REVIEW OF NEW 2019 CTI ATC 105 ACCEPTANCE TEST CODE FOR COOLING TOWERS

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Introduction

Typically, the primary goal of a cooling tower thermal performance test is to determine the cooling capacity of a cooling tower when operated at its design conditions of water flow, range, fan motor power (mechanical draft), dry bulb temperature (natural draft), and barometric pressure.

For a mechanical draft tower, cooling capability is defined as the ratio of circulating water flow rate (corrected to design fan motor power consumption) to the predicted water flow rate as determined by the cooling tower manufacturer's performance curves. Because the manufacturer's performance curves are equivalent representations of the tower performance at various operating and environmental conditions, the predicted waterflow rate is the flow rate of a cooling tower with 100% capability. Thus, the ratio of predicted water flow rate to the adjusted circulating waterflow rate is a constant which means tower capability is a constant despite testing at off design conditions. Said another way, the cooling tower test translates the performance of the tower at test conditions to an equivalent performance at design conditions.

COMMERCIAL CONSIDERATIONS

Timing of the Acceptance Test

The 2019 version of CTI ATC-105 requires that a contractual acceptance test be performed within 12 months of construction and that cooling towers with film type fill be operated for a minimum 1000 hours (about 6 weeks) with a heat load unless otherwise specified in the contract. The requirement for operation of the cooling tower under heat load requirement is specified because film fill performance will increase slightly as the tower ages and releasing agents in the surface of the fill are removed which changes the "wettability" of the fill and improves fill performance. The ATC-105 test code also requires that the acceptance test be performed at a wet bulb temperature within 15˚F of the design value. If the cooling tower design wet bulb is based on a 1 or 2 percent summer wet bulb temperature, code compliant wet bulb temperatures for most regions can be expected between late spring and early fall.
Taken together, these requirements place significant constraints on the window during which a code level acceptance test can be performed. The acceptable test window could collapse entirely if a tower is built several months before heat load is available. One way of avoiding this difficulty would be to include a contractual provision to extend the acceptance testing window to 18 months following tower construction. Alternately contractual provisions could tie the timing of the acceptance test to the operation of cooling tower rather than the completion of construction.

Test Tolerance

As defined by CTI ATC-105, a test tolerance is permitted deficiency in tower performance specified in the contract between the tower purchaser and the tower buyer. As long as the tower meets or exceeds the performance guarantee corrected for tolerance, the performance guarantee is deemed to have been filled. For instance, if there was a 3.2 percent tolerance specified in the contract, a cooling tower with a test capability of 97 percent would be contractually acceptable. The test tolerance should be specified in the tower purchase contract even if the value of the tolerance is zero. The test tolerance should not be confused with test uncertainty which is an estimation of the potential error in the test result (capability) due to errors in the test measurements.

Performance Curves

The performance curves provided by the manufacturer are integral in the evaluation of cooling tower performance. These curves are used to translate the measured performance during the test to the expected performance at design conditions. Therefore, the accuracy of the test result is dependent on the accuracy of the performance curves. The CTI ATC-105 test code recommends that performance curves be evaluated by the purchaser before the contract is signed. The authors recommend that the performance curves be required as part of bid submittal package and the review of the curves be part of the bid evaluation process. This will enable curves presented by different manufacturers to be compared for consistency. Session 4 of the 2018 CTI Education Seminar addresses the evaluation of cooling tower performance curves and is available from cti.org as a free download.

CONDUCT OF THE TEST

Preparation for the Test

The CTI ATC-105 test code requires that the cooling tower be prepared for testing in accordance with CTI PGT-156 Preparation for a Thermal Performance, Plume Abatement, or Drift Test. This document, available from CTI as a free download, specifies the preparations necessary for the performance of a thermal performance test. The CTI ATC-105 code requires that a contractual acceptance test be performed by a CTI-licensed test agent in the presence of the owner and manufacturer, if they desire to be present. For an acceptance test, these representatives shall be given adequate (undefined) notice prior to the test. The manufacturer shall be given permission and adequate (again undefined) notice to inspect and prepare the cooling tower for testing. This preparation would include balancing the water flow and insuring that the fan motor power is within code requirements. In the opinion of the authors, two to three weeks (more is better) should be given in order to fulfill the requirement for adequate notice.

Allowable Deviations from Design Conditions

The maximum deviation of test parameters from design conditions are summarized in Table 1.

Table 1 Allowable Deviation from Design Conditions

Parameter	Maximum Deviation from Design Conditions
Water flow rate	±10 percent of design flow
Fan motor power[1]	±15 percent of design motor power
Range	±20 of design range
Heat load	±20 of design heat duty
Wet bulb temperature	±8.5°C (15°F) from the design wet bulb temperature
Dry bulb temperature[2]	±14°C (25°F) from the design dry bulb temperature
Barometric pressure	±3.5 kPa (1 inHg)
Wind speed	4.5 m/s (10 mph)

[1] corrected to design air density
[2] applicable only to natural draft and wet/dry cooling towers

The 2019 version of the ATC-105 test code increases allowable deviation for fan motor power to 15 percent compared to 10 percent in the 2000 version. It should be noted that a deviation of 15 percent in fan power corresponds to a 5 percent variation in air flow rate.

Based on historical data from the CTI Annual Reports, in more than 30 percent of the new tower tests, the fan motor power was outside the test code limit. While the increase in the allowable deviation should reduce the percentage of towers failing to meet this requirement, the fan power for many acceptance tests is more than 15 percent below the design value. The new tower purchase contract should also specify which party is responsible for pitching fans to a value which will produce a fan motor power within the code limits.

Stability Requirements

The CTI ATC-105 test code also places restrictions on the variation of test parameters within a test period. The test parameter variation limits specified by the CTI ATC-105 test code are summarized in Table 2.

Table 2 Maximum Variation in Test Parameters

Parameter	Limit of Variation
Water flow rate (deviation)	±2 percent
Cooling Range (deviation)	±5 percent
Cooling Range (rate-of-change)	±5 percent
Wet bulb temperature (rate-of-change)	±1°C (2°F)
Wet bulb temperature (deviation)	±1.5°C (3°F)
Dry bulb temperature (rate-of-change)[1]	±3°C (5°F)
Dry bulb temperature (deviation)[1]	±4.5°C (7.5°F)

[1] applicable only to wet/dry or natural draft cooling towers

Deviation limits specify the permissible difference between individual readings and the average value of all readings for a specific parameter. Rate-of-change limits specify the permissible difference between the end points of a linear least-squares regression line fit of a time plot of a test parameter.

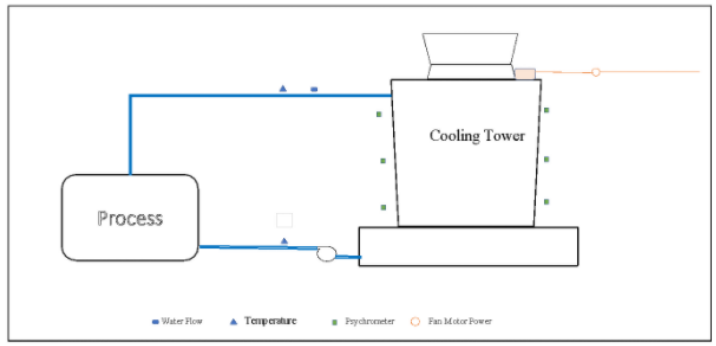
The 2019 version of CTI ATC-105 code clarifies the permissible cooling range deviation. In the 2000 version it was unclear whether the cooling range deviation was calculated from maximum-to-minimum or variation from parameter average. The new code version also adds a permissible rate-of-change for cooling range.

For most cooling towers, the water flow rate is measured with a pitot tube. For pitot tube flow measurements, the differential pressure between the total and static ports is measured by traversing the pipe at 10 points (20 points per diameter for large pipes) across two perpendicular diameters of each pipe carrying hot water to the tower. Each flow measurement takes from 1 to 4 hours depending on pipe size and access. For most multi-cell towers, it is necessary to traverse multiple risers to determine the water flow rate. Typically, water flow delivered to counterflow towers is measured in each hot water riser. For these measurements, monitoring the stability of water flow with the pitot tube is impractical and alternative measurements such as pump discharge pressure or condenser differential pressure must be used.

Test Instrumentation

The placement of the test instruments for a cooling tower thermal performance test is illustrated in Figure 1.

Figure 1 Primary Test Measurements



Inlet wet bulb temperature (and dry bulb temperature, if required) are measured with calibrated temperature sensors in mechanically aspirated psychrometers placed within 1.5m (5ft) from the air inlets. The required characteristics of the psychrometers are newly defined in Appendix O of the new test code. The number and placement of the psychrometers is specified in Appendix G, which has been extensively edited for the 2019 version of the test code.

Cold water temperature is typically measured downstream of the pumps. At this location, the water is well mixed so a representative temperature can be obtained by a single measurement in a flowing or thermal well at the outlet of each pump. A small correction, detailed in Appendix I of CTI ATC-105, is used to correct the measured temperature for the throttling and heat added by the pump. An array of submersible temperature sensors may be placed in the cooling tower outfall or flume to obtain a representative cold water temperature when 1) the pumps are remote from the cooling tower, 2) multiple towers share a common pump system, or 3) the primary heat source is between the tower and the pumps. When makeup water or auxiliary flow streams enter the circulating water system or cold water basin upstream of the cold water measurement, the measured cold water temperature must be corrected for the influences of these streams. Since the measured cold water temperature is generally insensitive to cooling tower makeup, makeup flow and makeup temperature measurements are frequently made with plant instruments. The magnitude of the possible error in cold water temperature due to measurements of pump pressure, makeup temperature, and makeup flow is detailed in Appendix U-1 of the revised test code.

Since the cooling tower is typically far removed from the heat generation process, measurement of the hot water temperature at a single location near the tower is usually sufficient. In some cases, the hot water temperature may not be well mixed at the tower when the cooling tower serves multiple processes with separate hot water return pipes. When the hot water streams at the tower are not well mixed, flow-weighted temperature measurements of pump pressure, makeup temperature, and makeup flow is detailed in Appendix U-1 of the revised test code.

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Water flow rate may be measured at either the inlet or outlet of the cooling tower. By far the most common method of water flow measurement utilizes a calibrated pitot tube at the tower inlet. Measurement with a pitot tube requires two pitot taps installed 90˚ apart in a straight run of pipe. Guidelines for the installation of pitot taps are found in CTI PTG-156. Since 2018, CTI-licensed test agents have been required to use pitot tubes incorporating a new elliptical design. This tube design is much less sensitive to positive bias caused by disturbed flow at the measurement location compared to the Simplex design which was previously used. Other methods for the measurement of water flow, detailed in CTI STD-146 Water Flow Measurement (currently under revision) are acceptable if properly installed and suitably calibrated.

Fan motor power consumption is generally measured in the motor control center for each fan motor with a calibrated hand-held meter. Since this measurement requires that MCC be opened under power, safety procedures require that these measurements be done by qualified (plant) personnel wearing flash protective gear. The CTI ATC-105 test specifies that the measured motor power be corrected for the voltage loss between the measurement point and fan motor. Methodology for the line loss correction is found in Appendix N (new in the 2019 test code). Because fan motor power consumption specified by the tower OEM in the development of performance curves may be based on either input or brake horsepower, care must be used to ensure that the test fan motor consumption used in performance calculations is used in the same manner as was used to generate the performance curves.

For the mechanical draft cooling towers, wind speed is to be measured at an elevation ½ the difference between the cold water basin curb and the air discharge elevation (e.g. fan stack exit plane) in an unobstructed location at least 30 m (100 ft) from the cooling tower.

Instrument Accuracy

The instrument accuracy and calibration frequency requirements established by CTI ATC-105 Section 3 are presented in Table 3.

Duration of the Test

For mechanical draft towers, a single one-hour test run is required. The normal practice is to record temperature data continuously during the manual measurements of water flow and fan motor power. When multiple hours of meeting code requirements of stability and proximity to design conditions are available, the licensed test agent may select the most stable hour for analysis. One method for selecting the most stable test period is presented in Appendix P (new in the 2019 version of the test code).

Table 3 Instrument Accuracy and Calibration Frequency

Measurement	Minimum Accuracy SI Units	Minimum Accuracy IP Units	Example Instruments	Calibration Frequency
Temperature[1]	0.05°C	0.10°F	100 Ω RTD	3 months
Water flow rate[2]	3%		Pitot tube	3 years[3]
Fan motor power	3%		Power meter	1 year
Barometric pressure	0.34 kPa	0.1 inHg	Barometer	Not specified
Water pressure	1%		Manual gage	Not specified
Differential pressure (pitot)	1%		Manometer	NA
Wind speed	0.5 m/s	1 mph	Anemometer	1 year

[1] lower accuracy devices may be used for measuring makeup and blow down temperature
[2] lower accuracy devices may be used for makeup and blowdown flow
[3] if undamaged

For natural draft cooling towers, six 1-hour periods collected over two days are required.

Natural Draft Cooling Towers

The performance of natural draft cooling towers is influenced by the wind speed at the cooling tower outlet and the temperature gradient of the atmosphere. The CTI ATC-105 test code recommends that values for the wind speed at the elevation of the tower outlet and the atmospheric temperature gradient for the performance test be established by contract. The code sets default values for these parameters if they are not specified in the contract. If no value for wind speed is established by contract, the default limit for windspeed at the elevation of the cooling tower air outlet is 10 mph. If no atmospheric temperature gradient is established by contract, the test code requires the dry bulb temperature gradient to be at least -0.65˚C/100m (-3.5˚F/1000 ft).

For cooling towers with safe access to the top of the shell, wind speed stations can be placed at the top of the cooling tower. The authors recommend at least two stations to assure that at least one station will be on the upwind side of the tower. When it is not possible to measure the wind speed at the cooling tower outlet elevation, the upper level wind speed must be evaluated based on visual observation of the plume or by correcting the wind speed measured at ground level to the elevation of the top of the cooling towers. Methods to correct wind speed for elevation are included in Appendix L of the new test code.

When practical, the test code requires the atmospheric temperature gradient be measured at 60m (200 ft) intervals up to 1.5 time the height of the cooling tower. This measurement requires a tethered balloon and will rarely be practical. In the absence of directly measured values for temperature gradient, the test code specifies that temperature at the upper level of the air inlet be at least 0.15˚C (0.25˚F) lower than the temperature at the lowest level of the air inlet.

In some cases, alternative measurements of upper level wind speed and air temperature gradient are available. For instance, nuclear plants are required to make these measurements on a continuous basis using annually calibrated instruments. The authors strongly recommend that methods used to evaluate upper level wind speed and air temperature gradient be detailed in a site-specific test plan for any natural draft cooling tower acceptance test.

EVALUATION OF RESULTS

Corrections to Cold Water Temperature

When the cold water temperature is measured using a flowing well downstream of the circulating water pump, the measured cold water temperature is corrected for throttling and heat added by the pump by:

$$T_{cw,c} = T_{cw,m} - c_g \frac{P_g}{\eta_{pump}}$$

Where

$T_{cw,c}$ = corrected cold water temperature, °C (°F)

$T_{cw,m}$ = measured cold water temperature, °C (°F)

P_g = gage pressure at pump discharge, kPa (psig)

η_{pump} = fractional pump efficiency, dimensionless

c_g = conversion factor, 0.000239 °C/kPa (0.002966 °F/psi)

The correction for a flowing well at the discharge of a pump with pressure of 35 psig is approximately 0.1˚F. If cold water temperature is measured in thermowell, the cold water correction is negligible.

When makeup is added upstream of the measurement of cold water temperature, the cold water temperature is corrected by:

$$T_{cw} = \frac{Q_{wt} T_{cw,c} - Q_{mu} T_{mu}}{Q_{wt} - Q_{mu}}$$

Where

Q_{wt} = circulating water flow rate

Q_{mu} = makeup water flow

T_{mu} = makeup water temperature

Fan Motor Power Corrections

The fan motor power is usually measured at the motor control center (MCC) rather than the motor terminals. In this case, the measured motor power must be corrected for the line loss between the MCC and the motor terminals. New example line loss calculations are provided in Appendix N in the new version of the CTI ATC-105 test code. The design fan motor power provided in the cooling tower specification is normally the brake motor power. If this is the case, the measured motor power is multiplied by the name plate efficiency of the fan motor.

Performance Curve Analysis

The CTI ATC-105 test code provides two different methods of analysis which use the test data and correction curves provided by the manufacturer to determine the performance of the cooling tower at design (contract) conditions of water flow, fan motor power, wet bulb temperature, and heat duty.

By far the most commonly used of these, is the performance curve method. The performance curves provided by the manufacturer consist of prediction of the cold water temperature as a function of wet bulb temperature. The test code specifies that performance curves are to be provided at 80 percent, 100 percent and 120 percent of design range for 90 percent, 100 percent and 110 percent of design water flow. The format of these curves is illustrated in Figures 2, 3, and 4.

Figure 2 Performance Curve at 90% Flow

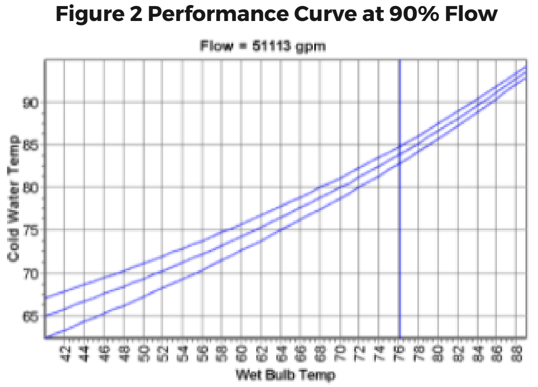


Figure 3 Performance Curve at 100% Flow

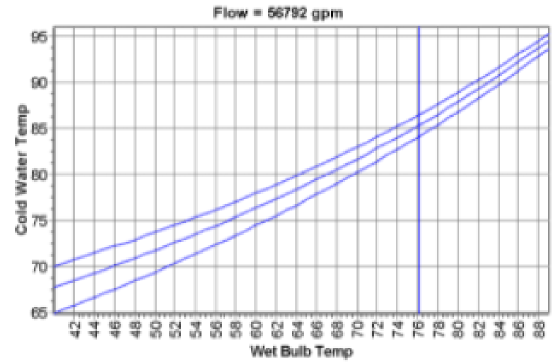
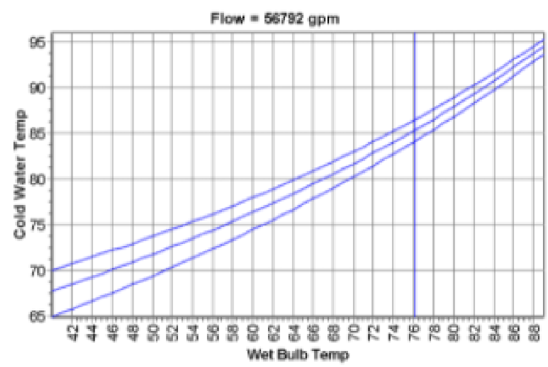
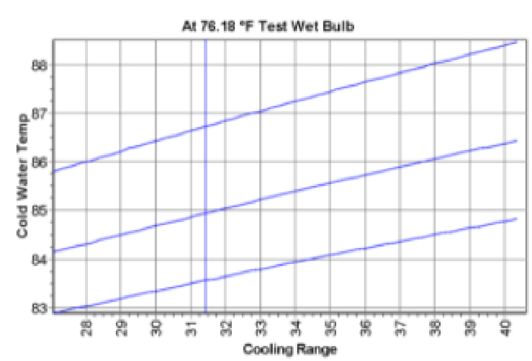


Figure 4 Performance Curve at 110% Flow



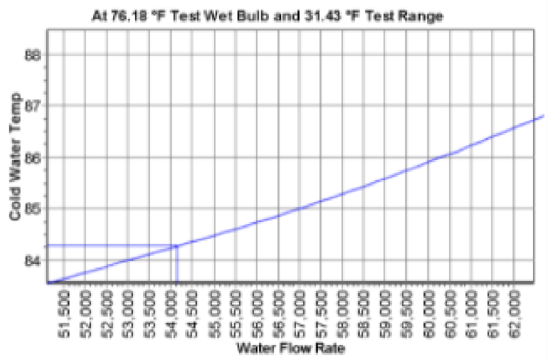
The performance curves are read at the test wet bulb to determine the predicted cold water at each design range and water flow. These values are interpolated to determine the predicted cold water at the test range. This interpolation process is illustrated in Figure 5.

Figure 5 Cold Water Temperature at Test Range



The cold water values are interpolated to determine the predicted water flow at the test cold water temperature. The interpolation process is illustrated in Figure 6.

Figure 6 Predicted Cold Water Temperature



The measured cold water flow is adjusted based on the test fan motor power by:

$$Q_{wt,adj} = Q_{wt}\left(\frac{W_d}{W_{t,c}}\right)^{1/3}\left(\frac{\rho_t}{\rho_d}\right)^{1/3}$$

Where

- Q_{wt} = measured cold water flow
- W_d = design fan motor power
- $W_{t,c}$ = measured fan motor power, corrected for line loss if necessary
- ρ_d = design air density at fan inlet
- ρ_t = test air density at fan inlet

For induced draft fans, the test air density is calculated by heat balance based on the measured psychrometric conditions, the test water flow, and the design L/G ratio. The capability of the cooling tower is calculated by:

$$C = \frac{Q_{wt,adj}}{Q_{w,pred}} \times 100$$

CTI provides a program, CTI Toolkit®, for the analysis of mechanical draft cooling tower performance. The output of this program is illustrated in Figure 7. The Toolkit program is used by most CTI-licensed test agents for the analysis of mechanical draft cooling tower test data.

Figure 7 Toolkit® Output

Tower Performance Report

Big Megawatt Station 09/12/19
Owner: New Era Power Company
Project: Big Megawatt Station
Location: Off the Highway
Manufacturer: Thuridon Cooling Towers
Tower Type: Induced Draft

Cooling Tower Design and Test Data

Parameters	Design	Test
Water Flow Rate	56792.0 gpm	57426.0 gpm
Hot Water Temp.	120.92 °F	115.70 °F
Cold Water Temp.	87.08 °F	84.27 °F
Wet Bulb Temp.	78.80 °F	76.18 °F
Dry Bulb Temp.	86.36 °F	77.94 °F
Fan Driver Power	143.40 bhp	151.50 bhp
Barometric Pressure	29.921 in. Hg.	29.180 in. Hg.
Liquid to Gas Ratio	1.300	1.301

Cold Water Temperatures vs. Range
At 76.18 °F Test Wet Bulb

Range	51112.8 gpm	56792.0 gpm	62471.2 gpm
27.07 °F	82.88 °F	84.14 °F	85.81 °F
33.84 °F	83.91 °F	85.37 °F	87.23 °F
40.61 °F	84.87 °F	86.49 °F	88.53 °F

Cold Water Temperature vs. Water Flow
At 76.18 °F Test Wet Bulb and 31.43 °F Test Range

51112.8 gpm	56792.0 gpm	62471.2 gpm
83.55 °F	84.94 °F	86.73 °F

Exit Air Properties

	Wet Bulb Temp	Density	Sp. Vol.	Enthalpy
Design	107.32	0.06782	15.5500	86.3249
Test	104.16	0.06665	15.7648	81.1835

Test Results

Adjusted Flow	Predicted Flow	CWT Deviation	Tower Capability
56057.4 gpm	54152.3 gpm	-0.50 °F	103.5%

This test result is only certified by CTI if the test data was collected by a CTI Licensed Testing Agency. See www.cti.org for an agency list.

Appendix D.bbp\Appendix D Test Data

Produced by CTI Toolkit© 3.0

The 2019 version of the ATC-105 test code provides expanded insight into the analysis of "helper" cooling towers. Helper cooling towers do not operate on a closed cooling water cycle. Helper cooling towers cool the water prior to discharge into a receiving water body. For helper cooling towers, the cooling tower range and heat duty are not solely a function of plant load but are also a function of wet bulb temperature and cooling tower performance. The analysis method for helper cooling towers is identical to that described the preceding paragraphs with the exception that the performance curves are provided as a function of hot water temperature instead of range. The methodology for analysis of helper cooling towers is specified in Section 11 and illustrated in Appendices Q and R of the 2019 test code.

The methods used to determine the performance for natural draft and wet/dry cooling towers are very similar to that described in the preceding paragraphs. At this time, the analysis of natural draft, wet/dry and helper cooling towers is not supported by CTI Toolkit®. Licensed CTI test agents use their own proprietary software for performance analysis of these types of cooling towers.

Uncertainty Analysis

The reported values from any measurement include some error. These errors are limited by using the quantity and quality of instruments specified in Appendix G and Section 3 of CTI ATC-105. The best use of the uncertainty analysis is as an estimate of the accuracy of the test. The uncertainty of a test conducted with code level instrumentation will vary depending on the design of the cooling tower, the atmospheric conditions at the time of the test, and the configuration of piping at the flow measurement location.

Some contractual requirements specify that an acceptance test is to be performed under the guidelines of the ASME PTC-23 test code which is a seldom-used alternative to the ATC-105 test code. The CTI ATC-105 test code differs from ASME PTC 23 code in that ATC-105 does not require an uncertainty analysis. However, Appendix U of ATC-105 does provide a detailed method for performing a cooling tower uncertainty analysis. The methodology used is consistent with ASME PTC 19.5 which determines a two-tailed 95% confidence interval.

To illustrate, consider a hypothetical cooling tower testing at a capability of 96% with a test uncertainty of 4%. For this tower, the probability that the actual performance of the cooling tower would meet or exceed its guarantee would be 2.5 percent (i.e. there is a 97.5% chance that the tower did not meet the contractual specification). The statistical implications of the uncertainty interval should be carefully considered before adopting the test uncertainty as a tolerance. An example of a summary of a cooling tower uncertainty analysis is provided in Table 4. In this example, the major contributors to the overall uncertainty are the systematic uncertainties for the water flow and wet bulb temperature which are approximately 3 percent each.

Table 4 Example Uncertainty Analysis

				Systematic Uncertainty				Random Uncertainty	
Parameter	Units	Sensitivity	Units	Instrumental	Spatial	Total	Capability	Total	Capability
Water Flow	gpm	7.15E-04	%/gpm	3346	2841	4389	3.14	NA	NA
Hot Water Temperature	°F	2.240	%/°F	0.17	NA	0.17	0.38	0.050	0.11
Cold Water Temperature	°F	-7.105	%/°F	0.17	0.1	0.20	1.40	0.026	0.19
Wet Bulb Temperature	°F	3.435	%/°F	0.34	0.74	0.82	2.81	0.022	0.08
Fan Motor Power	bhp	-0.172	%/hp	3.8	NA	3.78	0.65	NA	NA
Barometric Pressure	inHg	1.320	%/inHg	0.05	NA	0.05	0.07	NA	NA
Total Systematic Uncertainty		**4.50**	**%**						
Total Random Uncertainty		**0.23**	**%**						
Total Uncertainty		**4.51**	**%**						

Reporting

Scope

The CTI ATC-105 test code requires that test report must include:

- A summary including results and the design test values of test parameters
- Identification of any parameters that were out of code
- Capability analysis documentation
- The manufacturer's performance curves
- A sketch of the instrument layout
- Notation of building or heat sources in the vicinity of the cooling tower
- Original log sheets of test data

Distribution

For contractual acceptance tests, a single page preliminary report including all important data and the test result must be issued within 10 days of the test to parties to the test. The parties to an acceptance test include, at minimum, the cooling tower owner, tower rebuilder or manufacturer and the test agency. It is normal practice for CleanAir to issue this preliminary report before leaving the test site. The final test report is also issued to all test parties.

Conclusions

The 2019 version of the CTI ATC-105 represents an incremental change from the 2000 version. The changes do not significantly alter the conduct of the test, but constraints are placed on the test timing. The new test code makes small changes to the envelope of acceptable test conditions and codifies standard industry practice with respect to the measurement of wet bulb temperature.