BSR/ASHRAE Standard 30-2017R

Public Review Draft

Method of Testing Liquid Chillers

First Public Review (October 2018)
(Complete Draft for Full Review)

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FOREWORD

ASHRAE Standard 30 prescribes methods for obtaining performance data relating to liquid-chilling or liquid-heating equipment using any type of compressor. The intent of this standard is to provide uniform test methods to measure the performance of this equipment by addressing the test and instrumentation requirements, test procedures, data to be recorded, and calculations to generate and confirm valid test results.

The 2017 update realigns ASHRAE Standard 30 with the latest testing methods developed by AHRI Standard 550/590 committee members. The intention being this standard will assume the method of test while removing this content from AHRI Standards 550/590 and 551/591.

1. PURPOSE

1.1 The purpose of this standard is to prescribe methods of testing to measure the thermal capacity, energy efficiency, and water pressure drop of packaged liquid chiller equipment using a refrigerant vapor compression cycle.

1.2 This standard does not specify methods of establishing published ratings or performance tolerances.

2. SCOPE

2.1 This standard applies to liquid chilling or liquid heating packaged equipment using any type of compressor and using the following methods of heat rejection during the cooling cycle:

a) air cooled
b) evaporatively cooled
c) water cooled

2.2 This standard includes packaged equipment provided in more than one assembly if the separated or remote assemblies are designed to be used together and are connected together during the test.

2.3 This standard does not include the following types of equipment:

a) self-contained, mechanically refrigerated drinking-water coolers within the scope of ASHRAE Standard 18
b) unitary water-to-air heat pump equipment within the scope of ASHRAE Standard 37
c) absorption water chilling packages within the scope of ASHRAE Standard 182

2.4 This standard does not include testing of chillers in field installations.

2.5 This standard does not specify the test operating conditions.

2.6 This standard does not specify methods of performance ratings certification.

3. DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

air sampling tree. The air sampling tree is an air sampling tube assembly that draws air through sampling tubes in a manner to provide a uniform sampling of air entering the air-cooled condenser coil. See Section 6.3.1.4.2.1 for design details.

aspirating psychrometer. A piece of equipment with a monitored airflow section that draws a uniform airflow velocity through the measurement section and has probes for measurement of air temperature and humidity. See Section 6.3.1.4.2.2 for design details.

auxiliary power: (See *power.*)

capacity: a measurable physical quantity, the rate that heat (*energy*) is added to or removed from the *liquid* side of a *refrigerating system*. *Capacity* is defined as the mass flow rate of the *liquid* multiplied by the difference in enthalpy of *liquid* entering and leaving the heat exchanger. For the purposes of this standard, the enthalpy change is approximated as the sensible heat transfer using specific heat and temperature difference, and in some calculations, also the energy associated with liquid-side pressure losses.

> ***gross heating capacity:*** the *capacity* of the *water-cooled condenser* as measured by the total heat transferred from the refrigerant to the liquid in the *condenser*. This value includes both the sensible heat transfer and the friction heat losses from pressure drop effects of the *liquid* flow through the *condenser*. This value is used to calculate the *energy balance* of a test.
>
> ***gross cooling capacity:*** the *capacity* of the *evaporator* as measured by the total heat transferred from the liquid to the refrigerant in the *evaporator*. This value includes both the sensible heat transfer and the friction heat losses from pressure drop effects of the *liquid* flow through the *evaporator*. This value is used to calculate the *energy balance* of a test.
>
> ***net heating capacity:*** the *capacity* of the *condenser* available for useful heating of the thermal load, external to the liquid chilling system, calculated using only the sensible heat transfer.
>
> ***net cooling capacity:*** the *capacity* of the *evaporator* available for useful cooling of the thermal load, external to the liquid chilling system, calculated using only the sensible heat transfer.

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

condenser: a *refrigerating system* component which condenses refrigerant from vapor state to liquid state by the removal of heat. De-superheating and sub-cooling of the refrigerant may occur as well.

> ***air-cooled condenser:*** a *condenser*, including condenser fans, that condenses refrigerant vapor by rejecting heat to air mechanically circulated over its heat transfer surface, causing a temperature rise in the air.
>
> ***evaporatively-cooled condenser:*** a *condenser* 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.
>
> ***liquid-cooled condenser:*** a *condenser* that condenses refrigerant vapor by rejecting heat to *liquid* mechanically circulated over its heat transfer surface, causing a temperature rise in the *liquid*.
>
> ***liquid-cooled heat reclaim condenser:*** a *liquid-cooled condenser*, that may be either a separate parallel *condenser* in a *refrigerating system* using two or more *condensers*, or a portion of a *liquid-cooled condenser* with two or more *liquid* circuits, with the purpose of *heat recovery*.

design conditions: any set of operating conditions under which a single level of performance results and which causes only that level of performance to occur.

efficiency: performance at specified operating conditions, expressed as the ratio of the *capacity* output and the *total input power* of a process or a machine. Depending on the specific *efficiency* metric, the numerator and denominator may be switched, and the units of measure may be dimensionless or not. All efficiency metrics shall be stated in conjunction with a complete set of *operating conditions*.

> ***energy efficiency:*** any one of several metrics calculated as a ratio of two quantities, (1) thermal energy movement expressed as a rate and (2) required energy input to move that thermal energy. The numerator and denominator may be switched depending on the specific metric, and the units of measure may be dimensionless or not.
>
> ***cooling efficiency:*** a ratio of *net refrigerating capacity* and the *total input power*. The ratio may be inverted depending on the selected units of measure.
>
>> ***COP_R:*** coefficient of performance, the *cooling efficiency* expressed as a dimensionless ratio of *net refrigerating capacity* divided by the *total input power*.
>>
>> **EER:** energy efficiency ratio, the *cooling efficiency* expressed as a ratio of *net refrigerating capacity* divided by the *total input power*. *EER* shall use the following units of measure: *Btu*/h for *net refrigerating capacity* and W for *total input power*.
>>
>> **kW/ton$_R$:** power input per unit *capacity*, the *cooling efficiency* expressed as a ratio of the *total input power* divided by the *net refrigerating capacity*. *kW/tonR* shall use the following units of measure: kW for *total input power* and ton$_R$ for *net refrigerating capacity*.
>
> ***heating efficiency:*** a ratio of *net heating capacity* and the *total input power*.
>
>> ***COP_H:*** coefficient of performance, the *heating efficiency* expressed as a dimensionless ratio of *net heating capacity* divided by the *total input power*.
>>
>> ***COP_{HR}:*** coefficient of performance, the *heating efficiency* expressed as a dimensionless ratio of the sum of *net heating capacity* of a *water-cooled heat reclaim condenser* plus the *net refrigerating capacity* of an *evaporator*, divided by the *total input power*.

energy balance: a dimensionless ratio metric used to check for gross errors in measurement instrumentation and test results for units with a *water-cooled condenser* (with or without *water-cooled heat reclaim condenser*), defined as the difference between energy inputs and energy outputs to the liquid-chilling package, normalized to a percentage by dividing by the mean of the total input energy and the total output energy. For this standard, the energy inputs are generally limited to the *gross refrigerating capacity* and the *input power*, though other *auxiliary power* inputs are included when analysis demonstrates significance to the *energy balance*.

evaporator: a *refrigerating system* component which boils refrigerant from liquid state to vapor state by the addition of heat. Superheating of the refrigerant may occur as well. For the purposes of this standard, the heat is exchanged from a *liquid* as opposed to air, and in this context, an evaporator may also be called a cooler.

fouling factor: The thermal resistance due to fouling accumulated on the liquid side or air side heat transfer surface.

heat reclaim (or heat recovery): use of heat that would otherwise be wasted from a system or process.

liquid: the fluid being cooled in the *evaporator* (cooler) or heated in the *condenser*, as distinguished from refrigerant in the liquid state. Examples of liquids are water, glycol mixture, or other heat transfer fluid.

liquid-chilling system: a machine specifically designed to make use of a refrigeration cycle to remove heat from a *liquid* and reject the heat to a cooling medium, usually air or water. For the purposes of this standard, the system may be packaged (factory-made and prefabricated assembly) or field-erected. The refrigerant *condenser* may or may not be an integral part of a packaged liquid-chilling system.

liquid pressure drop: A measured value of the reduction in liquid pressure associated with the flow through a liquid- type heat exchanger.

operating condition tolerance: the maximum permissible variation between the time averaged measurement data observations and the specified (target) *operating conditions* as established in the test plan.

operating conditions: a unique set of system parameters resulting in a single level of performance.

percent load (%load): The part-load net capacity divided by the full-load net capacity at the full-load rating conditions, stated in decimal format. (e.g., 100% = 1.0).

power: the rate at which *energy* is transferred, used, or transformed.

> ***auxiliary power:*** *power* input to devices that are not integral to the operation of the vapor compression cycle, excluding power input to integrated pumps (if present) used for *liquid* in either the *evaporator* or the *condenser*. Including devices such as, but not limited to, oil pumps, refrigerant pumps, control power, fans, and heaters.
>
> ***input power:*** a term used to refer to the *power* input to any of the following:
>
> - the mechanical *power* input to the shaft of open compressors; or
> - the electrical *power* input at the motor terminals for hermetic compressors, semi-hermetic compressors, or motor-compressors; or
> - the electrical *power* at the input terminals for starter, motor-controller, or variable speed drive; or
> - the thermal energy or chemical energy input per unit of time for steam turbine, gas turbine, or combustion engine driven compressor.
>
> ***total input power:*** the sum of *input power* and *auxiliary power* to all components of a *liquid-chilling system*.

published ratings: a statement of the assigned values of those performance characteristics, under stated *design conditions*, by which a unit may 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*.

> ***application rating:*** a rating based on tests performed at application rating conditions (other than *standard design conditions*).
>
> ***standard rating:*** a rating based on tests performed at *standard design conditions*.

refrigerating system:

1. A combination of interconnected parts forming a closed circuit in which refrigerant is circulated for the purpose of extracting, then rejecting, heat.

2. A system that, in operation between a heat source (*evaporator*) and a heat sink (*condenser*) at two different temperatures, absorbs heat from the heat source at the lower temperature and rejects heat to the heat sink at the higher temperature.

standard design conditions: *rating conditions* used as the basis of comparison for performance characteristics.

steady state: a state or condition of a system or process that does not change in time, or a condition that changes only negligibly over a specified time interval.

temperature: measurement of warmth or coldness with respect to an arbitrary zero or to the absolute zero. Temperatures are indicated on defined scales, such as Kelvin and Rankine for absolute temperatures, and Celsius and Fahrenheit for ordinary temperatures.

> ***bubble-point temperature:*** a liquid-vapor equilibrium point for a volatile pure liquid or for a multi-component mixture of miscible, volatile pure component liquids, in the absence of noncondensables, where the *temperature* of the mixture at a defined pressure is the minimum temperature required for a vapor bubble to form in the liquid.
>
> ***dew-point temperature:*** a liquid-vapor equilibrium point for a volatile pure liquid or for a multi-component mixture of miscible, volatile pure component liquids, in the absence of noncondensables, where the *temperature* of the mixture at a defined pressure is the maximum temperature required for a liquid drop to form in the vapor.
>
> ***saturation temperature:***
>
> 1. The *temperature* where a substance changes between its liquid and its vapor phase. If the pressure in a system remains constant, a vapor at *saturation temperature* will begin to condense into its liquid phase as thermal energy is removed, and conversely, a liquid at *saturation temperature* will begin to evaporate as thermal energy is applied.
>
> 2. The equilibrium *temperature* of a pure refrigerant or an azeotropic refrigerant in a two-phase mixture of a vapor and liquid at a given absolute pressure.
>
> ***temperature of flowing liquid:*** the mixed mean stream *temperature* at a station perpendicular to the *liquid* flow direction.

total heat rejection: Heat rejected through the condenser, including heat utilized for heat recovery.

4. EQUIPMENT TYPES

4.1 This standard covers the following equipment types:

4.1.1 Vapor Compression Cycle

4.1.1.1 Driver types: electric motor, steam turbine, combustion engine.

		Heat Rejection		
		Liquid Cooled	Evaporatively Cooled	Air Cooled
Operating Mode	Cooling	✓	✓	✓
	Heating	✓	N/A	✓
	Heat Reclaim	✓	N/A	N/A
	Cooling & Heating	✓	N/A	N/A

N/A = Not Applicable (excluded from the scope of the standard)

5. CALCULATIONS AND CONVERSIONS

5.1 Fluid Properties

5.1.1 Water. One of the following two methods shall be used:

Method 1. Use of NIST REFPROP (see Informative Appendix A) to calculate physical properties such as density, specific heat, or enthalpy as a function of both pressure and temperature.

Method 2. Use the following polynomial equations to calculate density and specific heat of water as a function of temperature only.

$$\rho = (\rho_4 \cdot \mathrm{T}^4) + (\rho_3 \cdot \mathrm{T}^3) + (\rho_2 \cdot \mathrm{T}^2) + (\rho_1 \cdot \mathrm{T}) + \rho_0$$

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

	IP (°F)	SI (°C)
T	32~212	0~100

	IP (lbm/ft³)	SI (kg/m³)
-		
ρ_4	$-7.4704 \cdot 10^{-10}$	$-1.2556 \cdot 10^{-7}$
ρ_3	$5.2643 \cdot 10^{-7}$	$4.0229 \cdot 10^{-5}$
ρ_2	$-1.8846 \cdot 10^{-4}$	$-7.3948 \cdot 10^{-3}$
ρ_1	$1.2164 \cdot 10^{-2}$	$4.6734 \cdot 10^{-2}$
ρ_0	62.227	1000.2

	IP (Btu/lbm·°F)	SI (kJ/kg·K)
c_{p5}	$-4.0739 \cdot 10^{-13}$	$-3.2220 \cdot 10^{-11}$
c_{p4}	$3.1031 \cdot 10^{-10}$	$1.0770 \cdot 10^{-8}$
c_{p3}	$-9.2501 \cdot 10^{-8}$	$-1.3901 \cdot 10^{-6}$
c_{p2}	$1.4071 \cdot 10^{-5}$	$9.4433 \cdot 10^{-5}$
c_{p1}	$-1.0677 \cdot 10^{-3}$	$-3.1103 \cdot 10^{-3}$
c_{p0}	1.0295	4.2160

Note: Density and specific heat polynomial equations are curve fit from data generated by NIST REFPROP v9.1 (see Informative Appendix A) at 100 psia [689.5 kPa] and using a temperature range of 32°F to 212°F [0°C to 100°C]. 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.

5.1.2 Other Liquids. Physical properties of the liquid versus temperature, and also by concentration for solutions or mixtures, shall be determined from published data sources such as manufacturer data sheets. Systems utilizing aqueous solutions or mixtures shall be tested to measure or determine the concentration by mass of the liquid. Concentration test(s) shall be performed within two (2) weeks or less prior to the date of the chiller test(s), or within two (2) days after the test.

5.2 Data Processing. Data point measurements collected during the duration of the testing period shall be processed to calculate sample mean and sample standard deviation per the following equations. Calculate final performance metrics (Capacity, Efficiency, Liquid Pressure Drop) and other test results (Energy Balance, Voltage Balance, average values from redundant sensors) from the mean values of measurement data (this method of test is not intended for transient testing).

sample mean

$$\bar{x} = \frac{1}{n}\sum_{j=1}^{n}(x_j)$$

sample standard deviation

$$s = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(x_j - \bar{x})^2}$$

5.3 Redundant Measurements

5.3.1 When redundant sensors are used to measure the same property, the average of the sample means shall be used with associated uncertainty when calculating results.

$$\bar{y} = \frac{\overline{x_1} + \overline{x_2} + \cdots + \overline{x_n}}{n}$$

$$U_{\bar{y}} = \sqrt{\left(\theta_{\overline{x_1}}U_{\overline{x_1}}\right)^2 + \left(\theta_{\overline{x_2}}U_{\overline{x_2}}\right)^2 + \cdots + \left(\theta_{\overline{x_n}}U_{\overline{x_n}}\right)^2}$$

$$\theta_{\overline{x_i}} = \frac{1}{n}$$

5.3.2 Operating Condition Tolerance and Stability Criteria. For applying the operating condition tolerances of Table 7, calculate the average of the two redundant measurements from the sample mean of each measurement

$$\bar{x} = \frac{(\bar{x})_1 + (\bar{x})_2}{2}$$

For applying the stability criteria of Table 7, calculate the standard deviation as the root sum square from sample standard deviation of each measurement

$$s_x = \sqrt{\frac{(s_{x1})^2 + (s_{x2})^2}{2}}$$

5.4 Performance

5.4.1 Capacity. One of the following three methods shall be used depending on the available measurements and with consideration of the acceptable test uncertainty required by the parties. The sign convention, positive or negative, is to show all capacity values as positive whether energy is input into the chiller system or energy is removed from the chiller system. Adjust the sign for temperature difference or enthalpy difference accordingly by subtracting the lesser of inlet and outlet from the greater value. For pressure difference, however, the sign is significant with respect to the direction of energy flow.

5.4.1.1 Gross Capacity and Net Capacity given liquid volume flow rate, inlet and outlet temperatures, pressure loss, density, and specific heat. The density shall be calculated at the temperature and pressure coincident with the volume flow rate measurement. The specific heat shall be calculated at the mean of the entering and leaving temperatures and pressures.

5.4.1.1.1 Gross Capacity

$$Q' = V\rho c_p \Delta T + V\Delta p$$

$$U_{Q'} = \sqrt{(\theta_V U_V)^2 + \left(\theta_\rho U_\rho\right)^2 + \left(\theta_{c_p} U_{c_p}\right)^2 + (\theta_{\Delta T} U_{\Delta T})^2 + \left(\theta_{\Delta p} U_{\Delta p}\right)^2}$$

$$\theta_V = \rho c_p \Delta T + \Delta p$$

$$\theta_\rho = V c_p \Delta T$$

$$\theta_{c_p} = V\rho\Delta T$$

$$\theta_{\Delta T} = V\rho c_p$$

$$\theta_{\Delta p} = V$$

5.4.1.1.2 Net Capacity

$$Q = V\rho c_p \Delta T$$

$$U_Q = \sqrt{(\theta_V U_V)^2 + \left(\theta_\rho U_\rho\right)^2 + \left(\theta_{c_p} U_{c_p}\right)^2 + (\theta_{\Delta T} U_{\Delta T})^2}$$

$$\theta_V = \rho c_p \Delta T$$

$$\theta_\rho = V c_p \Delta T$$

$$\theta_{c_p} = V\rho\Delta T$$

$$\theta_{\Delta T} = V\rho c_p$$

5.4.1.2 Gross Capacity and Net Capacity given liquid mass flow rate, inlet and outlet temperatures, pressure loss, density, and specific heat. The specific heat and density shall be calculated at the mean of the entering and leaving temperatures and pressures.

5.4.1.2.1 Gross Capacity

$$Q' = m c_p \Delta T + m\frac{\Delta p}{\rho}$$

$$U_{Q'} = \sqrt{(\theta_m U_m)^2 + \left(\theta_{c_p} U_{c_p}\right)^2 + (\theta_{\Delta T} U_{\Delta T})^2 + \left(\theta_{\Delta p} U_{\Delta p}\right)^2 + \left(\theta_\rho U_\rho\right)^2}$$

$$\theta_m = c_p \Delta T + \frac{\Delta p}{\rho}$$

$$\theta_{c_p} = m\Delta T$$

$$\theta_{\Delta T} = m c_p$$

$$\theta_{\Delta p} = \frac{m}{\rho}$$

$$\theta_\rho = -\frac{m\Delta p}{\rho^2}$$

5.4.1.2.2 Net Capacity

$$Q = m c_p \Delta T$$

$$U_Q = \sqrt{(\theta_m U_m)^2 + \left(\theta_{c_p} U_{c_p}\right)^2 + (\theta_{\Delta T} U_{\Delta T})^2}$$

$$\theta_m = c_p \Delta T$$

$$\theta_{c_p} = m\Delta T$$

$$\theta_{\Delta T} = m c_p$$

5.4.1.3 Gross Capacity and Net Capacity from liquid mass flow rate, liquid enthalpy change between inlet and outlet, pressure loss, density. The density shall be calculated at the mean of the entering and leaving temperatures and pressures.

5.4.1.3.1 Gross Capacity

$$Q' = m\Delta h$$
$$U_{Q'} = \sqrt{(\theta_m U_m)^2 + (\theta_{\Delta h} U_{\Delta h})^2}$$
$$\theta_m = \Delta h$$
$$\theta_{\Delta h} = m$$

5.4.1.3.2 Net Capacity

$$Q = m\Delta h - m\frac{\Delta p}{\rho}$$
$$U_Q = \sqrt{(\theta_m U_m)^2 + (\theta_{\Delta h} U_{\Delta h})^2 + \left(\theta_{\Delta p} U_{\Delta p}\right)^2 + \left(\theta_\rho U_\rho\right)^2}$$
$$\theta_m = \Delta h - \frac{\Delta p}{\rho}$$
$$\theta_{\Delta h} = m$$
$$\theta_{\Delta p} = -\frac{m}{\rho}$$
$$\theta_\rho = \frac{m\Delta p}{\rho^2}$$

5.4.1.4 Temperature difference, Enthalpy difference, and Pressure difference

5.4.1.4.1 Temperature difference

$$\Delta T = \max(T_{in}, T_{out}) - \min(T_{in}, T_{out}) = |T_{in} - T_{out}|$$
$$U_{\Delta T} = \sqrt{\left(\theta_{T_{in}} U_{T_{in}}\right)^2 + \left(\theta_{T_{out}} U_{T_{out}}\right)^2}$$

$$\theta_{T_{in}} = sign(T_{in} - T_{out})$$

$$\theta_{T_{out}} = sign(T_{out} - T_{in})$$

where $sign(x) = 1\ if\ x > 0,\ sign(x) = -1\ if\ x < 0, and\ sign(x) = 0\ otherwise.$

5.4.1.4.2 Enthalpy difference

$$\Delta h = \max(h_{in}, h_{out}) - \min(h_{in}, h_{out}) = |h_{in} - h_{out}|$$
$$U_{\Delta h} = \sqrt{\left(\theta_{h_{in}} U_{h_{in}}\right)^2 + \left(\theta_{h_{out}} U_{h_{out}}\right)^2}$$
$$\theta_{h_{in}} = sign(h_{in} - h_{out})$$

$$\theta_{h_{out}} = sign(h_{out} - h_{in})$$

5.4.1.4.3 Pressure difference

For the case when energy is input into the system (i.e., heat into evaporator)

$$\Delta p = p_{in} - p_{out} - \Delta p_{adj}$$
$$U_{\Delta p} = \sqrt{\left(\theta_{p_{in}} U_{p_{in}}\right)^2 + \left(\theta_{p_{out}} U_{p_{out}}\right)^2 + \left(\theta_{\Delta p_{adj}} U_{\Delta p_{adj}}\right)^2}$$

$$\theta_{p_{in}} = 1$$
$$\theta_{p_{out}} = -1$$
$$\theta_{\Delta p_{adj}} = -1$$

For the case when energy is output from the system (i.e., heat rejected from condenser)

$$\Delta p = -\left(p_{in} - p_{out} - \Delta p_{adj}\right)$$
$$U_{\Delta p} = \sqrt{\left(\theta_{p_{in}} U_{p_{in}}\right)^2 + \left(\theta_{p_{out}} U_{p_{out}}\right)^2 + \left(\theta_{\Delta p_{adj}} U_{\Delta p_{adj}}\right)^2}$$
$$\theta_{p_{in}} = -1$$
$$\theta_{p_{out}} = 1$$
$$\theta_{\Delta p_{adj}} = 1$$

Δp_{adj} is defined in Section 5.4.4.

5.4.1.5 Total heat rejection

$$Q_{cd} + Q_{hrc}$$

5.4.2 Power

5.4.2.1 Thermal *input power* for a given fluid volume flow rate and higher heating value.

$$Q_{input} = V \cdot HHV$$
$$U_{Q_{input}} = \sqrt{(\theta_V U_V)^2 + (\theta_{HHV} U_{HHV})^2}$$
$$\theta_V = HHV$$
$$\theta_{HHV} = V$$

5.4.2.2 For use in efficiency calculations, determine the chiller *total input power*, by summation, including compressor and all auxiliary power requirements and any heat inputs to the prime mover.

$$W_{input} = \sum_i W_i + \sum_j Q_j$$
$$U_{W_{input}} = \sqrt{\sum_i \left[\left(\theta_{W_i} U_{W_i}\right)^2\right] + \sum_j \left[\left(\theta_{Q_j} U_{Q_j}\right)^2\right]}$$
$$\theta_{W_i} = 1$$
$$\theta_{Q_j} = 1$$

5.4.2.3 For use in *energy balance* calculations, determine the portion of the *total input power* that is transferred into the refrigerant circuit.

$$W_{refrig} = \sum_i W_i$$
$$U_{W_{refrig}} = \sqrt{\sum_i \left[\left(\theta_{W_i} U_{W_i}\right)^2\right]}$$
$$\theta_{W_i} = 1$$

5.4.3 Energy Efficiency. The Coefficient of Performance (COP) is defined in the following sections. Other efficiency metrics are derived as variations on the ratio of capacity and input work, or its inverse, and may be used according to the definitions in Section 3.

5.4.3.1 Cooling Energy Efficiency. The Cooling Coefficient of Performance (η_R) shall be calculated by:

$$\eta_R = \frac{Q_{ev}}{W_{input}}$$

$$U_{\eta_R} = \sqrt{\left(\theta_{Q_{ev}} U_{Q_{ev}}\right)^2 + \left(\theta_{W_{input}} U_{W_{input}}\right)^2}$$

$$\theta_{Q_{ev}} = \frac{1}{W_{input}}$$

$$\theta_{W_{input}} = -\frac{Q_{ev}}{W_{input}{}^2}$$

5.4.3.2 Heating Energy Efficiency.

5.4.3.2.1 The Heating Coefficient of Performance (η_H) shall be calculated by:

$$\eta_H = \frac{Q_{cd}}{W_{input}}$$

$$U_{\eta_H} = \sqrt{\left(\theta_{Q_{cd}} U_{Q_{cd}}\right)^2 + \left(\theta_{W_{input}} U_{W_{input}}\right)^2}$$

$$\theta_{Q_{cd}} = \frac{1}{W_{input}}$$

$$\theta_{W_{input}} = -\frac{Q_{cd}}{W_{input}{}^2}$$

5.4.3.2.2 The Average Heating Coefficient of Performance $\left(\eta_{H,avg}\right)$ for "T" Test Method, Section 8.5.3, shall be calculated by:

$$\eta_{H,avg} = \frac{(Q_{cd})_{avg}}{\left(W_{input}\right)_{avg}}$$

Where:

$$(Q_{cd})_{avg} = \frac{1}{\tau_2 - \tau_1}\int_{\tau_1}^{\tau_2} Q_{cd} \cdot \delta\tau = \frac{1}{\tau_2 - \tau_1}\sum_{i=1}^{n} (Q_{cd})_i \cdot \Delta\tau_i$$

$$\left(W_{input}\right)_{avg} = \frac{1}{\tau_2 - \tau_1}\int_{\tau_1}^{\tau_2} W_{input} \cdot \delta\tau = \frac{1}{\tau_2 - \tau_1}\sum_{i=1}^{n} \left(W_{input}\right)_i \cdot \Delta\tau_i$$

5.4.3.2.3 The Heat Reclaim Coefficient of Performance (η_{HR}) shall be calculated by:

$$\eta_{HR} = \frac{Q_{ev} + \mathrm{Q}_{\mathrm{hrc}}}{W_{input}}$$

$$U_{\eta_{HR}} = \sqrt{\left(\theta_{ev} U_{Q_{ev}}\right)^2 + \left(\theta_{Q_{hrc}} U_{Q_{hrc}}\right)^2 + \left(\theta_{W_{input}} U_{W_{input}}\right)^2}$$

$$\theta_{Q_{ev}} = \frac{1}{W_{input}}$$

$$\theta_{Q_{cd}} = \frac{1}{W_{input}}$$

$$\theta_{W_{input}} = -\frac{Q_{ev} + \mathrm{Q_{hrc}}}{{W_{input}}^2}$$

5.4.3.2.4 The Simultaneous Heating and Cooling Coefficient of Performance (η_{SHC}) shall be calculated by:

$$\eta_{SHC} = \frac{Q_{ev} + \mathrm{Q_{cd}}}{W_{input}}$$

$$U_{\eta_{SHC}} = \sqrt{\left(\theta_{ev}U_{Q_{ev}}\right)^2 + \left(\theta_{Q_{cd}}U_{Q_{cd}}\right)^2 + \left(\theta_{W_{input}}U_{W_{input}}\right)^2}$$

$$\theta_{Q_{ev}} = \frac{1}{W_{input}}$$

$$\theta_{\mathrm{Q_{cd}}} = \frac{1}{W_{input}}$$

$$\theta_{W_{input}} = -\frac{Q_{ev} + \mathrm{Q_{cd}}}{{W_{input}}^2}$$

5.4.4 Liquid Pressure Drop Correction. Measured liquid pressure drop values shall be adjusted to subtract additional static pressure drop due to piping external to the chiller connection points. The additional static pressure drop shall be the sum of all losses between the unit connections and the location of static pressure taps. Record the original measured value, the calculated adjustment value, and the final calculated result for liquid pressure drop.

$$\Delta \mathrm{p_{adj}} = \rho g\left[\sum_{\mathrm{i}} (\mathrm{h_f})_{\mathrm{i}} + \sum_{\mathrm{j}} (\mathrm{h_m})_{\mathrm{j}}\right]$$

5.4.4.1 The adjustment shall not exceed 10% of the measured liquid pressure drop.

5.4.4.2 The general form of the adjustment equation utilizes the methods in the Crane Technical Paper No. 410. A Darcy friction factor is determined using the Swamee-Jain Equation.

$$f = \frac{0.25}{\left[log_{10}\left(\frac{\epsilon/d}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

Pipe roughness values shall be either actual measurements or approximations based on handbook values. If using handbook values, consideration shall be given and values adjusted accordingly to the actual conditions of the pipe interior surface, which may have higher roughness versus the clean conditions of new pipe. Typical pipe roughness handbook values for reference:

Commercial Pipe, New Condition	ϵ (rms)	
	(m)	(ft)
Steel	5.5×10^{-5}	1.8×10^{-4}
Plastic	1.8×10^{-6}	6.0×10^{-6}

5.4.4.3 The head loss associated with a flow component or fitting shall be calculated using either the friction factor f or the loss coefficient, K. Use

$$h_f = \frac{f \cdot L \cdot v^2}{2 \cdot d \cdot g}$$

when the Darcy friction factor is used for straight pipe sections

$$h_m = K \cdot \frac{v^2}{2g}$$

when a K factor is specified for elbows and expansions/contractions

where:

	SI	IP
gravitational constant	$g = 9.80665\ \frac{m}{s^2}$	$g = 32.174\ \frac{ft}{s^2}$
conversion factor	$1\,N = 1\frac{kg \cdot m}{s^2}$	$1\,lb_f = 32.174\frac{lb_m \cdot ft}{s^2}$

Loss coefficients shall be from Section 5.4.4.4, Section 5.4.4.5, Crane Technical Publication 410, or ASHRAE Research Report RP-1034.

5.4.4.4 K factors for elbows fittings.

Table 1
K Factors for Elbow Fittings

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

5.4.4.5 K factors for expander or reducer fittings. The determination of the K factor for the expansion and contraction sections is a function of the diameter ratio ($\beta = \frac{d_1}{d_2},\ d_1 < d_2$) as well as the angle θ of the expansion or contraction (refer to Table 2b) . For typical commercially available gradual expansion or contraction fittings, an equation has been developed for θ as a function of the smaller diameter d_1 that best represents the pressure drop results found in ASHRAE Research Report RP-1034. The equation is valid in the range of 10° to 45° (refer to Table 2a). For sudden expansion or contractions, use the table values for θ > 45°. See Crane Technical Paper No. 410 for a more complete description of the loss coefficient equations.

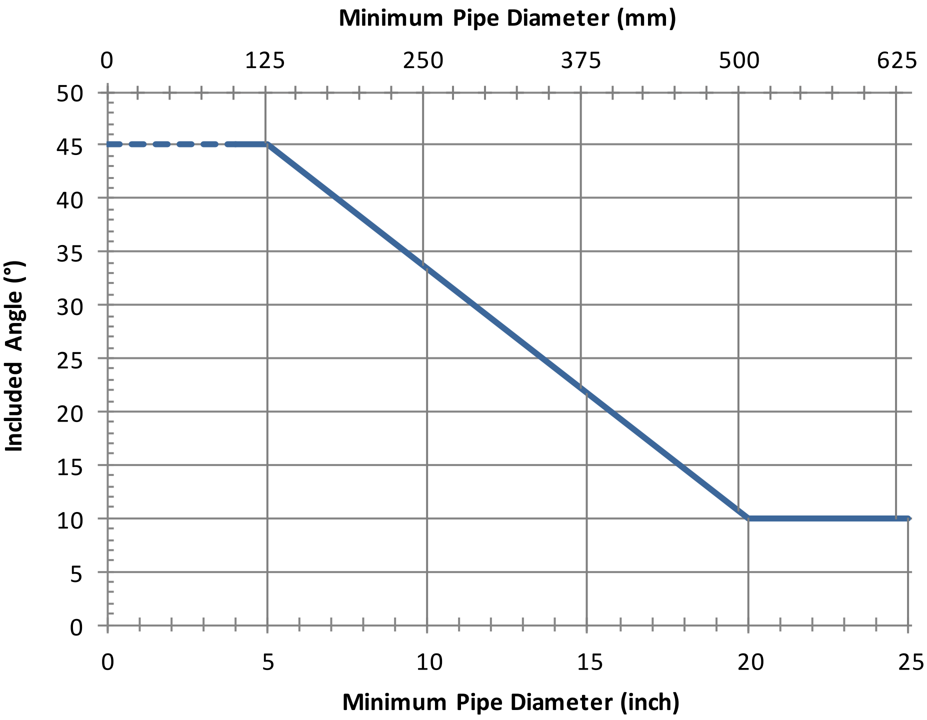

Figure 1. Included Angle Correlation for Gradual Expansion/Contraction Fittings

Table 2a

	$d_1 \le 127$ mm [$d_1 \le 5$ inch]	127 mm $< d_1 <$ 508 mm [5 inch $< d_1 <$ 20 inch]	$d_1 \ge 508$ mm $d_1 \ge 20$ inch
gradual expander, gradual reducer	$\theta = 45°$	$\theta = \frac{170}{3} - \frac{84d_1}{914.4}$ $\left[\theta = \frac{170 - 7d_1}{3}\right]$	$\theta = 10°$
sudden expansion, sudden contraction	$45° < \theta < 180°$	$45° < \theta < 180°$	$45° < \theta < 180°$

Table 2b

	$\theta \le 45°$	$\theta > 45°$
expansion	$K = \frac{2.6\sin(\frac{\theta}{2})(1-\beta^2)^2}{\beta^4}$	$K = \frac{(1-\beta^2)^2}{\beta^4}$
reduction	$K = \frac{0.8\sin(\frac{\theta}{2})(1-\beta^2)^2}{\beta^4}$	$K = \frac{0.5\sqrt{\sin(\frac{\theta}{2})}(1-\beta^2)}{\beta^4}$

Note: The values of the resistance coefficients (K) in the equations in the previous table are based on the velocity in the large pipe. To determine K values in terms of the smaller diameter, multiply equations by β^4.

5.5 Validation. Test results are validated by checking an *energy balance* and a voltage balance.

5.5.1 Energy Balance. Based on the first law of thermodynamics, or the law of conservation of energy, an *energy balance* calculation evaluates all of the measured energy flow into and out of a control volume. If there is a non-zero difference between energy flow in and energy flow out, greater than the *energy balance* measurement uncertainty, then either (a) the system is not at steady state (lack of equilibrium), or (b) some significant heat gain or heat loss has been omitted from the calculation, or (c) there is a measurement error to be corrected. The control volume shall include the entire chiller package, especially the refrigerant circuit(s) that convey thermal energy from a source to a sink (from the evaporator liquid to the condenser liquid). In many cases, heat losses or heat gain caused by radiation, convection, bearing friction, oil coolers, etc., are relatively small and may be either included or excluded without a problem in the overall energy balance.

5.5.1.1 Gross capacity shall be used for *energy balance* calculations.

5.5.1.2 Sum all energy sources flowing into and out of the system through the control volume boundary

5.5.1.2.1 Input Energy Sources

$$E_{in} = \sum_i E_{in_i}$$

$$U_{E_{in}} = \sqrt{\sum_i \left[\left(\theta_{E_{in_i}} U_{E_{in_i}}\right)^2\right]}$$

$$\theta_{E_{in_i}} = 1$$

5.5.1.2.2 Output Energy Sources

$$E_{out} = \sum_i E_{out_i}$$

$$U_{E_{out}} = \sqrt{\sum_i \left[\left(\theta_{E_{out_i}} U_{E_{out_i}}\right)^2\right]}$$

$$\theta_{E_{out_i}} = 1$$

5.5.1.3 Energy Balance. The general *energy balance* equation is expressed as the ratio of the difference between input and output energy to the mean of input and output energy.

$$E_{bal} = 2\frac{E_{in} - E_{out}}{E_{in} + E_{out}}$$

$$U_{E_{bal}} = \sqrt{\left(\theta_{E_{in}} U_{E_{in}}\right)^2 + \left(\theta_{E_{out}} U_{E_{out}}\right)^2}$$

$$\theta_{E_{in}} = \frac{4E_{out}}{(E_{in} + E_{out})^2}$$

$$\theta_{E_{out}} = -\frac{4E_{in}}{(E_{in} + E_{out})^2}$$

For liquid-cooled chillers, the total measured input power (W_{input}) to the chiller package is often assumed to equal the compressor work done on the refrigerant (W_{refrig}). In cases where the difference in the total power and the compressor work is significant, an analysis that provides a calculated value of W_{refrig} shall be performed and used in the energy balance equation. Cases for different chiller configurations are shown in 5.5.1.3.1 through 5.5.1.3.5.

5.5.1.3.1 A typical summation omitting the effect of the small heat losses and gains mentioned in Section 5.5.1.2..

$$E_{in} = \sum_i E_{in_i} = Q'_{ev} + \left(W_{refrig}\right)$$

$$E_{out} = \sum_i E_{out_i} = Q'_{cd} + Q'_{hrc}$$

5.5.1.3.2 In a hermetic package, where the motor is cooled by refrigerant, chilled liquid, or condenser liquid, the motor cooling load is included in the measured condenser load:

$W_{refrig} = W_{input}$ = electrical power input to the compressor motor terminals, kW

5.5.1.3.3 In a package using an open-type compressor with prime mover and external gear drive:

$$W_{refrig} = Q_{prime\ mover} - Q_{gear}$$

Where :

W_{refrig} = *Power* input to the compressor shaft, kW
$Q_{prime\ mover}$ = Power output of prime mover, kW
Q_{gear} = Friction loss in the gear box, kW

The value of $Q_{prime\ mover}$ shall be determined from the power input to prime mover using certified data from the prime mover manufacturer.

The value of Q_{gear} shall be determined from certified gear losses provided by the gear manufacturer.

5.5.1.3.4 In a package using an open-type compressor with direct drive or internal gear and the prime mover not furnished by the chiller manufacturer:

W_{refrig} = *Power* input to the compressor shaft, kW

For determination of W_{refrig} for turbine or engine operated machines, the turbine or engine manufacturer's certified power input/output data shall be used.

In the case of motor drive:

W_{refrig} = Power measured at motor terminals plus power to auxiliaries as in Section 6.3.1.7.

5.5.1.3.5 In a package using an open-type compressor with direct drive or internal gear and the prime mover is furnished by the manufacturer:

W_{refrig} = *Power* input to the compressor shaft, kW

For determination of W_{refrig} for turbine or engine operated machines, the certified power input/output data shall be used.

In the case of motor drive:

W_{refrig} = Power measured at motor terminals multiplied by the motor efficiency plus power to auxiliaries as in Section 6.3.1.7

5.5.1.4 Concurrent Redundant Verification Method for Air-cooled or Evaporatively-cooled Condensers or

Air-Source Evaporators for Heating Mode.

5.5.1.4.1 In lieu of an *energy balance*, redundant measurements (two or more measurement instruments instead of one, refer to Section 6.7.4) shall be taken for all parameters necessary to calculate capacity and energy efficiency.

5.5.2 Voltage Balance. Voltage balance is defined as the maximum absolute value of the voltage deviation from the average voltage, expressed in relative terms to the average voltage. For a three-phase system with three measured voltages, the equations are:

$$V_{bal} = \frac{max\left[\left|V_1 - V_{avg}\right|, \left|V_2 - V_{avg}\right|, \left|V_3 - V_{avg}\right|\right]}{V_{avg}}$$

$$V_{avg} = \frac{(V_1 + V_2 + V_3)}{3}$$

5.6 Conversions

5.6.1 All equations described in this standard assume consistent units. It is imperative that users of this standard ensure proper unit conversions in all calculations.

5.6.2 One ton of cooling, ton_R, is defined as $12000\ Btu_{IT}/h$.

5.6.3 $1\ Btu_{IT} = 1055.05585262\, J\ (exact\ conversion)$.

5.6.4 For all other unit conversions, refer to *NIST Special Publication 811, Guide for the Use of the International System of Units (SI)* or other authoritative source for appropriate unit conversions.

5.7 Rounding and Significant Digits

5.7.1 Calculations shall use measurement values with full numerical precision.

5.7.2 Numerical data are often obtained (or at least calculations can be made) with more digits than are justified by their accuracy or precision. In order not to be misleading, such data should 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.

5.7.3 Expanded uncertainty values on test reports shall be provided with two significant digits.

5.7.4 Calculations reporting values with expanded uncertainty shall be reported to the same level of significance as the expanded uncertainty.

5.7.4.1 Consider an example result (prior to rounding) with value 10.573593 ± 0.097369424.

5.7.4.2 Rounding the uncertainty to two significant digits yields ± 0.097.

5.7.4.3 The final result must be reported to the nearest 0.001 (the same significance as the uncertainty with two significant digits), yielding 10.574 ± 0.097.

5.7.5 The rules for identifying significant figures when writing or interpreting numbers are as follows:

5.7.5.1 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).

5.7.5.2 Zeroes appearing anywhere between two non-zero digits are significant. Example: 101.1203 has seven significant figures: 1, 0, 1, 1, 2, 0 and 3.

5.7.5.3 Leading zeroes are not significant. For example, 0.00052 has two significant figures: 5 and 2.

5.7.5.4 Trailing zeroes 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 might 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).

5.7.5.5 The significance of trailing zeroes in a number not containing a decimal point can be ambiguous. For example, it may not always be 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. Various conventions exist to address this issue:

> **5.7.5.5.1** A bar may be placed 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).
>
> **5.7.5.5.2** The last significant figure of a number may be underlined; for example, "2000" has two significant figures.
>
> **5.7.5.5.3** A decimal point may be placed after the number; for example "100." indicates specifically that three significant figures are meant.
>
> **5.7.5.5.4** In the combination of a number and a unit of measurement, the ambiguity can be avoided by choosing 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.
>
> **5.7.5.5.5** Ambiguity can also be avoided by use of scientific notation or exponential notation; for example, 1.30×10^3 W.

5.7.6 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 =$15\overline{4}00$.

5.7.7 The following rules shall be used in rounding values:

5.7.7.1 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.

5.7.7.2 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.

5.7.7.3 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.

6. TEST REQUIREMENTS

6.1 Tests shall report measurement values and calculated results in accordance with methods and procedures described in this method of test.

6.2 From a test perspective, it is best to maintain heat transfer surfaces by cleaning or maintaining proper liquid treatment to avoid highly fouled conditions and the associated efficiency loss.

6.3 Instrumentation. This section defines requirements for each type of measurement (temperature, flow, pressure, power). Instruments shall be selected, installed, operated, and maintained according to the requirements of Table 3. Further details are provided in this section for each measurement type.

Table 3 Requirements for Test Instrumentation

Measurement	Measurement System Accuracy[2,3,4,5]	Measurement Resolution[6, 7]	Selected, Installed, Operated, Maintained in Accordance With
Liquid Temperature	±0.11 Δ°C (±0.20 Δ°F)	0.005°C (0.01°F)	ANSI/ASHRAE Standard 41.1
Air Temperature	±0.11 Δ°C (±0.20 Δ°F)	0.05°C (0.1°F)	ANSI/ASHRAE Standard 41.1
Liquid Mass Flow Rate [1]	±1.0% RDG	4 significant figures	ANSI/ASHRAE Standard 41.8 or ASME Power Test Code PTC 19.5 (flow measurement) ASME MFC-16 (electromagnetic type) ASME MFC-3M (orifice & venturi type) ASME MFC-6M (vortex type) ASME MFC-11 (coriolis type) ISA Standard RP31.1 (turbine type)
Differential Pressure	±1.0% RDG	3 significant figures	ASME Power Test Code PTC 19.2
Electrical Power		4 significant figures (V, A, kW, Hz)	ANSI/ASHRAE Standard 41.11 IEEE C57.13
≤ 600V	±1.0% FS, ±2.0% RDG		
> 600 V	±1.5% FS, ±2.5% RDG		
Atmospheric Pressure	±1.0 kPa (±0.15 psia)	0.1 kPa (0.01 psia)	ASME Power Test Code PTC 19.2
Steam condensate mass flow rate	±1.0% RDG	4 significant figures	
Steam pressure	±1.0% RDG	3 significant figures	
Fuel volumetric flow rate	±1.0% RDG	4 significant figures	
Fuel energy content	-	3 significant figures	Gas quality shall be acquired by contacting the local authority and requesting a gas quality report for calorific value on the day of the test

Notes:

1. Accuracy requirement also applies to volumetric type meters.
2. Measurement system accuracy shall apply over the range of use during testing, as indicated by the Turn Down Ratio determined during calibration, i.e., from full scale down to a value of full scale divided by the Turn Down Ratio. For many types of instruments and/or systems, this may require exceeding the accuracy requirement at full scale.
3. %RDG = percent of Reading, %FS = percent of Full Scale for the useable range of the measurement instrument or measurement system.
4. If dual requirements are shown in the table, FS and RDG, then both requirements shall be met.
5. Current Transformers (CT's) and Potential Transformers (PT's) shall have a metering accuracy class of 0.3 or better, rated in accordance with IEEE C57.13.
6. Measurement resolution shown is the minimum requirement (most coarse resolution allowable). Better (finer) resolution is acceptable for instrument or panel displays, or computer screen displays. Resolution includes all parts of the measurement system, such as analog to digital conversion.
7. Significant figures (also known as significant digits) determined in accordance with Section 5.6.

6.3.1 Accuracy and Calibration

6.3.1.1 All instruments and measurement systems shall be calibrated over a range that meets or exceeds the range of test readings. Data acquisition systems shall be either calibrated as a system, or all individual component calibrations shall be documented in a manner that demonstrates the measurement system meets the accuracy requirements specified in Table 3. Calibrations shall include no less than four (4) points compared to a calibration standard. Calibration standards shall be traceable to NIST or equivalent laboratories that participate in inter-laboratory audits.

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

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

To determine the range over which the calibration achieves the required accuracy, a linear regression analysis is performed on the calibration data. Table 4 and the equations that follow explain the method of calculating the prediction interval. The data is plotted to show the residual errors versus the calibration reference standard. The standard error of estimate shall be calculated for the measurement system indicated values (post calibration) versus the calibration reference standard, then using the equations in the following section, plot a 95% prediction interval (α=5%) on both sides of the curve fit. The point(s) at which the prediction interval curve exceeds the required accuracy shall be the limit(s) of the range. See example using sample data in Figures 2a and 2b, in which the specified accuracy is ±1% of reading, and the useable range is from 100 to 13.4, or Turn Down Ratio of 7.5:1.

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

6.3.1.3 Accuracy of electrical measurements shall include all devices in the measurement system (i.e., power meter or power analyzer, potential transformers, current transformers, data acquisition signals). Liquid chilling or heating packages that utilize power-altering equipment, such as variable frequency drive or inverter, may require appropriate isolation and precautions to ensure that accurate power measurements are obtained. Chillers that utilize power-altering equipment may require the use of instrumentation that is capable of accurately measuring signals containing high frequency and/or high crest factors. In these cases, the instrumentation used shall have adequate bandwidth and/or crest factor specifications to ensure the electrical *input power* measurement errors are within the accuracy requirements of Table 4 for the quantity measured. Reference ASHRAE Standard 41.11 for examples of such measurements.

Table 4 Prediction Interval to Determine Range of Acceptable Accuracy

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

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

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

Where:

x = Variable representing any measurement value, such as temperature, flow rate, or power

$\hat{y}$ = Linear regression curve fit of the (x_j,y_j) calibration data used to compare indicated measurement values versus the calibration reference standard
$\hat{x}$ = Any value of x at which to evaluate the curve fit and prediction interval
$PI(\hat{x})$ = Prediction interval at the value of $\hat{x}$
n = Number of calibration data points
$\bar{x}$ = Mean of all measurement values from calibration points
SS_x = Sum of squares of x value differences to the mean

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

$$\bar{x} = \frac{1}{n}\sum_{j=1}^{n}\left(x_j\right)$$

$$SS_x = \sum_{j=1}^{n}\left(x_j - \bar{x}\right)^2$$

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

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

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

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

Where:

m = Slope of the regression line
c = Intercept (offset) of the regression line

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

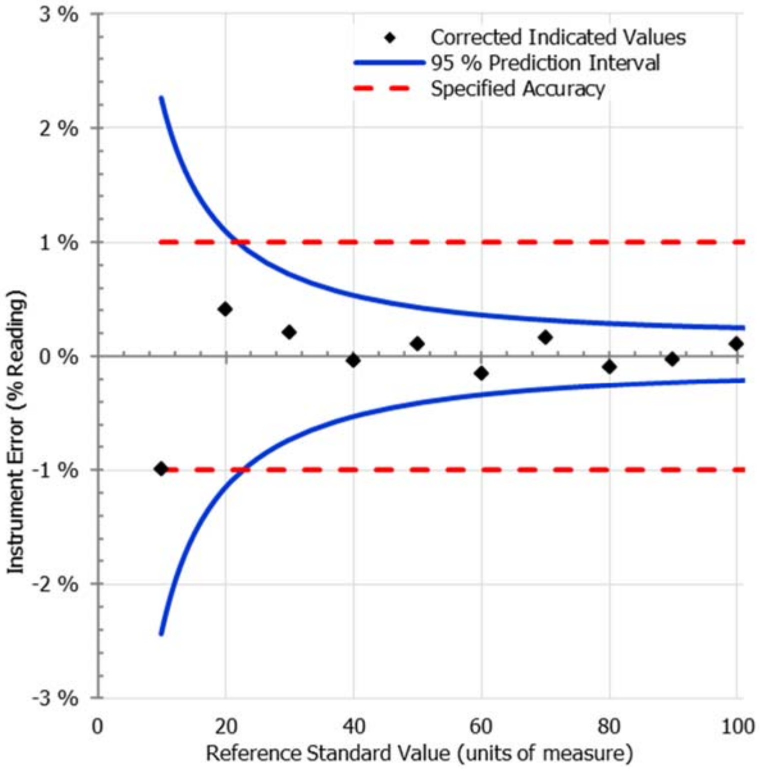

Figure 2a Sample of Relative Calibration Evaluation Data (Percent of Reading)

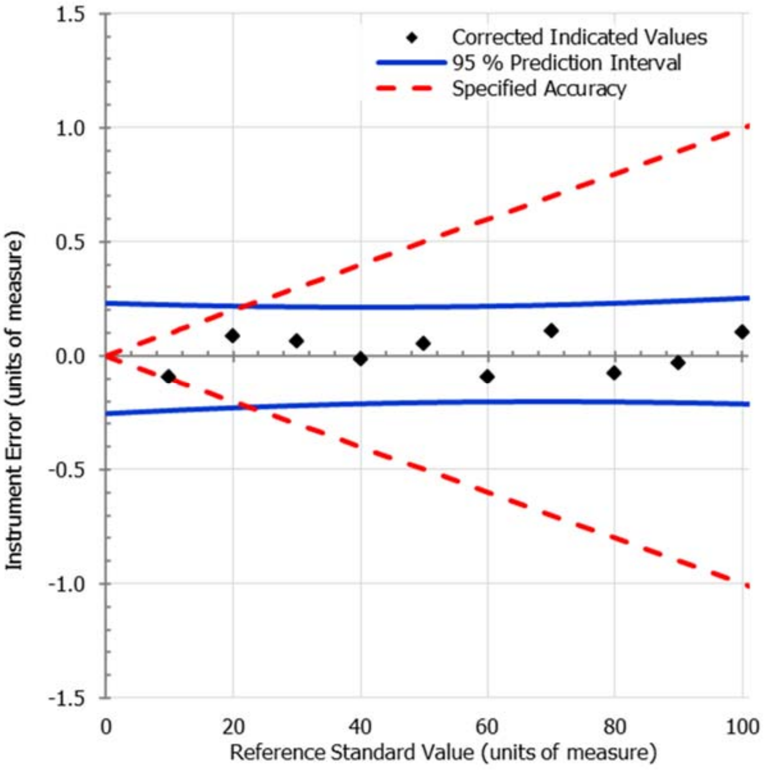

Figure 2b Sample of Absolute Calibration Evaluation Data

6.3.1.4 Temperature

6.3.1.4.1 Liquid. Measure entering and leaving liquid temperatures, °C (°F). Temperature sensor(s) shall be installed in a location that represents the average bulk fluid temperature.

Note*:* Non-mandatory but recommended practices to consider, especially if troubleshooting problems with energy balance. When deciding where to locate liquid temperature measurement sensors, consider the mixing effects of the piping configuration which may vary considerably across a range of flow rates. Check the spatial variation of temperature across a range of flow rates within a single plane perpendicular to the pipe, either with a movable (traversing) sensor or with multiple stationary sensors. If necessary, add flow conditioners or mixers.

6.3.1.4.1.1 Units with an optical integrated evaporator or condenser liquid pump shall be tested in either of the following two configurations.

If the pump is to be operational during the test, the pump shall not be located between the entering and leaving liquid temperature measurement locations. In this case, the unit must be modified to include a temperature measurement station between the pump and the heat exchanger. Care must be taken to ensure proper liquid mixing for an accurate representation of the bulk fluid temperature.

If the pump is not operational during the test, temperature measurements external to the unit shall be used. In this case, the liquid shall flow freely through the pump with the pump in the off position.

6.3.1.4.1.2 If evaporator or condenser liquid is used to add or remove heat to or from any other source(s) within the package, the temperature measurements shall be made at points so that the measurements reflect the Gross Capacity.

6.3.1.4.2 Air. Measurements shall be made with an instrument or instrument system, including read-out devices, meeting or exceeding the following accuracy and precision requirements detailed in Table 5a:

Table 5a. Temperature Measurement Requirements

Measurement	Accuracy	Measurement Resolution
Dry-Bulb and Wet-Bulb Temperatures[2]	≤ ±0.1 Δ°C (≤ ±0.2 Δ°F)	≤ ±0.05 Δ°C (≤ 0.1 Δ°F)
Air Sampling Tree Average Temperature[1]	≤ ±0.5 Δ°C (≤ ±1.0 Δ°F)	≤ ±0.05 Δ°C (≤ 0.1 Δ°F)

Notes:
1. If a thermopile is used for this measurement, then the thermocouple wire must have special limits of error, and all thermocouple junctions must be made from the same spool of wire; thermopile junctions are wired in parallel.
2. The accuracy specified is for the temperature indicating device and does not reflect the operation of the aspirating psychrometer.

To ensure adequate air distribution, thorough mixing, and uniform air temperature, it is important that the room and test setup is properly designed and operated. The room conditioning equipment airflow should be set such that recirculation of condenser discharged air is avoided. To check for the recirculation of condenser discharged air back into the condenser coil(s), the following method shall be used: Multiple individual reading thermocouples (at least one per sampling tree location) will be installed around the unit air discharge perimeter so that they are below the plane of condenser fan exhaust and just above the top of the condenser coil(s). These thermocouples may not indicate a temperature difference greater than 2.8 Δ°C (5.0 Δ°F) from the average inlet air. Air distribution at the test facility point of supply to the unit shall be reviewed and may require remediation prior to beginning testing. Mixing fans can be used to ensure adequate air distribution in the test room. If used, mixing fans must be oriented such that they are pointed away from the air intake so that the mixing fan exhaust direction is at an angle of 90°-270° to the air entrance to the condenser air inlet. Particular attention should be given to prevent recirculation of condenser fan exhaust air back through the unit.

A valid test shall meet the criteria for adequate air distribution and control of air temperature as shown in Table 5b.

Table 5b. Criteria for Air Distribution and Control of Air Temperature

Item	Purpose	Maximum Variation	
Dry-bulb Temperature		Δ°C	Δ°F
Deviation from the mean air dry-bulb temperature to the air dry-bulb temperature at any individual temperature measurement station [1]	Uniform temperature distribution	±1.00 (≤700 kW)	±2.00 (≤200 ton$_R$)
		±1.50 (>700 kW)	±3.00 (>200 ton$_R$)
Difference between dry-bulb temperature measured with air sampler thermopile and with aspirating psychrometer	Uniform temperature distribution	±0.80	±1.50
Difference between mean dry-bulb air temperature and the specified target test value [2]	Test condition tolerance, for control of air temperature	±0.50	±1.00
Mean dry-bulb air temperature variation over time (from the first to the last of the data sets)	Test operating tolerance, total observed range of variation over data collection time	±0.80	±1.00
Wet-bulb Temperature [3]			
Deviation from the mean wet-bulb temperature to the wet-bulb temperature at any individual temperature measurement station[1]	Uniform humidity distribution	±0.50	±1.00
Difference between mean wet-bulb air wet bulb temperature and the specified target test value [2]	Test condition tolerance, for control of air temperature	±0.50	±1.00

Mean wet-bulb air temperature variation over time	Test operating tolerance, total observed range of variation over data collection time (from the first to the last of the data sets)	±0.50	±1.00

Notes:
1. Each measurement station represents an average value as measured by a single Aspirating Psychrometer.
2. The mean dry-bulb temperature is the mean of all measurement stations.
3. The wet-bulb temperature measurement is only required for evaporatively-cooled units and heat pump chillers operating in the heating mode.

6.3.1.4.2.1 Air Sampling Tree Requirements. The air sampling tree is intended to draw a uniform sample of the airflow entering the Air-cooled Condenser section. A typical configuration for the sampling tree is shown in Figure 3 for a tree with overall dimensions of 1.2 m by 1.2 m (4 feet by 4 feet) sample. Other sizes and rectangular shapes can be used and should be scaled accordingly as long as the aspect ratio (width to height) of no greater than 2 to 1 is maintained. It shall be constructed of stainless steel, plastic, or other suitable, durable materials. It shall have a main flow trunk tube with a series of branch tubes connected to the trunk tube. It must have from 10 to 20 branch tubes. The branch tubes shall have appropriately spaced holes, sized to provide equal airflow through all the holes by increasing the hole size as you move further from the trunk tube to account for the static pressure regain effect in the branch and trunk tubes. The number of sampling holes shall be greater than 50. The average minimum velocity through the sampling tree holes shall be 0.75 m/sec (2.5 ft/sec) as determined by evaluating the sum of the open area of the holes as compared to the flow area in the aspirating psychrometer. The assembly shall have a tubular connection to allow a flexible tube to be connected to the sampling tree and to the aspirating psychrometer.

The sampling tree shall also be equipped with a grid to measure the average temperature of the airflow over the sampling tree. The grid shall have at least 16 points per sampling tree, evenly spaced across the sampling tree. The 16 points can be measured by a thermopile wired in parallel or by individual measurement devices. If individual measurement devices are used, then an average will be calculated to determine the air sampling tree temperature. The air sampling trees shall be placed within 15-30 cm (6-12 inches) of the unit to minimize the risk of damage to the unit while ensuring that the air sampling tubes are measuring the air going into the unit rather than the room air around the unit.

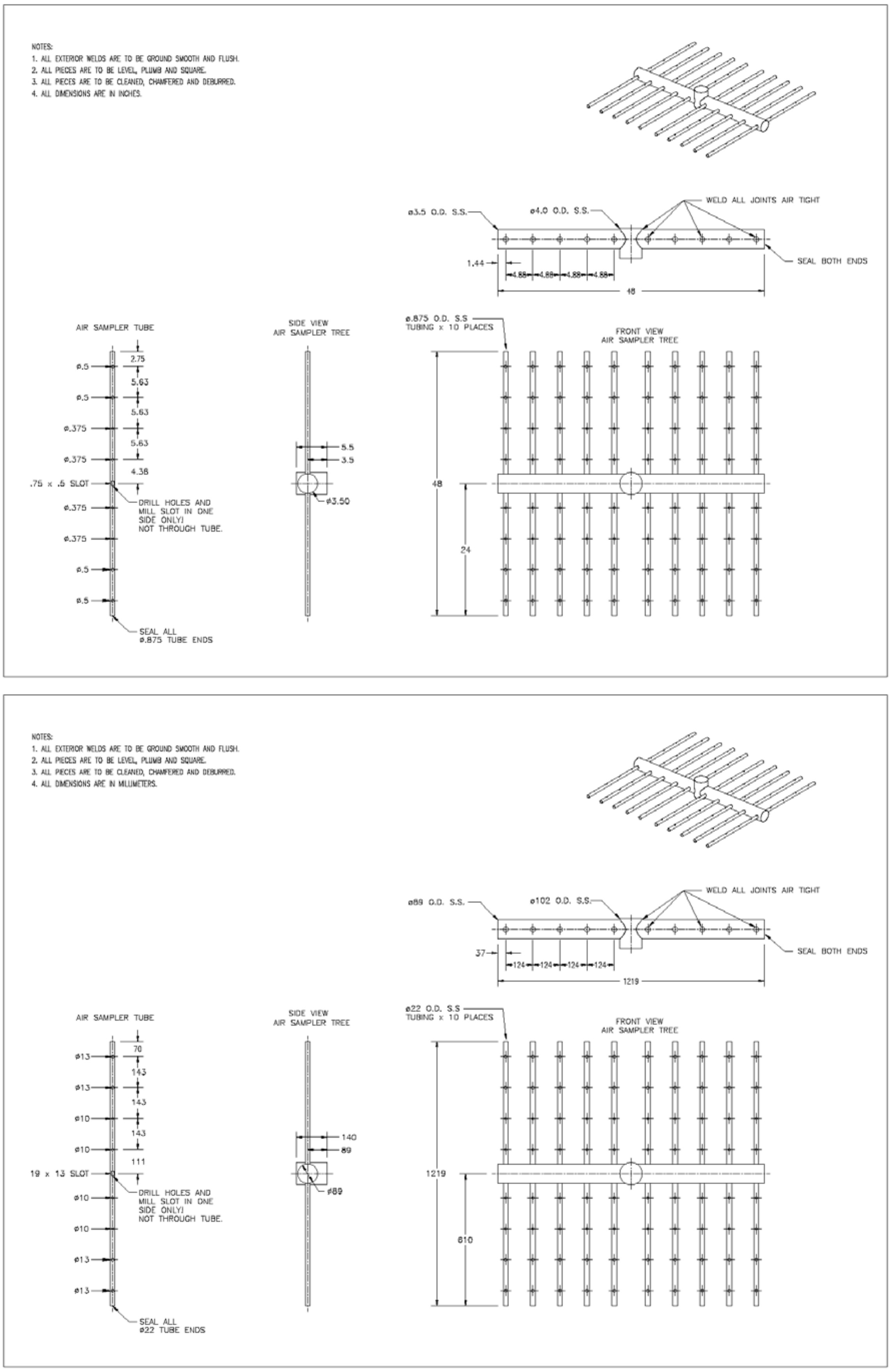

Figure 3. Typical Air Sampling Tree

Note: The 19 mm by 13 mm (0.75” by 0.50”) slots referenced in Figure 3 are cut into the branches of the sampling tree and are located inside of the trunk of the sampling tree. They are placed to allow air to be pulled into the main trunk from each of the branches. Drill holes and mill slot shall be on the same side of the sampling tube. The holes and slot shall only pass through the one side of the sampling tube.

6.3.1.4.2.2 Aspirating Psychrometer. The aspirating psychrometer consists of a flow section and a fan to draw air through the flow section and measures an average value of the sampled air stream. The flow section shall be equipped with two dry-bulb temperature probe connections, one of which will be used for the facility temperature measurement and one of which shall be available to confirm this measurement using an additional or a third-party’s temperature sensor probe. For applications where the humidity is also required, for testing of evaporatively-cooled units or heat pump chillers in heating mode, the flow section shall be equipped with two wet-bulb temperature probe connection zones, one of which will be used for the facility wet-bulb measurement and one of which shall be available to confirm the wet-bulb measurement using an additional or a third-party’s wet-bulb sensor probe. The psychrometer shall include a fan that either can be adjusted manually or automatically to maintain average velocity across the sensors. A typical configuration for the aspirating psychrometer is shown in Figure 4.

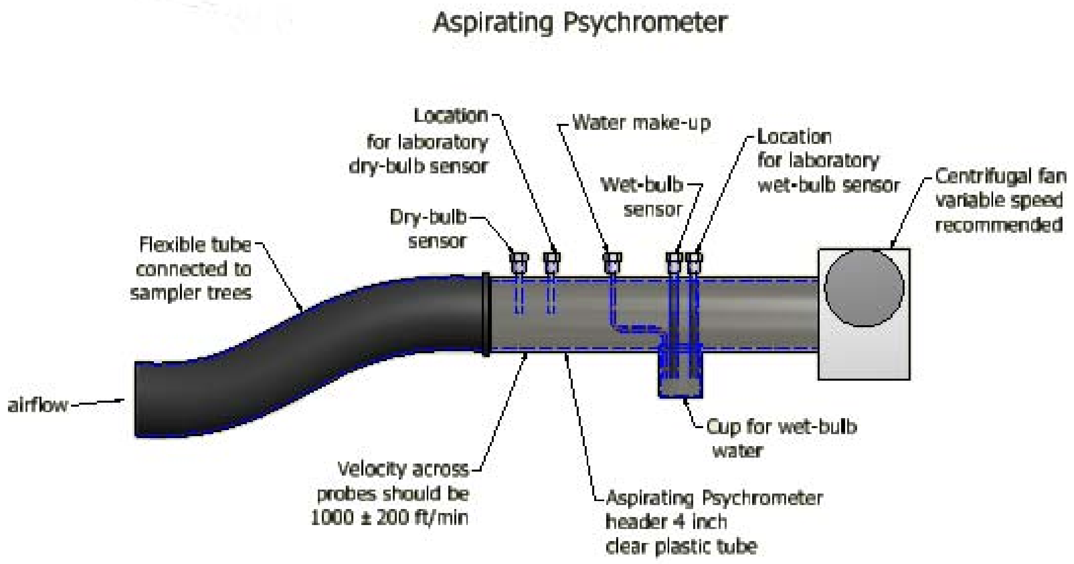

Figure 4. Aspirating Psychrometer

6.3.1.4.2.3 Test Setup Requirement. Air wet-bulb and/or dry-bulb temperature shall be measured at multiple locations entering the condenser, based on the airflow nominal face area at the point of measurement. Multiple temperature measurements will be used to determine acceptable air distribution and the mean air temperature.

6.3.1.5 Flow. Measure either liquid mass flow rate or volumetric flow rate and use the corresponding capacity calculation method in Section 5.4.1. If using a volumetric flow meter, the capacity calculation in Section 5.4.1.1 shall use the density corresponding to either of the following locations: (1) the temperature of the liquid at the location of flow meter; or (2) the liquid temperature measurement, either entering or leaving, which best represents the temperature at the flow meter. If the test plan specifies the target as a volumetric flow rate, the test plan shall reference whether the target volumetric flow rate applies at the inlet or outlet. If a volumetric measurement is made on the other connection location (opposite the test plan reference location), then the volumetric flow target at the measurement location shall be adjusted to have the same mass flow rate corresponding to the test plan target volumetric flow. If evaporator or condenser liquid is used to add or remove heat to or from any other source(s) within the package, the flow measurement(s) shall be made at points so that the measurements reflect the Gross Capacity.

6.3.1.6 Pressure. This section prescribes a measurement method for Liquid Pressure Drop across the heat exchanger. The measurement method only applies to pipe of circular cross section.

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

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

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

6.3.1.6.1.3 Static pressure taps shall maintain the following lengths of cylindrical straight pipe in the flow path adjacent to each pressure tap location in Table 6.

Table 6. Straight Length in Flow Path

Unit Connection, Nominal Pipe Size	Straight Length in Flow Path	
	Upstream of Pressure Tap	Downstream of Pressure Tap
≤75 mm (≤3 inches)	Minimum 10 · D	Minimum 3 · D
100, 125, or 150 mm (4, 5, or 6 inches)	Minimum 6 · D	Minimum 2 · D
≥200 mm (≥8 inches)	Minimum 3 · D	Minimum 1 · D

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

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

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

6.3.1.6.2.1 For design or evaluation purposes, flow resistance may be estimated by resistance coefficient K factor calculation methods as found in Crane Technical Paper No. 410. Generally, manifold tubing or piping can be evaluated using the K factor, and pressure tap holes can be evaluated using orifice flow equations (refer to Section 5).

6.3.1.6.2.2 For more information about the design of piezometer rings, see paper by Blake in the Informative References, Appendix A.

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

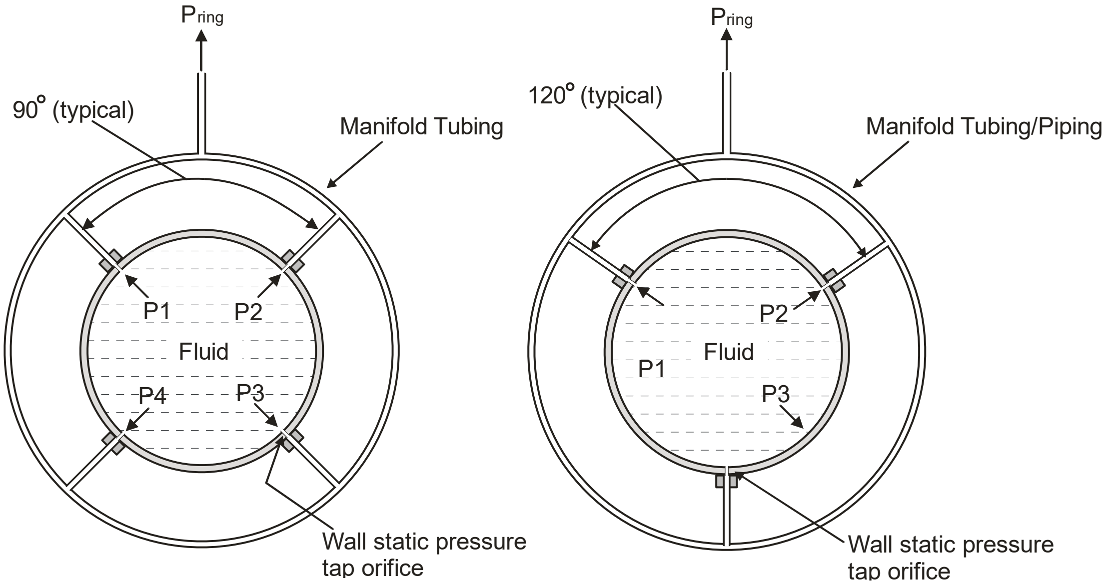

Figure 5a. Examples of Piezometer Ring/Manifold

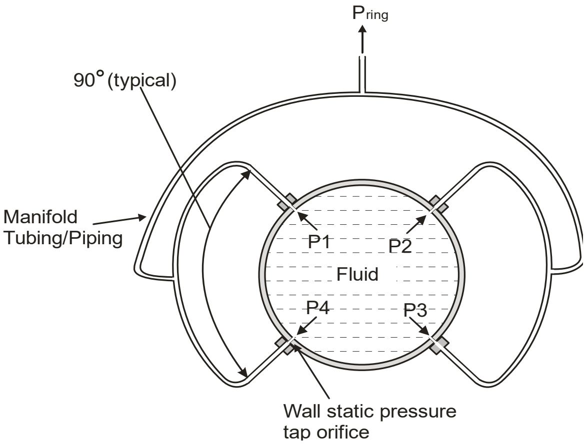

Figure 5b. Example of Triple-Tee Piezometer Ring/Manifold

6.3.1.7 Power. Power is the rate at which work is performed or energy is converted in electrical and mechanical systems. The total input power, including auxiliary power, shall be measured by summation of measurements at one or more locations defined in the following sections. Auxiliary power shall include those devices active during normal operation of the package; intermittent auxiliary power shall be reflected in the data points defined in Section 7, providing a time-averaged value over the duration of the test time period. For Liquid-cooled chillers, it will be necessary in some cases to make separate power measurements to segregate values and obtain valid energy balance.

Electrical measurements include voltage (for each phase), current (for each phase), power, and frequency (from a minimum of one phase). For units with a dual nameplate voltage rating, testing shall be performed at the lower of the two voltages. Electrical power measurements shall be made at appropriate location(s) to accurately measure the power input at the customer connection point(s) or terminals. The measurement location shall exclude losses from transformers or other equipment comprising the power supply of the test facility and shall minimize losses due to cabling from the measurement location to the connection point on the chiller.

6.3.1.7.1 For Air-cooled or Evaporatively-cooled Condensers, the test shall include the Condenser fan power and Condenser spray pump power in the measurement(s) of total input power.

6.3.1.7.2 For packages containing optional integrated liquid pumps, for evaporator or condenser, the test measurements shall exclude the pump power from the measurement of chiller input power (unless otherwise required by the applicable method of rating standard). For units tested with the integral pump turned off, the electrical power connection from the pump motor must be physically disconnected from the unit power by means of a contactor or disconnected wiring.

6.3.1.7.3 Power Measurement Considerations for Energy Balance. Input power that enters the refrigerant side of the circuit impacts the energy balance calculation. This includes compressor shaft input power and other refrigerant-cooled devices such as hermetic or semi-hermetic motors, variable speed drives, oil coolers, etc. If the energy balance validation criteria cannot be met, one possible cause is a significant quantity of input power lost to the ambient environment for air-cooled devices such as open-drive motors, starters, variable speed drives, oil coolers, controls, etc. If this is the case, then provide separate power measurement locations such that energy balance can be more accurately determined while also meeting the requirement to measure total input power to calculate efficiency.

6.3.1.7.4 **Electric Drive.** The input power shall be determined by measurement of electrical input to the chiller.

6.3.1.7.4.1 For electric-drive packages rated 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 and shall be measured on the input (line side). In the case of remote-mounted (free-standing) devices, substitute devices may be used during testing provided that they have similar power losses (within ±0.5%) and speed control method as the device supplied to the customer.

6.3.1.7.4.2 For electric-drive packages not rated with a starter or variable speed drive (not provided by the chiller manufacturer, in accordance with the applicable method of rating standard), input power shall be measured as close as practical to the compressor motor terminals. For the case of such packages rated for variable speed operation, a variable speed control method and variable speed drive type consistent with the chiller manufacturer installation requirements shall be used for the test.

6.3.1.7.4.3 When testing a chiller package that was rated with a motor supplied by others, the compressor shaft input power shall be measured by either of the following two methods:

Torque meter and rotational speed sensor installed between the compressor and another test motor used to conduct the test. Power is calculated from torque multiplied times speed.

Calibrated test motor with dynamometer or similar test data to determine the relationship between input and output power at the required load points. Electrical input power to the test motor is measured, then the corresponding output power is determined from calibration relationship.

6.3.1.7.5 Non-electric Drive. When turbine, engine drive, or other prime mover is employed, the total input power and compressor shaft input power for energy balance calculations shall be determined from steam or fuel consumption at measured supply and exhaust conditions and prime mover manufacturer's certified performance data. The total input power shall include the losses due to the prime mover and other driveline components such as a gearbox.

6.4 Plan. A test plan shall document all requirements for conducting the test. This includes a list of the required full load and part load test points and associated operating conditions, including adjusted liquid temperature targets based on the rated Fouling Factor Allowance.

6.5 Operating Condition Tolerances. Operating condition tolerances are defined to control two characteristics. The first is deviation of the mean value relative to the target value. The second is the stability, which is defined in statistical terms and allows excursions from the target that are brief in time and/or small in magnitude. Over the time period of each test point, the operating conditions shall be controlled to maintain the mean and standard deviation within the tolerances defined in Table 7.

Table 7 Definition of Operating Condition Tolerances and Stability Criteria

Measurement or Calculation Result		Applicable Operating Mode(s)	Values Calculated from Data Samples		Operating Condition Tolerance Limits	Stability Criteria
			Mean	Std Dev		
Net Capacity (Cooling or Heating)		Cooling, Heating, Heat Recovery	$\bar{Q}$	-	Unit with Continuous Unloading: Part Load test capacity shall be within 2% of the target part-load capacity [1] $\frac{\lvert\bar{Q}-Q_{target}\rvert}{Q_{100\%}} \le 2.000\%$	No requirement
					Units with Discrete Capacity Steps: Part Load test points shall be taken as close as practical to the specified part-load rating points as stated in the test plan	
Evaporator	Entering Water Temperature	Cooling	$\bar{T}$	s_T	No Requirement	$s_T \le 0.10$ °C [0.18 °F]
	Leaving Water Temperature				$\lvert\bar{T}-T_{target}\rvert \le 0.28$ Δ°C [0.50 Δ°F]	
Condenser	Entering Water Temperature					
	Leaving Water Temperature				No Requirement	
Evaporator	Entering Water Temperature [2]	Heating, Heat Recovery	$\bar{T}$	s_T	Heating portion: No requirement Defrost portion: $\lvert\bar{T}-T_{target}\rvert \le 1.11$ Δ°C [2.00 Δ°F]	Heating portion: $s_T \le$ 0.10 °C [0.18 °F] Defrost portion: $s_T \le 0.28$ °C [0.50 °F]
	Leaving Water Temperature [2]				Heating portion: $\lvert\bar{T}-T_{target}\rvert \le 0.28$ Δ°C [0.50 Δ°F] Defrost portion: no requirement	Heating portion: $s_T \le$ 0.10 °C [0.18 °F] Defrost portion: no requirement
Condenser	Leaving Water Temperature				$\lvert\bar{T}-T_{target}\rvert \le 0.28$ Δ°C [0.50 Δ°F]	$s_T \le 0.10$ °C [0.18 °F]
	Entering Water Temperature				No Requirement	

Table 7 Definition of Operating Condition Tolerances and Stability Criteria (contin.)

Evaporator or Condenser	Entering Air Mean Dry Bulb Temperature [3]	Cooling, Heating (non-frosting)	$\overline{T}$	s_T	$\left\|\overline{T} - T_{target}\right\| \le 0.56$ Δ°C [1.00 Δ°F]	$s_T \le 0.42$ °C [0.75 °F]
		Heating (frosting) [3]			Heating portion: $\left\|\overline{T} - T_{target}\right\| \le$ 1.11 Δ°C [2.00 Δ°F]	Heating portion: $s_T \le$ 0.56 °C [1.00 °F]
					Defrost portion: no requirement for $\overline{T}$	Defrost portion: $s_T \le 1.39$ °C [2.50°F]
	Entering Air Mean Wet Bulb Temperature [3]	Cooling, Heating (non-frosting)			$\left\|\overline{T} - T_{target}\right\| \le 0.56$ Δ°C [1.00 Δ°F]	$s_T \le 0.28$ °C [0.50 °F]
		Heating (frosting) [3]			Heating portion: $\left\|\overline{T} - T_{target}\right\| \le$ 0.83 Δ°C [1.50 Δ°F]	
					Defrost portion: no requirement for $\overline{T}$	
Water Flow (Volumetric, Entering)		Cooling, Heating, Heat Recovery	$\overline{V}_w$	s_{Vw}	$\frac{\left\|\overline{V}_w - V_{w,target}\right\|}{V_{w,target}} \le 5.000\%$	$\frac{s_{V_w}}{\overline{V}_w} \le 0.750\%$
Voltage [4] (if multiphase, this is the average of all phases)		Cooling, Heating, Heat Recovery	$\overline{V}$	s_V	$\frac{\left\|\overline{V} - V_{target}\right\|}{V_{target}} \le 10.00\%$	$\frac{s_V}{\overline{V}} \le 0.500\%$
Frequency [4]		Cooling, Heating, Heat Recovery	$\overline{\omega}$	s_ω	$\frac{\left\|\overline{\omega} - \omega_{target}\right\|}{\omega_{target}} \le 1.000\%$	$\frac{s_\omega}{\overline{\omega}} \le 0.500\%$
Condenserless Refrigerant Saturated Discharge Temperature		Cooling	$\overline{T}$	s_T	$\left\|\overline{T} - T_{target}\right\| \le 0.28$ Δ°C [0.50 Δ°F]	$s_T \le 0.14$ °C [0.25 °F]
Condenserless Liquid Temperature		Cooling	$\overline{T}$	s_T	$\left\|\overline{T} - T_{target}\right\| \le 0.56$ Δ°C [1.00 Δ°F]	$s_T \le 0.28$ °C [0.50 °F]
Steam Turbine Pressure/Vacuum [5]		Cooling, Heating, Heat Recovery	$\overline{p}$	s_p	$\left\|\overline{p} - p_{rating}\right\| \le 3.45$ kPa [0.500 psid]	$s_p \le 1.72$ kPa [0.250 psid]
Gas Turbine Inlet Gas Pressure [5]						Gas Turbine Inlet Gas Pressure [5]
Governor Control Compressor Speed [6]		Cooling, Heating, Heat Recovery	$\overline{n}$	s_n	$\frac{\left\|\overline{n} - n_{target}\right\|}{n_{target}} \le 0.500\%$	$\frac{s_n}{\overline{n}} \le 0.250\%$

Notes:

1. The ± 2.0% tolerance shall be calculated as 2.0% of the full load rated capacity (kW). 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.SI and NPLV.SI calculations. Outside this tolerance, interpolation shall be used.
2. 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.
3. When computing average air temperatures for heating mode tests, omit data samples collected during the defrost portion of the cycle.
4. 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 in 6.3.1.7. For dual nameplate voltage ratings, tests shall be performed at the lower of the two voltages.
5. For steam turbine and gas turbine drive machines the pressure shall be maintained at the nameplate rating values within the tolerance limits.
6. For speed controlled compressors the speed shall be maintained at the nameplate rating value within the tolerance limits.

6.6 Corrections. The following corrections shall be applied to test targets or test results when applicable.

6.6.1 Fouling Factor. Target liquid temperatures may be adjusted per the test plan in consideration of fouling of heat transfer surfaces.

6.6.2 Pressure Drop. The average measured Liquid Pressure Drop values during test shall be adjusted to subtract additional static pressure drop due to external piping. The additional static pressure drop shall be the sum of all losses between the unit connections and the location of static pressure taps. To account for measurement methods, the measured values of liquid pressure drop during testing shall be corrected per the methods defined in Section 5 prior to reporting the final test result for Liquid Pressure Drop.

6.7 Validation

6.7.1 Energy Balance. For the case of Liquid-cooled Condensers, measurement data shall be collected to calculate an *energy balance* (per Section 5.5.1) to substantiate the validity of each test point. Test validity tolerance for *energy balance* is found in Table 8. The energy balance (%) shall be within the allowable tolerance calculated per Section 5.6 for the applicable conditions.

For Air-cooled and Evaporatively-cooled Condensers, it is impractical to measure heat rejection in a test, and an energy balance cannot be readily calculated. To validate test accuracy, concurrent redundant instrumentation method per Section 6.7.4 shall be used to measure liquid temperatures, flow rates, and power inputs.

For heat reclaim units with Air-cooled Condensers or Liquid-cooled Condensers, where the capacity is not sufficient to fully condense the refrigerant, the concurrent redundant instrumentation methods in Section 6.7.4 shall be used.

For heat reclaim units with Liquid-cooled Condensers that fully condense the refrigerant, the energy balance method shall be used.

If evaporator liquid is used to remove heat from any other source(s) within the package, the temperature, pressure drop, and flow measurements of chilled liquid shall be made at points so that the measurements reflect the Gross Refrigerating Capacity.

If condenser liquid is used to cool the compressor motor or for some other incidental function within the package, the temperature, pressure drop, and flow measurements of condenser liquid must be made at points such that the measurements reflect the Gross Heating Capacity.

6.7.2 Voltage Balance. Multi-phase power supply with significant voltage unbalance can impact equipment operation and efficiency. Calculate voltage balance per Section 5.5.2. Test validity tolerance is found in Table 8. Voltage balance is not applicable to single phase units.

Table 8 Definition of Validity Tolerances

Parameter	Limits	Related Tolerance Equations[3]
Energy Balance[1]	$\lvert E_{bal} \rvert \leq Tol_4 \times 100\%$	IP: $Tol_4 = 0.074 - (0.049 \cdot \%Load) + \left(\frac{0.105}{\Delta T_{FL} \cdot \%Load}\right)$ SI: $Tol_4 = 0.074 - (0.049 \cdot \%Load) + \left(\frac{0.05833}{\Delta T_{FL} \cdot \%Load}\right)$
Voltage Balance[2]	$V_{bal} \leq 2.0\%$	

Notes:
1. Energy balance where applicable shall be calculated in accordance with Section 5.5.1.
2. Not applicable to single phase units. Voltage unbalance calculated per Section 5.5.2.
3. %Load and Tol_4 are in decimal form.

The following figure is a graphical representation of the related tolerance equation for energy balance as noted in Table 8.

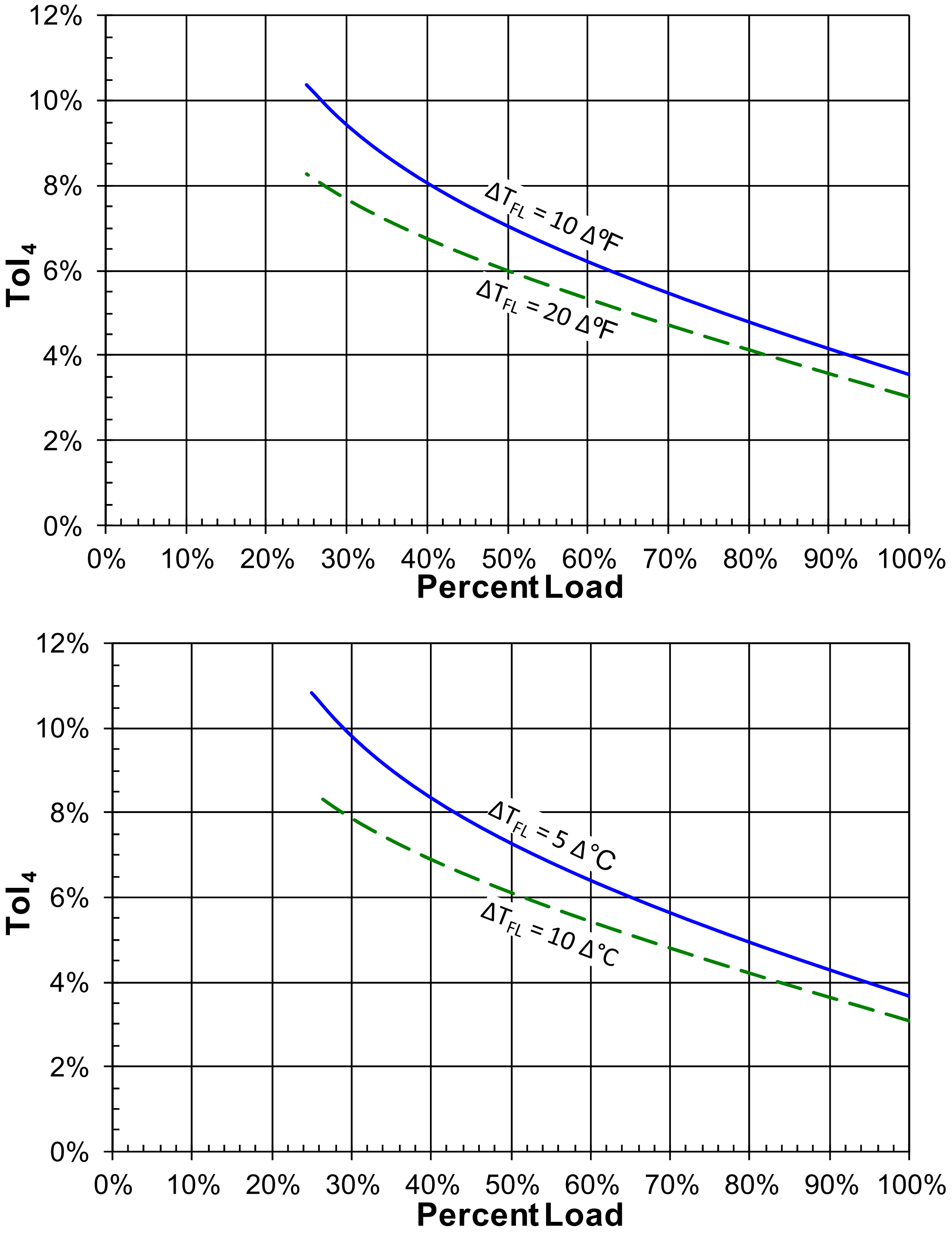

Figure 6 Energy Balance Tolerance (Tol$_4$) Curve

6.7.3 Uncertainty Analysis. This standard requires an uncertainty analysis for measurements and test results. Perform uncertainty analysis following the procedures in ASME PTC 19.1 *Test Uncertainty*.

6.7.4 Concurrent Redundant Instrumentation. For the case of Air-cooled or Evaporatively-cooled Condensers, or Air-source Evaporators for Heating Mode, redundant measurement data shall be collected to substantiate the validity of each test point.

6.7.4.1 Measurement of Verification. Redundant instrument measurements shall be within the limitation in the following sections:

6.7.4.1.1 Entering liquid temperature measurements shall not differ by more than 0.1 Δ°C (0.2 Δ°F).

6.7.4.1.2 Leaving liquid temperature measurements shall not differ by more than 0.1 Δ °C (0.2 Δ°F).

6.7.4.1.3 Flow measurements shall not differ by more than 2%.

6.7.4.1.4 Power input measurements shall not differ by more than 2%.

7. DATA TO BE RECORDED

7.1 Primary Data. Table 9 summarizes the data to be recorded during the test for each of the data point samples.

Table 9 Data to be Recorded During the Test

Type		Data Item
All Types	General	Time of day for each data point sample
		Atmospheric pressure
	Evaporator	T_{in}
		T_{out}
		m_w or V_w
		Δp_{test}
Liquid-cooled Condenser	Condenser	T_{in}
Liquid-cooled Heat Reclaim Condenser		T_{out}
		m_w or V_w
		Δp_{test}
Air-cooled Condenser	Condenser	Spatial average dry-bulb temperature of entering air
Evaporatively-cooled Condenser	Condenser	Spatial average dry-bulb temperature of entering air
		Spatial average wet-bulb temperature of entering air
Without Condenser	Compressor	Discharge temperature
		Discharge pressure
	Liquid Line	Liquid refrigerant temperature entering the expansion device
		Liquid pressure entering the expansion device
Electric Drive	Chiller	W_{input} (and W_{refrig} if needed)
		Voltage for each phase
		If 3-phase: average voltage
		Frequency for one phase
Non-Electric Drive	Chiller	W_{input} (and W_{refrig} if needed)
		If Steam Turbine: Steam consumption Steam supply pressure Steam supply temperature Steam exhaust pressure
		If Gas Turbine or Gas Engine: fuel consumption (natural gas or propane) calorific value
		If Internal Combustion Engine: liquid fuel consumption (diesel or gasoline) calorific value

7.2 Auxiliary Data. Table 10a summarizes the auxiliary data that shall be recorded for the test.

Table 10a. Auxiliary Data to be Recorded

Type	Data Item
All	Date, place, and time of test
	Names of test supervisor and witnessing personnel
	Ambient temperature at test site
	Nameplate data, including make, model, size, serial number, and refrigerant designation number, sufficient to completely identify the liquid chiller. Unit voltage and frequency shall be recorded.
	Prime mover nameplate data (motor, engine, or turbine).
Non-electric Drive	Fuel specification (if applicable) and calorific value

Table 10b summarizes optional auxiliary data (non-mandatory) that may be recorded during the test for diagnostic information.

Table 10b. Optional Auxiliary Data to be Recorded

Type	Data Item
Open-type compressor	Compressor driver rotational speed
Electric Drive	Current for each phase of electrical input to chiller package
All	Liquid pump input power for integral pump(s)

7.3 Refer to Normative Appendix B for schematics of each system type and the physical location of measurement instruments.

8. TEST PROCEDURES

8.1 Purpose. This section prescribes a method of testing for Liquid-chilling and Liquid-heating Packages using the vapor compression cycle and to verify capacity and power requirements at a specific set of steady-state conditions.

Testing shall be conducted at a facility designed specifically for that purpose where instrumentation is in place and load stability can be obtained.

Testing shall not be conducted in field installations to the provisions of this standard. Steady-state conditions and requirements for consistent, reliable measurement are difficult to achieve in field installations.

8.2 Test Procedures. For each test point at a specific load and set of operating conditions, the test will measure capacity, input power, and liquid-side pressure drop. Capacity, a measurement of the heat added to or removed from the liquid as it passes through the heat exchanger, may be cooling, heating, heat recovery, and/or heat reclaim according to the test plan. Net capacity is always required, and gross capacity is required when an energy balance requirement applies. Each test point will collect multiple data points versus time. The test shall use instrumentation meeting the requirements in Section 6 and calculations in Section 5

8.2.1 Setup. The chiller package to be tested shall be setup at the test facility in accordance with the manufacturer's instructions, including, but not limited to support of installation mounting points, connections for liquid, connections for power supply, test instrumentation, charging of refrigerant or oil, etc. Non-condensable gases, if present, shall be removed from the system

8.2.1.1 Condition of Heat Transfer Surfaces. The as tested Fouling Factors shall be assumed to be zero ($R_{foul} = 0.00\overline{0}\ \text{m}^2\cdot\text{K/kW} = 0.00\overline{0}\ \text{h}\cdot\text{ft}^2\cdot{}^\circ\text{F/Btu}$). Tests conducted in accordance with this standard may require cleaning of the heat transfer surfaces (in accordance with manufacturer's instructions) prior to conducting the test.

8.2.2 Operation. After setup is complete, the chiller will be started and operated to attain the target conditions of the test point per the test plan. The chiller is not required to operate continuously between different test points; shut down and re-start between test points is allowable.

8.2.2.1 General. Steady-state operating conditions and performance shall be maintained for a minimum test time period of 15 minutes, such that measurement parameters, associated standard deviations, and test results are within both the operating condition tolerances and test tolerances set forth in Section 6.5. If not within tolerance due to lack of stability, then continue testing until within tolerance. If not within tolerance but stability is acceptable, then stop testing to investigate and resolve instrumentation problems, then repeat the test. Resolving problems may require new calibration of instrumentation.

To minimize the effects of transient conditions, all measurement types should be taken as simultaneously as possible (flow, temperature, power, etc.). Software or other recording methods shall be used to capture time-stamped data points over the duration of the test time period. A minimum of 30 data point measurements shall be collected and recorded for each parameter at uniform time intervals. Intervals between time stamps shall not vary more than ±5% from the average time interval for all data points. Each data point measurement may represent either an individual reading from the measurement system, or a time averaged value from a larger number of data samples. In the case of using time averaging, whether in hardware or software, the time interval for averaging of data samples shall not exceed 1/60 of the total test time period. There is no limit on sampling rate, and various time averaging methods may be employed.

Measurement values include temperatures, flow rates, differential pressure, power, voltage, fuel or steam consumption, and atmospheric pressure. Calculate the average and standard deviation for each measurement value.

Test results include Net Capacity, Efficiency, and Liquid Pressure Drop (corresponding to certification program published rating values). Calculate test results using the mean of the test measurement values. Capacity may be calculated for each data point for purposes of test facility control, but the final result for capacity shall be calculated from the mean of all measurement values.

8.2.3 Adjustments

8.2.3.1 Controls. Manual operation of chiller controls is allowed to avoid cycling and disruption of test stability

8.2.3.2 Refrigerant. Refrigerant charge may be adjusted during setup, prior to conducting the test, in accordance with manufacturer's instructions which may require operation of the chiller. Refrigerant charge quantity shall be held constant for the duration of the test, including all test points in a series of full load and part load tests.

8.3 Chiller Condenser Entering Air Temperature Measurement Procedure

8.3.1 Purpose. The purpose of this section is to prescribe a method for measurement of the air temperature entering the Air-cooled or Evaporatively-cooled Condenser section of an Air-cooled Liquid-chilling Package. This section also defines the requirements for controlling the air stratification and what is considered acceptable for a test. Measurement of the air temperatures are needed to establish that the conditions are within the allowable tolerances of this standard. For air-cooled chillers operating in the cooling mode, only the dry-bulb temperature is required. For Evaporatively-cooled and heat pump chilled liquid packages operating in the heating mode, both the dry-bulb and wet-bulb temperatures are required for the test.

8.3.2 Test Setup Description. The use of air sampling trees as a measuring station reduces the time required to setup a test and allows an additional or third party sensor(s) for redundant dry-bulb and wet-bulb temperatures. Only the dry-bulb sensors need to be used for Air-cooled Condensers, but wet-bulb temperature shall be used with Evaporatively-cooled and heat pump chillers running in the heating mode.

The nominal face area may extend beyond the condenser coil depending on coil configuration and orientation and must include all regions through which air enters the unit. The nominal face area of the airflow shall be divided into a number of equal area sampling rectangles with aspect ratios no greater than 2 to 1. Each rectangular area shall have one air sampler tree.

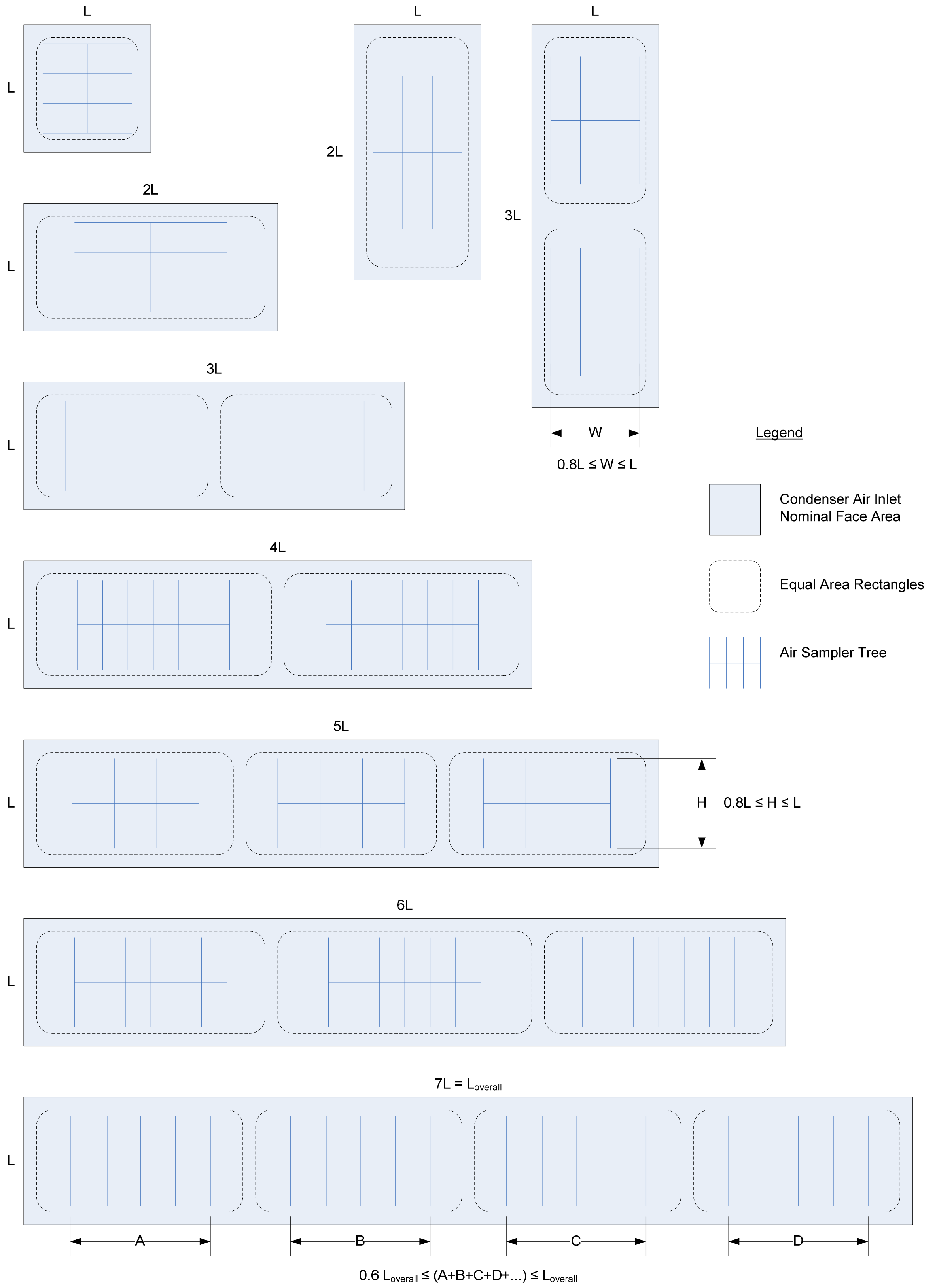

Figure 7a. Determination of Measurement Rectangles and Required Number of Air Sampler Trees

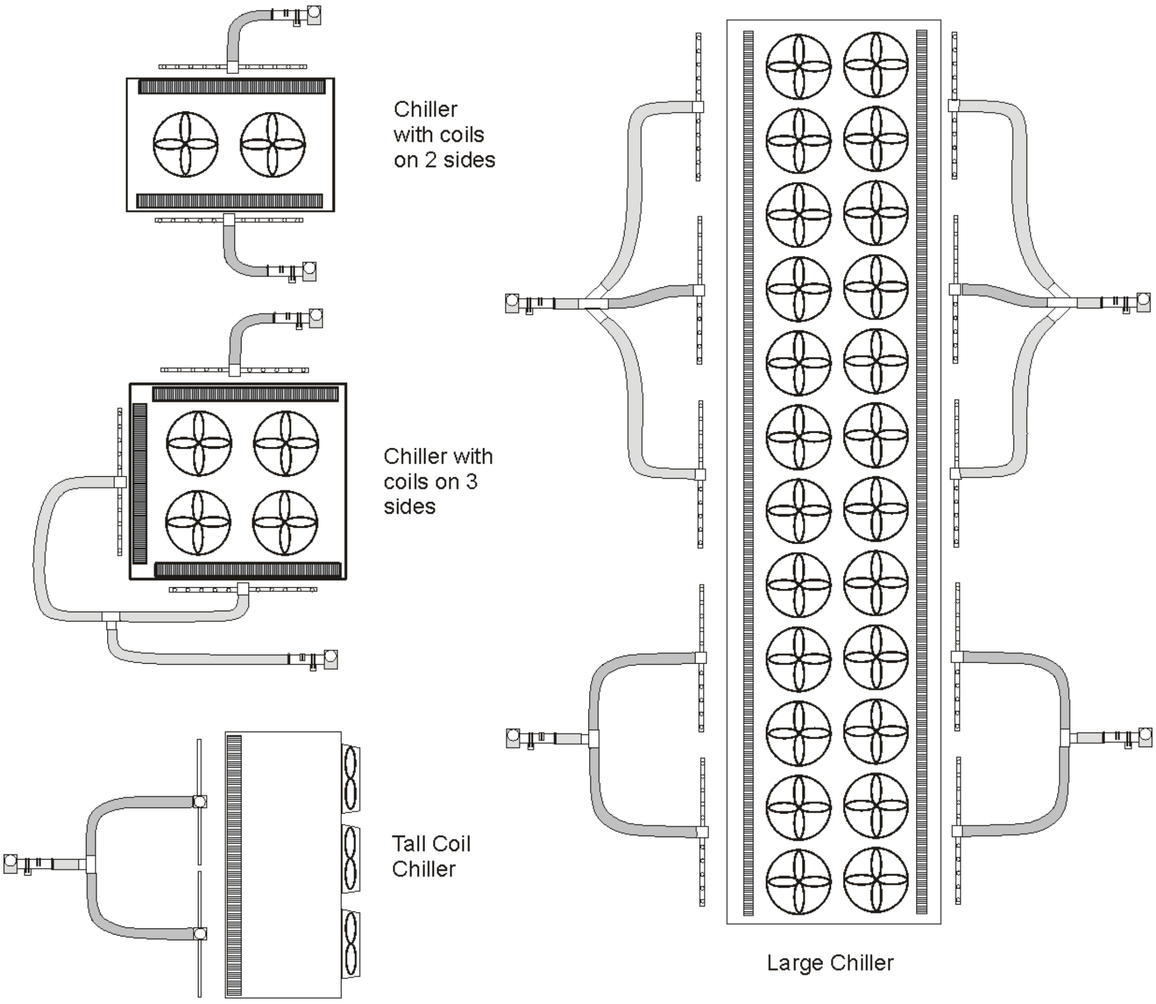

Figure 7b Typical Test Setup Configurations

A minimum of one aspirating psychrometer per side of a chiller shall be used. For units with three (3) sides, two (2) sampling aspirating psychrometers can be used but will require a separate air sampler tree for the third side. For units that have air entering the sides and the bottom of the unit, additional air sampling trees should be used.

A minimum total of two (2) air sampler trees shall be used in any case, in order to assess air temperature uniformity.

The air sampler trees shall be located at the geometric center of each rectangle; either horizontal or vertical orientation of the branches is acceptable. The sampling trees shall cover at least 80% of the height and 60% of the width of the air entrance to the unit (for long horizontal coils), or shall cover at least 80% of the width and 60% of the height of the air entrance (for tall vertical coils). The sampling trees shall not extend beyond the face of the air entrance area. It is acceptable to block all branch inlet holes that extend beyond the face of the unit. Refer to Figure 7a for examples of how an increasing number of air sampler trees are required for longer condenser coils.

A maximum of four (4) sampling trees shall be connected to each aspirating psychrometer. The sampling trees should be connected to the aspirating psychrometer using flexible tubing that is insulated and routed to prevent heat transfer to the air stream. In order to proportionately divide the flow stream for multiple sampling trees for a given aspirating psychrometer, the flexible tubing should be of equal lengths for each sampling tree. Refer to Figure 7b for some typical examples of air sampler tree and aspirating psychrometer setups.

For Part-load test points, aspirating psychrometers positioned at non-operating portions of the coil on the test chiller may be excluded from the calculations.

8.4 Liquid Pressure Drop Measurement Procedure

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

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

8.4.3 Correction Method. The average measured Liquid Pressure Drop values during test shall be adjusted to subtract additional static pressure drop due to external piping. The additional static pressure drop shall be the sum of all losses between the unit connections and the location of static pressure taps. Record the original measured value, the calculated adjustment value, and the final calculated corrected test result for Liquid Pressure Drop.

8.4.3.1 The adjustment shall not exceed 10% of the measured Liquid Pressure Drop.

8.4.3.2 Refer to Section 5.4.4 for the equations to be used.

8.5 Heating Capacity Test Procedure

8.5.1 This section prescribes methods of testing for measurement of liquid-side Heating Capacity for Air Source Heat Pump Liquid-heating Packages.

8.5.2 "S" Test Procedure

8.5.2.1 The dry-bulb temperature and liquid vapor content of the air entering the outdoor-side shall be sampled at equal intervals of one minute throughout the pre-conditioning and data collection periods. Over these same periods, all other applicable Table 7 non-frosting parameters used in evaluating equilibrium shall be sampled at equal intervals of five minutes. All data collected over the respective periods, except for parameters sampled between a defrost initiation and ten minutes after the defrost termination, shall be used to evaluate compliance with the test tolerances specified in Table 7.

8.5.2.2 The test room reconditioning apparatus and the equipment under test shall be operated until equilibrium conditions are attained, but for not less than one hour, before test data are recorded. At any time during the pre-conditioning period, the heat pump may undergo one or more defrost cycles if automatically initiated by its own controls. The pre-conditioning period may, in addition, end with a defrost cycle and this period ending defrost cycle may be either automatically or manually initiated. Ending the pre-conditioning period with a defrost cycle is especially recommended for Heating Capacity tests at low outdoor temperatures. If a defrost does occur, the heat pump shall operate in the heating mode for at least ten minutes after defrost termination prior to resuming or beginning the data collection described in Sections 8.5.2.1 and 8.5.2.2, respectively.

8.5.2.3 Once the pre-conditioning described in Section 8.5.2.2 is completed, the data required for the specified test shall be collected. These data shall be sampled at equal intervals that span five minutes or less. The net Heating Capacity Qcd shall be evaluated at equal intervals of five minutes. The capacity evaluated at the start of the data collection period, Qcd(t =0), shall be saved for purposes of evaluating Sections 8.5.2.4.1 or 8.5.2.5.1 compliance.

8.5.2.4 Test Procedures if the Pre-Conditioning Period Ends with a Defrost Cycle.

8.5.2.4.1 Data collection shall be suspended immediately if any of the following conditions occur prior to completing a 30-minute interval where Table 7 non-frosting test tolerances are satisfied:

8.5.2.4.1.1 If the heat pump undergoes a defrost;

8.5.2.4.1.2 If the indoor-side liquid temperature difference degrades such that the degradation ratio exceeds 0.050 (refer to Equation 8.5.2.6); or

8.5.2.4.1.3 If one or more of the applicable Table 7 non-frosting test tolerances are exceeded.

8.5.2.4.2 If the “S” test procedure is suspended because of Section 8.5.2.1.1, then the “T” test procedure described in Section 8.5.3 shall be used.

8.5.2.4.3 If the “S” test procedure is suspended because of 8.5.2.1.2, then the “T” test procedure described in 8.5.3 shall be used.

8.5.2.4.4 If the “S” test procedure is suspended because of Section 8.5.2.1.3, then another attempt at collecting data in accordance with 8.5.2 and the “S” test procedure shall be made as soon as steady performance is attained. An automatic or manually initiated defrost cycle may occur prior to making this subsequent attempt. If defrost does occur, the heat pump shall operate in the heating mode for at least ten minutes after defrost termination prior to beginning the data collection described in Section 8.5.2.3. The pre-conditioning requirements in Section 8.5.2.2 are not applicable when making this subsequent attempt.

8.5.2.4.5 If the “S” test procedure is not suspended in accordance with Section 8.5.2.4.1, then the sampling specified in Section 8.5.2.3 shall be terminated after 30 minutes of data collection. The test, for which the Table 7 test tolerances for non-frosting apply, shall be designated as a completed steady-state Heating Capacity test and shall use the average of the seven (7) samples at the reported net Heating Capacity.

8.5.2.5 Test Procedure if the Pre-conditioning Period Does Not End with a Defrost Cycle

8.5.2.5.1 Data collection shall be suspended immediately if any of the following conditions occur prior to completing a 30-minute interval where Table 7 non-frosting test tolerances are satisfied:

8.5.2.5.1.1 If the heat pump undergoes a defrost;

8.5.2.5.1.2 If the indoor-side liquid temperature difference degrades such that the degradation ratio exceeds 0.050 (refer to Equation 8.5.2.6); or

8.5.2.5.1.3 If one or more of the applicable Table 7 non-frosting test tolerances are exceeded.

8.5.2.5.2 If the “S” test procedure is suspended because of condition “a” of Section 8.5.2.5.1, then another attempt at collecting data in accordance with Sections 8.5.2.3 and 8.5.2.4 shall be made beginning ten minutes after the defrost cycle is terminated. The pre-conditioning requirements of Section 8.5.2.2 are not applicable when making this subsequent attempt.

8.5.2.5.3 If the “S” test procedure is suspended because of condition “b” of Section 8.5.2.5.1, then another attempt at collecting data in accordance with Sections 8.5.2.3 and 8.5.2.4 shall be made. This subsequent attempt shall be delayed until ten minutes after the heat pump completes a defrost cycle. This defrost cycle should be manually initiated, if possible, in order to avoid the delay of having to otherwise wait for the heat pump to automatically initiate a defrost.

8.5.2.5.4 If the “S” test procedure is suspended because of condition “c” of Section 8.5.2.5.1, then another attempt at collecting data in accordance with Section 8.5.2 and the “S” test procedure shall be made as soon as steady performance is attained. An automatic or manually initiated defrost cycle may occur prior to making this subsequent attempt. If a defrost does occur, the heat pump shall operate in the heating mode for at least ten minutes after defrost termination prior to beginning the data collection described in Section 8.5.2.3. The pre-conditioning requirements in Section 8.5.2.2 are not applicable when making this subsequent attempt.

8.5.2.5.5 If the “S” test procedure is not suspended in accordance with Section 8.5.2.5.1, then the sampling specified in Section 8.5.2.3 shall be terminated after 30 minutes of data collection. The test, for which the Table 7 test tolerances for non-frosting apply, shall be designated as a completed steady-state Heating Capacity test and shall use the average of the seven (7) samples at the reported net Heating Capacity.

8.5.2.6 Frosting capacity degradation ratio used in the “S” Test Procedure is defined as:

$$\text{Frosting capacity degradation ratio} = \frac{Q_{cd(\tau=0)} - Q_{cd(\tau)}}{Q_{cd(\tau=0)}}$$

8.5.3 “T” Test Procedure

8.5.3.1 Average Heating Capacity shall be determined using the indoor liquid temperature method. The normal outdoor-side airflow of the equipment shall not be disturbed.

8.5.3.2 No changes in the liquid flow or air flow settings of the heat pumps shall be made.

8.5.3.3 The test tolerance given in Table 7, “heat with frost,” shall be satisfied when conducting Heating Capacity tests using the “T” test procedure. As noted in Table 7, the test tolerances are specified for two sub-intervals. “Heat portion” consists of data collected during each heating interval; with the exception of the first ten minutes after defrost termination. “Defrost portion” consists of data collected during each defrost cycle plus the first ten minutes of the subsequent heating interval. In case of multiple refrigerant circuits, “Defrost portion” applies if any individual circuit is in defrost cycle. The test tolerance parameters in Table 7 shall be sampled throughout the pre-conditioning and data collection periods. For the purpose of evaluating compliance with the specified test tolerances, the dry-bulb temperature of the air entering the outdoor-side shall be sampled once per minute during the heat portion and once per 20 second intervals during the defrost portion. The liquid vapor content of the air entering the outdoor-side shall be sampled once per minute. All other Table 7 “heat with frost” parameters shall be sampled at equal intervals that span five minutes or less.

All data collected during each interval, heat portion, and defrost portion shall be used to evaluate compliance with the Table 7 “heat with frost” tolerances. Data from two or more heat portion intervals or two or more defrost portion intervals shall not be combined and then used in evaluating Table 7 “heat with frost” compliance. Compliance is based on evaluating data for each interval separately.

8.5.3.4 The test room reconditioning apparatus and the equipment under test shall be operated until equilibrium conditions are attained, but for not less than one hour. Elapsed time associated with a failed attempt using the “S” test procedure of Section 8.5.2 may be counted in meeting the minimum requirement for one hour of operation. Prior to obtaining equilibrium and completing one hour of operation, the heat pump may undergo a defrost(s) cycle if automatically initiated by its own controls.

8.5.3.5 Once the pre-conditioning described in Section 8.5.3.4 is completed, a defrost cycle shall occur before data are recorded. This defrost cycle should be manually initiated, if possible, in order to avoid the delay of having to otherwise wait for the heat pump to automatically initiate a defrost. Data collection shall begin at the termination of the defrost cycle and shall continue until one of the following criteria is met. If, at an elapsed time of three hours, the heat pump has completed at least one defrost cycle per refrigerant circuit, and a defrost cycle is not presently underway, then data collection shall be immediately terminated. If, at an elapsed time of three hours, the heat pump is conducting a defrost cycle, the cycle shall be completed before terminating the collection of data. If three complete cycles are concluded prior to three hours, data collection shall be terminated at the end of the third cycle, provided that each circuit in a multiple circuit design has had at least one defrost cycle. A complete cycle consists of a heating period and a defrost period, from defrost termination to defrost termination. For a heat pump where the first defrost cycle is initiated after three hours but before six hours have elapsed, data collection shall cease when this first defrost cycle terminates. Data collection shall cease at six hours if the heat pump does not undergo a defrost cycle within six hours.

8.5.3.6 In order to constitute a valid test, the test tolerances in Table 7 “heat with frost” shall be satisfied during the applicable Section 8.5.3.5 test period. Because the test begins at defrost termination and may end at a defrost termination, the first defrost portion interval will only include data from the first ten-minute heating interval while the last defrost portion interval could potentially include data only from the last defrost cycle.

8.5.3.7 The data required for the indoor liquid side capacity test method shall be sampled at equal intervals of five minutes, except during the following times when the liquid entering and leaving the indoor-side shall be sampled every ten seconds during

- Defrost cycles and
- The first ten minutes after a defrost termination (includes the first ten minutes of the data collection interval).

8.5.3.8 Average Heating Capacity and average input power shall be calculated in accordance with Section 5.4.3.2.2 using data from the total number of complete cycles that are achieved before data collection is terminated. In the event that the equipment does not undergo a defrost during the data collection interval, the entire six-hour data set shall be used for the calculations.

9. REPORTING OF RESULTS

9.1 General

9.1.1 Refrigerant designation shall be in accordance with ANSI/ASHRAE Standard 34.

9.1.2 Report shall identify Net Refrigerating Capacity or Net Heating Capacity (equations in Section 5.4.1), W (Btu/h or ton_R).

9.1.3 Total input power to chiller, W or kW or MW, shall be identified.

9.1.3.1 Excluding power input to integrated liquid pumps, when present (refer to Section 6.3.1.7.2).

9.1.4 Report shall identify Energy Efficiency, expressed as Energy Efficiency Ratio, Coefficient of Performance, or Power Input per Capacity, with qualifier to indicate operating mode (Cooling, Heating, Simultaneous Heating and Cooling, or Heat Recovery), Btu/W·h or W/W or kW/kW or kW/ton_R.

It is important to note that pump energy associated with pressure drop through the chiller heat exchangers is not included in the chiller input power. This is done because any adjustment to the chiller performance would confuse the overall system analysis for capacity and efficiency. It is therefore important for any system analysis to account for the cooling loads associated with the system pump energy and to include the pump power into the overall equations for system efficiency.

9.1.5 Chilled liquid entering and leaving temperatures, °C (ºF), or leaving liquid temperature and temperature difference, Δ°C(ΔºF)

9.1.5a Chillers with an integral pump: Evaporator heat exchanger Liquid Pressure Drop at rated water temperatures, kPa (ft H_2O (at 60ºF) or psid)

9.1.5b Chillers without an integral pump: Chilled Liquid Pressure Drop at rated water temperature (customer inlet to customer outlet), kPa (ft H_2O (at 60ºF) or psid).

Note: Due to industry typical practice, Liquid Pressure Drop is often reported in head (ft H_2O); however, test data is acquired in pressure, psid, for use in calculations.

9.1.6 Chilled liquid flow rate, L/s or m^3/h (gpm), at entering heat exchanger conditions.

9.1.7 Nominal voltage, V or kV, and frequency, Hz, for which ratings are valid. For units with a dual nameplate voltage rating, testing shall be performed at the lower of the two voltages.

9.1.8 Components that utilize Auxiliary Power shall be listed.

9.1.9 Part load weighted efficiency metric IPLV.IP or NPLV.IP, expressed as Energy Efficiency Ratio, Coefficient of Performance, or Power Input per Capacity, Btu/W·h or W/W or kW/kW or kW/ton_R, for Cooling operating mode only.

9.1.10 Test Results. Test Results shall be rounded to the number of significant figures identified in Section 5.7, using the definitions in Section 3, and rounding rules and formats in Section 5.7. A written test report shall be generated including the data included in Section 7 for each test point at a specific load and set of operating conditions.

9.2 Data. For each test point, at a specific load and set of operating conditions report the test time period and number of data point measurements. Include the sample mean and sample standard deviation for each measurement value (temperature, flow, pressure drop, power, etc.).

9.3 Calculations. Report the correction adjustment values Δp_{adj} and ΔT_{adj}, correction factors CF_Q and $CF\eta$ when applicable, and associated input data used for the correction calculations. Report the density, specific heat capacity, and mass flow values used for capacity calculations. Report all values of Q used in energy balance calculations.

9.4 Results. Report the test results following calculations and procedures identified in Sections 5 and 8. Table 11 provides a generic summary;

Table 11 Results to be Reported

Item	Units of Measure	
	SI	**IP**
Net Capacity (heating and/or cooling as applicable; corrected if applicable)	kW or W	ton_R or Btu/h
Gross Capacity (heating and cooling, only for liquid-cooled condenser type)	kW or W	ton_R or Btu/h
Input Power (W_{input}; and W_{refrig} as applicable)	kW or W	kW or W
Efficiency (corrected if applicable)	COP	kW/ton_R, EER, or COP
$\Delta p_{corrected}$	kPa	ft H_2O (at 60°F)
Energy Balance	%	%
Voltage Balance	%	%

9.4.1 Test Results Reporting Requirements

9.4.2 Tests shall report calculated results in accordance with methods and procedures described in this method of test, Section 5 and Section 8. The final test report shall include:

9.4.2.1 Name and address of the chiller test facility.

9.4.2.2 Report identification number and disclaimer.

9.4.2.3 Description of test chiller, including Model and Serial numbers.

9.4.2.4 Date and time of tests.

9.4.2.5 Instrumentation and calibration list from test facility.

9.4.2.6 Chilled Water Capacity.

9.4.2.7 Total Input Power.

9.4.2.8 Efficiency.

9.4.2.9 Chilled Water Pressure Drop.

9.4.2.10 Water-cooled Condenser.

9.4.2.10.1 Total Heat Rejection.

9.4.2.10.2 Condenser Water Pressure Drop.

9.4.2.10.3 Energy Balance.

9.4.2.11 Air Cooled Condenser.

9.4.2.11.1 Total Input Power.

9.4.2.11.2 Condenser Entering Air Temperature.

9.4.2.12 Evaporatively-cooled Condenser.

9.4.2.12.1 Total Input Power.

9.4.2.12.2 Condenser Entering Air Temperature Dry-Bulb.

9.4.2.12.3 Condenser Entering Air Temperature Wet-Bulb.

9.4.2.12.4 Make Up Water Flow Rate.

9.4.2.12.5 Make Up Water Temperature.

9.4.2.13 Water-cooled Condenser with Heat Reclaim.

9.4.2.13.1 Heat Rejection of Condenser.

9.4.2.13.2 Heat Reclaim Rejection.

10. NOMENCLATURE

Some symbols use a subscript suffix; multiple subscripts are separated by a comma. Equations in this standard use the following units of measure for dimensional consistency. See Section 5.6 for converting to or from other units of measure.

			SI		**IP**	
Group	**Symbol**	**Description**	**Unit Name**	**Unit Symbol**	**Unit Name**	**Unit Symbol**
General						
	CF	correction factor for atmospheric pressure adjustment				
	E	energy flow rate (thermal or electrical)	watt	W	British thermal unit (IT) per second	Btu/s
	E_{bal}	energy balance				
	L	length dimension	meter	m	foot	ft
	W	width dimension	meter	m	foot	ft
	H	height dimension	meter	m	foot	ft
	HHV	higher heating value at a specified reference temperature	kilojoule per kilogram	kJ/kg	British thermal unit (IT) per pound	Btu/lb
	n	rotational speed (such as motor or compressor)	revolution per minute	rpm	revolution per minute	rpm
	$\bar{x}$	sample mean (of a measurement)				
	$\bar{y}$	mean of redundant measurement sample means				
	s	standard deviation of a sample from a population				
	t	time	second	s	second	s
		date and time display formats: dd-mmm-yyyy hh:mm:ss.s				
	Δt	time interval	second	s	second	s
	Tol	tolerance				
	U	uncertainty of a variable				
	V	voltage	volt	V	volt	V
	W	power, rate at which work is performed	watt	W	watt	W
	θ	sensitivity coefficient for uncertainty				
	ω	frequency (electrical)	hertz	Hz	hertz	Hz

			SI		IP	
Group	**Symbol**	**Description**	**Unit Name**	**Unit Symbol**	**Unit Name**	**Unit Symbol**
Flow						
	m	mass flow rate	kilogram per second	kg/s	pound per second	lb/s
	V	volumetric flow rate	cubic meter per second	m^3/s	cubic foot per second	ft^3/s
	ρ	density	kilogram per cubic meter	kg/m^3	pound per cubic foot	lb/ft^3
Capacity						
	Q	net capacity, heat flow rate	watt	W	British thermal unit (IT)	Btu/h
	Q'	gross capacity, heat flow rate	watt	W	British thermal unit (IT)	Btu/h
	Q%	percent load				
	c_p	specific heat at constant pressure	kilojoule per kilogram kelvin	kJ/(kg·K)	British thermal unit (IT) per pound degree Fahrenheit	Btu/(lb·°F)
	h	enthalpy	kilojoule per kilogram	kJ/kg	British thermal unit (IT) per pound	Btu/lb
	Δh	enthalpy differential	kilojoule per kilogram	kJ/kg	British thermal unit (IT) per pound	Btu/lb
	T	temperature	degree Celsius	°C	degree Fahrenheit	°F
	ΔT	temperature differential (temperature interval)	degree Celsius	Δ°C	degree Fahrenheit	Δ°F

			SI		IP	
Group	**Symbol**	**Description**	**Unit Name**	**Unit Symbol**	**Unit Name**	**Unit Symbol**
Efficiency						
	η	efficiency, COP	watt per watt	W/W = 1	watt per watt	W/W = 1
		efficiency, EER			British thermal unit (IT) per watt hour	Btu/(W·h)
		efficiency, kW/ton_R			kilowatt per ton_R	kW/ton_R
	PLV	Part Load Value, referring to efficiency				
	IPLV	Integrated Part Load Value, referring to efficiency				
	NPLV	Non-standard Part Load Value, referring to efficiency				
Pressure Drop						
	d	pipe inside diameter dimension	millimeter	mm	inch	in
	ε	absolute roughness	meter	m	foot	ft
	f	Darcy friction factor				
	g	standard gravitational term	meter per second squared	m/s^2	foot per second squared	ft/s^2
	h_f	frictional head loss in pipe (pressure drop, pressure differential)	meter	m	foot	ft
	h_m	minor head loss in fittings (pressure drop, pressure differential)	meter	m	foot	ft
	K	resistance coefficient				
	p	pressure	kilopascal	kPa	pound-force per square inch	psia
	Δp	pressure differential	kilopascal	kPa	pound-force per square inch	psid or ft H_2O (at 60°F)
	r	radius of the centerline of the elbow	millimeter	mm	inch	in
	Re	Reynolds number				
	v	velocity, average across at the inlet cross section	meter per second	m/s	foot per second	ft/s

Subscripts	**Description**
atm	atmospheric
avg	average, equivalent to arithmetic mean
cd	condenser
corrected	corrected value representing an adjustment to a test value
DB	dry bulb, referring to temperature
disch	discharge, referring to compressor outlet of refrigerant circuit
ev	evaporator
FL	full load, referring to rated capacity at design conditions
H	heating
HR	heat recovery
hrc	heat reclaim, heat recovery
i	index value
in	inlet, entering, input
input	input
j	index value
liq	liquid
mean	mean, referring to arithmetic mean
OA	outdoor air
out	outlet, leaving, output
Q	capacity
r	refrigerant
R	cooling or refrigerating
refrig	refrigerant
ring	piezometer ring
sat	saturation, referring to either saturation temperature, or the mean of dew point and bubble point temperatures
SHC	simultaneous heating and cooling
t	time
test	test, result from a test measurement
w	water
WB	wet bulb, referring to temperature
X%	denoting a value for X% part load capacity (i.e., 75%)
η	efficiency

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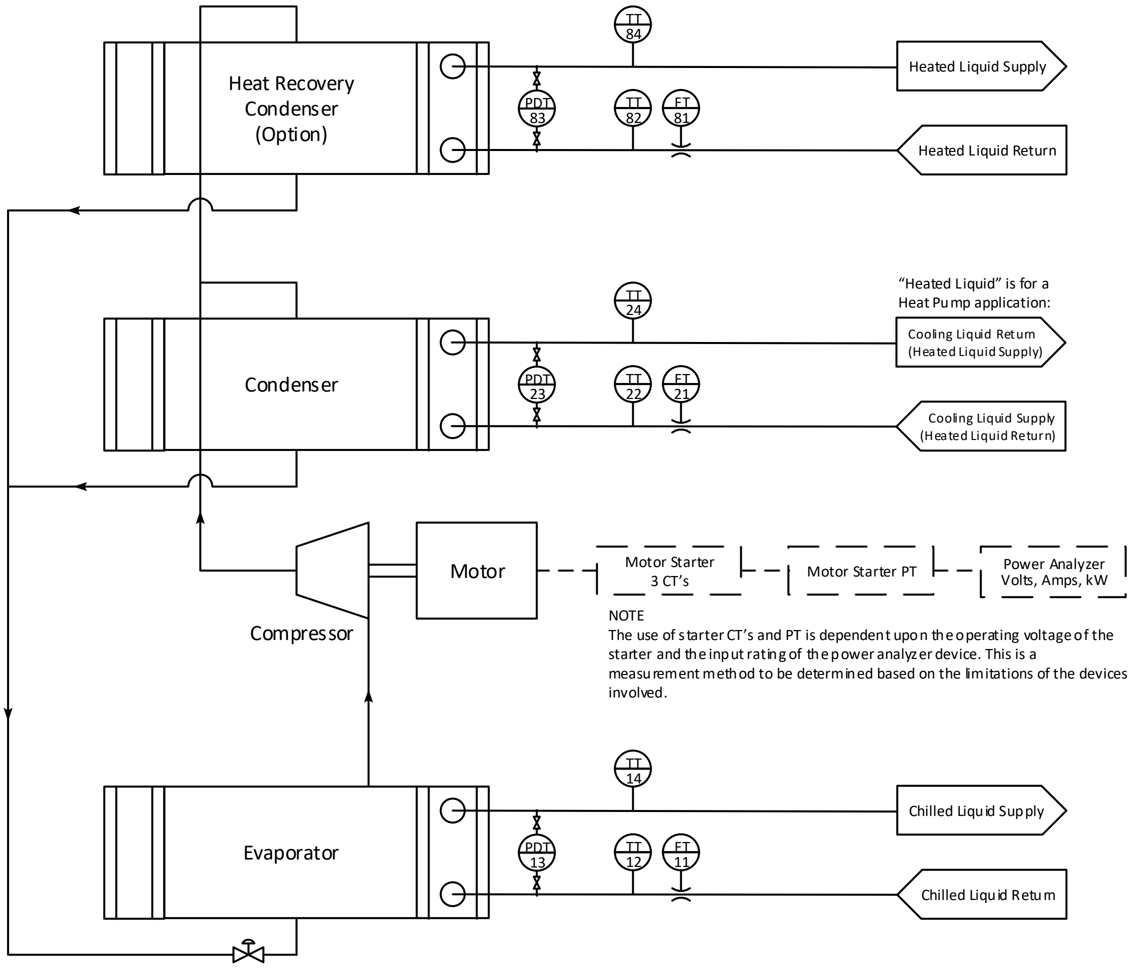
NORMATIVE APPENDIX B - MEASUREMENT POINTS

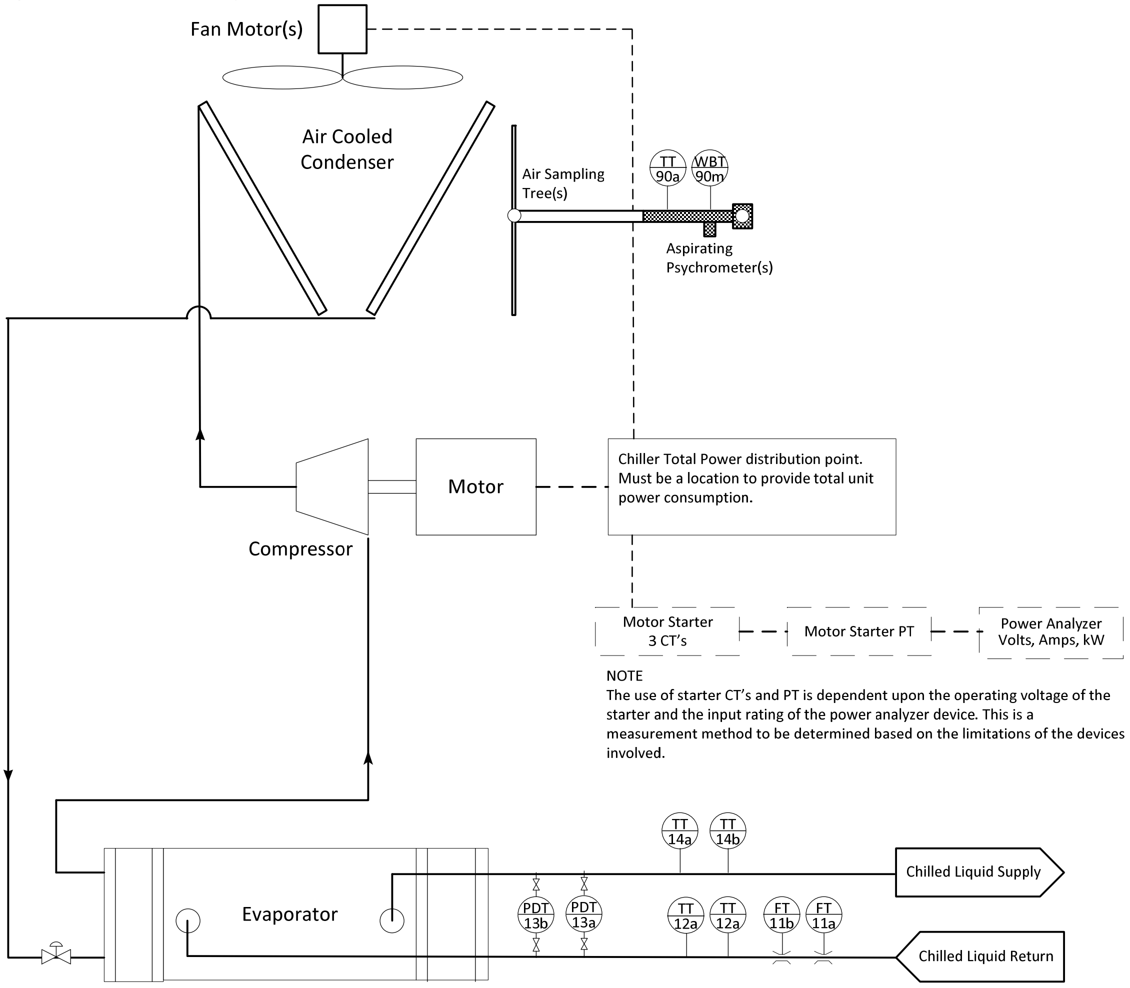
Figure B.1: Electrically-Driven Liquid-Cooled Chiller (with or without Heat Recovery) or Heat Pump



NOTE
The use of starter CT's and PT is dependent upon the operating voltage of the starter and the input rating of the power analyzer device. This is a measurement method to be determined based on the limitations of the devices involved.

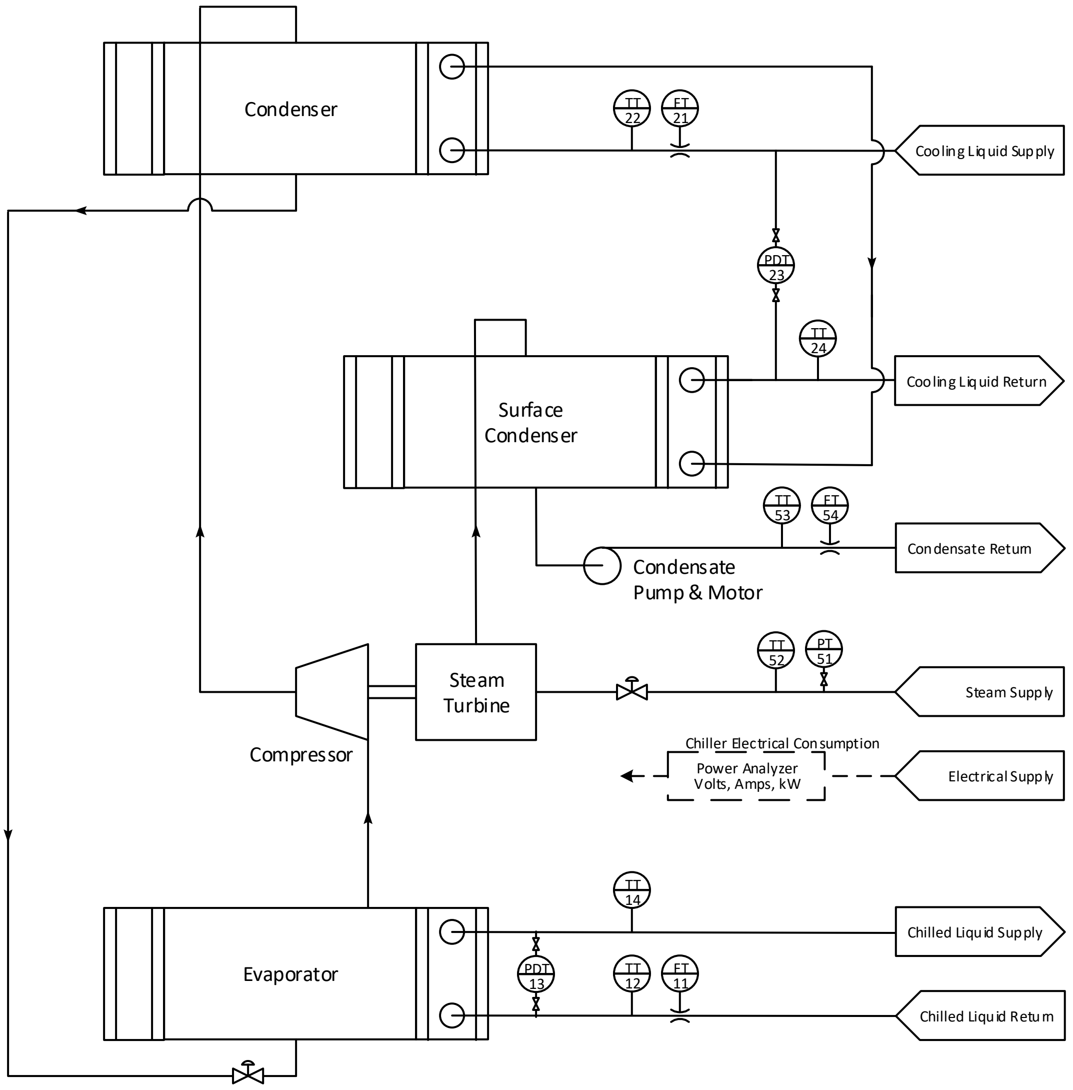
ID	Description of Measurement
FT-11	Evaporator liquid flow
TT-12	Evaporator inlet temperature
PDT-13	Evaporator pressure difference
TT-14	Evaporator outlet temperature
FT-21	Condenser liquid flow
TT-22	Condenser inlet temperature
PDT-23	Condenser pressure difference
TT-24	Condenser outlet temperature
FT-81	Heat recovery condenser (when included) liquid flow
TT-82	Heat recovery condenser (when included) inlet temperature
PDT-83	Heat recovery condenser (when included) difference
TT-84	Heat recovery condenser (when included) outlet temperature
Not identified	Power consumption for the Chiller, including any auxiliary systems included in the test boundary and includes voltage balance measurement.

Figure B.2 Electrically Driven Air-Cooled Chiller



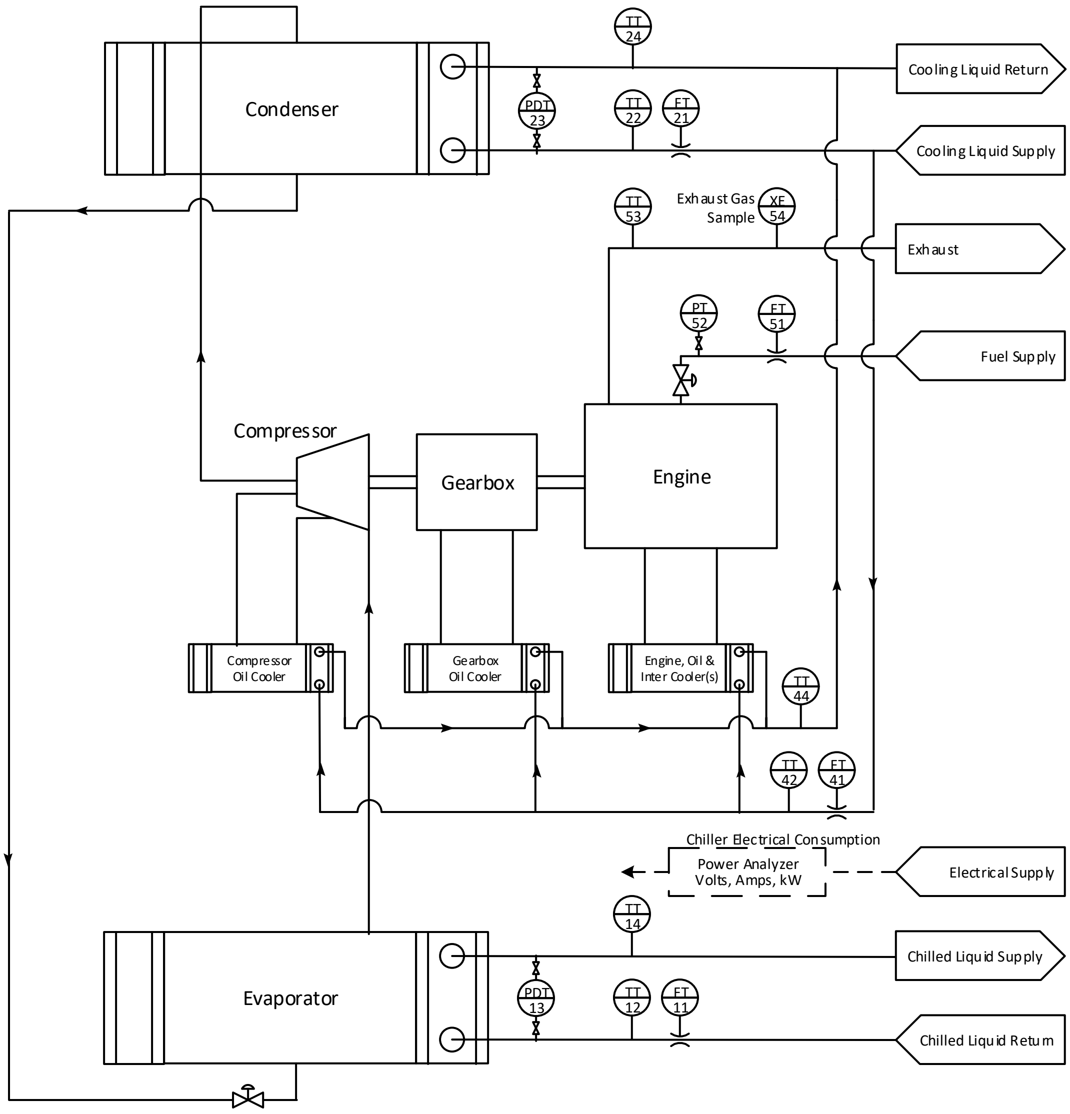
ID	Description of Measurement
FT-11a, b	Evaporator liquid flow (redundant measurements)
TT-12a, b	Evaporator inlet temperature (redundant measurements)
PDT-13a, b	Evaporator pressure difference (redundant measurements)
TT-14a, b	Evaporator outlet temperature (redundant measurements)
TT-90a to n	Ambient air temperature (one or more aspirating psychrometers)
WBT-90m	Entering Wet Bulb temperature for Evaporatively-cooled or Air-cooled in heating mode
Not identified	Power consumption for the Chiller, including any auxiliary systems included in the test boundary and includes voltage balance measurement.

Figure B.3 Steam Turbine-Driven Liquid-Cooled Chiller



ID	**Description of Measurement**
FT-11	Evaporator liquid flow
TT-12	Evaporator inlet temperature
PDT-13	Evaporator pressure difference
TT-14	Evaporator outlet temperature
FT-21	Condenser liquid flow
TT-22	Condenser inlet temperature
PDT-23	Condenser pressure difference
TT-24	Condenser outlet temperature
PT-51	Steam supply pressure
TT-52	Steam supply inlet temperature
TT-53	Steam condensate temperature
FT-54	Steam condensate flow
Not identified	Power consumption for the Chiller, including any auxiliary systems included in the test boundary and includes voltage balance measurement.

Figure B.4 Engine-Driven Liquid-Cooled Chiller



ID	Description of Measurement
FT-11	Evaporator liquid flow
TT-12	Evaporator inlet temperature
PDT-13	Evaporator pressure difference
TT-14	Evaporator outlet temperature
FT-21	Condenser liquid flow
TT-22	Condenser inlet temperature
PDT-23	Condenser pressure difference
TT-24	Condenser outlet temperature
FT-41	Cooling system liquid flow
TT-22	Cooling system liquid inlet temperature
TT-23	Cooling system liquid outlet temperature
PT-51	Fuel supply flow
TT-52	Fuel supply inlet pressure
TT-53	Exhaust temperature
Not identified	Power consumption for the Chiller, including any auxiliary systems included in the test boundary and includes voltage balance measurement.