ANSI/AHRI Standard 551/591 (SI) with Addendum 3

2011 Standard for

Performance Rating Of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle

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AHRI
AIR-CONDITIONING, HEATING, & REFRIGERATION INSTITUTE
we make life better™
2111 Wilson Boulevard, Suite 500
Arlington, VA 22201, USA
www.ahrinet.org
PH 703.524.8800
FX 703.562.1942

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AHRI STANDARD 551/591 (SI)-2011 WITH ADDENDUM 3

Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle

September 2013

Addendum 3 (dated September 2013) of AHRI Standard 551/591 (SI)-2011, *"Changes to AHRI Standard 551/591 (SI)-2011"* is provided as follows. The following changes have been incorporated (deletions are shown by shading in red, additions are shown by shading in gray) into the already published 2011 version of AHRI Standard 551/591 (SI) to avoid confusion:

Note: This addendum is not ANSI approved and is currently going through the process to do so.

The changes include:

1. Revision to Table 9.

To comply with this standard, published or reported values shall be in accordance with Table 9.

Table 9. Definition of Tolerances

		Limits	Related Tolerance Equations[2,3,4]
Capacity	Cooling or Heating Capacity for units with continuous unloading[1]	Full Load minimum: 100%- Tol_1 Full Load maximum: ~~102%~~-100%+ Tol_1 Part Load test capacity shall be within 2% of the target part-load capacity[5]	$Tol_1 = 0.105 - (0.07 \cdot \%Load) + \left(\frac{0.0833}{\Delta T_{FL} \cdot \%Load}\right)$ 20 ΔT_{FL}= Difference between entering and leaving chilled water temperature at full-load, K See Figure 3 for graphical representation of the Tol_1 tolerance.
	Cooling or Heating Capacity for units with discrete capacity steps	Full Load minimum: 100% - Tol_1 Full load maximum: no limit (Full Load shall be at the maximum stage of capacity) Part Load test points shall be taken as close as practical to the specified part-load rating points as stated in Table 3	
Water cooled heat balance (HB)		- $Tol_1 \leq HB \leq +Tol_1$	
Efficiency	EER	Minimum of: ~~(100%- Tol_1)·(rated EER)~~ (rated EER) / (100%+ Tol_1)	
	kW/ton_R	Maximum of: (100%+ Tol_1)·(rated kW/ton_R)	
	COP	Minimum of: ~~(100%- Tol_1)·(rated COP)~~	

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		(rated COP) / (100%+ Tol_1)	
	IPLV/NPLV (EER)	Minimum of: (100%- Tol_2)·(rated EER) (rated EER) / (100%+ Tol_2)	$Tol_2 = 0.065 + \left(\frac{0.194}{\Delta T_{FL}}\right)$ 21 See Figure 4 for graphical representation of the Tol_2 tolerance.
	IPLV/NPLV (kW/ton_R)	Maximum of: (100%+ Tol_2)·(rated kW/ton_R)	
	IPLV/NPLV (COP_R)	Minimum of: (100%- Tol_2)·(rated COP_R) (rated COP_R) / (100%+ Tol_2)	
Water Pressure Drop		Maximum of: (1.15)·(rated pressure drop at rated flow rate) or rated pressure drop plus 2 feet of H_2O, whichever is greater	

Notes:
1. The target set point condenser entering temperatures (Figure 1) for continuous unloading units will be determined at the target part load test point.
2. For air-cooled units, all tolerances are computed for values after the barometric adjustment is taken into account.
3. %Load and Tol_1 are in decimal form.
4. Tol_2 is in decimal form.
5. The ± 2.0% tolerance shall be calculated as 2.0% of the full load rated capacity ($tons_R$). For example, a nominal 50.0% part load point shall be tested between 48.0% and 52.0% of the full load capacity.

2. The Full-Load Tolerance examples were revised in Sections 5.6.2.

5.6.2 *Full-Load Tolerance Examples*. The allowable tolerance on full load capacity and efficiency (COP_R) shall be determined from 5.6.1.

Full-Load Examples.

Full-Load Example in EER

Rated Full-Load Performance:

Rated Capacity = 300 kW
Rated Power = 105 kW
Cooling ΔT_{FL} = 5 K

$$COP_C = \frac{300\ kW}{101\ kW} = 2.970\frac{W}{W}$$

$$Allowable\ Test\ Tolerance = T_1 = 10.5 - (.07 \times 100) + \left(\frac{833.3}{5 \times 100}\right) = 5.16\%$$

$$Allowable\ Test\ Tolerance = T_1 = 0.105 \cdot (0.07 \cdot 100\%) \cdot \left(\frac{0.0833}{5 \cdot 100\%}\right) = 5.17\%$$

$$Minimum\ Allowable\ Tolerance = 100\% - T1 = 100\% - 5.16\% = 94.84\%$$

$$Minimum\ Allowable\ Capacity = 94.84\% \times 300kW = 284.52kW$$

$$Minimum\ Allowable\ Capacity = (100\% - 5.17\%) \cdot 300\ kW = 284.49\ kW$$

$$Minimum\ Allowable\ COP_C = 94.84\% \times 2.970\frac{W}{W} = 2.817\frac{W}{W}$$

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$$Minimum\ Allowable\ COP_C = \frac{2.970\ \frac{W}{W}}{100\% + 5.17\%} = 2.824\frac{W}{W}$$

3. The Part-Load Tolerance examples were revised in Section 5.6.3

5.6.3 *Part-Load*. The tolerance on part-load efficiency ($COP_{C)}$ shall be the tolerance as determined from 5.6.1.

Part-Load Example in COP_C

Rated Part-Load Performance:

Power at 69.5% Rated Capacity	=	59.0 kW
69.5% Rated Capacity	=	208.5 kW
Cooling ΔT_{FL}	=	5 K

$$COP_C = \frac{208.5\,kW}{59.0\,kW} = 3.534\frac{W}{W}$$

$$Allowable\ Test\ Tolerance = T_1 = 10.5 - (.07 \times 69.5) + \left(\frac{833.3}{5 \times 100}\right) = 7.30\%$$

$$Allowable\ Test\ Tolerance = T_1 = 0.105 \cdot (0.07 \cdot 69.5\%) \cdot \left(\frac{0.0833}{5 \cdot 69.5\%}\right) = 8.03\%$$

$$Minimum\ Allowable\ Tolerance = 100\% - T1 = 100\% - 7.30\% = 92.70\%$$

$$Minimum\ Allowable\ Capacity = 92.7\% \times 208.5kW = 193.28kW$$

$$Minimum\ Allowable\ Capacity = (100\% - 8.30\%) \cdot 208.5kW = 191.76\ kW$$

$$Minimum\ Allowable\ COP_C = 92.7\% \times 3.534\frac{W}{W} = 3.276\frac{W}{W}$$

$$Minimum\ Allowable\ COP_C = \frac{3.524\ \frac{W}{W}}{100\% + 8.30\%} = 3.271\ \frac{W}{W}$$

4. Revision to Section C4.3

To determine the range over which the calibration achieves the required accuracy, a linear regression analysis is performed on the calibration data. The data is plotted to show the residual errors versus the calibration reference standard. [The standard error of estimate shall be calculated for the measurement system indicated values (post calibration) versus the calibration reference standard, then using equation C1 plot a 95% prediction interval (α=5%) on both sides of the calibration data points curve fit. The point(s) at which the prediction interval curve exceeds the required accuracy shall be the limit(s) of the range. Table C2 and the equations that follow explain the method of calculating the prediction interval. See example using sample data in Figures C1 and C2, in which the specified accuracy is ±1% of reading, and the useable range is from 100 to 22.5 13.4, or Turn Down Ratio of 4.4:1 7.5:1.

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5. Remove Table C2, Figures C1 and C2 and replace with revised Table C2, Figures C1 and C2.

Table C2. Prediction Interval to Determine Range of Acceptable Accuracy

	Reference Standard Value [1] x_j y_j j=1 to n	Corrected (As Left) Indicated Value [2] y_j x_j j=1 to n	Absolute Prediction Interval of Indicated Value	Relative Prediction Interval of Indicated Value	
				%RDG	%FS
Calibration Data	x_1 y_1	y_1 x_1	x_1 - $\hat{y} \pm PI(x_1)$	$\frac{x_1 - \hat{y} \pm PI(x_1)}{x_1}$ $\pm\frac{PI(x_1)}{x_1}$	$\pm\frac{PI(x_1)}{FS}$
	x_2 y_2	y_2 x_2	x_2 - $\hat{y} \pm PI(x_2)$	$\frac{x_1 - \hat{y} \pm PI(x_2)}{x_2}$ $\pm\frac{PI(x_2)}{x_2}$	$\pm\frac{PI(x_2)}{FS}$
	x_3 y_3	y_3 x_3	x_3 - $\hat{y} \pm PI(x_3)$	$\frac{x_1 - \hat{y} \pm PI(x_3)}{x_3}$ $\pm\frac{PI(x_3)}{x_3}$	$\pm\frac{PI(x_3)}{FS}$
	…	…	…	…	…
	x_n y_n	y_n x_n	x_n - $\hat{y} \pm PI(x_n)$	$\frac{x_1 - \hat{y} \pm PI(x_n)}{x_n}$ $\pm\frac{PI(x_n)}{x_n}$	$\pm\frac{PI(x_n)}{FS}$
Regression Statistics	$\bar{x}$ SS_x	s_ε	continuous curve ± PI $\hat{x} - \hat{y} \pm PI(\hat{x})$ varying $\hat{x}$ from min to max values of x_j	continuous curve ±PI% $\frac{\hat{x} - \hat{y} \pm PI(\hat{x})}{\hat{x}}$ varying $\hat{x}$ from min to max values of x_j	

Notes:
1. Reference Standard Value is the actual value determined or measured by the calibration standard.
2. Corrected Indicated Value is the value of the measured quantity given directly by a measuring system on the basis of its calibration curve ("as left" when the calibration process has been completed, not "as found" at the beginning of the calibration process).

$$PI(\hat{x}) = s_\varepsilon \cdot t_{\frac{\alpha}{2},n-2} \cdot \sqrt{1 + \frac{1}{n} + \frac{(\hat{x} - \bar{x})^2}{SS_x}} \qquad \text{C1}$$

Where:

x is a variable representing any measurement value, such as temperature, flow rate, or power

$\hat{y}$ is the linear regression curve fit of the (x_j,y_j) calibration data used to compare indicated measurement values versus the calibration reference standard

$\hat{x}$ is any value of x at which to evaluate the curve fit and prediction interval

$PI(\hat{x})$ is the prediction interval at the value of $\hat{x}$

FS is the value of x at full scale indicating the upper limit of the measurement range capability of the instrument or measurement system

n is the number of calibration data points

$\bar{x}$ is the mean of all measurement values from calibration points

SS_x is the sum of squares of x value differences to the mean

s_ε is the standard error of estimate, used to quantify the residual error of a measuring system after calibration against a reference calibration standard

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$$\overline{x} = \frac{1}{n}\sum_{j=1}^{n}\left(x_j\right) \quad \text{C2}$$

$$SS_x = \sum_{j=1}^{n}\left(x_j - \overline{x}\right)^2 \quad \text{C3}$$

$$s_\varepsilon = \sqrt{\frac{\sum_{j=1}^{n}\left(y_j - mx_j - c\right)^2}{n-2}} \quad \text{C4}$$

$$m = \frac{n\sum_{j=1}^{n} x_j y_j - \sum_{j=1}^{n} x_j \sum_{j=1}^{n} y_j}{n\sum_{j=1}^{n}\left(x_j\right)^2 - \left(\sum_{j=1}^{n} x_j\right)^2} \quad \text{C5}$$

$$c = \frac{\sum_{j=1}^{n}\left(x_j^2\right)\sum_{j=1}^{n} y_j - \sum_{j=1}^{n} x_j \sum_{j=1}^{n}\left(x_j y_j\right)}{n\sum_{j=1}^{n}\left(x_j^2\right) - \left(\sum_{j=1}^{n} x_j\right)^2} \quad \text{C6}$$

$$\hat{y} = m \cdot \hat{x} + c \quad \text{C7}$$

Where:

m = 1 = Slope of regression line due to the calibration process
c = 0 = Y-intercept of the regression line due to the calibration process
m = Slope of the regression line
c = Intercept (offset) of the regression line

$t_{\frac{\alpha}{2},n-2}$ = The critical value of Student's t distribution, at confidence level α/2 and degrees of freedom n-2
α = 5% = The significance level used by this standard
95% = 1-α = The prediction interval used by this standard

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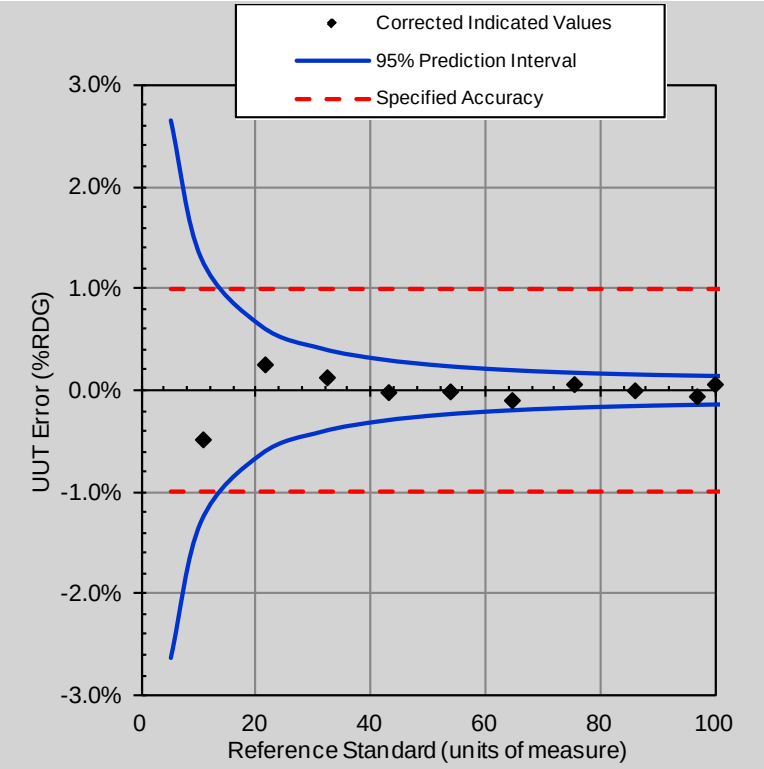


Figure C1. Sample of Relative Calibration Evaluation Data (Percent of Reading)

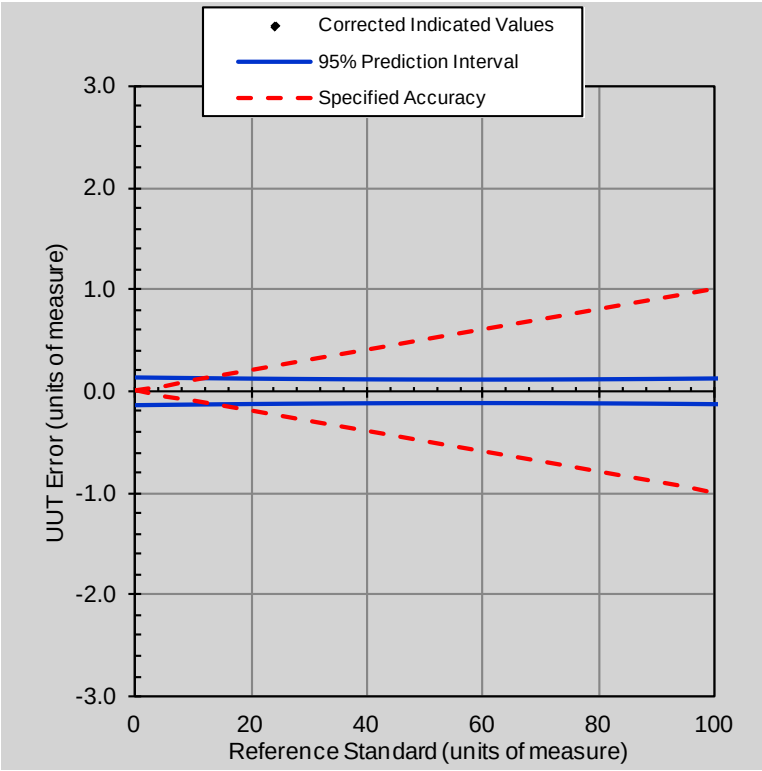


Figure C2. Sample of Absolute Calibration Evaluation Data (Percent of Full Scale)

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AHRI STANDARD 551/591 (SI)-2011 WITH ADDENDUM 2

Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle

June 2013

Addendum 2 (dated June 2013) of AHRI Standard 551/591 (SI)-2011, "*Changes to AHRI Standard 551/591 (SI)-2011"* is provided as follows. The following changes have been incorporated (deletions are shown by ~~strikethroughs~~, additions are shown by shading) into the already published 2011 version of AHRI Standard 551/591 (SI) to avoid confusion:

Note: This addendum is not ANSI approved and is currently going through the process to do so.

The changes include:

1. The effective date of Appendix G was revised.

This 2011 standard (as amended by Addenda 1 and 2) supersedes AHRI Standard 551/591 (SI)-2011 ~~and shall be effective 1 January 2013 and optional prior to that date~~.
The requirements of Appendix G shall be effective on January 1, 2014 and optional prior to that date.

2. The definition for "Water Pressure Drop" was revised.

3.19 *Water Pressure Drop*. ~~A measured value of~~ The reduction in static water pressure associated with the flow through a water-type heat exchanger. For this standard, the Water Pressure Drop shall include pressure losses due to nozzles, piping, or other interconnections included with the Water-Chilling or Water-Heating Package and shall include all pressure losses across the external unit connection points for water inlet and water outlet. ~~This~~ For Published Ratings, this value is expressed in ~~a rating in~~ feet H_2O at a reference water temperature of 60°F. For test measurements, this is a differential pressure expressed in ~~a~~ psid. (refer to Section 7 for converting units of measure).

3. Add new Informative Reference to Appendix B.

B1.6 Blake, K.A., "The design of piezometer rings," Journal of Fluid Mechanics, Volume 78, Part 2, pages 415-428, 1976.

4. "Water" was added to Section C3.1.3.3

C3.1.3.3 Measure Water Pressure Drop across the heat exchanger, kPa.

5. Remove Section C3.1.3.3.1 and replace with revised Section C3.1.3.3.1.

~~**C3.1.3.3.1** Static pressure taps shall be located external to the unit per Appendix G. Appendix G specifies the acceptable adjustment factors to be used to adjust the pressure drop measurement for external piping between the static pressure tap and the unit conversion.~~

C3.1.3.3.1 Static pressure taps shall be located per Appendix G. Depending on the design of chiller water connections, Appendix G may or may not require additional piping external to the unit for accurate measurements. External piping for the

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measurement purposes creates additional line losses between the static pressure tap and the unit connections. These additional losses are calculated and then subtracted from the raw measurement value as an adjustment method to obtain the reported test result for Water Pressure Drop across the unit connections. Appendix G specifies the calculation method for adjustment factors.

6. The title of Appendix G was revised.

Appendix G. Water Side Pressure Drop ~~Correction~~ Measurement Procedure – Normative 60

7. Remove Sections G1, G2 and G3, and replace with revised Sections G1, G2, and G3, including new Sections G4 and G5, and new Figures G1 and G2.

Figure G1. Examples of Piezometer Ring/Manifold 61
Figure G2. Example of Piezometer Triple-Tee Ring/Manifold 61
Figure G~~1~~3. Calibration Term for Included Angle for Expansion/Contraction Fittings 62

~~**G1** *Purpose*. The purpose of this appendix is to prescribe a method of compensating for friction losses associated with external piping sections used to determine water-side Water Pressure Drop.~~

~~**G2** *Background*. As a certified test point for the liquid to refrigerant heat exchangers, the water-side pressure drop needs to be determined by test. Since the measured pressure drop for this standard will be determined by using static pressure taps external to the unit in upstream and downstream piping, adjustment factors are allowed to compensate the reported pressure drop measurement for the external piping sections. For units with small connection sizes it is felt that straight pipe sections should be connected to the units with adequate spacing to obtain reasonable static pressure measurements. This is the preferred connection methodology. Units with larger size connections may be restricted in the upstream and downstream connection arrangement such that elbows or pipe diameter changes may be necessary. Numerous studies conclude that the determination of a calculated correction term for these external components may contain significant sources of error and therefore the use of external correction factors will be restricted as follows:~~

~~**G2.1** A requirement of the test arrangement is that the static pressure taps will be in a manifolded arrangement with a minimum of 3 taps located circumferentially around the pipe at equal angle spacing.~~

~~**G2.2** Correction factors will be limited to 10% of the pressure drop reading.~~

~~**G2.3** Unit connections with piping that have an internal diameter of 110mm and below will only allow for a frictional adjustment for a straight pipe section not to exceed 10 diameters of flow length between the unit and the static pressure measurement. The absolute roughness for the pipe will be assumed to be typical of clean steel piping.~~

~~**G2.4** Units with pipe connections greater than 110mm internal diameter may have an additional allowance for a 90 degree elbow and a diameter change in both the upstream and downstream unit connection. These static pressure taps will be located at least 3 diameters downstream of a flow expansion and at least 1 diameter away from either an elbow or a flow contraction. The sum of all corrections may not exceed 10% of the pressure drop reading.~~

~~**G3** *Procedure*. Derivation of Correction Factors – The general form of the adjustment equations utilize the methods in the Crane Technical Paper No. 410. A friction factor is determined using the Swamee-Jain equation of~~

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{\epsilon}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}\right)\right]^2} \quad \text{G1}$$

~~Where $\frac{\epsilon}{D}$ is the relative roughness, with ϵ the absolute roughness taken to be 0.045 mm and D the internal pipe diameter (mm). Re is the Reynolds number for the flow in the pipe.~~

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The pressure drop (h_L) associated with a flow component or fitting may be calculated using the friction factor as detailed above or the equation may use a K factor. The forms of the equations are:

$$h_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}$$ when friction factor is used for straight pipe sections or G2a

$$h_L = K \cdot \frac{V^2}{2g}$$ when a K factor is specified for elbows and expansions/contractions G2b

Where:

L/D is the ratio of pipe length to internal diameter
V is the average velocity calculated at the entrance to the component
g is the acceleration due to gravity

The K factors for the elbows utilize the equation set found in the Crane Technical Publication 410. A correction factor is computed for the following elbow arrangements:

Table G1. K Factors for Elbow Arrangements

Description	K Factor
Smooth elbow with r/D = 1	20·f
Smooth elbow with r/D= 1.5	14·f
Smooth elbow with r/D = 2	12·f
Smooth elbow with r/D = 3	12·f
Smooth elbow with r/D = 4	14·f
Segmented with 2·45° mitres	30·f
Segmented with 3·30° mitres	24·f
Segmented with 6·15° mitres	24·f

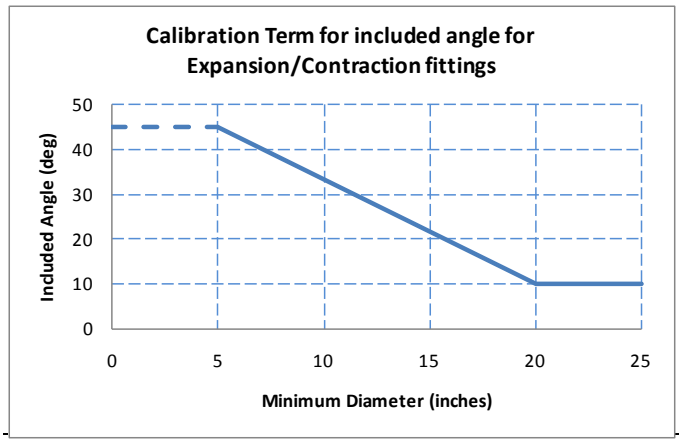
Where:

f = Darcy friction factor described above, and r/D is the radius (r) to the centerline of the elbow divided by the internal pipe diameter (D)

The determination of the K factor for the expansion and contraction sections is a function of the inlet to outlet diameter ratio as well as the angle of expansion and contraction. For purposes of this standard, the equation has been calibrated by assigning an angle term that best represents the pressure drop results found in the ASHRAE technical report 1034 RP for these expansion and contraction fittings. The user is directed to the Crane Technical Paper for a more complete description of the equations. The angle of expansion or contraction is detailed on the accompanying chart with limits placed at 45 degrees and 10 degrees.

An excel spreadsheet is available from AHRI for computation of the pressure drop adjustment factors.

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~~Figure G1. Calibration Term for Included Angle for Expansion/Contraction Fittings~~

G1 *Purpose.* The purpose of this appendix is to prescribe a measurement method for Water Pressure Drop and, when required, a correction method to compensate for friction losses associated with external piping measurement sections. The measurement method only applies to pipe of circular cross section.

G2 *Background.* As a certified test point for the liquid to refrigerant heat exchangers, the water-side pressure drop needs to be determined by test with acceptable measurement uncertainty. In some cases, the measured pressure drop per this standard will be determined by using static pressure taps external to the unit in upstream and downstream piping. When using external piping, adjustment factors are allowed to compensate the reported pressure drop measurement. Numerous studies conclude that the determination of a calculated correction term for these external components may contain significant sources of error and therefore the use of external correction factors will be restricted to limit the magnitude of these potential errors. For units with small connection sizes it is feasible that straight pipe sections be directly connected to the units with adequate length to obtain static pressure measurements with acceptable systematic errors due to instrument installation location. This is the preferred connection methodology. Units with larger size connections may have spatial limits in the upstream and downstream connection arrangement such that elbows or pipe diameter changes may be necessary to accommodate the available space at the test facility, or to provide mechanical support for piping weight loads. While this may increase the measurement uncertainty it is a practical compromise considering capital costs of test facilities.

G3 *Measurement Locations.* Static pressure taps shall simultaneously meet all of the following requirements:

G3.1 Static pressure taps may be in either the unit connections (i.e. nozzles) or in additional external piping provided for the purpose of test measurements.

G3.2 If using additional external piping, the piping arrangement shall use rigid pipe and may include fittings such as elbows, reducers, or enlargers between the pressure tap locations and the unit connections. Flexible hose is prohibited between the unit connections and the pressure taps.

G3.3 Static pressure taps shall maintain the following lengths of cylindrical straight pipe in the flow path adjacent to each pressure tap location in Table G1.

Table G1. Straight Length in Flow Path

Unit Connection, Nominal Pipe Size	Straight Length in Flow Path	
	Upstream of Pressure Tap	Downstream of Pressure Tap
≤75 mm	Minimum 10 · D	Minimum 3 · D
100, 125, or 150 mm	Minimum 6 · D	Minimum 2 · D
≥200 mm	Minimum 3 · D	Minimum 1 · D

D = The greatest pipe inside diameter dimension, using the nominal pipe size and pipe schedule nominal wall thickness, of the following locations:

- The pipe diameter at the pressure tap location
- The largest diameter of any reducer or enlarger fittings between the pressure tap location and unit connections
- The largest diameter of the first reducer or enlarger fitting between the pressure tap location and the test facility if any

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G4 *Static Pressure Taps.* Static pressure taps will be in a piezometer ring or piezometer manifold arrangement with a minimum of 3 taps located circumferentially around the pipe, all taps at equal angle spacing. To avoid introducing measurement errors from recirculating flow within the piezometer ring, each of the pipe tap holes shall have a flow resistance that is greater than or equal to 5 times the flow resistance of the piezometer ring piping connections between any pair of pressure taps. A "Triple-Tee" manifold arrangement using 4 pipe tap holes is the preferred arrangement, but not required if meeting the flow resistance requirement.

G4.1 For design or evaluation purposes, flow resistance may be estimated by resistance coefficient K factor calculation methods as found in Crane Technical Paper No. 410. Generally, manifold tubing or piping can be evaluated using the K factor and pressure tap holes can be evaluated using orifice flow equations (refer to Section G5.2).

G4.2 For more information about the design of piezometer rings see paper by Blake in the Informative References, see Appendix B.

G4.3 Provisions shall be made to bleed air out of the lines connected to pressure measurement devices. These provisions shall take into consideration the orientation of pressure taps and manifold connections.

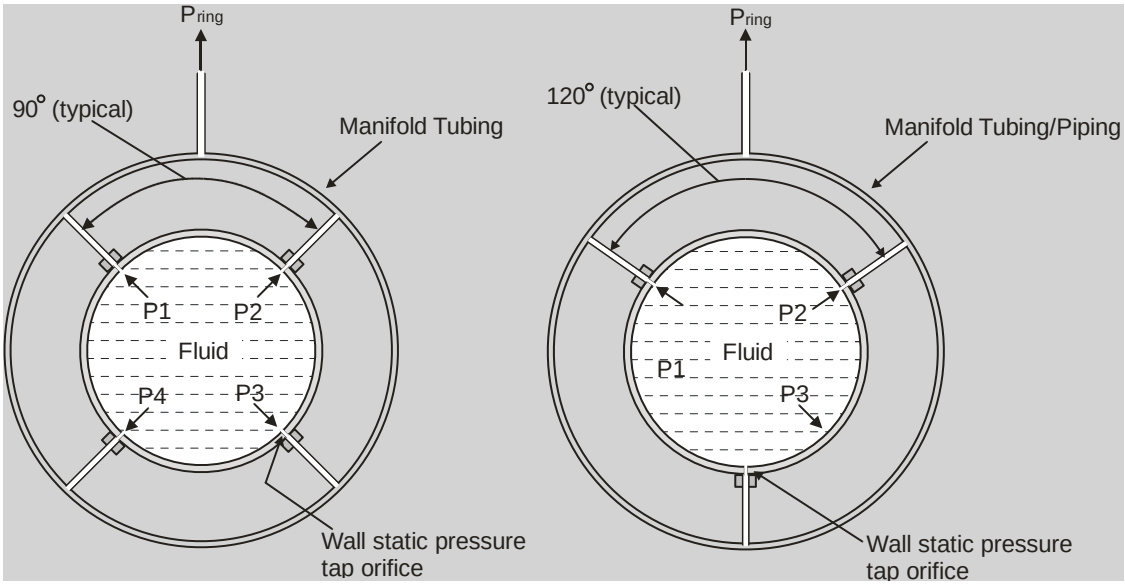


Figure G1. Examples of Piezometer Ring/Manifold

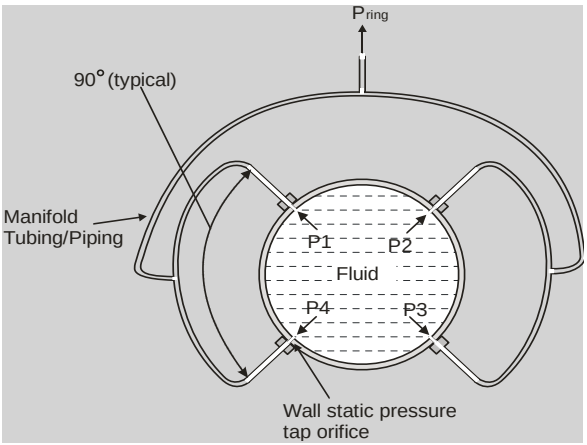


Figure G2. Example of Triple-Tee Piezometer Ring/Manifold

G5 *Correction Method.* Measured water pressure drop values shall be adjusted to subtract additional static pressure drop due to external piping. The additional static pressure drop shall be the sum of all losses between the unit connections and the

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location of static pressure taps. Record the original measured value, the calculated adjustment value, and the final calculated result for water pressure drop.

G5.1 The adjustment shall not exceed 10% of the measured water pressure drop.

G5.2 The general form of the adjustment equations utilize the methods in the Crane Technical Paper No. 410. A Darcy friction factor is determined using the Swamee-Jain Equation G1.

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{\epsilon}{3.7 \cdot D} + \frac{5.74}{Re^{0.9}}\right)\right]^2} \quad \text{G1}$$

Where:

ϵ = Absolute roughness, 0.045 mm (for purposes of this standard)
D = Internal pipe diameter, mm
Re = Reynolds number for the flow in the pipe

The pressure drop (h_L) associated with a flow component or fitting may be calculated using the friction factor as detailed above or the equation may use a K factor. These are shown in Equations G2 and G3.

$$h_L = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} \text{ when the Darcy friction factor is used for straight pipe sections} \quad \text{G2}$$

$$h_L = K \cdot \frac{V^2}{2g} \text{ when a K factor is specified for elbows and expansions/contractions} \quad \text{G3}$$

Where:

L = Pipe length, m
D = Internal Diameter, m
V = The average velocity calculated at the entrance to the component
g = The standard gravitational term 9.81 m/sec^2
K = Resistance coefficient specified in Crane Technical Publication 410. The K correction factor is computed for the following elbow arrangements as detailed in Table G2.

Table G2. K Factors for Elbow Arrangements

Description	K Factor
Smooth elbow with r/D = 1	20·f
Smooth elbow with r/D= 1.5	14·f
Smooth elbow with r/D = 2	12·f
Smooth elbow with r/D = 3	12·f
Smooth elbow with r/D = 4	14·f
Segmented with 2·45° miters	30·f
Segmented with 3·30° miters	24·f
Segmented with 6·15° miters	24·f
Where: r = radius of the centerline of the elbow, ft	

The determination of the K factor for the expansion and contraction sections is a function of the inlet to outlet diameter ratio as well as the angle of expansion and contraction. For purposes of this standard, an equation has been developed by assigning an angle term that best represents the pressure drop results found in the ASHRAE technical report 1034-RP for these expansion and contraction fittings. The user is directed to the Crane Technical Paper for a more complete description of the equations. The angle of expansion or contraction is detailed on the accompanying chart (Figure G3) with limits placed at 45 degrees and 10 degrees.

An Excel® spreadsheet is available from AHRI for computation of the pressure drop adjustment factors.

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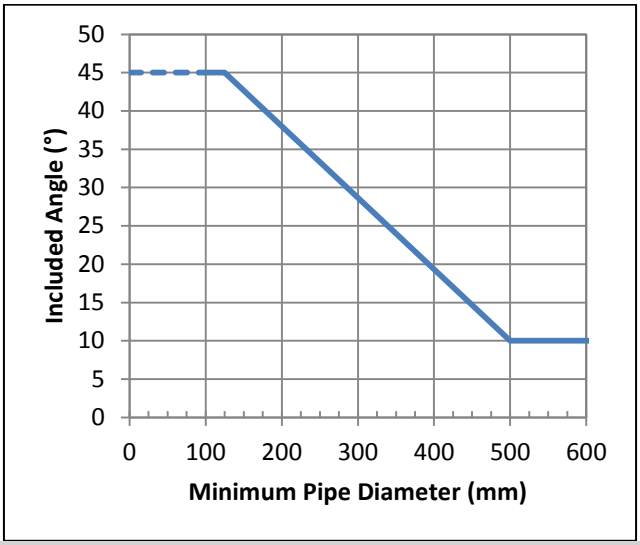


Figure G3. Correction Term for Included Angle for Expansion/Contraction Fittings

8. Include Cooling COP for Evaporatively Cooled Chiller, Air-Cooled Chiller, Condenserless Chiller, Air-Cooled HP (Cooling) and Air Cooled Heat Reclaim Chiller in Table 10.

Table 10. Published Values

Published Values	Units	Water-Cooled Chiller Cooling	Water-Cooled Heat Reclaim Chiller	Evaporatively Cooled Chiller	Air-Cooled Chiller	Condenserless Chiller	Air-Cooled HP Cooling	Air-Cooled HP Heating	Air-Cooled Heat Reclaim Chiller	Water to Water HP Cooling	Water to Water HP Heating
General											
Voltage	V	■	■	■	■	■	■	■	■	■	■
Frequency	Hz	■	■	■	■	■	■	■	■	■	■
Refrigerant Designation		■	■	■	■	■	■	■	■	■	■
Model Number		■	■	■	■	■	■	■	■	■	■
Net Capacity											
Refrigeration Capacity	kW	■	■	■	■	■	■		■	■	■
Heat Rejection Capacity	kW	■	■			■		■	■	■	■
Heat Reclaim Capacity	kW		■						■		
Efficiency											
Cooling COP	W/W	■	■	■	■	■	■		■	■	■
Heating COP	W/W							■			■
Heat Reclaim COP	W/W		■						■		
IPLV/NPLV	kW/kW										
	W/W	■		■	■	■	■			■	
	kW/kW										
Power											
Total Power	kW	■	■	■	■	■	■	■	■	■	■
Condenser Spray Pump Power	kW			■							
Fan Power	kW			■	■		■	■	■		
Cooling Mode Evaporator											

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Table 10. Published Values

Published Values	Units	Water-Cooled Chiller Cooling	Water-Cooled Heat Reclaim Chiller	Evaporatively Cooled Chiller	Air-Cooled Chiller	Condenserless Chiller	Air-Cooled HP Cooling	Air-Cooled HP Heating	Air-Cooled Heat Reclaim Chiller	Water to Water HP Cooling	Water to Water HP Heating
Entering Water[1]	ºC	■	■	■	■	■	■	■	■	■	■
Leaving Water[1]	ºC	■	■	■	■	■	■	■	■	■	■
Flow	L/s	■	■	■	■	■	■	■	■	■	■
Pressure Drop	kPa	■	■	■	■	■	■	■	■	■	■
Fouling Factor	$m^2 \cdot K/kW$	■	■	■	■	■	■	■	■	■	■
Cooling Mode Heat Rejection Exchanger											
Tower Condenser											
Entering Water[1]	ºC	■	■								
Leaving Water[1]	ºC	■	■								
Flow	L/s	■	■								
Pressure Drop	kPa	■	■								
Fouling Factor	$m^2 \cdot K/kW$	■	■								
Heat Reclaim Condenser											
Entering Water[1]	ºC		■						■		
Leaving Water[1]	ºC		■						■		
Flow	L/s		■						■		
Pressure Drop	kPa		■						■		
Fouling Factor	$m^2 \cdot K/kW$		■						■		
Dry-bulb air	ºC								■		
Heat Rejection Condenser											
Entering Water[1]	ºC									■	■
Leaving Water[1]	ºC									■	■
Flow	L/s									■	■
Pressure Drop	kPa									■	■
Fouling Factor	$m^2 \cdot K/kW$									■	■
Evaporatively Cooled											
Dry-bulb	ºC			■							
Wet-bulb	ºC			■							
Air Cooled											
Dry-bulb	ºC				■		■	■	■		
Wet-bulb	ºC							■			
Without Condenser											
Saturated Discharge	ºC					■					
Liquid Temperature or Subcooling	ºC					■					

[1]An alternate to providing entering and leaving water temperatures is to provide one of these along with the temperature difference across the heat exchanger

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9. Revise Table 2 to reflect soft conversion from ANSI/AHRI Standard 550/590 (I-P)-2011 with Addendum 2.

Table 2. Application Rating Conditions

	Evaporator			Condenser		
Cooling	Water Cooled			Water Cooled		
	Leaving Temperature[1], °C	Temperature Difference Across Heat Exchanger, °C	Fouling Factor Allowance	Entering Temperature[2], °C	Flow Rate, L/s·kW	Fouling Factor Allowance, m^2·K/kW
	2.2~~0~~ to ~~16.0~~ 15.6	~~3.0~~ 2.8 to 11.1~~0~~	≤ 0.18 m^2·K/kW	~~13.0~~ 12.8 to 40.6~~0~~	0.018~~02~~ to 0.108	≤ 0.18
				Air-Cooled		
				Entering Air Dry Bulb[3], °C		
				~~13.0~~12.8 to ~~52.0~~ 51.7		
				Evaporatively Cooled		
				Entering Air Wet Bulb[4], °C		
				10.0 to ~~27.0~~26.7		
Heating	Water Source Evaporator			Water Cooled Condenser		
	Entering Water Temperature[2], °C		Fouling Factor Allowance, m^2·K/kW	Leaving Water Temperature, °C	Temperature Difference Across Heat Exchanger, °C	Fouling Factor Allowance, m^2·K/kW
	4.0 to 27.0		≤ 0.18	40.6~~0~~ to ~~70.0~~ 71.1	~~3.0~~2.8 to 11.1~~0~~	≤ 0.18
	Air Source Evaporator					
	Entering Air temperature, °C					
	~~-10.0~~ -9.4 to 15.6 ~~16.0~~					

Notes:
1. Leaving evaporator water temperatures shall be published in rating increments of no more than 2.0 °C.
2. Entering water temperatures shall be published in rating increments of no more than 3.0 °C.
3. Entering air temperatures shall be published in rating increments of no more than 5.0 °C.
4. Air wet bulb temperatures shall be published in rating increments of no more than 1.5 °C.

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AHRI STANDARD 551/591 (SI)-2011 WITH ADDENDUM 1, Effective 1 January 2013

Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle

September 2012

Addendum 1 (dated September 2012) of AHRI Standard 551/591 (SI)-2011, *"Changes to AHRI Standard 551/591 (SI)-2011"* is provided as follows. The following changes have been incorporated (deletions are shown by ~~strikethroughs~~, additions are shown by shading) into the already published 2011 version of AHRI Standard 551/591 (SI) to avoid confusion:

Note: This addendum is not ANSI approved and is currently going through the process to do so.

The changes include:

10. The effective date was revised to 1 January 2013.

This standard supersedes AHRI Standard 550/590 (I-P)-2011 and shall be effective 1 January 2013 and optional prior to that date.

11. Add new definition for "Turn Down Ratio" which is referenced in Table C1.

3.17 *Turn Down Ratio.* The ratio of the maximum to the minimum measurement value in the range over which the measurement system meets the specified accuracy. Applicable to any measurement with an absolute zero scale.

12. Remove "the full load rated $tons_R$ at" from Table 9, add "of" and add footnote #5.

Table 9, Note 5. The ± 2.0% tolerance shall be calculated as 2.0% of the full load rated capacity ($tons_R$). For example, a nominal 50.0% part load point shall be tested between 48.0% and 52.0% of the full load rated capacity.

13. Add new Informative References to Appendix A.

A1.10 ASME Standard PTC 19.5-2004, *Flow Measurement, 2004*, American Society of Mechanical Engineers. ASME, Three Park Avenue, New York, NY 10016, U.S.A.

A1.16 Excel Spreadsheet for Calibration. Available as download from the AHRI web site (http://www.ahrinet.org/search+standards.aspx). Air-Conditioning and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

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A1.20 IEEE C57.13-1993 (R2003), *IEEE Standard Requirements for Instrument Transformers*, Institute of Electrical and Electronic Engineers, 2003.

14. Remove Section C4 and replace with revised Section C4, including revised Table C1, added new Table C2 and new Figures C1 and C2.

Table C1. ~~Accuracy~~ Requirements for Test Instrumentation 31
Table C2. Prediction Interval to Determine Range of Acceptable Accuracy 33
Figure C1. Sample of Calibration Evaluation Data (Percent of Reading) 34
Figure C2. Sample of Calibration Evaluation Data (Percent of Full Scale) 34

~~**C4** *Instrumentation.*~~

~~**C4.1** Instruments shall be selected, installed, operated, and maintained according to the requirements of Table C1.~~

~~**C4.2** All instruments and measurement systems shall be calibrated over a range that exceeds the range of test readings. Data acquisition systems shall be either calibrated as a system, or all individual component calibrations shall be documented in a manner that demonstrates the measurement system meets the accuracy requirements specified in Table C1. Calibrations shall include no less than four (4) points compared to a calibration standard. Calibration standards shall be traceable to NIST or equivalent laboratories that participate in inter-laboratory audits. It is recommended that standards such as ISO 17025 be used by test facilities to improve processes for the development and maintenance of instrument systems to achieve desired accuracy and precision levels.~~

~~**C4.3** Full scale range for instruments and measurement systems shall be such that readings will be at least 10% of full scale at any test point (i.e. at any Percent Load). A test facility may require multiple sets of instruments to accommodate a range of Water-Chilling or Water-Heating Package sizes.~~

~~**C4.4** Accuracy of electrical measurements shall include all devices in the measurement system (i.e. power meter or power analyzer, potential transformers, current transformers, data acquisition signals). Electrical measurements include voltage, current, power, and frequency for each phase. Electrical power measurements shall be made at appropriate location(s) to accurately measure the power input at the customer connection point(s) or terminals. The measurement location shall exclude losses from transformers, or other equipment comprising the power supply and shall minimize losses due to cabling from the measurement location to the connection point on the chiller. Liquid chillers that utilize power altering equipment, such as variable frequency drive or inverter, may require appropriate isolation and precautions to ensure that accurate power measurements are obtained. Liquid chillers that utilize power-altering equipment may require the use of instrumentation that is capable of accurately measuring signals containing high frequency and/or high crest factors. In these cases, the instrumentation used shall have adequate bandwidth and/or crest factor specifications to ensure the electrical power input measurement errors are within the accuracy requirements of Table C1 for the quantity measured.~~

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Table C1. Accuracy Requirements for Test Instrumentation

Measurement	Measurement System Accuracy[3]	Turn Down Ratio[3,7]	Display Resolution	Selected, Installed, Operated, Maintained in Accordance With
Liquid Temperature	±0.06°C	N/A	≤0.01°C	ANSI/ASHRAE Standard 41.1-1986 (RA 2006)
Air Temperature	±0.06°C	N/A	≤0.1°C	ANSI/ASHRAE Standard 41.1-1986 (RA 2006)
Liquid Mass Flow Rate[4]	±1.0% RDG[1]	10:1	a minimum of 4 significant digits	ASME MFC-3M-2004 (orifice & venturi type) ASME MFC-6M-1998 (vortex type) ASME MFC-11M-2003 (coriolis type) ASME MFC-16M-1995 (electromagnetic type) ISA Standard RP31.1-1977 (turbine type)
Differential Pressure	±1.0% RDG[1]	10:1	0.1 kPa	ASME Power Test Code PTC 19.2-2010
Electrical Power <= to 600V Over 600 V	[1, 2, 6] ±1.0% FS, ± 2.0% RDG ±1.5% FS, ±2.5% RDG	10:1	a minimum of 4 significant digits	IEEE 120-1989
Barometric Pressure	±1 kPa	1.5:1	0.1 kPa	ASME Power Test Code PTC 19.2-2010
Steam condensate mass flow rate	±1.0% RDG[1]	10:1	a minimum of 4 significant digits	
Steam pressure	±1.0% RDG[1]	10:1	1.0 barg	
Fuel volumetric flow rate	±1.0% RDG[1]	-	0.001 CMH[5]	
Fuel energy content	-	-	-	Gas quality shall be acquired by contacting the local authority and requesting a gas quality report for calorific value on the day of the test

Notes:

1. Percent of Reading = %RDG, %FS = percent of full scale for the measurement instrument or measurement system.
2. Current Transformers (CT's) and Potential Transformers (PT's) will have a metering class of 0.3 or better.
3. Measurement system accuracy shall apply over the range indicated by the turn down ratio, i.e. from full scale down to a value of full scale divided by the turn down ratio. For some instruments and/or systems this may require exceeding the accuracy requirement at full scale.
4. Accuracy requirement also applies to volumetric type meters.
5. CMH= Cubic Meters per Hour (m^3/h)
6. If dual requirements are shown in the table, both requirements shall be met.
7. Turn Down Ratio = the ratio of the maximum to the minimum measurement value in the range over which the measurement system meets the specified accuracy.

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C4 *Instrumentation.*

C4.1 Instruments shall be selected, installed, operated, and maintained according to the requirements of Table C1.

Table C1. Requirements for Test Instrumentation

Measurement	Measurement System Accuracy [2,3,4,5]	Display Resolution [6, 7]	Selected, Installed, Operated, Maintained in Accordance With
Liquid Temperature	±0.11°C	0.005°C	ANSI/ASHRAE Standard 41.1-1986 (RA 2006)
Air Temperature	±0.11°C	0.05°C	ANSI/ASHRAE Standard 41.1-1986 (RA 2006)
Liquid Mass Flow Rate [1]	±1.0% RDG	4 significant figures	ASME Power Test Code PTC 19.5-2004 (flow measurement) ASME MFC-16-2007 (electromagnetic type) ASME MFC-3M-2004 (orifice & venturi type) ASME MFC-6M-1998 (vortex type) ASME MFC-11-2006 (coriolis type) ISA Standard RP31.1-1977 (turbine type)
Differential Pressure	±1.0% RDG	3 significant figures	ASME Power Test Code PTC 19.2-2010
Electrical Power ≤ 600V > 600 V	±1.0% FS, ±2.0% RDG ±1.5% FS, ±2.5% RDG	4 significant figures (V, A, kW, Hz)	IEEE 120-1989 IEEE C57.13-1993 (R2003)
Barometric Pressure	±1.0 kPa	0.1 kPa	ASME Power Test Code PTC 19.2-2010
Steam condensate mass flow rate	±1.0% RDG	4 significant figures	
Steam pressure	±1.0% RDG	3 significant figures	
Fuel volumetric flow rate	±1.0% RDG	4 significant figures	
Fuel energy content	-	3 significant figures	Gas quality shall be acquired by contacting the local authority and requesting a gas quality report for calorific value on the day of the test

Notes.

1. Accuracy requirement also applies to volumetric type meters.
2. Measurement system accuracy shall apply over the range of use during testing, as indicated by the turn down ratio determined during calibration, i.e. from full scale down to a value of full scale divided by the turn down ratio. For many types of instruments and/or systems this may require exceeding the accuracy requirement at full scale.
3. Percent of Reading = %RDG, %FS = percent of full scale for the measurement instrument or measurement system.
4. If dual requirements are shown in the table, FS and RDG, then both requirements shall be met.
5. Current Transformers (CT's) and Potential Transformers (PT's) shall have a metering accuracy class of 0.3 or better, rated in accordance with IEEE C57.13.
6. Display resolution shown is the minimum requirement (most coarse resolution allowable). Better (finer) resolution is acceptable for instrument or panel displays, or computer screen displays. The display resolution shown is the preferred resolution for data reporting on test reports.
7. Significant figures (also known as significant digits) determined in accordance with section 7.2 of NIST Special Publication 260-100, "Handbook for SRM Users".

C4.2 All instruments and measurement systems shall be calibrated over a range that meets or exceeds the range of test readings. Data acquisition systems shall be either calibrated as a system, or all individual component calibrations shall be documented in a manner that demonstrates the measurement system meets the accuracy

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requirements specified in Table C1. Calibrations shall include no less than four (4) points compared to a calibration standard. Calibration standards shall be traceable to NIST or equivalent laboratories that participate in inter-laboratory audits.

Note: It is recommended that standards such as ISO 17025 be used by test facilities to improve processes for the development and maintenance of instrument systems to achieve desired accuracy and precision levels.

C4.3 For each instrument device in a measurement system, the calibration process shall identify the range over which the required accuracy can be achieved (specified accuracy from Table C1). This range shall be documented in a readily accessible format for verification (such as a manual of calibration records, or instrument labeling system, or work instructions for test facility operators). Many types of instruments have a usable range or Turn Down Ratio of 10:1, though some types are quite different. Differential pressure type flow meters may be limited to 3:1 range of flow (due to a differential pressure measurement range of 10:1). Some types of instruments, such as electromagnetic and coriolis type flow meters, or current transformers with low burden, may be capable of wider ranges such as 20:1 or more.

To determine the range over which the calibration achieves the required accuracy, the standard error of estimate shall be calculated for the measurement system indicated values (post calibration) versus the calibration reference standard, then using equation C1 plot a 95% prediction interval (α=5%) on both sides of the calibration data points. The point(s) at which the prediction interval curve exceeds the required accuracy shall be the limit(s) of the range. Table C2 and the equations that follow explain the method of calculating the prediction interval. See example using sample data in Figures C1 and C2, in which the useable range is from 100 to 22.5, or Turn Down Ratio of 4.4:1.

All test point readings (i.e. at any percent load, or at any operating test condition) shall be within the calibration range or Turn Down Ratio for each instrument device measurement. For a given type of measurement, multiple instruments may be required to cover a wide range of testing conditions for a given test facility, or a range of Water-Chilling or Water-Heating Package sizes. In the case of multiple instruments, procedures and protocols shall be established by the test facility for use by test operators regarding when and how to switch between instruments.

C4.4 Accuracy of electrical measurements shall include all devices in the measurement system (i.e. power meter or power analyzer, potential transformers, current transformers, data acquisition signals). Electrical measurements include voltage (for each phase), current (for each phase), power, and frequency (from one phase). Electrical power measurements shall be made at appropriate location(s) to accurately measure the power input at the customer connection point(s) or terminals. The measurement location shall exclude losses from transformers, or other equipment comprising the power supply and shall minimize losses due to cabling from the measurement location to the connection point on the chiller. Water chilling or heating packages that utilize power-altering equipment, such as variable frequency drive or inverter, may require appropriate isolation and precautions to ensure that accurate power measurements are obtained. Chillers that utilize power-altering equipment may require the use of instrumentation that is capable of accurately measuring signals containing high frequency and/or high crest factors. In these cases the instrumentation used shall have adequate bandwidth and/or crest factor specifications to ensure the electrical power input measurement errors are within the accuracy requirements of Table C1 for the quantity measured.

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Table C2. Prediction Interval to Determine Range of Acceptable Accuracy					
	Reference Standard Value [1] x_j j=1 to n	Corrected (As Left) Indicated Value [2] y_j j=1 to n	Absolute Prediction Interval of Indicated Value	Relative Prediction Interval of Indicated Value	
				%RDG	%FS
Calibration Data	x_1	y_1	$x_1 \pm PI(x_1)$	$\pm\frac{PI(x_1)}{x_1}$	$\pm\frac{PI(x_1)}{FS}$
	x_2	y_2	$x_2 \pm PI(x_2)$	$\pm\frac{PI(x_2)}{x_2}$	$\pm\frac{PI(x_2)}{FS}$
	x_3	y_3	$x_3 \pm PI(x_3)$	$\pm\frac{PI(x_3)}{x_3}$	$\pm\frac{PI(x_3)}{FS}$
	…	…	…	…	…
	x_n	y_n	$x_n \pm PI(x_n)$	$\pm\frac{PI(x_n)}{x_n}$	$\pm\frac{PI(x_n)}{FS}$
Regression Statistics	$\bar{x}$ SS_x	s_ε	continuous curve ±PI varying $\hat{x}$ from min to max values of x_j	continuous curve ±PI% varying $\hat{x}$ from min to max values of x_j	
Notes: 1. Reference Standard Value is the actual value determined or measured by the calibration standard. 2. Corrected Indicated Value is the value of the measured quantity given directly by a measuring system on the basis of its calibration curve (as left when the calibration process has been completed, not as found at the beginning of the calibration process).					

$$PI(\hat{x}) = s_\varepsilon \cdot t_{\frac{\alpha}{2},n-2} \cdot \sqrt{1+\frac{1}{n}+\frac{(\hat{x}-\bar{x})^2}{SS_x}} \qquad \text{C1}$$

Where:

x = A variable representing any measurement value, such as temperature, flow rate, or power and thus units will be dependent upon the variable being used

$PI(\hat{x})$ = The prediction interval at the value of $\hat{x}$

$\hat{x}$ = Any value of x at which to evaluate the prediction interval

FS = The value of x at full scale indicating the upper limit of the measurement range capability of the instrument or measurement system

n = The number of calibration data points

$\bar{x}$ = The mean of all measurement values from calibration points

SS_x = The sum of squares of x value differences to the mean

s_ε = The standard error of estimate, used to quantify the residual error of a measuring system after calibration against a reference calibration standard

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$$\overline{x} = \frac{1}{n}\sum_{j=1}^{n}\left(x_j\right) \quad \text{C2}$$

$$SS_x = \sum_{j=1}^{n}\left(x_j - \overline{x}\right)^2 \quad \text{C3}$$

$$s_\varepsilon = \sqrt{\frac{\sum_{j=1}^{n}\left(y_j - mx_j - c\right)^2}{n-2}} \quad \text{C4}$$

Where:

m = 1 = Slope of regression line due to the calibration process

c = 0 = Y-intercept of the regression line due to the calibration process

$t_{\frac{\alpha}{2},n-2}$ = The critical value of Student's t distribution, at confidence level α/2 and degrees of freedom n-2

α = 5% = The significance level used by this standard

95% = 1-α = The prediction interval used by this standard

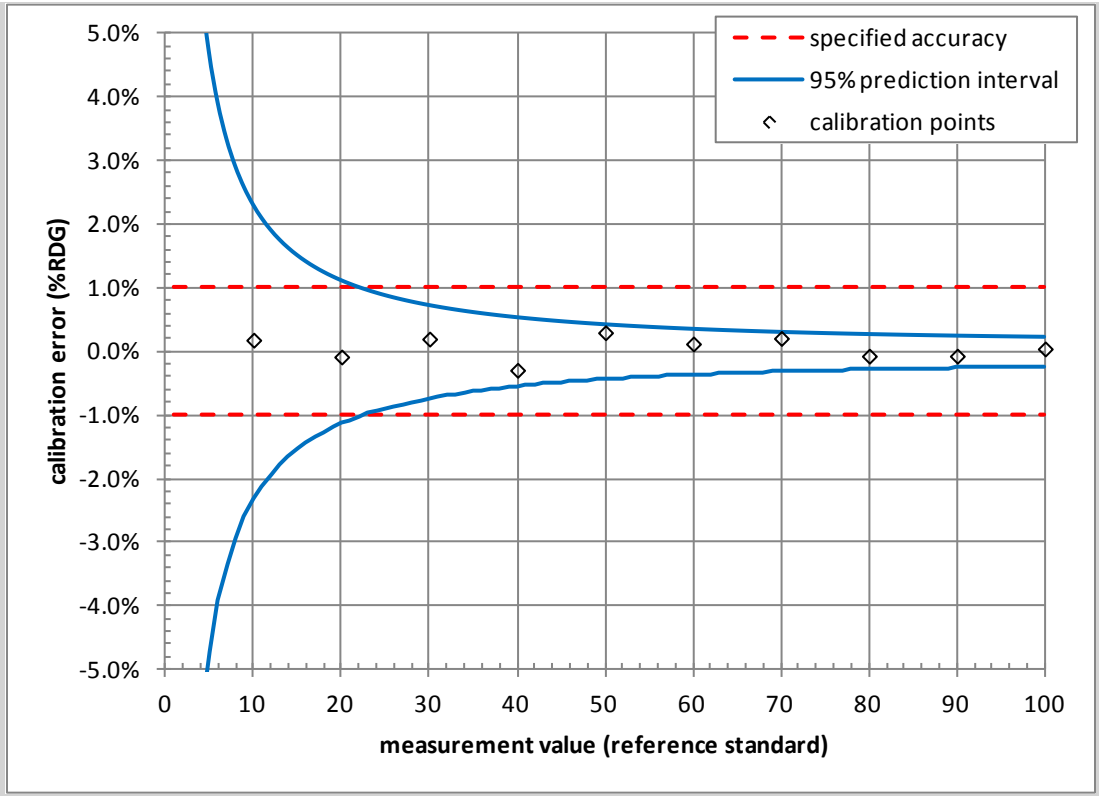


Figure C1. Sample of Calibration Evaluation Data (Percent of Reading)

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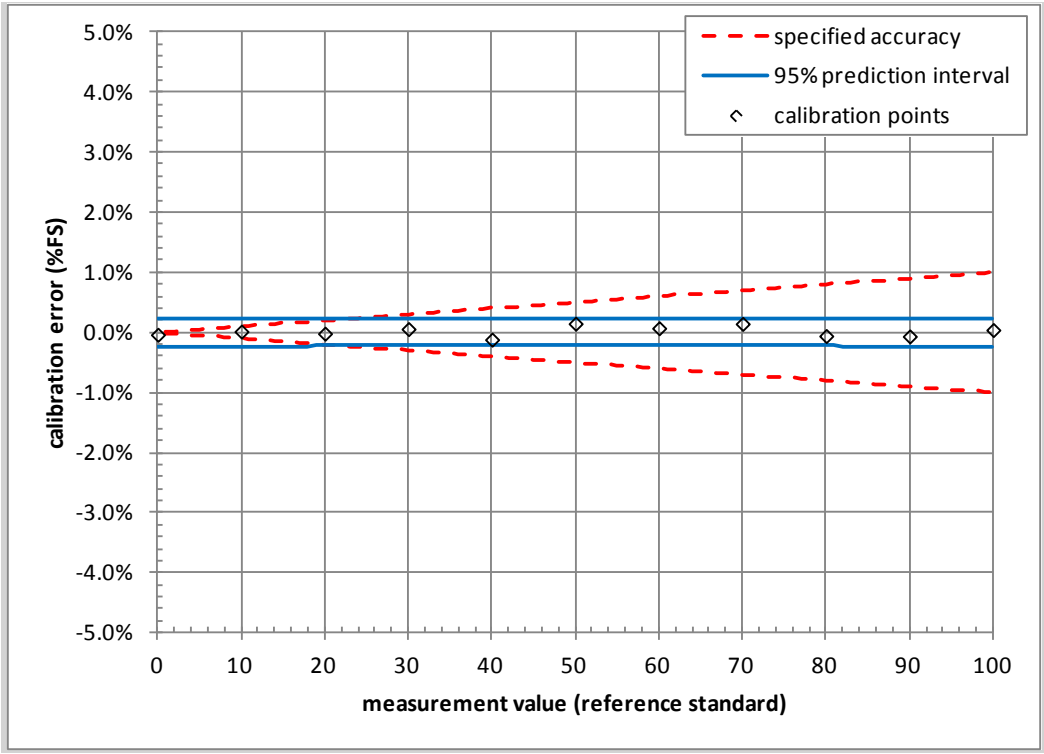


Figure C2. Sample of Calibration Evaluation Data (Percent of Full Scale)

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SAFETY DISCLAIMER

AHRI does not set safety standards and does not certify or guarantee the safety of any products, components or systems designed, tested, rated, installed or operated in accordance with this standard/guideline. It is strongly recommended that products be designed, constructed, assembled, installed and operated in accordance with nationally recognized safety standards and code requirements appropriate for products covered by this standard/guideline.

AHRI uses its best efforts to develop standards/guidelines employing state-of-the-art and accepted industry practices. AHRI does not certify or guarantee that any tests conducted under its standards/guidelines will be non-hazardous or free from risk.

AHRI CERTIFICATION PROGRAM PROVISIONS

The scope of the Certification Program is based on the latest edition of AHRI Standard 550/590 (I-P)-2011. This scope is current as of the publication date of the standard. Revisions to the scope of the certification program can be found on AHRI website www.ahrinet.org. The scope of the Certification Program should not be confused with the scope of the standard as the standard covers products that are not covered by a certification program.

Included in Certification Program:

50 Hz[a] and 60 Hz Air-Cooled Chiller (ACCL) Product Inclusions

- Chillers between 0 and 1,405 kW[b] manufactured prior to July 2013
- Chillers between 0 and 2,110 kW[b] manufactured after July 2013
- Units selected for use within the range of Application Rating Conditions as per AHRI Standard 551/591 (SI)
- Hermetic or open type, electric motor driven
- Up to 600 volts
- All compressor types
- Units intended for use with glycol or other secondary coolant for freeze protection with a leaving chilled fluid temperature above 0.0°C are certified when tested with water at Standard Rating Conditions.

Note a: 50 Hz products selectively certified as per Section 1.4 of the Air-Cooled Water Chilling Packages Using Vapor Compression Cycle Operations Manual
Note b: The cooling capacity, in kW at full-load AHRI Standard Rating Conditions per Table 1 of AHRI Standard 551/591 (SI).

60 Hz Water-Cooled Chiller (WCCL) Product Inclusions

- All compressor types
- Chillers rated between 0 and 8,800 kW[c] manufactured prior to January 2012
- Chillers rated between 0 and 10,550 kW[c] manufactured after to January 2012
- Hermetic or open type, electric motor driven
- Units selected for use within the range of Application Rating Conditions as per AHRI Standard 551/591 (SI)
- Voltages up to 11,000 volts
- Voltages up to 15,000 volts after June 15, 2011
- Positive Displacement Units intended for use with glycol or other secondary coolant for freeze protection with a leaving chilled fluid temperature above 0.0°C are certified when tested with water at Standard Rating Conditions.

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Note c: Rated capacity, kW, for Positive Displacement chillers is the net cooling capacity at full-load AHRI Standard Rating Conditions per Table 1 of AHRI Standard 551/591 (SI). Rated capacity, kW, for centrifugal chillers is the net cooling capacity at full-load AHRI Application Rating Conditions within the range permitted in Table 2 of AHRI Standard 551/591 (SI).

50 Hz WCCL Product Inclusions

- Centrifugal & screw chillers
- Chillers rated between 700 and 8,800 kW[d]
- Hermetic & open type, electric motor driven
- Units selected for use within the range of Application Rating Conditions as per AHRI Standard 551/591 (SI)
- Voltages up to 11,000 volts
- Voltages up to 15,000 volts after June 15, 2011
- Positive Displacement Units intended for use with glycol or other secondary coolant for freeze protection with a leaving chilled fluid temperature above 0.0°C are certified when tested with water at Standard Rating Conditions.

Note d: Rated capacity, kW, for Positive Displacement chillers is the net cooling capacity at full-load AHRI Standard Rating Conditions per Table 1 of AHRI Standard 551/591 (SI). Rated capacity, kW, for centrifugal chillers is the Net *Refrigerating* Capacity at full-load Application Rating Conditions within the range permitted in Table 2 of AHRI Standard 551/591 (SI).

Excluded from the Certification Program:

50 Hz and 60 Hz ACCL Product Exclusions

- Condenserless chillers
- Evaporatively cooled chillers
- Chillers above 1,405 kW manufactured prior to July 2013
- Chillers above 2,110 kW
- Chillers with voltages above 600 volts
- Glycol and other secondary coolants are excluded when leaving chiller fluid temperature is below 0.0°C
- Custom Units as defined in the section specific Operations Manual
- Field Trial Units as defined in the section specific Operations Manual
- Heat recovery & heat pump ratings are not certified, however manufacturers may elect to certify these chillers in the cooling mode and with the heat recovery option turned off
- Units for use outside of Application Rating Conditions
- Chillers that are not electrically driven, or that use open type compressors not supplied with motors by the manufacturer
- 50 Hz Air-Cooled units that the manufacturer elects not to certify

60 Hz WCCL Product Exclusions

- Condenserless chillers
- Evaporatively cooled chillers
- Chillers above 8,800 kW manufactured prior to January 2012
- Chillers above 10,550 kW
- Chillers with voltages above 11,000 volts prior to June 15, 2011
- Chillers with voltages above 15,000 volts
- Chillers that are not electrically driven
- Chillers with motors not supplied with the unit by the manufacturer
- Glycol and other secondary coolants are excluded when leaving chiller fluid temperature is below 0.0°C
- Custom Units as defined in the section specific Operations Manual
- Field Trial Units as defined in the section specific Operations Manual
- Units for use outside of Application Rating Conditions
- Heat recovery & heat pump ratings are not certified, however manufacturers may elect to certify these chillers in the cooling mode and with the heat recovery option turned off

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50 Hz WCCL Product Exclusions

- Condenserless chillers
- Evaporatively cooled chillers
- Reciprocating and scroll water-chilling packages
- Chillers below 700 kW
- Chillers above 8,800 kW manufactured prior to January 2012
- Chillers above 10,550 kW
- Chillers with voltages above 11,000 volts prior to June 15, 2011
- Chillers with voltages above 15,000 volts
- Chillers that are not electrically driven
- Chillers with motors not supplied with the unit by the manufacturer
- Glycol and other secondary coolants are excluded when leaving chiller fluid temperature is below 0.0°C
- Custom Units as defined in the section specific Operations Manual
- Units for use outside of Application Rating Conditions
- Field Trial Units as defined in the section specific Operations Manual
- Heat recovery & heat pump ratings are not certified, however manufacturers may elect to certify these chillers in the cooling mode and with the heat recovery option turned off

Certified Ratings

The Water-Cooled and Air-Cooled Certification Program ratings verified by test are:

Operating Conditions		Water-Cooled	Air-Cooled
Standard Rating Conditions[1]	Full Load	• Capacity[3] • Energy Efficiency • Water Pressure Drop	• Capacity[3] • Energy Efficiency • Water Pressure Drop
	Part Load	• IPLV[4] Energy Efficiency	• IPLV[4] Energy Efficiency
Application Rating Conditions[2]	Full Load	• Capacity[3] • Energy Efficiency • Water Pressure Drop	• Capacity[3] • Energy Efficiency • Water Pressure Drop
	Part Load	• NPLV[5] Energy Efficiency	• Not Applicable

Notes:
1. Standard Rating Conditions per AHRI Standard 550/590 Section 5.2
2. Application Rating Conditions per AHRI Standard 550/590 Section 5.3
3. Certified Capacity is the net Refrigerating Capacity per AHRI Standard 550/590 Section 3.3
4. Integrated Part-Load Value (IPLV) per AHRI Standard 550/590 Section 5.4
5. Non-Standard Part-Load Value (NPLV) per AHRI Standard 550/590 Section 5.4

With the following units of measure:

- Net Capacity, kW
- Energy Efficiency, Coefficient of Performance (COP_R), W/W
- Evaporator and/or condenser Water Pressure Drop, kPa

Note:

This 2011 standard (as amended by Addenda 1 and 2) supersedes AHRI Standard 551/591 (SI)-2011 and Addendum 1 ~~shall be effective 1 January 2013 and optional prior to that date~~

For IP ratings, see AHRI Standard 550/590 (I-P)-2011.

The requirements of Appendix G shall be effective on January 1, 2014 and optional prior to that date.

Accompanying this standard is an excel spreadsheet for the Computation of the Pressure Drop Adjustment Factors (http://www.ahrinet.org/search+standards.aspx).

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PERFORMANCE RATING OF WATER-CHILLING AND HEAT PUMP WATER-HEATING PACKAGES USING THE VAPOR COMPRESSION CYCLE

Section 1. Purpose

1.1 *Purpose*. The purpose of this standard is to establish for Water-Chilling and Water-Heating Packages using the vapor compression cycle: definitions; test requirements; rating requirements; minimum data requirements for Published Ratings; marking and nameplate data; and conformance conditions.

1.1.1 *Intent.* This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, efficiency regulators, contractors and users.

1.1.2 *Review and Amendment.* This standard is subject to review and amendment as technology advances.

Section 2. Scope

2.1 *Scope*. This standard applies to factory-made vapor compression refrigeration Water-Chilling and Water-Heating Packages including one or more hermetic or open drive compressors. These Water-Chilling and Water-Heating Packages include:

- Water-Cooled, Air-Cooled, or evaporatively-cooled condensers
- Water-Cooled heat reclaim condensers
- Air-to-water heat pump
- Water-to-water heat pumps with a capacity greater or equal to 40 kW. Water-to-water heat pumps with a capacity less than 40 kW are covered by the latest edition of AHRI Standard 320

Note that this standard covers products that may not currently be covered under a certification program.

Section 3. Definitions

All terms in this document follow the standard industry definitions in the current edition of ASHRAE *Terminology of Heating, Ventilation, Air Conditioning and Refrigeration* unless otherwise defined in this section.

3.1 *Auxiliary Power*. Power provided to devices that are not integral to the operation of the vapor compression cycle. Such as, but not limited to: oil pumps, refrigerant pumps, control power, and heaters.

3.2 *Bubble Point.* Refrigerant liquid saturation temperature at a specified pressure.

3.3 *Capacity*. A measurable physical quantity that characterizes the water side heat flow rate, kW. Capacity is defined as the mass flow rate of the water multiplied by the difference in enthalpy of water entering and leaving the heat exchanger, kW or tons. For this standard, the enthalpy change is approximated as the sensible heat transfer using specific heat and temperature difference, and in some calculations also the energy associated with water-side pressure losses.

3.3.1 *Gross Heating Capacity*. The capacity of the Water Cooled Condenser as measured by the heat transfer from the refrigerant in the condenser. This value includes both the sensible heat transfer and the pressure drop effects of the water flow through the condenser. This value is used to calculate the test heat balance. (Refer to Equations C12a and C12b).

3.3.2 *Gross Refrigerating Capacity*. The capacity of the water cooled evaporator as measured by the heat transfer to the refrigerant in the evaporator. This value includes both the sensible heat transfer and the pressure drop effects of the water flow through the evaporator. This value is used to calculate the test heat balance. (Refer to Equation C11).

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3.3.3 *Net Heating Capacity.* The capacity of the heating condenser available for useful heating of the thermal load external to the Water-Heating Package and is calculated using only the sensible heat transfer. (Refer to Equations 7a and 7b).

3.3.4 *Net Refrigerating Capacity*. The capacity of the evaporator available for cooling of the thermal load external to the Water-Chilling Package and is calculated using only the sensible heat transfer. (Refer to Equation 6).

3.4 *Compressor Saturated Discharge Temperature.* For single component and azeotrope refrigerants, it is the saturated temperature corresponding to the refrigerant pressure at the compressor discharge. For zeotropic refrigerants, it is the arithmetic average of the Dew Point and Bubble Point temperatures corresponding to refrigerant pressure at the compressor discharge. It is usually taken at or immediately downstream of the compressor discharge service valve (in either case on the downstream side of the valve seat), where discharge valves are used.

3.5 *Condenser*. A refrigeration system component which condenses refrigerant vapor. Desuperheating and sub-cooling of the refrigerant may occur as well.

3.5.1 *Air-Cooled Condenser.* A component which condenses refrigerant vapor by rejecting heat to air mechanically circulated over its heat transfer surface causing a rise in the air temperature.

3.5.2 *Evaporatively-Cooled Condenser.* A component which condenses refrigerant vapor by rejecting heat to a water and air mixture mechanically circulated over its heat transfer surface, causing evaporation of the water and an increase in the enthalpy of the air.

3.5.3 *Water-Cooled Condenser.* A component which utilizes refrigerant-to-water heat transfer means, causing the refrigerant to condense and the water to be heated.

3.5.4 *Water-Cooled Heat Reclaim Condenser.* A component which utilizes refrigerant-to-water heat transfer means, causing the refrigerant to condense and the water to be heated. This Condenser may be a separate condenser, the same as, or a portion of the Water-Cooled Condenser.

3.6 *Dew Point.* Refrigerant vapor saturation temperature at a specified pressure.

3.7 *Energy Efficiency.*

3.7.1 *Cooling Energy Efficiency*

3.7.1.1 *Cooling Coefficient of Performance (COP_R).* A ratio of the Net Refrigerating Capacity in watts to the power input values in watts at any given set of Rating Conditions expressed in watts/watt. (Refer to Equation 1)

3.7.1.2 *Power Input per Capacity.* A ratio of the power input, W_{INPUT}, supplied to the unit in kilowatts [kW], to the Net Refrigerating Capacity at any given set of Rating Conditions, expressed in kilowatts per ton_R of Refrigeration [kW/ton_R]. (Refer to Equation 3)

3.7.2 *Heating Energy Efficiency*

3.7.2.1 *Heating Coefficient of Performance (COP_H).* A ratio of the Net Heating Capacity in watts to the power input values in watts at any given set of Rating Conditions expressed in watts/watt. (Refer to Equation 4).

3.7.2.2 *Heat Reclaim Coefficient of Performance (COP_{HR}).* COP_{HR} applies to units that are operating in a manner that uses either all or only a portion of heat generated during chiller operation, q_{hrc}, to heat the occupied space, while the remaining heat, q_{cd}, if any, is rejected to the outdoor ambient. COP_{HR} takes into account the beneficial cooling capacity, q_{ev}, as well as the Heat Recovery capacity, q_{hrc} (Refer to Equation 5).

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