Fs.wb) \text{ 'ASHRAE Eq.(21a)}$$

'Calculate humidity ratio of the mixture

$$HUMIDRATIO = ((2501 - 2.381 * twb!) * Ws.wb - (tdb! - twb!)) / (2501 + 1.805 * tdb! - 4.186 * twb!) \text{ 'ASHRAE Eq.(33)}$$

IF HUMIDRATIO < 0! THEN PRINT "HumidRatio < 0 INVALID CONDITIONS": GOTO CHOICE

'Calculate saturated humidity ratio at tdb using saturation pressure(Pws) at
 'tdb and correction factor Fs at tdb

$$Ws.db = .62198 * Pws.db * Fs.db / (P! - Pws.db * Fs.db)$$
 'ASHRAE Eq.(21a)

'Calculate degree of saturation

$$DegofSat = HUMIDRATIO / Ws.db$$
 'ASHRAE Eq.(10)

'Calculate relative humidity

$$RelHumid = DegofSat / (1 - (1 - DegofSat) * (Fs.db * Pws.db / P!))$$
 'ASHRAE Eq.(23a)

'Calculate specific volume

$$Ra = 287.055 / 1000$$
 ' to change gas constant units convert kPa to Pa

$$SpVolume = Ra * (tdb! + 273.15) * (1 + 1.6078 * HUMIDRATIO) / P!$$
 'ASHRAE Eq. (26)

'Calculate density

$$Density = (1 + HUMIDRATIO) / SpVolume$$

'Calculate enthalpy

$$Enthalpy = 1.006 * tdb! + HUMIDRATIO * (2501 + 1.805 * tdb!)$$
 'ASHRAE Eq.(30)

PRINTVAL:

```
PRINT : PRINT USING "Enthalpy      = ####.#### &"; Enthalpy; UNITSS$(I%)
PRINT USING "Density          = #.##### &"; Density; UNITSS$(I% + 2)
PRINT USING "Specific Volume  = ###.#### &"; SpVolume; UNITSS$(I% + 4)
PRINT USING "Humidity Ratio   = #.##### &"; HUMIDRATIO; UNITSS$(I% + 6)
PRINT USING "Relative Humidity = ###.## percent"; RelHumid * 100
```

CHOICE:

```
PRINT : PRINT "Press any Key to Continue"
```

```
DO
```

```
CHOICES$ = INKEY$
```

```
LOOP UNTIL CHOICES$ <> ""
```

```
GOTO main
```

Enthalpy of Saturated Air - Water Vapor Mixtures at 101.325 kPa (sea level)

°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	°C
0	9.4783	9.6490	9.8203	9.9920	10.164	10.337	10.510	10.684	10.858	11.032	0
1	11.207	11.383	11.559	11.736	11.913	12.090	12.268	12.447	12.626	12.805	1
2	12.985	13.166	13.347	13.529	13.711	13.894	14.077	14.261	14.445	14.630	2
3	14.816	15.002	15.188	15.375	15.563	15.751	15.940	16.129	16.319	16.510	3
4	16.701	16.892	17.085	17.277	17.471	17.665	17.859	18.055	18.250	18.447	4
5	18.644	18.842	19.040	19.239	19.438	19.638	19.839	20.041	20.243	20.445	5
6	20.649	20.853	21.057	21.263	21.469	21.675	21.883	22.091	22.299	22.509	6
7	22.719	22.930	23.141	23.353	23.566	23.780	23.994	24.209	24.424	24.641	7
8	24.858	25.076	25.294	25.514	25.734	25.954	26.176	26.398	26.621	26.845	8
9	27.070	27.295	27.521	27.748	27.976	28.204	28.434	28.664	28.895	29.126	9
10	29.359	29.592	29.826	30.061	30.297	30.533	30.771	31.009	31.248	31.488	10
11	31.729	31.971	32.213	32.457	32.701	32.946	33.192	33.439	33.687	33.936	11
12	34.185	34.436	34.687	34.939	35.193	35.447	35.702	35.958	36.215	36.473	12
13	36.732	36.992	37.253	37.515	37.777	38.041	38.306	38.572	38.838	39.106	13
14	39.375	39.645	39.915	40.187	40.460	40.734	41.009	41.285	41.562	41.840	14
15	42.119	42.399	42.680	42.962	43.246	43.530	43.816	44.103	44.390	44.679	15
16	44.969	45.260	45.553	45.846	46.141	46.436	46.733	47.031	47.330	47.631	16
17	47.932	48.235	48.539	48.844	49.150	49.458	49.767	50.077	50.388	50.700	17
18	51.014	51.329	51.645	51.963	52.282	52.602	52.923	53.246	53.569	53.895	18
19	54.221	54.549	54.878	55.209	55.541	55.874	56.208	56.544	56.882	57.220	19
20	57.560	57.902	58.245	58.589	58.935	59.282	59.630	59.980	60.332	60.685	20
21	61.039	61.395	61.752	62.111	62.471	62.833	63.196	63.561	63.927	64.295	21
22	64.664	65.035	65.408	65.781	66.157	66.534	66.913	67.293	67.675	68.059	22
23	68.444	68.831	69.220	69.610	70.001	70.395	70.790	71.187	71.585	71.986	23
24	72.388	72.791	73.197	73.604	74.012	74.423	74.835	75.250	75.666	76.083	24
25	76.503	76.924	77.347	77.772	78.199	78.628	79.058	79.491	79.925	80.361	25
26	80.800	81.240	81.682	82.125	82.571	83.019	83.469	83.920	84.374	84.830	26
27	85.287	85.747	86.209	86.673	87.138	87.606	88.076	88.548	89.022	89.499	27
28	89.977	90.457	90.940	91.425	91.912	92.401	92.892	93.385	93.881	94.379	28
29	94.879	95.381	95.886	96.392	96.902	97.413	97.927	98.443	98.961	99.482	29
30	100.01	100.53	101.06	101.59	102.12	102.66	103.19	103.73	104.28	104.82	30
31	105.37	105.92	106.47	107.02	107.58	108.14	108.70	109.27	109.84	110.41	31
32	110.98	111.55	112.13	112.71	113.30	113.88	114.47	115.06	115.66	116.25	32
33	116.85	117.46	118.06	118.67	119.28	119.89	120.51	121.13	121.75	122.38	33
34	123.01	123.64	124.27	124.91	125.55	126.19	126.84	127.49	128.14	128.79	34
35	129.45	130.11	130.78	131.44	132.12	132.79	133.47	134.15	134.83	135.52	35
36	136.21	136.90	137.60	138.29	139.00	139.70	140.41	141.13	141.84	142.56	36
37	143.29	144.01	144.74	145.48	146.21	146.95	147.70	148.45	149.20	149.95	37
38	150.71	151.47	152.24	153.01	153.78	154.56	155.34	156.13	156.91	157.71	38
39	158.50	159.30	160.11	160.91	161.72	162.54	163.36	164.18	165.01	165.84	39
40	166.68	167.52	168.36	169.21	170.06	170.92	171.78	172.64	173.51	174.38	40
41	175.26	176.14	177.03	177.92	178.81	179.71	180.62	181.52	182.44	183.35	41
42	184.27	185.20	186.13	187.07	188.01	188.95	189.90	190.85	191.81	192.78	42
43	193.74	194.72	195.70	196.68	197.67	198.66	199.66	200.66	201.67	202.68	43
44	203.70	204.72	205.75	206.78	207.82	208.87	209.91	210.97	212.03	213.09	44
45	214.16	215.24	216.32	217.41	218.50	219.60	220.70	221.81	222.93	224.05	45
46	225.18	226.31	227.45	228.59	229.74	230.89	232.06	233.22	234.40	235.58	46
47	236.76	237.95	239.15	240.36	241.57	242.78	244.01	245.24	246.47	247.71	47
48	248.96	250.22	251.48	252.75	254.02	255.30	256.59	257.89	259.19	260.50	48
49	261.81	263.14	264.47	265.80	267.14	268.50	269.85	271.22	272.59	273.97	49
50	275.36	276.75	278.15	279.56	280.98	282.40	283.83	285.27	286.72	288.18	50
51	289.64	291.11	292.59	294.07	295.57	297.07	298.58	300.10	301.63	303.16	51
52	304.71	306.26	307.82	309.39	310.97	312.55	314.15	315.75	317.36	318.99	52
53	320.62	322.25	323.90	325.56	327.23	328.90	330.59	332.28	333.98	335.70	53
54	337.42	339.15	340.89	342.64	344.41	346.18	347.96	349.75	351.55	353.36	54
55	355.18	357.01	358.86	360.71	362.57	364.44	366.33	368.22	370.13	372.04	55
56	373.97	375.91	377.86	379.82	381.79	383.77	385.77	387.77	389.79	391.82	56
57	393.86	395.91	397.98	400.05	402.14	404.24	406.36	408.48	410.62	412.77	57
58	414.93	417.11	419.29	421.49	423.71	425.94	428.18	430.43	432.70	434.98	58
59	437.27	439.58	441.90	444.23	446.58	448.95	451.32	453.72	456.12	458.54	59
60	460.98	463.43	465.89	468.37	470.87	473.38	475.90	478.44	481.00	483.57	60
61	486.16	488.76	491.38	494.02	496.67	499.34	502.02	504.72	507.44	510.18	61
62	512.93	515.70	518.49	521.29	524.12	526.96	529.81	532.69	535.58	538.50	62
63	541.43	544.38	547.35	550.34	553.34	556.37	559.41	562.48	565.57	568.67	63
64	571.80	574.94	578.11	581.30	584.50	587.73	590.98	594.25	597.54	600.86	64
65	604.20	607.55	610.93	614.34	617.76	621.21	624.68	628.18	631.70	635.24	65
66	638.81	642.40	646.01	649.65	653.32	657.01	660.72	664.46	668.23	672.02	66
67	675.84	679.68	683.55	687.45	691.37	695.33	699.31	703.31	707.35	711.41	67
68	715.51	719.63	723.78	727.96	732.17	736.41	740.69	744.99	749.32	753.69	68
69	758.08	762.51	766.97	771.46	775.99	780.55	785.14	789.76	794.43	799.12	69
70	803.85	808.61	813.41	818.25	823.12	828.03	832.98	837.96	842.99	848.04	70
°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	°C

Properties of Saturated Air - Water Vapor Mixtures at 101.325 kPa (sea level)

°C	Enthalpy	Density	Sp Vol	HR	°C	°C	Enthalpy	Density	Sp Vol	HR	°C
0	9.4783	1.2893	0.77855	0.00379	0						
1	11.207	1.2844	0.78176	0.00408	1	36	136.21	1.11633	0.93069	0.03896	36
2	12.985	1.2795	0.78499	0.00438	2	37	143.29	1.11130	0.93701	0.04130	37
3	14.816	1.2746	0.78826	0.00471	3	38	150.71	1.10624	0.94353	0.04377	38
4	16.701	1.2697	0.79155	0.00505	4	39	158.50	1.10114	0.95027	0.04638	39
5	18.644	1.2649	0.79487	0.00542	5	40	166.68	1.09599	0.95724	0.04913	40
6	20.649	1.2601	0.79823	0.00582	6	41	175.26	1.09080	0.96446	0.05204	41
7	22.719	1.2552	0.80163	0.00624	7	42	184.27	1.08557	0.97194	0.05511	42
8	24.858	1.2504	0.80506	0.00668	8	43	193.74	1.08029	0.97969	0.05835	43
9	27.070	1.2457	0.80853	0.00716	9	44	203.70	1.07495	0.98774	0.06178	44
10	29.359	1.2409	0.81205	0.00766	10	45	214.16	1.06957	0.99610	0.06540	45
11	31.729	1.2361	0.81561	0.00820	11	46	225.18	1.06412	1.00479	0.06923	46
12	34.185	1.2314	0.81922	0.00877	12	47	236.76	1.05862	1.01384	0.07327	47
13	36.732	1.2266	0.82288	0.00937	13	48	248.96	1.05305	1.02326	0.07755	48
14	39.375	1.2219	0.82659	0.01001	14	49	261.81	1.04741	1.03308	0.08207	49
15	42.119	1.2172	0.83037	0.01069	15	50	275.36	1.04171	1.04332	0.08685	50
16	44.969	1.2124	0.83420	0.01141	16	51	289.64	1.03594	1.05402	0.09191	51
17	47.932	1.2077	0.83809	0.01218	17	52	304.71	1.03009	1.06521	0.09726	52
18	51.014	1.2030	0.84206	0.01299	18	53	320.62	1.02416	1.07691	0.10293	53
19	54.221	1.1983	0.84609	0.01385	19	54	337.42	1.01816	1.08916	0.10894	54
20	57.560	1.1935	0.85020	0.01476	20	55	355.18	1.01206	1.10201	0.11531	55
21	61.039	1.1888	0.85439	0.01572	21	56	373.97	1.00589	1.11549	0.12206	56
22	64.664	1.1841	0.85867	0.01674	22	57	393.86	0.99961	1.12966	0.12923	57
23	68.444	1.1794	0.86303	0.01782	23	58	414.93	0.99325	1.14456	0.13684	58
24	72.388	1.1746	0.86749	0.01896	24	59	437.27	0.98679	1.16025	0.14493	59
25	76.503	1.1698	0.87205	0.02017	25	60	460.98	0.98022	1.17680	0.15353	60
26	80.800	1.1651	0.87672	0.02145	26	61	486.16	0.97355	1.19426	0.16268	61
27	85.287	1.1603	0.88150	0.02280	27	62	512.93	0.96678	1.21272	0.17243	62
28	89.977	1.1555	0.88639	0.02422	28	63	541.43	0.95989	1.23225	0.18283	63
29	94.879	1.1507	0.89141	0.02573	29	64	571.80	0.95288	1.25296	0.19392	64
30	100.01	1.1459	0.89656	0.02733	30	65	604.20	0.94575	1.27493	0.20578	65
31	105.37	1.1410	0.90185	0.02901	31	66	638.81	0.93850	1.29830	0.21846	66
32	110.98	1.1361	0.90729	0.03079	32	67	675.84	0.93112	1.32318	0.23205	67
33	116.85	1.1312	0.91289	0.03267	33	68	715.51	0.92361	1.34972	0.24663	68
34	123.01	1.1263	0.91865	0.03466	34	69	758.08	0.91597	1.37809	0.26229	69
35	129.45	1.1213	0.92458	0.03675	35	70	803.85	0.90818	1.40846	0.27915	70

Properties of Saturated Air - Water Vapor Mixtures at 98.00 kPa

°C	Enthalpy	Density	Sp Vol	HR	°C	°C	Enthalpy	Density	Sp Vol	HR	°C
0	9.8008	1.2469	0.80513	0.00392	0						
1	11.555	1.2421	0.80846	0.00421	1	36	139.81	1.07886	0.96431	0.04037	36
2	13.359	1.2374	0.81182	0.00453	2	37	147.12	1.07396	0.97098	0.04279	37
3	15.218	1.2326	0.81521	0.00487	3	38	154.80	1.06901	0.97787	0.04536	38
4	17.133	1.2279	0.81863	0.00523	4	39	162.85	1.06403	0.98499	0.04807	39
5	19.108	1.2232	0.82209	0.00561	5	40	171.31	1.05901	0.99237	0.05093	40
6	21.148	1.2186	0.82558	0.00602	6	41	180.19	1.05394	1.00001	0.05395	41
7	23.255	1.2139	0.82911	0.00645	7	42	189.52	1.04882	1.00794	0.05715	42
8	25.433	1.2092	0.83268	0.00691	8	43	199.33	1.04365	1.01616	0.06052	43
9	27.686	1.2046	0.83629	0.00740	9	44	209.65	1.03844	1.02470	0.06409	44
10	30.020	1.2000	0.83995	0.00792	10	45	220.50	1.03316	1.03358	0.06786	45
11	32.437	1.1954	0.84366	0.00848	11	46	231.93	1.02783	1.04281	0.07184	46
12	34.944	1.1908	0.84742	0.00907	12	47	243.96	1.02244	1.05243	0.07605	47
13	37.545	1.1862	0.85123	0.00969	13	48	256.63	1.01698	1.06246	0.08051	48
14	40.244	1.1816	0.85510	0.01036	14	49	269.99	1.01146	1.07292	0.08522	49
15	43.049	1.1770	0.85904	0.01106	15	50	284.08	1.00587	1.08384	0.09021	50
16	45.964	1.1724	0.86304	0.01181	16	51	298.94	1.00021	1.09526	0.09549	51
17	48.996	1.1678	0.86710	0.01260	17	52	314.63	0.99447	1.10720	0.10109	52
18	52.151	1.1632	0.87124	0.01344	18	53	331.21	0.98865	1.11971	0.10702	53
19	55.436	1.1586	0.87546	0.01433	19	54	348.74	0.98276	1.13283	0.11330	54
20	58.858	1.1540	0.87975	0.01527	20	55	367.28	0.97677	1.14659	0.11996	55
21	62.424	1.1494	0.88414	0.01627	21	56	386.91	0.97070	1.16105	0.12704	56
22	66.143	1.1448	0.88861	0.01732	22	57	407.71	0.96454	1.17626	0.13455	57
23	70.022	1.1402	0.89318	0.01844	23	58	429.76	0.95828	1.19227	0.14253	58
24	74.071	1.1356	0.89785	0.01962	24	59	453.16	0.95192	1.20915	0.15102	59
25	78.298	1.1310	0.90263	0.02087	25	60	478.01	0.94546	1.22697	0.16006	60
26	82.714	1.1264	0.90752	0.02220	26	61	504.44	0.93890	1.24580	0.16968	61
27	87.328	1.1217	0.91253	0.02360	27	62	532.58	0.93222	1.26573	0.17995	62
28	92.152	1.1170	0.91767	0.02508	28	63	562.55	0.92544	1.28685	0.19091	63
29	97.197	1.1124	0.92295	0.02664	29	64	594.54	0.91853	1.30927	0.20261	64
30	102.47	1.1076	0.92836	0.02829	30	65	628.71	0.91151	1.33310	0.21514	65
31	108.00	1.1029	0.93393	0.03004	31	66	665.27	0.90436	1.35848	0.22856	66
32	113.78	1.0982	0.93965	0.03189	32	67	704.43	0.89708	1.38555	0.24296	67
33	119.84	1.0934	0.94554	0.03384	33	68	746.46	0.88967	1.41447	0.25843	68
34	126.18	1.0886	0.95161	0.03590	34	69	791.65	0.88213	1.44544	0.27507	69
35	132.83	1.0837	0.95786	0.03807	35	70	840.30	0.87444	1.47867	0.29302	70

Properties of Saturated Air - Water Vapor Mixtures at 94.00 kPa

°C	Enthalpy	Density	Sp Vol	HR	°C	°C	Enthalpy	Density	Sp Vol	HR	°C
0	10.219	1.1959	0.83962	0.00409	0	36	144.50	1.03379	1.00813	0.04220	36
1	12.005	1.1913	0.84311	0.00439	1	37	152.12	1.02903	1.01526	0.04475	37
2	13.844	1.1867	0.84663	0.00472	2	38	160.12	1.02423	1.02265	0.04744	38
3	15.739	1.1822	0.85018	0.00508	3	39	168.52	1.01939	1.03029	0.05028	39
4	17.694	1.1777	0.85377	0.00545	4	40	177.34	1.01451	1.03821	0.05328	40
5	19.711	1.1731	0.85740	0.00585	5	41	186.62	1.00958	1.04642	0.05646	41
6	21.795	1.1686	0.86106	0.00627	6	42	196.37	1.00461	1.05494	0.05981	42
7	23.950	1.1642	0.86477	0.00673	7	43	206.63	0.99958	1.06379	0.06336	43
8	26.179	1.1597	0.86852	0.00721	8	44	217.42	0.99450	1.07299	0.06711	44
9	28.486	1.1552	0.87232	0.00772	9	45	228.79	0.98937	1.08257	0.07107	45
10	30.878	1.1508	0.87617	0.00826	10	46	240.76	0.98417	1.09254	0.07526	46
11	33.357	1.1463	0.88007	0.00884	11	47	253.37	0.97892	1.10294	0.07970	47
12	35.929	1.1419	0.88402	0.00946	12	48	266.67	0.97360	1.11379	0.08439	48
13	38.599	1.1375	0.88804	0.01011	13	49	280.70	0.96821	1.12512	0.08937	49
14	41.373	1.1330	0.89212	0.01080	14	50	295.51	0.96276	1.13696	0.09463	50
15	44.257	1.1286	0.89627	0.01154	15	51	311.14	0.95723	1.14936	0.10020	51
16	47.256	1.1242	0.90049	0.01232	16	52	327.67	0.95162	1.16234	0.10612	52
17	50.378	1.1198	0.90478	0.01314	17	53	345.14	0.94594	1.17595	0.11238	53
18	53.628	1.1154	0.90915	0.01402	18	54	363.63	0.94017	1.19024	0.11903	54
19	57.014	1.1109	0.91360	0.01495	19	55	383.20	0.93432	1.20525	0.12609	55
20	60.543	1.1065	0.91815	0.01593	20	56	403.95	0.92837	1.22104	0.13359	56
21	64.224	1.1021	0.92278	0.01698	21	57	425.96	0.92234	1.23767	0.14156	57
22	68.064	1.0976	0.92752	0.01808	22	58	449.31	0.91621	1.25521	0.15004	58
23	72.073	1.0932	0.93236	0.01925	23	59	474.14	0.90998	1.27372	0.15907	59
24	76.259	1.0887	0.93731	0.02048	24	60	500.54	0.90365	1.29330	0.16869	60
25	80.632	1.0843	0.94238	0.02179	25	61	528.64	0.89721	1.31402	0.17896	61
26	85.203	1.0798	0.94758	0.02317	26	62	558.61	0.89066	1.33509	0.18992	62
27	89.982	1.0753	0.95290	0.02464	27	63	590.59	0.88400	1.35931	0.20163	63
28	94.981	1.0708	0.95836	0.02619	28	64	624.77	0.87722	1.38401	0.21417	64
29	100.21	1.0662	0.96397	0.02782	29	65	661.34	0.87032	1.41052	0.22761	65
30	105.69	1.0617	0.96974	0.02955	30	66	700.54	0.86329	1.43870	0.24203	66
31	111.42	1.0571	0.97567	0.03138	31	67	742.62	0.85613	1.46883	0.25753	67
32	117.43	1.0525	0.98177	0.03331	32	68	787.88	0.84885	1.50110	0.27422	68
33	123.72	1.0479	0.98806	0.03535	33	69	836.64	0.84142	1.53574	0.29221	69
34	130.32	1.0432	0.99454	0.03751	34	70	889.28	0.83386	1.5730	0.31167	70
35	137.24	1.0385	1.0012	0.03979	35						

Properties of Saturated Air - Water Vapor Mixtures at 90.00 kPa

°C	Enthalpy	Density	Sp Vol	HR	°C	°C	Enthalpy	Density	Sp Vol	HR	°C
0	10.675	1.1449	0.87719	0.00427	0	36	149.64	0.98872	1.05611	0.04420	36
1	12.496	1.1405	0.88086	0.00459	1	37	157.60	0.98410	1.06378	0.04687	37
2	14.373	1.1361	0.88455	0.00494	2	38	165.95	0.97945	1.07172	0.04970	38
3	16.308	1.1317	0.88829	0.00530	3	39	174.74	0.97475	1.07995	0.05269	39
4	18.305	1.1274	0.89206	0.00569	4	40	183.97	0.97002	1.08848	0.05585	40
5	20.368	1.1230	0.89588	0.00611	5	41	193.68	0.96523	1.09734	0.05919	41
6	22.501	1.1187	0.89973	0.00655	6	42	203.89	0.96040	1.10654	0.06272	42
7	24.707	1.1144	0.90363	0.00703	7	43	214.65	0.95551	1.11611	0.06646	43
8	26.992	1.1101	0.90759	0.00753	8	44	225.97	0.95057	1.12607	0.07041	44
9	29.359	1.1058	0.91159	0.00807	9	45	237.90	0.94557	1.13644	0.07459	45
10	31.813	1.1016	0.91565	0.00864	10	46	250.48	0.94052	1.14726	0.07902	46
11	34.359	1.0973	0.91976	0.00924	11	47	263.74	0.93540	1.15854	0.08370	47
12	37.003	1.0930	0.92394	0.00988	12	48	277.73	0.93021	1.17033	0.08866	48
13	39.749	1.0888	0.92818	0.01057	13	49	292.51	0.92496	1.18266	0.09392	49
14	42.605	1.0845	0.93249	0.01129	14	50	308.12	0.91964	1.19556	0.09949	50
15	45.575	1.0803	0.93687	0.01206	15	51	324.61	0.91424	1.20907	0.10539	51
16	48.666	1.0760	0.94133	0.01287	16	52	342.06	0.90877	1.22325	0.11166	52
17	51.885	1.0717	0.94588	0.01374	17	53	360.53	0.90322	1.23813	0.11831	53
18	55.239	1.0675	0.95051	0.01466	18	54	380.10	0.89758	1.25377	0.12537	54
19	58.736	1.0632	0.95523	0.01563	19	55	400.84	0.89186	1.27023	0.13287	55
20	62.383	1.0590	0.96004	0.01666	20	56	422.85	0.88605	1.28757	0.14085	56
21	66.189	1.0547	0.96496	0.01775	21	57	446.21	0.88014	1.30585	0.14934	57
22	70.162	1.0504	0.96999	0.01890	22	58	471.05	0.87414	1.32516	0.15838	58
23	74.312	1.0461	0.97514	0.02013	23	59	497.48	0.86804	1.34559	0.16802	59
24	78.648	1.0418	0.98040	0.02142	24	60	525.63	0.86183	1.36721	0.17831	60
25	83.181	1.0375	0.98580	0.02279	25	61	555.65	0.85552	1.39014	0.18930	61
26	87.922	1.0332	0.99133	0.02424	26	62	587.70	0.84909	1.41450	0.20105	62
27	92.882	1.0289	0.99700	0.02578	27	63	621.97	0.84256	1.44041	0.21363	63
28	98.073	1.0245	1.0028	0.02740	28	64	658.65	0.83590	1.46801	0.22712	64
29	103.51	1.0201	1.0088	0.02911	29	65	697.99	0.82912	1.49748	0.24160	65
30	109.20	1.0157	1.0150	0.03093	30	66	740.23	0.82222	1.52899	0.25717	66
31	115.17	1.0113	1.0213	0.03284	31	67	785.69	0.81518	1.56276	0.27395	67
32	121.42	1.0068	1.0278	0.03487	32	68	834.69	0.80802	1.59903	0.29205	68
33	127.98	1.0024	1.0346	0.03701	33	69	887.61	0.80071	1.63806	0.31163	69
34	134.85	0.9978	1.0415	0.03928	34	70	944.91	0.79327	1.68017	0.33284	70
35	142.07	0.9933	1.0487	0.04167	35						

Properties of Saturated Air - Water Vapor Mixtures at 86.00 kPa

°C	Enthalpy	Density	Sp Vol	HR	°C	°C	Enthalpy	Density	Sp Vol	HR	°C
0	11.174	1.0939	0.91828	0.00447	0	36	155.30	0.94365	1.10889	0.04640	36
1	13.033	1.0896	0.92214	0.00481	1	37	163.63	0.93918	1.11716	0.04922	37
2	14.950	1.0854	0.92604	0.00517	2	38	172.38	0.93467	1.12574	0.05220	38
3	16.929	1.0813	0.92997	0.00555	3	39	181.58	0.93012	1.13464	0.05535	39
4	18.974	1.0771	0.93395	0.00596	4	40	191.27	0.92552	1.14388	0.05869	40
5	21.087	1.0730	0.93797	0.00640	5	41	201.46	0.92088	1.15347	0.06221	41
6	23.273	1.0688	0.94204	0.00686	6	42	212.19	0.91608	1.16346	0.06594	42
7	25.536	1.0647	0.94616	0.00736	7	43	223.49	0.91144	1.17384	0.06989	43
8	27.881	1.0606	0.95033	0.00788	8	44	235.41	0.90664	1.18467	0.07407	44
9	30.313	1.0564	0.95456	0.00845	9	45	247.97	0.90178	1.19596	0.07849	45
10	32.836	1.0523	0.95885	0.00904	10	46	261.22	0.89686	1.20774	0.08318	46
11	35.456	1.0482	0.96320	0.00968	11	47	275.21	0.89188	1.22005	0.08814	47
12	38.178	1.0442	0.96762	0.01035	12	48	289.98	0.88683	1.23292	0.09340	48
13	41.008	1.0401	0.97212	0.01106	13	49	305.59	0.88171	1.24640	0.09897	49
14	43.953	1.0360	0.97668	0.01182	14	50	322.09	0.87653	1.26052	0.10488	50
15	47.017	1.0319	0.98133	0.01263	15	51	339.56	0.87126	1.27534	0.11116	51
16	50.209	1.0278	0.98606	0.01348	16	52	358.05	0.86592	1.29099	0.11782	52
17	53.536	1.0237	0.99089	0.01439	17	53	377.65	0.86050	1.30725	0.12490	53
18	57.004	1.0196	0.99580	0.01535	18	54	398.43	0.85499	1.32447	0.13242	54
19	60.622	1.0155	1.0008	0.01637	19	55	420.49	0.84940	1.34261	0.14042	55
20	64.398	1.0114	1.0059	0.01745	20	56	443.92	0.84372	1.36176	0.14895	56
21	68.341	1.0073	1.0112	0.01860	21	57	468.83	0.83794	1.38198	0.15802	57
22	72.461	1.0032	1.0165	0.01981	22	58	495.35	0.83207	1.40337	0.16771	58
23	76.766	0.99909	1.0220	0.02109	23	59	523.62	0.82609	1.42604	0.17804	59
24	81.268	0.99495	1.0276	0.02245	24	60	553.77	0.82001	1.45008	0.18909	60
25	85.977	0.99079	1.0334	0.02389	25	61	585.97	0.81383	1.47563	0.20091	61
26	90.905	0.98662	1.0393	0.02541	26	62	620.42	0.80753	1.50281	0.21357	62
27	96.063	0.98244	1.0454	0.02702	27	63	657.32	0.80111	1.53179	0.22715	63
28	101.47	0.97823	1.0516	0.02873	28	64	696.90	0.79458	1.56274	0.24174	64
29	107.13	0.97400	1.0580	0.03053	29	65	739.44	0.78793	1.59586	0.25743	65
30	113.06	0.96975	1.0646	0.03244	30	66	785.23	0.78115	1.63137	0.27435	66
31	119.28	0.96548	1.0714	0.03445	31	67	834.63	0.77424	1.66952	0.29261	67
32	125.80	0.96117	1.0785	0.03658	32	68	888.02	0.76719	1.71062	0.31238	68
33	132.65	0.95684	1.0857	0.03884	33	69	945.85	0.76001	1.75498	0.33381	69
34	139.83	0.95248	1.0932	0.04122	34	70	1008.67	0.75268	1.80301	0.3571	70
35	147.38	0.94808	1.1009	0.04374	35						

Properties of Saturated Air - Water Vapor Mixtures at 82.00 kPa

°C	Enthalpy	Density	Sp Vol	HR	°C	°C	Enthalpy	Density	Sp Vol	HR	°C
0	11.721	1.0428	0.96341	0.00469	0	36	161.55	0.89858	1.16722	0.04884	36
1	13.623	1.0388	0.96749	0.00504	1	37	170.29	0.89425	1.17619	0.05182	37
2	15.585	1.0348	0.97160	0.00542	2	38	179.48	0.88989	1.18550	0.05497	38
3	17.612	1.0308	0.97576	0.00582	3	39	189.16	0.88548	1.19517	0.05830	39
4	19.708	1.0268	0.97997	0.00625	4	40	199.35	0.88103	1.20521	0.06183	40
5	21.876	1.0229	0.98422	0.00671	5	41	210.08	0.87652	1.21566	0.06556	41
6	24.121	1.0189	0.98852	0.00720	6	42	221.38	0.87197	1.22654	0.06951	42
7	26.447	1.0149	0.99289	0.00772	7	43	233.30	0.86737	1.23788	0.07370	43
8	28.859	1.0110	0.99734	0.00827	8	44	245.88	0.86270	1.24970	0.07813	44
9	31.362	1.0071	1.0018	0.00886	9	45	259.15	0.85798	1.26205	0.08282	45
10	33.961	1.0031	1.0063	0.00949	10	46	273.16	0.85320	1.27495	0.08780	46
11	36.662	0.99921	1.0110	0.01015	11	47	287.96	0.84836	1.28845	0.09307	47
12	39.471	0.99529	1.0156	0.01086	12	48	303.61	0.84345	1.30258	0.09866	48
13	42.393	0.99137	1.0204	0.01161	13	49	320.16	0.83846	1.31740	0.10460	49
14	45.435	0.98745	1.0253	0.01241	14	50	337.68	0.83341	1.33295	0.11090	50
15	48.604	0.98354	1.0302	0.01326	15	51	356.24	0.82828	1.34928	0.11759	51
16	51.907	0.97962	1.0353	0.01416	16	52	375.91	0.82307	1.36646	0.12470	52
17	55.351	0.97570	1.0404	0.01511	17	53	396.79	0.81778	1.38455	0.13227	53
18	58.945	0.97177	1.0456	0.01612	18	54	418.95	0.81241	1.40362	0.14032	54
19	62.697	0.96784	1.0510	0.01719	19	55	442.50	0.80695	1.42375	0.14889	55
20	66.616	0.96391	1.0565	0.01833	20	56	467.56	0.80139	1.44502	0.15803	56
21	70.711	0.95996	1.0621	0.01953	21	57	494.25	0.79574	1.46753	0.16779	57
22	74.992	0.95600	1.0678	0.02081	22	58	522.70	0.79000	1.49139	0.17820	58
23	79.469	0.95204	1.0737	0.02216	23	59	553.07	0.78415	1.51672	0.18934	59
24	84.153	0.94805	1.0797	0.02359	24	60	585.53	0.77820	1.54364	0.20126	60
25	89.056	0.94406	1.0858	0.02510	25	61	620.26	0.77214	1.57231	0.21404	61
26	94.190	0.94004	1.0922	0.02670	26	62	657.49	0.76596	1.60288	0.22776	62
27	99.569	0.93601	1.0987	0.02840	27	63	697.45	0.75968	1.63556	0.24250	63
28	105.21	0.93196	1.1054	0.03019	28	64	740.43	0.75327	1.67054	0.25837	64
29	111.12	0.92789	1.1123	0.03209	29	65	786.72	0.74674	1.70807	0.27549	65
30	117.31	0.92379	1.1194	0.03410	30	66	836.68	0.74008	1.74843	0.29398	66
31	123.82	0.91966	1.1267	0.03623	31	67	890.73	0.73329	1.79193	0.31401	67
32	130.64	0.91551	1.1343	0.03847	32	68	949.34	0.72637	1.83893	0.33575	68
33	137.80	0.91133	1.1421	0.04085	33	69	1013.03	0.71930	1.88986	0.35939	69
34	145.33	0.90712	1.1502	0.04337	34	70	1082.46	0.7121	1.94521	0.38519	70
35	153.24	0.90287	1.1586	0.04603	35						

Enthalpy of Saturated Air - Water Vapor Mixtures at 29.921 in Hg (sea level)

°F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	°F
0	0.83528	0.86371	0.89216	0.92062	0.94912	0.97763	1.0062	1.0347	1.0633	1.0919	0
1	1.1205	1.1492	1.1778	1.2065	1.2352	1.2640	1.2927	1.3215	1.3503	1.3791	1
2	1.4080	1.4369	1.4658	1.4947	1.5236	1.5526	1.5816	1.6106	1.6397	1.6687	2
3	1.6978	1.7269	1.7561	1.7852	1.8144	1.8436	1.8729	1.9021	1.9314	1.9607	3
4	1.9901	2.0195	2.0488	2.0783	2.1077	2.1372	2.1667	2.1962	2.2257	2.2553	4
5	2.2849	2.3145	2.3442	2.3739	2.4036	2.4333	2.4631	2.4929	2.5227	2.5525	5
6	2.5824	2.6123	2.6422	2.6722	2.7022	2.7322	2.7622	2.7923	2.8224	2.8525	6
7	2.8827	2.9129	2.9431	2.9733	3.0036	3.0339	3.0642	3.0946	3.1250	3.1554	7
8	3.1859	3.2164	3.2469	3.2774	3.3080	3.3386	3.3692	3.3999	3.4306	3.4613	8
9	3.4921	3.5229	3.5537	3.5846	3.6155	3.6464	3.6774	3.7083	3.7394	3.7704	9
10	3.8015	3.8326	3.8638	3.8950	3.9262	3.9574	3.9887	4.0200	4.0514	4.0828	10
11	4.1142	4.1457	4.1772	4.2087	4.2402	4.2718	4.3035	4.3351	4.3668	4.3986	11
12	4.4304	4.4622	4.4940	4.5259	4.5578	4.5898	4.6218	4.6538	4.6859	4.7180	12
13	4.7501	4.7823	4.8145	4.8468	4.8791	4.9114	4.9438	4.9762	5.0086	5.0411	13
14	5.0736	5.1062	5.1388	5.1714	5.2041	5.2368	5.2696	5.3024	5.3352	5.3681	14
15	5.4010	5.4340	5.4670	5.5000	5.5331	5.5662	5.5994	5.6326	5.6659	5.6992	15
16	5.7325	5.7659	5.7993	5.8328	5.8663	5.8998	5.9334	5.9671	6.0007	6.0345	16
17	6.0682	6.1021	6.1359	6.1698	6.2038	6.2378	6.2718	6.3059	6.3400	6.3742	17
18	6.4084	6.4427	6.4770	6.5113	6.5458	6.5802	6.6147	6.6493	6.6839	6.7185	18
19	6.7532	6.7879	6.8227	6.8575	6.8924	6.9274	6.9623	6.9974	7.0325	7.0676	19
20	7.1028	7.1380	7.1733	7.2086	7.2440	7.2794	7.3149	7.3504	7.3860	7.4217	20
21	7.4574	7.4931	7.5289	7.5647	7.6006	7.6366	7.6726	7.7087	7.7448	7.7809	21
22	7.8172	7.8534	7.8898	7.9261	7.9626	7.9991	8.0356	8.0722	8.1089	8.1456	22
23	8.1824	8.2192	8.2561	8.2930	8.3300	8.3671	8.4042	8.4414	8.4786	8.5159	23
24	8.5533	8.5907	8.6281	8.6657	8.7032	8.7409	8.7786	8.8164	8.8542	8.8921	24
25	8.9300	8.9680	9.0061	9.0442	9.0824	9.1207	9.1590	9.1974	9.2358	9.2743	25
26	9.3129	9.3515	9.3902	9.4290	9.4678	9.5067	9.5457	9.5847	9.6238	9.6629	26
27	9.7022	9.7414	9.7808	9.8202	9.8597	9.8992	9.9389	9.9786	10.018	10.058	27
28	10.098	10.138	10.178	10.218	10.258	10.299	10.339	10.379	10.420	10.460	28
29	10.501	10.541	10.582	10.623	10.664	10.705	10.746	10.787	10.828	10.869	29
30	10.911	10.952	10.994	11.035	11.077	11.119	11.160	11.202	11.244	11.286	30
31	11.328	11.370	11.413	11.455	11.497	11.540	11.582	11.625	11.668	11.710	31
32	11.755	11.796	11.836	11.877	11.918	11.959	12.000	12.041	12.082	12.124	32
33	12.165	12.206	12.248	12.289	12.331	12.373	12.414	12.456	12.498	12.540	33
34	12.582	12.624	12.666	12.708	12.750	12.792	12.835	12.877	12.920	12.962	34
35	13.005	13.047	13.090	13.133	13.176	13.219	13.262	13.305	13.348	13.391	35
36	13.435	13.478	13.521	13.565	13.608	13.652	13.696	13.740	13.784	13.827	36
37	13.871	13.916	13.960	14.004	14.048	14.093	14.137	14.182	14.226	14.271	37
38	14.316	14.360	14.405	14.450	14.495	14.540	14.586	14.631	14.676	14.722	38
39	14.767	14.813	14.858	14.904	14.950	14.996	15.042	15.088	15.134	15.180	39
40	15.226	15.273	15.319	15.366	15.412	15.459	15.506	15.552	15.599	15.646	40
41	15.693	15.741	15.788	15.835	15.883	15.930	15.978	16.025	16.073	16.121	41
42	16.169	16.217	16.265	16.313	16.361	16.409	16.458	16.506	16.555	16.604	42
43	16.652	16.701	16.750	16.799	16.848	16.898	16.947	16.996	17.046	17.095	43
44	17.145	17.195	17.244	17.294	17.344	17.394	17.445	17.495	17.545	17.596	44
45	17.646	17.697	17.748	17.799	17.849	17.901	17.952	18.003	18.054	18.106	45
46	18.157	18.209	18.260	18.312	18.364	18.416	18.468	18.520	18.572	18.625	46
47	18.677	18.730	18.783	18.835	18.888	18.941	18.994	19.047	19.101	19.154	47
48	19.207	19.261	19.315	19.368	19.422	19.476	19.530	19.585	19.639	19.693	48
49	19.748	19.802	19.857	19.912	19.967	20.022	20.077	20.132	20.187	20.243	49
50	20.298	20.354	20.410	20.466	20.522	20.578	20.634	20.690	20.747	20.803	50
51	20.860	20.917	20.974	21.031	21.088	21.145	21.202	21.260	21.317	21.375	51
52	21.433	21.491	21.549	21.607	21.665	21.723	21.782	21.840	21.899	21.958	52
53	22.017	22.076	22.135	22.194	22.254	22.313	22.373	22.433	22.493	22.553	53
54	22.613	22.673	22.734	22.794	22.855	22.916	22.976	23.037	23.099	23.160	54
55	23.221	23.283	23.344	23.406	23.468	23.530	23.592	23.654	23.717	23.779	55
56	23.842	23.905	23.968	24.031	24.094	24.157	24.221	24.284	24.348	24.412	56
57	24.476	24.540	24.604	24.668	24.733	24.798	24.862	24.927	24.992	25.057	57
58	25.123	25.188	25.254	25.320	25.385	25.451	25.518	25.584	25.650	25.717	58
59	25.784	25.850	25.917	25.985	26.052	26.119	26.187	26.255	26.322	26.390	59
60	26.459	26.527	26.595	26.664	26.733	26.802	26.871	26.940	27.009	27.079	60
61	27.148	27.218	27.288	27.358	27.428	27.499	27.569	27.640	27.711	27.782	61
62	27.853	27.924	27.996	28.067	28.139	28.211	28.283	28.355	28.428	28.500	62
63	28.573	28.646	28.719	28.792	28.866	28.939	29.013	29.087	29.161	29.235	63
64	29.309	29.384	29.458	29.533	29.608	29.683	29.759	29.834	29.910	29.986	64
65	30.062	30.138	30.214	30.291	30.367	30.444	30.521	30.598	30.676	30.753	65
66	30.831	30.909	30.987	31.065	31.144	31.222	31.301	31.380	31.459	31.539	66
67	31.618	31.698	31.778	31.858	31.938	32.018	32.099	32.179	32.260	32.342	67
68	32.423	32.504	32.586	32.668	32.750	32.832	32.915	32.997	33.080	33.163	68
69	33.246	33.330	33.413	33.497	33.581	33.665	33.749	33.834	33.919	34.004	69
70	34.089	34.174	34.259	34.345	34.431	34.517	34.603	34.690	34.777	34.86356	70
°F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	°F

Enthalpy of Saturated Air - Water Vapor Mixtures at 29.921 in Hg (sea level)

°F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	°F
71	34.951	35.038	35.125	35.213	35.301	35.389	35.478	35.566	35.655	35.744	71
72	35.833	35.922	36.012	36.102	36.192	36.282	36.372	36.463	36.554	36.645	72
73	36.736	36.827	36.919	37.011	37.103	37.195	37.288	37.381	37.474	37.567	73
74	37.660	37.754	37.848	37.942	38.036	38.131	38.226	38.321	38.416	38.511	74
75	38.607	38.703	38.799	38.895	38.992	39.089	39.186	39.283	39.380	39.478	75
76	39.576	39.674	39.773	39.871	39.970	40.070	40.169	40.269	40.368	40.468	76
77	40.569	40.669	40.770	40.871	40.973	41.074	41.176	41.278	41.380	41.483	77
78	41.586	41.689	41.792	41.895	41.999	42.103	42.207	42.312	42.417	42.522	78
79	42.627	42.733	42.838	42.945	43.051	43.157	43.264	43.371	43.479	43.586	79
80	43.694	43.802	43.911	44.019	44.128	44.238	44.347	44.457	44.567	44.677	80
81	44.788	44.898	45.009	45.121	45.232	45.344	45.457	45.569	45.682	45.795	81
82	45.908	46.022	46.135	46.250	46.364	46.479	46.594	46.709	46.825	46.940	82
83	47.057	47.173	47.290	47.407	47.524	47.641	47.759	47.877	47.996	48.115	83
84	48.234	48.353	48.473	48.593	48.713	48.833	48.954	49.075	49.197	49.318	84
85	49.440	49.563	49.685	49.808	49.932	50.055	50.179	50.303	50.428	50.552	85
86	50.678	50.803	50.929	51.055	51.181	51.308	51.435	51.562	51.690	51.818	86
87	51.946	52.075	52.204	52.333	52.463	52.593	52.723	52.853	52.984	53.116	87
88	53.247	53.379	53.511	53.644	53.777	53.910	54.044	54.178	54.312	54.446	88
89	54.581	54.717	54.852	54.988	55.125	55.261	55.398	55.536	55.674	55.812	89
90	55.950	56.089	56.228	56.367	56.507	56.648	56.788	56.929	57.070	57.212	90
91	57.354	57.496	57.639	57.782	57.926	58.070	58.214	58.358	58.503	58.649	91
92	58.794	58.940	59.087	59.234	59.381	59.529	59.676	59.825	59.974	60.123	92
93	60.272	60.422	60.572	60.723	60.874	61.026	61.177	61.330	61.482	61.635	93
94	61.789	61.943	62.097	62.252	62.407	62.562	62.718	62.874	63.031	63.188	94
95	63.345	63.503	63.661	63.820	63.979	64.139	64.299	64.459	64.620	64.781	95
96	64.943	65.105	65.267	65.430	65.594	65.757	65.921	66.086	66.251	66.417	96
97	66.583	66.749	66.916	67.083	67.251	67.419	67.587	67.756	67.926	68.096	97
98	68.266	68.437	68.608	68.780	68.952	69.125	69.298	69.471	69.645	69.820	98
99	69.995	70.170	70.346	70.522	70.699	70.876	71.054	71.232	71.411	71.590	99
100	71.769	71.949	72.130	72.311	72.493	72.675	72.857	73.040	73.224	73.408	100
101	73.592	73.777	73.962	74.148	74.335	74.522	74.709	74.897	75.086	75.275	101
102	75.464	75.654	75.845	76.036	76.227	76.419	76.612	76.805	76.998	77.192	102
103	77.387	77.582	77.778	77.974	78.171	78.368	78.566	78.764	78.963	79.162	103
104	79.362	79.563	79.764	79.965	80.168	80.370	80.573	80.777	80.982	81.186	104
105	81.392	81.598	81.804	82.012	82.219	82.427	82.636	82.846	83.056	83.266	105
106	83.477	83.689	83.901	84.114	84.327	84.541	84.756	84.971	85.187	85.403	106
107	85.620	85.838	86.056	86.275	86.494	86.714	86.934	87.156	87.377	87.600	107
108	87.823	88.046	88.270	88.495	88.721	88.947	89.174	89.401	89.629	89.857	108
109	90.087	90.317	90.547	90.778	91.010	91.242	91.475	91.709	91.943	92.178	109
110	92.414	92.650	92.887	93.125	93.363	93.602	93.842	94.082	94.323	94.565	110
111	94.807	95.050	95.294	95.538	95.783	96.029	96.275	96.522	96.770	97.018	111
112	97.268	97.517	97.768	98.019	98.271	98.524	98.777	99.031	99.286	99.542	112
113	99.789	100.05	100.31	100.57	100.83	101.09	101.35	101.61	101.87	102.14	113
114	102.40	102.67	102.93	103.20	103.46	103.73	104.00	104.27	104.54	104.81	114
115	105.08	105.35	105.62	105.90	106.17	106.45	106.72	107.00	107.28	107.55	115
116	107.83	108.11	108.39	108.67	108.96	109.24	109.52	109.81	110.09	110.38	116
117	110.67	110.95	111.24	111.53	111.82	112.11	112.41	112.70	112.99	113.29	117
118	113.58	113.88	114.18	114.48	114.77	115.07	115.37	115.68	115.98	116.28	118
119	116.59	116.89	117.20	117.50	117.81	118.12	118.43	118.74	119.05	119.36	119
120	119.68	119.99	120.31	120.62	120.94	121.26	121.57	121.89	122.21	122.54	120
121	122.86	123.18	123.51	123.83	124.16	124.48	124.81	125.14	125.47	125.80	121
122	126.14	126.47	126.80	127.14	127.47	127.81	128.15	128.49	128.83	129.17	122
123	129.51	129.85	130.20	130.54	130.89	131.24	131.58	131.93	132.28	132.63	123
124	132.99	133.34	133.69	134.05	134.41	134.76	135.12	135.48	135.84	136.20	124
125	136.57	136.93	137.30	137.66	138.03	138.40	138.77	139.14	139.51	139.88	125
126	140.26	140.63	141.01	141.39	141.77	142.15	142.53	142.91	143.29	143.68	126
127	144.06	144.45	144.84	145.23	145.62	146.01	146.40	146.79	147.19	147.59	127
128	147.98	148.38	148.78	149.18	149.59	149.99	150.39	150.80	151.21	151.62	128
129	152.03	152.44	152.85	153.26	153.68	154.10	154.51	154.93	155.35	155.77	129
130	156.20	156.62	157.05	157.47	157.90	158.33	158.76	159.19	159.63	160.06	130
131	160.50	160.93	161.37	161.81	162.26	162.70	163.14	163.59	164.04	164.48	131
132	164.93	165.39	165.84	166.29	166.75	167.21	167.66	168.12	168.59	169.05	132
133	169.51	169.98	170.45	170.91	171.39	171.86	172.33	172.81	173.28	173.76	133
134	174.24	174.72	175.20	175.69	176.17	176.66	177.15	177.64	178.13	178.62	134
135	179.12	179.61	180.11	180.61	181.11	181.62	182.12	182.63	183.14	183.65	135
136	184.16	184.67	185.18	185.70	186.22	186.74	187.26	187.78	188.31	188.83	136
137	189.36	189.89	190.42	190.96	191.49	192.03	192.57	193.11	193.65	194.19	137
138	194.74	195.29	195.84	196.39	196.94	197.50	198.05	198.61	199.17	199.73	138
139	200.30	200.86	201.43	202.00	202.57	203.15	203.72	204.30	204.88	205.46	139
140	206.04	206.63	207.22	207.80	208.40	208.99	209.58	210.18	210.78	211.38	140
°F	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	°F

Properties of Saturated Air - Water Vapor Mixtures at 29.921 in Hg (sea level)

°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F
0	0.8352	0.08625	11.6034	0.00079	0	71	34.951	0.07402	13.7313	0.01639	71
1	1.1205	0.08606	11.6294	0.00083	1	72	35.833	0.07386	13.7697	0.01697	72
2	1.4080	0.08587	11.6555	0.00087	2	73	36.736	0.07369	13.8086	0.01757	73
3	1.6978	0.08568	11.6816	0.00092	3	74	37.660	0.07353	13.8479	0.01819	74
4	1.9901	0.08550	11.7078	0.00097	4	75	38.607	0.07336	13.8877	0.01883	75
5	2.2849	0.08531	11.7340	0.00102	5	76	39.576	0.07320	13.9279	0.01949	76
6	2.5824	0.08512	11.7603	0.00107	6	77	40.569	0.07303	13.9687	0.02017	77
7	2.8827	0.08494	11.7866	0.00113	7	78	41.586	0.07287	14.0100	0.02087	78
8	3.1859	0.08475	11.8129	0.00119	8	79	42.627	0.07270	14.0518	0.02159	79
9	3.4921	0.08457	11.8394	0.00125	9	80	43.694	0.07254	14.0942	0.02234	80
10	3.8015	0.08439	11.8659	0.00132	10	81	44.788	0.07236	14.1372	0.02311	81
11	4.1142	0.08420	11.8924	0.00138	11	82	45.908	0.07220	14.1807	0.02390	82
12	4.4304	0.08402	11.9190	0.00145	12	83	47.057	0.07203	14.2249	0.02472	83
13	4.7501	0.08384	11.9457	0.00153	13	84	48.234	0.07186	14.2697	0.02556	84
14	5.0736	0.08366	11.9725	0.00161	14	85	49.440	0.07170	14.3151	0.02643	85
15	5.4010	0.08348	11.9993	0.00169	15	86	50.678	0.07153	14.3612	0.02733	86
16	5.7325	0.08330	12.0263	0.00177	16	87	51.946	0.07136	14.4080	0.02825	87
17	6.0682	0.08312	12.0533	0.00186	17	88	53.247	0.07119	14.4556	0.02920	88
18	6.4084	0.08294	12.0803	0.00195	18	89	54.581	0.07102	14.5038	0.03019	89
19	6.7532	0.08276	12.1075	0.00205	19	90	55.950	0.07085	14.5528	0.03120	90
20	7.1028	0.08259	12.1348	0.00215	20	91	57.354	0.07068	14.6026	0.03224	91
21	7.4574	0.08241	12.1622	0.00226	21	92	58.794	0.07051	14.6532	0.03332	92
22	7.8172	0.08223	12.1896	0.00237	22	93	60.272	0.07034	14.7046	0.03443	93
23	8.1824	0.08206	12.2172	0.00249	23	94	61.789	0.07017	14.7569	0.03557	94
24	8.5533	0.08188	12.2449	0.00261	24	95	63.345	0.07000	14.8100	0.03675	95
25	8.9300	0.08170	12.2727	0.00273	25	96	64.943	0.06983	14.8641	0.03797	96
26	9.3129	0.08153	12.3006	0.00287	26	97	66.583	0.06965	14.9191	0.03922	97
27	9.7022	0.08136	12.3287	0.00300	27	98	68.266	0.06948	14.9751	0.04051	98
28	10.098	0.08118	12.3568	0.00315	28	99	69.995	0.06930	15.0321	0.04184	99
29	10.501	0.08101	12.3851	0.00330	29	100	71.769	0.06913	15.0901	0.04321	100
30	10.911	0.08084	12.4136	0.00345	30	101	73.592	0.06895	15.1492	0.04463	101
31	11.328	0.08066	12.4422	0.00362	31	102	75.464	0.06877	15.2094	0.04609	102
32	11.755	0.08049	12.4710	0.00379	32	103	77.387	0.06860	15.2707	0.04759	103
33	12.165	0.08032	12.4995	0.00395	33	104	79.362	0.06842	15.3333	0.04914	104
34	12.582	0.08015	12.5281	0.00411	34	105	81.392	0.06824	15.3970	0.05073	105
35	13.005	0.07998	12.5569	0.00428	35	106	83.477	0.06806	15.4620	0.05238	106
36	13.435	0.07981	12.5858	0.00445	36	107	85.620	0.06788	15.5283	0.05407	107
37	13.871	0.07964	12.6148	0.00463	37	108	87.823	0.06769	15.5959	0.05582	108
38	14.316	0.07947	12.6440	0.00482	38	109	90.087	0.06751	15.6649	0.05762	109
39	14.767	0.07930	12.6733	0.00501	39	110	92.414	0.06733	15.7353	0.05948	110
40	15.226	0.07913	12.7028	0.00522	40	111	94.807	0.06714	15.8073	0.06140	111
41	15.693	0.07897	12.7324	0.00542	41	112	97.268	0.06695	15.8807	0.06337	112
42	16.169	0.07880	12.7623	0.00564	42	113	99.798	0.06677	15.9558	0.06541	113
43	16.652	0.07863	12.7922	0.00586	43	114	102.40	0.06658	16.0324	0.06751	114
44	17.145	0.07846	12.8224	0.00609	44	115	105.08	0.06639	16.1108	0.06967	115
45	17.646	0.07830	12.8528	0.00633	45	116	107.83	0.06620	16.1909	0.07190	116
46	18.157	0.07813	12.8833	0.00658	46	117	110.67	0.06601	16.2729	0.07421	117
47	18.677	0.07796	12.9141	0.00684	47	118	113.58	0.06581	16.3567	0.07658	118
48	19.207	0.07780	12.9450	0.00710	48	119	116.59	0.06562	16.4425	0.07903	119
49	19.748	0.07763	12.9762	0.00738	49	120	119.68	0.06542	16.5303	0.08156	120
50	20.298	0.07747	13.0075	0.00766	50	121	122.86	0.06523	16.6201	0.08416	121
51	20.860	0.07730	13.0391	0.00795	51	122	126.14	0.06503	16.7122	0.08685	122
52	21.433	0.07714	13.0710	0.00826	52	123	129.51	0.06483	16.8065	0.08963	123
53	22.017	0.07697	13.1030	0.00857	53	124	132.99	0.06463	16.9031	0.09249	124
54	22.613	0.07681	13.1354	0.00890	54	125	136.57	0.06443	17.0021	0.09545	125
55	23.221	0.07664	13.1679	0.00923	55	126	140.26	0.06422	17.1036	0.09850	126
56	23.842	0.07648	13.2008	0.00958	56	127	144.06	0.06402	17.2077	0.10165	127
57	24.476	0.07631	13.2339	0.00994	57	128	147.98	0.06381	17.3145	0.10490	128
58	25.123	0.07615	13.2673	0.01031	58	129	152.03	0.06360	17.4241	0.10826	129
59	25.784	0.07599	13.3009	0.01069	59	130	156.20	0.06339	17.5367	0.11173	130
60	26.459	0.07582	13.3349	0.01109	60	131	160.50	0.06318	17.6522	0.11532	131
61	27.148	0.07566	13.3692	0.01150	61	132	164.93	0.06296	17.7709	0.11902	132
62	27.853	0.07549	13.4038	0.01192	62	133	169.51	0.06275	17.8929	0.12285	133
63	28.573	0.07533	13.4387	0.01235	63	134	174.24	0.06253	18.0182	0.12680	134
64	29.309	0.07517	13.4740	0.01280	64	135	179.12	0.06231	18.1471	0.13089	135
65	30.062	0.07500	13.5096	0.01327	65	136	184.16	0.06209	18.2797	0.13512	136
66	30.831	0.07484	13.5456	0.01375	66	137	189.36	0.06187	18.4162	0.13949	137
67	31.618	0.07468	13.5820	0.01425	67	138	194.74	0.06164	18.5566	0.14401	138
68	32.423	0.07451	13.6187	0.01476	68	139	200.30	0.06142	18.7012	0.14869	139
69	33.246	0.07435	13.6558	0.01529	69	140	206.04	0.06119	18.8502	0.15353	140
70	34.089	0.07418	13.6934	0.01583	70						
°F	Enthalpy	Density	SpVol	HR	°F	°F	Enthalpy	Density	SpVol	HR	°F

Properties of Saturated Air - Water Vapor Mixtures at 29.00 in Hg

°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F
0	0.86173	0.08359	11.9724	0.00081	0	71	35.533	0.07172	14.1793	0.01692	71
1	1.1484	0.08341	11.9993	0.00086	1	72	36.437	0.07156	14.2193	0.01752	72
2	1.4374	0.08323	12.0262	0.00090	2	73	37.362	0.07140	14.2599	0.01814	73
3	1.7288	0.08304	12.0532	0.00095	3	74	38.310	0.07124	14.3009	0.01878	74
4	2.0227	0.08286	12.0802	0.00100	4	75	39.280	0.07108	14.3425	0.01944	75
5	2.3193	0.08268	12.1073	0.00105	5	76	40.274	0.07092	14.3845	0.02012	76
6	2.6186	0.08250	12.1344	0.00111	6	77	41.292	0.07076	14.4271	0.02082	77
7	2.9208	0.08232	12.1616	0.00117	7	78	42.335	0.07060	14.4703	0.02155	78
8	3.2260	0.08214	12.1888	0.00123	8	79	43.403	0.07044	14.5141	0.02230	79
9	3.5343	0.08196	12.2162	0.00129	9	80	44.499	0.07027	14.5584	0.02307	80
10	3.8459	0.08179	12.2435	0.00136	10	81	45.621	0.07011	14.6033	0.02386	81
11	4.1610	0.08161	12.2710	0.00143	11	82	46.772	0.06994	14.6489	0.02468	82
12	4.4795	0.08143	12.2985	0.00150	12	83	47.951	0.06978	14.6951	0.02553	83
13	4.8018	0.08126	12.3261	0.00158	13	84	49.160	0.06962	14.7421	0.02640	84
14	5.1280	0.08108	12.3537	0.00166	14	85	50.400	0.06946	14.7897	0.02730	85
15	5.4582	0.08091	12.3815	0.00174	15	86	51.672	0.06929	14.8380	0.02823	86
16	5.7926	0.08073	12.4093	0.00183	16	87	52.976	0.06913	14.8870	0.02918	87
17	6.1314	0.08056	12.4372	0.00192	17	88	54.314	0.06896	14.9369	0.03017	88
18	6.4747	0.08038	12.4652	0.00202	18	89	55.686	0.06880	14.9875	0.03119	89
19	6.8228	0.08021	12.4933	0.00212	19	90	57.094	0.06863	15.0389	0.03223	90
20	7.1759	0.08004	12.5215	0.00222	20	91	58.539	0.06847	15.0911	0.03332	91
21	7.5341	0.07987	12.5498	0.00233	21	92	60.021	0.06830	15.1442	0.03443	92
22	7.8978	0.07970	12.5783	0.00244	22	93	61.543	0.06813	15.1982	0.03558	93
23	8.2670	0.07953	12.6068	0.00256	23	94	63.105	0.06797	15.2532	0.03676	94
24	8.6420	0.07936	12.6354	0.00269	24	95	64.708	0.06780	15.3090	0.03798	95
25	9.0232	0.07919	12.6642	0.00282	25	96	66.353	0.06763	15.3659	0.03924	96
26	9.4106	0.07902	12.6931	0.00296	26	97	68.043	0.06746	15.4237	0.04054	97
27	9.8046	0.07885	12.7221	0.00310	27	98	69.779	0.06729	15.4826	0.04188	98
28	10.206	0.07868	12.7513	0.00325	28	99	71.561	0.06712	15.5426	0.04326	99
29	10.613	0.07851	12.7806	0.00340	29	100	73.391	0.06695	15.6037	0.04468	100
30	11.029	0.07834	12.8101	0.00356	30	101	75.271	0.06677	15.6659	0.04614	101
31	11.452	0.07817	12.8397	0.00373	31	102	77.202	0.06660	15.7294	0.04765	102
32	11.885	0.07801	12.8695	0.00391	32	103	79.187	0.06643	15.7940	0.04921	103
33	12.300	0.07784	12.8990	0.00407	33	104	81.226	0.06625	15.8599	0.05081	104
34	12.723	0.07768	12.9287	0.00424	34	105	83.322	0.06608	15.9271	0.05247	105
35	13.151	0.07751	12.9585	0.00441	35	106	85.475	0.06590	15.9957	0.05418	106
36	13.587	0.07735	12.9884	0.00459	36	107	87.689	0.06572	16.0657	0.05593	107
37	14.031	0.07718	13.0185	0.00478	37	108	89.965	0.06554	16.1371	0.05775	108
38	14.481	0.07702	13.0487	0.00497	38	109	92.305	0.06536	16.2100	0.05962	109
39	14.940	0.07685	13.0791	0.00517	39	110	94.712	0.06518	16.2844	0.06155	110
40	15.406	0.07669	13.1097	0.00538	40	111	97.186	0.06500	16.3604	0.06353	111
41	15.880	0.07653	13.1404	0.00560	41	112	99.732	0.06482	16.4381	0.06558	112
42	16.363	0.07636	13.1713	0.00582	42	113	102.35	0.06464	16.5175	0.06770	113
43	16.855	0.07620	13.2025	0.00605	43	114	105.04	0.06445	16.5987	0.06988	114
44	17.355	0.07604	13.2337	0.00629	44	115	107.82	0.06427	16.6817	0.07213	115
45	17.865	0.07588	13.2652	0.00654	45	116	110.67	0.06408	16.7665	0.07445	116
46	18.385	0.07572	13.2969	0.00679	46	117	113.61	0.06389	16.8534	0.07684	117
47	18.914	0.07555	13.3288	0.00706	47	118	116.63	0.06370	16.9422	0.07931	118
48	19.454	0.07539	13.3609	0.00733	48	119	119.74	0.06351	17.0332	0.08186	119
49	20.004	0.07523	13.3933	0.00761	49	120	122.95	0.06332	17.1264	0.08448	120
50	20.565	0.07507	13.4259	0.00791	50	121	126.25	0.06312	17.2218	0.08720	121
51	21.137	0.07491	13.4587	0.00821	51	122	129.65	0.06293	17.3195	0.09000	122
52	21.720	0.07475	13.4918	0.00852	52	123	133.15	0.06273	17.4197	0.09289	123
53	22.315	0.07459	13.5251	0.00885	53	124	136.76	0.06254	17.5224	0.09587	124
54	22.923	0.07443	13.5587	0.00918	54	125	140.48	0.06234	17.6277	0.09895	125
55	23.543	0.07427	13.5925	0.00953	55	126	144.31	0.06214	17.7357	0.10213	126
56	24.176	0.07411	13.6266	0.00989	56	127	148.27	0.06193	17.8466	0.10541	127
57	24.823	0.07395	13.6611	0.01026	57	128	152.35	0.06173	17.9603	0.10880	128
58	25.484	0.07379	13.6958	0.01064	58	129	156.55	0.06153	18.0772	0.11230	129
59	26.158	0.07363	13.7308	0.01104	59	130	160.89	0.06132	18.1971	0.11592	130
60	26.847	0.07347	13.7662	0.01144	60	131	165.37	0.06111	18.3204	0.11966	131
61	27.552	0.07331	13.8019	0.01187	61	132	169.99	0.06090	18.4471	0.12353	132
62	28.272	0.07315	13.8379	0.01230	62	133	174.76	0.06069	18.5773	0.12753	133
63	29.008	0.07300	13.8743	0.01275	63	134	179.69	0.06048	18.7113	0.13166	134
64	29.760	0.07284	13.9110	0.01322	64	135	184.78	0.06026	18.8491	0.13593	135
65	30.530	0.07268	13.9481	0.01370	65	136	190.04	0.06004	18.9909	0.14035	136
66	31.317	0.07252	13.9856	0.01419	66	137	195.47	0.05982	19.1369	0.14493	137
67	32.122	0.07236	14.0235	0.01471	67	138	201.09	0.05960	19.2873	0.14966	138
68	32.945	0.07220	14.0618	0.01524	68	139	206.90	0.05938	19.4423	0.15456	139
69	33.788	0.07204	14.1005	0.01578	69	140	212.90	0.05915	19.6020	0.15964	140
70	34.650	0.07188	14.1396	0.01635	70						
°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F

Properties of Saturated Air - Water Vapor Mixtures at 28.00 in Hg

°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F
0	0.89243	0.08071	12.4005	0.00084	0	71	36.210	0.06922	14.6999	0.01754	71
1	1.1808	0.08053	12.4284	0.00089	1	72	37.139	0.06906	14.7419	0.01816	72
2	1.4715	0.08036	12.4563	0.00093	2	73	38.090	0.06891	14.7845	0.01881	73
3	1.7647	0.08018	12.4843	0.00098	3	74	39.064	0.06875	14.8276	0.01947	74
4	2.0606	0.08000	12.5123	0.00104	4	75	40.062	0.06859	14.8712	0.02016	75
5	2.3592	0.07983	12.5404	0.00109	5	76	41.085	0.06844	14.9155	0.02086	76
6	2.6606	0.07965	12.5686	0.00115	6	77	42.132	0.06828	14.9602	0.02159	77
7	2.9650	0.07948	12.5968	0.00121	7	78	43.206	0.06813	15.0056	0.02234	78
8	3.2726	0.07931	12.6250	0.00127	8	79	44.306	0.06797	15.0516	0.02312	79
9	3.5833	0.07914	12.6534	0.00134	9	80	45.434	0.06781	15.0983	0.02392	80
10	3.8975	0.07896	12.6818	0.00141	10	81	46.590	0.06765	15.1456	0.02475	81
11	4.2152	0.07879	12.7103	0.00148	11	82	47.776	0.06750	15.1936	0.02560	82
12	4.5366	0.07862	12.7388	0.00155	12	83	48.992	0.06734	15.2423	0.02648	83
13	4.8618	0.07845	12.7674	0.00163	13	84	50.239	0.06718	15.2917	0.02738	84
14	5.1911	0.07828	12.7962	0.00172	14	85	51.517	0.06702	15.3418	0.02832	85
15	5.5245	0.07811	12.8250	0.00180	15	86	52.829	0.06686	15.3928	0.02928	86
16	5.8623	0.07795	12.8538	0.00189	16	87	54.175	0.06670	15.4445	0.03027	87
17	6.2046	0.07778	12.8828	0.00199	17	88	55.555	0.06654	15.4971	0.03130	88
18	6.5517	0.07761	12.9119	0.00209	18	89	56.972	0.06638	15.5505	0.03235	89
19	6.9036	0.07744	12.9411	0.00219	19	90	58.426	0.06622	15.6048	0.03344	90
20	7.2608	0.07728	12.9704	0.00230	20	91	59.918	0.06606	15.6600	0.03457	91
21	7.6233	0.07711	12.9998	0.00241	21	92	61.450	0.06590	15.7161	0.03573	92
22	7.9913	0.07694	13.0293	0.00253	22	93	63.023	0.06573	15.7732	0.03692	93
23	8.3652	0.07678	13.0590	0.00266	23	94	64.637	0.06557	15.8312	0.03815	94
24	8.7451	0.07661	13.0887	0.00279	24	95	66.295	0.06541	15.8903	0.03942	95
25	9.1313	0.07645	13.1186	0.00292	25	96	67.997	0.06524	15.9505	0.04073	96
26	9.5240	0.07629	13.1487	0.00306	26	97	69.745	0.06508	16.0118	0.04208	97
27	9.9236	0.07612	13.1788	0.00321	27	98	71.541	0.06491	16.0741	0.04347	98
28	10.330	0.07596	13.2092	0.00336	28	99	73.386	0.06474	16.1377	0.04491	99
29	10.744	0.07580	13.2397	0.00352	29	100	75.281	0.06458	16.2024	0.04639	100
30	11.166	0.07563	13.2703	0.00369	30	101	77.229	0.06441	16.2684	0.04791	101
31	11.596	0.07547	13.3011	0.00387	31	102	79.230	0.06424	16.3357	0.04948	102
32	12.035	0.07531	13.3322	0.00405	32	103	81.286	0.06407	16.4043	0.05111	103
33	12.457	0.07515	13.3628	0.00422	33	104	83.400	0.06390	16.4743	0.05278	104
34	12.886	0.07499	13.3937	0.00439	34	105	85.573	0.06373	16.5457	0.05450	105
35	13.322	0.07483	13.4247	0.00457	35	106	87.807	0.06356	16.6185	0.05628	106
36	13.765	0.07467	13.4558	0.00476	36	107	90.104	0.06338	16.6929	0.05811	107
37	14.215	0.07451	13.4871	0.00495	37	108	92.466	0.06321	16.7688	0.06000	108
38	14.674	0.07435	13.5186	0.00515	38	109	94.896	0.06303	16.8464	0.06195	109
39	15.140	0.07419	13.5503	0.00536	39	110	97.395	0.06286	16.9257	0.06396	110
40	15.614	0.07404	13.5821	0.00558	40	111	99.966	0.06268	17.0066	0.06604	111
41	16.097	0.07388	13.6141	0.00580	41	112	102.61	0.06250	17.0894	0.06818	112
42	16.589	0.07372	13.6463	0.00603	42	113	105.33	0.06232	17.1740	0.07038	113
43	17.090	0.07356	13.6787	0.00627	43	114	108.13	0.06214	17.2606	0.07266	114
44	17.600	0.07341	13.7113	0.00652	44	115	111.02	0.06196	17.3491	0.07501	115
45	18.120	0.07325	13.7441	0.00677	45	116	113.99	0.06178	17.4397	0.07743	116
46	18.649	0.07309	13.7772	0.00704	46	117	117.04	0.06159	17.5324	0.07993	117
47	19.189	0.07294	13.8104	0.00731	47	118	120.19	0.06141	17.6274	0.08251	118
48	19.740	0.07278	13.8439	0.00759	48	119	123.43	0.06122	17.7246	0.08517	119
49	20.301	0.07263	13.8777	0.00789	49	120	126.77	0.06103	17.8243	0.08792	120
50	20.873	0.07247	13.9117	0.00819	50	121	130.21	0.06084	17.9264	0.09076	121
51	21.458	0.07232	13.9459	0.00851	51	122	133.76	0.06065	18.0310	0.09368	122
52	22.054	0.07216	13.9804	0.00883	52	123	137.41	0.06046	18.1383	0.09671	123
53	22.662	0.07201	14.0152	0.00917	53	124	141.18	0.06027	18.2484	0.09983	124
54	23.283	0.07185	14.0503	0.00951	54	125	145.07	0.06007	18.3613	0.10306	125
55	23.917	0.07170	14.0856	0.00987	55	126	149.07	0.05987	18.4772	0.10639	126
56	24.565	0.07154	14.1213	0.01025	56	127	153.20	0.05968	18.5962	0.10983	127
57	25.227	0.07139	14.1573	0.01063	57	128	157.47	0.05948	18.7184	0.11338	128
58	25.903	0.07123	14.1936	0.01103	58	129	161.87	0.05927	18.8440	0.11706	129
59	26.593	0.07108	14.2302	0.01144	59	130	166.41	0.05907	18.9730	0.12085	130
60	27.299	0.07092	14.2672	0.01186	60	131	171.10	0.05887	19.1056	0.12478	131
61	28.021	0.07077	14.3045	0.01230	61	132	175.94	0.05866	19.2420	0.12884	132
62	28.758	0.07061	14.3422	0.01275	62	133	180.94	0.05845	19.3823	0.13304	133
63	29.513	0.07046	14.3803	0.01322	63	134	186.10	0.05824	19.5267	0.13738	134
64	30.284	0.07030	14.4187	0.01370	64	135	191.44	0.05803	19.6755	0.14188	135
65	31.073	0.07015	14.4576	0.01420	65	136	196.96	0.05782	19.8285	0.14653	136
66	31.881	0.07000	14.4969	0.01471	66	137	202.67	0.05760	19.9862	0.15135	137
67	32.707	0.06984	14.5366	0.01524	67	138	208.57	0.05738	20.1488	0.15633	138
68	33.552	0.06969	14.5767	0.01579	68	139	214.68	0.05717	20.3164	0.16150	139
69	34.418	0.06953	14.6173	0.01636	69	140	221.00	0.05694	20.4893	0.16685	140
70	35.303	0.06938	14.6584	0.01694	70						
°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F

Properties of Saturated Air - Water Vapor Mixtures at 27.00 in Hg

°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F
0	0.92540	0.07783	12.8605	0.00087	0	71	36.939	0.06672	15.2602	0.01821	71
1	1.2155	0.07765	12.8894	0.00092	1	72	37.895	0.06657	15.3044	0.01886	72
2	1.5081	0.07748	12.9184	0.00097	2	73	38.874	0.06642	15.3492	0.01952	73
3	1.8033	0.07731	12.9475	0.00102	3	74	39.877	0.06627	15.3945	0.02021	74
4	2.1013	0.07714	12.9766	0.00107	4	75	40.904	0.06612	15.4405	0.02093	75
5	2.4020	0.07698	13.0057	0.00113	5	76	41.958	0.06596	15.4870	0.02166	76
6	2.7057	0.07681	13.0350	0.00119	6	77	43.037	0.06581	15.5342	0.02242	77
7	3.0125	0.07664	13.0643	0.00125	7	78	44.144	0.06566	15.5820	0.02320	78
8	3.3226	0.07647	13.0936	0.00132	8	79	45.278	0.06551	15.6305	0.02401	79
9	3.6360	0.07631	13.1231	0.00139	9	80	46.442	0.06536	15.6797	0.02484	80
10	3.9529	0.07614	13.1526	0.00146	10	81	47.635	0.06520	15.7296	0.02570	81
11	4.2735	0.07598	13.1822	0.00153	11	82	48.858	0.06505	15.7803	0.02658	82
12	4.5979	0.07581	13.2118	0.00161	12	83	50.113	0.06490	15.8317	0.02750	83
13	4.9263	0.07565	13.2416	0.00169	13	84	51.400	0.06474	15.8839	0.02844	84
14	5.2588	0.07548	13.2714	0.00178	14	85	52.721	0.06459	15.9369	0.02941	85
15	5.5957	0.07532	13.3014	0.00187	15	86	54.076	0.06443	15.9907	0.03041	86
16	5.9371	0.07516	13.3314	0.00196	16	87	55.467	0.06428	16.0454	0.03145	87
17	6.2833	0.07500	13.3615	0.00206	17	88	56.894	0.06412	16.1010	0.03251	88
18	6.6343	0.07483	13.3918	0.00216	18	89	58.359	0.06397	16.1575	0.03361	89
19	6.9905	0.07467	13.4221	0.00227	19	90	59.862	0.06381	16.2149	0.03475	90
20	7.3520	0.07451	13.4526	0.00239	20	91	61.406	0.06365	16.2734	0.03592	91
21	7.7190	0.07435	13.4832	0.00250	21	92	62.991	0.06349	16.3328	0.03712	92
22	8.0918	0.07419	13.5139	0.00263	22	93	64.619	0.06334	16.3933	0.03837	93
23	8.4707	0.07403	13.5447	0.00275	23	94	66.290	0.06318	16.4549	0.03965	94
24	8.8558	0.07387	13.5757	0.00289	24	95	68.007	0.06302	16.5176	0.04097	95
25	9.2474	0.07372	13.6069	0.00303	25	96	69.771	0.06286	16.5814	0.04234	96
26	9.6459	0.07356	13.6381	0.00318	26	97	71.583	0.06270	16.6464	0.04374	97
27	10.051	0.07340	13.6695	0.00333	27	98	73.444	0.06253	16.7126	0.04520	98
28	10.464	0.07324	13.7011	0.00349	28	99	75.357	0.06237	16.7801	0.04669	99
29	10.885	0.07308	13.7329	0.00365	29	100	77.323	0.06221	16.8489	0.04823	100
30	11.313	0.07293	13.7648	0.00383	30	101	79.343	0.06204	16.9191	0.04982	101
31	11.750	0.07277	13.7969	0.00401	31	102	81.420	0.06188	16.9907	0.05146	102
32	12.197	0.07261	13.8293	0.00420	32	103	83.554	0.06171	17.0637	0.05316	103
33	12.626	0.07246	13.8612	0.00437	33	104	85.750	0.06155	17.1382	0.05490	104
34	13.062	0.07230	13.8934	0.00456	34	105	88.007	0.06138	17.2142	0.05670	105
35	13.505	0.07215	13.9257	0.00474	35	106	90.328	0.06121	17.2918	0.05855	106
36	13.956	0.07200	13.9581	0.00494	36	107	92.716	0.06104	17.3711	0.06047	107
37	14.414	0.07184	13.9908	0.00514	37	108	95.172	0.06087	17.4521	0.06244	108
38	14.881	0.07169	14.0236	0.00534	38	109	97.699	0.06070	17.5349	0.06448	109
39	15.355	0.07154	14.0566	0.00556	39	110	100.30	0.06053	17.6195	0.06658	110
40	15.839	0.07138	14.0898	0.00578	40	111	102.97	0.06036	17.706	0.06875	111
41	16.331	0.07123	14.1232	0.00601	41	112	105.73	0.06018	17.7944	0.07098	112
42	16.832	0.07108	14.1568	0.00625	42	113	108.56	0.06001	17.8849	0.07329	113
43	17.342	0.07093	14.1906	0.00650	43	114	111.48	0.05983	17.9774	0.07567	114
44	17.863	0.07078	14.2246	0.00676	44	115	114.49	0.05965	18.0722	0.07813	115
45	18.393	0.07062	14.2589	0.00702	45	116	117.58	0.05947	18.1692	0.08066	116
46	18.933	0.07047	14.2934	0.00730	46	117	120.77	0.05929	18.2685	0.08328	117
47	19.485	0.07032	14.3282	0.00758	47	118	124.05	0.05911	18.3703	0.08598	118
48	20.047	0.07017	14.3631	0.00788	48	119	127.44	0.05893	18.4746	0.08877	119
49	20.620	0.07002	14.3984	0.00818	49	120	130.93	0.05874	18.5815	0.09165	120
50	21.206	0.06987	14.4339	0.00850	50	121	134.52	0.05856	18.6911	0.09462	121
51	21.803	0.06972	14.4697	0.00882	51	122	138.23	0.05837	18.8035	0.09769	122
52	22.412	0.06957	14.5058	0.00916	52	123	142.05	0.05818	18.9188	0.10086	123
53	23.035	0.06942	14.5422	0.00951	53	124	145.99	0.05799	19.0371	0.10414	124
54	23.670	0.06927	14.5789	0.00987	54	125	150.05	0.05780	19.1586	0.10752	125
55	24.320	0.06912	14.6159	0.01024	55	126	154.25	0.05761	19.2834	0.11102	126
56	24.983	0.06897	14.6532	0.01063	56	127	158.57	0.05742	19.4116	0.11463	127
57	25.661	0.06882	14.6909	0.01103	57	128	163.04	0.05722	19.5433	0.11837	128
58	26.353	0.06867	14.7289	0.01144	58	129	167.65	0.05702	19.6787	0.12223	129
59	27.061	0.06852	14.7673	0.01187	59	130	172.42	0.05682	19.8179	0.12622	130
60	27.785	0.06837	14.8060	0.01231	60	131	177.34	0.05662	19.9611	0.13036	131
61	28.525	0.06822	14.8451	0.01276	61	132	182.42	0.05642	20.1085	0.13463	132
62	29.282	0.06807	14.8847	0.01323	62	133	187.67	0.05622	20.2602	0.13905	133
63	30.056	0.06792	14.9246	0.01372	63	134	193.10	0.05601	20.4165	0.14363	134
64	30.848	0.06777	14.9649	0.01422	64	135	198.72	0.05580	20.5775	0.14837	135
65	31.658	0.06762	15.0057	0.01473	65	136	204.53	0.05559	20.7434	0.15328	136
66	32.488	0.06747	15.0469	0.01527	66	137	210.54	0.05538	20.9144	0.15836	137
67	33.336	0.06732	15.0886	0.01582	67	138	216.76	0.05517	21.0908	0.16362	138
68	34.205	0.06717	15.1308	0.01639	68	139	223.19	0.05495	21.2728	0.16908	139
69	35.095	0.06702	15.1734	0.01698	69	140	229.86	0.05473	21.4608	0.17474	140
70	36.006	0.06687	15.2166	0.01759	70						
°F	Enthalpy	Density	SpVol	HR	°F	°F	Enthalpy	Density	SpVol	HR	°F

Properties of Saturated Air - Water Vapor Mixtures at 26.00 in Hg

°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F
0	0.96090	0.07494	13.3558	0.00091	0	71	37.725	0.06422	15.8649	0.01893	71
1	1.2530	0.07478	13.3859	0.00095	1	72	38.710	0.06407	15.9115	0.01960	72
2	1.5476	0.07461	13.4161	0.00101	2	73	39.719	0.06393	15.9588	0.02030	73
3	1.8449	0.07445	13.4463	0.00106	3	74	40.754	0.06378	16.0066	0.02102	74
4	2.1451	0.07429	13.4766	0.00112	4	75	41.814	0.06364	16.0551	0.02176	75
5	2.4482	0.07412	13.5069	0.00117	5	76	42.900	0.06349	16.1042	0.02252	76
6	2.7543	0.07396	13.5373	0.00124	6	77	44.014	0.06334	16.1540	0.02331	77
7	3.0637	0.07380	13.5678	0.00130	7	78	45.157	0.0632	16.2045	0.02412	78
8	3.3765	0.07364	13.5983	0.00137	8	79	46.328	0.06305	16.2558	0.02496	79
9	3.6927	0.07348	13.6290	0.00144	9	80	47.530	0.06290	16.3078	0.02583	80
10	4.0126	0.07332	13.6597	0.00151	10	81	48.763	0.06275	16.3606	0.02673	81
11	4.3362	0.07316	13.6905	0.00159	11	82	50.027	0.06260	16.4141	0.02765	82
12	4.6639	0.07300	13.7213	0.00167	12	83	51.324	0.06245	16.4685	0.02860	83
13	4.9957	0.07284	13.7523	0.00176	13	84	52.656	0.06230	16.5238	0.02958	84
14	5.3318	0.07269	13.7834	0.00185	14	85	54.022	0.06215	16.5799	0.03060	85
15	5.6725	0.07253	13.8146	0.00194	15	86	55.424	0.06200	16.6369	0.03164	86
16	6.0178	0.07237	13.8458	0.00204	16	87	56.863	0.06185	16.6949	0.03272	87
17	6.3680	0.07221	13.8772	0.00214	17	88	58.341	0.06170	16.7539	0.03383	88
18	6.7233	0.07206	13.9087	0.00225	18	89	59.858	0.06155	16.8138	0.03498	89
19	7.0840	0.07190	13.9403	0.00236	19	90	61.416	0.06140	16.8748	0.03616	90
20	7.4502	0.07175	13.9721	0.00248	20	91	63.015	0.06125	16.9368	0.03738	91
21	7.8221	0.07159	14.0039	0.00260	21	92	64.658	0.06109	16.9999	0.03864	92
22	8.2001	0.07144	14.0359	0.00273	22	93	66.346	0.06094	17.0642	0.03994	93
23	8.5843	0.07129	14.0681	0.00286	23	94	68.080	0.06078	17.1297	0.04127	94
24	8.9750	0.07113	14.1004	0.00300	24	95	69.861	0.06063	17.1963	0.04265	95
25	9.3726	0.07098	14.1328	0.00315	25	96	71.691	0.06047	17.2642	0.04408	96
26	9.7771	0.07083	14.1654	0.00330	26	97	73.572	0.06031	17.3334	0.04555	97
27	10.189	0.07067	14.1982	0.00346	27	98	75.504	0.06016	17.4039	0.04706	98
28	10.609	0.07052	14.2312	0.00362	28	99	77.491	0.06000	17.4759	0.04862	99
29	11.036	0.07037	14.2643	0.00380	29	100	79.534	0.05984	17.5492	0.05023	100
30	11.472	0.07022	14.2976	0.00398	30	101	81.633	0.05968	17.6240	0.05190	101
31	11.916	0.07007	14.3311	0.00417	31	102	83.792	0.05952	17.7004	0.05361	102
32	12.372	0.06992	14.3649	0.00436	32	103	86.013	0.05936	17.7783	0.05538	103
33	12.808	0.06977	14.3982	0.00454	33	104	88.296	0.05920	17.8578	0.05720	104
34	13.251	0.06962	14.4318	0.00473	34	105	90.645	0.05903	17.9390	0.05908	105
35	13.702	0.06947	14.4655	0.00493	35	106	93.062	0.05887	18.0220	0.06102	106
36	14.161	0.06932	14.4994	0.00513	36	107	95.548	0.05870	18.1068	0.06302	107
37	14.628	0.06917	14.5335	0.00534	37	108	98.107	0.05854	18.1934	0.06509	108
38	15.103	0.06903	14.5677	0.00555	38	109	100.74	0.05837	18.2820	0.06722	109
39	15.587	0.06888	14.6022	0.00578	39	110	103.45	0.05820	18.3726	0.06942	110
40	16.080	0.06873	14.6369	0.00601	40	111	106.24	0.05803	18.4653	0.07169	111
41	16.582	0.06858	14.6718	0.00625	41	112	109.11	0.05786	18.5601	0.07403	112
42	17.093	0.06844	14.7069	0.00650	42	113	112.07	0.05769	18.6571	0.07645	113
43	17.615	0.06829	14.7423	0.00675	43	114	115.12	0.05752	18.7564	0.07894	114
44	18.146	0.06814	14.7779	0.00702	44	115	118.26	0.05735	18.8582	0.08152	115
45	18.688	0.06800	14.8137	0.00730	45	116	121.49	0.05717	18.9624	0.08418	116
46	19.240	0.06785	14.8498	0.00758	46	117	124.82	0.05699	19.0691	0.08692	117
47	19.803	0.06771	14.8862	0.00788	47	118	128.26	0.05682	19.1786	0.08975	118
48	20.378	0.06756	14.9228	0.00818	48	119	131.80	0.05664	19.2908	0.09268	119
49	20.965	0.06741	14.9597	0.00850	49	120	135.45	0.05646	19.4058	0.09570	120
50	21.564	0.06727	14.9969	0.00883	50	121	139.21	0.05628	19.5239	0.09883	121
51	22.175	0.06712	15.0344	0.00917	51	122	143.09	0.05609	19.6450	0.10205	122
52	22.799	0.06698	15.0723	0.00952	52	123	147.09	0.05591	19.7694	0.10539	123
53	23.437	0.06683	15.1104	0.00988	53	124	151.23	0.05572	19.8971	0.10883	124
54	24.088	0.06669	15.1488	0.01026	54	125	155.49	0.05554	20.0283	0.11239	125
55	24.753	0.06654	15.1876	0.01064	55	126	159.89	0.05535	20.1631	0.11607	126
56	25.433	0.06640	15.2268	0.01105	56	127	164.43	0.05516	20.3017	0.11988	127
57	26.128	0.06625	15.2663	0.01146	57	128	169.13	0.05496	20.4442	0.12381	128
58	26.839	0.06611	15.3062	0.01189	58	129	173.97	0.05477	20.5908	0.12788	129
59	27.566	0.06597	15.3465	0.01233	59	130	178.98	0.05458	20.7416	0.13210	130
60	28.309	0.06582	15.3872	0.01279	60	131	184.16	0.05438	20.8969	0.13645	131
61	29.069	0.06568	15.4282	0.01326	61	132	189.51	0.05418	21.0568	0.14097	132
62	29.846	0.06553	15.4698	0.01375	62	133	195.04	0.05398	21.2215	0.14564	133
63	30.642	0.06539	15.5117	0.01425	63	134	200.77	0.05378	21.3912	0.15047	134
64	31.456	0.06524	15.5541	0.01477	64	135	206.69	0.05357	21.5662	0.15548	135
65	32.289	0.06510	15.5970	0.01531	65	136	212.82	0.05337	21.7467	0.16067	136
66	33.142	0.06495	15.6404	0.01587	66	137	219.17	0.05316	21.9330	0.16605	137
67	34.016	0.06481	15.6842	0.01644	67	138	225.74	0.05295	22.1252	0.17163	138
68	34.910	0.06466	15.7286	0.01704	68	139	232.55	0.05274	22.3238	0.17741	139
69	35.826	0.06452	15.7735	0.01765	69	140	239.61	0.05252	22.5289	0.18341	140
70	36.764	0.06437	15.8190	0.01828	70						
°F	Enthalpy	Density	SpVol	HR	°F	°F	Enthalpy	Density	SpVol	HR	°F

Properties of Saturated Air - Water Vapor Mixtures at 25.00 in Hg

°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F
0	0.99926	0.07206	13.8908	0.00094	0	71	38.577	0.06172	16.5196	0.01971	71
1	1.2934	0.07190	13.9222	0.00099	1	72	39.593	0.06158	16.5689	0.02041	72
2	1.5902	0.07174	13.9536	0.00105	2	73	40.635	0.06144	16.6188	0.02114	73
3	1.8898	0.07158	13.9851	0.00110	3	74	41.703	0.06130	16.6693	0.02188	74
4	2.1924	0.07143	14.0166	0.00116	4	75	42.798	0.06116	16.7206	0.02266	75
5	2.4980	0.07127	14.0482	0.00122	5	76	43.921	0.06101	16.7726	0.02345	76
6	2.8068	0.07111	14.0799	0.00129	6	77	45.073	0.06087	16.8253	0.02428	77
7	3.1190	0.07096	14.1117	0.00135	7	78	46.254	0.06073	16.8788	0.02513	78
8	3.4346	0.07080	14.1435	0.00142	8	79	47.466	0.06059	16.9331	0.02600	79
9	3.7539	0.07065	14.1754	0.00150	9	80	48.709	0.06044	16.9882	0.02691	80
10	4.0770	0.07050	14.2074	0.00157	10	81	49.985	0.06030	17.0442	0.02784	81
11	4.4041	0.07034	14.2395	0.00166	11	82	51.294	0.06016	17.1010	0.02880	82
12	4.7352	0.07019	14.2717	0.00174	12	83	52.638	0.06001	17.1588	0.02980	83
13	5.0707	0.07004	14.3040	0.00183	13	84	54.017	0.05987	17.2174	0.03082	84
14	5.4107	0.06989	14.3364	0.00192	14	85	55.432	0.05972	17.2770	0.03188	85
15	5.7554	0.06974	14.3689	0.00202	15	86	56.886	0.05957	17.3376	0.03297	86
16	6.1049	0.06958	14.4015	0.00212	16	87	58.378	0.05943	17.3992	0.03410	87
17	6.4596	0.06943	14.4343	0.00223	17	88	59.910	0.05928	17.4619	0.03526	88
18	6.8195	0.06928	14.4671	0.00234	18	89	61.484	0.05913	17.5257	0.03645	89
19	7.1850	0.06913	14.5001	0.00245	19	90	63.101	0.05899	17.5906	0.03769	90
20	7.5563	0.06898	14.5333	0.00258	20	91	64.761	0.05884	17.6566	0.03896	91
21	7.9335	0.06884	14.5665	0.00270	21	92	66.467	0.05869	17.7239	0.04028	92
22	8.3171	0.06869	14.5999	0.00284	22	93	68.220	0.05854	17.7924	0.04164	93
23	8.7071	0.06854	14.6335	0.00298	23	94	70.022	0.05839	17.8622	0.04303	94
24	9.1039	0.06839	14.6672	0.00312	24	95	71.873	0.05824	17.9333	0.04448	95
25	9.5078	0.06824	14.7011	0.00327	25	96	73.776	0.05809	18.0058	0.04590	96
26	9.9190	0.06810	14.7352	0.00343	26	97	75.732	0.05794	18.0796	0.04751	97
27	10.338	0.06795	14.7694	0.00360	27	98	77.743	0.05779	18.1550	0.04909	98
28	10.765	0.06780	14.8038	0.00377	28	99	79.810	0.05763	18.2318	0.05073	99
29	11.200	0.06766	14.8385	0.00395	29	100	81.936	0.05748	18.3102	0.05241	100
30	11.644	0.06751	14.8733	0.00414	30	101	84.123	0.05732	18.3903	0.05415	101
31	12.096	0.06737	14.9083	0.00433	31	102	86.373	0.05716	18.4720	0.05595	102
32	12.560	0.06722	14.9436	0.00454	32	103	88.686	0.05701	18.5554	0.05780	103
33	13.004	0.06708	14.9785	0.00473	33	104	91.067	0.05685	18.6406	0.05971	104
34	13.456	0.06693	15.0136	0.00492	34	105	93.516	0.05669	18.7277	0.06168	105
35	13.915	0.06679	15.0489	0.00512	35	106	96.037	0.05653	18.8166	0.06371	106
36	14.383	0.06665	15.0843	0.00533	36	107	98.632	0.05637	18.9076	0.06581	107
37	14.859	0.06650	15.1200	0.00555	37	108	101.30	0.05621	19.0006	0.06798	108
38	15.344	0.06636	15.1559	0.00577	38	109	104.05	0.05604	19.0957	0.07021	109
39	15.838	0.06622	15.1919	0.00601	39	110	106.88	0.05588	19.1931	0.07252	110
40	16.341	0.06608	15.2283	0.00625	40	111	109.78	0.05572	19.2927	0.07490	111
41	16.854	0.06594	15.2648	0.00650	41	112	112.80	0.05555	19.3946	0.07736	112
42	17.376	0.06579	15.3016	0.00676	42	113	115.90	0.05538	19.4991	0.07990	113
43	17.909	0.06565	15.3386	0.00703	43	114	119.09	0.05521	19.6060	0.08252	114
44	18.452	0.06551	15.3759	0.00730	44	115	122.37	0.05504	19.7157	0.08522	115
45	19.006	0.06537	15.4135	0.00759	45	116	125.76	0.05487	19.8280	0.08801	116
46	19.571	0.06523	15.4513	0.00789	46	117	129.25	0.05470	19.9432	0.09090	117
47	20.148	0.06509	15.4895	0.00820	47	118	132.85	0.05453	20.0613	0.09388	118
48	20.736	0.06495	15.5279	0.00852	48	119	136.56	0.05435	20.1825	0.09696	119
49	21.337	0.06481	15.5666	0.00885	49	120	140.39	0.05418	20.3068	0.10014	120
50	21.951	0.06467	15.6057	0.00919	50	121	144.34	0.05400	20.4345	0.10343	121
51	22.577	0.06453	15.6450	0.00954	51	122	148.41	0.05382	20.5655	0.10683	122
52	23.217	0.06439	15.6847	0.00990	52	123	152.62	0.05364	20.7002	0.11034	123
53	23.871	0.06425	15.7248	0.01028	53	124	156.96	0.05346	20.8386	0.11397	124
54	24.539	0.06411	15.7652	0.01067	54	125	161.44	0.05327	20.9808	0.11773	125
55	25.222	0.06397	15.8059	0.01108	55	126	166.08	0.05309	21.1270	0.12161	126
56	25.921	0.06383	15.8471	0.01149	56	127	170.86	0.05290	21.2775	0.12563	127
57	26.635	0.06369	15.8886	0.01193	57	128	175.80	0.05271	21.4323	0.12979	128
58	27.365	0.06355	15.9306	0.01237	58	129	180.91	0.05252	21.5916	0.13409	129
59	28.111	0.06341	15.9730	0.01283	59	130	186.19	0.05233	21.7557	0.13854	130
60	28.875	0.06327	16.0158	0.01331	60	131	181.66	0.05214	21.9247	0.14316	131
61	29.657	0.06313	16.0590	0.01380	61	132	197.31	0.05195	22.0989	0.14793	132
62	30.457	0.06299	16.1028	0.01431	62	133	203.15	0.05175	22.2785	0.15288	133
63	31.276	0.06285	16.1470	0.01484	63	134	209.20	0.05155	22.4637	0.15800	134
64	32.114	0.06271	16.1916	0.01538	64	135	215.47	0.05135	22.6548	0.16332	135
65	32.972	0.06257	16.2368	0.01594	65	136	221.96	0.05115	22.8521	0.16883	136
66	33.851	0.06243	16.2826	0.01652	66	137	228.68	0.05094	23.0558	0.17454	137
67	34.751	0.06229	16.3288	0.01712	67	138	235.65	0.05074	23.2663	0.18047	138
68	35.673	0.06215	16.3756	0.01774	68	139	242.88	0.05053	23.4839	0.18662	139
69	36.617	0.06201	16.4230	0.01837	69	140	250.37	0.05032	23.7089	0.19300	140
70	37.585	0.06187	16.4710	0.01903	70						
°F	Enthalpy	Density	Sp Vol	HR	°F	°F	Enthalpy	Density	Sp Vol	HR	°F

PART III — APPENDIX I

CORRECTING COLD WATER TEMPERATURE FOR HEAT ADDED BY PUMP

Section I1. General

When the cold water temperature is measured on the discharge side of the circulating pump by means of a bubbler and flow control valve, as illustrated in Figure I-1, the temperature reading is affected by the energy input from the pump to the water, which is reflected in two phenomena:

- 1) A temperature increase in the water due to the inefficiency of the pump.
- 2) A temperature increase as the water is throttled (adiabatically) from a higher pressure to the lower atmospheric pressure.

Point 2

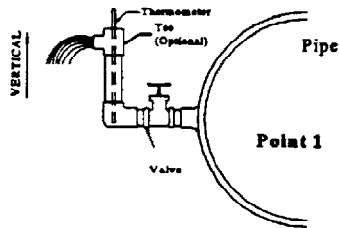


Figure I-1. Temperature Tap

Accordingly, the temperature measurement must be adjusted to more accurately reflect the true temperature of the water leaving the tower.

Section I2. Adjustments

To adjust the temperature measured at the bubbler, the total energy input from the pump to the water must be expressed as a temperature rise (ΔT) which can then be subtracted from the measured value. The value for ΔT is calculated as:

$$\begin{aligned} \text{SI: } \Delta T &= \frac{P_1 \cdot 0.0002390}{\eta_{\text{pump}}} \\ \text{IP: } \Delta T &= \frac{P_1 \cdot 0.002966}{\eta_{\text{pump}}} \end{aligned} \quad (\text{I-1})$$

where P_1 represent the gage pressure (above atmospheric pressure) on the discharge side of the pump. This calculated value for ΔT is to be **subtracted** from the measured temperature to better reflect the true temperature of the water leaving the cooling tower.

Section I3. Derivation of Equations

I3.1 Pressure Considerations. As with all throttling processes, expansion across a flow control valve is an essentially adiabatic process where $\Delta h_w = 0$

But also:

$$\Delta h_w = \Delta U + \Delta \left(\frac{P \cdot V}{J} \right) \quad (\text{I-2})$$

Therefore:

$$(U_2 - U_1) + \left(\frac{P_2 \cdot V_2}{J} \right) - \left(\frac{P_1 \cdot V_1}{J} \right) = 0 \quad (\text{I-3})$$

where:

Referring back to Figure I-1, Point 1 is inside the cold water main on the discharge side of the pump at some pressure P_1 (gage) above atmospheric.

Point 2 is downstream of the throttling valve at pressure $P_2 = \text{atmospheric} = 0$ gage.

Thus, since $P_2 = 0$:

$$(U_2 - U_1) = \Delta U = \frac{P_1 \cdot V_1}{J} \quad (\text{I-4})$$

And since $\Delta U = c_{pw} \cdot \Delta T$, then :

$$\Delta T = \frac{P_1 \cdot V_1}{c_{pw} \cdot J} \quad (\text{I-5})$$

Next, substituting known values for both IP and SI:

$$\begin{aligned} \text{SI: } \Delta T &= \frac{(P_1) \cdot (0.001 \text{ m}^3/\text{kg})}{(4.186 \text{ kJ/kg} \cdot ^\circ\text{C}) \cdot (1 \text{ N} \cdot \text{m/J})} \\ \text{IP: } \Delta T &= \frac{(P_1) \cdot (144 \text{ in}^2/\text{ft}^2) \cdot (0.016 \text{ ft}^3/\text{lb}_m)}{(1.0 \text{ Btu/lb}_m \cdot ^\circ\text{F}) \cdot (778 \text{ ft} \cdot \text{lb/Btu})} \end{aligned} \quad (\text{I-6})$$

which then reduce to:

$$\begin{aligned} \text{SI: } \Delta T &= (0.0002390)(P_1) \\ \text{IP: } \Delta T &= (0.002966)(P_1) \end{aligned} \quad (\text{I-7})$$

Equation I-7 can be considered a representation of the useful work done by the pump in raising the pressure from atmospheric (in the cold water basin) to P_1 . Now the heat added due to the inefficiency of the pump must be considered.

I3.2 Pump Efficiency Considerations

By definition, the Efficiency of the pump is the useful work divided by the total energy input such that:

$$\eta_{\text{pump}} = \frac{W_{\text{useful}}}{W_{\text{total}}} \quad (\text{I-8})$$

and rearranging:

$$W_{\text{total}} = \frac{W_{\text{useful}}}{\eta_{\text{pump}}} \quad (\text{I-9})$$

Since the useful work of the pump, expressed as a ΔT , is described in Equation I-7, this can be substituted into Equation I-9 to express the total energy input to the water as a temperature rise in the water when the temperature is measured at the atmospheric side of the bubbler and valve:

$$\begin{aligned} \text{SI: } \Delta T &= \frac{P_1 \cdot 0.0002390}{\eta_{\text{pump}}} \\ \text{IP: } \Delta T &= \frac{P_1 \cdot 0.002966}{\eta_{\text{pump}}} \end{aligned} \quad (\text{I-1})$$

SYMBOLS:

- cpw = Specific heat of water, 4.180 kJ/kg•°C (1.0 BTU/lb_m•°F)
- hw = enthalpy of water, kJ/kg, (BTU/lb_m)
- U = internal energy, kJ/kg (BTU/lb_m)
- P = pressure, kPa (psi)
- J = mechanical equivalent of heat, 1 N•m/J (778 ft•lb/BTU)
- V = Specific Volume, 0.001 m³/kg (0.016 ft³/lb_m)
- T = temperature, °C (°F)
- η_{pump} = efficiency, dimensionless

PART III — APPENDIX J

ADJUSTING MEASURED DATA FOR THERMAL LAG

Section J1. General

In most testing situations, the measurement point for the Cold Water Temperature can be located sufficiently close to the cooling tower that it is quite representative of the temperature of the water as it leaves the fill and falls into the cold water basin. However, where the basin is significantly large and/or the measurement station is at some distance from the tower, this may not be the case. This difference between the instantaneous temperatures of the water at the measurement point and as it leaves the fill is termed "Thermal Lag" and can affect the evaluation of the tower performance.

Section J2. Adjustment for Thermal Lag

The time interval from when the cooled water first reaches the collecting basin until it reaches the Cold Water Temperature measurement station can be estimated as:

$$\text{lag} = \frac{\text{VOL}_{\text{basin}}}{60Q_{wt}} \quad (\text{J-1})$$

where:

lag = thermal lag time, minutes

$\text{VOL}_{\text{basin}}$ = volume of water in basin during test, L (gal).

Q_{wt} = test water circulation rate, L/s (g/s).

In those instances where the value of the thermal lag equals or exceeds **five minutes**, the test period shall be lengthened by a like amount and the test averages based on compensating time spans to negate the effect of the thermal lag.

Specifically, for an overall test period ranging from a starting time t_1 to ending time t_2 , the minimum duration of the test in minutes

is $(t_2 - t_1) \geq 60 + \text{lag}$. The following readings shall be averaged over the time period t_1 through $(t_2 - \text{lag})$:

- (a) Hot Water Temperature (T_{hw}).
- (b) Dry-bulb Temperature - if required (T_{db}).
- (c) Wet-bulb Temperature (T_{wb}).
- (d) Flow Rate of Circulating Water (Q_w).
- (e) Flow Rate and Temperature of any water other than the circulating water entering the tower basin [e.g. Make-up (Q_{mu} and T_{mu})].

The remaining data (listed below) shall be averaged over the time period $(t_1 + \text{lag})$ through t_2 :

- (f) Temperature of main stream of Cold Water leaving the tower (T_{cw}).
- (g) Flow Rate and Temperature of any water other than the circulating water leaving the tower basin [e.g. Blowdown (Q_{bd} and T_{bd})].

For example, for a system with exactly a 10 minute thermal lag the total duration of the test must extend for at least 70 minutes (60+lag). If the test started at 1:00, hot water, dry bulb, wet bulb, flowrate, and makeup flowrate would be averaged for the period 1:00 to 2:00, while cold water temperature and blowdown flowrate would be averaged for the period 1:10 to 2:10.

PART III — APPENDIX K

REFERENCES

K.1 References — Normative.

Listed here are standards, handbooks, and other publications essential to the implementation of this standard. All references in this section are considered a part of this standard.

1. *ASME Performance Test Code (PTC) 19.1 - 1985(R1990), Instruments and Apparatus, Part 1, Measurement Uncertainty*, American Society of Mechanical Engineers (ASME), United Engineering Center, 345 East 47th Street, New York, NY 10017
2. *ASME Performance Test Code (PTC) 19.3 - 1974(R1986), Temperature Measurement*, American Society of Mechanical Engineers (ASME), United Engineering Center, 345 East 47th Street, New York, NY 10017
3. *CTI Document FSP-136(93), Preparation and Procedures for an Official CTI Thermal Performance Test*, Cooling Tower Institute, PO Box 73383, Houston, TX 77273, 1993
4. *CTI Bulletin STD-145(95), International System of Units (SI) Conversion Standard*, Cooling Tower Institute, PO Box 73383, Houston, TX 77273, 1991
5. *CTI Bulletin STD-146(95), Standard for Water Flow Measurement*, Cooling Tower Institute, PO Box 73383, Houston, TX 77273, 1995
6. *Standard Methods for the Examination of Water, Sewage, and Industrial Wastes, 19th Edition*, American Public Health Association, Publication Sales Office, P.O. Box 753, Waldorf, MD 20604, 1995

K.2 References — Informative.

Listed here are standards, handbooks, and other publications which may provide useful information and background, but are not considered essential to the implementation of this standard. References in this section are not considered a part of this standard.

1. *ASHRAE Handbook — Fundamentals*, Chapter 6, "Psychrometrics", American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA, 1997.
2. *ASHRAE Handbook — HVAC Systems and Equipment*, Chapter 36, "Cooling Towers", American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 1791 Tullie Circle, Atlanta, GA 30329, 1996.
3. *ASME Performance Test Code (PTC) 30 - 1991, Air Cooled Heat Exchangers*, American Society of Mechanical Engineers (ASME), United Engineering Center, 345 East 47th Street, New York, NY 10017
4. *ASME Performance Test Code (PTC) 23 - 1986 (R1992), Atmospheric Water Cooling Equipment*, American Society of Mechanical Engineers (ASME), United Engineering Center, 345 East 47th Street, New York, NY 10017
5. *Cooling Tower Performance Curves*, Cooling Technology Institute, PO Box 73383, Houston, TX 77273, 1991
6. *CTI Bulletin STD-201(96), Standard for the Certification of Water-Cooling Tower Thermal Performance*, Cooling Technology Institute, PO Box 73383, Houston, TX 77273, 1991

PART III —APPENDIX L

DETERMINING WIND VELOCITY ON NATURAL DRAFT COOLING TOWERS

Section L1. General

On natural draft cooling towers, the wind at the top of the shell, can have a significant effect on the thermal performance. For this reason, the code imposes a limitation on the wind velocity at the top of the shell.

Section L2. Determining Wind Velocity

The preferred way is to *measure* the wind velocity at the discharge of the shell using a cup anemometer positioned at the right altitudes on a meteorological mast or suspended from a balloon, upwind of the cooling tower. However, too often this method is not practical.

L2.1 One alternative, visual observation of the plume, can give some indication of the wind velocity at the top of the shell, since the plume angle bears some relationship to the ratio of exit air velocity and wind velocity. Such visual evaluation is subject to human interpretation, assumes that all natural draft cooling towers have essentially the same exit air velocity, and is affected by the dilution rate of the plume into the atmosphere and the weather conditions. Also, in mild weather, there may be almost no visible plume rising from the cooling tower.

L2.2 A second alternative, measuring the wind velocity near ground level (3 to 10 m above grade) and then predicting the wind velocity at the discharge of the shell using an equation is easy, but does not always yield a good comparison to the *actual* velocity at the top of the shell. After extensive research using meteorological masts, equations were developed that represent the relationship of the wind velocity as a function of altitude. It should be noted that these equations were developed primarily for use in structural design of tall structures, where conservatism in estimated velocities (*i.e.* loads) for elevated structures was desired. There is no precise way to correlate velocities measured at a low elevation to actual velocities at a higher elevation. Two equations are in common use to *estimate* wind velocity at altitude, and yield similar results:

- Hellman law:

$$V = K [(1+2.81) \cdot \log_{10}(Z + 4.75)]$$

- German Cooling tower test code DIN 1947 law:

$$V = (K_D) (Z)^{0.2}$$

where:

V = wind velocity (m/s)

Z = altitude (m)

K, K_D = constant

Using these equations, the wind velocity at the top of the shell, in average, can be estimated from the wind velocity measured at ground level.

- Hellman law:

$$V_t = V_g \left[\frac{[(1+2.81) \cdot \log_{10}(Z_t + 4.75)]}{[(1+2.81) \cdot \log_{10}(Z_g + 4.75)]} \right]$$

- German Cooling tower test code DIN 1947 law:

$$V_t = V_g \left(\frac{Z_t}{Z_g} \right)^{0.2}$$

where:

V_t = Wind velocity at the top of the shell (m/s).

V_g = Wind velocity at ground level between 3 to 10 m (10 to 33 ft) (m/s).

Z_t = Level of the top of the shell compare to the ground level (m).

Z_g = Level of the wind velocity measurement from the ground level (m).

PART III — APPENDIX M

EXPRESSING TOWER CAPABILITY AS A FUNCTION OF DEVIATION FROM DESIGN COLD WATER TEMPERATURE

Section M1. General

The purpose of this appendix is to provide a methodology for determining cooling tower capability as a function of temperature deviation from design cold water temperature.

Section M2. Methodology

The Capability of a cooling tower, as determined by a performance test, is usually reported as a percentage of the design water flow rate. It is calculated from the ratio of the Adjusted Test Flow Rate to the flow rate predicted from the manufacturer's data for the measured test conditions.

$$\%CAP = \left(\frac{Q_{\text{adjust}}}{Q_{\text{pred}}} \right) \cdot 100 \quad (\text{M-1})$$

This equation shows that tower capability is inversely proportional to predicted flow (Q_{pred}). From that it follows that if a cooling tower is operating with design (100%) flow, design range, design fan power and at design wet bulb temperature, but producing a cold water temperature equal to that expected when operating at 90% design flow, the tower capability is:

$$\%CAP = \left(\frac{100\%}{90\%} \right) \cdot 100 = 111.11\% \quad (\text{M-2})$$

Similarly, if the tower were producing a cold water temperature equal to that expected when operating at 110% design flow, the tower capability would be:

$$\%CAP = \left(\frac{100\%}{110\%} \right) \cdot 100 = 90.91\% \quad (\text{M-3})$$

Using this approach in conjunction with the Performance Curves supplied by the tower manufacturer, three points of tower leaving water temperature as a function of tower capability can be readily obtained and plotted. The curve can then be used to determine the tower leaving water temperature at design flow, range, and fan motor power for any capability falling within the scope of the curve. Extrapolation of the curve to any significant degree is not recommended.

From the manufacturers performance curves, tabulate the cold water temperatures predicted for the design range, design wet bulb temperature and, if applicable, the design Relative Humidity for each flow rate for which performance curves are provided.

Section M3. Example

M3.1 SI Example. Refer to the example test evaluation in Appendix C.

Step 1. On each of the three performance curves submitted by the manufacturer, enter the abscissa at the design wet bulb temperature of 26.0°C and project a line vertically upward to intersect the design range curve (18.8°C). From the ordinate, read the cold water temperature corresponding to the intersect:

% Flow	% Capability	CWT (°C)
90%	111.11%	29.84°
100%	100.00%	30.60°
110%	90.91%	31.36°

Step 2. With Cold Water Temperature as the ordinate and Tower % Capability as the abscissa, plot the tabulated Cold Water Temperatures at the corresponding values for % Capability and fit a curve through the three points. Extrapolation beyond the submitted data is not recommended.

Step 3. Enter the abscissa at the % Tower Capability determined by the test (102.2%) and project a line vertically upward to intersect the curve. At the intersection, read the corresponding Cold Water Temperature as 30.44°C. The difference between this temperature and the Design Cold Water Temperature is the Cold Water Temperature Deviation associated with the tested tower capability, -0.16°C.

M3.2 IP Example. Refer to the example test evaluation in Appendix D.

Step 1. On each of the three performance curves submitted by the manufacturer, enter the abscissa at the design wet bulb temperature of 78.8°F and project a line vertically upward to intersect the 100% Range curve (33.84°F). From the ordinate, read the cold water temperature corresponding to the intersect:

% Flow	% Capability	CWT (°F)
90%	111.11%	85.71°
100%	100.00%	87.07°
110%	90.91%	88.84°

Step 2. With Cold Water Temperature as the ordinate and Tower % Capability as the abscissa, plot the tabulated Cold Water Temperatures at the corresponding values for % Capability and fit a curve through the three points. Extrapolation beyond the submitted data is not recommended.

Step 3. Enter the abscissa at the % Tower Capability determined by the test (101.4%) and project a line vertically upward to intersect the curve. At the intersection, read the corresponding Cold Water Temperature as 86.85°F. The difference between this temperature and the Design Cold Water Temperature is the Cold Water Temperature Deviation associated with the tested tower capability, -0.22°F.

Figure M-1. Tower Capability as a Function of Deviation From Design Cold Water Temperature
(From Appendix C)

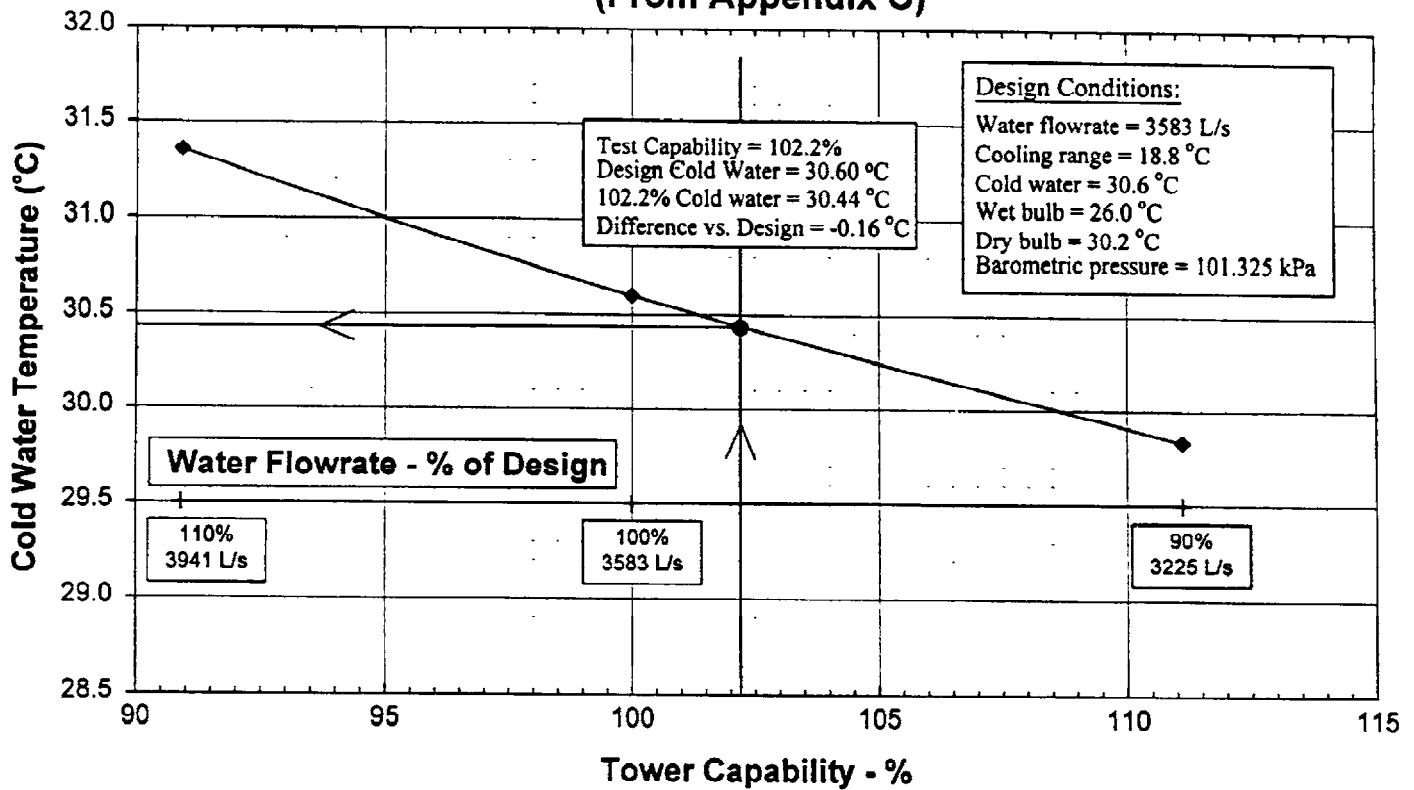
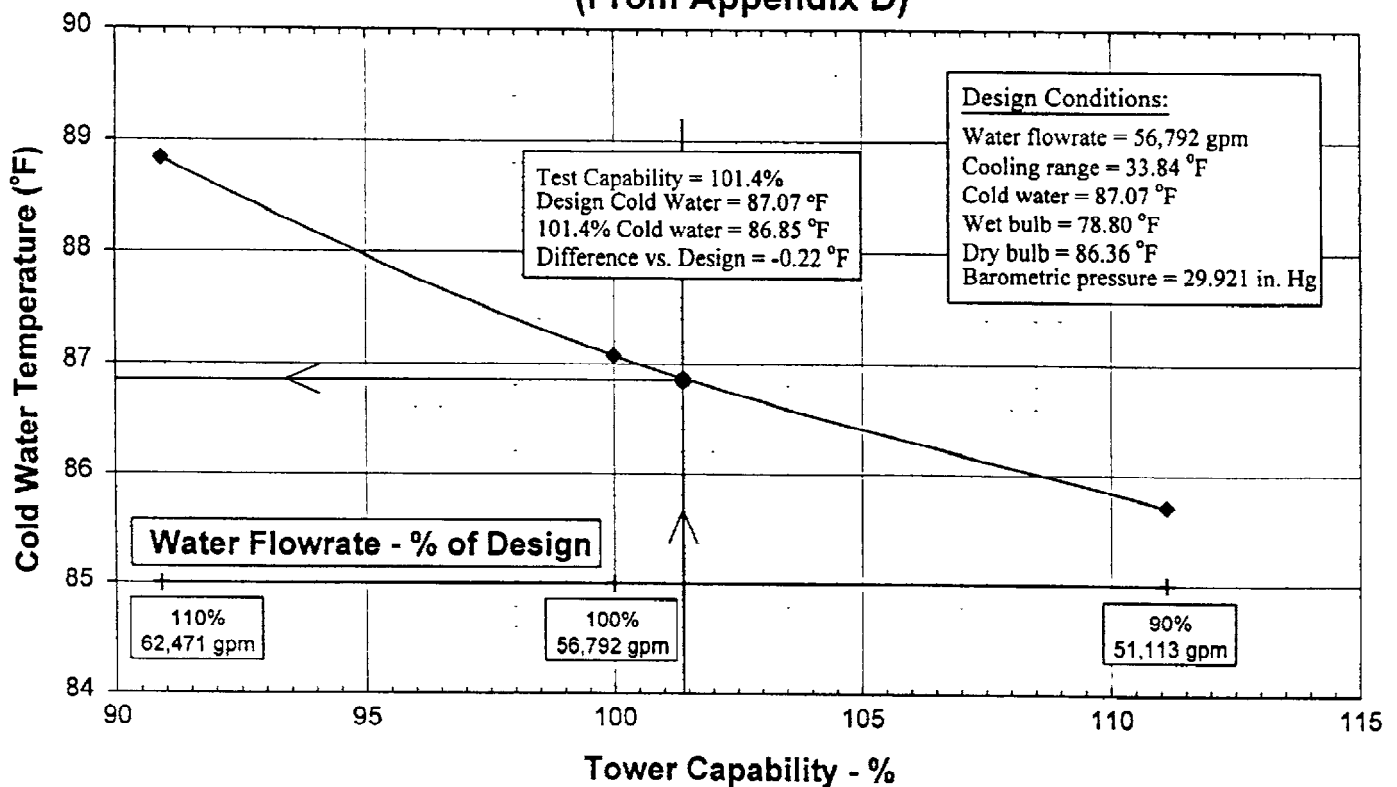


Figure M-2. Tower Capability as a Function of Deviation From Design Cold Water Temperature
(From Appendix D)



PART III — APPENDIX N

SAMPLE TEST FORMS

FOR USE WITH
TEST CODE
ATC-105

*Consent for making
a test and test report
to prove a CWT is
when determined
of the group
the test
For record-keep and
test report

COOLING TOWER INSTITUTE DATA SHEET "A" RECORD SUMMARY SHEET

NOTE: ALL DATA SHALL BE RECORDED IN THIS
CHANGES OR CORRECTIONS MUST BE INITIALED BY CTT OBSERVER.

FILE NO. _____

TEST DATE _____

DESIGN

TEST

WATER FLOW RATE, US GPM _____
NUMBER OF OPERATING CELLS _____
FAN HP PER CELL _____
ACFM PER CELL _____
ELEVATION, FEET _____
BAROMETRIC PRESSURE, IN. HG _____
HOT WATER TEMPERATURE, °F _____
COLD WATER TEMPERATURE, °F _____
RANGE, °F _____
INLET WET-BULB TEMPERATURE, °F _____
APPROACH, °F _____
INLET DRY-BULB TEMPERATURE, °F *** _____
PUMPING HEAD, FEET _____
TDS, PPM _____
OIL CONTENT, PPM _____
L/G _____
KAY/L _____
CHARACTERISTIC CURVE SLOPE _____
CAPABILITY _____

TO BE ANSWERED BY THE CTT OBSERVER:

1. DO EQUIPMENT CONDITIONS MEET PROVISIONS OF ATC-105 PARA 2.02
2. DO OPERATING CONDITIONS MEET PROVISIONS OF ATC-105 PARA 2.04
3. DO TEST CONDITIONS MEET PROVISIONS OF ATC-105 PARA 2.06
4. WERE ALL INSTRUMENTS FURNISHED OR APPROVED BY CTT?

YES

NO

REMARKS & EXCEPTIONS:

SUPPLEMENTAL SHEETS ENCLOSED:
FORM ATC-105B _____
FORM ATC-105C _____
FORM ATC-105D _____
FORM ATC-105E _____
OTHERS _____

We certify that the test data recorded herein was taken during the subject test and that the test was conducted in accordance with CTT Test Code ATC-105 with the above noted exceptions. These exceptions are acceptable in the understanding in determining the capability of the subject Cooling Tower.

CTI Observer _____ Date _____

Manufacturer _____

Purchaser _____

This test valid only when stamped with official CTT stamp — 42 —

FOR USE WITH CTT
TEST CODE ATC-105

COOLING TOWER INSTITUTE ACCEPTANCE TEST PROCEDURE

FILE NO. _____

TEST DATE _____

DATA SHEET "B" WET BULB TEMPERATURES

RUN	TIME	WET BULB TEMPERATURE STATIONS				RUN AVG
		1	2	3	4	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

TEST OVERPASS

INSTRUMENT IDENTIFICATION

CTI FORM ATC-105 B

DATA SHEET "C"

TEST DATE _____

ACCEPTANCE TEST PROCEDURE
DATA SHEET "D"
SKETCH SHEET

TEST DATE _____

[illegible][illegible]

SHOW BELOW THE PLAN VIEW OF COOLING TOWER INDICATE
POINTS WHERE REQUIRED MEASUREMENTS WERE TAKEN ALSO
SHOW DISTANCES TO OBSTRUCTIONS OR OTHER EQUIPMENT IN
IMMEDIATE VICINITY OF TOWER TESTED INDICATE CELLS

NOT OPERATING AT TIME OF TEST. DRAW TOWER SKETCH WITH
LONGITUDINAL AXIS HORIZONTAL AND COOLING TOWER NORTH
END OR TOWER TOWARD LEFT SIDE OF SKETCH. INDICATE AL-
L SOUTH OF TOWER AXIS REFERENCED TO AN ARROW!

SAMPLE

MEAS ON		UNIT	
INSTRUMENT IDENTIFICATION		TEST CAUSE	
RUN	TIME		
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
TEST AVERAGE			

NAME OF		UNIT	
INSTRUMENT IDENTIFICATION		DATE CALIB	
RUN	TIME		
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
EST AVERAGE			

2. 500 mg 17C 13C

• **CONSTITUTION D**.....

COOLING TOWER INSTITUTE
ACCEPTANCE TEST PROCEDURE
DATA SHEET
WATER FLOW MEASUREMENT
PITOT TUBE

FILE NO. _____

TEST DATE _____

FOR USE WITH CTI
TEST CODE ATC 100

COOLING TOWER INSTITUTE
ACCEPTANCE TEST PROCEDURE
DATA SHEET "F"

FILE NO _____

TEST DATE _____

PREPARE IN TRIPLICATE

POT TUBE MAKE MODEL		SERIAL NO	PIPE SIZE INCHES NOM IN	10 IN
DATE CALIB	TUBE COEFFICIENT	AREA & VOLS OF SO FT A W		

[illegible]

	TIME	d
a		
b		
c		

2. $\sin \theta = \frac{1}{\sqrt{10}}$ ($100^\circ < \theta < 180^\circ$) $\Rightarrow \sqrt{6} \left(\frac{\quad}{\quad} \right)$

GASIS AIR/WATER MANOMETER

* CALCULATED VALUE DECREASED BY DISTANCE FROM END OF MYOT TUBE TO CENTERLINE OF IMPACT HOLE

TEST SITE LOG SHEET

Date _____ Test Engineer on site at _____ Left site _____
Day's activity and remarks:

Date _____ Test Engineer on site _____ Left site _____
Day's activity and remarks:

Purchaser Initial _____

Date _____ Test Engineer on site at _____ Left site _____

COOLING TECHNOLOGY INSTITUTE

P.O. Box 73383 • Houston, Texas 77273
281.583.4087 • Fax 281.537.1721 • <http://www.cti.org>
February 2000 • Printed in U.S.A.

Revised February 2000

CTI Code ATC-105(00)