2003 STANDARD for

PERFORMANCE RATING OF WATER - CHILLING PACKAGES USING THE VAPOR COMPRESSION CYCLE

AIR-CONDITIONING & REFRIGERATION INSTITUTE

Standard 550/590

4100 N. FAIRFAX DR., SUITE 200 • ARLINGTON, VIRGINIA 22203

IMPORTANT

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ARI CERTIFICATION PROGRAM PROVISIONS

Scope of the Certification Program

60 Hz Power	
Included in Certification Program	
Water-Cooled	**Air-Cooled**
All compressor types	All compressor types
Rated up to 2000 tons [7034 kW] at ARI Standard Rating Conditions	Rated up to 200 tons [703 kW] at ARI Standard Rating Conditions
Hermetic & open type, electric motor driven	Hermetic & open type, electric motor driven
Voltages up to 5000 volts	Voltages up to 600 volts
Excluded from Certification Program	
Water-Cooled	**Air-Cooled**
Condenserless chillers	Condenserless chillers
Evaporatively cooled chillers	Evaporatively cooled chillers
Chillers above 2000 tons [7034 kW]	Chillers above 200 tons [703 kW]
Chillers with voltages above 5000 volts	Chillers with voltages above 600 volts
Chillers powered by other than electric motor drives	Chillers powered by other than electric motor drives
Chillers with motors not supplied with the unit by The manufacturer	Secondary coolant ratings (other than water) Free cooling
Secondary coolant ratings (other than water)	Heat recovery & heat pump ratings
Free cooling	
Heat recovery & heat pump ratings	

ARI CERTIFICATION PROGRAM PROVISIONS (CONTINUED)

Scope of the Certification Program (Continued)

50 Hz Power	
Included in Certification Program	
Water-Cooled	**Air-Cooled**
Centrifugal & screw chillers with continuous unloading	Not applicable
Rated 200 - 1000 tons [703-3517 kW] at ARI Standard Rating Conditions	
Hermetic & open type, electric motor driven	
Voltages up to 5000 volts	
Excluded from Certification Program	
Water-Cooled	**Air-Cooled**
Scroll & reciprocating compressor chillers with step unloading	Not applicable
Condenserless chillers	
Evaporatively cooled chillers	
Chillers below 200 tons [703 kW]	
Chillers above 1000 tons [3517 kW]	
Chillers with voltages above 5000 volts	
Chillers powered by other than electric motor drives	
Chillers with motors not supplied with the unit by The manufacturer	
Secondary coolant ratings (other than water)	
Free cooling	
Heat recovery & heat pump ratings	

Certified Ratings

The Certification Program ratings verified by test are:

1. Capacity, tons [kW]
2. Energy Efficiency, as applicable:
   - Power Input per Capacity, kW/ton [kW/kW]
   - Energy Efficiency Ratio (EER), Btu/(W·h)
   - Coefficient of Performance (COP), watts/watt [W/W]
3. Water pressure drop, psi or ft H_2O [kPa]
4. Integrated Part-Load Value (IPLV) (Section 5.4.1)
5. Non-Standard Part-Load Value (NPLV) (Section 5.4.1)

Items 1- 5 are at Standard Rating Conditions (Section 5.2) and at non-standard Rating Conditions (Section 5.3) for both full and part load (Section 5.4 for part-load performance requirements).

Note:

This standard supersedes ARI Standard 550/590-98 with addenda.

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PERFORMANCE RATING OF WATER-CHILLING PACKAGES USING THE VAPOR COMPRESSION CYCLE

Section 1. Purpose

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

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

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

Section 2. Scope

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

- Water-Cooled, Air-Cooled, or Evaporatively-Cooled Condensers,
- Air-Cooled or Water-Cooled Heat Reclaim Condensers,
- Packages supplied without a Condenser.

Section 3. Definitions

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

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

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

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

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

3.3.2 *Air-Cooled Heat Reclaim Condenser.* A component which condenses refrigerant vapor in the process of rejecting the heat of condensation to air causing a rise in the air temperature. This Condenser may be a separate Condenser the same as or a portion of the Air-Cooled Condenser.

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

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

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

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

3.5 *Energy Efficiency.*

3.5.1 *Coefficient of Performance (COP).* A ratio of the cooling capacity in watts [W] to the Total Power Input, in watts [W] at any given set of Rating Conditions, expressed in watts/watt [W/W].

3.5.2 *Energy Efficiency Ratio (EER).* A ratio of the cooling capacity in Btu/h [W] to the Total Power Input in watts [W] at any given set of Rating Conditions, expressed in Btu/(W·h).

3.5.3 *Heat Reclaim Coefficient of Performance (COP_{HR})*. A ratio of the Net Heat Reclaim Capacity (Btu/h) to the Total Power Input to the unit, W converted to Btu/h

3.5.4 *Power Input per Capacity.* A ratio of the Total Power Input to the unit, in kW to the Net Refrigerating Capacity at any given set of Rating Conditions, expressed in kW/ton [kW/kW].

3.6 *Fouling Factor*. The thermal resistance due to fouling accumulated on the heat transfer surface.

3.6.1 *Fouling Factor Allowance*. Provision for anticipated fouling during use specified in $h \cdot ft^2 \cdot {}^oF/Btu$ [$m^2 \cdot {}^oC/W$].

3.7 *Net Heat Reclaim Capacity*. A quantity defined as the mass flow rate of the condenser water multiplied by the difference in enthalpy of water entering and leaving the heat reclaim Condenser, Btu/h [kW].

3.8 *Net Refrigeration Capacity*. A quantity defined as the mass flow rate of the evaporator water multiplied by the difference in enthalpy of water entering and leaving the evaporator, Btu/h or tons [kW].

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

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

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

3.10 *Published Ratings*. A statement of the assigned values of those performance characteristics, under stated Rating 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.

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

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

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

3.1.1 *Standard Rating Conditions*. Rating Conditions used as the basis of comparison for performance characteristics.

3.12 *"Shall" or "Should"*. "Shall" or "should" shall be interpreted as follows:

3.12.1 *Shall*. Where "shall" or "shall not" is used for a provision specified, that provision is mandatory if compliance with the standard is claimed.

3.12.2 *Should,* "Should" is used to indicate provisions which are not mandatory but which are desirable as good practice.

3.13 *Total Power Input*. Power input of all components of the unit.

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

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

Section 4. Test Requirements

4.1 *Test Requirements*. Ratings shall be established at the Rating Conditions specified in Section 5. Ratings shall be verified by tests conducted in accordance with the test method and procedures described in Appendix C.

Section 5. Rating Requirements

5.1 *Standard Ratings.* Standard Ratings for all Water-Chilling Packages shall be established at the Standard Rating Conditions specified in 5.2.

5.2 *Standard Rating Conditions.* Water-Chilling Packages shall be rated at conditions specified in Table 1. Heat Reclaim Water-Chilling Packages shall be rated at conditions specified in Table 2 and properly identified as the Heat Reclaim Standard Rating. Standard Ratings shall include a water-side Fouling Factor Allowance of 0.00025 $h \cdot ft^2 \cdot {}^{\circ}F/Btu$ [0.000044 $m^2 \cdot {}^{\circ}C/W$] for the Condenser and 0.0001 $h \cdot ft^2 \cdot {}^{\circ}F/Btu$ [0.000018$m^2 \cdot {}^{\circ}C/W$] for the evaporator.

5.3 *Application Rating Conditions.* Application Ratings should include the following range of Rating Conditions or be within the operating limits of the equipment:

All Condenser Types:

Leaving chilled water temperature ......40.0 to 48.0ºF [4.4 to 8.9ºC] in increments of 2ºF or less [1ºC or less].

Water-Cooled Condensers:

Entering condenser water temperature ......65.0 to 105.0ºF [18.3 to 40.6ºC] in increments of 5ºF or less [3°C or less].

Air-Cooled Condensers:

Entering Condenser air dry-bulb temperature ......55.0 to 125.0°F [12.8 to 51.7°C] dry-bulb in increments of 10°F or less [6°C or less].

Evaporatively-Cooled Condensers:

Entering Condenser air wet-bulb temperature ......50.0 to 80.0°F [10.0 to 26.7°C] wet-bulb in increments of 2.5°F or less [1.4°C or less].

5.4 *Part-Load Rating.* Water-Chilling Packages which are capable of capacity reduction shall be rated at 100% and at each step of capacity reduction provided by the refrigeration system(s) as published by the manufacturer. Part-load ratings points shall be presented in one or more of the following three ways:

a. *IPLV*- Based on the conditions defined in Table 3.
b. *NPLV*- Based on the conditions defined in Table 3.
c. *Separate Part-Load Data Point(s) Suitable for Calculating IPLV or NPLV.* In addition, other part-load points may also be presented.

5.4.1 *Determination of Part- Load Performance.* For Water-Chilling Packages covered by this standard, the IPLV or NPLV shall be calculated as follows:

a. Determine the part-load energy efficiency at 100%, 75%, 50%, and 25% load points at the conditions specified in Table 3.

b. Use the following equation to calculate the IPLV or NPLV.

$$\begin{matrix}\text{IPLV}\\\text{or}\\\text{NPLV}\end{matrix} = 0.01A + 0.42B + 0.45C + 0.12D \qquad \text{1a}$$

For COP and EER:

where: A = COP or EER at 100%
B = COP or EER at 75%
C = COP or EER at 50%
D = COP or EER at 25%

For kW/ton:

$$\begin{matrix}\text{IPLV}\\\text{or}\\\text{NPLV}\end{matrix} = \frac{1}{\frac{0.01}{A} + \frac{0.42}{B} + \frac{0.45}{C} + \frac{0.12}{D}} \qquad \text{1b}$$

where: A = kW/Ton at 100%
B = kW/Ton at 75%
C = kW/Ton at 50%
D = kW/Ton at 25%

5.4.1.1 For a derivation of equations 1a and 1b, and an example of an IPLV or NPLV calculation, see Appendix D. The weighting factors have been based on the weighted average of the most common building types and operations using average weather in 29 U.S. cities, with and without airside economizers.

Table 1. Standard Rating Conditions

	Water-Cooled	Evaporatively-Cooled	Air-Cooled
Condenser Water			
Entering	85.0 ºF 29.4 ºC		
Flow Rate	3.0 gpm/ton 0.054 L/s per kW		
Condenser Fouling Factor Allowance			
Water-Side	0.00025 h · ft^2 · ºF/Btu 0.000044 m^2 · ºC/ W		
Air-Side		0.0 ft^2 · ºF/Btu 0.0 m^2 · ºC/W	0.0 h · ft^2 · ºF/Btu 0.0 m^2 · ºC/W
Entering Air			
Dry-Bulb			95.0 ºF 35.0 ºC
Wet-Bulb		75.0 ºF 23.9 ºC	
Evaporator Water			
Leaving	44.0 ºF 6.7 ºC	44.0 ºF 6.7 ºC	44.0 ºF 6.7 ºC
Flow Rate	2.4 gpm/ton 0.043 L/s per kW	2.4 gpm/ton 0.043 L/s per kW	2.4 gpm/ton 0.043 L/s per kW
Evaporator Fouling Factor Allowance			
Water-Side	0.0001 h · ft^2 ºF/Btu 0.000018 m^2 · ºC/W	0.0001 h · ft^2 ºF/Btu 0.000018 m^2 · ºC/W	0.0001 h · ft^2 ºF/Btu 0.000018 m^2 · ºC/W
Without Condenser			
Saturated Discharge	105.0 ºF 40.6 ºC	105.0 ºF 40.6 ºC	125.0 ºF 51.7 ºC
Liquid Refrigerant	98.0 ºF 36.7 ºC	98.0 ºF 36.7 ºC	105.0 ºF 40.6 ºC
Barometric Pressure	29.92 in Hg 101.3 kPa	29.92 in Hg 101.3 kPa	29.92 in Hg 101.3 kPa

Table 2. Heat Reclaim Standard Rating Conditions

Temperature	Water-Cooled	Evaporatively-Cooled	Air-Cooled
Condenser Water			
Entering	75.0 ºF 23.9 ºC		
Flow Rate	Flow rate same as in standard cooling ratings	Flow rate same as in standard cooling ratings	Flow rate same as in standard cooling ratings
Entering Air			
Dry-Bulb			40.0 ºF 4.4 ºC
Wet-Bulb		38.0 ºF 3.3 ºC	
Evaporator Water Leaving	44.0 ºF 6.7ºC	44.0 ºF 6.7ºC	44.0 ºF 6.7ºC
Field Fouling Allowance	0.00025 h · ft^2 · ºF/Btu	0.0 h · ft^2 · ºF/Btu	0.0 h · ft^2 · ºF/Btu
Heat Reclaim Condenser			
Entering	105.0 ºF or 95.0 ºF 40.6 ºC or 35.0 ºC		70.0 ºF 21.1ºC
Leaving	120.0 ºF or 105.0 ºF 48.9 ºC or 40.6 ºC		95.0 ºF 35.0 ºC
Barometric Pressure	29.92 in Hg 101.3 kPa	29.92 in Hg 101.3 kPa	29.92 in Hg 101.3 kPa

Table 3. Part-Load Conditions for Rating

	IPLV		NPLV	
Evaporator (All Types)				
100% load LWT	[2]44.0 ºF	6.7 ºC	[2]Selected LWT	[2]Selected LWT
0% load LWT	44.0 ºF	6.7 ºC	Same as 100% load	Same as 100% load
Flow Rate (gpm)	[3]2.4 gpm/ton	0.043 L/s per kW	[3]Selected gpm/ton	[3][L/s per kW]
F.F.A.	0.0001 h · ft2 · ºF/Btu	0.000018 m^2 · ºC/ W	As Specified	As Specified
[1]*Water-Cooled Condenser*				
100% load EWT	[2]85.0ºF	29.4 ºC	[2]Selected EWT	[2]Selected EWT
75% load EWT	75.0 ºF	23.9 ºC	[4]	[4]
50% load EWT	65.0 ºF	18.3 ºC	[4]	[4]
25% load EWT	65.0 ºF	18.3 ºC	[4]	[4]
0% load EWT	65.0 ºF	18.3 ºC	65.0 ºF	18.3 ºC
Flow rate (gpm) [L/s]	[3]3.0 gpm/ton	0.054 L/s per kW	[3]Selected gpm/ton	[3]L/s per kW
F.F.A.	0.00025 h · ft2 · ºF/Btu	0.000044 m^2 · ºC/ W	As Specified	As Specified
[1]*Air-Cooled Condenser (*Use Figure 2)			No Rating Requirements	
100% load EDB	95.0 ºF	35.0 ºC		
75% load EDB	80.0 ºF	26.7 ºC		
50% load EDB	65.0 ºF	18.3 ºC		
25% load EDB	55.0 ºF	12.8 ºC		
0% load EDB	55.0 ºF	12.8 ºC		
F.F.A.	0.0 h·ft^2·ºF/Btu	0.0 m^2·ºC/W		
[1]*Evaporatively-Cooled Condenser*			No Rating Requirements	
100% load EWB	75.0 ºF	23.9 ºC		
0% load EWB	50.0 ºF	10.0 ºC		
F.F.A.	0.0 h·ft^2·ºF/Btu	0.0 m^2·ºC/W		
Air-Cooled Without Condenser			No Rating Requirements	
100% load SDT	125.0 ºF	51.7 ºC		
0% load SDT	55.0 ºF	12.8 ºC		
Water and Evaporatively-Cooled Without Condenser			No Rating Requirements	
100% load SDT	105.0 ºF	40.6 ºC		
0% load SDT	65.0 ºF	18.3 ºC		

1 If the unit Manufacturer's recommended minimum temperatures are greater than those specified in Table 3, then those may be used in lieu of the specified temperatures.
2 Corrected for Fouling Factor Allowance by using the calculation method described in C6.3
3 The flow rates are to be held constant at full load values for all part-load conditions.
4 For part-load entering condenser water temperatures, the temperature should vary linearly from the selected EWT at 100% load to 65.0 ºF at 50% loads, and fixed at 65.0°F for 50% to 0% loads.

SDT - saturated discharge temperature
LWT - leaving water (liquid) temperature
EWT - entering water (liquid) temperature
EDB - entering air dry-bulb temperature
EWB - entering air wet-bulb temperature
F.F.A. - Fouling Factor Allowance

5.4.1.2 The IPLV or NPLV rating requires that the unit efficiency be determined at 100%, 75%, 50% and 25% at the conditions as specified in Table 3. If the unit, due to its capacity control logic can not be operated at 75%, 50%, or 25% capacity then the unit shall be operated at other load points and the 75%, 50%, or 25% capacity efficiencies shall be determined by plotting the efficiency versus the % load using straight line segments to connect the actual performance points (Figure 1). The 75%, 50%, or 25% load efficiencies shall then be determined from the curve. Extrapolation of data shall not be used. An actual chiller capacity point equal to or less than the required rating point must be used to plot the data. For example, if the minimum actual capacity is 33% then the curve can be used to determine the 50% capacity point, but not the 25% capacity point.

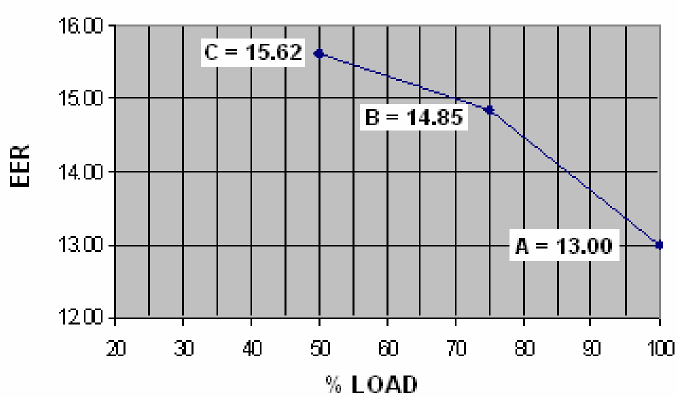

Figure 1. Part-Load Efficiency Curve

If a unit cannot be unloaded to the 25%, 50%, or 75% capacity point, then the unit shall be run at the minimum step of unloading at the condenser entering water or air temperature based on Table 3 for 25%, 50% or 75% capacity points as required. The efficiency shall then be determined by using the following equation:

$$EER = \frac{\text{Measured Cooling Capacity}}{C_D \cdot \text{Measured Total Power Input}} \qquad 2$$

where C_D is a degradation factor to account for cycling of the compressor for capacities less than the minimum step of capacity. C_D should be calculated using the following equation:

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

where LF is the load factor calculated using the following equation:

$$LF = \frac{\frac{\%\,FL}{100} \cdot (Full\ load\ unit\ capacity)}{(Part-load\ unit\ capacity)}$$

where % FL is the % of full load at standard rating points, i.e. 75%, 50%, and 25%.

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

5.4.1.3 *Sample Calculation.* The following is an example of an IPLV calculation:

Part-Load Values Provided

Step	Capacity (tons)	Input (kW)	EER
3 (full)	100.0	92.3	13.00
2	72.1	57.4	15.07
1*	41.3	31.3	15.83
1**	41.8	33.3	15.06

* Minimum possible unit capacity at load conditions.
** Performance at minimum step at 25% load conditions

Using the above data the part-load EER value can be calculated.

Part-Load Values Provided

Point	Load%	Capacity (tons)	EER
A	100%	100	13.00
B	75%	75	14.85
C	50%	50	15.62

Because the unit cannot unload to 25% capacity, the following additional calculations are required to determine point "D", using the minimum capacity data point listed above that was determined at the minimum step of capacity at the conditions of a 25% capacity.

$$LF = \frac{(0.25) \text{ x } (100)}{41.8} = 0.60$$

C_D = (-0.13 x 0.60) + 1.13 = 1.05

$$EER = \frac{41.8 \text{ x } 12000}{1.05 \text{ x } 33.3 \text{ x } 1000} = 14.35 \frac{Btu}{(W \cdot h)}$$

Using the A, B, C and D efficiencies the IPLV can then be calculated as follows:

IPLV (EER) = (0.01 x 13.00) + (0.42 x 14.85) + (0.45 x 15.62) + (0.12 x 14.35)
=15.12 Btu/(W·h)

5.5 *Fouling Factor Allowances*. When ratings are published, they shall include those with Fouling Factors as specified in Table 1. Additional ratings, or means of determining those ratings, at other Fouling Factor Allowances may also be published.

5.5.1 *Method of Establishing Clean and Fouled Ratings from Laboratory Test Data.*

5.5.1.1 A series of tests shall be run in accordance with the method outlined in Appendix C to establish the unit's performance.

5.5.1.2 Evaporator water-side and condenser water-side or air-side heat transfer surfaces shall be considered clean during testing. Tests will be assumed to reflect Fouling Factors of 0.0 h·ft^2 °F/Btu [0.0 m^2°C/W].

5.5.1.3 To determine the capacity of the Water-Chilling Package at the rated fouling conditions, the procedure defined in C6.3 shall be used to determine an adjustment for the evaporator and or condenser water temperatures.

5.6 *Tolerances*.

5.6.1 *Allowable Tolerances*. The allowable test tolerance on capacity, tons [kW], EER, COP, Power Input per Capacity kW/ton [kW/kW] and heat balance shall be determined from the following equation:

Tolerance %

$$= 10.5 - (0.07 \text{ x } \%FL) + \left(\frac{E}{DT_{FL} \text{ x } \%FL}\right)$$

DT_{FL} = Difference between entering and leaving chilled water temperature at full load, °F [°C]

E = 1500 for IP, [833.3] for SI units

See Figure 3 for graphical representation only.

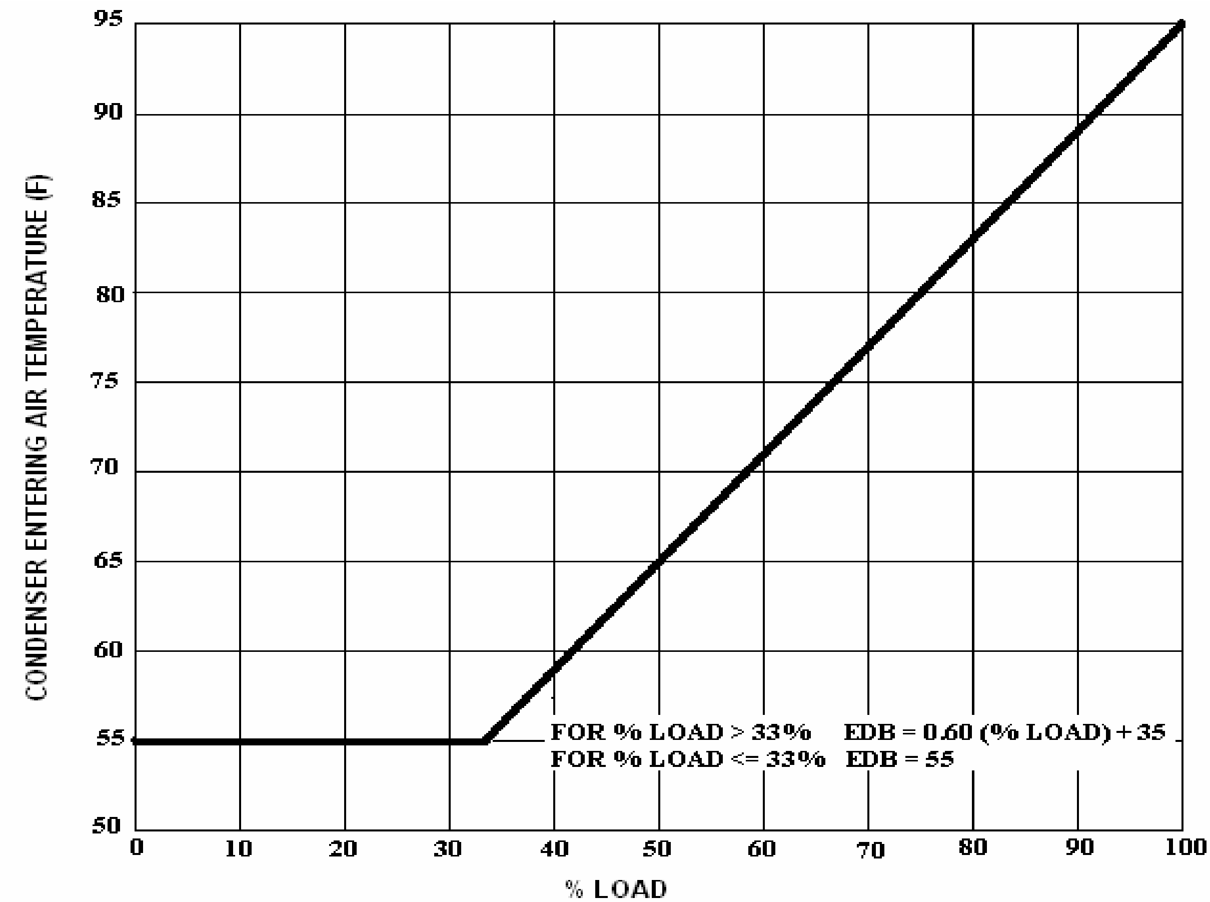

Figure 2. Air-Cooled Condenser Entering Air Temperature vs. % Load

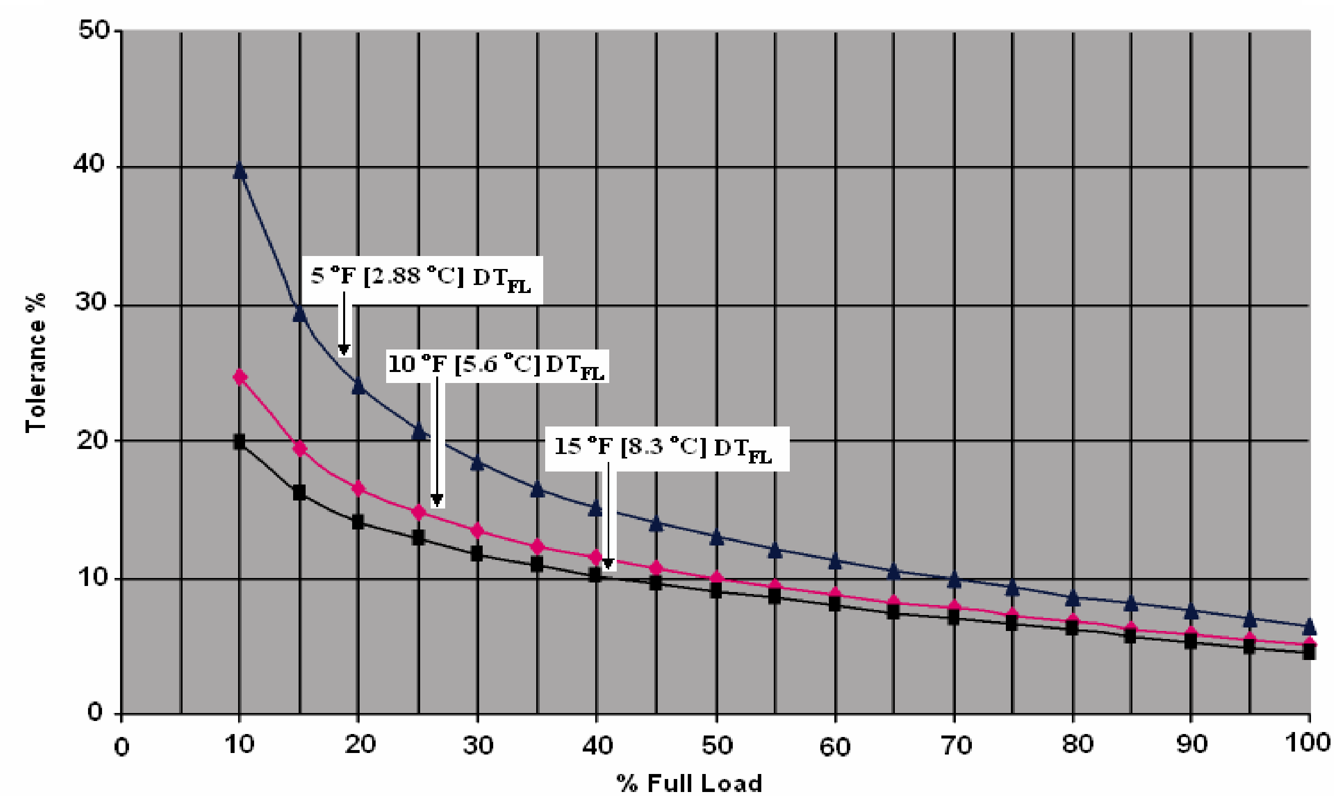

Figure 3. Allowable Tolerance Curves for Full and Part Load

5.6.2 *Full Load*. To comply with this standard, published or reported Net Refrigeration Capacity shall be based on data obtained in accordance with the provisions of this section, and shall have a Net Refrigeration Capacity and full load efficiency of not less than 100 % of its ratings within the allowable tolerance. The allowable tolerance shall be determined by the equation specified in 5.6.1.

Water pressure drop in the evaporator and Condenser shall not exceed 115 % of the rated pressure drop at the specified water flow rate.

Full Load Example in EER (in IP Units only for clarity):

Rated Full Load Performance

Rated Capacity = 100 tons
Rated Power = 92.3 kW
Evaporator DT_{FL} = 10°F

$$EER = \frac{100\text{ tons x }12000\text{ Btu/ton}\cdot\text{h}}{92.3\text{ kW x }1000\text{W/kW}} = 13.0\frac{\text{Btu}}{(\text{W}\cdot\text{h})}$$

Allowable Test Tolerance =

$$10.5 - (0.07 \text{ x } 100\%) + \frac{1500}{10 \text{ x } 100\%}$$

= 10.5 - 7 + 1.5 = 5%

Min. Allowable Capacity =

$$\frac{(100\text{ tons} - 5\text{ tons})}{100} \text{ x } 100 = 95 \text{ tons}$$

Min. Allowable EER =

$$\frac{(100 - 5)}{100} \text{ x } 13.0\frac{\text{Btu}}{(\text{W}\cdot\text{h})} = 12.35 \frac{\text{Btu}}{(\text{W}\cdot\text{h})}$$

Max. power at min. capacity =

$$\frac{95 \text{ tons x } 12000 \text{ Btu/ton}\cdot\text{h}}{12.35\frac{\text{Btu}}{(\text{W}\cdot\text{h})}\text{x}1000} = 92.3\text{ kW}$$

Full Load Example in kW/ton (in IP Units only for clarity):

Rated full load performance

Rated capacity = 100 tons
Rated power = 70 kW
Cooling DT_{FL} = 10ºF

$$\text{Total Power Input per Capacity} = 0.70\frac{\text{kW}}{\text{ton}}$$

Allowable Test Tolerance:

$$\text{Tolerance} = 10.5 - (.07 \text{ x } 100) + \frac{(1500)}{(10 \text{ x } 100)}$$

= 10.5 – 0 7 + 1.5 = 5%

$$\text{Min. allowable capacity} = \frac{(100 - 5)}{100}\text{ x } 100$$

= 95 tons

$$Max.allowable\, kW / ton = \frac{(100+5)}{100} x.70$$

= .735 kW/ton

Max. power at min. capacity

= .735 x 95 = 69.825 kW

5.6.3 *Part-Load*. The tolerance on part-load EER shall be the tolerance as determined from 5.6.1.

Part-Load Example in EER (in IP Units only for clarity):

Rated Part-Load Performance

Power at 69.5% Rated Capacity = 59.6 kW
69.5% Rated Capacity = 69.5 tons
Cooling DT_{FL} = 10.0°F

$$EER = \frac{69.5 \text{ x } 12000}{59.6 \text{ x } 1000} = 14.0\frac{\text{Btu}}{(\text{W}\cdot\text{h})}$$

Allowable Test Tolerance =

$$10.5 - (0.07 \cdot 69.5\%) + \frac{1500}{10 \text{ x } 69.5\%}$$

= 10.5 - 4.87 + 2.16 = 7.8%

Min. Allowable EER =

$$\frac{(100 - 7.8)}{100} \times 14.0 = 12.91 \text{ EER}$$

Part-Load Example in kW/ton (in IP Units only for clarity):

Rated Part-Load Performance

50% capacity	=	50 tons
50% power	=	35 kW
Total Power Input per Ton	=	0.70 kW/ton
Full Load DT_{FL}	=	10ºF

Allowable Test Performance

$$\text{Tolerance} = 10.5 - (.07 \times 50) + \frac{(1500)}{10 \times 50}$$

$$= 10.5 - 3.5 + 3 = 10\%$$

Max. allowable Total Power Input per Ton

$$= \frac{(100 + 10\%)}{100} \times .70$$

$$= 0.77 \text{ kW/ton}$$

5.6.4 *IPLV and NPLV Tolerances*. The allowable tolerance on IPLV and NPLV shall be determined by the following equation:

$$\text{Allowable Percent Tolerance} = 6.5 + \frac{35}{DT_{FL}}$$

See Figure 4

The single number IPLV or NPLV, calculated for the part-load conditions, shall not be less than the rated IPLV or NPLV, less the allowable tolerance.

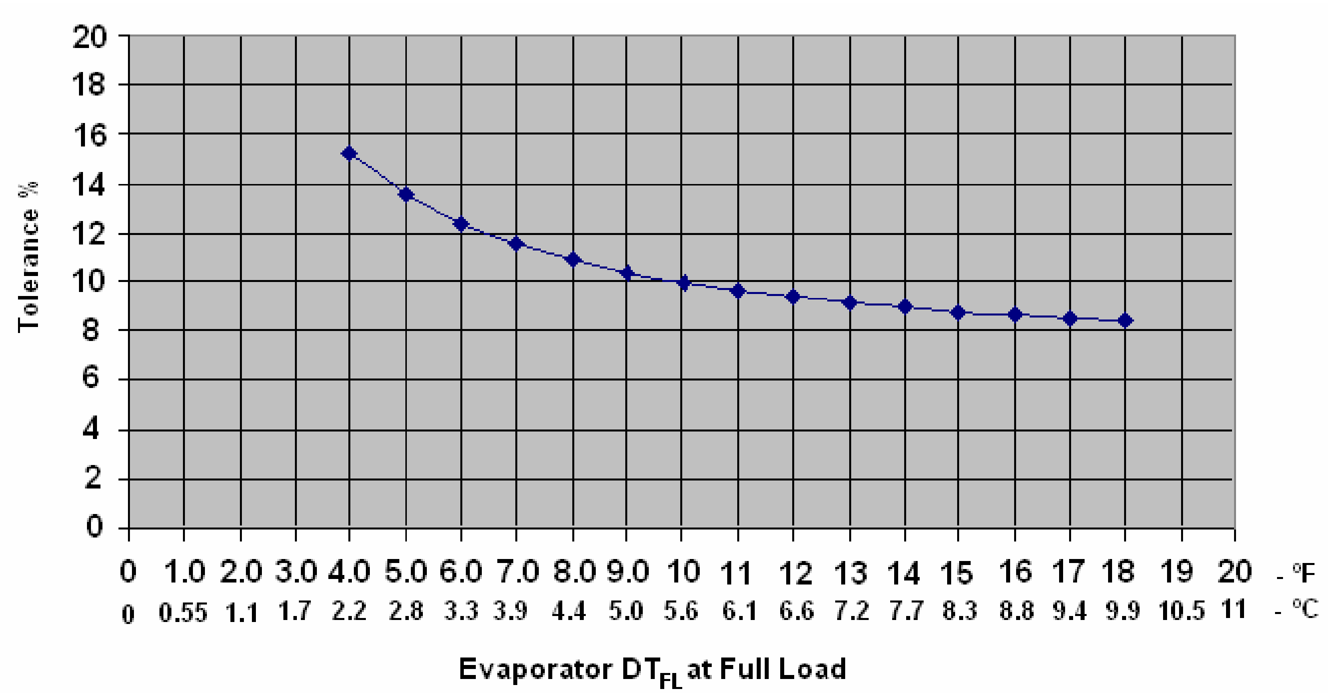

Figure 4. IPLV and NPLV Tolerance Curve

Section 6. Minimum Data Requirements for Published Ratings

6.1 *Minimum Data Requirements for Published Ratings.* As a minimum, Published Ratings shall include all Standard Ratings. All claims to ratings within the scope of this standard shall include the statement "Rated in accordance with ARI Standard 550/590." All claims to ratings outside the scope of the standard shall include the statement "Outside the scope of ARI Standard 550/590." Wherever Application Ratings are published or printed, they shall include a statement of the conditions at which the ratings apply.

6.2 *Published Ratings*. Published Ratings shall state all of the standard operating conditions and shall include the following.

6.2.1 *General.*

6.2.1.1 Refrigerant designation in accordance with ANSI/ASHRAE Standard 34.

6.2.1.2 Model number designations providing identification of the Water-Chilling Packages to which the ratings shall apply.

6.2.1.3 Net Refrigeration Capacity, tons [kW].

6.2.1.4 Total Power Input to chiller, bhp or kW, as applicable.

6.2.1.5 Energy Efficiency, expressed as EER, COP or kW/ton.

6.2.1.6 Evaporator Fouling Factor, h · ft2 · ºF/Btu [m^2 · ºC/ W], as stated in Table 1.

6.2.1.7 Chilled water entering and leaving temperatures, ºF [ºC] (as stated in Table 1), or leaving water temperature and temperature difference, ºF [ºC].

6.2.1.8 Evaporator water pressure drop (inlet to outlet), psi or ft H_2O [kPa].

6.2.1.9 Chilled water flow rate, gpm [L/s].

6.2.1.10 Nominal voltage, V, and frequency, Hz, for which ratings are valid.

6.2.2 *Water-Cooled Condenser Packages*.

6.2.2.1 Condenser water pressure drop (inlet to outlet), psi or ft H_2O [kPa].

6.2.2.2 Any two of the following:

Entering condenser water temperature, ºF [ºC]
Leaving condenser water temperature, ºF [ºC]
Water temperature rise through the condenser, ºF [ºC]

6.2.2.3 Condenser water flow rate, gpm [L/s].

6.2.2.4 Condenser Fouling Factor, h · ft2 · ºF/Btu [m^2 · ºC/ W], as stated in Table 1.

6.2.3 *Air-Cooled Condenser Packages.*

6.2.3.1 Entering air dry-bulb temperature, ºF [ºC] (as stated in Table 1).

6.2.3.2 Power input to fan(s), kW [kW].

6.2.4 *Evaporatively-Cooled Condenser Packages*.

6.2.4.1 Entering air wet-bulb temperature, ºF [ºC] (as stated in Table 1).

6.2.4.2 Power input to fan(s) and pump(s), kW [kW].

6.2.4.3 Condenser spray pump power consumption, kW [kW].

6.2.4.4 Statement of Condenser Fouling Factor Allowance on heat exchanger, h · ft2 · ºF/Btu [m^2 · ºC/ W].

6.2.5 *Packages without Condenser (for use with Remote Condensers).*

6.2.5.1 Compressor saturated discharge temperature, ºF [ºC] (as stated in Table 1).

6.2.5.2 Liquid refrigerant temperature entering chiller package, ºF [ºC] (as stated in Table 1).

6.2.5.3 Condenser heat rejection capacity requirements, Btu/h [kW].

6.2.6 *Heat Reclaim Condenser(s)*.

6.2.6.1 Heat Reclaim Capacity, MBtu/h [kW].

6.2.6.2 Water pressure drop, psi or ft H_2O [kPa] or air pressure drop, in H_2O [kPa].

6.2.6.3 Entering and leaving heat reclaim Condenser air or water temperatures, ºF [ºC] (stated in Table 2).

6.2.6.4 Heat reclaim Condenser air flow rate, cfm [m^3/s] or heat reclaim Condenser water flow rate, gpm [L/s].

6.2.6.5 Fouling Factor, h · ft2 · ºF/Btu [m^2 · ºC/ W], as stated in Table 1 (for water heat reclaim Condensers only).

Section 7. Marking and Nameplate Data

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

a. Manufacturer's name and location
b. Model number designation providing complete identification
c. Refrigerant designation (in accordance with ANSI/ASHRAE Standard 34
d. Voltage, phase and frequency

Nameplate voltages for 60 Hertz systems shall include one or more of the equipment nameplate voltage ratings shown in Table 1 of ARI Standard 110. Nameplate voltages for 50 Hertz systems shall include one or more of the utilization voltages shown in Table 1 of IEC Standard Publication 60038.

Section 8. Conformance Conditions

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

APPENDIX A. REFERENCES - NORMATIVE

A.1 Listed here are all standards, handbooks and other publications essential to the formation and implementation of the standards. All references in this appendix are considered as part of the standard.

A1.1 ANSI/ASHRAE Standard 30-1995, *Method of Testing Liquid Chilling Packages*, 1995, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./1791 Tullie Circle, N.E., Atlanta, Georgia, 30329, U.S.A.

A1.2 ANSI/ASHRAE Standard 34-2001 with Addenda, *Number Designation and Safety Classification of Refrigerants,* 2001, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./1791 Tullie Circle, N.E., Atlanta, Georgia, 30329, U.S.A.

A1.3 ANSI/ASHRAE Standard 41.1-86 (RA 2001), *Measurements Guide - Section on Temperature Measurements*, 2001, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. ASHRAE, 25 West 43rd Street, 4th Fl., New York, NY, 10036, U.S.A./1791 Tullie Circle, N.E., Atlanta, Georgia, 30329, U.S.A.

A1.4 ARI Standard 110-2002, *Air-Conditioning and Refrigerating Equipment Nameplate Voltages*, 2002, Air-Conditioning and Refrigeration Institute, 4100 North Fairfax Drive, Suite 200, Arlington, VA 22203, U.S.A.

A1.5 ASHRAE *Terminology of Heating Ventilation, Air Conditioning and Refrigeration,* Second Edition, 1991, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. ASHRAE, 1791 Tullie Circle, N.E., Atlanta, Georgia, 30329, U.S.A.

A1.6 ASME Standard PTC 19.2-1987, *Instruments and Apparatus, Part 2, Pressure Measurement,* 1987, American Society of Mechanical Engineers. ASME, 345 East 47th Street, New York, NY 10017, U.S.A.

A1.7 IEC Standard Publication 60038, *IEC Standard Voltages*, 1983, International Electrotechnical Commission, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland.

A1.8 ISA Standard RP31.1, *Recommended Practice Specification, Installation, and Calibration of Turbine Flowmeters,* 1977, Instrument Society of America, ISA, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, NC 27709, U.S.A.

APPENDIX B. REFERENCES - INFORMATIVE

None.

APPENDIX C. METHOD OF TESTING WATER-CHILLING PACKAGES USING THE VAPOR COMPRESSION CYCLE - NORMATIVE

C1. *Purpose*. The purpose of this appendix is to prescribe a method of testing for Water-Chilling Packages using the vapor compression cycle and to verify capacity and power requirements at a specific set of conditions.

Testing shall occur where instrumentation and load stability is provided.

Testing shall not be conducted in field installations where steady state conditions are difficult to achieve and provisions for measurement are not made.

C2. *Definitions*. Definitions for this appendix are identical with those in Section 3 of this standard.

C3. *Test Methods.*

C3.1 *Test Method.*

C3.1.1 The test will measure net cooling capacity (tons of refrigeration) and energy requirements, at a specific set of conditions.

C3.1.2 To confirm that steady-state conditions have been established at the specific set of conditions and within the tolerances set forth in C6.2.1, three sets of data shall be taken, at a minimum of five-minute intervals. To minimize the effects of transient conditions, test readings should be taken as simultaneously as possible.

C3.1.3 The test shall include a measurement of the net heat removed from the water as it passes through the evaporator by determination of the following:

a. Water flow rate, gpm [L/s]
b. Temperature difference between entering and leaving water °F, [°C]

C3.1.4 The heat removed from the chilled water is equal to the product of the chilled water flow rate, the water temperature difference, and the specific heat of the water defined by equation C6.

C3.1.5 If supplied with the Water-Chilling Package, the test shall include simultaneous determination of the heat reclaim Condenser capacity by obtaining the data as defined in C5.1.6 for Water-Cooled Heat Reclaim Condensers and C5.1.7 for Air-Cooled Heat Reclaim Condensers.

C3.1.5.1 For Water-Cooled Heat Reclaim Condensers, the heat reclaim capacity shall be determined by obtaining the following data:

a. Fluid flow rate, gpm [L/s]
b. Temperature difference between entering and leaving water °F, [°C]

The heat rejected through the heat reclaim Condenser is equal to the product of the heat reclaim Condenser water flow rate, the water temperature difference, and the specific heat of water as defined by equation C7.

C3.1.5.2 For Air-Cooled Heat Reclaim Condensers, the heat reclaim capacity shall be determined by obtaining the following data:

a. Heat Reclaim Condenser air flow rate, standard cfm [m^3/s] (for air)
b. Heat reclaim Condenser air temperature difference between entering and leaving air

The heat rejected through the Air-Cooled Heat Reclaim Condenser is equal to the product of the heat reclaim Condenser airflow rate, the air temperature difference, and the specific heat of moist air as defined by equation C8.

C3.1.5.3 The test shall include the determination of the compressor power requirement. This power shall be determined by measurement of electrical input to the motor drive (see C7.1.4). For motors supplied by others, the determination of compressor shaft horsepower input shall be outlined in the test procedure. For Air-Cooled or Evaporatively-Cooled Condensers, the test shall include the determination of the Condenser fan and Condenser spray pump power requirements.

C3.1.5.4 *Non-Electric Drive.* Where turbine or engine drive is employed, compressor shaft horsepower input shall be determined from steam, gas, or oil consumption, at measured supply and exhaust conditions and prime mover manufacturer's certified performance data.

C3.1.6 *Test Verification.*

C3.1.6.1 For the case of Water-Cooled Condensers, in addition to the determination of net heat removed and energy input required, data shall be taken to prepare a heat balance (C6.4.1) to substantiate the validity of the test.

C3.1.6.2 For Air-Cooled and Evaporatively- Cooled Condensers, it is impractical to measure heat rejection in a test; therefore, a heat balance cannot be calculated. To verify test accuracy, concurrent redundant instrumentation method (C6.4.2) shall be used to measure water temperatures, flow rates, and power inputs.

C3.1.6.3 For heat reclaim units with Air-Cooled Condensers or Water-Cooled Condensers, where the capacity is not sufficient to fully condense the refrigerant, the concurrent redundant instrumentation methods (C6.4.2) shall be used.

C3.1.6.4 For heat reclaim units with Water-Cooled Condensers that fully condense the refrigerant, the heat balance methods (C6.4.1) shall be used.

C3.2 *Condition of Heat Transfer Surfaces.*

C3.2.1 Tests conducted in accordance with this standard may require cleaning (in accordance with manufacturer's instructions) of the heat transfer surfaces. The as tested Fouling Factors shall then be assumed to be 0.0 h · ft^2 · °F/Btu [0.0 m^2 · °C/W].

C4 *Instrumentation.*

C4.1 Accuracy of instruments selected shall be in accordance with ANSI/ASHRAE Standard 30.

C4.2 Temperature measurements shall be made in accordance with ANSI/ASHRAE Standard 41.1.

C4.3 Flowmeters shall be constructed and installed in accordance with the applicable portion of ANSI/ASHRAE Standard 30. Turbine flow meters may be also used in accordance with ISA Standard RP31.1.

C4.4 Scales for analog meters shall be such that readings will be at least one-third of full scale deflection. All instruments, including gauges and thermometers shall be calibrated over the range of test readings.

C4.5 Pressure measurements shall be made in accordance with ASME Power Test Code PTC 19.2.

C5 *Measurements.*

C5.1 *Data to be Recorded During the Test.*

C5.1.1 *Test Data.* Compressor/ Evaporator (All Condenser Types):

a. Temperature of water entering evaporator, °F [°C]
b. Temperature of water leaving evaporator, °F [°C]
c. Chilled water flow rates, gpm [L/s]
d. Power input to compressor electrical power, kW [kW]

   Steam consumption of turbine, lb/h [kg/h]

   Steam supply pressure, psig [kPa]

   Steam supply temperature, ºF [ºC]

   Steam exhaust pressure, psig or in Hg vac [kPa], or

Gas consumption of turbine or engine, therms or ft^3/h, [m^3/s] and calorific value, Btu/ft^3, [J/L], or

Fuel consumption of diesel or gasoline, gal/h [L/s] and calorific value, Btu/gal [J/L]

e. Evaporator water pressure drop (inlet to outlet), psi or ft H_2O [kPa]
f. Electrical power input to controls and auxiliary equipment, kW [kW] (if not included in d)

C5.1.2 Water-Cooled *Condenser).*

a. Temperature of water entering the Condenser, °F [°C]
b. Temperature of water leaving the Condenser, °F [°C]
c. Condenser water flow rate, gpm [L/s]
d. Condenser water pressure drop (inlet to outlet), psi or ft H_2O [kPa]

C5.1.3 *Air-Cooled Condenser.*

a. Dry-bulb temperature of air entering the Condenser, °F [°C]
b. Condenser fan motor power consumption, kW [kW]
c. Barometric pressure, in Hg [kPa]

C5.1.4 *Evaporatively-Cooled Condenser.*

a. Wet-bulb temperature of air entering the Condenser, °F [°C]
b. Condenser fan motor power consumption, kW [kW]
c. Condenser spray pump power consumption, kW [kW]
d. Barometric pressure, in Hg [kPa]

C5.1.5 *Without Condenser.*

a. Discharge temperature leaving compressor, °F [°C]
b. Discharge pressure leaving compressor, psig [kPa]
c. Liquid refrigerant temperature entering the expansion device, °F [°C]
d. Liquid pressure entering the expansion device, psig [kPa]

C5.1.6 *Water-Cooled Heat Reclaim Condenser.*

a. Temperature of heat reclaim entering Condenser water, °F [°C]
b. Temperature of heat reclaim leaving Condenser water, °F [°C]
c. Heat reclaim Condenser water flow rate, gpm [L/s]
d. Heat reclaim Condenser water pressure drop (inlet to outlet), psi or ft H_2O [kPa]

C5.1.7 *Air-Cooled Heat Reclaim Condenser.*

a. Dry-bulb temperature of air entering the heat reclaim Condenser, °F [°C]
b. Dry-bulb temperature of air leaving the heat reclaim Condenser, °F [°C]
c. Heat reclaim Condenser standard air flow rate, cfm, [m^3/s]
d. Barometric pressure, in Hg [kPa]

C5.1.8 If chilled water is used to remove heat from any other source(s) within the package, the temperature and flow measurements of chilled water must be made at points so that the measurement reflects the net package cooling capacity.

C5.1.9 If Condenser water is used to cool the compressor motor or for some other incidental function within the package, the temperature and flow measurements of condenser water must be made at points, so that the measurement reflects the gross package heat rejection.

C5.2 *Auxiliary Data to be Recorded for General Information.*

C5.2.1 Nameplate data including make, model, size and refrigerant, sufficient to completely identify the water chiller. Unit voltage and frequency should be recorded.

C5.2.2 Compressor driver or input rpm for open-type compressors.

C5.2.3 Ambient temperature at test site, °F [°C].

C5.2.4 Actual voltage, V, and current, Amps, for each phase of all electric motor drives.

C.5.2.5 Motor, engine or turbine nameplate data.

C5.2.6 Pressure, in H_2O [kPa], temperature, °F [°C] and exhaust pressure, in H_2O [kPa] for steam turbine nameplate data.

C5.2.7 Fuel gas specification for gas turbine drive, including pressure, in H_2O [kPa].

C5.2.8 Heat balance for C6.4.

C5.2.9 Date, place, and time of test.

C5.2.10 Names of test supervisor and witnessing personnel.

C6 *Test Procedure.*

C6.1 *Preparation for Test.*

C6.1.1 The Water-Chilling Package, which has been completely connected in accordance with the manufacturer's instructions and is ready for normal operation, shall be provided with the necessary instrumentation.

C6.1.2 The test shall not be started until non-condensables have been removed from the system.

C6.1.3 At the manufacturer's option, Condenser and cooler surfaces may be cleaned as provided in C3.2.1.

C6.2 *Operations and Limits.*

C6.2.1 Start the system and establish the testing conditions in accordance with the following tolerances and instructions.

C6.2.1.1 *Evaporator (All Condenser Types)*

a. The chilled water flow rate, gpm [L/s], shall not deviate more than ± 5% from that specified.
b. The individual readings of water temperature leaving the evaporator shall not vary from the specified values by more than 0.5°F [0.3°C]. Care must be taken to insure that these water temperatures are the average bulk stream temperatures.
c. The leaving chilled water temperature shall be adjusted by an increment calculated per C6.3 corresponding to the specified field fouling allowance required for test.
d. Part-load tests for Water-Chilling Packages which have continuous capacity modulation must be taken within ± 2% of the full load tons at the specified part load capacity.
e. For water chillers with discrete steps of capacity control, the part-load tests shall be taken as close as practical to the specified part-load capacity as per Table 3.

C6.2.1.2 *Water-Cooled Condenser.*

a. The water flow rate, gpm [L/s], through the Condenser shall not deviate more than ± 5% from that specified.
b. The individual readings of water temperatures entering the refrigerant Condenser shall not vary from the specified values by more than 0.5°F [0.3°C]. Care must be taken to insure that these water temperatures are the

average bulk stream temperatures.

c. The entering condensing water temperature shall be adjusted by an increment calculated per C6.3 corresponding to the specified Fouling Factor Allowance.

C6.2.1.3 *Air-Cooled Condenser, Including Heat Reclaim.*

a. The average entering air dry-bulb temperature to the Condenser shall not vary from the specified values by more than 1.0°F [0.6°C].

b. For heat reclaim Air-Cooled Condensers the Condenser air flow rate shall not deviate from that required for test by more than ± 5%.

C6.2.1.4 *Evaporatively-Cooled Condenser.*

a. The entering air wet-bulb temperature shall not vary from the values required for test by more than 0.5°F [0.3°C].

C6.2.1.5 *Chiller Without Condenser.*

a. The saturated discharge temperature shall not vary from the values required for test by more than 0.5°F [0.3°C].

b. The liquid refrigerant temperature shall not vary from the specified values by more than 1.0°F [0.6°C].

C6.2.1.6 *Miscellaneous.*

a. For electrically driven machines, voltage and frequency *at the unit terminals* shall be maintained at the nameplate values within tolerances of ± 10% on voltage and ± 1% on frequency.

b. For steam-turbine driven machines, steam conditions to the turbine, and Condenser pressure or vacuum, shall be maintained at nameplate values.

c. For gas-turbine or gas-engine operating machines, gas pressure to turbine or engine, and exhaust back-pressure at the turbine or engine shall be maintained at nameplate values.

d. In all cases, the governor, if provided, shall be adjusted to maintain rated compressor speed.

C6.3 *Method for Simulating Fouling Factor Allowance at Full Load and Part-Load Conditions.*

C6.3.1 Obtain the log mean temperature difference (LMTD) for the evaporator and/or Condenser using the following equation at the specified Fouling Factor Allowance (ff_{sp}).

$$LMTD = \frac{R}{\ln\left(1 + \frac{R}{S}\right)} \qquad C1$$

R = Water temperature range
= absolute value (t_{wl} - t_{we}), °F[°C]

S = Small temperature difference
= absolute value (t_s - t_{wl}), °F [°C]

C6.3.2 Derivation of LMTD:

$$LMTD = \frac{(t_s - t_{we}) - (t_s - t_{w1})}{\ln\left[\frac{t_s - t_{we}}{t_s - t_{w1}}\right]}$$

$$= \frac{(t_{w1} - t_{we})}{\ln\left[\frac{(t_s - t_{w1}) + (t_{w1} - t_{we})}{t_s - t_{w1}}\right]}$$

The Incremental LMTD (ILMTD) is determined using the following equation:

$$ILMTD = ff_{sp}\ \left(\frac{q}{A}\right) \qquad C2$$

C6.3.3 The water temperature needed to simulate the additional fouling, TD_a, can now be calculated:

$$TD_a = S_{sp} - S_c \qquad \text{C3a}$$

$$TDa = S_{sp} - \frac{R}{e^Z - 1} \qquad \text{C3b}$$

where:

$$Z = \frac{R}{LMTD - ILMTD}$$

$$S_c = \frac{R}{e^z - 1}$$

S_{sp} = Small temperature difference as specified, °F [°C]
S_c = Small temperature difference as tested in cleaned condition, °F[°C]

The water temperature difference, TD_a, is then added to the Condenser entering water temperature or subtracted from the evaporator leaving water temperature to simulate the additional Fouling Factor.

C6.3.4 *Example-Condenser Fouling Inside Tubes* (in I.P Units for clarity):

Specified Fouling Factor Allowance,
ff_{sp} =0.00025 h · ft^2 ·°F/Btu
Condenser load, q = 2,880,000 Btu/h

Specified Condenser leaving water temp, T_{wl} = 95°F

Specified Condenser entering water temp, T_{we} = 85 °F

Inside* tube surface area, A_i = 550 ft^2

*(Since fouling is inside tubes in this example)

Saturated condensing temperature,
t_s = 101 °F

$$S_{sp} = t_s - t_{wl} = 101 - 95 = 6\ °F$$

$$R = t_{wl} - t_{we} = 95 - 85 = 10\ °F$$

$$LMTD = \frac{R}{\ln(1 + R/S)}$$

$$= \frac{10}{\ln(1 + 10/6)} = 10.2$$

$$ff_{sp} = 0.00025$$

$$ILMTD = ff_{sp}\left(\frac{q}{A}\right)$$

$$= 0.00025\left[\frac{2,880,000}{550}\right]$$

$$= 1.31$$

$$TD_a = Ssp - \frac{R}{e^Z - 1}$$

where:

$$Z = \frac{R}{LMTD - ILMTD}$$

$$Z = \frac{10}{10.2 - 1.31} = 1.125$$

$$TD_a = 6.0 - \frac{10}{e^{1.125} - 1}$$

$$= 6.0 - 4.8 = 1.2°F$$

The entering Condenser water temperature for testing is then raised 1.2°F to simulate the Fouling Factor Allowance of 0.00025 h · ft^2 · °F/Btu. The entering condenser water temperature will be 85 + 1.2 or 86.2°F.

C6.4 *Test Verification:*

C6.4.1 *Heat Balance-Substantiating Test.*

C6.4.1.1 *Calculation of Heat Balance.* In most cases, heat losses or heat gain caused by radiation, convection, bearing friction, oil coolers, etc., are relatively small and may or may not be considered in the overall heat balance.

Omitting the effect of the small heat losses and gains mentioned above, the general heat balance equation is as follows:

$$q_{ev} + W_{input} = q_{cd} + q_{hrc}$$

where:

W_{input} = compressor work input as defined in C6.4.1.2 through C6.4.1.4

C6.4.1.2 In a hermetic package, where the motor is cooled by refrigerant, chilled water or condenser water, the motor cooling load will be included in the measured condenser load, hence

W_{input} = electrical power input to the compressor motor, Btu/h [kW]

C6.4.1.3 In a package using an open-type compressor with prime mover and external gear drive:

$$W_{input} = q_{prime\ mover} - q_{gear}$$

where:

W_{input} = Power input to the compressor shaft, Btu/h [kW]

$q_{prime\ mover}$ = Power delivered by prime mover, Btu/h [kW]

q_{gear} = Friction loss in the gear box, Btu/h [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.

C6.4.1.4 In a package using an open-type compressor with direct drive and the prime mover not furnished by the manufacturer:

W_{input} = power input to the compressor shaft, Btu/h [kW]

For determination of W_{input} 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_{input} = power measured at motor terminals plus power to auxiliaries as in C.7.1.4.

C6.4.1.5 *Percent Heat Balance.* Heat balance, in %, is defined as:

$$\frac{\left(q_{ev} + W_{input}\right) - \left(q_{cd} + q_{hrc}\right)}{q_{cd} + q_{hrc}} \times 100 \qquad \text{C4}$$

For any test of a liquid cooled chiller to be acceptable, the heat balance (%) shall be within the allowable tolerance calculated per 5.6 for the applicable conditions.

C6.4.2 *Concurrent Redundant Verification Test for Air-Cooled or Evaporatively- Cooled Condensers.*

C6.4.2.1 *Capacity Calculation Method.* Calculate the capacity of the cooler using one set of instrumentation. Also calculate the capacity of the cooler using the redundant set of instrumentation. For a valid test, these two calculated values must agree within the tolerance specified in Section 5.6. The tested capacity of the machine shall be the average of these two values.

C6.4.2.2 *Power Calculation Method.* The power measured by the two sets of instruments must be within 2% at all loads. The tested power of the machine shall be the average of the two measured powers.

C6.4.2.3 *Efficiency Calculation Method.* Efficiency shall be calculated using the measured (averaged) values and must comply within the tolerances of 5.6.

C7 *Calculation of Results*

C7.1 *Capacity and Power.*

C7.1.1 The capacity, tons, shall be obtained by the following equation:

$$\text{Capacity} = \frac{c \cdot m_w \left(t_e - t_1\right)}{12{,}000} \qquad \text{C5}$$

The capacity, Btu/h [kW], shall be obtained from the following equation:

$$q_{ev} = c \cdot m_w \, (t_e - t_l) \qquad \text{C6}$$

C7.1.2 *Water-Cooled Heat Reclaim Condensers.* If used, the Water-Cooled Heat Reclaim Condenser capacity Btu/h [kW] shall be calculated using the following equation.

$$q_{hrc} = c \cdot m_w \left(t_1 - t_e\right) \qquad \text{C7}$$

C7.1.3 *Air-Cooled Heat Reclaim Condensers* If used, the Air-Cooled Heat Reclaim Condenser capacity (Btu/h) shall be calculated using the following equation.

$$q_{hrc} = 1.08 \, cfm_{hrc} \left(t_1 - t_e\right) \qquad \text{C8}$$

where:

$$1.08 = 0.244 \text{ x } \frac{60}{13.5}$$

0.244 = Specific heat of moist air at 70°F and 50% rh (Btu/°F · lb dry air)
60 = min/hr
13.5 = Specific volume of moist air at 70°F db and 50% rh (ft^3/lb dry air)

The capacity (kW) shall be calculated using the following equation.

$$q_{hrc} = 4355 \, cfm_{hrc} \left(t_l - t_e\right) \qquad \text{C9}$$

where:

$$4355 = 1.021 \text{ x } \frac{3600}{0.844}$$

1.021 = Specific heat of moist air at 21.1°C and 50% rh (kJ/kg°K · kg dry air)
3600 = sec/hr
0.844 = Specific volume of moist air at 21.1°C db and 50% rh (mt^3/kg dry air)

C7.1.4 Power consumption shall be determined as follows:

C7.1.4.1 For motor driven centrifugal and rotary screw compressors where the motor is supplied by the manufacturer, the compressor power input shall be measured as close as practical to the compressor motor terminals. If a frequency conversion device or motor starter is furnished as part of the compressor circuit, the compressor power input shall be measured at the input terminals of the frequency converter or motor starter. For remote starters or frequency converters, line losses shall be subtracted. If the Water-Chilling Package being tested is not equipped with the starter or frequency converter furnished for it, then a starter or frequency converter of similar type shall be used for the test.

C7.1.4.2 Power consumption of auxiliaries shall be measured during normal operation of the package and included in total power consumption.

C7.1.4.3 For open-type compressors, where the motor and/or gear set is not supplied by the manufacturer, or for engine or turbine drives, the compressor shaft input shall be determined as stated in C6.4.1.3 or C6.4.1.4 .

C7.1.4.4 For Air-Cooled or Evaporatively-Cooled Condensers, the additional Condenser fan and Condenser spray pump power consumption shall be measured as close as practical to the motors.

C7.1.4.5 *Validity of Test.* Calculate the heat balance for each of the three test points (C3.1.2). All three heat balances must be within the tolerance specified in 5.6. Then average the data taken from the three test points and calculate capacity and power input per C7 using averaged data for reporting purpose.

C8 *Symbols and Subscripts.* The symbols and subscripts used are as follows:

Symbols:

A = Total heat transfer surface, ft^2 [m^2] for evaporator or Condenser
c = Specific heat of water at average water temperature, Btu/lb °F [kJ/kg °K]
cfm = Air flow rate, ft^3/min [m^3/s]
e = Base of natural logarithm
ff = Fouling Factor Allowance h · ft2 · ºF/Btu [m^2 · ºC/ W]
m = Mass flow rate, lb/h [kg/s]
q = Capacity in Btu/h [kW]
R = Water temperature range, °F [°C]
= Absolute value (t_{wl}- t_{we},), °F [°C]
S = Small temperature difference
= Absolute value (t_s-t_{wl},), °F [°C]
t = Temperature, °F [°C]
t_s = Saturated vapor temperature for single component or azeotrope refrigerants and for zeotropic refrigerants it is the arithmetic average of the dew point and bubble point temperatures corresponding to refrigerant pressure., °F [°C]

Subscripts:

a = Additional fouling
c = Clean
cd = Condenser
e = Entering
ev = Evaporator
f = Fouled or fouling
hrc = Heat reclaim
i = Inside
l = Leaving
o = Outside
s = Saturation
sp = Specified
w = Water

APPENDIX D. DERIVATION OF INTEGRATED PART LOAD VALUE (IPLV) - NORMATIVE

D1 *Purpose.* This appendix is intended to show the derivation of the Integrated Part-Load Value (IPLV).

D2 *Scope.* This appendix is for equipment covered by this standard. The IPLV equations and procedure are intended to provide a consistent method for calculating a single number part-load performance figure of merit for Water-Chilling Packages. The equation was derived to provide a representation of the average part-load efficiency for a single chiller only. However, it is best to use a comprehensive analysis that reflects the actual weather data, building load characteristics, operational hours, economizer capabilities and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the chiller and system efficiency. This becomes increasingly important with multiple chiller systems because individual chillers operating within multiple chiller systems are more heavily loaded than single chillers within single chiller systems.

D3 *Equation and Definition of Terms*.

D3.1 The energy efficiency of a chiller is commonly expressed in one of the three following ratios:

a. Coefficient of Performance, COP
b. Energy Efficiency Ratio, EER
c. Total Power Input per Capacity kW/ton [kW/kW]

These three alternative ratios are related as follows:

COP = .293 EER	EER = 3.413 COP
kW/ton = 12/EER	EER = 12/(kW/ton)
kW/ton = 3.516/COP	COP = 3.516/(kW/ton)

The following equation is used when an efficiency is expressed as EER [Btu/(W·h)] or COP [W/W]:

$$IPLV = 0.01\,A + 0.42\,B + 0.45\,C + 0.12\,D \qquad \text{D1a}$$

where:

*A = EER or COP at 100% capacity
*B = EER or COP at 75% capacity
*C = EER or COP at 50% capacity
*D = EER or COP at 25% capacity

The following equation is used when the efficiency is expressed in Total Power Input per Capacity, kW/ton:

$$IPLV = \frac{1}{\frac{0.01}{A} + \frac{0.42}{B} + \frac{0.45}{C} + \frac{0.12}{D}} \qquad \text{D1b}$$

where:

*A = kW/ton at 100% capacity
*B = kW/ton at 75% capacity
*C = kW/ton at 50% capacity
*D = kW/ton at 25% capacity

The IPLV or NPLV rating requires that the unit efficiency be determined at 100%, 75%, 50% and 25% at the conditions as specified in Table 3. If the unit, due to its capacity control logic can not be operated at 75%, 50%, or 25% capacity then the unit can be operated at other load points and the 75%, 50%, or 25% capacity efficiencies should be determined by plotting the efficiency versus the % load using straight line segments to connect the actual performance points. The 75%, 50%, or 25% load efficiencies can then be determined from the curve. Extrapolation of data shall not be used. An actual chiller capacity point equal to or less than the required rating point must be used to plot the data. For example, if the minimum actual capacity is 33% then the curve can be used to determine the 50% capacity point, but not the 25% capacity point.

If a unit cannot be unloaded to the 25%, 50%, or 75% capacity point, then the unit should be run at the minimum step of unloading at the condenser entering water or air temperature based on Table 3 for the 25%, 50% or 75% capacity points as required. The efficiency shall then be determined by using the following equation:

$$EER = \frac{Btu/h_{measured}}{C_D \cdot W_{measured}} \qquad \text{D2}$$

where C_D is a degradation factor to account for cycling of the compressor for capacities less than the minimum step of capacity. C_D should be calculated using the following equation:

$$C_D = (-0.13 \cdot LF) + 1.13 \qquad \text{D3}$$

The load factor LF should be calculated using the following equation:

* at operating conditions per Tables 1 and 3

$$LF = \frac{\frac{\%\,Load}{100} \cdot (\text{Full load unit capacity})}{(\text{Part} - \text{Load unit capacity})} \qquad D4$$

where:

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

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

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

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

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

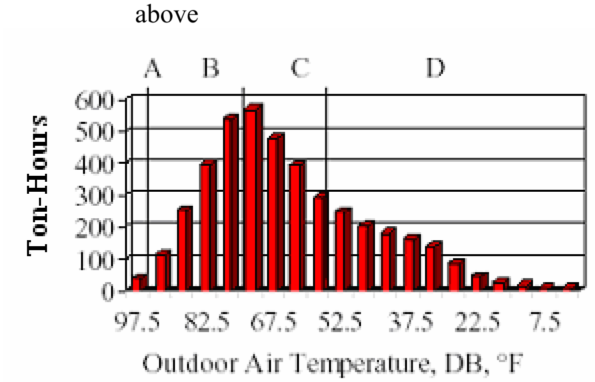

Figure D1. Ton-Hour Distribution Categories

The following assumptions were used:

a. Modified ASHRAE Temperature Bin Method for energy calculations was used.
b. Weather data was a weighted average of 29 cities across the U.S.A, specifically targeted because they represented areas where 80% of all chiller sales occurred over a 25 year period (1967-1992).
c. Building types were a weighted average of all types (with chiller plants only) based on a DOE study of buildings in 1992 [DOE/EIA-0246(92)].
d. Operational hours were a weighted average of various operations (with chiller plants only) taken from the DOE study of 1992 and a BOMA study (1995 BEE Report).
e. A weighted average of buildings (with chiller plants only) with and without some form of economizer, based upon data from the DOE and BOMA reports, was included.
f. The bulk of the load profile used in the last derivation of the equation was again used, which assumed that 38% of the buildings' load was average internal load (average of occupied vs. unoccupied internal load). It varies linearly with outdoor ambient and mean Condenser wet-bulb (MCWB) down to 50°F DB, then flattens out below that to a minimum of 20% load.
g. Point A was predetermined to be the design point of 100% load and 85°F ECWT/95°F EDB for IPLV/NPLV. Other points were determined by distributional analysis of ton-hours, MCWB's and EDBs. ECWTs were based upon actual MCWBs plus an 8°F tower approach.

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

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

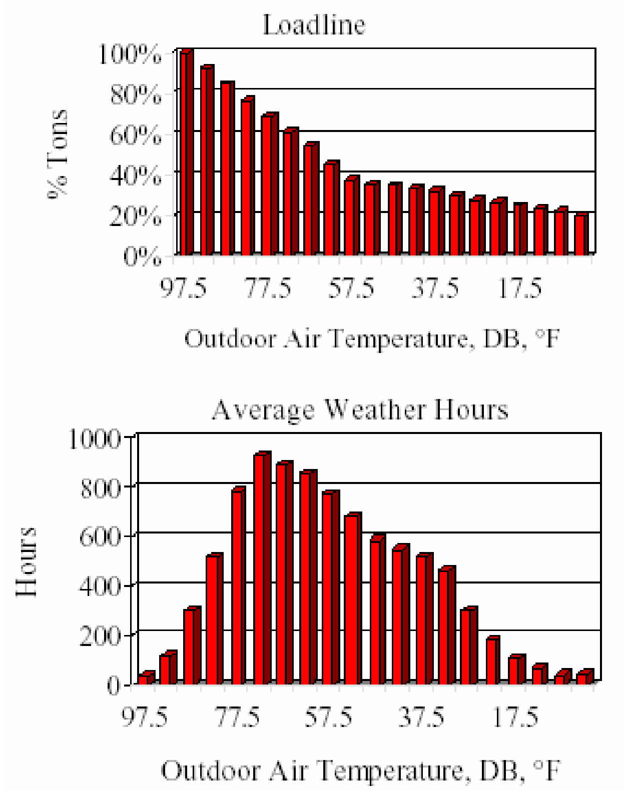

Figure D2. Bin Groupings

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

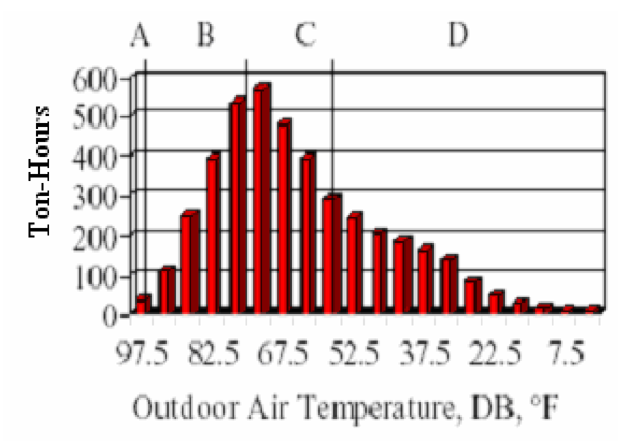

Figure D3. Group 1 Ton-Hour Distribution Categories

Point A	=	1 bin for Design Bin
Point B	=	4 bins for Peak Bin
Point C	=	4 bins for Low Bin
Point D	=	all bins below 55°F for Min Bin

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

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

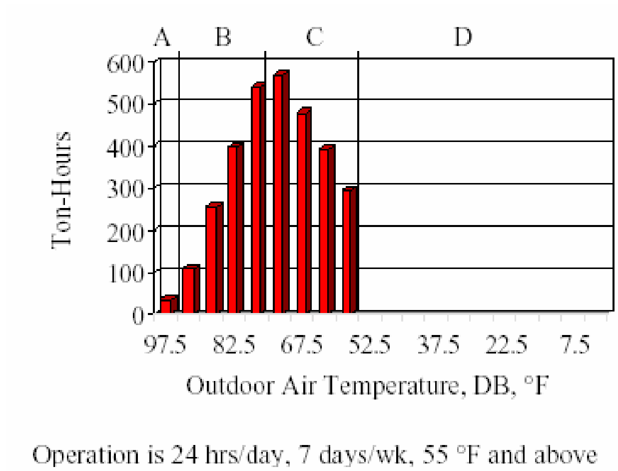

Figure D4. Group 2 Ton-Hour Distribution Categories

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

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

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

This calculates to the following new equation:
IPLV equation (kW/ton):

$$IPLV = \frac{1}{\frac{0.014}{A} + \frac{0.416}{B} + \frac{0.446}{C} + \frac{0.124}{D}} \qquad \text{D5}$$

A	=	kW/ton @ 100% Load and 85°F ECWT or 95°F EDB
B	=	kW/ton @ 76.1% Load and 75.6°F ECWT or 82.1°F EDB

C = kW/ton @ 50.9% Load and 65.6°F ECWT or 65.8°F EDB

D = kW/ ton @ 32.2% Load and 47.5°F ECWT or 39.5°F EDB

Rounding off and rationalizing:

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

A = kW/ton @ 100% Load and 85°F ECWT or 95°F EDB

B = kW/ton @ 75% Load and 75°F ECWT or 80°F EDB

C = kW/ton @ 50% Load and 65°F ECWT or 65°F EDB

D = kW/ton @ 25% Load and 65°F ECWT or 55°F EDB

After rounding off and applying the rationale of where the manufacturers' and the current test facilities capabilities lie, the final equation D1b is shown in Section D3.1.

							C/S						Chiller	
							Min Bin		Low Bin		Peak Bin		Des Bin	
Outside Temp (ºF)	Average DB (ºF)	OA DB	Total Hours	DBH	Total Ton-Hrs	Cooling Load %	DBH	Ton-Hrs	DBH	Ton-Hrs	DBH	Ton-Hrs	DBH	Ton-Hrs
95-99	97.5	97.5	37	3608	37	100%	0	0	0	0	0	0	3608	37
90-94	92.5	92.5	120	11100	111	92%	0	0	0	0	11100	111	0	0
85-89	87.5	87.5	303	26513	256	85%	0	0	0	0	26513	256	0	0
80-84	82.5	82.5	517	42653	397	77%	0	0	0	0	42653	397	0	0
75-79	77.5	77.5	780	60450	539	69%	0	0	0	0	60450	539	0	0
70-74	72.5	72.5	929	67353	570	61%	0	0	67353	570	0	0	0	0
65-69	67.5	67.5	894	60345	479	54%	0	0	60345	479	0	0	0	0
60-64	62.5	62.5	856	53500	393	46%	0	0	53500	393	0	0	0	0
55-59	57.5	57.5	777	44678	296	38%	0	0	44678	296	0	0	0	0
50-54	52.5	52.5	678	35595	247	36%	35595	247	0	0	0	0	0	0
45-49	47.5	47.5	586	27835	204	35%	27835	204	0	0	0	0	0	0
40-44	42.5	42.5	550	23375	183	33%	23375	183	0	0	0	0	0	0
35-39	37.5	37.5	518	19425	163	32%	19425	163	0	0	0	0	0	0
30-34	32.5	32.5	467	15178	140	30%	15178	140	0	0	0	0	0	0
25-29	27.5	27.5	299	8223	84	28%	8223	84	0	0	0	0	0	0
20-24	22.5	22.5	183	4118	49	27%	4118	49	0	0	0	0	0	0
15-19	17.5	17.5	111	1943	28	25%	1943	28	0	0	0	0	0	0
10-14	12.5	12.5	68	850	16	23%	850	16	0	0	0	0	0	0
05-09	7.5	7.5	40	300	9	22%	300	9	0	0	0	0	0	0
00-04	2.5	2.5	47	118	9	20%	118	9	0	0	0	0	0	0
Total	57.9	57.9	8670	507155	4210	DBH Total	136958	1132	225628	1738	140715	1303	3608	37
						Weighting:		26.9%		41.3%		30.9%		0.9%
						EDB ºF:		38.6		65.4		81.8		95.0
						Load:		31.9%		50.3%		75.7%		100%
								D		C		B		A

Table D1. Group 1 Air-Cooled IPLV Data and Calculation

														C/S	Chiller
								Min Bin		Low Bin		Peak Bin		Des Bin	
Outside Temp (ºF)	Average DB (ºF)	MC WB (sy)	CWH	Total Hours	CWH	Total Ton-Hrs	Cooling Load %	CWH	Ton-Hrs	CWH	Ton-Hrs	CWH	Ton-Hrs	CWH	Ton-Hrs
95-99	97.5	72	80	37	2960	37	100%	0	0	0	0	0	0	2960	37
90-94	92.5	71	79	120	9480	111	92%	0	0	0	0	9480	111	0	0
85-89	87.5	69	77	303	23331	256	85%	00	0	0	0	23331	256	0	0
80-84	82.5	68	76	517	39292	397	77%	00	0	0	0	39292	397	0	0
75-79	77.5	66	74	780	57720	539	69%	0	0	0	0	57720	539	0	0
70-74	72.5	63	71	929	65959	570	61%	0	0	65959	570	0	0	0	0
65-69	67.5	59	67	894	59898	479	54%	0	0	59898	479	0	0	0	0
60-64	62.5	55	63	856	53928	393	46%	0	0	53928	393	0	0	0	0
55-59	57.5	50	59	777	45843	296	38%	0	0	45843	296	0	0	0	0
50-54	52.5	45	55	678	37290	247	36%	37290	247	0	0	0	0	0	0
45-49	47.5	41	52	586	30472	204	35%	30472	204	0	0	0	0	0	0
40-44	42.5	37	49	550	26950	183	33%	26950	183	0	0	0	0	0	0
35-39	37.5	32	45	518	23310	163	32%	23310	163	0	0	0	0	0	0
30-34	32.5	27	41	467	19147	140	30%	19147	140	0	0	0	0	0	0
25-29	27.5	22	40	299	11960	84	28%	11960	84	0	0	0	0	0	0
20-24	22.5	17	40	183	7320	49	27%	7320	49	0	0	0	0	0	0
15-19	17.5	13	40	111	4440	28	25%	4440	28	0	0	0	0	0	0
10-14	12.5	8	40	68	2720	16	23%	2720	16	0	0	0	0	0	0
05-09	7.5	4	40	40	1600	9	22%	1600	9	0	0	0	0	0	0
00-04	2.5	1	40	47	1880	9	20%	1880	9	0	0	0	0	0	0
Total	57.9	49.3	60.0	8670	525500	4210	CWH Total	167089	1132	225628	1738	129823	1303	2960	37
							Weighting		26.9%		41.3%		30.9%		0.9%
							ECWT ºF		47.1		65.3		81.8		85.0
							Load		31.9%		50.3%		75.7%		100%
									D		C		B		A

Table D2. Group 1 Water-Cooled IPLV Data and Calculation

Group 1	**% Load**	**ECWT**	**EDB**	**Weight**	**Group 2**	**% Load**	**ECWT**	**EDB**	**Weight**
A	100.0%	85.0 ºF	95.0 ºF	0.95%	A	100.0%	85.0 ºF	95.0 ºF	1.2%
B	75.7%	75.5 ºF	81.8 ºF	30.9%	B	75.7%	75.5 ºF	81.8 ºF	42.3%
C	50.3%	65.3 ºF	65.4 ºF	41.3%	C	50.3%	65.3 ºF	65.4 ºF	56.5%
D	31.9%	47.1 ºF	38.6 ºF	26.9%	D	N/A	N/A	N/A	0.0%
IPLV =	$\frac{1}{.009/A + .309/B + .413/C + .269/D}$				IPLV =	$\frac{1}{.012/A + .423/B + .565/C + 0.0/D}$			
Group 3	% Load	ECWT	EDB	Weight	Group 4	% Load	ECWT	EDB	Weight
A	100.0%	85.0 ºF	95.0 ºF	1.5%	A	100.0%	85.0 ºF	95.0 ºF	1.8%
B	75.7%	75.6 ºF	82.2 ºF	40.9%	B	76.4%	75.6 ºF	82.2 ºF	50.1%
C	50.3%	65.8 ºF	66.0 ºF	39.2%	C	51.3%	65.8 ºF	66.0 ºF	48.1%
D	31.9%	47.7 ºF	40.0 ºF	18.4%	D	N/A	N/A	N/A	0.0%
IPLV =	$\frac{1}{.015/A + .409/B + .392/C + .184/D}$				IPLV =	$\frac{1}{.018/A + .501/B + .481/C + 0.0/D}$			

Table D3. Group 1 - 4 IPLV Summary