2000 Standard for

Absorption Water Chilling and Water Heating Packages

IMPORTANT

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Note:

This standard supersedes ARI Standard 560-92.

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ABSORPTION WATER CHILLING
AND WATER HEATING PACKAGES

Section 1. Purpose

1.1   *Purpose*. The purpose of this standard is to establish for Absorption Water Chilling and Water Heating Packages: 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 water-cooled single-effect steam and hot water operated water chilling units, water-cooled double-effect steam and hot water operated water chilling units, and double-effect Direct-Fired (natural gas, oil, LP gas) water chilling/heating units. Water is the refrigerant and LiBr (lithium bromide) the absorbent. See definitions in Section 3.

2.2   *Exclusions*. This standard does not apply to air-cooled applications, heat pump applications, exhaust gas fired applications, and non-standard units.

Section 3. Definitions

Definitions. All terms in this document shall 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   *Absorption Water Chilling and Water Heating Package.* A factory designed and prefabricated assembly employing water as the refrigerant and consisting of an evaporator, absorber, condenser, generator(s) and solution heat exchangers, with interconnections and accessories used for chilling or heating water. The package utilizes single or multiple reconcentrations of an absorbent solution. The reconcentrations of the absorbent are known as effects. A single effect package employs one step reconcentration of the absorbent in the generator. Water vapor is released after the heat energy is introduced into the generator. The concentrated absorbent is returned to the absorber where it can absorb water vapor flashed off in the evaporator. A double effect package employs a two step reconcentration of the absorbent through the use of an additional high temperature generator. An absorption package can be further defined by the following:

3.1.1   *Direct Fired Package*. This type of package reconcentrates the absorbent from heat energy through the combustion of natural gas, LP gas or oil.

3.1.2   *Indirect Fired Package.* This type of package reconcentrates the absorbent from heat energy from steam or hot water.

3.2   *Coefficient of Performance (COP)*. A ratio of Cooling/Heating Capacity in watts [W] to the power input values in watts [W] at any given set of rating conditions expressed in watts/watt [W/W]. For heating *COP*, supplementary resistance heat shall be excluded.

3.3   *Cooling Only Mode.* Operational mode of a Direct-Fired chiller/heater which supplies (only) chilled water.

3.4   *Energy Input.* The heat content of the fuel, steam or hot water excluding the electrical input.

3.4.1   *Direct Fired*. Energy Input is the gross heating content of the fuel based on the Higher Heating Value in MBH [kW].

3.4.2 *Indirect Fired*. Energy Input is the heat content of the steam or hot water in MBH [kW].

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

3.5.1 *Field Fouling Allowance*. Provision for anticipated fouling during use, h≅ft^2 EF/Btu [m^2 EC/W].

3.6 *Heating Only Mode*. Operational mode of a Direct-Fired chiller/heater which supplies only hot water.

3.7 *Higher Heating Value (HHV)*. The amount of heat produced per unit of fuel when complete combustion takes place at constant pressure, the products of combustion are cooled to the initial temperature of the fuel and air, and the vapor formed during combustion is condensed, Btu/lb or Btu/ft^3 [W/m^3] for gaseous fuel, or Btu/lb [J/kg] or Btu/gal for liquid fuel.

3.8 *High Pressure Steam*. Steam pressures above 15.0 psig [103 kPa], but below 150 psig [1030 kPa].

3.9 *Hot Water Heating Option*. Hot water can be provided from an absorption chiller/heater through either of two circuits:

3.9.1 Through the evaporator circuit (2-pipe system); typically applied at temperatures up to 140EF [60.0EC] (standard temperature hot water).

3.9.2 Through a separate hot water heat exchanger (4-pipe system); typically applied at temperatures above 140EF [60.0EC] up to and including 175EF [79.4EC] and/or for simultaneous heating/cooling operation (high temperature hot water).

3.10 *Integrated Part-Load Value (IPLV)*. A single number part-load efficiency figure of merit calculated per the methods described in 5.3 referenced to Standard Rating Conditions.

3.11 *Low Pressure Steam*. Steam pressures 15.0 psig [103 kPa] and below.

3.12 *Net Cooling/Heating Capacity*. The net cooling/ heating capacity is considered as the usable capacity to the user's system.

3.13 *Non-Standard Part-Load Value (NPLV)*. A single number part-load efficiency figure of merit calculated per the method described in 5.3 referenced to conditions other than *IPLV* Conditions (for units that are not designed to operate at AHRI Standard Rating Conditions).

3.14 *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. As used herein, 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.

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

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

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

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

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

3.16 *Simultaneous Heating/Cooling Mode*. Operational mode of a Direct-Fired absorption chiller/heater whereby chilled water and hot (heating) water are produced at the same time.

Section 4. Test Requirements

4.1   *Test Requirements.* All tests for chiller or chiller/heater ratings shall be conducted in accordance with the test method specified in Appendix C.

Section 5. Rating Requirements

5.1   *Standard Rating Conditions.* Published Ratings for all Absorption Water Chilling Packages shall include the Standard Rating, corresponding to the applicable Standard Rating Conditions shown in Table 1, and identified as the Standard Rating. Standard Ratings shall include a water-side fouling factor allowance for the absorber/condenser of 0.00025 h≅ft^2≅EF/Btu [0.000044 m^2≅EC/W] and for the evaporator of 0.0001 h≅ft^2≅EF/Btu [0.000018 m^{2}AEC/W].

5.2   *Application Rating Conditions.* Application Ratings (at other than Standard Rating Conditions) include ratings at the following range of conditions or within the operating limits of the equipment:

Leaving chilled water temperature..40 to 48EF [4.4 to 8.9EC] in increments of 2EF [1EC] or less.

Entering absorber/condenser water temperature ....70.0 to 90EF [26.7 to 32.2EC] in increments of 5EF [3EC] or less.

Absorber/condenser water flow rate limit.....................................2.8 to 6.0 gpm/ton [0.05 to 0.11 L/s per kW].

Evaporator chilled water flow rate limit ....1.6 to 3.0 gpm/ton [0.03 to 0.05 L/s per kW].

Heating water flow rate (double effect heating cycle) ....manufacturer's standard gpm/ton [L/s per kW].

Steam pressure (at steam valve or inlet..0 to 15.0 psig [0 to 103 kPa gauge] in increments of header of a single stage unit) 2.0 psi [14 kPa] or less – manufacturer to specify.

Steam pressure (at steam valve or inlet header ....0 to 125 psig [0 to 861 kPa] in increments of 15.0 psi of a two-stage unit [103 kPa] or less – manufacturer to specify.

Hot water (to generator) temperature ....180EF to 400EF [82EC to 204EC].

5.3   *Part-Load Ratings*. The intent of part-load ratings is to permit the development of part-load performance over a range of operating conditions.

> **5.3.1**   Part-Load rating points shall be presented in one or more of the following three ways:
>
> > **5.3.1.1**   *Integrated Part-Load Value (IPLV).* Based on the conditions defined in Table 2.
> >
> > **5.3.1.2**   *Non-Standard Part-Load Value (NPLV)*. Based on the conditions defined in Table 2.
> >
> > **5.3.1.3**   *Separate Part-Load Data Point(s) Suitable for Calculating IPLV or NPLV*. In addition, other part-load points may also be presented.
>
> **5.3.2**   *Determination of Part-Load Performance*. For water chilling packages covered by this standard, Part-Load Values (*IPLV* or *NPLV*) shall be calculated as follows:
>
> > **5.3.2.1**   Determine the part-load energy efficiency at 100%, 75%, 50%, and 25% load points at the conditions specified in Table 2.

5.3.2.2   Use the following equation to calculate the *IPLV* or *NPLV*:

For *COP*:

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

(1a)

Where: A = *COP* at 100%
B = *COP* at 75%
C = *COP* at 50%
D = *COP* at 25%

For MBH/ton:

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

(1b)

Where: A = MBH/ton at 100%
B = MBH/ton at 75%
C = MBH/ton at 50%
D = MBH/ton at 25%

5.3.2.3   For a derivation of equations (1a), (1b) and 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.

5.3.2.4   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 2. If the unit, due to its capacity control logic, cannot be operated at 25% capacity, then the unit can be operated at its minimum capacity and the 25% chiller capacity point shall then be determined by using the following equation:

$$COP = \frac{Net\ Output}{C_D \times Net\ Input}$$

(2)

Where C_D is a degradation factor to account for cycling of the chiller for capacities less than the minimum capacity. C_D shall be calculated using the following equation:

$$C_D = (\text{-}0.13 \times LF) + 1.13$$

The factor *LF* shall be calculated using the following equation:

$$LF = \frac{\dfrac{\%\ Load}{100} \cdot (Full\ Load\ Unit\ Capacity)}{(Minimum\ Unit\ Capacity)}$$

Where:

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

Minimum Unit Capacity is the measured or calculated unit capacity from which standard rating points are determined using the method above.

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

Part-Load Values Provided				
Point	Load %	Capacity (tons)	MBH	*COP*
A	100	100	1200	1.00
B	75	75	849	1.06
C	50	50	536	1.12
MIN	35	35	368	1.14

Using the above data, the part-load *COP* value can be calculated.

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

$$LF = \frac{(0.25)\,x\,(1.00)}{35.0} = 0.71$$

$$C_D = (-0.13 \; x \; 0.71) + 1.13 = 1.04$$

$$COP = \frac{35.0 \; tons \; x \; 12000 \; Btu/ton \cdot h}{1.04 \; x \; 368 \; x \; 1000} = 1.10$$

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

$$IPLV\,(COP) \; = \; (0.01\,x\,1.00) + (0.42\,x\,1.06) + (\,0.45\,x\,1.12) + (0.12\,x\,1.10) = 1.09$$

5.4 *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.

5.4.1 *Method of Establishing Cleaned and Fouled Ratings from Laboratory Test Data.*

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

5.4.1.2 Evaporator water-side and absorber/condenser water-side heat transfer surfaces shall be considered clean during testing. Tests will be assumed to reflect Fouling Factors of 0.000 h≅ft^2 EF/Btu [0.000 m^2≅EC/W].

5.4.1.3 To determine the capacity of the chiller package at the rated fouling conditions, the procedure defined in C7.3 shall be used to determine an adjustment for the evaporator and or absorber/condenser water temperatures.

5.4.1.4 To simulate fouling factor allowance at full and part-load conditions, the method defined in C7.3 shall be used.

5.5   *Tolerances.*

5.5.1   *Allowable Tolerances.* The allowable test tolerance on capacity tons [kW]; *COP*; MBH/ton and heat balance shall be determined from the following equation:

U.S. Standard Units: DT_{FL} in ºF

Tolerance, %

$$= 10.5 - (0.07 \ x \ \%FL) \ + \ (\frac{1500}{DT_{FL} \ x \ \%FL})$$

or

SI Units: DT_{FL} in EC

Tolerance, %

$$= 10.5 - 0.07 \ x \ \%FL \ + \ (\frac{833.3}{DT_{FL} \ x \ \%FL})$$

Where:

        FL =   Full Load
        DT_{FL} =   Difference between entering and leaving chilled water temperature at full load, EF [EC]

See Figure 1 for graphical representation only.

5.5.2   *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 5.5.1.

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

Full Load Example in *COP* (for Direct Fired Chillers):

Rated Full Load Performance:

    Rated Capacity   = 100 tons
    Rated Input   = 1200 MBH
    Evaporator DT_{FL} = 10EF

$$COP = \frac{100 \ tons \ x \ 12000 \ Btu/ton \cdot h}{1200 \ MBH \ x \ 1000} = 1.0$$

Allowable Test Tolerance:

Tolerance =

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

$$= 10.5 - 7 + 1.5 = 5 \ \%$$

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Min. Allowable Capacity =

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

Min. Allowable *COP* =

$$\frac{100 \ - \ 5}{100} \ x \ 1.0 \ = \ 0.95$$

Max. MBH at min. capacity =

$$\frac{95 \ tons \ x \ 12000 \ Btu/ton \times h}{0.95 \ x \ 1000} = 1200 \ MBH$$

Full Load Example in MBH/ton (Direct Fired Chillers):

Rated Full Load Performance:

Rated Capacity = 100 tons
Rated Input = 1200 MBH
Cooling DT_{FL} = 10EF

$$MBH/ton = 12 \ \frac{MBH}{ton}$$

Allowable Test Performance:

$$Tolerance = 10.5 - (0.07 \ x \ 100) + \frac{(1500)}{(10 \ x \ 100)}$$

$$= \ 10.5 \ - \ 7 \ + \ 1.5 \ = \ 5\%$$

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

$$= \ 95 \ tons$$

Max. allowable MBH/ton $= \dfrac{(100 + 5)}{100} \ x \ 12$

$$= 12.6 \ MBH/ton$$

Max. MBH at min. capacity =

$$12.6 \ MBH/ton \ x \ 95 = \ 1197 \ MBH$$

5.5.3 *Part-Load*. The tolerance on part-load *COP* shall be the tolerance as determined from 5.5.1.

Part-Load Example in *COP* (Direct Fired Chillers):

Rated Part-Load Performance:

Input at 75% Rated Capacity = 849 MBH
75% Rated Capacity = 75 tons
Cooling DT_{FL} = 10.0EF

$$COP = \frac{75 \ x \ 12000}{849 \ x \ 1000} = 1.06$$

Allowable Test Tolerance:

$$Tolerance = 10.5 - (0.07 \ x \ 75) + \frac{(1500)}{(10 \ x \ 75)}$$

$$= 10.5 - 5.25 + 2.00 = 7.25\%$$

Min. Allowable COP =

$$\frac{100 \ - \ 7.25}{100} \ x \ 1.06 \ = \ 0.983$$

<u>Part-Load Example in MBH/ton (Direct Fired Chillers):</u>

Rated Part-Load Performance:

75% capacity = 75 tons
75% input = 849 MBH
MBH/ton = 11.32 MBH
Full Load DT_{FL} = 10EF

Allowable Test Performance:

$$Tolerance = 10.5 - (0.07 \ x \ 75) \ + \frac{(1500)}{10 \ x \ 75}$$

$$= \ 10.5 \ - \ 5.25 \ + \ 2.0 \ = \ 7.25 \ \%$$

Max. allowable MBH/ton =

$$\frac{(100 + 7.25)}{100} \ x \ 11.32$$

$$= \ 12.14 \ MBH/ton$$

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

Allowable Tolerance, %:

$$= 6.5 \ + \ \frac{35}{DT_{FL}} \ \ for \ \ DT_{FL} \ in \ °F$$

$$= 6.5 \ + \ \frac{19.4}{DT_{FL}} \ \ for \ \ DT_{FL} \ in \ °C$$

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Where DT_{FL} as specified in 5.5.1

See Figure 2 *IPLV* and *NPLV* Tolerance Curve.

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.

Section 6. Minimum Data Requirements for Published Ratings

6.1 *Minimum Data Requirements for Published Ratings*. Published Ratings shall include all Standard Ratings. All claims to ratings within the scope of this standard shall include the verbiage "Rated in accordance with AHRI Standard 560". All claims to ratings outside the scope of this standard shall include the verbiage "Outside the scope of AHRI Standard 560". 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 Model number designations providing identification of the water chilling packages to which the ratings shall apply.

6.2.1.2 Net refrigerating capacity, tons [kW].

6.2.1.3 Total Energy Input to the chiller in MBH [kW], as applicable.

6.2.1.3.1 Direct Fired, MBH [kW] based on Higher Heating Value.

6.2.1.3.2 Indirect Fired, MBH [kW].

6.2.1.4 Chiller Efficiency, expressed as *COP* or MBH/ton (as defined in 3.2).

6.2.1.5 Evaporator Fouling Factor, as stated in Table 1.

6.2.1.6 Chilled water entering and leaving temperatures, EF [EC] (as stated in Table 1), or leaving water temperature and temperature difference, EF [EC].

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

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

6.2.1.9 Average electrical power consumption, kW [kW] for all auxiliary components including solution and refrigerant pumps, purge, control panel, burner fan, burner controls, etc. Power required by system water pumps shall be excluded.

6.2.1.10 Absorber/condenser water pressure drop (inlet to outlet), psi or ft H_2O [kPa].

6.2.1.11 Any two of the following:

Entering absorber/condenser water temperature, EF [EC].

Leaving absorber/condenser water temperature, EF [EC].

Water temperature rise through the absorber/condenser, EF [EC].

6.2.1.12 Absorber/condenser water flow rate, gpm [L/s].

6.2.1.13 Fouling Factors, as stated in Table 1.

6.2.2 *Hot Water Heating Option.*

6.2.2.1 Heating capacity, MBH [kW].

6.2.2.2 Heating water pressure drop, psi or ft H_2O [kPa]

6.2.2.3 Entering and leaving water temperatures, EF [EC] (stated in Table 1).

6.2.2.4 Heating water flow rate, gpm [L/s].

6.2.2.5 Fouling Factor, as stated in   Table 1.

Section 7. Marking and Nameplate Data

7.1 *Marking and Nameplate Data.* At a minimum, a nameplate attached to each unit shall provide the following:

a. Manufacturer's name and location
b. Model number designation providing complete identification
c. Voltage, V, phase, and frequency, Hz.

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 38.

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 its *Purpose* (Section 1) and *Scope* (Section 2) unless such claims meet all the requirements of the Standard.

Table 1. Standard Rating Conditions			
	Single Stage Indirect Fired	Two-Stage Indirect Fired	Two-Stage Direct Fired
Absorber / Condenser Water			
Entering Water Temperature	85.0EF [29.4EC]	85.0EF [29.4EC]	85.0EF [29.4EC]
Water Flow Rate	3.6 gpm/ton [0.065 L/s per kW]	4.0 gpm/ton [0.072 L/s per kW]	4.0 gpm/ton [0.072 L/s per kW]
Water-Side Fouling Factor	0.00025 hAft^2 AEF/Btu [0.000044 m^2 AEC/W]	0.00025 hAft^2 AEF/Btu [0.000044 m^2 AEC/W]	0.00025 hAft^2 AEF/Btu [0.000044 m^2 AEC/W]
Evaporator			
Leaving Water Temperature	44EF [6.7EC]	44EF [6.7EC]	44EF [6.7EC]
Water 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]
Water-Side Fouling Factor	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]
Energy Input			
Fuel Heat Content	N/A	N/A	HHV[c]
Steam Pressure[b]	[a]	[a]	N/A
Tube-Side Fouling Factor (Steam)	0.000 hAft^2 AEF/Btu [0.0000 m^2 AEC/W]	0.000 hAft^2 AEF/Btu [0.0000 m^2 AEC/W]	N/A
Hot Water Entering Temperature	[a]	[a]	N/A
Hot Water Leaving Temperature	[a]	[a]	N/A
Hot Water Flow Rate	[a]	[a]	N/A
Tube-Side Fouling Factor (Hot Water)	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]	N/A
Energy Output (Hot Water)			
Hot Water Leaving Temperature	N/A	N/A	[a]
Hot Water Entering Temperature	N/A	N/A	[a]
Hot Water Flow Rate	N/A	N/A	[a]
Tube-Side Fouling Factor	N/A	N/A	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]

[a]   Manufacturer specified conditions.
[b]   After energy control valve at inlet flange of chiller
[c]   Higher Heating Value

Table 2. Part-Load Rating Conditions (All Chiller Types)		
	IPLV	*NPLV*
Absorber / Condenser		
Entering Water Temperature[b]		
100% load	85.0EF [29.4 EC]	Selected EWT[b]
75% load	77.5EF [25.3 EC]	[d]
50% load	70.0EF [21.1EC]	[d]
25% load	70.0EF [21.1EC]	[d]
0% load	70.0EF [21.1EC]	70.0EF [21.1EC]
Water Flow Rate	Refer to Table 1	Selected gpm/ton [L/s per kW] [3]
Water-Side Fouling Factor	0.00025 hAft^{2}AEF/Btu [0.000044 m^{2}AEC/W]	[a]
Evaporator		
Leaving Water Temperature[a]	44EF [6.7 EC]	[a]
Water Flow Rate	Refer to Table 1	[a]
Water-Side Fouling Factor	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]	[a]
Energy Input		
Fuel Heat Content (Direct Fired only)	HHV	HHV[f]
Steam Pressure[e]	[a]	[a]
Hot Water Entering Temperature	[a]	[a]
Hot Water Leaving Temperature[a]	[a]	[a]
Hot Water Flow Rate	Refer to Table 1	[a]
Tube-Side Fouling Factor	0.0001 hAft^2 AEF/Btu [0.000018 m^2 AEC/W]	[a]

[a]   Manufacturer specified conditions.
[b]   If the unit manufacturer=s recommended minimum temperatures are greater than those specified in Table 2, then those may be used in lieu of the specified temperatures.
[c]   The flow rates are to be held constant at full load values for all part-load conditions.
[d]   For part-load entering condenser water temperatures, the temperature should vary linearly from the selected EWT at 100% load, to 70EF at 50% load, and fixed at 70EF for 50% to 0% loads.
[e]   After energy control valve at inlet flange of chiller
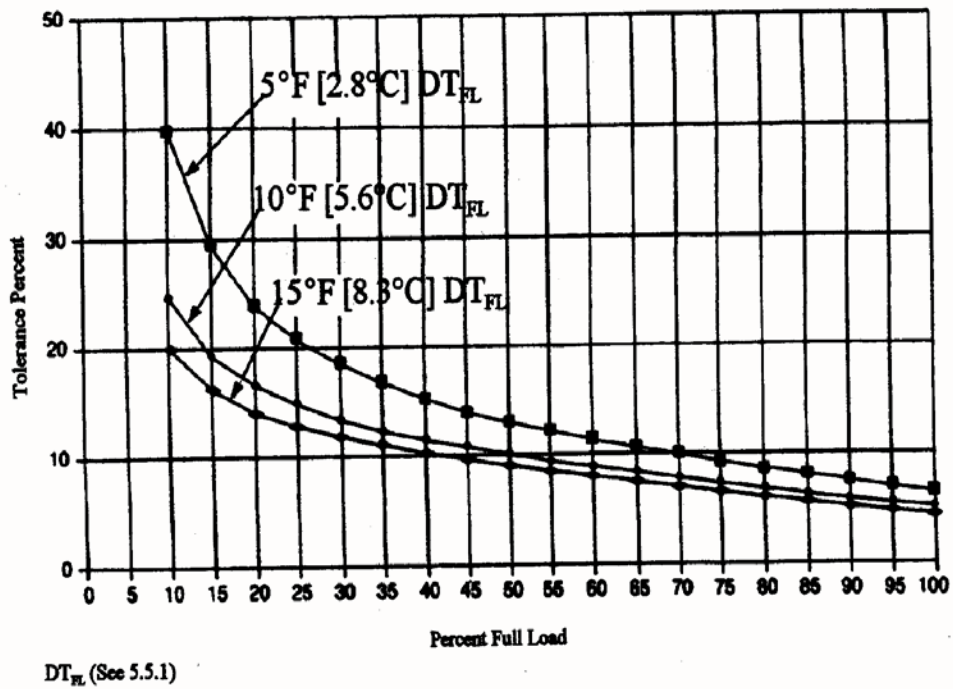[f]   Higher Heating Value

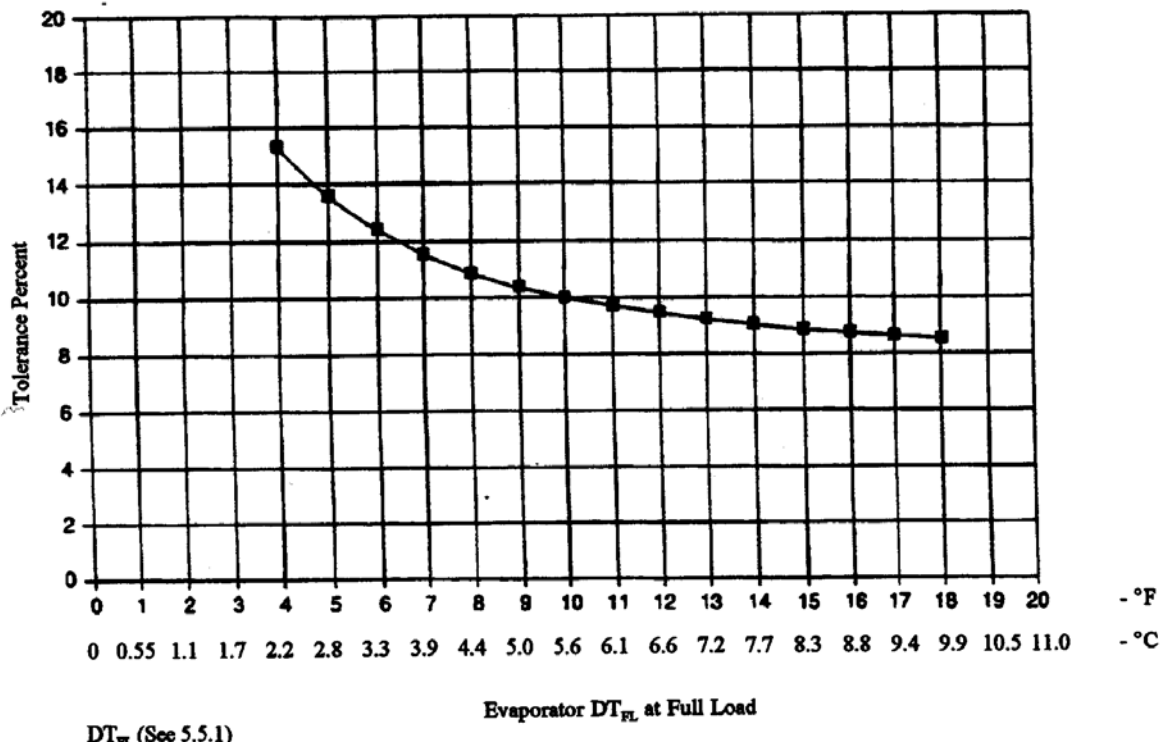**Figure 1. Allowable Tolerance Curves for Full and Part-Load**

Figure 2. *IPLV* and *NPLV* Tolerance Curve

APPENDIX A. REFERENCES – NORMATIVE

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

A1.1   AHRI Standard 110-1997 (formerly ARI Standard 110-97), *Air-Conditioning and Refrigerating Equipment Nameplate Voltages*, 1997, Air-Conditioning, Heating, and Refrigeration Institute, 2111 Wilson Boulevard, Suite 500, Arlington, VA 22201, U.S.A.

A1.2   ASHRAE Standard 30-1995, *Method of Testing Liquid Chilling Packages*, 1995, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.3   ASHRAE Standard 41.1-86, *Measurements Guide – Section on Temperature Measurements*, 1986, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.4   *ASHRAE Terminology of Heating Ventilation, Air Conditioning and Refrigeration, Second Edition*, Second Edition, 1991, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329, U.S.A.

A1.5   ASME Standard PTC 19.2-1998, *Instruments and Apparatus: Part 2 Pressure Measurement*, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

A1.6   IEC Standard Publication 38-1983, *IEC Standard Voltages*, 1983, International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, 1211 Geneva 20, Switzerland.

A1.7   ISA - RP31.1-1977, *Specification, Installation, and Calibration of Turbine Flowmeters*, International Society for Measurement and control, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, NC 27709, U.S.A.

APPENDIX B. REFERENCES – INFORMATIVE

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

B1.1   ANSI B109.1-1986, *Diaphragm Type Gas Displacement Meters (500 Cubic Foot per Hour Capacity and Under)*, American National Standards Institute, 11 West 42nd Street, New York, NY 10036, U.S.A.

B1.2   ANSI B109.2-1986, *Diaphragm Type Gas Displacement Meters (Over 500 Cubic Foot per Hour Capacity)*, American National Standards Institute, ANSI, 11 West 42nd Street, New York, NY 10036, U.S.A.

B1.3   ANSI B109.3-1986, *Rotary Type Gas Displacement Meters*, American National Standards Institute, 11 West 42nd Street, New York, NY 10036 U.S.A.

B1.4   ASME *Fluid Meters – Their Theory and Applications*, 1959, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

B1.5   ASME Standard PTC 19.5-1972, *Application Part II of Fluid Meters,* American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, U.S.A.

APPENDIX C. METHOD OF TESTING ABSORPTION WATER CHILLING AND WATER HEATING PACKAGES - NORMATIVE

C1 *Purpose.*

    C1.1 *Purpose.* The purpose of this appendix is to prescribe a method of testing Absorption Water Chilling and Water Heating Packages to verify capacity and heat Energy Input requirements at a specific set of conditions.

    It is intended that this testing will occur where instrumentation and load stability can be provided.

    It is not the intent of this standard to provide for testing in typical field installations where steady state conditions are often difficult to achieve and provisions for measurement are not made.

C2 *Scope.*

    C2.1 *Scope.* This appendix applies to Absorption Water Chilling Packages used to chill or heat water, as defined in Section 3 of this Standard.

C3 *Definitions.*

    C3.1 *Definitions.* Definitions of this appendix are identical with those in Section 3 of this Standard.

C4 *Test Method.*

    C4.1 *Test Method.* The test will measure Net Cooling Capacity tons, MBH [kW] or Net Heating Capacity, MBH [kW] and heat Energy Input requirements, at a specific set of conditions.

        C4.1.1 After steady-state conditions have been established at the specific set of conditions and within the tolerance set forth in C7.2, three sets of data shall be taken, at a minimum of 5 minute intervals. To minimize the effects of transient conditions, test readings should be taken as simultaneously as possible.

        C4.1.2 The test shall include a measurement of the net heat removed (or added) from (to) the water as it passes through the chilled water or heating water circuit by determination of the following:

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

        C4.1.3 The heat removed from the chilled water (or added to the heating water), q, is equal to the product of the chilled water or heating water flow rate, m_w, the water temperature difference between entering and leaving water, $(t_e - t_l)$, the specific heat of water, c, and the specific heat of the water, as shown in the following equation:

$$q = c \cdot m_w \cdot (t_e - t_l)$$

        C4.1.4 The test shall include the determination of the Absorption Water Chilling and Water Heating Package heat input energy. This heat energy shall be determined by a measurement as outlined in the test procedure (see Section C7).

        C4.1.5 In addition to the determination of net heat removed and heat energy input required, data shall be taken to prepare a heat balance to substantiate the validity of the test.

C4.2 *Conditions of Heat Transfer Surfaces.*

C4.2.1 Tests conducted in accordance with this standard may require cleaning (in accordance with manufacturer's instructions) of the heat transfer surfaces. The "as-tested" water-side Fouling Factors shall then be assumed to be 0.000 h·ft^2·EF/Btu [0.0000m$^2 \cong$EC/W].

C5 *Instruments*

C5.1 Instruments shall be selected from the types listed in ASHRAE Standard 30.

C5.1.1 Accuracy of instruments selected shall be in accordance with ASHRAE Standard 30.

C5.1.2 Temperature measurements shall be made in accordance with ASHRAE Standard 41.1.

C5.1.3 Flowmeters shall be constructed and installed in accordance with the applicable portion of ASHRAE Standard 30. Turbine flowmeters may be also used in accordance with ISA-RP31.1.

C5.1.4 Scales for analog meters are such that readings shall be at least one-third of full scale deflection. All instruments, including gauges and thermometers, shall be calibrated over the range of test readings.

C5.1.5 Pressure measurements shall be made in accordance with ASME Standard PTC 19.2.

C6 *Measurements*

C6.1 Data to be recorded after steady-state conditions have been established:

C6.1.1 *Test Data*

  a. Temperature of water entering evaporator, EF [EC]
  b. Temperature of water leaving evaporator, EF [EC]
  c. Temperature of water entering absorber, EF [EC]
  d. Temperature of water leaving condenser, EF [EC]
  e. Evaporator water flow rate, gpm [L/s]
  f. Absorber/condenser water flow rate, gpm [L/s]
  g. Heat Energy Input from one of the following:
    1. Steam consumption, lb/hr [kg/hr] Steam supply pressure, psig [kPa] Steam supply temperature, EF [EC] Steam condensate temperature, EF [EC]
    2. Hot water flow rate, gpm [L/s]
       Hot water supply temperature, EF [EC]
       Hot water leaving temperature, EF [EC]
    3. Gas consumption, ft^3/hr [m^3/hr]
       Higher Heating Value, HHV, Btu/ft^3 [J/m^3]
       Gas pressure entering gas train, in H$_2$0 or psig [mbar]
    4. Oil consumption, gph [L/s]
       Higher Oil Heating Value, Btu/gal [J/L]
       Oil classification (for example, Class A Heavy Oil)
  h. Temperature of water entering heating circuit, EF [EC] (Direct Fired heating units)
  i. Temperature of water leaving heating circuit, EF [EC] (Direct Fired heating units)
  j. Flow rate of heating water, gpm [L/s] (Direct Fired heating units)

C6.1.2 Evaporator water pressure drop (inlet to outlet), psi or ft H$_2$O [kPa].

C6.1.3 Absorber/condenser water pressure drop (inlet to outlet), psi or ft H$_2$O [kPa].

C6.1.4 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.

C6.1.5 If absorber/condenser water is used for some other incidental function within the package, the temperature and flow measurements of absorber/condenser water must be made at points so that the measurement reflects the total package heat rejection.

C6.1.6 If steam condensate is used for some incidental functional use, the heat content used must be added to the heat input for heat balance purposes.

C6.1.7 Steam mass flow measurement should be done by measuring steam condensate flow. If condensate flow is measured in an open tank, then a condensate cooler may be necessary to prevent flashing.

C6.2 Auxiliary data to be recorded for general information.

C6.2.1 Nameplate data, including make and model, sufficient to completely identify the water-chilling (heating) package.

C6.2.2 Hot or heating water pressure drop (inlet to outlet) psi or ft H_2O [kPa] (if applicable).

C6.2.3 Ambient temperature at test site, EF [EC].

C6.2.4 Barometric pressure at test site, in Hg [kPa].

C6.2.5 Heat Balance – Per C7.4.

C6.2.6 Date, place and time of test.

C6.2.7 Name of test supervisor and witnessing personnel.

C7 *Test Procedure*

C7.1 *Preparation for Test*

C7.1.1 The Absorption Water Chilling (Heating) Package, which has been completely installed in accordance with the manufacturer's instructions and is ready for normal operation, shall be provided with the necessary instruments.

C7.1.2 The test shall not be started until non-condensables have been removed from the system.

C7.1.3 At the manufacturer's option, tubes in the absorber, condenser, evaporator, and separate (hot water) heat exchanger (if used for heating) may be cleaned as provided in C4.2.

C7.2 *Operation and Limits*

C7.2.1 Start the system and establish the testing conditions in accordance with the following tolerances and instructions:

    a. The chilled water flow shall not deviate more than $\forall$ 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^{o}F [0.3^{o}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 C7.3 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. The water flow through the absorber/condenser shall not deviate more than ± 5% from that specified

    f.   The individual readings of water temperatures entering the absorber/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

    g.   The entering absorber/ condenser water temperature shall be adjusted by an increment calculated per C7.3 corresponding to the specified Field Fouling Allowance

    h.   The leaving hot water temperature shall be increased by an increment calculated per C7.3 corresponding to the specified Field Fouling Allowance (Direct Fired heating units)

    i.   Steam supply pressure shall be maintained within ± 0.2 psig [± 1.4 kPa] for single stage and ± 2.0 psig [± 14 kPa] for double effect of the specified pressure and shall be furnished dry or within the superheat range specified by the chiller manufacturer

    j.   Gas and oil heating values to be used for testing are as measured or verified by supplier. Flue gas back pressure shall be maintained within range specified by the manufacturer.

    k.   Hot water supply temperature to generators shall be maintained within ± 5°F [± 3°C] of the specified temperature and the hot water flow rate shall be maintained within ± 5% of the specified flow rate

    l.   Chiller package shall be supplied with nameplate voltage and frequency

C7.3   *Method for Simulating Field Fouling Allowance at Full and Part-Load Conditions.*

C7.3.1 Obtain the log mean temperature difference (*LMTD*) for the evaporator and/or absorber/condenser using Equation C1 at the specified Field Fouling Allowance (ff_{sp}).

Due to the complexity of analyzing the fouling effect in the condenser and absorber separately, the two heat exchangers have been combined in an approximate calculation for convenience.

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

C7.3.2 *Derivation of LMTD*:

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

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

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

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

C7.3.3 The water temperature difference, TD_a, needed to simulate the additional fouling can be calculated:

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

$$TD_a = S_{sp} - \frac{R}{e^z - 1} \qquad\qquad (C3b)$$

Where:

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

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

S_{sp} = Small temperature difference as specified
S_c = Small temperature difference as tested in cleaned condition

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

C7.3.4 *Example-Absorber/Condenser Fouling Inside Tubes (in U.S. Standard units only, for clarity).*

Specified Field Fouling Allowance:

$ff_{sp} = 0.00025 \text{ h} \cdot \text{ft}^2 \cdot \text{F/Btu}$

Absorber/condenser load:	$q = 13{,}000$ MBH
Absorber/condenser leaving water temperature:	$t_{wl} = 101^{o}$F
Specified absorber/condenser entering water temperature,	$t_{we} = 85^{o}$F
Absorber/condenser inside* tube surface area,	$A = 1500 \text{ ft}^2$

Saturated condensing temperature:

t_s = 106°F
S_{sp} = t_s - t_{wl} = 106 - 101 = 5°F
R = t_{wl} - t_{we} = 101 - 85 = 16°F

$$LMTD = \frac{R}{ln \ (1 \ + \ R/S_{sp})} \qquad\qquad C1$$

$$= \frac{16}{1n \ (\ 1 + 16/5 \ )} = 11.15$$

_____
* Since fouling is inside tubes in this example

$ff_{sp} = 0.00025 \text{ h} \cdot \text{ft}^2 \cdot {}^{o}\text{F/Btu}$

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

$$= 0.00025 \left(\frac{13{,}000 \ x \ 1000}{1{,}500} \right)$$

$$= \ 2.16$$

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

$$TD_a = S_{sp} - \frac{R}{e^z - 1} \qquad (C3b)$$

$$TD_a = 5.0 - 3.25$$

$$= 1.75^oF$$

The entering absorber/condenser water temperature for testing is then raised 1.75^oF to simulate the field fouling allowance of $0.00025 \ h \cdot ft^2 \cdot {}^oF/Btu$. The entering absorber/condenser temperature will be $85 + 1.75 \ {}^oF$ or $86.8 \ {}^oF$.

C7.3.5 *Symbols and Subscripts.* The symbols and subscripts used in Equations *C1* through *C3b* are as follows:

A	=	Total heat transfer inside surface, ft^2 $[m^2]$ for evaporator or absorber and condenser
c	=	Specific heat of water at average water temperature, Btu/lb ^oF [kJ/kg ^oC]
e	=	Base for natural logarithm
ff	=	Fouling factor allowance
q	=	Total heat rejection rate or net refrigerant capacity of evaporator, Btu/h [W]
R	=	Water temperature range = absolute value $(t_{wl} - t_{we})$, ^oF $[^oC]$
S	=	Small temperature difference = absolute value $(t_s - t_{wl})$, ^oF $[^oC]$
t	=	Temperature, ^oF $[^oC]$
TD	=	Temperature Difference

Subscripts:

a	=	Additional fouling
c	=	Cleaned
e	=	Entering
f	=	Fouled or fouling
l	=	Leaving
s	=	Saturated vapor
sp	=	Specified
w	=	Water

C7.4 *Heat Balance – Substantiating Test*

C7.4.1 *Basic: Total Heat In-Total Heat Out.* In most cases for single-effect absorption units, heat losses or heat gain caused by radiation, convection, etc., are relatively small and need not be considered in the overall heat balance, but compensated for in the heat balance closure allowance (see C7.4.3).

C7.4.2 For double-effect machines the high stage generator and solution heat exchangers heat loss may be significant for an uninsulated surface. Since this surface is normally insulated on the job site, the heat loss due to an uninsulated high stage generator and solution heat exchangers surface can be subtracted from the measured value. The heat loss can be determined by heat transfer calculations or verification by tests.

C7.4.3 Omission of the small heat losses and gains mentioned in C7.4.1 results in a percent heat balance equation as follows:

$$HB = \frac{q_{hs} + q_{ev} - q_c}{q_c} \ x \ 100 \qquad (C4)$$

where:

q_{hs} = Input from heat source
q_{ev} = Net Cooling Capacity
q_c = Heat rejection to the cooling tower

Any consistent system of heat units may be used in the above equation.

For any test of a water cooled chiller to be acceptable, the heat balance (%) shall be within the allowable tolerance calculated per 5.5.1 for the applicable conditions.

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

D1   *Purpose.*

D1.1   *Purpose.* This appendix is intended to show the derivation of the Integrated Part-Load Value (*IPLV*).

D2   *Scope.*

D2.1   *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 number for water chilling products. 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 two following ratios:

Coefficient of Performance:

$$COP = \frac{Net\ Output}{Net\ Input} \tag{D1a}$$

Energy Input per Ton:

$$MBH/ton = \frac{MBH\ input}{tons\ refrigeration\ effect} \tag{D1b}$$

The following equation is used when an efficiency is expressed as *COP* [W/W]:

$$IPLV\ or\ NPLV\ = 0.01A+0.42B+0.45C+0.12D \tag{D2a}$$

Where:

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

The following equation is used when the efficiency is expressed in MBH/ton:

$$IPLV = \frac{1}{\dfrac{0.01}{A}+\dfrac{0.42}{B}+\dfrac{0.45}{C}+\dfrac{0.12}{D}} \tag{D2b}$$

Where:

$\ast$A = MBH/ton at 100% capacity
$\ast$B = MBH/ton at 75% capacity
$\ast$C = MBH/ton at 50% capacity
$\ast$D = MBH/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 2. If the unit, due to its capacity control logic cannot be operated at 25% capacity, then the unit can be operated at its minimum capacity and the 25% chiller capacity point shall then be determined by using the following equation:

$$COP = \frac{Net\ Output}{C_D \times Net\ Input} \qquad\qquad (D3)$$

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

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

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

$$LF = \frac{\dfrac{\%\ Load}{100} \cdot (Full\ Load\ Unit\ Capacity)}{(Minimum\ Unit\ Capacity)}$$

$\ast$ At operating conditions per Table 1 and 2.

Where:

% Load is the standard rating point i.e. 25%

Minimum 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.
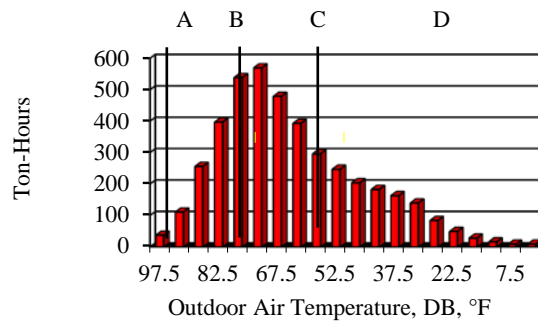
Figure D1. Ton-Hours Distribution Categories

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

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 USA, 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 Department of Energy /Energy Information Administration [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 Building Owner=s Management Association [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, were 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 MCWB down to 50EF 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 85EF ECWT for *IPLV*/*NPLV*. Other points were determined by distributional analysis of ton-hours, MCWB=s. ECWTs were based upon actual MCWBs plus an 8EF 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:
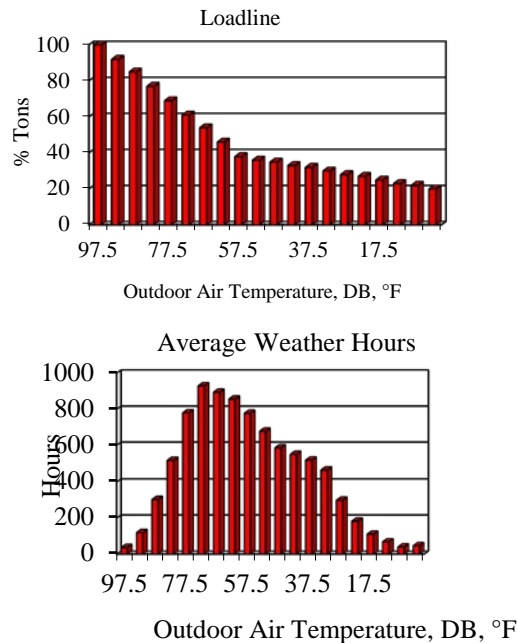
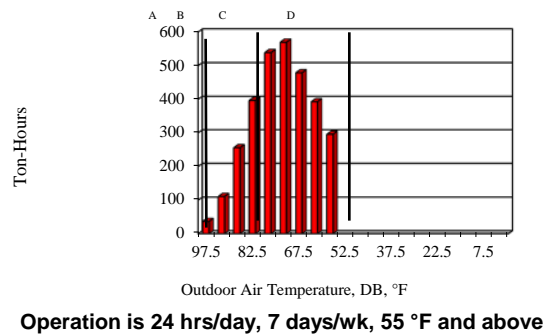**Figure D2. Bin Groupings – Ton-Hours**
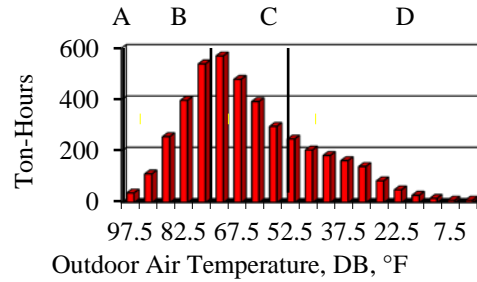
Figure D3. Group 1 Ton-Hours Distribution Categories

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 Figure D4, note that the categories are distributed as follows:

    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 55EF for Min Bin

See Table D1 for Water Cooled calculations. The result is average weightings, ECWT=s, and % Loads.

$$IPLV = \frac{1}{\dfrac{0.01}{A} + \dfrac{0.42}{B} + \dfrac{0.45}{C} + \dfrac{0.12}{D}} \quad (D2b)$$

Operation is 24 hrs/day, 7 days/wk, 55 °F and above

Figure D4. Group 2 Ton-Hours Distribution Categories

The next step would be to begin again with Group 2 Ton- Hour distribution as shown in Figure D4. Note Group 2 is Group 1, but with 100% Economizer at 55EF.

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

The next step is to determine the percentage 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 (MBH/ton):

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

Where:

A	=	MBH/ton @ 100% Capacity and 85.0EF	ECWT
B	=	MBH/ton @ 76.1% Capacity and 75.6EF	ECWT
C	=	MBH/ton @ 50.9% Capacity and 65.6EF	ECWT
D	=	MBH/ton @ 32.2% Capacity and 47.5EF	ECWT

Rounding off and rationalizing:

Where:

A	=	MBH/ton @ 100% and 85.0EF ECWT
B	=	MBH/ton @ 75% and 77.5EF ECWT
C	=	MBH/ton @ 50% and 70.0EF ECWT
D	=	MBH/ton @ 25% and 70.0EF ECWT

After rounding off and applying the rationale of where the manufacturers= and the current test facilities= capabilities lie, as well as recommended operational practices, the final Equation *D2b* was derived in Section D3.1.

Table D1. Group 1 Water Cooled *IPLV* Data and Calculation															
								Min Bin		Low Bin		Peak Bin		Des Bin	
Outside Temp. (°F)	Average DB (°F)	MCWB	CWH	Total Hours	CWH	Total % Ton-Hrs	Cooling Load (%)	CWH	Ton-Hrs	CWH	Ton-Hrs	CWH	Ton-Hrs	DBH	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%	0	0	0	0	23331	256	0	0
80-84	82.5	68	76	517	39292	397	77%	0	0	0	0	39292	397	0	0
75-79	77.5	66	74	780	57720	539	69%	0	0	0	0	57720	539	0	0
70-74	72.5	63	71	929	65959	570	61%	0	0	65959	570	0	0	0	0
65-69	67.5	59	67	894	59898	479	54%	0	0	59898	479	0	0	0	0
60-64	62.5	55	63	856	53928	393	46%	0	0	53928	393	0	0	0	0
55-59	57.5	50	59	777	45843	296	38%	0	0	45843	296	0	0	0	0
50-54	52.5	45	55	678	37290	247	36%	37290	247	0	0	0	0	0	0
45-49	47.5	41	52	586	30472	204	35%	30472	204	0	0	0	0	0	0
40-44	42.5	37	49	550	26950	183	33%	26950	183	0	0	0	0	0	0
35-39	37.5	32	45	518	23310	163	32%	23310	163	0	0	0	0	0	0
30-34	32.5	27	41	467	19147	140	30%	19147	140	0	0	0	0	0	0
25-29	27.5	22	40	299	11960	84	28%	11960	84	0	0	0	0	0	0
20-24	22.5	17	40	183	7320	49	27%	7320	49	0	0	0	0	0	0
15-19	17.5	13	40	111	4440	28	25%	4440	28	0	0	0	0	0	0
10-14	12.5	8	40	68	2720	16	23%	2720	16	0	0	0	0	0	0
05-09	7.5	4	40	40	1600	9	22%	1600	9	0	0	0	0	0	0
00-04	2.5	1	40	47	1880	9	20%	1880	9	0	0	0	0	0	0
Total	57.9	49.3	60.0	8670	525500	4210	**CWH Total**	167089	1132	225628	1738	129823	1303	2960	37
							Weighting:		26.9%		41.3%		30.9%		0.9%
							ECWT EF:		47.1		65.3		81.8		85.0
							Load		31.9%		50.3%		75.7%		100%
									D		**C**		**B**		**A**

DB – Dry-Bulb   ECWT – Entering Condenser Water Temperature

MCWB – Mean Coincident Wet-Bulb   EDB – Entering Dry-Bulb

CWH – Condenser Water Hours (ECWT *x* hours from weather for water-cooled)

Table D2. Group 1 – 4 *IPLV* Summary									
Group 1	**% Load**	**ECWT**	**EDB**	**Weight**	**Group 2**	**% Load**	**ECWT**	**EDB**	**Weight**
A	100.0%	85.0EF	95.0EF	0.95%	A	100.0%	85.0EF	95.0EF	1.2%
B	75.7%	75.5EF	81.8EF	30.9%	B	75.7%	75.5EF	81.8EF	42.3%
C	50.3%	65.3EF	65.4EF	41.3%	C	50.3%	65.3EF	65.4EF	56.5%
D	31.9%	47.1EF	38.6EF	26.9%	D	N/A	N/A	N/A	0.0%
IPLV =	$\dfrac{1}{.009/A + .309/B + .413/C + .269/D}$				*IPLV =*	$\dfrac{1}{.012/A + .423/B + .565/C + 0.0/D}$			
Group 3	**% Load**	**ECWT**	**EDB**	**Weight**	**Group 4**	**% Load**	**ECWT**	**EDB**	**Weight**
A	100.0%	85.0EF	95.0EF	1.5%	A	100.0%	85.0EF	95.0EF	1.8%
B	75.7%	75.6EF	82.2EF	40.9%	B	76.4%	75.6EF	82.2EF	50.1%
C	50.3%	65.8EF	66.0EF	39.2%	C	51.3%	65.8EF	66.0EF	48.1%
D	31.9%	47.7EF	40.0EF	18.4%	D	N/A	N/A	N/A	0.0%
IPLV =	$\dfrac{1}{.015/A + .409/B + .392/C + .184/D}$				*IPLV =*	$\dfrac{1}{.018/A + .501/B + .481/C + 0.0/D}$			