2023 Standard for

Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle

Approved American National Standard
ANSI
Approved by ANSI on 5 June 2023

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ICS Codes: 23.120 and 27.080

Note:

This standard supersedes AHRI Standard 550/590-2020 (I-P) (Addendum 1).
For SI ratings, see AHRI Standard 551/591-2023 (SI).

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Intent

This standard is intended for the guidance of the industry, including manufacturers, engineers, installers, contractors, and users.

Review and Amendment

This standard is subject to review and amendment as technology advances.

2023 Edition

This edition of ANSI/AHRI Standard 550/590 (I-P)*, Performance Rating of Water-chilling and Heat Pump Water-heating Packages Using the Vapor Compression Cycle*, was prepared by Chiller Standards Technical Committee. The standard was approved by the Applied Standards Subcommittee on 6 February 2023. The standard was approved as an American National Standard (ANS) on 5 June 2023.

Origin and Development of AHRI Standard number

Publication history, prior to consolidation:

ARI Standard 590-1986, *Positive Displacement Compressor Water-Chilling Packages*

ARI Standard 550-1990, *Centrifugal and Rotary Screw Water-Chilling Packages*

ARI Standard 550-1992, *Centrifugal and Rotary Screw Water-Chilling Packages*

ARI Standard 590-1992, *Positive Displacement Compressor Water-Chilling Packages*

The standards were first consolidated as ARI Standard 550/590-1998, *Water Chilling Packages Using the Vapor Compression Cycle.* Subsequent revisions were:

ARI Standard 550/590-2003, *Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

AHRI Standard 550/590-2011, *Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

ANSI/AHRI Standard 550/590 (I-P)-2012 with Addendum 1, *Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

AHRI Standard 550/590-2011 (with Addenda 1 and 2), *Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

AHRI Standard 550/590-2011 (with Addenda 1, 2 and 3), *Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

AHRI Standard 550/590-2015, *Performance Rating of Water-chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

AHRI Standard 550/590 (I-P)-2015 (with Errata), *Performance Rating of Water-chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle (with Errata)* [Published 2017]

AHRI Standard 550/590 (I-P)-2015 (with Errata), *Performance Rating of Water-chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle (with Errata)* [Published 2018]

AHRI Standard 550/590 (I-P)-2018, *Performance Rating of Water-chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

AHRI Standard 550/590 (I-P)-2020, *Performance Rating of Water-chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

AHRI Standard 550/590-2020 (I-P) (Addendum 1), *Performance Rating of Water-chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*

Summary of Changes

ANSI/AHRI Standard 550/590-2023 (I-P) contains the following update(s) to the previous edition:

- Revise current ANS to align with 2020 versions
- Incorporate Addendum 1 from AHRI 550/590-2020 (I-P)
- Addresses three interpretations to AHRI 550/590-2020 (I-P)
  - Interpretation to AHRI Standards 550/590 – 2020 (I-P) and 551/591 – 2020 (SI) – 1
  - Interpretation to AHRI Standards 550/590 – 2020 (I-P) and 551/591 – 2020 (SI) – 2
  - Interpretation to AHRI Standards 550/590 – 2020 (I-P) and 551/591 – 2020 (SI) – 3
- Editorial corrections and minor clarifications as needed
- Update references

September 2024: Editorial update to Section 5.4.1.4 to correct a cross-reference to notes in Table 6 that do not exist:

> **5.4.1.4** *Other Part-load Points.* Other part-load points, within the Application Rating limits of Table 5 and method defined in Section 5.4.4, that do not meet the requirements of Table 6~~, Notes 3, 4, 5, or 6~~ (i.e. variable water flow rates or other entering Condenser water temperatures). Neither IPLV.IP nor NPLV.IP shall be calculated for such points and shall not be a requirement for publication per Section 6.

Committee Personnel

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Chiller Standards Technical Committee Scope:

The Chiller Standards Technical Committee is responsible for the development and maintenance of AHRI standards and guidelines pertaining to Performance Rating of Liquid-Chilling and Heat Pump Liquid-Heating Packages using the Vapor Compression Cycle, Absorption Liquid Chilling and Liquid Heating Packages, Fouling Factor Applications related to Air Conditioning and Refrigeration, and Non-condensable Gas Purge Equipment for use with Low Pressure Centrifugal Liquid Chillers.

Out of scope for this STC are water-to-water heat pumps with a capacity less than 135,000 Btu/h as covered by ASHRAE/AHRI/ISO Standard 13256-2, and air-to-water units designed exclusively to heat potable water as covered by AHRI Standard 1300.

Product definitions are as defined on the AHRI website Applied Sector page.

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Applied Standards Subcommittee Scope:

The scope of the Applied Standards Subcommittee is standards and guidelines related to the end products that are part of the AHRI Applied Industry Sector. (The definition of and list of products associated with each sector are found on the AHRI website.

These lists represent the membership at the time the Standards Technical Committee and Standards Subcommittee were balloted on the final text of this edition. Since that time, changes in the membership may have occurred. Membership on these committees shall not in and of itself constitute an endorsement by the committee members or their employers of any document developed by the committee on which the member serves.

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Section 1. Purpose

1.1 *Purpose*. This standard establishes definitions, test requirements, rating requirements, minimum data requirements for Published Ratings, marking and nameplate data, conversions and calculations, nomenclature, and conformance conditions for Water-chilling and Heat Pump Water-heating Packages using the vapor compression cycle.

Section 2. Scope

2.1 *Scope*. This standard applies to factory-made Water-chilling and Water-heating Packages utilizing the vapor compression cycle as defined in Section 3. These Water-chilling and Water-heating Packages include:

2.1.1 Water-cooled, Air-cooled, or Evaporatively-cooled Condensers
2.1.2 Water-cooled heat recovery Condensers
2.1.3 Air-to-water heat pumps
2.1.4 Water-to-water heat pumps with a Capacity greater or equal to 135,000 Btu/h.

2.2 *Exclusions*.

2.2.1 Water-to-water heat pumps with a Capacity less than 135,000 Btu/h are covered by the latest edition of ASHRAE/ANSI/AHRI/ISO Standard 13256-2.

2.2.2 Air-to-water units designed exclusively to heat potable water as covered by the latest edition of ANSI/AHRI Standard 1300.

2.2.3 Water-chilling Packages are excluded when the Condenser is actively adiabatically-cooled. An adiabatically-cooled Condenser is an Air-cooled Condenser that uses evaporative cooling to pre-cool air before that air reaches the dry heat transfer surface.

2.2.4 Water-chilling or Water-heating packages with both an Air-cooled Condenser and a Water-cooled Condenser are outside the scope of this standard when operating in any mode (cooling, heating, heat recovery, or simultaneous heating and cooling) with the heat rejection split between the Air-cooled Condenser and Water-cooled Condenser.

2.2.5 Units with Evaporators or Condensers that use any liquid other than water are outside the scope of this standard.

Section 3. Definitions

All terms in this document follow the standard industry definitions in the *ASHRAE Terminology* website unless otherwise defined in this section.

3.1 *Expressions of Provision.* Terms that provide clear distinctions between requirements, recommendations, permissions, options, and capabilities.

3.1.1 *"Can" or "cannot".* Express an option or capability

3.1.2 *"May".* Signifies a permission expressed by the document.

3.1.3 *"Must".* Indication of unavoidable situations and does not mean that an external constraint referred to is a requirement of the document.

3.1.4 *"Shall" or "shall not".* Indication of mandatory requirements to strictly conform to the standard and where deviation is not permitted.

3.1.5 *"Should" or "should not".* Indication of recommendations rather than requirements. In the negative form, a recommendation is the expression of potential choices or courses of action that is not preferred but not prohibited.

3.2 *Standard Specific Definitions*

3.2.1 *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, fans and heaters.

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

3.2.3 *Capacity*. A measurable physical quantity that characterizes the water side heat flow rate. Capacity is the product of the water mass flow rate and the change in water enthalpy entering and leaving the heat exchanger, measured at the point of the field connection. For this standard, the enthalpy change is approximated as the sensible heat transfer using specific heat and temperature difference.

3.2.3.1 *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 20 and 21).

3.2.3.2 *Net Refrigerating Capacity*. The Capacity of the Evaporator available for cooling of the thermal load external to the Water-chilling Package and it is calculated using only the sensible heat transfer. (Refer to Equation 18).

Note: The method of test referenced in Sections 4.1 and 4.2 defines and makes use of gross heating capacity and gross refrigerating capacity, which consider the energy associated with water-side pressure losses.

3.2.4 *Compressor Saturated Discharge Temperature (SDT).* For single component and azeotrope refrigerants, it is the saturated temperature corresponding to the refrigerant pressure at the compressor discharge measured downstream of any refrigerant circuit components like mufflers, oil separators and discharge valves at the point of field connection. For zeotropic refrigerants, it is the arithmetic average of the Dew Point and Bubble Point temperatures corresponding to refrigerant pressure at the compressor discharge.

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

3.2.5.1 *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.

3.2.5.2 *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.

3.2.5.3 *Remote Condenser.* Any Condenser that is installed as a separate assembly from the rest of the Water-chilling or Water-heating Package with field installed interconnecting piping.

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

3.2.5.5 *Water-cooled Heat Recovery Condenser.* A component or components which utilizes refrigerant-to-water heat transfer means, causing the refrigerant to condense and the water to be heated. This Condenser can be a separate Condenser, the same as, or a portion of the Water-Cooled Condenser. The heat rejected can be done through a single or multiple heat exchangers, including desuperheaters as defined in ANSI/AHRI Standard 470.

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

3.2.7 *Energy Efficiency.*

3.2.7.1 *Cooling Energy Efficiency.*

3.2.7.1.1 *Cooling Coefficient of Performance (COP_R).* A ratio of the Net Refrigerating Capacity to the Total Input Power at any given set of Rating Conditions. (Refer to Equation 14a).

3.2.7.1.2 *Energy Efficiency Ratio (EER).* A ratio of the Net Refrigerating Capacity to the Total Input Power at any given set of Rating Conditions. (Refer to Equation 14b)

3.2.7.1.3 *Power Input per Capacity (kw/ton_R).* A ratio of the Total Input Power to the Net Refrigerating Capacity at any given set of Rating Conditions. (Refer to Equation 14c).

3.2.7.2 *Heating Energy Efficiency.*

3.2.7.2.1 *Heating Coefficient of Performance (COP_H).* A ratio of the Net Heating Capacity to the Total Input Power at any given set of Rating Conditions. (Refer to Equation 15).

3.2.7.3 Energy efficiency metrics for simultaneous heating and cooling operating modes.

3.2.7.3.1 *Heat Recovery Coefficient of Performance (COP_{HR}).* A ratio of the Net Heat Recovery Capacity plus the Net Refrigerating Capacity to the Total Input Power at any given set of Rating Conditions. 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 a load, 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 16).

3.2.7.3.2 *Simultaneous Heating and Cooling Coefficient of Performance (COP_{SHC}).* A ratio of the Net Heating Capacity plus the Net Refrigerating Capacity to the Total Input Power at any given set of Rating Conditions. COP_{SHC} applies to units that are operating in a manner that uses both the net heating and refrigerating capacities generated during operation. COP_{SHC} takes into account the beneficial Capacity, Q_{ev}, as well as the heating Capacity, Q_{cd}, (Refer to Equation 17).

3.2.8 *Evaporator.* A refrigeration system component which evaporates refrigerant liquid. Superheating of the refrigerant can occur as well.

3.2.8.1 *Remote Evaporator.* Any Evaporator that is installed as a separate assembly from the rest of the Water-chilling or Water-heating Package with field installed interconnecting piping.

3.2.9 *Fouling Factor (R_{foul}).* The thermal resistance due to fouling accumulated on the water side or air side heat transfer surface.

3.2.9.1 *Fouling Factor Allowance ($R_{foul,sp}$).* A specified value for Published Ratings as a provision for anticipated thermal resistance due to water side or air side fouling during use, expressed in $h \cdot ft^2 \cdot {}^oF/Btu$.

3.2.10 *Liquid Refrigerant Temperature (LIQ).* The temperature of the refrigerant liquid leaving the Condenser but prior to the expansion device.

3.2.11 *Part-load Value (PLV).* A single number figure of merit expressing part-load efficiency for equipment on the basis of weighted operation at various partial load capacities for the equipment.

3.2.11.1 *Integrated Part-Load Value (IPLV.IP).* A single number part-load efficiency figure of merit calculated per the method described in this standard at Standard Rating Conditions.

3.2.11.2 *Non-Standard Part-Load Value (NPLV.IP).* A single number part-load efficiency figure of merit calculated per the method described in this standard referenced to conditions other than IPLV.IP conditions. (i.e. For units that are not designed or selected to operate at Standard Rating Conditions.)

3.2.12 *Percent Load (%Load).* The ratio of the part-load rated net Capacity to the Full Load Capacity, stated in decimal format (e.g.100% = 1.0).

3.2.12.1 *Full Load (100% Load).* The highest Capacity at which the chiller has been rated at specific conditions. Corresponds to the 100% Load point utilized in IPLV.IP or NPLV.IP.

3.2.13 *Published Ratings*. A statement of the assigned values of those performance characteristics, under stated Rating Conditions, by which a unit can be chosen to fit its application. These values apply to all units of like nominal size and type (identification) produced by the same manufacturer. The term Published Rating includes the rating of all performance characteristics shown on the unit or published in specifications, advertising or other literature controlled by the manufacturer, at stated Rating Conditions.

3.2.13.1 *Application Rating.* A rating based on tests performed at Application Rating Conditions (other than Standard Rating Conditions).

3.2.13.2 *Standard Rating*. A rating based on tests performed at Standard Rating Conditions.

3.2.14 *Rating Conditions*. Any set of operating conditions under which a single level of performance results and which causes only that level of performance to occur.

3.2.14.1 *Appplication Rating Conditions*. A set of operating conditions within the range of Table 5 selected for a customer application (other than Standard Rating Conditions).

3.2.14.2 *Standard Rating Conditions*. A set of operating conditions used as the basis of comparison for performance characteristics, per Table 4.

3.2.15 *Significant Figure(s)*. Each of the digits of a number that are used to express it to the required degree of accuracy, starting from the first nonzero digit (Refer to Sections 4.3 and 6.2).

3.2.16 *Total Input Power* (W_{input}). Combined power input of all components of the unit, including Auxiliary Power and excluding integral pumps.

3.2.17 *Water-chilling or Water-heating Package.* A factory-made and prefabricated assembly (not necessarily shipped as one package) of one or more compressors, Condensers and Evaporators, with interconnections and accessories designed for the purpose of cooling or heating water. It is a machine specifically designed to make use of a vapor compression refrigeration cycle to remove heat from water and reject the heat to a cooling medium, usually air or water. The refrigerant Condenser can be an integral or separate part of the package.

3.2.17.1 *Heat Recovery Water-chilling Package*. A factory-made package designed for the purpose of chilling water and containing a Condenser for recovering heat. Where such equipment is provided in more than one assembly, the separate assemblies are to be designed to be used together, and the requirements of rating outlined in this standard are based upon the use of matched assemblies. It is a package specifically designed to make use of the refrigerant cycle to remove heat from the water source and to reject the heat to another fluid for heating use. Any excess heat can be rejected to another medium, usually air or water.

3.2.17.2 *Heat Pump Water-heating Package*. A factory-made package designed for the purpose of heating water. Where such equipment is provided in more than one assembly, the separate assemblies are to be designed to be used together, and the requirements of rating outlined in this standard are based upon the use of matched assemblies. It is a package specifically designed to make use of the refrigerant cycle to remove heat from an air or water source and to reject the heat to water for heating use. This unit can include valves to allow for reverse-cycle (cooling) operation.

3.2.17.3 *Condenserless Chiller.* A factory-made package designed for the purpose of chilling water but is not supplied with a Condenser. A separate air, water or evaporatively cooled Condenser interfaces with the Condenserless Chiller.

3.2.18 *Water Pressure Drop*. The reduction in static water pressure associated with the flow through a water-type heat exchanger.

Section 4. Test Requirements

4.1 *Test Requirements*. Ratings shall be established at the Rating Conditions specified in Section 5. Testing to validate ratings shall be conducted in accordance with the test method and procedures described in this standard and ANSI/ASHRAE Standard 30. Where there are discrepancies between this standard and ANSI/ASHRAE Standard 30, this standard shall prevail

4.2 Tests shall report measurement values and calculated results in accordance with methods and procedures described in ANSI/ASHRAE Standard 30. Refer to Appendix E for examples showing average data samples collected between each time stamp for the test data points in accordance with ANSI/ASHRAE Standard 30.

4.3 *Rounding.* Calculations shall use measurement values without rounding as defined below. Reported measurement data and calculated test results shall round values to a number of Significant Figures per Section 6. Energy balance and voltage balance shall be rounded to four (4) Significant Figures.

4.3.1 Numerical data are often obtained (or at least calculations can be made) with more digits than are justified by their accuracy or precision. For clarity, such data shall be rounded to the number of figures consistent with the confidence that can be placed in them when reported in final form. However, more digits shall be retained at intermediate stages of calculation to avoid compounding of rounding errors; retain no less than two additional Significant Figures than the final reported value, or as many digits as possible. The number of Significant Figures is the number of digits remaining when the data are rounded.

4.3.2 The rules for identifying Significant Figures when writing or interpreting numbers are as follows:

4.3.2.1 All non-zero digits are considered significant. For example, 91 has two Significant Figures (9 and 1), while 123.45 has five Significant Figures (1, 2, 3, 4 and 5).

4.3.2.2 Zeros appearing anywhere between two non-zero digits are significant. Example: 101.1203 has seven Significant Figures: 1, 0, 1, 1, 2, 0 and 3.

4.3.2.3 Leading zeros are not significant. For example, 0.00052 has two Significant Figures: 5 and 2.

4.3.2.4 Trailing zeros in a number containing a decimal point are significant. For example, 12.2300 has six Significant Figures: 1, 2, 2, 3, 0 and 0. The number 0.000122300 still has only six Significant Figures (the zeros before the 1 are not significant). In addition, 120.00 has five Significant Figures since it has three trailing zeros. This convention clarifies the precision of such numbers; for example, if a measurement precise to four decimal places (0.0001) is given as 12.23 then it can be misunderstood that only two decimal places of precision are available. Stating the result as 12.2300 makes clear that it is precise to four decimal places (in this case, six Significant Figures).

4.3.2.5 The significance of trailing zeros in a number not containing a decimal point can be ambiguous. For example, it is not always clear if a number like 1300 is precise to the nearest unit (and just happens coincidentally to be an exact multiple of a hundred) or if it is only shown to the nearest hundred due to rounding or uncertainty. One of the following conventions shall be used to address this issue:

4.3.2.5.1 Place a bar over the last Significant Figure; any trailing zeros following this are insignificant. For example, $13\overline{0}0$ has three Significant Figures (and hence indicates that the number is precise to the nearest ten).

4.3.2.5.2 Underline the last Significant Figure of a number; for example, "$2\underline{0}00$" has two Significant Figures.

4.3.2.5.3 Place a decimal point after the number; for example, "100." indicates specifically that three Significant Figures are meant.

4.3.2.5.4 In the combination of a number and a unit of measurement, choose a suitable unit prefix. For example, the number of Significant Figures in a power measurement specified as 1300 W is ambiguous, while a power of 1.30 kW is not.

4.3.2.5.5 Use scientific notation or exponential notation; for example, 1.30×10^3 W.

4.3.2.6 In multiplication and division, the operation with the least number of Significant Figures determines the numbers to be reported in the result. For example, the product 1256 x 12.2 = 15323.2 is reported as $15\overline{3}00$. In addition and subtraction, the least number of figures to either the right or the left of the decimal point determines the number of Significant Figures to be reported. Thus, the sum of 120.05 + 10.1 + 56.323 = 156.473 is reported as 156.5 because 10.1 defines the reporting level. In complex calculations involving multiplications and additions, for example, the operation is done serially, and the final result is rounded according to the least number of Significant Figures involved. Thus: (1256 x 12.2) + 125 = 15323.2 + 125 =$15\overline{4}00$.

4.3.3 The following rules shall be used in rounding values:

4.3.3.1 When the digit next beyond the one to be retained is less than five, the retained figure is kept unchanged. For example: 2.541 becomes 2.5 to two Significant Figures.

4.3.3.2 When the digit next beyond the one to be retained is greater than or equal to five, the retained figure is increased by one. For example; 2.453 becomes 2.5 to two Significant Figures.

4.3.3.3 When two or more figures are to the right of the last figure to be retained, they are to be considered as a group in rounding decisions. Thus in 2.4(501), the group (501) is considered to be >5 while for 2.5(499), (499) is considered to be <5.

4.4 *Water Connections*. Ratings shall be established with a single entering and single leaving connection per water circuit as follows:

4.4.1 *Water-cooled Condensers.* Units with multiple Water-cooled Condenser heat exchangers shall be tested with all Water-cooled Condenser heat exchangers connected for the duration of the test.

4.4.2 *Water-cooled Heat Recovery Condenser.* Units with multiple Water-cooled Heat Recovery Condenser heat exchangers shall be tested with all Water-cooled Heat Recovery Condenser heat exchangers connected for the duration of the test.

4.4.3 *Evaporator.* Units with multiple Evaporator heat exchangers shall be tested with all Evaporator heat exchangers connected for the duration of the test.

4.5 *Refrigerant Tubing for Remote Condenser or Remote Evaporator.* The unit shall be installed with interconnecting refrigerant tubing. The equivalent length of that tubing shall be no less than the rated length per Section 5.9. All refrigerant tubing and components shall be installed within the same test room as all other parts of the tested equipment. Refrigerant tubing line sizes, insulation, and details of installation shall be in accordance with the manufacturer's published recommendation and shall be recorded prior to testing.

4.6 *Corrections.* This section defines fouling factor related adjustments to target temperature values, as well as corrections to test measurements for water-side pressure drop, and corrections to test results for atmospheric pressure.

4.6.1 *Method for Simulating Fouling Factor Allowance.* The calculations in this section apply to Evaporators and Condensers using water, for Full Load and part load operating conditions. The resultant fouling factor correction, ΔT_{adj}, is added or subtracted to the target test water temperature as appropriate to simulate the fouled condition.

$$\Delta T_{range} = \left|T_{out,w} - T_{in,w}\right| \quad 1$$

$$\Delta T_{small,sp} = \left|T_{sat,r} - T_{out,w}\right| \quad 2$$

Where $T_{sat,r}$ is the saturated vapor temperature for single component or azeotrope refrigerants, or for zeotropic refrigerants $T_{sat,r}$ is the arithmetic average of the Dew Point and Bubble Point temperatures, corresponding to refrigerant pressure.

Calculate the Log Mean Temperature Difference (ΔT_{LMTD}) for the Evaporator and/or Condenser using the following equation at the Fouling Factor Allowance (R_{foul}) specified by the rated performance, and the corresponding specified small temperature difference, $\Delta T_{small,sp}$.

$$\Delta T_{LMTD} = \frac{\Delta T_{range}}{\ln\left(1+\frac{\Delta T_{range}}{\Delta T_{small,sp}}\right)} \quad 3$$

Calculate the incremental log mean temperature difference (ΔT_{ILMTD}) using Equation 4:

$$\Delta T_{ILMTD} = R_{foul}\left(\frac{Q}{A_w}\right) \quad 4$$

Where Q is the rated net Capacity and A_w is the water-side heat transfer surface area for the heat exchanger, which is inside or outside surface area depending on the heat exchanger design.

The water temperature adjustment needed to simulate the additional fouling, ΔT_{adj}, can now be calculated:

$$Z = \frac{\Delta T_{range}}{\Delta T_{LMTD} - \Delta T_{ILMTD}} \quad 5$$

$$\Delta T_{small,clean} = \frac{\Delta T_{range}}{e^{Z}-1} \quad 6$$

$$\Delta T_{adj} = \Delta T_{small,sp} - \Delta T_{small,clean} \quad 7$$

Where $\Delta T_{small,sp}$ is the small temperature difference as rated at a specified Fouling Factor Allowance, and $\Delta T_{small,clean}$ is the small temperature difference as rated in a clean condition with no fouling.

ΔT_{adj} is used for both Evaporator and Condenser water temperature corrections and shall be calculated separately for each heat exchanger. ΔT_{adj} shall be added to the controlled target temperature for condensing heat exchangers and subtracted from the controlled target temperature for evaporating heat exchangers. Operating condition tolerance limits per Table 1 apply to the adjusted target temperature. The test requires control over one temperature and the flow rate in a heat exchanger; the uncontrolled, unadjusted temperature can vary.

Note: See informative Appendix F for calculation examples of Fouling Factor Allowances to correct temperature targets.

4.6.1.1 *Condensing heat exchangers in cooling mode.* The corrected water temperature target for condensing heat exchangers in cooling mode shall be calculated using Equation 8:

$$T_{in,adj} = T_{in,w} + \Delta T_{adj} \quad 8$$

4.6.1.2 *Evaporating heat exchangers in cooling mode.* The corrected water temperature target for evaporating heat exchangers in cooling mode shall be calculated using Equation 9:

$$T_{out,adj} = T_{out,w} - \Delta T_{adj} \quad 9$$

4.6.1.3 *Condensing heat exchangers in heating mode.* The corrected water temperature target for condensing heat exchangers in heating mode shall be calculated using Equation 10:

$$T_{out,adj} = T_{out,w} + \Delta T_{adj} \quad 10$$

4.6.1.4 *Evaporating heat exchangers in heating mode.* The corrected water temperature target for evaporating heat exchangers in heating mode shall be calculated using Equation 11:

$$T_{out,adj} = T_{out,w} - \Delta T_{adj} \quad (11)$$

4.6.1.5 *Special Consideration for Multiple Refrigerant Circuits.*

For units that have multiple refrigeration circuits for the Evaporator or Condenser, and the following items are known for each heat exchanger: refrigerant saturation temperatures, inlet and outlet water temperatures, and water flow rates; an adjustment temperature $\Delta T_{adj,i}$ shall be computed for each heat exchanger and then combined into a single water temperature adjustment. For series water circuits, the intermediate water temperatures are calculated when measurement is not practical. For this purpose a weighted average for the $\Delta T_{adj,i}$ values shall be computed as follows:

$$\Delta T_{adj,weighted} = \frac{\Sigma(Q_i \cdot \Delta T_{adj,i})}{\Sigma(Q_i)} \quad (12)$$

Where 'i' is equal to the number of heat exchangers.

For this purpose, the weighted temperature adjustment, $\Delta T_{adj,weighted}$, shall be added to the condenser entering water temperature or subtracted from the Evaporator leaving water temperature to simulate the additional fouling factor adjustment.

4.6.1.6 *Derivation of Log Mean Temperature Difference (LMTD).*

This derivation is included for reference only:

$$\Delta T_{LMTD} = \frac{(T_{sat,r} - T_{in,w}) - (T_{sat,r} - T_{out,w})}{\ln\left[\frac{T_{sat,r} - T_{in,w}}{T_{sat,r} - T_{out,w}}\right]} = \frac{(T_{out,w} - T_{in,w})}{\ln\left[\frac{(T_{sat,r} - T_{out,w}) + (T_{out,w} - T_{in,w})}{T_{sat,r} - T_{out,w}}\right]} = \frac{(T_{out,w} - T_{in,w})}{ln\left[1 + \frac{(T_{out,w} - T_{in,w})}{T_{sat,r} - T_{out,w}}\right]} = \frac{\Delta T_{range}}{ln\left(1 + \frac{\Delta T_{range}}{\Delta T_{small,sp}}\right)} \quad (13)$$

4.7 *Validation.* Measurement data validation shall be in accordance with ANSI/ASHRAE Standard 30 except as noted below.

4.7.1 *Redundant Voltage Measurement.* Where redundant voltage measurement is required, the average voltage shall not differ by more than 2% from either measurement.

4.7.2 *Operating Condition Tolerances and Stability Criteria.* Measured data shall be in accordance with Table 1.

Table 1. Definition of Operating Condition Tolerances and Stability Criteria

Measurement or Calculation Result		Applicable Operating Mode(s)	Values Calculated from Data Samples: Mean	Values Calculated from Data Samples: Standard Deviation	Operating Condition Tolerance Limits	Stability Criteria
Net Capacity (Cooling or Heating)		Cooling, Heating, Heat Recovery	$\bar{Q}$	-	Unit with Continuous Unloading: [1] Part Load test Capacity shall be within 2% of the target part-load Capacity [2] $\frac{\left\lvert \bar{Q} - Q_{target} \right\rvert}{Q_{100\%}} \leq 2.000\%$	No requirement
					Units with Discrete Capacity Steps: Part Load test points shall be taken at the capacity steps closest to the specified part-load rating points as stated in Table 6. If not within the target range[2] of part-load Capacity then interpolate per Section 5.4.3.2.	
Evaporator	Entering Water Temperature	Cooling	$\bar{T}$	s_T	No Requirement	$s_T \leq 0.18$ °F
Evaporator	Leaving Water Temperature	Cooling	$\bar{T}$	s_T	$\left\lvert \bar{T} - T_{target} \right\rvert \leq 0.50$ °F	$s_T \leq 0.18$ °F
Condenser	Entering Water Temperature	Cooling	$\bar{T}$	s_T	$\left\lvert \bar{T} - T_{target} \right\rvert \leq 0.50$ °F	$s_T \leq 0.18$ °F
Condenser	Leaving Water Temperature	Cooling	$\bar{T}$	s_T	No Requirement	$s_T \leq 0.18$ °F
Condenser	Entering Air Mean Dry Bulb Temperature [3]	Cooling with fan cycling	$\bar{T}$	s_T	$\left\lvert \bar{T} - T_{target} \right\rvert \leq 1.00$ °F	$S_T \leq 0.75$ °F
Condenser	Entering Air Mean Wet Bulb Temperature [3]	Cooling with fan cycling	$\bar{T}$	s_T	$\left\lvert \bar{T} - T_{target} \right\rvert \leq 1.00$ °F	$S_T \leq 0.75$ °F
Evaporator	Entering Water Temperature [3]	Heating, Heat Recovery	$\bar{T}$	s_T	Heating portion: No requirement Defrost portion: $\left\lvert \bar{T} - T_{target} \right\rvert \leq 2.00$ °F	Heating portion: $s_T \leq 0.18$ °F Defrost portion: $s_T \leq 0.50$ °F
Evaporator	Leaving Water Temperature [3]	Heating, Heat Recovery	$\bar{T}$	s_T	Heating portion: $\left\lvert \bar{T} - T_{target} \right\rvert \leq 0.50$ °F Defrost portion: no requirement	Heating portion: $s_T \leq 0.18$ °F Defrost portion: no requirement
Condenser	Leaving Water Temperature	Heating, Heat Recovery	$\bar{T}$	s_T	$\left\lvert \bar{T} - T_{target} \right\rvert \leq 0.50$ °F	$s_T \leq 0.18$ °F
Condenser	Entering Water Temperature	Heating, Heat Recovery	$\bar{T}$	s_T	No Requirement	$s_T \leq 0.18$ °F

Table 1. Definition of Operating Condition Tolerances and Stability Criteria (continued)

Measurement or Calculation Result		Applicable Operating Mode(s)	Values Calculated from Data Samples		Operating Condition Tolerance Limits	Stability Criteria
			Mean	Standard Deviation		
Evaporator or Condenser	Entering Air Mean Dry Bulb Temperature [1]	Cooling, Heating (non-frosting)	$\bar{T}$	s_T	$\lvert\bar{T} - T_{target}\rvert \leq 1.00$ °F	$s_T \leq 0.75$ °F
		Heating (frosting) [4]			Heating portion: $\lvert\bar{T} - T_{target}\rvert \leq 2.00$ °F	Heating portion: $s_T \leq 1.00$ °F
					Defrost portion: no requirement for $\bar{T}$	Defrost portion: $s_T \leq 2.50$ °F
	Entering Air Mean Wet Bulb Temperature [1]	Cooling, Heating (non-frosting)			$\lvert\bar{T} - T_{target}\rvert \leq 1.00$ °F	$s_T \leq 0.50$ °F
		Heating (frosting) [4]			Heating portion: $\lvert\bar{T} - T_{target}\rvert \leq 1.50$ °F	Heating portion: $s_T \leq 0.75$ °F
					Defrost portion: no requirement for $\bar{T}$	No requirement
Water Flow (Volumetric, Entering)		Cooling, Heating, Heat Recovery	$\bar{V}_w$	s_{Vw}	$\frac{\lvert\bar{V}_w - V_{w,target}\rvert}{V_{w,target}} \leq 5.000\%$	$\frac{s_{V_w}}{\bar{V}_w} \leq 0.750\%$
Voltage [5] (if multiphase, this is the average of all phases)		Cooling, Heating, Heat Recovery	$\bar{V}$	s_V	$\frac{\lvert\bar{V} - V_{target}\rvert}{V_{target}} \leq 10.00\%$	$\frac{s_V}{\bar{V}} \leq 0.500\%$
Frequency [5]		Cooling, Heating, Heat Recovery	$\bar{\omega}$	s_{ω}	$\frac{\lvert\bar{\omega} - \omega_{target}\rvert}{\omega_{target}} \leq 1.000\%$	$\frac{s_{\omega}}{\bar{\omega}} \leq 0.500\%$
Condenserless Refrigerant Saturated Discharge Temperature		Cooling	$\bar{T}$	s_T	$\lvert\bar{T} - T_{target}\rvert \leq 0.50$ °F	$s_T \leq 0.25$ °F
Condenserless Liquid Temperature		Cooling	$\bar{T}$	s_T	$\lvert\bar{T} - T_{target}\rvert \leq 1.00$ °F	$s_T \leq 0.50$ °F
Steam Turbine Pressure/Vacuum [6]		Cooling, Heating, Heat Recovery	$\bar{p}$	s_p	$\lvert\bar{p} - p_{rating}\rvert \leq 0.500$ psid	$s_p \leq 0.250$ psid
Gas Turbine Inlet Gas Pressure [6]						
Governor Control Compressor Speed [7]		Cooling, Heating, Heat Recovery	$\bar{n}$	s_n	$\frac{\lvert\bar{n} - n_{target}\rvert}{n_{target}} \leq 0.500\%$	$\frac{s_n}{\bar{n}} \leq 0.250\%$

Notes:

1. The target set point condenser entering temperatures (Table 6) are determined at the target part-load test point.
2. The ± 2.0% tolerance shall be calculated as 2.0% of the Full Load rated Capacity (ton_R). For example, a nominal 50.0% part load point shall be tested between 48.0% and 52.0% of the Full Load Capacity to be used directly for IPLV.IP and NPLV.IP calculations. Outside this tolerance, interpolation shall be used.
3. The “heat portion” shall apply when the unit is in the heating mode except for the first ten minutes after terminating a defrost cycle. The “defrost portion” shall include the defrost cycle plus the first ten minutes after terminating the defrost cycle.
4. When computing average air temperatures for heating mode tests, omit data samples collected during the defrost portion of the cycle.
5. For electrically driven machines, voltage and frequency shall be maintained at the nameplate rating values within tolerance limits and stability criteria on voltage and frequency when measured at the locations specified by ANSI/ASHRAE Standard 30. For dual nameplate voltage ratings, tests shall be performed at the lower of the two voltages.
6. For steam turbine and gas turbine drive machines the pressure shall be maintained at the nameplate rating values within the tolerance limits.
7. For speed-controlled compressors the speed shall be maintained at the nameplate rating value within the tolerance limits.

4.8 *Air Temperature Measurement.* In addition to Table 1, air temperature measurement shall be in accordance with Table 2. For evaporatively-cooled units and heat pump chillers operating in heating mode, either wet-bulb temperature or dewpoint shall be measured. If dewpoint is measured, wet-bulb temperature shall be calculated and recorded.

Table 2. Temperature Measurement Requirements

Measurement	Measurement System Accuracy	Measurement Resolution	Selected, Installed, Operated, Maintained in Accordance with
Dry-Bulb and Wet-Bulb Temperatures	Per ANSI/ASHRAE Standard 30	Per ANSI/ASHRAE Standard 30	ANSI/ASHRAE Standard 41.1
Air Sampling Tree Average Temperature	Per ANSI/ASHRAE Standard 30	Per ANSI/ASHRAE Standard 30	
Dewpoint Temperature	±0.4 °F	≤ 0.1 °F	

4.9 *Air Sampling Array Requirements.* The air sampling array is an alternative to utilizing a thermopile grid. Measurement devices shall be positioned to measure at the four (4) locations shown in Figure 1 within 5% of overall width and height, where W and H are condenser air inlet nominal face area width and height.

Where the W or H dimension is less than or equal to two (2) ft, at least one (1) temperature measurement shall be used in that dimension. For example, if W = 2 ft and H = 4 ft, at least two (2) temperature measurements shall be used for that area.

Table 3 criteria for air distribution and control of air temperature shall be met. For evaporatively-cooled units and heat pump chillers operating in heating mode, either wet-bulb temperature or dewpoint shall be measured. If dewpoint is measured, wet-bulb temperature shall be calculated and recorded. Wet-bulb temperature is not required for other unit types.

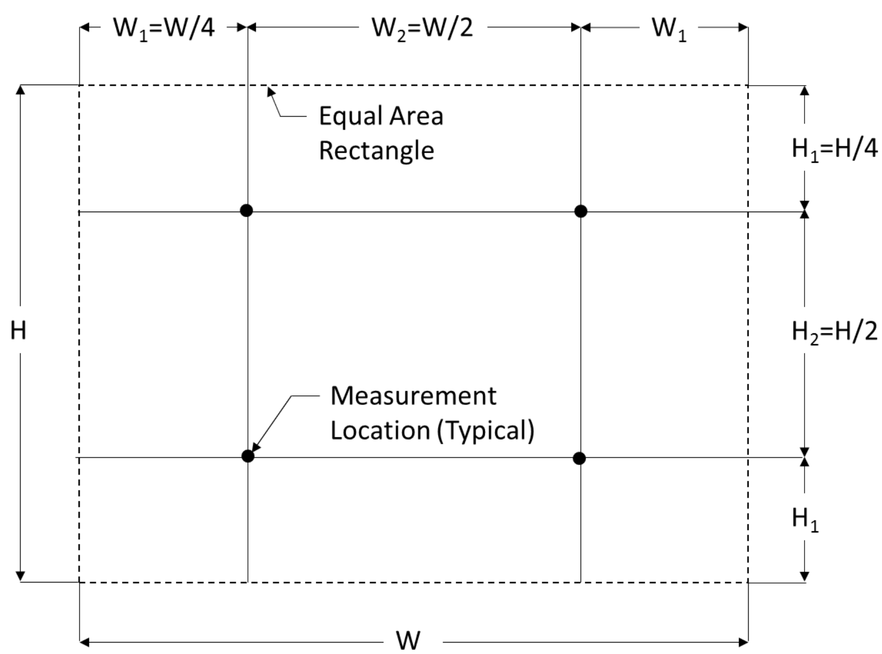

Figure 1. Air Sampling Array

Table 3. Criteria for Air Distribution and Control of Air Temperature

Item	Purpose	Deviation from Mean Value, °F
Dry-bulb Temperature		
Mean measurement of an Air Sampling Array	Uniform temperature distribution	±2.00 ($\leq$200.0 ton_R)
		±3.00 (>200.0 ton_R)
Individual measurements in an Air Sampling Array	Uniform temperature distribution	±1.50
Condenser discharge air recirculation measurement as compared to associated Air Sampling Array.	Recirculation Check	±5.00
Wet-bulb Temperature		
Wet-bulb temperature at any individual temperature measurement station	Uniform humidity distribution	±1.00

Section 5. Rating Requirements

5.1 *Rating Metrics*.

5.1.1 *Cooling Energy Efficiency*. The general forms of the Cooling Energy Efficiency terms are listed as Equations 14a through 14c. These terms are calculated at both design point and at part load conditions.

Note: Refer to Section 5.4.3.2.7 for part load degradation factor adjustment and Appendix C for atmospheric pressure adjustment.

5.1.1.1 The Cooling Coefficient of Performance (COP_R), kW/kW, shall be calculated using Equation 14a:

$$COP_R = \frac{Q_{ev}}{K3 \cdot W_{input}} \tag{14a}$$

5.1.1.2 The Energy Efficiency Ratio (EER), Btu/(W·h), shall be calculated using Equation 14b:

$$EER = \frac{Q_{ev}}{K7 \cdot W_{input}} \tag{14b}$$

5.1.1.3 The Power Input per Capacity, kW/ton_R, shall be calculated using Equation 14c:

$$\frac{kW}{ton_R} = \frac{K5 \cdot W_{input}}{Q_{ev}} \tag{14c}$$

5.1.2 *Heating Energy Efficiency*. The general forms of the Heating Energy Efficiency terms are listed as Equations 15 through 17. These terms are calculated at both design point and at part load conditions.

Note: Refer to Section 5.4.3.2.7 for part load degradation factor adjustment and Appendix C for atmospheric pressure adjustment.

5.1.2.1 The Heating Coefficient of Performance (COP_H), kW/kW, shall be calculated using Equation 15:

$$COP_H = \frac{Q_{cd}}{K3 \cdot W_{input}} \tag{15}$$

5.1.2.2 The Heat Recovery Coefficient of Performance (COP_{HR}), kW/kW shall be calculated using Equation 16:

$$COP_{HR} = \frac{Q_{ev} + Q_{hrc}}{K3 \cdot W_{input}} \quad 16$$

5.1.2.3 The Simultaneous Heating and Cooling Coefficient of Performance (COP_{SHC}), kW/kW, shall be calculated using Equation 17:

$$COP_{SHC} = \frac{Q_{cd} + Q_{ev}}{K3 \cdot W_{input}} \quad 17$$

5.1.3 *Net Refrigerating Capacity*. The Net Refrigerating Capacity, Btu/h, for the Evaporator shall use the water temperatures, water mass flow rate and water properties at the Evaporator entering and leaving conditions and be calculated using Equation 18:

$$Q_{ev} = m_w \cdot c_p \cdot (T_{in} - T_{out}) \quad 18$$

Specific heat c_p is taken at the average of entering and leaving water temperatures. When expressing water flow rate in volumetric terms for ratings, the conversion from mass flow rate shall use water density corresponding to entering water temperature (Refer to Equation 37). The volumetric flow rate shall be calculated using Equation 19:

$$V_w = \frac{m_w}{\rho_{in}} \cdot K10 \quad 19$$

5.1.4 *Net Heating Capacity*. The Net Heating Capacity, Btu/h, for either a heat rejection, or heat recovery Condenser, and other heat rejection devices (e.g. oil coolers, inverters, etc.), shall use the water temperatures, water flow rate, and water properties at the entering and leaving conditions and be calculated using Equations 20 or 21:

$$Q_{cd} = m_w \cdot c_p \cdot (T_{out} - T_{in}) \quad 20$$

$$Q_{hrc} = m_w \cdot c_p \cdot (T_{out} - T_{in}) \quad 21$$

Specific heat c_p is taken at the average of entering and leaving water temperatures. When expressing water flow rate in volumetric terms for ratings, the conversion from mass flow rate shall use water density corresponding to entering water temperature (Refer to Equations 19 and 37).

5.1.5 *Water Pressure Drop.* 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. For Published Ratings, this value is expressed in feet H_2O at a reference water temperature of 60 °F. For test measurements, this is a differential pressure expressed in psid. (Refer to Section 7 for converting units of measure). For the calculation of Water Pressure Drop, Refer to ANSI/ASHRAE Standard 30. Note the requirements for a single inlet and single outlet as described in Section 4.4.

5.2 *Standard Ratings and Conditions.* Standard Ratings for all Water-chilling Packages shall be established at the Standard Rating Conditions. These packages shall be rated for cooling, heat recovery, or heating performance at conditions specified in Table 4. Standard Ratings shall include a water-side Fouling Factor Allowance as specified in the notes section of Table 4. Chiller packages consisting of multiple units and rated as a single package shall be tested as rated.

Table 4. Standard Rating Conditions

Operating Category	Conditions	Cooling Mode Evaporator[2]			Cooling Mode Heat Rejection Heat Exchanger												
					Tower (Water Conditions)[3]			Heat/Recovery (Water Conditions)[4]		Evaporatively-cooled Entering Temperature[5, 7]		Air-cooled (AC) Entering Temperature[5, 7]		Without Condenser			
														Air-cooled Refrigerant Temperature		Water & Evaporatively Cooled Refrigerant Temperature	
		Entering Temperature, ºF	Leaving Temperature, ºF	Flow Rate, gpm/ton$_R$	Entering Temperature, ºF	Leaving Temperature, ºF	Flow Rate, gpm/ton$_R$	Entering Temperature, ºF	Leaving Temperature, ºF	Dry-Bulb, ºF	Wet-Bulb, ºF	Dry-Bulb, ºF	Wet-Bulb, ºF	SDT, ºF	LIQ, ºF	SDT, ºF	LIQ, ºF
All Cooling	Standard	54.00	44.00	Note - 8	85.00	94.30	Note - 9	--	--	95.00	75.00	95.00	--	125.00	105.00	105.00	98.00
AC Heat Pump High Heating[6]	Low	--	105.00	Note - 1	--	--	--	--	--	--	--	47.00	43.00	--	--	--	--
	Medium	--	120.00	Note - 1	--	--	--	--	--	--	--	47.00	43.00	--	--	--	--
	High	--	140.00	Note - 1	--	--	--	--	--	--	--	47.00	43.00	--	--	--	--
AC Heat Pump Low Heating[6]	Low	--	105.00	Note - 1	--	--	--	--	--	--	--	17.00	15.00	--	--	--	--
	Medium	--	120.00	Note - 1	--	--	--	--	--	--	--	17.00	15.00	--	--	--	--
	High	--	140.00	Note - 1	--	--	--	--	--	--	--	17.00	15.00	--	--	--	--
Water Cooled Heating	Low	--	44.00	Note - 8	--	--	--	95.00	105.00	--	--	--	--	--	--	--	--
	Medium	--	44.00	Note - 8	--	--	--	105.00	120.00	--	--	--	--	--	--	--	--
	High	--	44.00	Note - 8	--	--	--	120.00	140.00	--	--	--	--	--	--	--	--
	Boost	--	65.00	Note - 8	--	--	--	120.00	140.00	--	--	--	--	--	--	--	--
Heat Recovery	Low	--	44.00	Note - 8	75.00	--	Note - 9	95.00	105.00	40.00	38.00	40.00	38.00	--	--	--	--
	Medium	--	44.00	Note - 8	75.00	--	Note - 9	105.00	120.00	40.00	38.00	40.00	38.00	--	--	--	--
	Hot Water 1	--	44.00	Note - 8	75.00	--	Note - 9	90.00	140.00	40.00	38.00	40.00	38.00	--	--	--	--
	Hot Water 2	--	44.00	Note - 8	75.00	--	Note - 9	120.00	140.00	40.00	38.00	40.00	38.00	--	--	--	--

Notes:

1. The water flow rate used for the heating tests of reverse cycle air to water heat pumps shall be the flow rate determined during the cooling test.
2. The rating Fouling Factor Allowance for the cooling mode Evaporator or the heating Condenser for AC reversible cycles shall be R_{foul} = 0.000100 h·ft^2·ºF/Btu.
3. The rating Fouling Factor Allowance for tower heat exchangers shall be R_{foul} = 0.000250 h·ft^2·ºF/Btu.
4. The rating Fouling Factor Allowance for heating and heat recovery heat exchangers shall be R_{foul} = 0.000100 h·ft^2·ºF/Btu for closed loop and R_{foul} = 0.000250 h·ft^2·ºF/Btu for open loop systems.
5. Evaporatively cooled Condensers and Air-Cooled Condensers shall be rated with a Fouling Factor Allowance of zero, R_{foul} = 0.000 h·ft^2·ºF/Btu.
6. A reversible cycle is assumed where the cooling mode Evaporator becomes the condenser circuit in the heating mode.
7. Air-cooled & evaporatively-cooled unit ratings are at standard atmospheric condition (sea level). Measured test data shall be corrected to an atmospheric pressure of 14.696 psia per Appendix C.
8. Rated water flow is determined by the water temperatures at the rated Cooling Capacity.
9. Rated water flow is determined by the water temperatures at the rated Capacity and rated efficiency.

5.3 *Application Rating Conditions.* Full and part-load Application Ratings shall include the range of Rating Conditions listed in Table 5 or be within the operating limits of the equipment. For guidance to the industry, designing to large Fouling Factors significantly impacts the performance of the chiller. It is best to maintain heat transfer surfaces by cleaning or maintaining proper water treatment to avoid highly fouled conditions and the associated efficiency loss. From a test perspective, highly fouled conditions are simulated with clean tubes by testing at decreased Evaporator water temperatures and increased Condenser water temperatures. High Fouling Factors can increase or decrease these temperatures to conditions outside test loop or equipment capabilities. For this test standard, the application range for the water side fouling shall be between clean (0.000) and 0.001000 h·ft^2·°F/Btu. Fouling Factors above these values are outside of the scope of this standard and shall be noted as such.

Table 5. Full and Part-load Application Rating Conditions

<table>
<tr><th></th><th colspan="3">Evaporator</th><th colspan="3">Condenser</th></tr>
<tr><td rowspan="9">Cooling</td><td colspan="3">Water Cooled</td><td colspan="3">Water Cooled</td></tr>
<tr><td>Leaving Temperature[1], °F</td><td>Temperature Difference Across Heat Exchanger[5], °F</td><td>Fouling Factor Allowance, h·ft^2·°F/Btu</td><td>Entering Temperature[2], °F</td><td>Flow Rate, gpm/ton_R [5, 7]</td><td>Fouling Factor Allowance, h·ft^2·°F/Btu</td></tr>
<tr><td rowspan="7">36.00 to 70.00</td><td rowspan="7">5.00 to 20.00</td><td rowspan="7">0.00$\overline{0}$ to 0.00100</td><td>55.00 to 115.00</td><td>1.00$\overline{0}$ to 6.00$\overline{0}$</td><td>0.00$\overline{0}$ to 0.00100</td></tr>
<tr><td colspan="3">Air-Cooled</td></tr>
<tr><td colspan="2">Entering Air Dry Bulb[3], °F</td><td>Atmospheric Pressure[6], psia</td></tr>
<tr><td colspan="2">55.0 to 125.6</td><td>11.56 to 15.20</td></tr>
<tr><td colspan="3">Evaporatively Cooled</td></tr>
<tr><td colspan="2">Entering Air Wet Bulb[4], °F</td><td>Atmospheric Pressure[6], psia</td></tr>
<tr><td colspan="2">50.0 to 80.0</td><td>11.56 to 15.20</td></tr>
<tr><td rowspan="6">Heating</td><td colspan="3">Water Source Evaporator</td><td colspan="3">Water Cooled Condenser</td></tr>
<tr><td colspan="2">Entering Water Temperature[1], °F</td><td>Fouling Factor Allowance, h·ft^2·°F/Btu</td><td>Leaving Water Temperature[2], °F</td><td>Temperature Difference Across Heat Exchanger[5], °F</td><td>Fouling Factor Allowance, h·ft^2·°F/Btu</td></tr>
<tr><td colspan="2">40.00 to 80.00</td><td>0.00$\overline{0}$ to 0.00100</td><td rowspan="4">105.00 to 160.00</td><td rowspan="4">5.00 to 30.00</td><td rowspan="4">0.00$\overline{0}$ to 0.00100</td></tr>
<tr><td colspan="3">Air Source Evaporator</td></tr>
<tr><td>Entering Air Temperature, °F</td><td colspan="2">Atmospheric Pressure[6], psia</td></tr>
<tr><td>15.00 to 60.00</td><td colspan="2">11.56 to 15.20</td></tr>
</table>

Notes:
1. Evaporator water temperatures shall be published in rating increments of no more than 4.00 °F.
2. Condenser water temperatures shall be published in rating increments of no more than 5.00 °F.
3. Entering air temperatures shall be published in rating increments of no more than 10.0 °F.
4. Air wet bulb temperatures shall be published in rating increments of no more than 2.5 °F.
5. Applies to design point only, not part-load points.
6. Rated altitude not exceeding 6500 ft. Measured test data shall be corrected per Appendix C to the application rating atmospheric pressure.
7. The normalized flow rate is per unit of Evaporator Capacity.

5.3.1 For the purpose of this standard, published Application Ratings shall use a standardized relationship between rated geometric altitude (Z_H) above mean sea level and atmospheric pressure (p_{atm}). This enables chiller Application Ratings to be published based on the nominal altitude at the installation location without consideration of local weather variations on atmospheric pressure. Test data however shall be corrected on the basis of atmospheric pressure at the time of the test. See Section 7 and Appendix C.

5.4 *Part-load Ratings.* Water-chilling Packages shall be rated at 100%, 75%, 50%, and 25% load relative to the full-load rating Net Refrigerating Capacity at the conditions defined in Table 6. For chillers capable of operating in multiple modes (cooling, heating, and /or heat recovery), part-load ratings are only required for cooling mode operation.

5.4.1 *Cooling Part-load Ratings.* Cooling mode Part-load ratings shall be presented in one of the four following ways:

5.4.1.1 *IPLV.IP*. Based on the conditions defined in Table 6 and method defined in Section 5.4.3.

5.4.1.2 *NPLV.IP*. Based on the conditions defined in Table 6 and method defined in Section 5.4.3. It is optional to publish NPLV.IP when Table 8, Note 5 applies.

5.4.1.3 *Individual Part-load Data Point(s).* Individual part-load data point(s) used for calculating IPLV.IP or NPLV.IP as defined in Table 6.

5.4.1.4 *Other Part-load Points.* Other part-load points, within the Application Rating limits of Table 5 and method defined in Section 5.4.4, that do not meet the requirements of Table 6~~, Notes 3, 4, 5, or 6~~ (i.e. variable water flow rates or other entering Condenser water temperatures). Neither IPLV.IP nor NPLV.IP shall be calculated for such points and shall not be a requirement for publication per Section 6.

5.4.2 *Heating Part-load Ratings.* Heat Pump Water-heating Packages and Heat Recovery Water-chilling Packages can be rated at individual part load points. Neither IPLV.IP nor NPLV.IP shall be calculated for such points.

5.4.3 *Determination of Part-load Performance*. For Water-chilling Packages covered by this standard, the IPLV.IP or NPLV.IP shall be calculated as follows:

Determine the Part-load energy efficiency at 100%, 75%, 50%, and 25% load points at the conditions specified in Table 6.

Use Equation 22a to calculate the IPLV.IP or NPLV.IP for units rated with COP_R and EER.

$$\text{IPLV.IP or NPLV.IP} = 0.01 \cdot A + 0.42 \cdot B + 0.45 \cdot C + 0.12 \cdot D \qquad \text{22a}$$

For COP_R and EER where:

A = COP_R or EER at 100% load
B = COP_R or EER at 75% load
C = COP_R or EER at 50% load
D = COP_R or EER at 25% load

Use Equation 22b to calculate the IPLV.IP or NPLV.IP for units rated with kW/ton_R:

$$\text{IPLV.IP or NPLV.IP} = \frac{1}{\frac{0.01}{A} + \frac{0.42}{B} + \frac{0.45}{C} + \frac{0.12}{D}} \qquad \text{22b}$$

Where:

A = Power Input per Capacity, kW/ton_R at 100% load
B = Power Input per Capacity, kW/ton_R at 75% load
C = Power Input per Capacity, kW/ton_R at 50% load
D = Power Input per Capacity, kW/ton_R at 25% load

5.4.3.1 For a derivation of Equations 22a and 22b, and an example of an IPLV.IP or NPLV.IP calculation, see Appendix D. The weighting factors have been based on the weighted average of the most common building types and operations using average weather in 29 U.S. cities, with and without airside economizers.

Table 6. Part-load Conditions for Rating

	IPLV.IP	NPLV.IP
Evaporator (All Types)		
All loads LWT[2], ºF	44.00	User defined LWT
Flow Rate[3], gpm/ton$_R$	Per Table 4	Per Table 4[3]
R_{foul}, h·ft^2·ºF/Btu	0.000100	User defined
Water-cooled Condenser [1,2]		
100% load EWT, ºF	85.00	User defined EWT
75% load EWT, ºF	75.00	Equation 24
50% load EWT, ºF	65.00	Equation 24
25% load EWT, ºF	65.00	Equation 24
Flow rate[3], gpm/ton$_R$	Note[3]	User defined flow rate
R_{foul}, h·ft^2·ºF/Btu	0.000250	User defined
Air-cooled Condenser[1,4]		
100% load EDB, ºF	95.0	User defined EDB
75% load EDB, ºF	80.0	Equation 23
50% load EDB, ºF	65.0	Equation 23
25% load EDB, ºF	55.0	Equation 23
R_{foul}, h·ft^2·ºF/Btu	0.000	User defined
Evaporatively-cooled Condenser[1,4]		
100% load EWB, ºF	75.00	User defined EWB
75% load EWB, ºF	68.75	Equation 25
50% load EWB, ºF	62.50	Equation 25
25% load EWB, ºF	56.25	Equation 25
R_{foul}, h·ft^2·ºF/Btu	0.000	User defined
Air-cooled Without Condenser		
100% load SDT, ºF	125.00	User defined SDT
75% load SDT, ºF	107.50	Equation 26
50% load SDT, ºF	90.00	Equation 26
25% load SDT, ºF	72.50	Equation 26
R_{foul}, h·ft^2·ºF/Btu	0.000	User defined
Water-cooled or Evaporatively-cooled Without Condenser		
100% load SDT, ºF	105.00	User defined SDT
75% load SDT, ºF	95.00	Equation 27 or 28
50% load SDT, ºF	85.00	Equation 27 or 28
25% load SDT, ºF	75.00	Equation 27 or 28
R_{foul}, h·ft^2·ºF/Btu	0.000	User defined

Notes:

1. If the unit manufacturer's recommended minimum temperatures are greater than those specified in Table 6, then those shall be used in lieu of the specified temperatures. If head pressure control is active below the rating temperature, then tests shall be run per the Section 5.8 test procedure.
2. Correct for Fouling Factor Allowance by using the calculation method described in Section 4.6.
3. The flow rates are to be held constant at full-load values for all part-load conditions as per Table 4.
4. Air-cooled and evaporatively-cooled unit ratings are at standard atmospheric condition (sea level). Measured data shall be corrected to standard atmospheric pressure of 14.696 psia per Appendix C.

5.4.3.2 The IPLV.IP or NPLV.IP rating requires that the unit efficiency be determined at 100%, 75%, 50% and 25% at the conditions as specified in Table 6. If the unit, due to its capacity control logic cannot be operated at 75%, 50%, or 25% within ±2% Percent Load as required by Table 1, then the unit shall be operated at other load points and the 75%, 50%, or 25% capacity efficiencies shall be determined using interpolation as defined in 5.4.5. Extrapolation of data shall not be used. The capacity points as close as possible to the rating load shall be used.

For example, if the minimum actual Capacity is 33% then the curve can be used to determine the 50% capacity point, but not the 25% capacity point. When unit cannot be unloaded to or below the rating point refer to section 5.4.3.2.7 for the use of degradation procedure.

Note: %Load shown in the equations below is in decimal form (e.g.100 %Load = 1.0) and is defined in Section 3.12.

5.4.3.2.1 *IPLV.IP Interpolation.* If the units cannot run at any of the 75%, 50% or 25% load points within a tolerance of ±2% but is capable of running at load above and below the rating Percent Load of 75%, 50% or 25% interpolation of the test points shall be used to determine the rating efficiency using the Condenser entering condition listed in Table 6. The same Condenser temperature shall be used for both interpolation points. The capacity point closest to the desired rating load point shall be used.

Note: In the 2020 and later versions of AHRI Standard 550/590 (I-P), the part-load rating Condenser temperatures have been fixed at the 100%, 75%, 50% and 25% load values shown in Table 6. In the 2018 and prior versions of the AHRI Standard 550/590 (I-P) the Condenser temperature was a function of the actual load and required iteration if the Capacity measured was not what was assumed to get the Condenser temperature for the test. This change does not impact the units that can run at the 75%, 50%, and 25% load conditions; however, for interpolating ratings the Condenser temperature is now fixed at the 75%, 50% and 25% load rating points. Two tests are run at different loads above and below the rating point at the same Condenser temperature. For example, if the unit is an air-cooled chiller and the rating for 75% load is being determined, but the unit can only run at 80% Percent Load and 60% load, then the unit can be run at the 80% and 60% load at 80.0 °F ambient temperature. Figure 2 also shows the difference between the AHRI Standard 550/590 (I-P)-2020 and the prior version of AHRI Standard 550/590 (I-P) for this example air cooled 75% rating point.

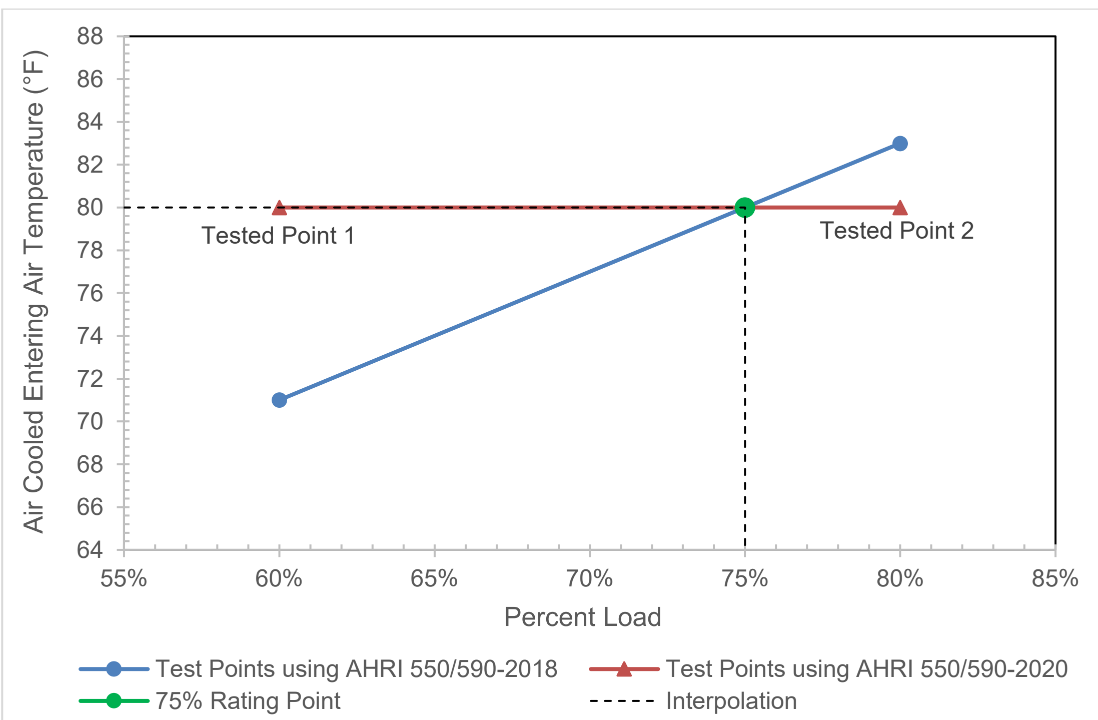

Figure 2. Interpolated IPLV.IP Condition

In the Figure 2 example, the following calculations for interpolation are used (see Equations 32 and 33).

Point 1: (60%, 11.00)
Point 2: (80%, 10.50)
Interpolated Point: (75%, η_{int})

$$\text{exponent} = \log_{10}(11.00) + (0.75 - 0.60) \cdot \frac{[\log_{10}(10.50) - \log_{10}(11.00)]}{(0.80 - 0.60)} = 1.026240146$$

$$\eta_{int} = 10^{(1.026240146)} = 10.62\ EER$$

5.4.3.2.2 Entering air dry-bulb temperature (EDB), °F, for an Air-cooled Condenser at NPLV.IP part load conditions shall use Equation 23 where $T_{100\%}$ is the selected 100% Load EDB temperature:

$$\text{EDB} = \begin{cases} \frac{3}{2}(T_{100\%} - 55)\left(\%Load - \frac{1}{3}\right) + 55 & \text{for Load } > 100\%/3 \\ 55 & \text{for Load } \leq 100\%/3 \end{cases} \quad (23)$$

Note: In the case of an Air-cooled Chiller, the Load term used to calculate the EDB temperature is based on the adjusted Capacity after using the atmospheric pressure correction.

5.4.3.2.3 Entering water temperature (EWT), °F, for a Water-cooled Condenser at NPLV.IP part load conditions shall use Equation 24 where $T_{100\%}$ is the selected 100% Load EWT:

$$\text{EWT} = \begin{cases} 2(T_{100\%} - 65)\left(\%Load - \frac{1}{2}\right) + 65 & \text{for Load } > 50\% \\ 65 & \text{for Load } \leq 50\% \end{cases} \quad (24)$$

5.4.3.2.4 Entering air wet-bulb temperature (EWB), °F, for an Evaporatively-cooled Condenser at NPLV.IP part load conditions shall use Equation 25:

$$\text{EWB} = (T_{100\%} - 50) \cdot \%Load + 50 \quad (25)$$

5.4.3.2.5 Saturated discharge temperature (SDT), °F, for an air-cooled unit without Condenser at NPLV.IP part load conditions shall use Equation 26:

$$\text{AC SDT} = (T_{100\%} - 55) \cdot \%Load + 55 \quad (26)$$

5.4.3.2.6 Saturated discharge temperature (SDT), °F, for a water-cooled or evaporatively-cooled unit without Condenser at NPLV.IP part load conditions shall use Equation 27 or 28:

$$\text{water-cooled: SDT} = (T_{100\%} - 65) \cdot \%Load + 65 \quad (27)$$

$$\text{evaporatively-cooled: SDT} = (T_{100\%} - 65) \cdot \%Load + 65 \quad (28)$$

5.4.3.2.7 If a unit cannot be unloaded to the 25%, 50%, or 75% capacity point, then the unit shall be run at the minimum step of unloading at the Condenser entering water or air temperature based on Table 6 for 25%, 50% or 75% capacity points as required. The efficiency shall then be determined by using Equations 29a, 29b, or 29c:

$$EER_{CD} = \frac{\text{EER}_{\text{Test}}}{\text{C}_\text{D}} \quad (29a)$$

$$\text{COP}_{\text{R,CD}} = \frac{\text{COP}_{\text{Test}}}{\text{C}_\text{D}} \quad (29b)$$

$$\left(\frac{\text{kW}}{\text{ton}_\text{R}}\right)_{CD} = \left(\frac{\text{kW}}{\text{ton}_\text{R}}\right)_{Test} \cdot \text{C}_\text{D} \quad (29c)$$

5.4.3.2.8 EER_{Test}, COP_{RTest}, and kW/ton_{RTest} are the efficiency at the test conditions (after atmospheric pressure adjustment as per Appendix C, as applicable) and C_D is a degradation factor to account for cycling of the compressor for capacities less than the minimum step of Capacity.

C_D shall be calculated using Equation 30:

$$C_D = (-0.13 \cdot LF) + 1.13 \qquad 30$$

Where LF is the load factor calculated using Equation 31:

$$LF = \frac{(\%Load)\ (Q_{100\%})}{(Q_{min\%Load})} \qquad 31$$

Part-load unit Capacity is the measured or calculated unit Capacity from which Standard Rating points are determined using the method above.

5.4.3.3 *Procedures for Testing and Calculation of IPLV.IP or NPLV.IP for Continuous Capacity Control Units.*

For fully continuous capacity controlled units or units with a combination of staged Capacity and continuous Capacity covered by this standard, the IPLV.IP or NPLV.IP shall be calculated using test data and or rating data using the following procedures.

For test purposes, units shall be provided with manual means to adjust the unit refrigeration Capacity by adjusting variable capacity compressor(s) Capacity and or the stages of refrigeration Capacity as defined by the manufacturer's instructions.

The following sequential steps shall be followed:

5.4.3.3.1 *Step 1.* The unit shall be configured per the manufacturer's instructions, including setting of stages of refrigeration and variable capacity compressor loading percent for each of the four rating points of 100%, 75%, 50%, and 25%.

The Condenser entering temperature shall be adjusted per the requirements of Table 6 as determined by the rating Percent Load of 100%, 75%, 50% and 25% and be within the required temperature limits per Table 1 for the 100% rating point and for the 75%, 50% and 25% points if the adjusted Capacity is within 2% of the rating Percent Load. If the adjusted measured Percent Load difference is outside the 2% tolerance, as defined by Table 1, then the interpolation procedure defined in 5.4.3.2 shall be used with a point above and below the rating Percent Load. If the unit can operate with head pressure control active during any of the tests at the specified Condenser temperature which can cause cycling and stable test conditions cannot be maintained, then the applicable procedures defined in Sections 5.4.4.2 and/or 5.8 shall be used.

If the unit is an air-cooled chiller or evaporatively-cooled, then the measured Capacity and efficiency shall be adjusted for atmospheric pressure using the procedures of Appendix C. No adjustment is required for water-cooled units.

The full-load Capacity shall be within the tolerance range defined by Table 7. If the Capacity is not in compliance with the requirements, the test shall be repeated.

If the adjusted part load test Capacity is within ±2% of the target Percent Load of 75%, 50% and 25% then the adjusted efficiency can be used directly to calculate the IPLV.IP or NPLV.IP. If the adjusted Capacity of any point is not within the ±2% tolerance as required by Table 1, then the test shall be repeated or move to Step 2 or Step 3.

5.4.3.3.2 *Step 2.* If the unit, due to its capacity control logic cannot be operated at the rating 75%, 50%, or 25% Percent Load point within ±2%, then additional test points for use in interpolation are required. Capacity staging and variable Capacity shall be selected to have one test as close as possible to the desired rating point with an adjusted Capacity above the desired rating Percent Load rating point of 75%, 50% and 25% and a second test as close as possible to the desired rating Percent Load with an adjusted Capacity below the desired rating Percent Load of 75%, 50%, and 25%.

The Condenser entering temperature shall be adjusted per the requirements of Table 6 for the rating point Percent Load and be within the required temperature limits per Table 1. The same Condenser entering air temperature shall be used for both interpolation points.

The test Capacity and efficiency for air and evaporatively-cooled chillers shall then be adjusted for atmospheric pressure using the procedures of Appendix C. No adjustment is required for water-cooled units.

Interpolation per Section 5.4.5 between the two adjusted capacity points shall then be used to determine the efficiency at the rating 75%, 50% or 25% Percent Load point, using the entering Condenser temperature per Table 6 at the rating Percent Load. Data shall not be extrapolated and there shall be a test point above and below the rating Percent Load point.

5.4.3.3.3 *Step 3.* If the unit cannot be unloaded to any of the 75%, 50%, or 25% rating points at the minimum stage of unloading then the unit shall be run at the minimum stage of Capacity for each of the test points where appropriate.

The Condenser entering temperature shall be adjusted per the requirements of Table 6 using the rating Percent Load of 75%, 50%, or 25% and be within the required temperature limits per Table 1. If the unit can operate with head pressure control active during the test at a specified Condenser temperature which can cause cycling and stable test conditions cannot be maintained, then the Section 5.8 test procedure shall be followed.

The Capacity and efficiency for air and evaporatively-cooled chillers shall then be adjusted for atmospheric pressure using the procedures of Appendix C. No adjustment is required for Water-cooled chillers.

If the data for the lowest stage of Capacity is above the desired rating point load with allowance for the 2% tolerance then the efficiency shall then be adjusted for cyclic degradation using the degradation procedures outlined in 5.4.3.2.7.

5.4.3.3.4 *Step 4.* Once the adjusted efficiency for each of the 100%, 75%, 50% and 25% Percent Load rating points is determined using Steps 1, 2, or 3 as appropriate, then the IPLV.IP or NPLV.IP shall be calculated using Equation 22a or 22b.

5.4.3.4 *Procedures for Testing and Calculation of IPLV.IP or NPLV.IP for Discrete Capacity Step Controlled Units.*

For discrete capacity step controlled units, including units with only a single stage of Capacity, the IPLV.IP or NPLV.IP shall be calculated using test data and or rating data obtained using the following procedures.

For test purposes, units shall be provided with manual means to adjust the unit refrigeration Capacity by adjusting the stages of refrigeration Capacity as defined by the manufacturer's instructions.

The following sequential steps shall be followed:

5.4.3.4.1 *Step 1.* The unit shall be configured per the manufacturer's instructions, including setting of stages of refrigeration for each of the 4 rating Percent Load rating points of 100%, 75%, 50%, and 25%.

The Condenser entering temperature shall be adjusted per the requirements of Table 6 as determined by the rating Percent Load of 100%, 50%, 75% and 25% and be within the required temperature limits per Table 1. If the unit can operate with head pressure control active during the test at the specified Condenser temperature which can cause cycling and stable test conditions cannot be maintained, then the Section 5.8 test procedure shall be followed.

If the unit is an air-cooled chiller, then the measured Capacity and efficiency shall be adjusted for atmospheric pressure using the procedures of Appendix C. No adjustment is required for Water-cooled units.

If the adjusted part load test Capacity is within 2% of the target Percent Load as required by Table 1, of 75%, 50% and 25% then the adjusted efficiency can be used directly to calculate the IPLV.IP or NPLV.IP. If the adjusted Capacity of any point is not within the 2% tolerance, then move to Step 2 or 3.

5.4.3.4.2 *Step 2.* If the unit, due to its capacity control logic cannot be operated at the rating 75%, 50%, or 25% Percent Load point within 2%, then additional test points for use in interpolation as defined in Section 5.4.5 are required. Capacity staging shall be selected to have one test as close as possible to the desired rating point with an adjusted Capacity above the desired rating Percent Load rating point of 75%, 50% and 25% and a second test as close as possible to the desired rating Percent Load with an adjusted Capacity below the desired rating Percent Load of 75%, 50%, and 25%. Capacity staging with a Capacity greater or less than the capacity staging closest to the desired rating point shall not be used.

The Condenser entering temperature shall be adjusted per the requirements of Table 6 using the rating point Percent Load and be within the required temperature limits per Table 1. The rating point Percent Load Condenser entering temperature shall be used for both interpolation points.

The test Capacity and efficiency shall then be adjusted for atmospheric pressure using the procedures of Appendix C.

Interpolation per Section 5.4.5 between the two adjusted capacity points shall then be used to determine the efficiency at the rating 75%, 50% or 25% Percent Load point. Data shall not be extrapolated and there shall be a test point above and below the rating Percent Load point.

5.4.3.4.3 *Step 3.* If the unit cannot be unloaded to any of the 75%, 50%, or 25% rating points within 2% at the minimum stage of unloading then the unit shall be run at the minimum stage of Capacity for each of the test points where appropriate.

The Condenser entering temperature shall be adjusted per the requirements of Table 6 using the rating Percent Load of 75%, 50%, or 25% and be within the required temperature limits per Table 1. If the unit can operate with head pressure control active during the test at the specified Condenser temperature which can cause cycling and stable test conditions cannot be maintained, then the Section 5.8 test procedure shall be followed.

The Capacity and efficiency shall then be adjusted for atmospheric pressure for air and evaporatively-cooled chillers using the procedures of Appendix C. No adjustment is required for Water-cooled units.

The efficiency shall then be adjusted for cyclic degradation using the procedures defined in 5.4.3.2.7.

5.4.3.4.4 *Step 4.* Once the adjusted efficiency for each of the 100%, 75%, 50% and 25% rating Percent Load rating points is determined using step 1, 2, or 3 as appropriate, then the IPLV.IP or NPLV.IP shall be calculated using Equations 22a or 22b.

5.4.4 *Determination of Part-load Performance within Application Rating Limits*. Part load points not meeting the requirements of IPLV.IP or NPLV.IP, but within the Application Rating Condition limits in Table 5, shall be calculated as follows:

5.4.4.1 For continuous capacity control chillers that can run at the application Percent Load within ±2% of the desired Percent Load determine the part-load energy efficiency at the application Percent Load and Condenser entering temperature.

5.4.4.2 If the chiller is expected to have capacity cycling at the Application Ratings Conditions, due to either compressor on/off staging or discrete step capacity control, then the rating method shall use logarithmic interpolation between two other non-cycling rating points, closest to the rating load listed in Table 6 with one point above and another point below the rating condition. The Condenser entering temperature shall be held constant at the desired part load rating point. Interpolation per Section 5.4.5 shall then be used to determine the efficiency at the Application Rating Conditions. Extrapolation shall not be used. For units operating in head pressure control, see Section 5.8.

5.4.4.3 If the application Percent Load is below the lowest capacity stage of the unit then a performance point shall be determined at the application part load Condenser entering temperature and lowest stage of Capacity and the efficiency adjusted for cyclic degradation using the procedure in Section 5.4.3.2.7.

5.4.4.4 If the unit can operate with head pressure control active during the test at the specified applicable Percent Load and Condenser entering temperature, causing cycling such that stable test conditions cannot be maintained, then Section 5.8 test procedure shall be followed.

5.4.5 *Interpolation of Efficiency Values.* Calculations shall use the following method (Equations 32 and 33) when interpolating between two efficiency values η_1 and η_2 at different load points to determine an intermediate efficiency value η_{int} at another load point.

Point 1: $(\%Load_1, \eta_1)$
Point 2: $(\%Load_2, \eta_2)$
Interpolated Point: $(\%Load_{int}, \eta_{int})$

$$\text{exponent} = \log_{10}(\eta_1) + (\%Load_{int} - \%Load_1) \cdot \frac{[\log_{10}(\eta_2) - \log_{10}(\eta_1)]}{(\%Load_2 - \%Load_1)} \quad 32$$

$$\eta_{int} = 10^{(\text{exponent})} \quad 33$$

5.5 *Publication of Ratings*. Wherever ratings are published or printed, they shall be consistent with the test method and procedures described in Sections 4 and 5 and ANSI/ASHRAE Standard 30, with consideration given to operating modes and sequence dependent (nondeterministic) control logic such as cycling of components.

5.6 *Fouling Factor Allowances*. When ratings are published, they shall include those with Fouling Factors as specified in Table 4 or within the ranges defined in Table 5.

5.6.1 *Method of Establishing Clean and Fouled Ratings.*

5.6.1.1 A series of tests shall be run in accordance with the method outlined in Section 4 and ANSI/ASHRAE Standard 30 to establish the performance of the unit.

5.6.1.2 Evaporator water-side and Condenser water-side or air-side heat transfer surfaces shall be considered clean during testing. Test conditions shall reflect Fouling Factors of zero (0.000) $h \cdot ft^2 \cdot °F/Btu$.

5.6.1.3 To determine the Capacity of the Water-chilling Package at the rated water-side fouling conditions, the procedure defined in Section 4.6 shall be used to determine an adjustment for the Evaporator and or Condenser water temperatures.

5.7 *Tolerances*.

5.7.1 *Tolerance Limit*. The tolerance limit for test results for net Capacity, full and part load Efficiency, and Water Pressure Drop shall be determined from Table 7. The tolerance limit (i.e. minimum or maximum acceptable value for Capacity, Efficiency, or Water Pressure Drop) shall be rounded to the number of Significant Figures in Table 8 prior to comparison with a test result rounded to the same number of Significant Figures.

The tolerance limits are intended to be used when testing a unit to verify and confirm performance. They take into consideration the following:

5.7.1.1 *Uncertainty of Measurement*. When testing a unit, there are variations that result from instrumentation accuracy and installation affects, as well as test facility stability.

5.7.1.2 *Uncertainty of Test Facilities*. The tested performance of the same unit tested in multiple facilities can vary due to setup variations.

5.7.1.3 *Uncertainty due to Manufacturing*. During the manufacturing of units, there are variations due to manufacturing production tolerances that can impact the performance from unit to unit.

5.7.1.4 *Uncertainty of Performance Prediction Models*. Due to the large complexity of options, manufacturers can use performance prediction models to determine ratings.

To comply with this standard, any test per Section 4.1 to verify published or reported values shall be in accordance with Table 7.

Table 7. Definition of Tolerances

		Limits	Related Tolerance Equations[2,3]
Capacity	Cooling or heating Capacity for units with continuous unloading[1]	Full Load minimum: 100%- Tol_1 Full Load maximum: 100%+ Tol_1	$Tol_1 = 0.105 - (0.07 \cdot \%Load) + \left(\frac{0.15}{\Delta T_{FL} \cdot \%Load}\right)$ 34 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)	
Efficiency	EER	Minimum of: (rated EER) / (100%+ Tol_1)	
	kW/ton_R	Maximum of: (100%+ Tol_1)·(rated kW/ton_R)	
	COP	Minimum of: (rated COP) / (100%+ Tol_1)	
	IPLV.IP NPLV.IP EER	Minimum of: (rated EER) / (100%+ Tol_2)	$Tol_2 = 0.065 + \left(\frac{0.35}{\Delta T_{FL}}\right)$ 35 See Figure 4 for graphical representation of the Tol_2 tolerance.
	IPLV.IP NPLV.IP kW/ton_R	Maximum of: (100%+ Tol_2)·(rated kW/ton_R)	
	IPLV.IP NPLV.IP COP_R	Minimum of: (rated COP_R) / (100%+ Tol_2)	
Water Pressure Drop		$\Delta p_{corrected} \leq Tol_3$	$Tol_3 = \max\begin{cases} 1.15 \cdot \Delta p_{rated} \\ \Delta p_{rated} + 2\ ft\ H_2O \end{cases}$ 36

Notes:
1. The target set point Condenser entering temperatures (Table 6) are determined at the target part load test point.
2. For air-cooled units and evaporatively-cooled units, all tolerances are computed for values after the atmospheric correction is taken into account.
3. %Load, Tol_1 and Tol_2 are in decimal form (e.g.100% Load = 1.0).

Figure 3 is a graphical representation of the related tolerance equation for Capacity and efficiency as noted in Table 7.

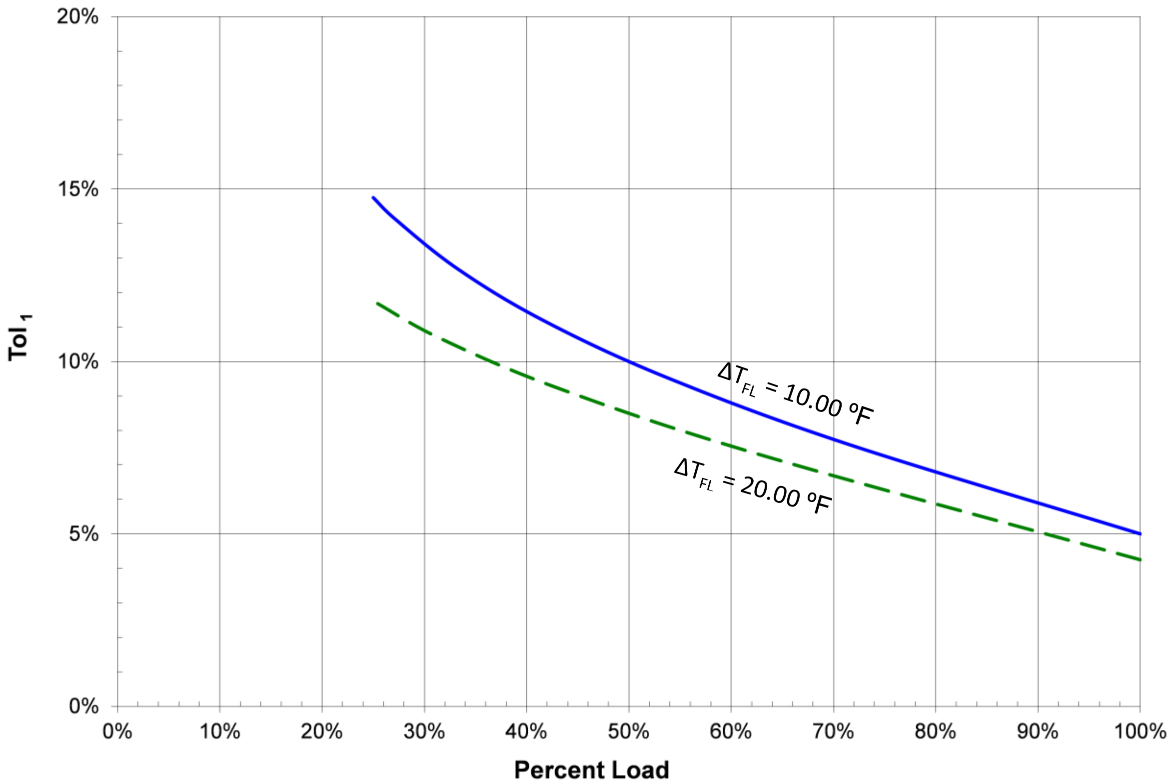

Figure 3. Allowable Tolerance (Tol_1) Curves for Full and Part-load Points

Figure 4 is a graphical representation of the related tolerance equation for IPLV.IP and NPLV.IP as noted in Table 7. The PLV line shown can represent either IPLV.IP or NPLV.IP depending on use.

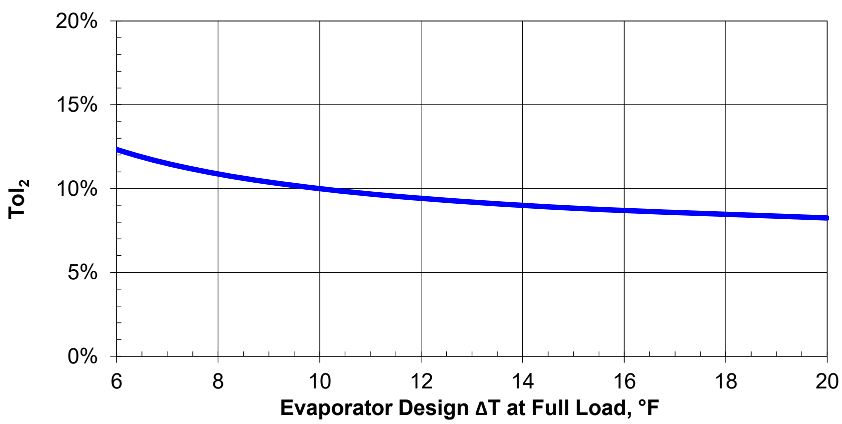

Figure 4. IPLV.IP and NPLV.IP Tolerance (Tol_2) Curve

5.7.2 *Allowable Operating Condition Tolerances.* Tests shall be conducted while maintaining the tolerance limits on operating conditions defined in Table 1. Measurement values and calculation results shall not deviate from published rating values more than the operating condition tolerance limits determined from Table 1.

5.8 *Head Pressure Control*. For units that have head pressure control to ensure proper flow of refrigerant through the expansion valve during low Condenser temperature conditions, the head pressure controls shall be enabled and operated in automatic control mode. The setting shall be set at the factory settings or as defined in the installation instruction.

If during part load testing the head pressure control is engaged by the control logic, then it shall be used to control the operation of the unit. If the unit can be run and stable conditions are obtained as required by Table 1, then a standard test shall be run. If the head pressure control results in cycling of the Condenser fans and unstable conditions as defined in Table 1, then the following modified test procedure defined in Section 5.8.1 shall be used.

5.8.1 *Head Pressure Control Time Average Test Procedure*. A series of two tests shall be run. Prior to the first test, the Condenser operating condition, as defined by Table 6, shall be approached from at least a 10.0 °F higher temperature until the entering air temperature is within the Operating Condition Tolerance Limits as defined by Table 1. When on conditions, the test shall be started and measurements shall be taken per the requirements in ANSI/ASHRAE Standard 30. During the test, the requirements of Table 1 for Condenser for cooling with fan cycling shall be satisfied. Note that ANSI/ASHRAE Standard 30 allows for longer test periods with longer time averages for measurements to permit meeting the test validity requirements in Table 1.

Following the first test completion, the Condenser condition shall be reduced at least 5.0 °F below the desired temperature. It shall then be gradually increased until the entering air temperature is within the Operating Condition Tolerance Limits as defined by Table 1. When on conditions, the second test shall be started and measurements shall be taken per the requirements in ANSI/ASHRAE Standard 30. During the test, the requirements of Table 1 for Condenser for cooling with fan cycling shall be satisfied. Note that ANSI/ASHRAE Standard 30 allows for longer test periods with longer time averages for measurements to permit meeting the test validity requirements in Table 1.

The test results for both tests shall then be averaged to determine the tested performance for the rating point.

5.9 *Refrigerant Tubing for Remote Condenser and Evaporator*. Refrigerant tubing lengths shall be expressed in equivalent lengths. Equivalent lengths shall be calculated per Chapter 1 of the ASHRAE Refrigeration Handbook. Standard Ratings shall be established with at least 25 ft length on each line of interconnecting refrigerant tubing. Refrigerant tubing shall be sized and insulated per the manufacturer's instructions. Application Ratings can be established at other tubing lengths.

Section 6. Minimum Data Requirements for Published Ratings

6.1 *Minimum Data Requirements for Published Ratings.* As a minimum, Published Ratings shall include either Standard Ratings or Application Ratings, per either Section 5.2 or 5.3. Rated Capacity $Q_{100\%}$, for chillers rated at Standard Rating Conditions is the net Capacity at full-load AHRI Standard Rating Conditions per Table 1. Rated Capacity $Q_{100\%}$, for chillers rated at Application Rating Conditions is the net Capacity at full-load AHRI Application Rating Conditions within the range permitted in Table 5.

All claims to ratings within the scope of this standard shall include the statement "Rated in accordance with AHRI Standard 550/590 (I-P)". All claims to ratings outside the scope of the standard shall include the statement "Outside the scope of AHRI Standard 550/590 (I-P)". Wherever Application Ratings are published or printed, they shall include a statement of the conditions at which the ratings apply.

6.2 *Published Ratings*. Published Ratings shall state all of the operating conditions used to establish the ratings and be rounded to the number of Significant Figures shown in Table 8, using the definitions, rounding rules and formats in Section 4.3.

Table 8. Published Values[1]

Published Values	Units	Significant Figures[2]	Water-Cooled Chiller (Cooling)	Water-Cooled Heat Recovery Chiller	Evaporatively Cooled Chiller	Air-Cooled Chiller	Condenserless Chiller	Air-Cooled HP (Cooling)	Air-Cooled HP (Heating)	Air Cooled Heat Recovery Chiller	Water to Water HP (Cooling)	Water to Water HP (Heating)	Simultaneous Heating and Cooling
General													
Voltage[3]	V, kV	3	■	■	■	■	■	■	■	■	■	■	■
Frequency	Hz	2	■	■	■	■	■	■	■	■	■	■	■
Refrigerant Designation in accordance with ANSI/ASHRAE Standard 34	-	-	■	■	■	■	■	■	■	■	■	■	■
Model Number	-	-	■	■	■	■	■	■	■	■	■	■	■
Operating Mode (Cooling, Heating, Simultaneous Heating and Cooling, or Heat Recovery)	-	-	■	■	■	■	■	■	■	■	■	■	■
Net Capacity													
Full Load Refrigerating Capacity[4]	ton_R, Btu/h	4	■	■	■	■	■	■		■	■	■	■
Heat Rejection or Heating Capacity	ton_R, MBtu/h	4	□	■			■		■	■	□	■	
Heat Recovery Capacity	ton_R, MBtu/h	4		■						■			
Efficiency													
Cooling EER	Btu/W·h	4											
Cooling COP_R	kW/kW, W/W	4	■	■	■	■	■	■		■	■	■	
Cooling kW/ton_R	kW/ton_R	4											
Heating COP_H	kW/kW	4							■			■	
Simultaneous Heating and Cooling COP_{SHC}	kW/kW, W/W	4											■
Heat Recovery COP_{HR}	kW/kW	4		■						■			
	Btu/W·h	4											
IPLV.IP or NPLV.IP[5]	kW/kW	4	■		■	■	■	■			■		
	kW/ton_R	4											
Power													
Total Input Power[6,7,8,9,10]	kW, W, MW	4	■	■	■	■	■	■	■	■	■	■	■
Condenser Spray Pump Power *[optional]*	kW, W, MW	Note 11			■								
Fan Power *[optional]*	kW, W, MW	Note 11			■	■		■	■	■			
Cooling Mode Evaporator													
Entering Water[12]	ºF	Note 13	■	■	■	■	■	■	■	■	■	■	■
Leaving Water[12]	ºF	Note 13	■	■	■	■	■	■	■	■	■	■	■
Entering Flow	Gpm	4	■	■	■	■	■	■	■	■	■	■	■
Water Pressure Drop	ft H_2O[14], psid	3	■	■	■	■	■	■	■	■	■	■	■
Fouling Factor	h·ft^2·ºF/Btu	3	■	■	■	■	■	■	■	■	■	■	■

Table 8. Published Values (continued)

Published Values	Units	Significant Figures[3]	Water-Cooled Chiller (Cooling)	Water-Cooled Heat Recovery Chiller	Evaporatively Cooled Chiller	Air-Cooled Chiller	Condenserless Chiller	Air-Cooled HP (Cooling)	Air-Cooled HP (Heating)	Air Cooled Heat Recovery Chiller	Water to Water HP (Cooling)	Water to Water HP (Heating)	Simultaneous Heating and Cooling
Cooling Mode Heat Rejection Exchanger													
Tower Condenser													
Entering Water[12]	°F	Note 13	■	■									
Leaving Water[12]	°F	Note 13	■	■									
Entering Flow	Gpm	4	■	■									
Water Pressure Drop	ft H_2O[14], psid	3	■	■									
Fouling Factor	h·ft^2·°F/Btu	3	■	■									
Heat Recovery Condenser													
Entering Water[12]	°F	Note 13		■						■			
Leaving Water[12]	°F	Note 13		■						■			
Entering Flow	Gpm	4		■						■			
Water Pressure Drop	ft H_2O[14], psid	3		■						■			
Fouling Factor	h·ft^2·°F/Btu	3		■						■			
Dry-bulb air	°F	Note 13								■			
Heat Rejection Condenser													
Entering Water[12]	°F	Note 13									■	■	■
Leaving Water[12]	°F	Note 13									■	■	■
Entering Flow	Gpm	4									■	■	■
Water Pressure Drop	ft H_2O[14], psid	3									■	■	■
Fouling Factor	h·ft^2·°F/Btu	3									■	■	■
Evaporatively Cooled													
Dry-bulb	°F	Note 13			■								
Wet-bulb	°F	Note 13			■								
Fouling Factor	h·ft^2·°F/Btu	3			■								
Altitude or Atmospheric Pressure[15]	ft, psia	Note 15			■								
Air Cooled													
Dry-bulb	°F	Note 13				■		■	■	■			
Wet-bulb	°F	Note 13							■				
Altitude or Atmospheric Pressure[15]	ft, psia	Note 13				■		■	■	■			
Without Condenser													
Compressor Saturated Discharge Temperature	°F	Note 13					■						
Liquid Temperature or Subcooling	°F	Note 13					■						
Integral Pumps													
Pump Power	W, kW, MW	4	□	□	□	□	□	□	□	□	□	□	□
Water Pressure Drop	ft H_2O[14], psid	3	■	■	■	■	■	■	■	■	■	■	■

Table 8. Published Values (continued)

Published Values	Units	Significant Figures[3]	Water-Cooled Chiller (Cooling)	Water-Cooled Heat Recovery Chiller	Evaporatively Cooled Chiller	Air-Cooled Chiller	Condenserless Chiller	Air-Cooled HP (Cooling)	Air-Cooled HP (Heating)	Air Cooled Heat Recovery Chiller	Water to Water HP (Cooling)	Water to Water HP (Heating)	Simultaneous Heating and Cooling
Remote Condenser or Evaporator													
Equivalent length of each line of interconnecting refrigerant tubing	ft	2	■	■	■	■	■	■	■	■	■	■	■

Notes:

1. Table key: ■ = required, □ = optional
2. Published Ratings and final reported test values shall be rounded to the number of Significant Figures shown in this table.
3. A single published rating can be used for dual nameplate voltage equipment (e.g. 208/230 or 208-230). Refer to AHRI Standard 110.
4. For electric-drive packages provided with starters, transformers, gearboxes, or variable speed drives, whether self-contained or remote-mounted (free-standing), the input power shall include the power losses due to those components. Full Load Refrigerating Capacity is the Full Load Net Refrigerating Capacity at the Rating Conditions and shall equal the 'A' point IPLV.IP or NPLV.IP capacity.
5. It is optional to publish NPLV when any cooling mode part-load condition results in an Evaporator LWT greater than the Condenser EWT, EDB, EWB, or SDT at the same rating condition. Refer to Section 5.4 for IPLV.IP or NPLV.IP rating requirements.
6. Exclude input power to integrated water pumps, when present.
7. When a motor or other non-electric drive is not included with the Water-chilling or Water-heating Package, assume a speed control method consistent with the chiller manufacturer installation requirements, and use the compressor shaft input power when determining the Total Input Power.
8. For non-electric drive packages, such as turbine or engine drive, the input power shall include the losses due to the prime mover and other driveline components such as a gearbox.
9. When the Water-chilling or Water-heating Package does not include some components, which are provided by another party independently from the chiller manufacturer, the input power and any losses associated with those components shall be determined as follows:
   a. For electric-drive packages rated for fixed-speed operation but not including a starter, use the compressor motor terminal input power when determining the Total Input Power.
   b. For electric-drive packages rated for variable-speed operation but not including a variable speed drive, assume a variable speed control method and variable speed drive type consistent with the chiller manufacturer installation requirements, and use the compressor motor terminal input power when determining the Total Input Power.
10. Components that utilize Auxiliary Power shall be listed.
11. When published, Auxiliary Power values shall be displayed with the same precision as the Total Input Power (same number of decimal places if using the same unit of measure).
12. An alternate to providing entering and leaving water temperatures is to provide one of these along with the temperature difference across the heat exchanger
13. Commonly used units of measure for temperature are not on an absolute scale; however, proper use of Significant Figures requires an absolute scale. For simplicity, this standard specifies the number of decimal places as follows:
    a. Water temperatures round to two decimal places.
    b. Refrigerant Temperatures (actual or saturated) round to one decimal place.
    c. Air temperatures round to one decimal place.
14. ft H_2O at 60 °F.
15. Altitude based on standard atmosphere; refer to Section 5.3.1 and Section 7 for conversion to atmospheric pressure. To provide adequate Significant Figures for conversion to atmospheric pressure, display altitude as an integer value. If rounding altitude, round to an increment not exceeding 10 ft. Atmospheric pressure shall be published with four significant digits.

Section 7. Units of Measure, Conversions and Water Properties

7.1 *Units of measure.* The British thermal unit (Btu) used in this standard is the International Table Btu defined as $1\ Btu_{IT} = 1055.055\ 852\ 62\ J$ (corresponding to $1\ calorie = 4.1868\ J$). Throughout this standard, all instances of Btu without the 'IT' subscript shall use this definition.

7.2 *Conversions.* For units that require conversion the following factors in Table 9 shall be utilized:

Table 9. Conversion Factors[1]

To Convert From	Multiply By	To	Factor Name
1 ft H_2O (at 60 ºF)	0.43310	psi	K1
inch Hg (at 32 ºF)	0.49115	psia	K2
kilowatt (kW)	3,412.14	Btu/h	K3
watt (W)	3.41214	Btu/h	K4
ton of refrigeration (ton_R)	12,000	Btu/h	K5
ton of refrigeration (ton_R)	3.51685	kilowatt (kW)	K6
kilowatt (kW)	1,000	watt (W)	K7
MBtu/h	1,000,000	Btu/h	K8
$\frac{lb_f}{in^2} \cdot \frac{ft^3}{lb_m}$	0.18505	$\frac{Btu}{lb_m}$	K9
cubic feet per hour $\left(\frac{ft^3}{h}\right)$	0.124675	gallon per minute (gpm)	K10

Note:
1. For Water Pressure Drop, the conversion from water column "ft H_2O" to "psi" is per ASHRAE Fundamentals Handbook. Note that 60ºF is used as the reference temperature for the density of water in the manometer.

7.3 *Water Side Properties Calculation Methods*. One of the following calculation methods shall be utilized. In both cases, the value of the water temperature or pressure to be used as input is dependent on the context of the calculation using the density and specific heat terms. This standard shall be used where discrepancies exist between these methods and those prescribed by ANSI/ASHRAE Standard 30.

Method 1. Use NIST REFPROP software (version 10.0 or later) to calculate physical properties density and specific heat, as a function of both pressure and temperature.

Method 2. Use polynomial Equations 37 and 38 respectively to calculate density and specific heat of water as a function of temperature only.

$$\rho = (\rho_4 \cdot T^4) + (\rho_3 \cdot T^3) + (\rho_2 \cdot T^2) + (\rho_1 \cdot T) + \rho_0 \qquad 37$$

Where:

$\rho_0 = 62.227\ lb_m / ft^3$
$\rho_1 = 1.2164 \cdot 10^{-2}\ lb_m / ft^3$
$\rho_2 = -1.8846 \cdot 10^{-4}\ lb_m / ft^3$
$\rho_3 = 5.2643 \cdot 10^{-7}\ lb_m / ft^3$
$\rho_4 = -7.4704 \cdot 10^{-10}\ lb_m / ft^3$
T = Water temperature (32 to 212) °F

$$c_p = \left(c_{p5} \cdot T^5\right) + \left(c_{p4} \cdot T^4\right) + \left(c_{p3} \cdot T^3\right) + \left(c_{p2} \cdot T^2\right) + \left(c_{p1} \cdot T\right) + c_{p0} \quad 38$$

Where:

$C_{p0} = 1.0295$ Btu / $lb_m \cdot$ °F
$C_{p1} = -1.0677 \cdot 10^{-3}$ Btu / $lb_m \cdot$ °F
$C_{p2} = 1.4071 \cdot 10^{-5}$ Btu / $lb_m \cdot$ °F
$C_{p3} = -9.2501 \cdot 10^{-8}$ Btu / $lb_m \cdot$ °F
$C_{p4} = 3.1031 \cdot 10^{-10}$ Btu / $lb_m \cdot$ °F
$C_{p5} = -4.0739 \cdot 10^{-13}$ Btu / $lb_m \cdot$ °F
T = Water temperature (32 to 212) °F

Note*:* Density and specific heat polynomial equations are curve fit from data generated by NIST REFPROP v10.0 (see Normative Appendix A) at 100 psia and using a temperature range of 32ºF to 212ºF. The 100 psia value used for the water property curve fits was established as a representative value to allow for the calculation of water side properties as a function of temperature only. This eliminates the complexity of measuring and calculating water side properties as a function of both temperature and pressure. This assumption, in conjunction with a formulation for Capacity that does not make explicit use of enthalpy values, provides a mechanism for computing heat exchanger Capacity for fluids other than pure water where specific heat data are generally known but enthalpy curves are not available.

7.4 *Converting Altitude to Atmospheric Pressure*. Use Equation 39 to convert between altitude and atmospheric pressure. The relationship is based on the International Standard Atmosphere (ISA) and represents a mean value of typical weather variations. The ISA is defined by ICAO Document 7488/3. The slight difference between geometric altitude (Z_H) and geopotential altitude (H) is ignored for the purposes of this standard ($Z_H \cong H$).

$$p_{atm} = p_0 \cdot \left[\frac{T_0}{T_0 + \beta 1 \cdot (Z_H - Z_{H0})}\right]^{\left(\frac{g_0}{\beta 2} \cdot \frac{M_0}{R*}\right)} \quad 39$$

Where:
$\beta 1 = -0.00198\ K/ft$
$\beta 2 = -0.0065\ K/m$
$Z_{H0} = 0 ft$
$g_0 = 9.80665\ m/s^2$
$M_0 = 28.96442\ kg/kmol$
$R* = 8314.32\ J/(K \cdot kmol)$
$p_0 = 14.696\ psia$
$T_0 = 288.15\ K$

Section 8. Symbols and Subscripts

8.1 *Symbols and Subscripts*. The symbols and subscripts used are listed in Table 10:

Table 10. Symbols and Subscripts

Symbol	Description	Unit Name	Unit Symbol
A	Efficiency at 100% load. COP, EER, or kW/ton$_R$ depending on use.		varies
A_w	Heat transfer surface area used in Fouling Factor adjustment calculations (water-side), as used in Appendix C.	square foot	ft^2
A_Q	Correction factor, Capacity, polynomial equation coefficient	dimensionless	-
A_η	Correction factor, efficiency, polynomial equation coefficient	dimensionless	-
B	Efficiency at 75% load. COP, EER, or kW/Ton depending on use.		varies
B_Q	Correction factor, Capacity, polynomial equation coefficient	dimensionless	-
B_η	Correction factor, efficiency, polynomial equation coefficient	dimensionless	-
C	Efficiency at 50% load. COP, EER, or kW/Ton depending on use.		varies
C_D	Degradation factor	dimensionless	-
CF_Q	Atmospheric correction factor for Capacity	dimensionless	-
CF_η	Atmospheric correction factor for efficiency	dimensionless	-
COP_H	Efficiency, coefficient of performance, heating	dimensionless	-
COP_{HR}	Efficiency, coefficient of performance, heat recovery	dimensionless	-
COP_R	Efficiency, coefficient of performance, cooling	dimensionless	-
$COP_{R,CD}$	Efficiency, coefficient of performance, cooling, corrected with degradation factor	dimensionless	-
COP_{SHC}	Efficiency, coefficient of performance, simultaneous cooling & heating	dimensionless	-
c_p	Specific heat at constant pressure	British thermal unit (IT) per pound degree Fahrenheit	Btu/(lb·°F)
C_Q	Correction factor, Capacity, polynomial equation coefficient	dimensionless	-
C_η	Correction factor, efficiency, polynomial equation coefficient	dimensionless	-
CWH	Cooling water hours	degree Fahrenheit hour	°F·h
D	Efficiency at 25% load. COP, EER, or kW/Ton depending on use.		varies
DBH	Dry bulb hours	degree Fahrenheit hour	°F·h
D_Q	Correction factor, Capacity, equation term	dimensionless	-
D_η	Correction factor, efficiency, equation term	dimensionless	-
EDB	Entering Dry Bulb Temperature	degree Fahrenheit	°F
EER	Efficiency, Energy Efficiency Ratio	Btu per watt hour	Btu/(W·h)

Table 10. Symbols and Subscripts

Symbol	Description	Unit Name	Unit Symbol
EER_{CD}	Efficiency, Energy Efficiency Ratio, corrected with degradation factor	Btu per watt hour	Btu/(W·h)
EER_{Test}	Efficiency, Energy Efficiency Ratio, test value	Btu per watt hour	Btu/(W·h)
EWB	Entering wet bulb temperature	degree Fahrenheit	°F
EWT	Entering Water Temperature	degree Fahrenheit	°F
ECWT	Entering Condenser water temperature	degree Fahrenheit	°F
g, g_0	Standard gravitational term	foot per second squared	ft/s^2
H	Geopotential altitude (see section 7.3)	foot	ft
IPLV	Efficiency, Integrated Part Load Value. kW/Ton, COP, or EER		varies
IPLV.IP	Efficiency, Integrated Part Load Value when calculated and reported in accordance with AHRI Standard 550/590 (I-P) in IP units. COP, EER, or kW/Ton	Btu per watt hour, kilowatt per kilowatt, or kilowatt per ton of refrigeration	Btu/(W·h), kW/kW or kW/ton_R
K1 – K10	Refer to Table 9		varies
kW/ton_R	Efficiency, Power Input per Capacity	kilowatt per ton of refrigeration	kW/ton_R
$\left(\frac{kW}{ton_R}\right)_{CD}$	Efficiency, Power Input per Capacity, corrected with degradation factor	kilowatt per ton of refrigeration	kW/ton_R
$\left(\frac{kW}{ton_R}\right)_{Test}$	Efficiency, Power Input per Capacity, test value	kilowatt per ton of refrigeration	kW/ton_R
LF	Load factor	dimensionless	-
%Load	The ratio of the part-load rated net Capacity, stated in decimal format (e.g.100% = 1.0)	dimensionless	-
$\%Load_1, \%Load_2$	%Load used to interpolate, stated in decimal format (e.g.100% = 1.0)	dimensionless	-
LWT	Leaving Water Temperature	degree Fahrenheit	°F
m_w	Mass flow rate, water	pound (avoirdupois) per hour	lb/h
M_0	Constant used in Equation 39	kilogram per kilomole	kg/kmol
$\bar{n}$	Mean rotational speed (compressor), calculated from data samples	revolution per minute	RPM
n_{target}	Target test rotational speed (compressor)	revolution per minute	RPM

Table 10. Symbols and Subscripts

Symbol	Description	Unit Name	Unit Symbol
NPLV	Efficiency, Non-standard Part Load Value. kW/Ton, COP, or EER depending on use.		varies
$NPLV.IP$	Efficiency, Non-standard Part Load Value when calculated and reported in accordance with AHRI Standard 550/590 (I-P) in IP units. kW/Ton, COP, or EER depending on use.	Btu per watt hour, kilowatt per kilowatt, or kilowatt per ton of refrigeration	Btu/(W·h), kW/kW or kW/ton$_R$
OA	Outside air		-
p	Pressure	pound-force per square inch	psia
$\bar{p}$	Mean pressure, calculated from data samples	pound-force per square inch	psia
p_{atm}	Atmospheric pressure	pound-force per square inch	psia
p_0	Standard atmospheric pressure	pound-force per square inch	psia
p_{rating}	Rated Atmospheric pressure at design condition	pound-force per square inch	psia
p_{test}	Atmospheric pressure measured during testing	pound-force per square inch	psia
Q	Capacity (heat flow rate); net Capacity	Btu per hour	Btu/h
Q_{cd}	Net Capacity, Condenser (heating)	Btu per hour	Btu/h
Q_{ev}	Net Capacity, Evaporator (cooling)	Btu per hour	Btu/h
Q_{hrc}	Net Capacity, Condenser (heat recovery)	Btu per hour	Btu/h
Q_i	Heat transfer rate for each heat exchanger	Btu per hour	Btu/h
Q_{test}	Test results for net Capacity, uncorrected for atmospheric pressure	Btu per hour	Btu/h
$Q_{corrected,standard}$	Test results for net Capacity, corrected to standard atmospheric pressure	Btu per hour	Btu/h
$Q_{corrected,application}$	Test results for net Capacity, corrected to application rating atmospheric pressure	Btu per hour	Btu/h

Table 10. Symbols and Subscripts

Symbol	Description	Unit Name	Unit Symbol
$Q_{100\%}$	Test results for unit net Capacity at 100% load point	Btu per hour	Btu/h
$Q_{min\%Load}$	The measured or calculated unit net Capacity at the minimum step of Capacity including atmospheric pressure corrections as applicable	Btu per hour	Btu/h
Q_{target}	Target test part-load net Capacity	Btu per hour	Btu/h
$\overline{Q}$	Mean net Capacity, calculated from data samples	Btu per hour	Btu/h
R*	Constant used in Equation 39	Joules per Kelvin kilomole	J/(K·kmol)
R_{foul}	Fouling Factor Allowance	hour-foot squared-degree Fahrenheit per Btu	h·ft2·°F/Btu
SDT	Saturated Discharge Temperature	degree Fahrenheit	°F
s_n	Standard deviation of governor speed		varies
s_p	Standard deviation of turbine pressure		varies
s_T	Standard deviation of temperature measurement samples		varies
s_V	Standard deviation of voltage		varies
s_ω	Standard deviation of frequency		varies
s_{vw}	Standard deviation of volumetric water flow measurement samples		varies
T	Temperature	degree Fahrenheit	°F
$\overline{T}$	Mean temperature, calculated from data samples	degree Fahrenheit	°F
T_{in}	Entering water temperature	degree Fahrenheit	°F
$T_{in,w}$	Temperature, water entering	degree Fahrenheit	°F
Tol_1	Tolerance 1, performance tolerance limit	dimensionless	-
Tol_2	Tolerance 2, IPLV and NPLV performance tolerance limit	dimensionless	-
Tol_3	Tolerance 3, Tolerance on water side pressure drop	foot of water	ft H_2O (at 60 °F)

Table 10. Symbols and Subscripts

Symbol	Description	Unit Name	Unit Symbol
T_{out}	Leaving water temperature	degree Fahrenheit	°F
$T_{out,w}$	Temperature, water leaving	degree Fahrenheit	°F
$T_{sat,r}$	Temperature, saturated refrigerant	degree Fahrenheit	°F
T_{target}	Target test temperature	degree Fahrenheit	°F
T_0	Conversion from degree Celcius to Kelvin	Kelvin	K
$T_{100\%}$	Selected 100% Load temperature	degree Fahrenheit	°F
V_w	Volumetric flow rate	gallon per minute	gpm
$\overline{V}_w$	Mean volumetric flow rate calculated from data samples	gallon per minute	gpm
$V_{w,target}$	Target test volumetric flow rate	gallon per minute	gpm
$\overline{V}$	Mean Voltage calculated from data samples	volt	V
V	Voltage	volt	V
V_{target}	Target test Voltage	volt	V
W_{input}	Power, Total Input Power	kilowatt	kW
Z	Equation term (as used in Equation 5)	dimensionless	-
Z_H, Z_{H0}	Geometric altitude	foot	ft
$\Delta p_{corrected}$	Pressure differential corrected for adjustment through equation found in ASHRAE 30	pound force per square inch, or foot of water	psid or ft H_2O
Δp_{rated}	Pressure differential at rated water temperatures (inlet to outlet)	pound force per square inch, or foot of water	psid or ft H_2O (at 60 °F)
ΔT_{adj}	Temperature differential, additional temperature differential due to fouling	degree Fahrenheit	°F
$\Delta T_{adj,i}$	Computed temperature adjustment for each heat exchanger	degree Fahrenheit	°F
$\Delta T_{adj,weighted}$	Weighted temperature adjustment	degree Fahrenheit	°F

Table 10. Symbols and Subscripts

Symbol	Description	Unit Name	Unit Symbol
ΔT_{FL}	Temperature differential, at rated Full Load design conditions	degree Fahrenheit	°F
ΔT_{ILMTD}	Incremental log mean temperature difference	degree Fahrenheit	°F
ΔT_{LMTD}	Log mean temperature difference	degree Fahrenheit	°F
ΔT_{range}	Temperature differential when referenced to entering and leaving heat exchanger fluid temperatures	degree Fahrenheit	°F
$\Delta T_{small,clean}$	Small temperature difference as tested in clean condition	degree Fahrenheit	°F
$\Delta T_{small,sp}$	Small temperature difference as specified	degree Fahrenheit	°F
$\beta 1, \beta 2$	Constants used in Equation 39	Kelvin per foot or Kelvin per meter	K/ft or K/m
η_1, η_2	Efficiency values used to interpolate (EER or kW/ton)	Btu per watt hour or kilowatt per ton of refrigeration	Btu/(W·h) or kW/ton_R
η_{int}	Interpolated efficiency (EER or kW/ton)	Btu per watt hour or kilowatt per ton of refrigeration	Btu/(W·h) or kW/ton_R
η_{test}	Test results for Efficiency (EER or kW/ton)), uncorrected for atmospheric pressure.	Btu per watt hour or kilowatt per ton of refrigeration	Btu/(W·h) or kW/ton_R
$\eta_{test,100\%}$	Efficiency (EER or kW/ton)) measured in Full Load test, for atmospheric pressure correction.	Btu per watt hour or kilowatt per ton of refrigeration	Btu/(W·h) or kW/ton_R
$\eta_{corrected,standard}$	Test results for Efficiency (EER or kW/ton), corrected to standard atmospheric pressure	Btu per watt hour or kilowatt per ton of refrigeration	Btu/(W·h) or kW/ton_R
$\eta_{corrected,application}$	Test results for Efficiency (EER or kW/ton), corrected to standard atmospheric pressure	Btu per watt hour or kilowatt per ton of refrigeration	Btu/(W·h) or kW/ton_R
ρ	Density	pound (avoirdupois) per cubic foot	lb/ft3

Table 10. Symbols and Subscripts			
Symbol	Description	Unit Name	Unit Symbol
ρ_{in}	Density of water entering the heat exchanger	pound (avoirdupois) per cubic foot	lb/ft3
ω	Frequency (electrical)	Hertz	Hz
ω_{target}	Target test Frequency (electrical)	Hertz	Hz
$\overline{\omega}$	Mean frequency (electrical), calculated from data samples	Hertz	Hz

Section 9. Marking and Nameplate Data

9.1 *Marking and Nameplate Data*. As a minimum, the nameplate shall display the following:

9.1.1 Manufacturer's name and location
9.1.2 Model number designation providing performance-essential identification
9.1.3 Refrigerant designation (in accordance with ANSI/ASHRAE Standard 34)
9.1.4 Voltage, phase and frequency
9.1.5 Serial number

9.2 *Nameplate Voltage*. Where applicable, nameplate voltages for 60 Hertz systems shall include one or more of the equipment nameplate voltage ratings shown in Table 1 of AHRI Standard 110. Where applicable, nameplate voltages for 50 Hertz systems shall include one or more of the utilization voltages shown in Table 1 of IEC Standard 60038.

Section 10. Conformance Conditions

10.1 *Conformance.* While conformance with this standard is voluntary, conformance shall not be claimed or implied for products or equipment within the standard's *Purpose* (Section 1) and *Scope* (Section 2) unless such product claims meet all of the requirements of the standard and all of the testing and rating requirements are measured and reported in complete compliance with the standard. Any product that has not met all the requirements of the standard cannot reference, state, or acknowledge the standard in any written, oral, or electronic communication.

Section 11. Operating Requirements

11.1 *Operating Requirements***.** Chillers with air-cooled Condensers and published operability at an entering air dry-bulb temperature of 125.6 °F shall comply with provisions of this section.

11.1.1 *High Temperature Operating Requirements*.

11.1.1.1 *High Temperature Condition*. The chiller shall be capable of an Application Rating at entering air dry-bulb temperature of 125.6 °F.

11.1.1.2 *Operability at High Temperature Condition*. The chiller shall be capable of the following when operating at the above condition and following test requirements of Section 4.1. When all power to the equipment is momentarily interrupted for a period sufficient to cause the compressor to stop (loss of power not to exceed 5 seconds), and power is then restored, the unit shall be capable to resume continuous operation within one hour of restoration of power, and shall be capable to operate continuously without interruption for one hour thereafter. Operation and resetting of safety devices after power loss but prior to establishment of continuous operation can be used to meet this operability requirement. For information only, average cooling Capacity and input power are reported if conducting a test to demonstrate this capability.

APPENDIX A. REFERENCES – NORMATIVE

A1 Listed here are all standards, handbooks and other publications essential to the formation and implementation of the standards. All references in this appendix are considered as part of the standard.

A1.1 AHRI Standard 110-2016, *Air-Conditioning, Heating and Refrigerating Equipment Nameplate Voltages*, 2016, Air-Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.2 AHRI Standard 551/591 (SI)-2023, *Performance Rating of Water-Chilling and Heat Pump Water-Heating Packages Using the Vapor Compression Cycle*, 2018, Air-Conditioning, Heating and Refrigeration Institute, 2311 Wilson Boulevard, Suite 400, Arlington, VA 22201, U.S.A.

A1.3 ANSI/AHRI/ASHRAE/ISO Standard 13256-2:1998 (RA 2012), *Water-to-Water and Brine-to-Water Heat Pumps – Testing and Rating for Performance*, 1998, ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./ 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A..

A1.4 ANSI/ASHRAE Standard 30-2019, *Method of Testing Liquid Chillers,* 2019, ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./ 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

A1.5 ANSI/ASHRAE Standard 34-2019 with Addenda, *Number Designation and Safety Classification of Refrigerants,* 2016, ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./ 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

A1.6 ANSI/ASHRAE Standard 41.1-2013, *Measurements Guide - Section on Temperature Measurements*, 2013, ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./ 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

A1.7 ASHRAE *Fundamentals Handbook*, 2021, ASHRAE, 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

A1.8 ASHRAE *Refrigeration Handbook*, 2018, ASHRAE, 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

A1.9 ASHRAE Terminology. ASHRAE. Accessed June 27, 2022. https://www.ashrae.org/technicalresources/free-resources/ashrae-terminology.

A1.10 ICAO Document 7488/3-1993, *Manual of the ICAO Standard Atmosphere, Third Edition.* 1993, International Civil Aviation Organization, 999 Robert-Bourassa Boulevard, Montréal, Quebec H3C 5H7, Canada. http://aviadocs.net/icaodocs/Docs/ICAO_Doc7488.pdf.

A1.11 IEC Standard 60038-2009, *IEC Standard Voltages*, 2009, International Electrotechnical Commission, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland.

A1.12 NIST. Lemmon, E.W., Huber, M.L., McLinden, M.O. NIST Standard Reference Database 23: Reference Fluid Thermodynamic and Transport Properties-REFPROP, Version 10.0, National Institute of Standards and Technology, Standard Reference Data Program, Gaithersburg.

APPENDIX B. REFERENCES – INFORMATIVE

B1 Listed here are standards, handbooks and other publications which may provide useful information and background but are not considered essential. References in this appendix are not considered part of the standard.

B1.1 ANSI/ASHRAE Standard 140-2020, *Method of Test for Evaluating Building Performance Simulation Software*, 2020, ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./ 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

B1.2 ANSI/ASHRAE Standard 90.1 (I-P)-1989, *Energy Standard for Buildings Except for Low-Rise Residential Buildings,* 1989*,* ASHRAE, 180 Technology Parkway NW, Peachtree Corners, GA 30092, U.S.A.

B1.3 *Commercial Buildings Characteristics 1992;* April 1994, DOE/EIA-0246(92).

APPENDIX C. ATMOSPHERIC PRESSURE ADJUSTMENT – NORMATIVE

C1 *Purpose.* This appendix prescribes a method of adjusting measured test data according to the local atmospheric pressure.

C2 *Background.* In order to ensure that performance can be uniformly compared from one unit to another and from one manufacturer to another, performance testing for air-cooled and evaporatively-cooled chillers shall be corrected for air density variations. To accomplish this, use the following two (2) correction factors (CF_Q, $CF\eta$) to correct test data at test load points back to standard atmospheric pressure at sea level, for Standard Rating Conditions, or to correct to another atmospheric pressure corresponding to a site altitude for Application Rating Conditions. These correction factors use an empirical method of correction based on industry average values across a wide variety of chillers. The correction factors are based on pressure rather than altitude, in order to include the effects of weather variations. Test data shall be corrected from actual tested atmospheric pressure to rated atmospheric pressure for comparison to Published Ratings. The correction multiplier for efficiency and Capacity at the 0% load point shall be 1.0. Intermediate correction multipliers at part-load points shall be calculated at each part-load point where the % load value is based on the measured Capacity at that load point divided by the 100% load point measured Capacity.

Note: These factors are not intended to serve as selection code correction factors. For selection codes component models that properly adjust for variation in atmospheric pressure as related to fan, heat exchanger and compressor power and Capacity should be used.

The correction factors (CF_Q, $CF\eta$) shall be limited to a value corresponding to an atmospheric pressure of 11.56 psia (approximately 6500 feet altitude). Correction factors for measured atmospheric pressure readings below the minimum shall be equal to the value determined at 11.56 psia.

C3 *Procedure for Correcting Test Data to Standard Rating Condition Atmospheric Pressure.* Air-cooled and evaporatively-cooled chillers are tested at the local conditions. The data is then corrected to sea level and standard pressure, using Equations C1, C2, C3, C4, C5, and C6, by multiplying the measured data by the appropriate correction factor (CF). Both factors are in the form of a second order polynomial equations:

$$D_Q = A_Q \cdot p^2 + B_Q \cdot p + C_Q \tag{C1}$$

$$D_h = A_\eta \cdot p^2 + B_\eta \cdot p + C_\eta \tag{C2}$$

$$\left(CF_Q\right)_{P=P_{test}} = 1 + \left(\frac{Q_{\%Load}}{Q_{100\%}}\right) \cdot \left(D_Q - 1\right) \cdot exp\left\{-0.35 \cdot \left[\left(D_\eta \cdot \eta_{test,100\%}\right) - 9.6\right]\right\} \tag{C3}$$

$$\left(CF_\eta\right)_{P=P_{test}} = 1 + \left(\frac{Q_{\%Load}}{Q_{100\%}}\right) \cdot \left(D_\eta - 1\right) \cdot exp\left\{-0.35 \cdot \left[\left(D_\eta \cdot \eta_{test,100\%}\right) - 9.6\right]\right\} \tag{C4}$$

$$Q_{corrected,standard} = Q_{test}\left(CF_Q\right)_{P=P_{test}} \tag{C5}$$

$$\eta_{corrected,standard} = \eta_{test}\left(CF_\eta\right)_{P=P_{test}} \tag{C6}$$

If efficiency η is expressed in kW/ton_R first convert the kW/ton to EER and then after calculating $Q_{corrected,standard}$ and $\eta_{corrected,standard}$, convert $\eta_{corrected,standard}$ back to kW/ton_R.

Where $Q_{100\%}$ and $\eta_{test,100\%}$ are test results at Full Load rating point for Standard Rating Conditions, or Full Load ratings for Application Rating Conditions.

Table C1. Correction Factor (CF) Coefficients

	Capacity D_Q			Efficiency D_h		
Units of Measure for P	A_Q	B_Q	C_Q	A_η	B_η	C_η
IP (psia)	1.1273E-03	-4.1272E-02	1.36304E+00	2.4308E-03	-9.0075E-02	1.79872E+00
Note: E indicates scientific notation, example: 1E-02 = 0.01						

C**4** *Procedure for Correcting Test Data to Application Rating Condition Atmospheric Pressure.* First use the method in Section 7 to correct from tested atmospheric pressure to standard sea level atmospheric pressure. Then reverse the method to correct to the application rated atmospheric pressure P_{rated} (Equations C7 and C8).

$$Q_{corrected,application} = \frac{Q_{corrected,standard}}{(CF_Q)_{P=P_{rating}}} \quad \text{C7}$$

$$\eta_{corrected,application} = \frac{\eta_{corrected,standard}}{(CF_\eta)_{P=P_{rating}}} \quad \text{C8}$$

APPENDIX D. DERIVATION OF INTEGRATED PART-LOAD VALUE (IPLV.IP) – INFORMATIVE

D1 *Purpose.* This appendix is an informative appendix that has been included in the standard to document the derivation of the Integrated Part-Load Value (IPLV.IP) weighting factors and temperatures.

D2 *Background*. Prior to the publication of ANSI/ASHRAE Standard 90.1-1989 which included an AHRI proposal for IPLV.IP, the Standard Rating Condition, design efficiency (full-load/design ambient), was the only widely accepted metric used to compare relative chiller efficiencies. A single chiller's design rating condition represents the performance at the simultaneous occurrence of both full-load and design ambient conditions which typically are the ASHRAE 1% weather conditions. The design efficiency contains no information representative of the chiller's operating efficiency at any off-design condition (part-load, reduced ambient).

The IPLV.IP metric was developed to create a numerical rating of a single chiller as simulated by 4 distinct operating conditions, established by taking into account blended climate data to incorporate various load and ambient operating conditions. The intent was to create a metric of part-load/reduced ambient efficiency that, in addition to the design rating, can provide a useful means for regulatory bodies to specify minimum chiller efficiency levels and for engineering firms to compare chillers of like technology. The IPLV.IP value was not intended to be used to predict the annualized energy consumption of a chiller in any specific application or operating conditions.

There are many issues to consider when estimating the efficiency of chillers in actual use. Neither IPLV.IP nor design rating metrics on their own can predict a building's energy use. Additionally, chiller efficiency is only a single component of many which contribute to the total energy consumption of a chiller plant. It is for this reason that building energy analysis programs, compliant with ANSI/ASHRAE Standard 140, that are capable of modeling not only the building construction and weather data but also reflect how the building and chiller plant operate should be used. In this way the building designer and operator can better understand the contributions that the chiller and other chiller plant components make to the total chiller plant energy use. Modeling software can also be a useful tool for evaluating different operating sequences for the purpose of obtaining the lowest possible energy usage of the entire chiller plant. To use these tools, a complete operating model of the chiller, over the intended load and operating conditions, should be used.

In summary, it is best to use a comprehensive analysis that reflects the actual weather data, building load characteristics, operational hours, economizer capabilities and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the chiller and system efficiency. The IPLV.IP (NPLV.IP) rating is used to compare the performance of similar technologies, enabling a side-by-side relative comparison, and to provide a second certifiable rating point that can be referenced by energy codes. A single metric, such as design efficiency or IPLV.IP should not be used to quantify energy savings.

D3 *Equation and Definition of Terms*.

D3.1 The energy efficiency of a chiller is commonly expressed in one of the three following ratios: Coefficient of Performance (COP_R), Energy Efficiency Ratio (EER) for cooling only and Total Input Power per Capacity (kW/ton_R).

These three alternative ratios are related as follows:

$COP_R = 0.293071\ EER$,	$EER = 3.41214\ COP_R$
$kW/ton_R = 12/EER$,	$EER = 12/(kW/ton_R)$
$kW/ton_R = 3.51685/COP_R$	$COP_R = 3.51685/(kW/ton_R)$

Equation D1 is used when an efficiency is expressed as EER [Btu/(W·h)] or COP_R [W/W]:

$$IPLV.IP = 0.01A + 0.42B + 0.45C + 0.12D \quad \text{D1}$$

Where, at operating conditions per Tables D-1 and D-3:

A = EER or COP_R at 100% Capacity
B = EER or COP_R at 75% Capacity
C = EER or COP_R at 50% Capacity

D = EER or COP_R at 25% Capacity

Equation D2 is used when the efficiency is expressed in Total Input Power per Capacity, kW/ton_R:

$$\text{IPLV.IP} = \frac{1}{\frac{0.01}{A}+\frac{0.42}{B}+\frac{0.45}{C}+\frac{0.12}{D}} \quad \text{D2}$$

Where, at operating conditions per Tables D-1 and D-3:

A = kW/ton_R at 100% Capacity
B = kW/ton_R at 75% Capacity
C = kW/ton_R at 50% Capacity
D = kW/ton_R at 25% Capacity

The IPLV.IP or NPLV.IP rating requires that the unit efficiency be determined at 100%, 75%, 50% and 25% at the conditions as specified in Table 6. If the unit, due to its capacity control logic cannot be operated at 75%, 50%, or 25% Capacity then the unit can be operated at other load points and the 75%, 50%, or 25% capacity efficiencies should be determined by plotting the efficiency versus the % load using straight line segments to connect the actual performance points. The 75%, 50%, or 25% load efficiencies can then be determined from the curve. Extrapolation of data is not used. An actual chiller capacity point equal to or less than the required rating point is used to plot the data. For example, if the minimum actual Capacity is 33% then the curve can be used to determine the 50% capacity point, but not the 25% capacity point.

If a unit cannot be unloaded to the 25%, 50%, or 75% capacity point, then the unit should be run at the minimum step of unloading at the Condenser entering water or air temperature based on Table D3 for the 25%, 50% or 75% capacity points as required. The efficiency is determined by using Equation D3:

$$EER_{CD} = \frac{\text{EER}_{\text{Test}}}{\text{C}_{\text{D}}} \quad \text{D3}$$

Where C_D is a degradation factor to account for cycling of the compressor for capacities less than the minimum step of Capacity. C_D should be calculated using Equation D4:

$$\text{C}_{\text{D}} = (-0.13 \cdot \text{LF}) + 1.13 \quad \text{D4}$$

The load factor LF should be calculated using Equation D5:

$$\text{LF} = \frac{\%\text{Load}\cdot(\text{Full Load unit capacity})}{(\text{Part}-\text{Load unit Capacity})} \quad \text{D5}$$

Where:

%Load is the standard rating point i.e. 75%, 50% and 25%.

Part-Load unit Capacity is the measured or calculated unit Capacity from which standard rating points are determined using the method above.

D3.2 *Equation Constants.* The constants 0.01, 0.42, 0.45 and 0.12 (refer to Equations D1 and D2) are based on the weighted average of the most common building types, and operating hours, using average USA weather data. To reduce the number of data points, the ASHRAE based bin data was reduced to a design bin and three bin groupings as illustrated in Figure D1.

D3.3 *Equation Derivation.* The ASHRAE Temperature Bin Method was used to create four separate IPLV.IP or NPLV.IP formulas to represent the following building operation categories:

Group 1 - 24 hrs/day, 7 days/wk, 0°F and above
Group 2 - 24 hrs/day, 7 days/wk, 55°F and above
Group 3 - 12 hrs/day, 5 days/wk, 0°F and above
Group 4 - 12 hrs/day, 5 days/wk, 55°F and above

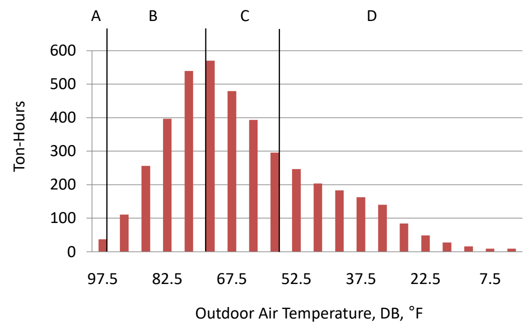

Figure D1. Ton$_R$-Hour Distribution Categories

The following assumptions were used:

D3.3.1 Modified ASHRAE Temperature Bin Method for energy calculations was used.

D3.3.2 Weather data was a weighted average of 29 cities across the U.S.A, specifically targeted because they represented areas where 80% of all chiller sales occurred over a 25 year period (1967-1992).

D3.3.3 Building types were a weighted average of all types (with chiller plants only) based on a DOE study of buildings in 1992 [DOE/EIA-0246(92)].

D3.3.4 Operational hours were a weighted average of various operations (with chiller plants only) taken from the DOE study of 1992 and a BOMA study (1995 BEE Report).

D3.3.5 A weighted average of buildings (with chiller plants only) with and without some form of economizer, based upon data from the DOE and BOMA reports, was included.

D3.3.6 The bulk of the load profile used in the last derivation of the equation was again used, which assumed that 38% of the buildings' load was average internal load (average of occupied vs. unoccupied internal load). It varies linearly with outdoor ambient and mean Condenser wet-bulb (MCWB) down to 50 °F DB, then flattens out below that to a minimum of 20% load.

D3.3.7 Point A was predetermined to be the design point of 100% load and 85°F ECWT/95 °F EDB for IPLV.IP or NPLV.IP. Other points were determined by distributional analysis of ton$_R$-hours, MCWBs and EDBs. ECWTs were based upon actual MCWBs plus an 8 °F tower approach.

The individual equations that represent each operational type were then averaged in accordance with weightings obtained from the DOE and BOMA studies.

The load line was combined with the weather data hours (Figure D2) to create ton$_R$-hours (Figure D3) for the temperature bin distributions. See graphs below:

Figure D2. Bin Groupings –Ton_R Hours

A more detailed derivation of the Group 1 equation is presented here to illustrate the method. Groups 2, 3, and 4 are done similarly, but not shown here. In the chart below, note that the categories are distributed as follows:

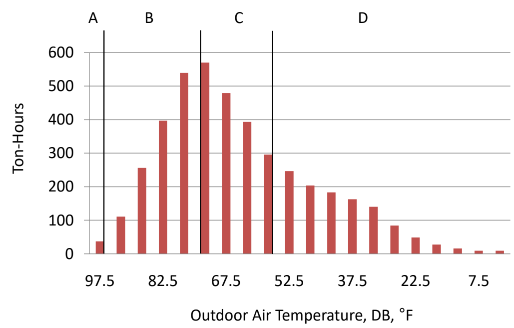

Figure D3. Group 1 Ton_R-Hour Distribution Categories

Point A	=	1 bin for design bin
Point B	=	4 bins for peak bin
Point C	=	4 bins for low bin
Point D	=	all bins below 55 °F for min bin

See Table D1 for Air Cooled and Table D2 for water-cooled calculations. The result is average weightings, ECWT's (or EDB's), and % Loads.

The next step is to begin again with Group 2 Ton Hour distribution as below. Note Group 2 is Group 1, but with 100% Economizer at 55 °F.

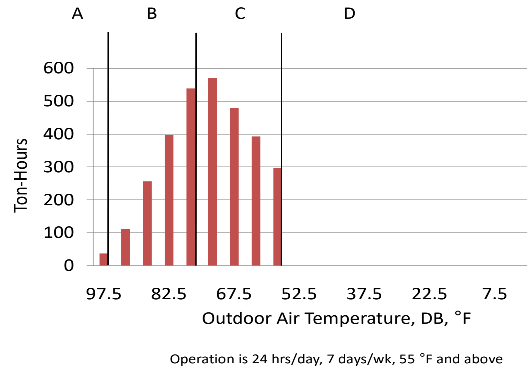

Figure D4. Group 2 Ton_R-Hour Distribution Categories

After creating similar tables as in Tables D1 and D2 for Groups 2, 3, and 4, the resulting Group IPLV.IP or NPLV.IP equations are in Table D3.

The next step is to determine the % of each group which exists in buildings with central chiller plants, so that one final equation can be created from the four. From the DOE and BOMA studies, using goal seeking analysis, it was determined that:

Group 1 - 24.0%
Group 2 - 12.2%
Group 3 - 32.3%
Group 4 - 31.5%

This calculates to the following new equation:
IPLV.IP equation (kW/ton_R):

$$\text{IPLV.IP} = \frac{1}{\frac{0.014}{A} + \frac{0.416}{B} + \frac{0.446}{C} + \frac{0.124}{D}}$$

A = kW/ton_R @ 100% Load and 85°F ECWT or 95 °F EDB
B = kW/ton_R@ 76.1% Load and 75.6°F ECWT or 82.1 °F EDB
C = kW/ton_R@ 50.9% Load and 65.6°F ECWT or 65.8 °F EDB
D = kW/ton_R@ 32.2% Load and 47.5°F ECWT or 39.5 °F EDB

Rounding off and rationalizing:

$$\text{IPLV.IP} = \frac{1}{\frac{0.01}{A} + \frac{0.42}{B} + \frac{0.45}{C} + \frac{0.12}{D}}$$

A = kW/ton_R@ 100% Load and 85 °F ECWT or 95 °F EDB
B = $kWton_R$@ 75% Load and 75 °F ECWT or 80 °F EDB
C = kW/ton_R @ 50% Load and 65 °F ECWT or 65 °F EDB
D = kW/ton_R@ 25% Load and 65 °F ECWT or 55 °F EDB

After rounding off and applying the rationale of where the manufacturers' and the current test facilities' capabilities lie, the final Equation D2 is shown in Section D3.1.

Table D1. Group 1 Air-cooled IPLV.IP Data and Calculation														
													C/S	Chiller
							Min Bin		Low Bin		Peak Bin		Design Bin	
Outside Temperature, °F	Average EDB, °F	OA EDB, °F	Total Hours, h	DBH, °F·h	Total, tonR·h	Cooling Load, %	DBH, °F·h	tonR·h	DBH, °F·h	tonR·h	DBH, °F·h	tonR·h	DBH, °F·h	tonR·h
95-99	97.5	97.5	37	3608	37	100%	0	0	0	0	0	0	3608	37
90-94	92.5	92.5	120	11100	111	92%	0	0	0	0	11100	111	0	0
85-89	87.5	87.5	303	26513	256	85%	0	0	0	0	26513	256	0	0
80-84	82.5	82.5	517	42653	397	77%	0	0	0	0	42653	397	0	0
75-79	77.5	77.5	780	60450	539	69%	0	0	0	0	60450	539	0	0
70-74	72.5	72.5	929	67353	570	61%	0	0	67353	570	0	0	0	0
65-69	67.5	67.5	894	60345	479	54%	0	0	60345	479	0	0	0	0
60-64	62.5	62.5	856	53500	393	46%	0	0	53500	393	0	0	0	0
55-59	57.5	57.5	777	44678	296	38%	0	0	44678	296	0	0	0	0
50-54	52.5	52.5	678	35595	247	36%	35595	247	0	0	0	0	0	0
45-49	47.5	47.5	586	27835	204	35%	27835	204	0	0	0	0	0	0
40-44	42.5	42.5	550	23375	183	33%	23375	183	0	0	0	0	0	0
35-39	37.5	37.5	518	19425	163	32%	19425	163	0	0	0	0	0	0
30-34	32.5	32.5	467	15178	140	30%	15178	140	0	0	0	0	0	0
25-29	27.5	27.5	299	8223	84	28%	8223	84	0	0	0	0	0	0
20-24	22.5	22.5	183	4118	49	27%	4118	49	0	0	0	0	0	0
15-19	17.5	17.5	111	1943	28	25%	1943	28	0	0	0	0	0	0
10-14	12.5	12.5	68	850	16	23%	850	16	0	0	0	0	0	0
05-09	7.5	7.5	40	300	9	22%	300	9	0	0	0	0	0	0
00-04	2.5	2.5	47	118	9	20%	118	9	0	0	0	0	0	0
Total	57.9	57.9	8760	507155	4210	DBH Total	136958	1132	225628	1738	140715	1303	3608	37
						Weighting:		26.9%		41.3%		30.9%		0.9%
						EDB °F:		38.6		65.4		81.8		95.0
						Load:		31.9%		50.3%		75.7%		100%
						Points		D		C		B		A

Table D2. Group 1 Water-cooled IPLV.IP Data and Calculation

														C/S	Chiller
								Min Bin		Low Bin		Peak Bin		Design Bin	
Outside Temperature, °F	Average EDB, °F	OA EWB, °F	CWH, °F·h	Total Hours, h	CWH, °F·h	Total ton$_R$-, h	Cooling Load, %	CWH, °F·h	ton$_R$-, h	CWH, °F·h	ton$_R$-, h	CWH, °F·h	ton$_R$-, h	CWH, °F·h	ton$_R$-, h
95-99	97.5	72	80	37	2960	37	100%	0	0	0	0	0	0	2960	37
90-94	92.5	71	79	120	9480	111	92%	0	0	0	0	9480	111	0	0
85-89	87.5	69	77	303	23331	256	85%	0	0	0	0	23331	256	0	0
80-84	82.5	68	76	517	39292	397	77%	0	0	0	0	39292	397	0	0
75-79	77.5	66	74	780	57720	539	69%	0	0	0	0	57720	539	0	0
70-74	72.5	63	71	929	65959	570	61%	0	0	65959	570	0	0	0	0
65-69	67.5	59	67	894	59898	479	54%	0	0	59898	479	0	0	0	0
60-64	62.5	55	63	856	53928	393	46%	0	0	53928	393	0	0	0	0
55-59	57.5	50	59	777	45843	296	38%	0	0	45843	296	0	0	0	0
50-54	52.5	45	55	678	37290	247	36%	37290	247	0	0	0	0	0	0
45-49	47.5	41	52	586	30472	204	35%	30472	204	0	0	0	0	0	0
40-44	42.5	37	49	550	26950	183	33%	26950	183	0	0	0	0	0	0
35-39	37.5	32	45	518	23310	163	32%	23310	163	0	0	0	0	0	0
30-34	32.5	27	41	467	19147	140	30%	19147	140	0	0	0	0	0	0
25-29	27.5	22	40	299	11960	84	28%	11960	84	0	0	0	0	0	0
20-24	22.5	17	40	183	7320	49	27%	7320	49	0	0	0	0	0	0
15-19	17.5	13	40	111	4440	28	25%	4440	28	0	0	0	0	0	0
10-14	12.5	8	40	68	2720	16	23%	2720	16	0	0	0	0	0	0
05-09	7.5	4	40	40	1600	9	22%	1600	9	0	0	0	0	0	0
00-04	2.5	1	40	47	1880	9	20%	1880	9	0	0	0	0	0	0
Total	57.9	49.3	60.0	8760	525500	4210	CWH Total	167089	1132	225628	1738	129823	1303	2960	37
							Weighting:		26.9%		41.3%		30.9%		0.9%
							ECWT °F:		47.1		65.3		75.5		85.0
							Load:		31.9%		50.3%		75.7%		100%
							Points:		D		C		B		A

Table D3. Group 1 – 4 IPLV.IP Summary

Group 1	% Load	ECWT, ºF	EDB, ºF	Weight	Group 2	% Load	ECWT, ºF	EDB, ºF	Weight
A	100.0%	85.0	95.0	0.95%	A	100.0%	85.0	95.0	1.2%
B	75.7%	75.5	81.8	30.9%	B	75.7%	75.5	81.8	42.3%
C	50.3%	65.3	65.4	41.3%	C	50.3%	65.3	65.4	56.5%
D	31.9%	47.1	38.6	26.9%	D	N/A	N/A	N/A	0.0%
IPLV.IP =	$\frac{1}{0.009/A + 0.309/B + 0.413/C + 0.269/D}$				IPLV.IP =	$\frac{1}{0.012/A + 0.423/B + 0.565/C + 0.0/D}$			
Group 3	% Load	ECWT, ºF	EDB, ºF	Weight	Group 4	% Load	ECWT, ºF	EDB, ºF	Weight
A	100.0%	85.0	95.0	1.5%	A	100.0%	85.0	95.0	1.8%
B	75.7%	75.6	82.2	40.9%	B	76.4%	75.6	82.2	50.1%
C	50.3%	65.8	66.0	39.2%	C	51.3%	65.8	66.0	48.1%
D	31.9%	47.7	40.0	18.4%	D	N/A	N/A	N/A	0.0%
IPLV.IP =	$\frac{1}{0.015/A + 0.409/B + 0.392/C + 0.184/D}$				IPLV.IP =	$\frac{1}{0.018/A + 0.501/B + 0.481/C + 0.0/D}$			

APPENDIX E. AVERAGING – INFORMATIVE

E1 *Purpose*. This appendix describes a method to average data samples collected between each time stamp for the test data points collected in accordance with ANSI/ASHRAE Standard 30.

E2 *General.* Per the requirements of ANSI/ASHRAE Standard 30, averaging of data samples between each time stamp can be employed and reported for each of the 30 or more data points required to be collected and reported at uniform time intervals. This averaging can be performed either within hardware or software, either within the measuring instrument or a data acquisition system, can use any method of averaging (e.g. simple moving average or a weighted moving average of trailing points), with the requirement that the time interval across which data samples are averaged to create each data point does not exceed 1/60 of the total test time period. If choosing to test for the minimum allowable time period of 15 minutes, then the method of averaging only uses samples from a time period not exceeding 15 seconds. Choosing a longer test time period allows a longer averaging time period (e.g. a 20 minute test period allows 20 second averaging). Recording or reporting of the data samples is not required, due to the fact that some hardware implementations of averaging (also referred to as filtering or smoothing for some measurement instrument types) never indicate or communicate the internally collected samples. The resulting data points are then used to calculate the mean and standard deviation in accordance with Section C3.2, for use in judging compliance with the operating condition tolerance limit and the stability criteria found in Table 1.

E3 *Examples.* Two examples are provided using leaving Evaporator water temperature. The sample data (raw data) shown in Tables I1.2 and I2.2 and the summary of sample data shown in Tables E1.2 and E2.2are provided for informational purposes only to demonstrate the concept, even though this data is not required to be recorded or reported. Visual representations of sample data are provided in Figures E1 and E2.

Example #1 is a data set that meets the target test condition of 44.00 °F within the operating condition tolerance limit of ±0.50 °F and stability criteria to have a standard deviation not exceeding 0.18 °F as found in Table 1 for leaving Evaporator water and cooling mode operation. Example #2 is a similar data set that does not meet the stability criteria. Both examples have chosen to use a 20 minute test time period. The data acquisition system is capable of collecting data samples at 5 second intervals. The maximum allowable averaging is employed by taking the average of 5 data samples collected over the trailing 20 second time period (t=0, -5, -10, -15, -20 seconds).

E3.1 *Example #1.* Referring to Table E1.2, the data point value 44.56 for time = 0:00:30.0 was calculated as the average of sample values 44.51, 44.41, 44.67, 44.57, and 44.65 °F. The prior sample value of 44.28 °F was discarded since it is outside the allowable 20 second time interval for averaging.

Table E1.1. Summary of Example #1

Item	Averaging	Count	Mean, °F	Standard Deviation, °F
Data Samples (All Raw Data)	None	246	44.33	0.20
Data Points (Averaged Data Samples)	Simple moving average for 20 seconds (using the trailing 5 samples)	41	44.33	0.14

For the data points, the mean value is within the operating condition tolerance interval of 44.00±0.50 °F, and the standard deviation is within the stability criterion of less than or equal to 0.18 °F, so this test point is valid. Note that in this example, the use of averaging significantly reduced the standard deviation.

Table E1.2. Data for Example #1

Test Time	Data Sample	Data Point Time	Data Point
-0:00:25.0	44.68		
-0:00:20.0	44.63		
-0:00:15.0	44.72		
-0:00:10.0	44.21		
-0:00:05.0	44.66		
0:00:00.0	44.54	0:00:00.0	44.55
0:00:05.0	44.28		
0:00:10.0	44.65		
0:00:15.0	44.57		
0:00:20.0	44.67		
0:00:25.0	44.41		
0:00:30.0	44.51	0:00:30.0	44.56
0:00:35.0	44.29		
0:00:40.0	44.52		
0:00:45.0	44.66		
0:00:50.0	44.46		
0:00:55.0	44.70		
0:01:00.0	44.63	0:01:00.0	44.59
0:01:05.0	44.58		
0:01:10.0	44.53		
0:01:15.0	44.44		
0:01:20.0	44.37		
0:01:25.0	44.29		
0:01:30.0	44.42	0:01:30.0	44.41
0:01:35.0	44.41		
0:01:40.0	44.53		
0:01:45.0	44.30		
0:01:50.0	44.77		
0:01:55.0	44.26		
0:02:00.0	44.71	0:02:00.0	44.51
0:02:05.0	44.54		
0:02:10.0	44.37		
0:02:15.0	44.36		
0:02:20.0	44.56		
0:02:25.0	44.35		
0:02:30.0	44.48	0:02:30.0	44.42
0:02:35.0	44.59		
0:02:40.0	44.38		
0:02:45.0	44.49		
0:02:50.0	44.75		
0:02:55.0	44.27		
0:03:00.0	44.57	0:03:00.0	44.49
0:03:05.0	44.70		
0:03:10.0	44.42		
0:03:15.0	44.37		
0:03:20.0	44.23		
0:03:25.0	44.51		
0:03:30.0	44.32	0:03:30.0	44.37
0:03:35.0	44.31		
0:03:40.0	44.30		
0:03:45.0	44.70		
0:03:50.0	44.69		
0:03:55.0	44.62		

Table E1.2. Data for Example #1 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:04:00.0	44.46	0:04:00.0	44.55
0:04:05.0	44.45		
0:04:10.0	44.28		
0:04:15.0	44.68		
0:04:20.0	44.44		
0:04:25.0	44.61		
0:04:30.0	44.57	0:04:30.0	44.52
0:04:35.0	44.70		
0:04:40.0	44.63		
0:04:45.0	44.31		
0:04:50.0	44.27		
0:04:55.0	44.29		
0:05:00.0	44.51	0:05:00.0	44.40
0:05:05.0	44.58		
0:05:10.0	44.41		
0:05:15.0	44.63		
0:05:20.0	44.57		
0:05:25.0	44.23		
0:05:30.0	44.16	0:05:30.0	44.40
0:05:35.0	44.35		
0:05:40.0	44.31		
0:05:45.0	44.16		
0:05:50.0	44.22		
0:05:55.0	44.16		
0:06:00.0	44.30	0:06:00.0	44.23
0:06:05.0	44.26		
0:06:10.0	44.63		
0:06:15.0	44.11		
0:06:20.0	44.41		
0:06:25.0	44.20		
0:06:30.0	44.10	0:06:30.0	44.29
0:06:35.0	44.15		
0:06:40.0	44.17		
0:06:45.0	44.49		
0:06:50.0	44.47		
0:06:55.0	44.53		
0:07:00.0	44.08	0:07:00.0	44.35
0:07:05.0	44.34		
0:07:10.0	44.12		
0:07:15.0	44.38		
0:07:20.0	44.05		
0:07:25.0	44.22		
0:07:30.0	44.08	0:07:30.0	44.17
0:07:35.0	44.24		
0:07:40.0	44.47		
0:07:45.0	44.46		
0:07:50.0	44.55		
0:07:55.0	44.13		
0:08:00.0	44.39	0:08:00.0	44.40
0:08:05.0	44.41		
0:08:10.0	44.40		
0:08:15.0	44.35		
0:08:20.0	44.36		

Table E1.2. Data for Example #1 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:08:25.0	44.10		
0:08:30.0	44.26	0:08:30.0	44.29
0:08:35.0	44.02		
0:08:40.0	44.05		
0:08:45.0	44.22		
0:08:50.0	44.50		
0:08:55.0	44.06		
0:09:00.0	44.42	0:09:00.0	44.25
0:09:05.0	44.24		
0:09:10.0	44.10		
0:09:15.0	44.16		
0:09:20.0	44.19		
0:09:25.0	44.39		
0:09:30.0	44.36	0:09:30.0	44.24
0:09:35.0	44.34		
0:09:40.0	44.11		
0:09:45.0	44.34		
0:09:50.0	44.30		
0:09:55.0	44.09		
0:10:00.0	44.47	0:10:00.0	44.26
0:10:05.0	44.15		
0:10:10.0	44.40		
0:10:15.0	44.32		
0:10:20.0	44.44		
0:10:25.0	44.25		
0:10:30.0	44.14	0:10:30.0	44.31
0:10:35.0	44.52		
0:10:40.0	44.49		
0:10:45.0	44.16		
0:10:50.0	44.20		
0:10:55.0	44.15		
0:11:00.0	44.05	0:11:00.0	44.21
0:11:05.0	44.17		
0:11:10.0	44.14		
0:11:15.0	44.52		
0:11:20.0	44.26		
0:11:25.0	44.22		
0:11:30.0	44.23	0:11:30.0	44.27
0:11:35.0	44.49		
0:11:40.0	44.26		
0:11:45.0	44.31		
0:11:50.0	44.42		
0:11:55.0	44.50		
0:12:00.0	44.41	0:12:00.0	44.38
0:12:05.0	44.43		
0:12:10.0	44.19		
0:12:15.0	44.50		
0:12:20.0	44.53		
0:12:25.0	44.44		
0:12:30.0	44.13	0:12:30.0	44.36
0:12:35.0	44.59		
0:12:40.0	44.52		
0:12:45.0	44.56		

Table E1.2. Data for Example #1 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:12:50.0	44.22		
0:12:55.0	44.43		
0:13:00.0	44.17	0:13:00.0	44.38
0:13:05.0	44.41		
0:13:10.0	44.45		
0:13:15.0	44.21		
0:13:20.0	44.45		
0:13:25.0	44.53		
0:13:30.0	44.10	0:13:30.0	44.35
0:13:35.0	44.10		
0:13:40.0	44.61		
0:13:45.0	44.58		
0:13:50.0	44.26		
0:13:55.0	44.27		
0:14:00.0	44.52	0:14:00.0	44.45
0:14:05.0	44.61		
0:14:10.0	44.14		
0:14:15.0	44.38		
0:14:20.0	44.43		
0:14:25.0	44.54		
0:14:30.0	44.45	0:14:30.0	44.39
0:14:35.0	44.15		
0:14:40.0	44.35		
0:14:45.0	44.56		
0:14:50.0	44.38		
0:14:55.0	44.28		
0:15:00.0	44.10	0:15:00.0	44.33
0:15:05.0	44.14		
0:15:10.0	44.18		
0:15:15.0	44.20		
0:15:20.0	44.05		
0:15:25.0	44.54		
0:15:30.0	44.13	0:15:30.0	44.22
0:15:35.0	44.53		
0:15:40.0	44.12		
0:15:45.0	44.09		
0:15:50.0	44.58		
0:15:55.0	44.37		
0:16:00.0	44.51	0:16:00.0	44.33
0:16:05.0	44.17		
0:16:10.0	44.42		
0:16:15.0	44.04		
0:16:20.0	44.01		
0:16:25.0	44.24		
0:16:30.0	44.00	0:16:30.0	44.14
0:16:35.0	44.14		
0:16:40.0	44.38		
0:16:45.0	44.17		
0:16:50.0	44.02		
0:16:55.0	44.10		
0:17:00.0	43.98	0:17:00.0	44.13
0:17:05.0	44.49		
0:17:10.0	44.50		

Table E1.2. Data for Example #1 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:17:15.0	44.16		
0:17:20.0	44.23		
0:17:25.0	44.21		
0:17:30.0	43.99	0:17:30.0	44.22
0:17:35.0	44.04		
0:17:40.0	44.02		
0:17:45.0	44.14		
0:17:50.0	44.01		
0:17:55.0	44.16		
0:18:00.0	44.47	0:18:00.0	44.16
0:18:05.0	44.32		
0:18:10.0	44.02		
0:18:15.0	43.92		
0:18:20.0	44.03		
0:18:25.0	43.97		
0:18:30.0	44.42	0:18:30.0	44.07
0:18:35.0	43.96		

Table E1.2. Data for Example #1 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:18:40.0	44.23		
0:18:45.0	43.94		
0:18:50.0	43.95		
0:18:55.0	44.25		
0:19:00.0	44.18	0:19:00.0	44.11
0:19:05.0	44.22		
0:19:10.0	44.06		
0:19:15.0	44.02		
0:19:20.0	44.24		
0:19:25.0	44.28		
0:19:30.0	44.28	0:19:30.0	44.18
0:19:35.0	44.28		
0:19:40.0	43.87		
0:19:45.0	44.19		
0:19:50.0	44.36		
0:19:55.0	44.41		
0:20:00.0	44.11	0:20:00.0	44.19

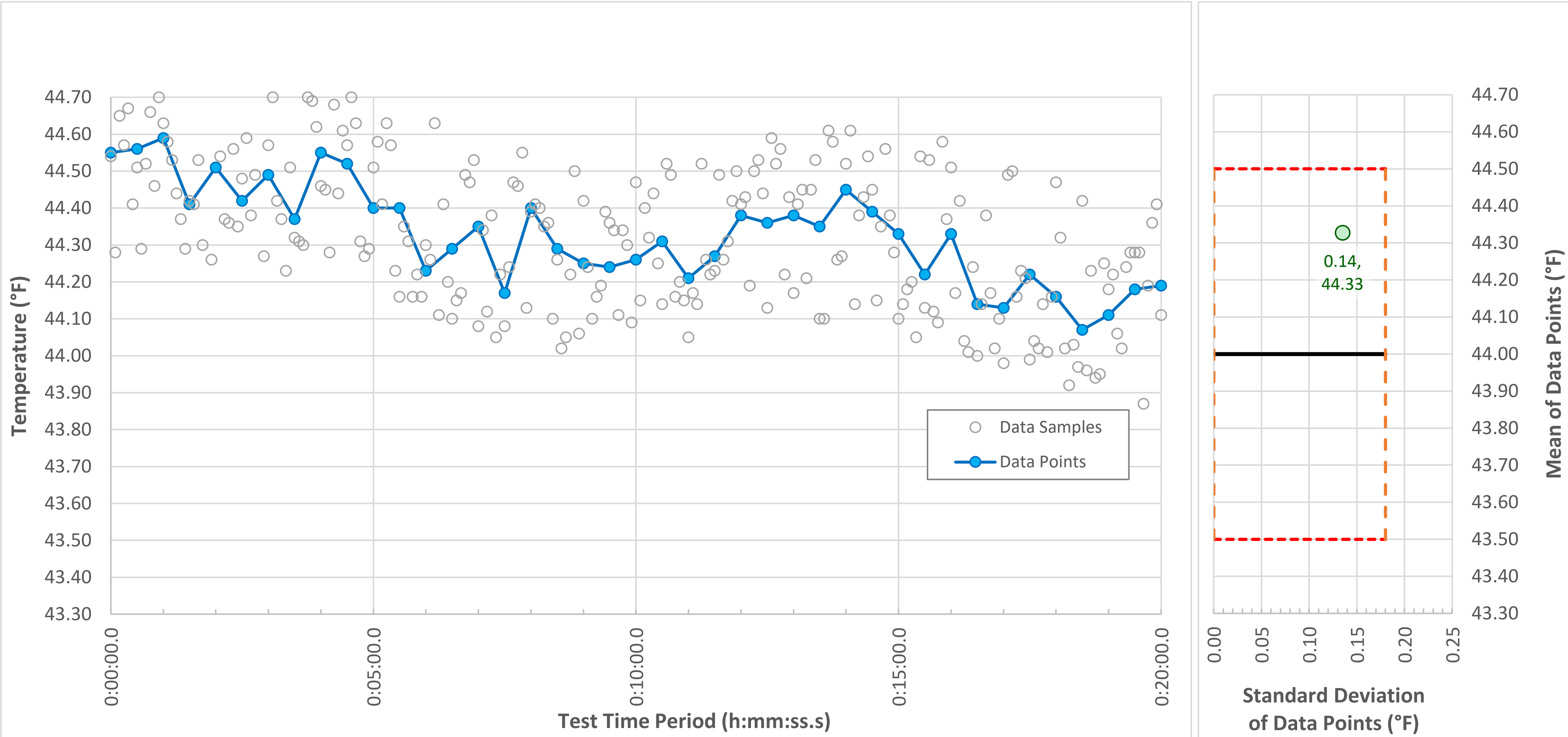

Figure E1. Example #1 Charts

Left panel: Plot of the data samples (246) and data points (41) versus time.

Right panel: Plot of the mean and standard deviation of the data points. Solid black line indicates the test target condition. Dashed lines indicate the Table 1 limits. This test point is valid due to meeting both the operating condition tolerance limit and the stability criteria (inside the dashed lines).

E3.2 *Example #2.* Referring to Table E2.2, the data point value 44.56 for time = 0:00:30.0 was calculated as the average of sample values 44.60, 44.45, 44.40, 44.49, and 44.85 °F. The prior sample value of 44.83 °F was discarded since it is outside the allowable 20 second time interval for averaging.

Table E2.1. Summary of Example #2.

Item	Averaging	Count	Mean, °F	Standard Deviation, °F
Data Samples (All Raw Data)	None	246	44.11	0.26
Data Points (Averaged Data Samples)	Simple moving average for 20 seconds (using the trailing 5 samples)	41	44.10	0.22

While the mean value is within the operating condition tolerance interval of 44.00±0.50 °F, the standard deviation exceeds the stability criterion of less than equal to 0.18 °F, so this test point is not valid and is either repeated, or operation continued and a new set of test data collected. Note that in this example, the use of averaging was not as effective as in the prior example for reducing the standard deviation, due to the water temperature change versus time, or lack of sufficient stability.

Table E2.2. Data for Example #2

Test Time	Data Sample	Data Point Time	Data Point
-0:00:25.0	44.47		
-0:00:20.0	44.42		
-0:00:15.0	44.47		
-0:00:10.0	44.53		
-0:00:05.0	44.70		
0:00:00.0	44.49	0:00:00.0	44.52
0:00:05.0	44.83		
0:00:10.0	44.85		
0:00:15.0	44.49		
0:00:20.0	44.40		
0:00:25.0	44.45		
0:00:30.0	44.60	0:00:30.0	44.56
0:00:35.0	44.80		
0:00:40.0	44.57		
0:00:45.0	44.41		
0:00:50.0	44.40		
0:00:55.0	44.70		
0:01:00.0	44.68	0:01:00.0	44.55
0:01:05.0	44.50		
0:01:10.0	44.40		
0:01:15.0	44.33		
0:01:20.0	44.79		
0:01:25.0	44.63		
0:01:30.0	44.37	0:01:30.0	44.50
0:01:35.0	44.63		
0:01:40.0	44.54		
0:01:45.0	44.39		
0:01:50.0	44.58		
0:01:55.0	44.30		
0:02:00.0	44.66	0:02:00.0	44.49
0:02:05.0	44.32		
0:02:10.0	44.51		
0:02:15.0	44.72		
0:02:20.0	44.29		
0:02:25.0	44.28		
0:02:30.0	44.70	0:02:30.0	44.50
0:02:35.0	44.50		
0:02:40.0	44.44		
0:02:45.0	44.38		
0:02:50.0	44.60		
0:02:55.0	44.43		
0:03:00.0	44.41	0:03:00.0	44.45
0:03:05.0	44.60		
0:03:10.0	44.24		
0:03:15.0	44.32		
0:03:20.0	44.34		
0:03:25.0	44.52		
0:03:30.0	44.50	0:03:30.0	44.38
0:03:35.0	44.21		
0:03:40.0	44.47		
0:03:45.0	44.30		
0:03:50.0	44.29		
0:03:55.0	44.22		

Table E2.2. Data for Example #2 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:04:00.0	44.39	0:04:00.0	44.33
0:04:05.0	44.20		
0:04:10.0	44.22		
0:04:15.0	44.32		
0:04:20.0	44.17		
0:04:25.0	44.40		
0:04:30.0	44.45	0:04:30.0	44.31
0:04:35.0	44.04		
0:04:40.0	44.07		
0:04:45.0	44.03		
0:04:50.0	44.23		
0:04:55.0	44.04		
0:05:00.0	44.27	0:05:00.0	44.13
0:05:05.0	44.10		
0:05:10.0	44.34		
0:05:15.0	44.31		
0:05:20.0	44.16		
0:05:25.0	44.34		
0:05:30.0	44.09	0:05:30.0	44.25
0:05:35.0	44.35		
0:05:40.0	44.07		
0:05:45.0	43.91		
0:05:50.0	44.18		
0:05:55.0	44.17		
0:06:00.0	43.92	0:06:00.0	44.05
0:06:05.0	43.93		
0:06:10.0	44.11		
0:06:15.0	44.07		
0:06:20.0	44.30		
0:06:25.0	44.06		
0:06:30.0	43.91	0:06:30.0	44.09
0:06:35.0	44.28		
0:06:40.0	44.25		
0:06:45.0	44.18		
0:06:50.0	44.07		
0:06:55.0	43.87		
0:07:00.0	43.86	0:07:00.0	44.05
0:07:05.0	43.87		
0:07:10.0	44.23		
0:07:15.0	43.86		
0:07:20.0	43.87		
0:07:25.0	43.87		
0:07:30.0	44.17	0:07:30.0	44.00
0:07:35.0	43.83		
0:07:40.0	43.94		
0:07:45.0	44.00		
0:07:50.0	44.03		
0:07:55.0	43.89		
0:08:00.0	44.13	0:08:00.0	44.00
0:08:05.0	44.06		
0:08:10.0	43.76		
0:08:15.0	43.98		
0:08:20.0	44.09		

Table E2.2. Data for Example #2 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:08:25.0	44.11		
0:08:30.0	44.16	0:08:30.0	44.02
0:08:35.0	43.92		
0:08:40.0	44.06		
0:08:45.0	44.05		
0:08:50.0	43.76		
0:08:55.0	44.08		
0:09:00.0	43.67	0:09:00.0	43.92
0:09:05.0	43.86		
0:09:10.0	43.93		
0:09:15.0	44.11		
0:09:20.0	43.74		
0:09:25.0	43.98		
0:09:30.0	43.66	0:09:30.0	43.88
0:09:35.0	43.79		
0:09:40.0	43.82		
0:09:45.0	44.11		
0:09:50.0	43.80		
0:09:55.0	43.74		
0:10:00.0	43.67	0:10:00.0	43.83
0:10:05.0	43.75		
0:10:10.0	43.81		
0:10:15.0	44.09		
0:10:20.0	43.67		
0:10:25.0	44.07		
0:10:30.0	43.95	0:10:30.0	43.92
0:10:35.0	44.15		
0:10:40.0	43.81		
0:10:45.0	43.98		
0:10:50.0	44.03		
0:10:55.0	44.10		
0:11:00.0	43.79	0:11:00.0	43.94
0:11:05.0	44.03		
0:11:10.0	43.82		
0:11:15.0	43.73		
0:11:20.0	43.89		
0:11:25.0	44.05		
0:11:30.0	43.83	0:11:30.0	43.86
0:11:35.0	44.17		
0:11:40.0	43.73		
0:11:45.0	43.77		
0:11:50.0	43.86		
0:11:55.0	44.16		
0:12:00.0	44.19	0:12:00.0	43.94
0:12:05.0	43.88		
0:12:10.0	43.98		
0:12:15.0	43.81		
0:12:20.0	44.11		
0:12:25.0	44.08		
0:12:30.0	43.91	0:12:30.0	43.98
0:12:35.0	43.92		
0:12:40.0	43.78		
0:12:45.0	44.16		

Table E2.2. Data for Example #2 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:12:50.0	43.99		
0:12:55.0	44.04		
0:13:00.0	43.83	0:13:00.0	43.96
0:13:05.0	43.79		
0:13:10.0	44.18		
0:13:15.0	43.85		
0:13:20.0	43.90		
0:13:25.0	44.23		
0:13:30.0	43.91	0:13:30.0	44.01
0:13:35.0	44.21		
0:13:40.0	43.98		
0:13:45.0	44.08		
0:13:50.0	43.88		
0:13:55.0	43.94		
0:14:00.0	44.21	0:14:00.0	44.02
0:14:05.0	44.10		
0:14:10.0	43.80		
0:14:15.0	44.08		
0:14:20.0	44.15		
0:14:25.0	43.81		
0:14:30.0	43.87	0:14:30.0	43.94
0:14:35.0	43.84		
0:14:40.0	44.21		
0:14:45.0	44.06		
0:14:50.0	43.88		
0:14:55.0	44.17		
0:15:00.0	44.12	0:15:00.0	44.09
0:15:05.0	44.18		
0:15:10.0	43.88		
0:15:15.0	44.03		
0:15:20.0	44.05		
0:15:25.0	44.24		
0:15:30.0	43.77	0:15:30.0	43.99
0:15:35.0	43.87		
0:15:40.0	44.24		
0:15:45.0	43.78		
0:15:50.0	44.06		
0:15:55.0	43.93		
0:16:00.0	43.82	0:16:00.0	43.97
0:16:05.0	44.17		
0:16:10.0	44.18		
0:16:15.0	43.87		
0:16:20.0	44.17		
0:16:25.0	44.06		
0:16:30.0	43.99	0:16:30.0	44.05
0:16:35.0	44.14		
0:16:40.0	43.77		
0:16:45.0	44.03		
0:16:50.0	43.72		
0:16:55.0	44.16		
0:17:00.0	44.00	0:17:00.0	43.94
0:17:05.0	43.88		
0:17:10.0	43.83		

Table E2.2. Data for Example #2 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:17:15.0	43.81		
0:17:20.0	44.16		
0:17:25.0	43.89		
0:17:30.0	43.72	0:17:30.0	43.88
0:17:35.0	44.14		
0:17:40.0	44.03		
0:17:45.0	44.10		
0:17:50.0	44.02		
0:17:55.0	43.75		
0:18:00.0	43.93	0:18:00.0	43.97
0:18:05.0	44.14		
0:18:10.0	44.13		
0:18:15.0	43.84		
0:18:20.0	43.99		
0:18:25.0	44.14		
0:18:30.0	43.97	0:18:30.0	44.01
0:18:35.0	43.85		

Table E2.2. Data for Example #2 (Continued)

Test Time	Data Sample	Data Point Time	Data Point
0:18:40.0	43.92		
0:18:45.0	44.10		
0:18:50.0	44.04		
0:18:55.0	43.82		
0:19:00.0	43.96	0:19:00.0	43.97
0:19:05.0	44.00		
0:19:10.0	43.98		
0:19:15.0	43.89		
0:19:20.0	43.81		
0:19:25.0	43.78		
0:19:30.0	43.77	0:19:30.0	43.85
0:19:35.0	43.76		
0:19:40.0	44.07		
0:19:45.0	44.03		
0:19:50.0	44.13		
0:19:55.0	43.97		
0:20:00.0	44.14	0:20:00.0	44.07

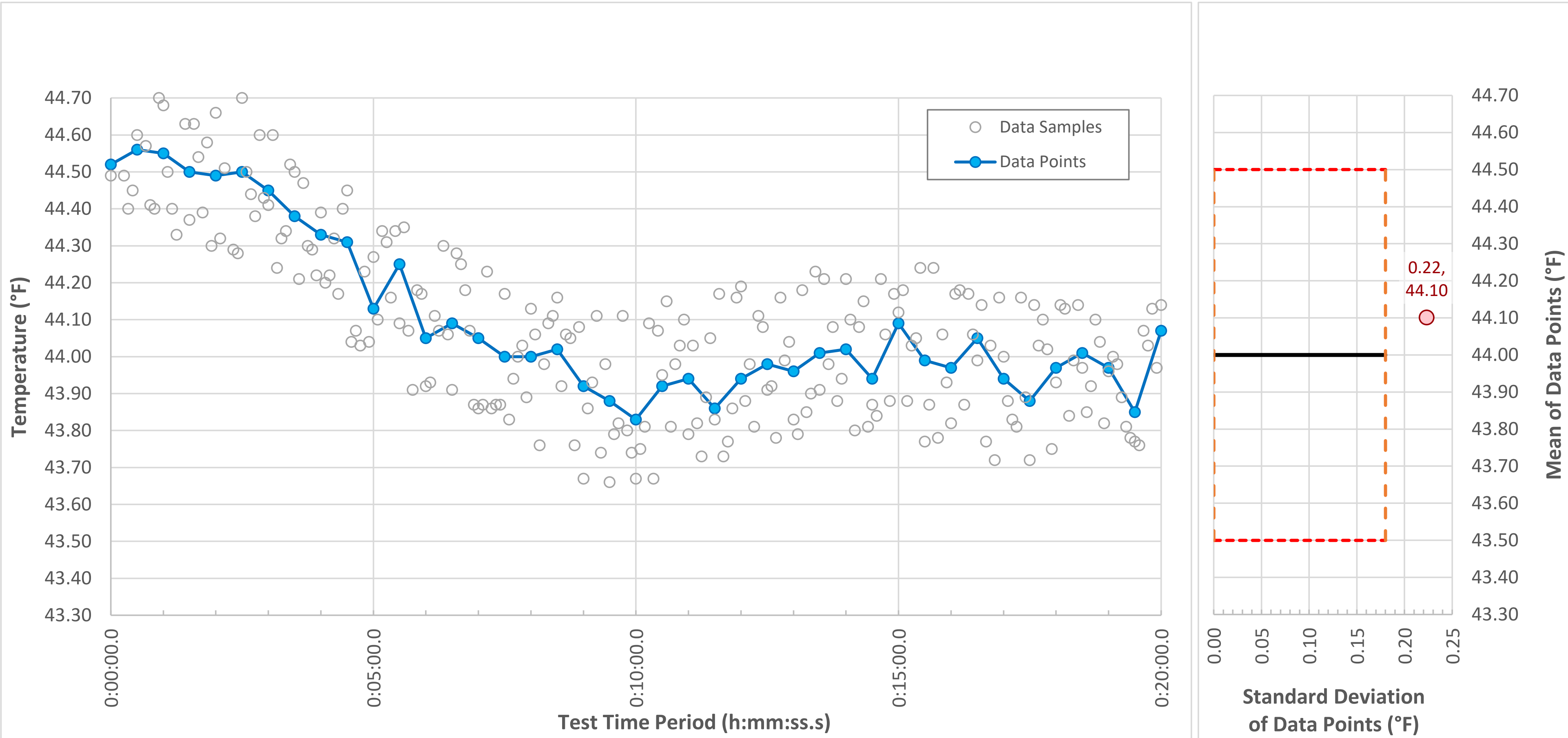

Figure E2. Example #2 Charts

Left panel: Plot of the data samples (246) and data points (41) versus time.

Right panel: Plot of the mean and standard deviation of the data points. Solid black line indicates the test target condition. Dashed lines indicate the Table 1 limits. This test point is invalid due to not meeting the stability criteria (outside the dashed lines).

APPENDIX F. EXAMPLES – INFORMATIVE

F1 *Purpose*. This appendix provides example calculations to clarify the requirements of the standard.

F2 *Examples.* Example calculations are detailed below for fouling factor correction, concurrent redundant verification, IPLV.IP and NPLV.IP, tolerance limits, and atmospheric pressure adjustment.

F2.1 *Fouling Factor Correction - Condenser Fouling Inside Tubes*.

Specified Fouling Factor Allowance, R_{foul} = 0.000250 h·ft^2·°F/Btu
Condenser load, Q_{cd} = 2,880,000 Btu/h
Specified Condenser leaving water temp, $T_{out,w}$ = 95.00 °F
Specified Condenser entering water temp, $T_{in,w}$ = 85.00 °F
Specified saturated condensing temperature with specified fouling, $T_{sat,r}$ = 101.00 °F
Inside tube surface area, A = 550 ft^2 (since fouling is inside tubes in this example)

$$\Delta T_{range} = \left|T_{out,w} - T_{in,w}\right| = 95.00 - 85.00 = 10.00\ °F$$

$$\Delta T_{small,sp} = \left|T_{sat,r} - T_{out,w}\right| = 101.00 - 95.00 = 6.00\ °F$$

$$\Delta T_{LMTD} = \frac{\Delta T_{range}}{\ln\left(1 + \frac{\Delta T_{range}}{\Delta T_{small,sp}}\right)} = \frac{10.00}{\ln\left(1 + \frac{10.00}{6.00}\right)} = 10.1955\ °F$$

$$\Delta T_{ILMTD} = R_{foul}\left(\frac{Q_{cd}}{A_w}\right) = 0.000250 \cdot \left(\frac{2{,}880{,}000}{550}\right) = 1.30909\ °F$$

$$Z = \frac{\Delta T_{range}}{\Delta T_{LMTD} - \Delta T_{ILMTD}} = \frac{10.00}{10.1955 - 1.30909} = 1.12532$$

$$\Delta T_{small,clean} = \frac{\Delta T_{range}}{e^Z - 1} = \frac{10.00}{e^{1.12532} - 1} = 4.80\ °F$$

$$\Delta T_{adj} = \Delta T_{small,sp} - \Delta T_{small,clean} = 6.00 - 4.80 = 1.20\ °F$$

The target Condenser water temperature for testing is then raised 1.20°F to simulate the Fouling Factor Allowance of 0.000250 h·ft^2·°F/Btu. When operating in cooling mode, the entering Condenser water temperature is: $T_{in,adj} = 85.00 + 1.20 = 86.20$ °F. When operating in heating mode, the leaving Condenser water temperature is: $T_{out,adj} = 95.00 + 1.20 = 96.20$ °F.

F2.2 *Concurrent Redundant Verification.*

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F2.2.1 *Net Refrigeration Capacity.*

$T_{in,1}$ = 54.10 °F, $T_{in,2}$ = 53.91 °F (difference of 0.19°F is acceptable)
$T_{out,1}$ = 44.10 °F, $T_{out,2}$ = 43.90 °F (difference 0.20°F is acceptable)
$m_{w,1}$ = 101020 lbm/h, $m_{w,2}$ = 99080 lbm/h (difference of 1.94% is acceptable)

$T_{in,avg}$ = 54.005 °F
$T_{out,avg}$ = 44.000 °F
$m_{w,avg}$ = 100050 lbm/h

Properties of water are calculated per Section 7.2 as follows:
c_p = 1.0018 Btu/lbm·°F using an average entering and leaving temperature of (54.005+44.000)/2 = 49.0025 °F

Net Refrigeration Capacity:

Q_{ev} = 100050 lbm/h · 1.0018 Btu/lbm·°F · (54.005 °F – 44.000 °F)
Q_{ev} = 83.62 ton_R

F2.2.2 *Voltage.*

$V_{1,a}$ = 466 V, $V_{1,b}$ = 469 V
$V_{2,a}$ = 468 V, $V_{2,b}$ = 470 V
$V_{3,a}$ = 466 V, $V_{3,b}$ = 469 V

$V_{a,avg}$ = 467 V, $V_{b,avg}$ = 469 V (difference of 0.43% is acceptable)
V_{avg} = 468 V

F2.3 *IPLV.IP and NPLV.IP.*

F2.3.1 *IPLV.IP with Proportional Capacity Control for a Water-Cooled Chiller.*

The chiller is a water-cooled centrifugal chiller with proportional capacity control that can be tested at each of the four rating Percent Load points of 100%, 75%, 50% and 25% as defined in Table 6 for standard rating conditions per Table 4. For the 50% point the chiller could not be adjusted to be within 2% of the required rating point load of 50% so two tests were run and interpolation was used. Table F1 shows the test results required to calculate IPLV.IP.

Table F1. Example F2.3.1 Test Results

Test No	Target Rating % Load, %	Target Capacity, ton_R	Measured Net Capacity, ton_R	Measured % Load, %	Different from Target Capacity, %	Target Condenser EWT, °F	Measured Power, kW	Efficiency, kw/ton_R
1	100.0	500.0	515.0	103.0	3.000	85.00	296.6	0.5748
2	75.0	375.0	381.0	76.20	1.200	75.00	196.6	0.5160
3	50.0	250.0	266.0	53.20	3.200	65.00	140.7	0.5289
4	50.0	250.0	239.0	47.80	-2.200	65.00	131.1	0.5487
5	25.0	125.0	130.0	26.00	1.000	65.00	97.50	0.7500

Test 1 can be used for the Full Load IPLV.IP rating point A directly as the Capacity is within 3% of the target per Table 7. Test 2 can also be used for the IPLV.IP rating point B because it is within 2% of the target Capacity per Table 1. Test 3 cannot be used directly for the IPLV.IP rating point C because the Capacity is 3.2% greater than the required load of 50%, and the allowable tolerance of ±2% as defined in Table 1. Another test could be run to try to get the Capacity within 2%, but for this test series it was chosen to run a lower capacity test for to use for interpolation. Test 5 can be used directly for the IPLV.IP rating point D because the Capacity is within 1% of the target Capacity for 25% load. Table F2 shows the IPLV.IP rating point data that can then be used to calculate the IPLV.IP.

Table F2. Example F2.3.1 Calculations

Rating Point	Target Rating % Load, %	Measured Net Capacity, ton_R	Measured Power, kW	Efficiency, kw/ton_R	Comment
A	100.0	515.0	296.6	0.5748	Use test point 1 directly.
B	75.0	381.0	196.6	0.5160	Use test point 2 directly.
C	50.0	-	-	0.5405	Interpolated test 3 and 4.
D	25.0	130.0	97.50	0.7592	Use test point 5 directly.

The IPLV.IP calculations are shown below using the rating data for IPLV.IP ratings points A, B, C and D.

$$\text{IPLV.IP} = \frac{1}{\frac{0.01}{0.5748} + \frac{0.42}{0.5160} + \frac{0.45}{0.5405} + \frac{0.12}{0.7592}} = 0.5489$$

F2.3.2 *NPLV.IP with Proportional Capacity Control for a Water-Cooled Chiller.*

The chiller is a water-cooled centrifugal chiller that has proportional capacity control, and can be run at the 100%, 75%, and 50% part-load rating points, but is not able to unload below 27.7% and the required 25% test point D cannot be run. Because this unit is a Configurable Unit and was selected for the lift associated with these non-standard operating conditions the IPLV.IP rating metric should not be used and instead the NPLV.IP metric used with the NPLV.IP conditions and requirements of Table 6. Table F3 shows the test results required to calculate NPLV.IP.

Table F3. Example F2.3.2 Test Results

Test No	Target Rating % Load, %	Target Capacity, ton_R	Measured Net Capacity, ton_R	Measured % Load, %	Different from Target Capacity, %	Target Condenser EWT, ºF	Measured Power, kW	Efficiency, kw/ton_R
1	100.0	800.0	803.7	100.5	0.463	89.00	507.9	0.6320
2	75.00	600.0	608.2	76.0	1.025	77.00	316.9	0.5210
3	50.00	400.0	398.5	49.8	-0.188	65.00	183.3	0.4600
4	25.00	200.0	221.5	27.7	2.688	65.00	125.2	0.5652

Test 1 is within the allowable Capacity tolerance as defined in Table 7 so the test data can be used directly in the NPLV.IP calculations for rating point A. Tests 2 and 3 are within the allowable tolerance of ±2% in Table 1, so they can also be used to directly for the NPLV.IP rating points B and C, respectively. Test 4 was run at the lowest Capacity unloading capability of the chiller and the capacity load of 27.7% is outside the allowable tolerance of ±2% in Table 1 so it cannot be used directly. Because this is the lowest capacity point it is not acceptable to use interpolation where a rating point above and below the 25% is used. Extrapolation cannot be used. Therefore, for NPLV.IP rating point D determination a degradation factor is applied to the measured efficiency to reflect that the unit cycles at a 25% load point. Table F4 shows the data that can then be used to calculate the NPLV.IP.

Table F4. Example F2.3.2 Calculations

Rating Point	Target Rating % Load, %	Measured Net Capacity, ton_R	Measured Power, kW	LF	C_D	Efficiency, kW/ton_R	Comment
A	100.0	803.7	507.9	-	-	0.6320	Use Test 1 directly.
B	75.00	608.2	316.9	-	-	0.5210	Use Test 2 directly.
C	50.00	398.5	183.3	-	-	0.4600	Use Test 3 directly.
D	25.00	-	-	0.902935	1.012619	0.5724	Use Test 4 with C_D.

The following is a summary of the calculations for the degradation of rating Test 4:

$$\text{LF} = \frac{0.25 \cdot 800}{221.5} = 0.902935$$

$$C_D = (-0.13 \cdot 0.902935) + 1.13 = 1.012619$$

$$\frac{\text{kW}}{\text{ton}_{\text{R25\%,CD}}} = 1.0126 \cdot 0.5652 = 0.5724 \ \ \text{kW/ton}_\text{R}$$

With the data for the 4 NPLV.IP rating points A, B, C, and D the NPLV.IP can then be calculated using Equation 18b

$$\text{NPLV.IP} = \frac{1}{\frac{0.01}{0.6320} + \frac{0.42}{0.5210} + \frac{0.45}{0.4600} + \frac{0.12}{0.5724}} = 0.4975$$

F2.3.3 *IPLV.IP with 10 Stages of Capacity Control for an Air-Cooled Chiller.*

The chiller is an air-cooled chiller with 10 stages of Capacity that can unload down to a minimum of 15% of rated load. Only 7 stages of capacity control are used for the computation of rating point data for the IPLV.IP calculations. The standard procedures require that for interpolation capacity points closest to the desired ratings point are used. Larger or smaller capacity points from other stages cannot be used. Because this is an air-cooled chiller the test performance is corrected to standard atmospheric pressure of 14.696 psia using the procedures in Appendix C. The test data was run when the atmospheric pressure was 14.420 psia. Table F5 shows the test required to calculate IPLV.IP including corrections for atmospheric pressure.

Table F5. Example F2.3.3 Test Results

Test No	Target Rating % Load, %	Target Capacity, ton_R	Measured Net Capacity, ton_R	Measured Total Power, kW	Measured Efficiency, Btu/W·h	Capacity Correction Factor	Efficiency Correction Factor	Corrected Capacity, ton_R	Corrected Efficiency, Btu/W·h	Corrected Measured % Load, %	Different from target Capacity, %	Target EDB, ºF
1	100.0	150.0	148.2	170.3	10.44	1.0017	1.0039	148.4	10.48	98.97	-1.034	95.0
2	75.0	112.5	124.5	125.8	11.88	1.0014	1.0032	124.7	11.91	83.12	8.117	80.0
3	75.0	112.5	105.7	93.81	13.52	1.0012	1.0028	105.8	13.56	70.55	-4.449	80.0
4	50.0	75.0	82.4	66.82	14.80	1.0009	1.0021	82.48	14.83	54.98	4.985	65.0
5	50.0	75.0	62.8	49.52	15.22	1.0007	1.0016	62.84	15.24	41.90	-8.103	65.0
6	25.0	37.5	45.2	36.23	14.97	1.0005	1.0012	45.22	14.99	30.15	5.149	55.0
7	25.0	37.5	22.5	19.01	14.20	1.0003	1.0006	22.51	14.21	15.00	-10.00	55.0

Before using the test data to calculate the IPLV.IP the data is corrected for the atmospheric pressure of 14.420 psia per Appendix C. The calculations for test point 2 are shown below as an example of the atmospheric correction calculations.

Capacity $Q_{75\%Load}$ = 124.5 ton_R
Capacity $Q_{100\%Load}$ = 148.2 ton_R
Efficiency $\eta_{tested\ FL}$ = 10.44 Btu/W·h
Efficiency η_{test} = 11.88 Btu/W·h
Atmospheric pressure p_{atm} = 14.42 psia

Correction factor $D_Q = 0.0011273 \cdot 14.42^2 - 0.041272 \cdot 14.42 + 1.36304 = 1.0023$
Correction factor $D\eta = 0.0024308 \cdot 14.42^2 - 0.090075 \cdot 14.42 + 1.79872 = 1.0053$

Correction Factor $CF_Q = 1 + (124.5/148.2) \cdot (1.0023-1) \cdot \exp[-0.35 \cdot (1.0053 \cdot 10.44-9.6)] = 1.0014$
Correction Factor $CF\eta = 1 + (124.5/148.2) \cdot (1.0053-1) \cdot \exp[-0.35 \cdot (1.0053 \cdot 10.44-9.6)] = 1.0032$

Corrected Capacity $Q_{corrected} = 124.5 \cdot 1.0014 = 124.7$ ton_R
Corrected efficiency $\eta_{corrected} = 11.88 \cdot 1.0032 = 11.91$ Btu/W·h

Once the corrections are made then the following Table F6 shows the calculations that are done to determine the IPLV.IP rating points.

Table F6. Example F2.3.3 Calculations

Rating Point	Target Rating % Load, %	Measured Net Capacity, kW	Measured Power, kW	LF	C_D	Efficiency, Btu/W	Comment
A	100.0	148.2	170.3	-	-	10.48	Use test 1 directly.
B	75.00	-	-	-	-	12.98	Interpolate test 2 and 3.
C	50.00	-	-	-	-	14.99	Interpolate test 4 and 5.
D	25.00	-	-	-	-	14.72	Interpolate test 6 and 7.

Test 1 is within the allowable Capacity tolerance of 5% as defined in Table 7 so the atmospheric pressure corrected test data can be used directly in the IPLV.IP calculations for rating point A. For rating points B, C, and D the measured Capacity is greater or less than the required load ±2% as required by Table 1, so interpolation is used. There are stages of Capacity to either side of the 75%, 50%, and 25% rating points that allow for interpolation. The capacity stages closest to the rating points are used (Figure F1). So, for rating points B interpolation is used using atmospheric corrected test 2 and 3 and similar interpolation for rating points C and D.

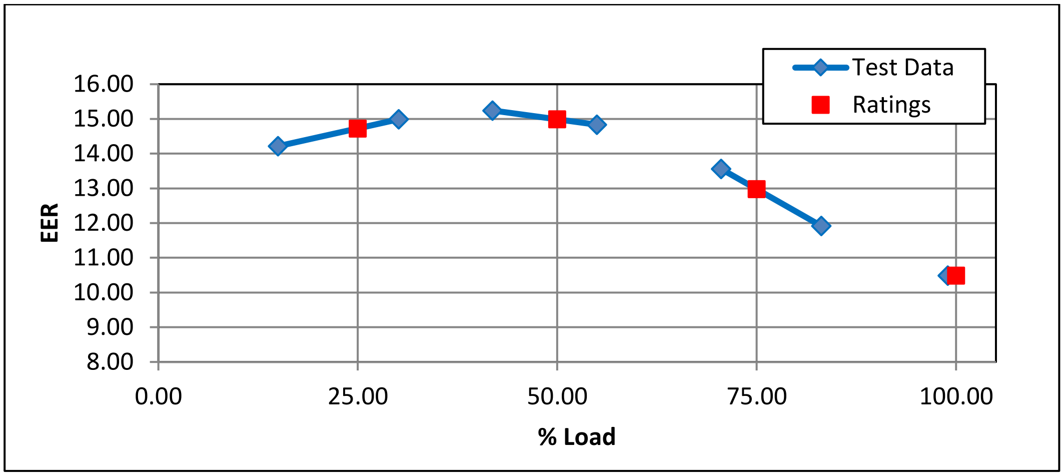

Figure F1. Rating Point Interpolation

An example of the interpolation is shown below for the 25% point D calculation.

Desired Rating Point D % Load = 25%
Test Point 1 % Load = 30.15%
Test Point 1 Efficiency = 14.99 Btu/W·h
Test Point 2 % Load = 15.00%
Test Point 2 Efficiency = 14.21 Btu/W·h

$$\text{exponent} = \log_{10}(14.21) + (.3015 - .1500) \cdot \frac{[\log_{10}(14.99) - \log_{10}(14.21)]}{(0.3015 - 0.1500)}$$

$$= 1.167900538$$

$$\eta_{int} = 10^{(1.67900538)} = 14.72\ \frac{Btu}{W \cdot h}$$

The IPLV.IP can then be calculated using the efficiencies determined from the interpolation for the IPLV.IP rating point A, B, C and D. Note: because the ratings are in EER, Equation 18a is used.

$$\text{IPLV.IP} = (0.01 \cdot 10.48) + (0.42 \cdot 12.95) + (0.45 \cdot 14.99) + (0.12 \cdot 14.72) = 14.05$$

F2.3.4 *IPLV.IP with 3 Stages of Capacity Control for an Air-Cooled Chiller.*

The chiller is an air-cooled chiller with 3 stages of Capacity the last stage of Capacity greater than the required 25% rating point. The degradation factor (C_D) is used for rating point D. This unit also has a head pressure control system that reduces the number of operating condenser fans, and it has a hysteresis to prevent rapid cycling so for test point D two tests (test 6 and test 7) were run as defined by 5.8 to determine the average performance. Test 6 was run by approaching from a 10.0 ºF warmer ambient temperature to the desired 55.0 ºF temperature which resulted in all the condenser fans running. Test 7 was run by approaching from a -5.0 ºF colder ambient temperature to the desired 55.0 ºF and this resulted in partial condenser fan operation. The two tests are then averaged as required by section 5.8 Because this is an air-cooled chiller, the test performance is corrected to standard atmospheric pressure of 14.696 psia using the procedures in Appendix C. The test data was run when the atmospheric pressure was 14.20 psia. Table F7 shows the test required to calculate IPLV.IP including corrections for atmospheric pressure.

Table F7. Example F2.3.4 Test Results												
Test No	Target Rating % Load	Target Capacity, ton_R	Measured Net Capacity, ton_R	Measured Total Power, kW	Measured Efficiency, Btu/W·h	Capacity Correction Factor	Efficiency Correction Factor	Corrected Capacity, ton_R	Corrected Efficiency, Btu/W·h	Measured % Load, %	Difference from target Capacity, %	Target EDB, ºF
1	100.0	110.0	110.2	138.1	9.576	1.0042	1.0096	110.7	9.667	100.60	0.601	95.0
2	75.0	82.50	122.1	127.4	11.50	1.0046	1.0106	122.7	11.623	111.51	36.51	80.0
3	75.0	82.50	79.30	77.70	12.25	1.0030	1.0069	79.54	12.33	72.31	-2.692	80.0
4	50.0	55.00	86.30	73.71	14.05	1.0033	1.0075	86.58	14.15	78.71	28.71	65.0
5	50.0	55.00	51.30	43.20	14.25	1.0019	1.0045	51.40	14.31	46.73	-3.273	65.0
6	25.0	27.50	46.50	40.90	13.64	1.0018	1.0040	46.58	13.70	42.35	17.35	55.0
7	25.0	27.50	44.18	40.08	13.23	1.0017	1.0038	44.25	13.28	40.23	15.23	55.0
Avg 6,7	25.0	27.50	45.34	40.49	13.43	1.0017	1.0039	45.42	13.49	41.29	16.29	55.0

Test 1 is within the allowable Capacity tolerance of 5% as defined in Table 7 so the atmospheric pressure corrected test data can be used directly in the IPLV.IP calculations for rating point A. Tests 2 and 3 are not within the allowable ±2% for Capacity as required by Table 1, so rating point B is determined by interpolation. The same is true for rating point C where again interpolation is used. For rating point D the average of test 6 and 7 should be used as required by section 5.8 for head pressure control. As the average corrected Capacity is greater than the ±2% for Capacity required by Table 1 a degradation calculation is used. Table F8 shows the data that can then be used to calculate the IPLV.IP.

Table F8. Example F2.3.4 Calculations							
Rating Point	Target Rating % Load, %	Measured Net Capacity, kW	Measured Power, kW	LF	C_D	Efficiency, Btu/W·h	Comment
A	100.0	110.2	138.1	-	-	9.667	Use test 1 directly.
B	75.00	-	-	-	-	12.28	Interpolate test 2 and 3.
C	50.00	-	-	-	-	14.30	Interpolate test 4 and 5.
D	25.00	-	-	0.605520	1.051282	12.83	Use test 6,7 average with C_D

The following is a summary of the calculations for the degradation of the average 6,7 test data:

$$\text{LF} = \frac{0.25 \cdot 110.0}{45.42} = 0.605520$$

$$C_D = (-0.13 \cdot 0.605520) + 1.13 = 1.051282$$

$$\text{EER}_{25\%,\text{CD}} = \frac{13.49}{1.051282} = 12.83 \ \text{Btu/W·h}$$

The IPLV.IP can then be calculated using the efficiencies determined from the interpolation for the IPLV.IP rating point A, B, C and D. Note: because the ratings are in EER, Equation 18a is used.

$$\text{IPLV.IP} = (0.01 \cdot 9.667) + (0.42 \cdot 12.28) + (0.45 \cdot 14.30) + (0.12 \cdot 12.83) = 13.23 \ \frac{\text{Btu}}{\text{W}} \cdot \text{h}$$

F2.3.5 *IPLV.IP with 1 Stage of Capacity Control for a Water-Cooled Chiller.*

The chiller is a water-cooled chiller with 1 stage of Capacity, so the degradation procedure factor (C_D) defined in section 5.4.3.2.7 is used to generate the rating data for the 75%, 50%, and 25% IPLV.IP rating points. The unit can only run at full-load, thus additional performance information is used with the unit running at the 75.00 ºF entering Condenser water temperature for the B rating point and at 65.00 ºF Condenser entering water for the C and D rating point. The Condenser water temperature is 65.00 ºF for both the 50% and 25% rating points because the load is equal to or less than 50%, thus only 3 test points are required to generate the IPLV.IP rating data. Table F9 shows the test required to calculate IPLV.IP.

Table F9. Example F2.3.5 Test Results

Test No	Target Rating % Load, %	Target Capacity, ton_R	Measured Net Capacity, ton_R	Measured % Load	Different from Target Capacity	Target Condenser EWT, ºF	Measured Power, kW	Efficiency, kw/ton_R
1	100.0	15.00	15.30	102.0	2.000	85.00	11.90	0.7778
2	75.0	11.25	17.30	115.3	40.33	75.00	10.60	0.6127
3	50.0	7.500	19.80	132.0	82.00	65.00	11.30	0.5707

Test 1 is within the allowable Capacity tolerance of 5.00% as defined in Table 7 so the test data can be used directly in the IPLV.IP calculations for rating point A. For the B, C, and D rating points degradation factors are applied to the ratings test results. The IPLV.IP rating point data is shown in Table F10.

Table F10. Example F2.3.5 Calculations

Rating Point	Target Rating % Load, %	Measured Net Capacity, ton_R	Measured Power, kW	LF	C_D	Efficiency, kw/ton_R	Comment
A	100.0	15.30	11.90	-	-	0.7778	Use test 1 directly
B	75.00	-	-	0.650289	1.045462	0.6406	Use test 2 with C_D
C	50.00	-	-	0.378788	1.080758	0.6168	Use test 3 with C_D
D	25.00	-	-	0.189394	1.105379	0.6308	Use test 4 with C_D

The IPLV.IP can then be calculated using the efficiencies determined from the degradation factor method for the IPLV.IP rating points A, B, C and D. Note: because the ratings are in kW/ton_R, Equation 18b is used.

$$\text{IPLV.IP} = \frac{1}{\frac{0.01}{0.7778} + \frac{0.42}{0.6406} + \frac{0.45}{0.6168} + \frac{0.12}{0.6308}} = 0.6296 \frac{\text{kW}}{\text{ton}_\text{R}}$$

F2.3.6 *IPLV.IP with Continuous Unloading for an Air-Cooled Chiller.*

The chiller is an air-cooled chiller with continuous unloading. Because this is an air-cooled chiller, the test performance is corrected to standard atmospheric pressure of 14.696 psia using the procedures in Appendix C. The test data was run when the atmospheric pressure was 13.50 psia. Table F11 shows the test required to calculate IPLV.IP including corrections for atmospheric pressure.

Table F11. Example F2.3.6 Test Results

Test No	Target Rating % Load, %	Target Capacity, ton_R	Measured Net Capacity, ton_R	Measured Total Power, kW	Measured Efficiency, Btu/W·h	Capacity Correction Factor	Efficiency Correction Factor	Corrected Capacity, ton_R	Corrected Efficiency, Btu/W·h	Measured % Load, %	Different from Target Capacity, %	Target EDB, ºF
1	100.0	200.0	197.2	243.5	9.718	1.0099	1.0226	199.2	9.938	99.58	-0.419	95.0
2	75.0	150.0	149.1	146.0	12.25	1.0075	1.0171	150.2	12.46	75.11	0.111	80.0
3	50.0	100.0	100.2	87.00	13.82	1.0051	1.0115	100.7	13.98	50.35	0.353	65.0
4	25.0	50.0	56.50	51.30	13.22	1.0029	1.0065	56.66	13.30	28.33	3.331	55.0

Test 1 is within the allowable Capacity tolerance of 5.00% as defined in Table 7 so the test data can be used directly in the IPLV.IP calculations for rating point A. Tests 2 and 3 can be used for rating points B and C respectively as they are within the ±2% for Capacity as required by Table 1. Test 4 cannot be used directly because the Capacity is 3.33% above the ±2% for Capacity as required by Table 1 and because it is the lowest unloading capability of the unit, a degradation factor (C_D) is applied. Table F12 shows the data that can then be used to calculate the IPLV.IP.

Table F12. Example F2.3.6 IPLV.IP Calculations

Rating Point	Target Rating % Load, %	Corrected Capacity, ton_R	Corrected Efficiency, Btu/W·h	LF	C_D	Efficiency, Btu/W·h	Comment
A	100.0	197.2	9.938	-	-	9.938	Use test 1 directly.
B	75.00	149.1	12.46	-	-	12.46	Use test 2 directly.
C	50.00	100.2	13.98	-	-	13.98	Use test 3 directly.
D	25.00	56.50	13.30	0.882440	1.015283	13.10	Use test 4 with C_D.

The IPLV.IP can be calculated using the efficiencies determined from the IPLV.IP rating point A, B, C and D.

$$\text{IPLV.IP} = (0.01 \cdot 9.938) + (0.42 \cdot 12.46) + (0.45 \cdot 13.98) + (0.12 \cdot 13.10) = 13.20\frac{\text{Btu}}{\text{W}} \cdot \text{h}$$

F2.3.7 *IPLV.IP with Proportional Capacity Control for an Evaporatively Cooled Chiller*

The chiller is an evaporatively-cooled chiller with proportional capacity control. Because this is an air-cooled chiller, the test performance is corrected to standard atmospheric pressure of 14.696 psia using the procedures in Appendix C. The test data was run when the atmospheric pressure was 14.10 psia. Table F13 shows the test required to calculate IPLV.IP including corrections for atmospheric pressure.

Table F13. Example F2.3.7 Test Results

Test No	Target Rating % Load, %	Target Capacity, ton_R	Measured Net Capacity, ton_R	Measured Total Power, kW	Measured Efficiency, Btu/W·h	Capacity Correction Factor	Efficiency Correction Factor	Corrected Capacity, ton_R	Corrected Efficiency, Btu/W·h	Measured % Load, %	Different from Target Capacity, %	Target EWB, °F
1	100.0	150.0	151.0	125.2	14.47	1.0009	1.0020	151.1	14.50	100.8	0.757	75.00
2	75.0	112.5	114.0	84.55	16.18	1.0007	1.0015	114.1	16.20	76.05	1.051	68.75
3	50.0	75.00	73.50	57.27	15.40	1.0004	1.0010	73.53	15.42	49.02	-0.979	62.50
4	25.0	37.50	42.00	45.82	11.00	1.0002	1.0006	42.01	11.01	28.01	3.007	57.00

Test 1 is within the allowable Capacity tolerance of 5.00% as defined in Table 7 so the test data can be used directly in the IPLV.IP calculations for rating point A. Tests 2 and 3 can be used for rating points B and C respectively as they are within the ±2% for Capacity as required by Table 1. Test 4 can only unload to 28.01% and therefore is above the ±2% for Capacity as required by Table 1 and because it is the lowest unloading capability of the unit, a degradation factor (C_D) is applied. Table F14 shows the data that can then be used to calculate the IPLV.IP.

Table F14. Example F2.3.7 Calculations

Rating Point	Target Rating % Load, %	Corrected Capacity, ton_R	Corrected Efficiency, Btu/W·h	LF	C_D	Efficiency, Btu/W·h	Comment
A	100.0	151.0	14.50	-	-	14.50	Use test 1 directly.
B	75.00	114.0	16.20	-	-	16.20	Use test 2 directly.
C	50.00	73.50	15.42	-	-	15.42	Use test 3 directly.
D	25.00	-	-	0.892635	1.013957	10.85	Use test 4 with C_D.

The IPLV.IP can be calculated using the efficiencies determined from IPLV.IP rating points A, B, C and D.

$$\text{IPLV.IP} = (0.01 \cdot 14.50) + (0.42 \cdot 16.20) + (0.45 \cdot 15.42) + (0.12 \cdot 10.85) = 15.19\ \frac{\text{Btu}}{\text{W}} \cdot \text{h}$$

F2.4 *Tolerance Limits*. The tolerance limit on Capacity and efficiency is determined from Section 5.6.1.

F2.4.1 *EER at Full-Load.*

Rated Full-load Performance:

Rated Capacity = 100.0 ton_R
Rated Power = 111.0 kW
Cooling ΔT_{FL} = 10.00 ºF

$$\text{EER} = \frac{100.0\ \text{ton}_R \cdot \text{K5}}{111.0\ \text{kW} \cdot \text{K7}} = 10.81\ \frac{\text{Btu}}{\text{W}} \cdot \text{h}$$

$$\text{Tolerance Limit} = \text{Tol}_1 = 0.105 - (0.07 \cdot 1.00) + \left(\frac{0.15}{10.00 \cdot 1.00}\right) = 0.05000$$

$$\text{Minimum Allowable Capacity}(\text{ton}_R) = (1.00 - 0.05) \cdot 100.0\ \text{ton}_R = 95.00\ \text{ton}_R$$

$$\text{Minimum Allowable EER}\left(\frac{\text{Btu}}{\text{W} \cdot \text{h}}\right) = \frac{10.81}{1.000 + 0.050} = 10.30\ \left(\frac{\text{Btu}}{\text{W} \cdot \text{h}}\right)$$

F2.4.2 *EER at Part-load.*

Rated Part-load Performance:

Power at 69.5% Rated Capacity = 59.60 kW
69.5% Rated Capacity = 69.50 ton_R
Cooling ΔT_{FL} = 10.00°F

$$\text{EER} = \frac{69.50\ \text{ton}_R \cdot 12{,}000\ \frac{\text{Btu}}{\text{h} \cdot \text{tonR}}}{59.6\ \text{kW} \cdot 1{,}000\ \frac{\text{W}}{\text{kW}}} = 13.99\ \frac{\text{Btu}}{\text{W} \cdot \text{h}}$$

$$\text{Tolerance Limit} = \text{Tol}_1 = 0.105 - (0.07 \cdot 0.695) + \left(\frac{0.15}{10.00 \cdot 0.695}\right) = 0.07793$$

$$\text{Minimum Allowable EER} = \frac{13.99}{1.00 + 0.07793} \frac{\text{Btu}}{\text{W} \cdot \text{h}} = 12.98\ \frac{\text{Btu}}{\text{W} \cdot \text{h}}$$

F2.4.3 *kW/ton at Full-Load.*

Rated Full-load Performance:

Rated Capacity = 100.0 ton_R
Rated Power = 70.00 kW
Cooling ΔT_{FL} = 10.00ºF

$$\text{kW/ton}_R = \frac{70.00\ \text{kW}}{100.0\ \text{ton}_R} = 0.7000\ \frac{\text{kW}}{\text{ton}_R}$$

$$\text{Tolerance Limit} = \text{Tol}_1 = 0.105 - (0.07 \cdot 1.00) + \left(\frac{0.15}{10.00 \cdot 1.00}\right) = 0.05 = 0.05000$$

$$\text{Min. Allowable Capacity} = (1.00 - 0.05) \cdot 100.0\ \text{ton}_R = 95.00\ \text{ton}_R$$

$$\text{Max. Allowable kW/ton}_R = (1.00 + 0.05) \cdot 0.7000\ \frac{\text{kW}}{\text{ton}_R} = 0.7350\ \frac{\text{kW}}{\text{ton}_R}$$

F2.4.4 *kW/ton at Part-load.*

Rated Part-load Performance:

Power at 50% Rated Capacity = 35.00 kW
50% Rated Capacity = 50.00 ton_R
Cooling ΔT_{FL} = 10.00 °F

$$\frac{kW}{ton_R} = \frac{35.00\ kW}{50.00\ ton_R} = 0.7000\frac{kW}{ton_R}$$

$$\text{Tolerance Limit} = Tol_1 = 0.105 - (0.07 \cdot 0.50) + \left(\frac{0.15}{10.00 \cdot 0.50}\right) = 0.1000$$

$$\text{Maximum Allowable}\frac{kW}{ton_R} = (1.00 + 0.10) \cdot 0.700 = 0.7700\frac{kW}{ton_R}$$

F2.4.5 *COP at Full-Load (Heat Pump).*

Rated Full-load Performance:

Rated Heating Capacity = 1,500,000 Btu/h
Rated Power = 70.00 kW
Condenser ΔT_{FL} = 10.00ºF

$$\text{Heating } COP_H = \frac{1{,}500{,}000\frac{Btu}{h}}{70\ kW \cdot 3{,}412.14\ Btu/h \cdot kW} = 6.280\ \frac{kW}{kW}$$

$$\text{Tolerance Limit} = Tol_1 = 0.105 - (0.07 \cdot 1.00) + \left(\frac{0.15}{10.00 \cdot 1.00}\right) = 0.05 = 0.05000$$

$$\text{Min. Allowable Capacity} = (1.00 - 0.05)\ \cdot 1{,}500{,}000\ Btu/h = 1{,}425{,}000\frac{Btu}{h}$$

$$\text{Min. Allowable } COP_H = \frac{6.280\ \frac{W}{W}}{1.00 + 0.05} = 5.981\ \frac{W}{W}$$

F2.5 *Atmospheric Pressure Adjustment*. The atmospheric pressure adjustment is determined in accordance with Appendix C.

F2.5.1 *Altitude of 3500 feet.*

A chiller has Published Ratings of 200.0 ton_R and 10.500 EER at sea level. The chiller is tested at an altitude of about 3500 feet.

The measured test results:
Capacity Q_{test} = 198.5 ton_R
Efficiency η_{test} = 10.35 EER
Air pressure P_{test} = 13.00 psia

Correction factor D_Q = 0.0011273·13.00² –0.041272·13.00 + 1.36304 = 1.0170

Correction factor D_h = 0.0024308·13.00²–0.090075·13.00 + 1.79872 = 1.0386

Correction factor CFq = 1+ (198.5 / 198.5) · (1.0170 – 1) · exp [-0.35·(1.0386·10.35 – 9.6)] = 1.0114

Correction factor CFη = 1+ (198.5 / 198.5) · (1.0386 – 1) ·exp [-0.35·(1.0386·10.35 – 9.6)] = 1.0258

Corrected test Capacity $Q_{corrected\ standard}$ = 198.5·1.0114= 200.8 ton_R

Corrected test efficiency $\eta_{corrected\ standard}$ = 10.35·1.0258 = 10.62 EER

Part load efficiency and capacity correction factors for the following example are determined using the same calculation process as for the 100% Load Point example:

With a part load test result Capacity of 160 ton_R and a 198.5 ton_R test result for 100% load point Capacity. The chiller is tested at an altitude of about 3500 feet,

The measured test results for the part load test;

Capacity Q_{test}	= 160.00 ton_R
Efficiency $\eta_{tested\ ,100\%}$	= 10.35 EER
Efficiency η_{test}	= 12.60 EER
Air Pressure P_{test}	= 13.00 psia

Correction factor D_Q = 0.0011273·13.00² –0.041272·13.00 + 1.36304 = 1.0170

Correction factor $D\eta$ = 0.0024308·13.00²–0.090075·13.00 + 1.79872 = 1.0386

Correction Factor CFq = 1 + (160.0/198.5) ·(1.0170-1) ·exp[-0.35·(1.0386·10.35-9.6)] = 1.0092

Correction Factor CFη = 1+ (160.0/198.5) ·(1.0386-1·exp[-0.35·(1.0386·10.35-9.6)] = 1.0208

Corrected test Capacity $Q_{corrected\ standard}$ = 160.0·1.0092 = 161.5 ton_R

Corrected test efficiency $\eta_{corrected\ standard}$ = 12.60·1.0208 = 12.86 EER

F2.5.2 *Altitude of 1000 feet.*

The same chiller from the example in Section F2.5.1 also has published Application Ratings of 199.3 ton_R and 10.42 EER at 1000 feet, corresponding to rated atmospheric pressure of 14.17 psia. The chiller is tested at an altitude of about 3500 feet.

The measured test results:

Capacity Q_{tested}	= 198.5 ton_R
Efficiency η_{tested}	= 10.35 EER
Air pressure P_{test}	= 13.00 psia

From prior example calculations:
Corrected test Capacity $Q_{corrected,standard}$ = 200.8 ton_R
Corrected test efficiency $\eta_{corrected,standard}$ = 10.62 EER

Next calculate correction factors for the application rating value of P_{rated}=14.17 psia:

Correction factor D_Q = 0.0011273·14.17² –0.041272·14.17 + 1.36304 = 1.0045

Correction factor $D\eta$ = 0.0024308·14.17²–0.090075·14.17 + 1.79872 = 1.0104

Correction factor CFq = 1+ (198.5 / 198.5) · (1.0045 – 1) · exp [-0.35·(1.0104·10.35 – 9.6)] = 1.0034

Correction factor CFη = 1+ (198.5 / 198.5) · (1.0104 – 1) ·exp [-0.35·(1.0104·10.35 – 9.6)] = 1.0077

Corrected test Capacity $Q_{corrected,application}$ = 200.8 / 1.0034 = 200.1 ton_R

Corrected test efficiency $\eta_{corrected,application}$ = 10.62 / 1.0077 = 10.54 EER