FORM 160.72-TD2 (498)

1992

STANDARD for

CENTRIFUGAL AND ROTARY SCREW WATER-CHILLING PACKAGES

Standard 550

AIR-CONDITIONING &
REFRIGERATION
INSTITUTE

4301 NORTH FAIRFAX DRIVE, SUITE 425, ARLINGTON, VIRGINIA 22203

IMPORTANT

SAFETY RECOMMENDATION

It is strongly recommended that the product be designed, constructed, assembled and installed in accordance with nationally recognized safety requirements appropriate for products covered by this standard.

ARI, as a manufacturers' trade association, uses its best efforts to develop standards, employing state-of-the-art and accepted industry practices. However, ARI does not certify or guarantee safety of any products, components or systems designed, tested, rated, installed or operated in accordance with these standards or that any tests conducted under its standards will be non-hazardous or free from risk.

ARI CERTIFICATION PROGRAM PROVISIONS

Scope of the Certification Program

All water-cooled centrifugal and rotary screw water-chilling packages rated below 1600 tons at ARI Standard Rating Conditions, of the hermetic and open type, electric motor driven 60 Hz below 5000 volts, as covered by this standard, are included in the Certification Program. Included are chillers with single bundle shells (single water circuits or multiple condensers on a single water circuit are included). It is recognized that more than one condenser can be used on a single water circuit on a chiller.

Certified Ratings

The Certification Program ratings verified by test are:

1. Capacities (ton) [kW],
2. Power Inputs per Ton (kW/ton) [kW/kW],
3. Water Pressure Drops (see Section 5.1.8) (psi or feet of water) [kPa], all of the above at standard rating conditions (see Section 5.1.1) and at application rating conditions (see Section 5.1.2) for both full and part loads (see Section 5.1.6 for part load performance requirements),
4. Integrated Part Load Values (IPLV's) (see Section 5.1.6), and
5. Application Part Load Values (APLV's) (see Section 5.1.6).

Note:
This standard supersedes ARI Standard 550-90.

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TABLE OF CONTENTS

CENTRIFUGAL AND ROTARY SCREW WATER-CHILLING PACKAGES

Section 1. Purpose

1.1 *Purpose.* The purpose of this standard is to establish, for centrifugal and rotary screw water-chilling packages: definitions and nomenclature; a description of what constitutes such a package; published rating conditions; standard requirements for testing and a basis for published ratings; and proper refrigerant designation in systems.

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

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

Section 2. Scope

2.1 *Scope.* This standard applies to centrifugal and rotary screw water-chilling packages as defined in 3.2.

2.1.1 This standard applies to both hermetic and open centrifugal and rotary screw water-chilling packages which have continuous capacity modulation, whether driven by an electric motor, steam turbine or other prime mover.

2.1.2 This standard does not include sanitary provisions necessary for the handling of potable liquids.

Section 3. Definitions

3.1 Definitions in ASHRAE "Terminology of Heating, Ventilation, Air-Conditioning and Refrigeration" apply except as indicated by the definitions following in this section.

3.2 *Centrifugal and Rotary Screw Water-Chilling Package.* A factory-designed and prefabricated assembly (not necessarily shipped as one package) of one or more compressors, condensers, and water coolers, with interconnections and accessories.

3.2.1 An *open centrifugal or rotary screw compressor* is defined as having a shaft or other moving part extending through a casing to be driven by an outside source of power, thus requiring a stuffing box, shaft seal, or equivalent, between a fixed and a moving part.

3.2.2 A *hermetic centrifugal or rotary screw compressor* is defined as consisting of a compressor with its prime mover and drive, all of which are enclosed as to operate in the refrigerant atmosphere.

3.2.3 A *purge* is a device for removing non-condensable gas and moisture from refrigerant condensers.

3.2.4 A *pump-out system* is a system which facilitates transfer of refrigerant from one heat exchanger to another or to or from a storage vessel.

3.3 *Coefficient Performance (COP).* The ratio of net cooling capacity divided by energy input rate, expressed in consistent units.

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

3.4.1 *Field Fouling Allowance.* Provision for anticipated fouling during use specified in hr sq ft F/Btu [m^2°C/W].

3.5 *Integrated Part Load Value (IPLV).* A single number part-load efficiency figure of merit calculated per the method described in 5.1.7 referenced to Standard Rating Conditions (see Table 1).

3.6 *Application Part Load Value (APLV).* A single number part-load efficiency figure of merit calculated per the method described in 5.1.7 referenced to Selected Application Rating Conditions (see Table 1).

3.7 *Published Rating.* A statement in the form of catalogs or computer output, 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.

3.7.1 A *Standard Rating* is a rating at Standard Rating Conditions based on test data.

3.7.2 An *application rating* is a rating at application rating conditions (other than Standard Rating Conditions).

3.7.3 *Selected Application Rating* is a rating developed at specific application conditions.

3.8 *Manufacturer.* The manufacturer of the water-chilled package unless otherwise stated.

3.9 *"Shall," "Should," or "It Is Recommended"* shall be interpreted as follows:

3.9.1 *Shall.* Where "shall" is used for a provision specified, that provision is mandatory if compliance with the standard is claimed.

3.9.2 *Should or It Is Recommended.* "Should" or "it is recommended" is used to indicate provisions which are not mandatory but which are desirable as good practice.

Section 4. Standard Equipment

4.1 A centrifugal or rotary screw water-chilling package shall include the following standard equipment:

1. Compressor and drive assembly consisting of one or more centrifugal or rotary screw single or multi-stage compressor(s) with necessary lubrication system(s).

    a. Hermetic drive: Electric motor and necessary gears enclosed in the refrigerant atmosphere.

    b. Open drive: Prime mover, with gears and couplings as necessary (except when furnished by others.)

2. Refrigerant condenser: A refrigerant-

to-water, refrigerant-to-air or evaporatively cooled heat exchanger, to reject heat from the refrigerant cycle.

3. Cooler (refrigerant evaporator): A refrigerant-to-water heat exchanger, which removes heat from the chilled liquid.

4. Controls as necessary to regulate package capacity and meet applicable safety requirements specified by others.

Section 5. Published Rating Requirements

5.1 *Published Ratings.* Published ratings consist of Standard Ratings and application ratings, whether published in catalogs or as computer output.

5.1.1 *Standard Rating Conditions.* Standard Ratings shall be determined at Standard Rating Conditions, as follows:

Cooler (All Condenser Types)

Leaving chilled water temperature...........44 F [6.7°C]

Cooler water-side field fouling allowance.....0.00025 hr sq ft F/Btu [0.000044m^2°C/W]

Cooler refrigerant-side fouling factor allowance......0.0000 hr sq ft F/Btu [0.0000m^2°C/W]

Chilled water flow rate.....2.4 gpm/ton [0.043 L/s per kW]

Condenser (Water-cooled)

Entering condenser water temperature..........85 F [29.4°C]

Condenser water-side field fouling allowance.....0.00025 hr sq ft F/Btu [0.000044 m^2°C/W]

Condenser refrigerant-side fouling factor allowance..0.0000 hr sq ft F/Btu [0.0000 m^2°C/W]

Condenser water flow rate.3.0 gpm/ton [0.054 L/s for each kW capacity]

Condenser (Air-cooled)

Air entering condenser...95 F [35.0°C] dry bulb

Condenser refrigerant-side fouling factor allowance..0.0000 hr sq ft F/Btu [0.0000m^2°C/W]

Condenser air-side fouling factor allowance.................0.0000

Barometric Pressure....29.92 in. Hg [101 kPa]

Condenser (Evaporatively-cooled)

Air entering condenser...75 F [23.9°C] wet-bulb

Condenser refrigerant-side fouling factor allowance..0.0000 hr sq ft F/Btu [0.0000 m^2°C/W]

Condenser air-side field fouling allowance.........0.00000 hr sq ft F/Btu [0.0000 m^2°C/W]

Barometric Pressure.....29.92 in. Hg [101 kPa]

5.1.2 *Application Rating Conditions.*

It is recommended that application ratings (at other than Standard Rating Conditions) include ratings at the following range of conditions:

All Condenser Types

Leaving chilled water
temperature..................40-48 F [4.4 to 8.9°C]
increments 2 F or less.[1°C or less]

Condenser (Water-cooled)

Entering condenser water
temperature..60-105 F[15.6 to 40.6°C]
in increments 5 F or less [3°C or less]

Condenser (Air-cooled)

Entering air temperature to the
condenser.....55-125 F[12.8 to 51.7°C] dry bulb
in increments 10 F or less[6°C or less]

Condenser (Evaporatively-cooled)

Entering air temperature to
condenser....50-80 F [10.0 to 26.7°C] wet bulb
in increments 2.5 F or
less...................[1.5°C or less]

5.1.2.1 *Field Fouling Allowances*. When application ratings are published, they shall include those with field fouling allowances as specified in 5.1.1. Additional application ratings, or means of determining these ratings, at other field fouling allowances may also be published (see 5.2).

5.1.3 *Determination of Ratings*. Published ratings shall be determined from test results in accordance with the following:

a. Cooler and condenser water-side heat transfer surfaces shall be considered clean during testing. Tests will be assumed to reflect a fouling factor of 0.000 sq ft F/Btu [0.0000 m^2°C/W].

b. To determine published ratings at any field fouling allowance from test data at a fouling factor of 0.000 hr sq F/Btu [0.0000 m^2°C/W], the calculations for fouling adjustment described in ARI Standard 450 for *Water-Cooled Refrigerant Condensers, Remote Type* and ARI Standard 480 for *Refrigerant-Cooled Liquid Coolers, Remote Type* shall be used.

5.1.4 *Net Tons*. The published tons of refrigeration [kW] are considered as net usable tons [kW] to the customer's system.

5.1.5 *Power Input*. Published power input requirements shall be the power required from the customer's power source and shall include the average power required by all components of the package including the purge, oil pumps, oil heaters, motor starters, frequency converters and controls furnished by the manufacturer. Power required by water pumps shall be excluded.

5.1.6 *Part Load Performance.* Part load performance of a centrifugal or rotary water-chilling package, may be presented in three ways:

a. Integrated Part Load Value (IPLV) which is based on Standard Rating Conditions (see Table 1).

b. Application Part Load Value (APLV) which is based on a Selected Application Rating Condition (see Table 1).

c. Separate part load data point(s).

5.1.6.1 IPLV and APLV values shall be determined by test at the conditions prescribed in Table 1.

5.1.6.2 For water-chilling packages covered by this Standard, Part Load Values (IPLV or APLV) shall be calculated as follows:

a. Determine the kW/ton at 100 percent; 75 percent; 50 percent and 25 percent load points at the conditions specified in Table 1.

b. Use the following equation to calculate IPLV or APLV:

SI Metric Units -

$$IPLV \text{ or } APLV = 0.17A + 0.39B + 0.33C + 0.11D \qquad (1a)$$

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

U.S. Standard Units -

$$IPLV \text{ or } APLV = \frac{1}{\frac{0.17}{A} + \frac{0.39}{B} + \frac{0.33}{C} + \frac{0.11}{D}} \qquad (1b)$$

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

For a derivation of equation (1) see Appendix B.

c. If the package cannot be operated at the 25% load point, operate it at minimum capacity with the condenser entering water (liquid) temperature (EWT) corresponding to 25% capacity conditions. Then calculate kW/ton at the measured kW divided by 25% of the 100% load capacity obtained by test.

5.1.7 *Published Rating Data.* Published rating data (in catalogs or computer output) shall include package designation(s), Standard Ratings for each such package and any additional application ratings elected. The rating at any condition shall include:

Compressor/Cooler (All Condenser Types)

a. Nominal voltage and frequencies for which ratings are valid.

b. Refrigerant selections for which ratings are valid.

c. Capacity, tons of refrigeration [kW]

d. Power input requirements, compressor shaft horsepower (if prime mover is not supplied) Kilowatt input for open or hermetic drives. kW (see 5.1.6).

e. Leaving chilled water temperature, F [°C]

f. Cooler liquid pressure drop (inlet to outlet), psi or feet of water [kPa]

g. Pass or baffle arrangements and rated water flows, gpm [L/s]

h. Maximum and minimum recommended flow rates for relatively clean water

Condenser (Water-cooled)

a. Entering condenser water temperatures, F [°C]

b. Condenser water pressure drop (inlet to outlet), psi or feet of water [kPa]

c. Statement of field fouling allowances in heat exchanger

d. Pass or baffle arrangements and rated water flows, gpm [L/s]

e. Maximum and minimum recommended flow rates for relatively clean water. (Any limitation on water flow rates to minimize erosion, corrosion, or fouling should take into consideration the quality of the water and any materials it may have in suspension, tube material, as well as the number of expected operating hours per year.)

Condenser (Air-cooled)

a. Entering air dry-bulb temperature to the condenser, F [°C]

b. Condenser fan motor power consumption, kW

Table 1. Part Load Conditions for Rating

	IPLV	APLV
Cooler (All Types)		
100% load LWT	* 44 F [6.7°C]	* Selected LWT
0% load LWT	44 F [6.7°C]	Same as 100% load
Flow rate (gpm)	** 2.4 gpm/ton [0.043	** Selected gpm/ton
Field fouling allowance (F.F.A.)	L/s per kW]	As specified
	0.00025	
Condenser (Water-Cooled)		
100% load EWT		* Selected EWT
0% load EWT	* 85 F [29.4°C]	*** 60 F [15.6°C]
Flow rate (gpm) [L/s]	*** 60 F [15.6°C]	** Selected gpm/ton
	** 3.0 gpm/ton [0.054	[L/s per kW]
F.F.A.	L/s per kW]	As specified
	0.00025	
Condenser (Air-Cooled)		
100% load EDB		Selected EDB
0% load EDB	95 F [35.0°C]	*** 55 F [12.8°C]
F.F.A.	*** 55 F [12.8°C]	0.000
	0.000	
Condenser (Evaporatively-Cooled)		
100% load EWB		Selected EWB
0% load EWB	75 F [23.9°C]	*** 50 F [10.0°C]
F.F.A.	*** 50 F [10.0°C]	0.000
	0.000	

* Corrected for field fouling allowance by using the calculation method described in A7.3.

** The flow rates (gpm) are to be held constant at full load values for all part load conditions.

** Condenser entering fluid or air temperature varies linearly from 100% load values to 0% load values.

LWT is leaving water (liquid) temperature.
EWT is entering water (liquid) temperature.
EDB is entering air dry bulb temperature.
EWB is entering air wet bulb temperature.
F.F.A. is field fouling allowance in hrft F/Btu [m^2°C/W]

Condenser (Evaporatively-cooled)

a. Entering air wet-bulb temperature to condenser, F [°C]

b. Condenser fan motor power consumption, kW

c. Condenser spray pump power consumption, kW

d. Statement of field fouling allowance on heat exchanger.

5.2 *Water-Side Fouling.*

5.2.1 *Fouling at Standard Rating Condition.* The choice of 0.00025 hr sq ft F/Btu [0.000044 m^2°C/W] for coolers, and condensers for the Standard Rating Condition field fouling allowance which is the basis for published rating conditions (see 5.1.1 and 5.1.2.1) provides equipment selections which anticipate the effect of typical fouling in cooler and condenser water circuits. Fouling tends to reduce capacity and increase power consumption. An application should remain within the limits of the field fouling allowance if acceptable water quality is maintained by treatment, and the heat exchanger surfaces are periodically cleaned.

5.2.2 *Additional Fouling.* Conditions such as water hardness, organic material, suspended solids and/or water velocity may necessitate the use of a greater field fouling allowance than that provided in the Standing Rating of equipment.

5.2.3 *Adjustments for Additional Fouling.* Published ratings may include the effects of additional field fouling allowance. Such ratings shall be determined by using the methods described in 5.1.3b.

5.3 *Verification of Capacity and Power Requirements.* Where verification of capacity and power requirements is required, it shall be by test in accordance with the method set forth in Appendix A to this standard.

5.4 *Tolerances.*

5.4.1 *Allowable Tolerance.* The allowable test tolerance on capacity (tons) [kW], power input per ton (kW/ton) [kW/kW] and heat balance, shall be determined from the following equation:

Tolerance in percent tons [kW], percent kW/ton [kW/kW] or percent heat balance

$$= 10.5 - 0.07 \times \%\ FL + (1500/(DT_{FL} \times \%\ FL))$$

(U.S. Standard Units DT_{FL} in F.)

$$[= 10.5 - 0.07 \times \%\ FL + (833.3/DT_{FL} \times \%\ FL)]$$

[SI units DT_{FL} in °C]

Where FL = Full Load

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

See Figure 1. Allowable Tolerance Curves for Full and Part Load for graphical representation only.

5.4.2 *Full Load.* Published ARI ratings shall be such that any production package shall, upon test have a full load capacity not less than 100 percent of its rated capacity less the allowable tolerance and a full load power input per ton (kW/ton) [kW/kW] of not more than 100 percent of its rated kW/ton [kW/kW] plus the allowable tolerance. The allowable tolerance shall be determined by the equation specified in 5.4.1.

Water pressure drop in the cooler and condenser shall not exceed 115 percent of rated pressure drop at rated gpm, [L/s].

Example (Full load): (in U.S. Standard Units only for clarity)

Rated Full Load Performance

Rated Capacity = 100 tons

Rated Power = 70 kW

Cooling DT_{FL} = 10F

$$\text{kW/ton} = .70 \ \frac{kW}{ton}$$

Allowable Test Performance:

$$\text{Tolerance} = 10.5 - (.07 \times 100) + \frac{(1500)}{(10 \times 100)} = 10.5 - 7 + 1.5 = 5\%$$

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

$$= 95 \text{ tons}$$

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

$$= .735 \text{ kW/ton}$$

Max. kW at min. capacity

= .735 x 95 = 69.825

5.4.3 *Part Load.* The tolerance on part load power input per ton (kW/ton) shall be the tolerance for kW/ton determined by the equation specified in 5.4.1.

Example (Part Load): (in U.S. Standard Units only for clarity)

Rated Part Load Performance:

50% capacity	= 50 tons
50% power	= 35 kW
kW/ton	= .70 kW/ton
Full load DT_{FL}	= 10F

Allowable Test Performance:

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

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

$$\text{Max. allowable kW/ton} = \frac{(100+10\%)}{100} \text{x } .70$$

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

5.4.4 *IPLV and APLV Tolerance.* The allowable tolerance on IPLV and APLV shall be determined by the following equation:

Allowable Tolerance (percent)
= 6.5 + 35/DT_{FL}............DT_{FL} in F

[= 6.5 + 19.4/DT_{FL}]........DT_{FL} in °C

DT_{FL} as specified in 5.4.1 see Figure 2. IPLV and APLV Tolerance Curve

The single number IPLV or APLV, calculated for the part load conditions which apply, shall not exceed the rated IPLV or APLV by more than the allowed tolerance.

Section 6. Refrigerant Designation

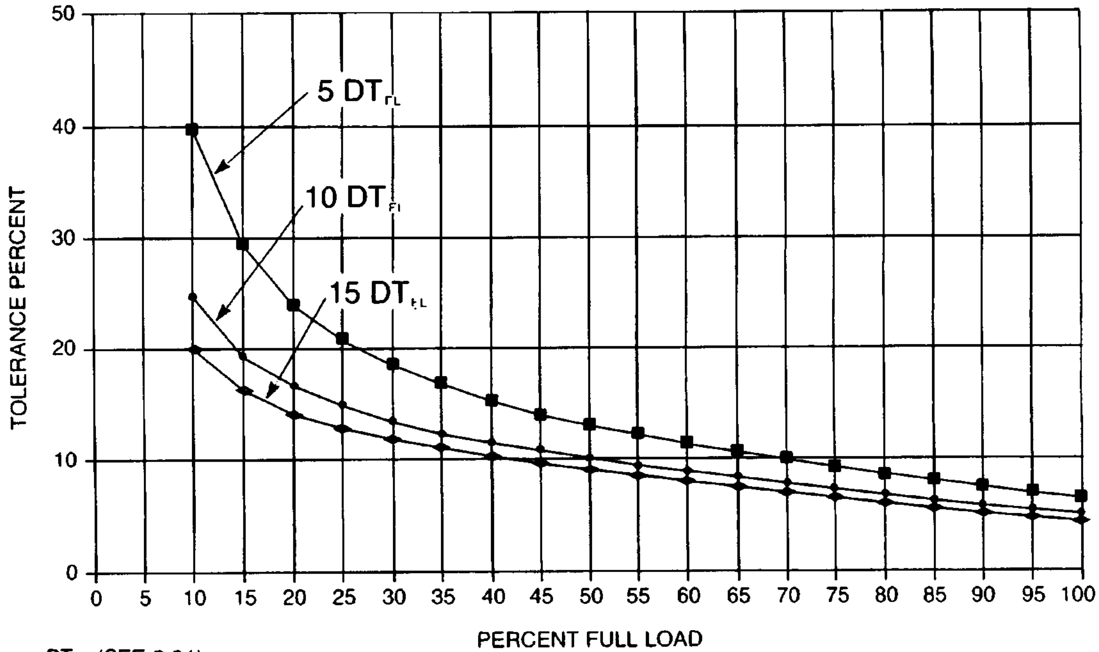
6.1 The refrigerant designation shall be specified on the package nameplate.

6.1.1 The refrigerant designation shall be in accordance with the ANSI/ASHRAE 34-1992 Standard *Number Designation of Refrigerants*.

Section 7. Voluntary Conformance

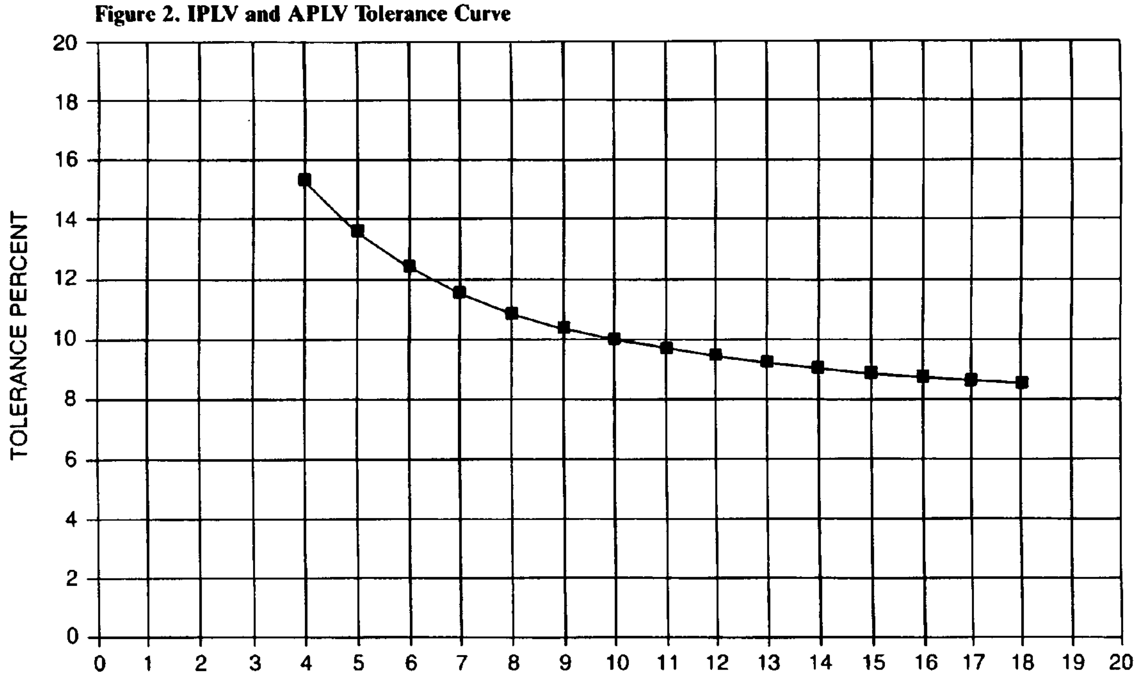
7.1 *Conformance*. While conformance with this standard is voluntary, conformance shall not be claimed or implied for products or equipment within its *Purpose* (Section 1) and *Scope* (Section 2) unless such claims meet all of the requirements of the Standard.

Figure 1. Allowable Tolerance Curves For Full And Part Load



DT_{FL} (SEE 5.5.1)

Figure 2. IPLV and APLV Tolerance Curve



DT_{FL} (SEE 5.5.1)

APPENDIX A

STANDARD REQUIREMENTS FOR TESTING CENTRIFUGAL AND ROTARY SCREW WATER-CHILLING PACKAGES

Section A1. Purpose

A1.1 *Purpose.* The purpose of this appendix is to prescribe a method of testing centrifugal and rotary screw water-chilling packages to verify capacity and power 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.

Section A2. Scope

A2.1 *Scope.* This appendix applies to centrifugal and rotary water-chilling packages used to chill water, as defined in Section 3 of this standard.

Section A3. Definitions

A3.1 *Definitions.* Definitions for this appendix are identical with those in Section 3 of this standard.

Section A4. Test Methods

A4.1 *Test Method.*

A4.1.1 The test will measure net cooling capacity (tons of refrigeration) and energy requirements, at a specific set of conditions.

A4.1.2 To confirm that steady-state conditions have been established at the specific set of conditions and within the tolerances set forth in A7.2, three sets of data shall be taken, at approximately five-minute intervals. To minimize the effects of transient conditions, test readings should be taken as nearly simultaneously as possible.

A4.1.3 The test shall include a measurement of the net heat removed from the water as it passes through the cooler by determination of the following:

a. Water flow rate

b. Temperature difference between entering and leaving water

A4.1.4 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 water.

A4.1.5 The test shall include the

determination of the compressor power requirement. This power shall be determined by measurement of electrical input to motor drive (see 5.1.6). For motors supplied by others the determination of compressor shaft horsepower input shall be as 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.

A4.1.5.1 *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.

A4.1.6 In addition to the determination of net heat removed and energy input required, data shall be taken to prepare a heat balance to substantiate the validity of the test.

A4.2 *Condition of Heat Transfer Surfaces.*

A4.2.1 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 0.0000 hr sq ft F/Btu [0.0000 $m^2 \cdot °C/W$].

Section A5. Instruments

A5.1 Instruments shall be selected from the types listed in ASHRAE Standard *Method of Testing Liquid Chilling Packages* (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Standard 30-78).

A5.1.1 Accuracy of instruments selected shall be in accordance with that specified in ASHRAE Standard 30-78.

A5.1.2 Temperature measurements shall be made in accordance with ASHRAE Standard *Measurements Guide--Section on Temperature Measurements* (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Standard 41.1-86).

A5.1.3 Flowmeters shall be constructed and installed in accordance with the applicable portion of the ASME "Fluid Meters--Their Theory and Application." Turbine flow meters may also be used in accordance with ISA-RP31.1-1977, "Recommended Practice Specification, Installation, and Calibration of Turbine Flowmeters."

A5.1.4 Scales for analog meters shall be such that readings will be at least one-half of full scale deflection. All instruments, including gages and thermometers shall be calibrated over the range of test readings.

A5.1.5 Pressure measurements shall be made in accordance with ASME Power Test Code PTC 19.2-1987, "Instruments and Apparatus, Part 2, Pressure Measurement."

Section A6. Measurements

A6.1 *Data to be Recorded During the Test:*

A6.1.1 *Test Data.*

Compressor/Cooler (All Condenser Types)

a. Temperature of water entering cooler, F[°C]

b. Temperature of water leaving cooler, F[°C]

c. Chilled water flow rate, gpm or lbs/hr [L/s]

d. Power input to compressor, kW or

e. Steam consumption of turbine, lbs/hr [kg/hr]
Steam supply pressure, psig [kPa]
Steam supply temperature, F[°C]
Steam exhaust pressure, psig or inches Hg. vac. [kPa] or

f. Gas consumption of turbine or engine, therms or cu ft per hr, [L/s] and calorific value, Btu per cu ft, [J/L], or

g. Fuel consumption of diesel or gasoline engine, gallons per hr, [L/s] and calorific value, Btu per gallon [J/L]

h. Cooler water pressure drop (inlet to outlets), psi or feet of water [kPa]

i. Electrical power input to controls and auxiliary equipment, kW

Condenser (Water-cooled)

a. Temperature of entering condenser water, F[°C]

b. Temperature of leaving condenser water, F[°C]

c. Condenser water flow rate, gpm or lb/hr [L/s]

d. Condenser water pressure drop (inlet to outlet), psi or feet of water [kPa]

Condenser (Air-cooled)

a. Dry-bulb temperature of air entering the condenser, F[°C]

b. Condenser fan motor power consumption, kW

c. Barometric pressure, in. Hg [kPa]

Condenser (Evaporatively-cooled)

a. Wet bulb temperature of air entering the condenser, F[°C]

b. Condenser fan motor power consumption, kW

c. Condenser spray pump power consumption, kW

d. Barometric pressure, in. Hg [kPa]

A6.1.2 If chilled water is used to cool the compressor motor or for some incidental function within the package, the temperature and flow measurements of chilled water must be made at points beyond such take-offs and returns, so that the measured rise reflects net cooling capacity.

A6.1.3 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 ahead of such take-offs and returns, so that the measured rise reflects gross condenser heat rejection.

A6.2 *Auxiliary Data to be Recorded for General Information.*

A6.2.1 Nameplate data including make, model, size and refrigerant, sufficient to completely identify the water-chilling package.

A6.2.2 Compressor driver or input rpm for open-type compressors.

A6.2.3 Ambient temperature at test site, F[°C].

A6.2.4 Actual voltage, and current in amperes for each phase, of all electric motor drives.

A6.2.5 Motor, engine or turbine nameplate data.

A6.2.6 Pressure, temperature and exhaust pressure for steam turbine drives.

A6.2.7 Fuel gas specification for gas turbine drive, including pressure, in. water [kPa].

A6.2.8 Heat balance for A7.4.

A6.3 *Record Data.*

A6.3.1 Date, place and time of test.

A6.3.2 Names of test supervisor and witnessing personnel.

Section A7. Test Procedure

A7.1 *Preparation for Test.*

A7.1.1 The centrifugal or rotary screw 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 instruments.

A7.1.2 The test shall not be started until non-condensables have been removed from the system.

A7.1.3 At the manufacturers option condenser and cooler surfaces may be cleaned as provided in A4.2.1.

A7.2 *Operations and Limits.*

A7.2.1 Start the system and establish the testing conditions in accordance with the following tolerances and instructions:

a. *Cooler (All Condenser Types)*

(1) The chilled water flow shall not deviate more than ±5 percent from that specified.

(2) The individual readings of water temperature leaving the cooler 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.

(3) The leaving chilled water temperature shall be adjusted by an increment calculated per A7.3 corresponding to the specified field fouling allowance.

(4) Part load tests must be taken within ±2% of the full load tons at the specified part load capacity.

b. *Condenser (Water-Cooled)*

(1) The water flow through the condenser shall not deviate more than ±5 percent from that specified.

(2) 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 have been taken to insure that these water temperatures are the average bulk stream temperatures.

(3) The entering condensing water temperature shall be adjusted by an increment calculated per A7.3 corresponding to the specified field fouling allowance.

c. *Condenser (Air- or Evaporatively-Cooled)*

The individual readings of water temperature leaving the cooler and the saturated refrigerant condensing temperature corresponding to the compressor discharge pressure (regulating the condenser air flow if necessary) shall not vary from the specified values by more than 0.5 F [0.3°C]. Care must be taken to insure that the cooler water temperature is the average bulk stream temperature and the condensing temperature is measured as close to the compressor discharge port as practical. For an evaporative condenser calculate an appropriate correction to be applied to the corresponding specified field fouling allowance.

d. *Miscellaneous*

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

(2) For steam-turbine driven machines, steam conditions to the turbine, and condenser pressure or vacuum, shall be maintained at nameplate values.

(3) For gas-turbine or gas-engine operated machines, gas pressure to turbine or engine, and exhaust back-

pressure at the turbine or engine shall be maintained at name-plate values.

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

A7.3 *Method for Simulating Field Fouling Allowance at Full and Part Load Conditions.*

A7.3.1 Obtain the log mean temperature difference (LMTD) for the cooler and/or condenser using the following equation at the specified field fouling allowance (ff_{sp}).

$$LMTD = \frac{R}{\ln(1 + R/S)} \qquad \text{(A1)}$$

A7.3.2 Derivation of LMTD:

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

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

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

$$ILMTD = ff_{sp}\left(\frac{q}{A}\right) \qquad \text{(A2)}$$

A7.3.3 The water temperature difference TD_a needed to simulate the additional fouling, TD_a, can now be calculated:

$$TD_a = S_{sp} - S_c \qquad \text{(A3a)}$$

$$TD_a = S_{sp} - \frac{R}{e^z - 1} \qquad \text{(A3b)}$$

Where:

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

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

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 condenser entering water temperature or subtracted from the cooler leaving water temperature to simulate the additional fouling factor.

A7.3.4 *Example--Condenser Fouling Inside Tubes* (in U.S. Standard units only, for clarity)

Specified field fouling allowance ff_{sp} = 0.00025 hr sq ft F/Btu

Condenser load, q = 2,880,000 Btuh

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 sq ft

*(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

$$LMTD = \frac{R}{ln\ (1 + R/S)} \quad \text{(A1)}$$

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

$ff_{sp} = 0.00025$

$$ILMTD = ff_{sp}\left(\frac{q}{A}\right) \quad \text{(A2)}$$

$$= 0.00025\left(\frac{2,880,000}{550}\right)$$

$$= 1.31$$

$$TD_a = S_{sp} - \frac{R}{e^{z} - 1} \quad \text{(A3b)}$$

Where:

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

$$= 6.0 - 4.8$$

$$= 1.2 \text{ F}$$

The entering condenser water temperature for testing is then raised 1.2 F to simulate the field fouling allowance of 0.00025 hr sq ft F/Btu. The entering condenser water temperature will be 85 + 1.2 or 86.2F.

A7.3.5 *Symbols and Subscripts.* The symbols and subscripts used in Equations A1 through A3b are as follows:

Symbols:

A = Total heat transfer surface, sq ft [m²] for cooler or condenser

A = A_i for fouling inside tubes

A = A_o for fouling outside tubes

e = Base of natural logarithm

q = Total heat rejection rate or net refrigerant capacity of cooler, Btuh [W]

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

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

t = Temperature, F[°C]

ff_{sp} = Specified field fouling allowance

Subscripts:

a = additional fouling

e = entering

c = cleaned

f = fouled or fouling

i = inside

o = outside

l = leaving

s = saturated vapor

w = water

sp = specified

A7.4 *Heat Balance-Substantiating Test.*

A7.4.1 *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:

$$q_{ev} + W_{input} = q_c$$

Where:

q_{ev} = net cooling capacity of liquid cooler, tons [kW]

W_{input} = compressor work input as defined in Paragraphs (a), (b), or (c) below

q_c = net heat rejected to the condenser, tons [kW]

a. 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 expressed in tons [kW]

b. 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, expressed in tons [kW]

$q_{prime\ mover}$ = power delivered by prime mover expressed in tons [kW]

q_{gear} = friction loss in gear box, tons [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.

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

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.

W_{input} = power input to the compressor shaft, expressed in tons [kW]

In the case of motor drive:

W_{input} = power measured at

motor terminals.

A7.4.2 *Percent Heat Balance.* Heat balance, in percent, is defined as:

$$\frac{q_{ev} + W_{input} - q_c}{q_c} X\ 100 \qquad (A4)$$

For any test of a liquid cooled chiller to be acceptable, the heat balance (percent) shall be within the allowable tolerance calculated per 5.4.1 for the applicable conditions.

For air or evaporatively cooled condenser, it is impractical to measure heat rejection in a test, therefore a heat balance cannot be calculated.

Section A8. Calculation of Results

A8.1 *Capacity and Power.*

A8.1.1 The capacity in tons [kW] shall be obtained by the following equations:

$$tons = \frac{c\ w\,(t_e - t_l)}{12{,}000}$$

$$[kW = 4.187\ cw\ (t_e - t_l)] \quad (A5)$$

Where:

c = specific heat of water at average water temperature, Btu/(lb.F) [kJ/kg.°C]

w = mass flow rate of chilled water, lb per hr [kg/s]

t_e = temperature of water entering the cooler, F[°C]

t_l = temperature of water leaving the cooler, F[°C]

A8.1.2 Power consumption shall be determined as follows (consistent with 5.1.6):

a. 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.

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

c. 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 A7.4.1 b or c.

d. 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.

A8.1.3 *Validity of Test.* Calculate the heat balance for each of the three test points (A4.1.2). All three heat balances must be within the tolerance specified (A7.4.2). Then average the data taken (A6.1.1) from the three test points and calculate capacity and power input per A8.1.1 and A8.1.2 using averaged data for reporting purpose.

APPENDIX B

DERIVATION OF INTEGRATED PART LOAD VALUES (IPLV AND APLV)

Section B1. Purpose

B1.1 *Purpose.* This appendix is intended to show the derivation and an example of the calculation of the Integrated Part Load Value (IPLV) or Application Part Load Value (APLV).

Section B2. Scope

B2.1 *Scope.* This appendix is for equipment covered by this standard. The basic equations and procedure are intended to provide a consistent procedure for calculating a single number part load performance number for water chilling products.

The basic equations (1a) and (1b) as shown in section B3.1 were developed based on a typical office building located in Atlanta. The weather data used for this building was obtained from ASHRAE weather data for the city of Atlanta. A typical office building profile was assumed with 2125 hours of mechanical cooling per year, which was determined based on operation from 7 a.m. to 6 p.m. 5 days per week, and from 7 a.m. to 1 p.m. on Saturdays. The building was equipped with an air side economizer. A single chiller was used for this building and was sized to be at full capacity at the design full load conditions. The design conditions for the building were:

Summer Design Dry Bulb Temperature = 94 F
Summer Design Wet Bulb Temperature = 74 F
Zero Load Dry Bulb Temperature = 35 F

The building load was assumed to vary linearly with the ambient temperature.

The details for the building are summarized in Figures B1 to B4 and in Table B5.

It should be stressed that the equation derived from the above data is intended to be a typical building model, but because of wide variations among actual buildings we strongly recommend that actual energy analysis be used to determine the part load performance and energy use for the chiller and building. The following are some items that can affect the chiller energy efficiency at part load;

- Ambient Temperature Profile
- Building Load Profile
- Water Temperature Setpoints
- Cooling Tower Size and Control
- Number of Chillers
- Control of chillers

Section B3. Equation and Definition of Terms

B3.1 The energy efficiency of a chiller is commonly expressed in one of the three following ratios:

Coefficient of Performance

$$COP = \frac{kW\ refrigeration\ effect}{kW\ input} \qquad (1a)$$

Energy Efficiency Ratio

$$EER = \frac{Btu/hr\ refrigeration\ effect}{watt\ input} \qquad (1b)$$

Power per Ton

$$kW/ton = \frac{kW\ input}{tons\ refrigeration\ effect} \qquad (1c)$$

These three alternative dimensions 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

General Equation. The following equation should be used when the efficiency is expressed in capacity divided by unit input power. An efficiency expressed as EER (Btuh/watt) or COP (kw/kw) should use this equation.

$$IPLV \text{ or } APLV = 0.17A + 0.39B + 0.33C + 0.11D \qquad (2a)$$

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 should be used when the efficiency is expressed in input power divided by unit capacity. When the efficiency is expressed in kw/ton then this equation should used.

$$\begin{matrix} IPLV \\ or \\ APLV \end{matrix} = \frac{1}{\frac{0.17}{A} + \frac{0.39}{B} + \frac{0.33}{C} + \frac{0.11}{D}} \qquad (2b)$$

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 and APLV rating requires that the unit efficiency be determined at 100%, 75%, 50% and 25% at the conditions as specified in table 1. If the unit cannot be operated at the 25% capacity point, the 25% point should be determined with the condenser entering water (liquid) temperature corresponding to the 25% capacity conditions. The efficiency should be calculated by using the measured power at these conditions and 25% of the full load capacity.

B3.2 *Equation Constants* The constants 0.17, 0.39, 0.33, and 0.25 are based on the typical office building in Atlanta. To reduce the number of machine data points the ASHRAE based bin data was reduced to 4 bins as shown below;

BIN	LOAD RANGE
1	100%-75%
2	75%-50%
3	50%-25%
4	25%-0%

Using the ASHRAE data for mechanical cooling hours of operation and the average chiller performance for the load bin the following equation can be used to calculate a weighted part load performance rating.

$$\begin{matrix} IPLV \\ or \\ APLV \end{matrix} = 0.3421 \times \frac{(A + B)}{2} + 0.4311 \times \frac{(B + C)}{2} + 0.2268 \times \frac{(C + D)}{2} + 0.00 \times (D)$$

The above equation can be simplified to:

$$\begin{matrix} IPLV \\ or \\ APLV \end{matrix} = 0.17A + 0.39B + 0.33C + 0.11D \qquad (2a)$$

B3.3 *Sample Calculation* The following is an example of a kw/ton IPLV based calculation;

CHILLER PERFORMANCE DATA

% LOAD	CAPACITY (TONS)	POWER (KW)
100%	400	280
75%	300	186
50%	200	120
33%*	132	95

* Minimum possible unit capacity

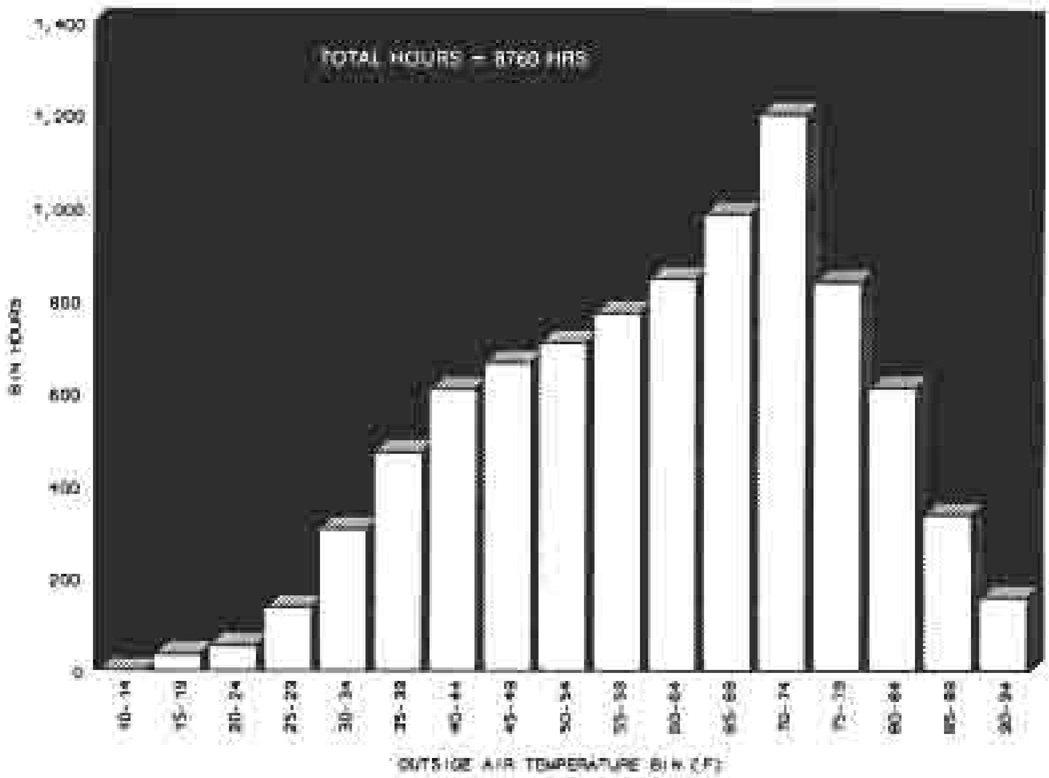
Using the above data the part load kw/ton values can be calculated.

POINT	LOAD	CAP (TONS)	POWER (KW)	EFF. (KW/TON)
A	100%	400	280	0.70
B	75%	300	186	0.62
C	50%	200	120	0.60
D	25%	100	132	1.32

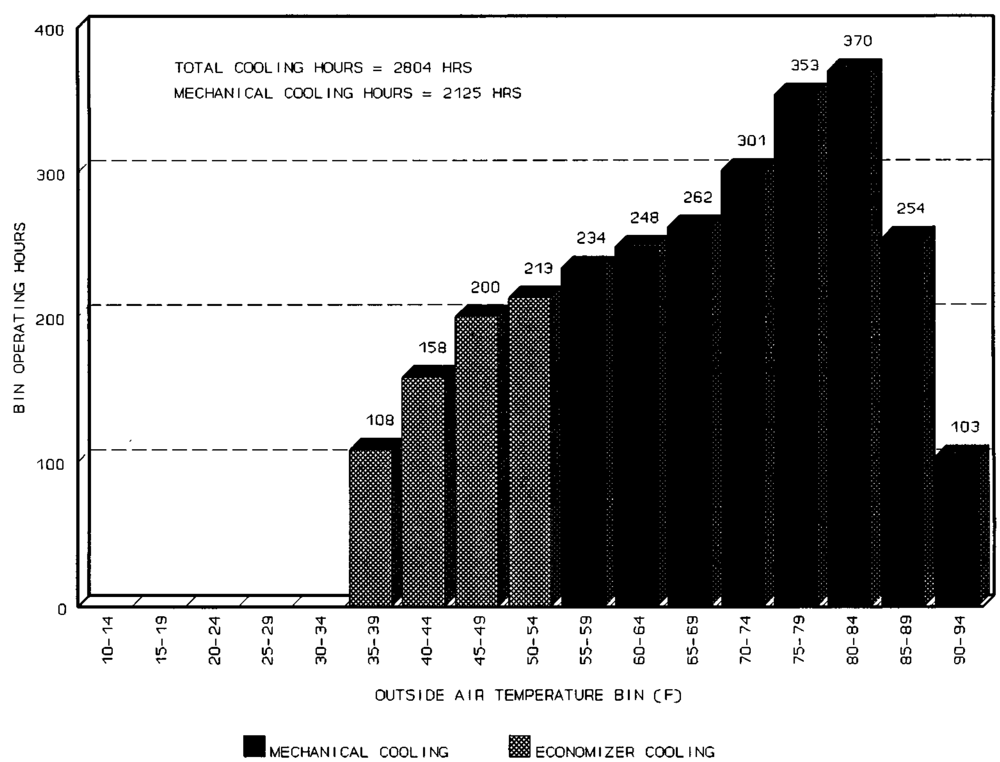
$$IPLV = \frac{1}{\frac{0.17}{0.70} + \frac{0.39}{0.62} + \frac{0.33}{0.60} + \frac{0.11}{1.32}}$$

$$= .66\ kw/ton$$

ATLANTA ASHRAE WEATHER DATA BIN HOURS
FIGURE B1

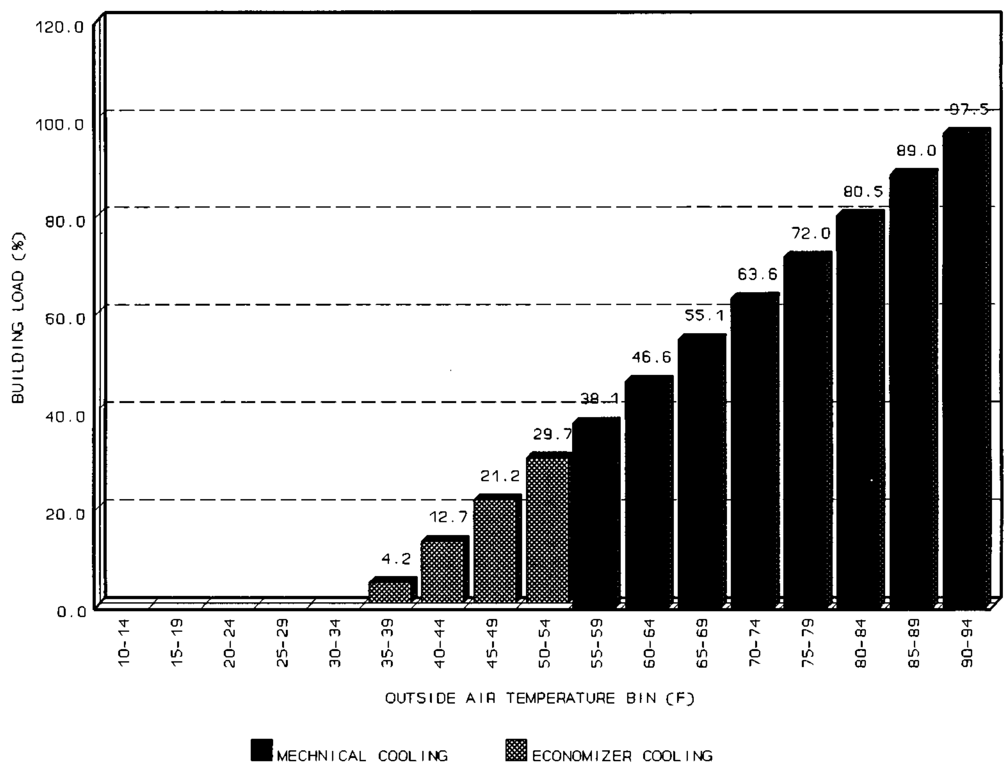


ATLANTA OFFICE BUILDING COOLING OPERATING HOURS
FIGURE B2



ATLANTA OFFICE BUILDING COOLING LOAD PROFILE

FIGURE B3



IPLV BIN MECHANICAL COOLING HOURS

FIGURE B4

TOTAL OPERATING HOURS = 2125 HRS

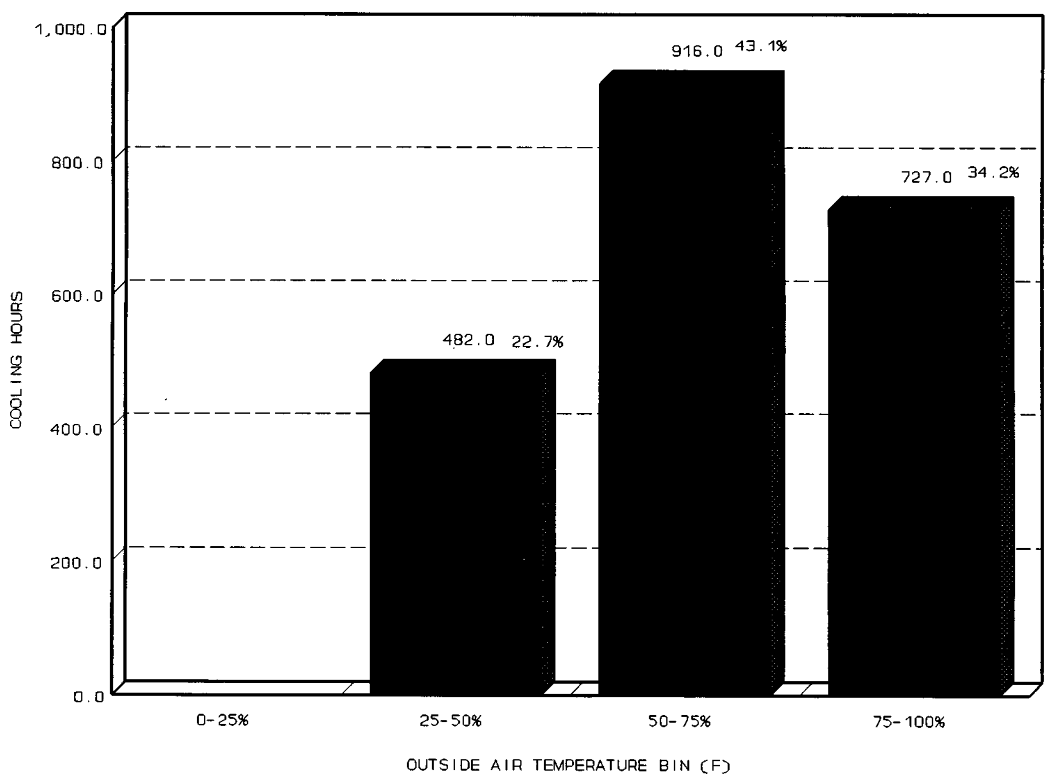


TABLE B5. ATLANTA OFFICE BUILDING SUMMARY

OUTSIDE TEMP. (F)	AVG DB. (F)	TOTAL BIN HOURS	TOTAL COOLING HOURS	COOLING LOAD (%)	0-25% BIN HOURS	25-50% BIN HOURS	50-75% BIN HOURS	75-100% BIN HOURS
100-105	102.5	0	0	100.00	0	0	0	0
95-99	97.5	0	0	100.00	0	0	0	0
90-94	92.5	156	103 M	97.56	0	0	0	103
85-89	87.5	367	254 M	88.96	0	0	0	254
80-84	82.5	611	370 M	80.51	0	0	0	370
75-79	77.5	838	353 M	72.03	0	0	353	0
70-74	72.5	1201	301 M	63.56	0	0	301	0
65-69	67.5	986	262 M	55.08	0	0	262	0
60-64	62.5	846	248 M	46.61	0	248	0	0
55-59	57.5	773	234 M	38.14	0	234	0	0
50-54	52.5	709	213 E	29.66	0	0	0	0
45-49	47.5	666	200 E	21.19	0	0	0	0
40-44	42.5	608	158 E	12.71	0	0	0	0
35-39	37.5	471	108 E	4.24	0	0	0	0
30-34	32.5	305	0	0	0	0	0	0
25-29	27.5	135	0	0	0	0	0	0
20-24	22.5	53	0	0	0	0	0	0
15-19	17.5	35	0	0	0	0	0	0
10-14	12.5	0	0	0	0	0	0	0
TOTAL		8760	2125 M		0	482 M	916 M	727 M
% TOTAL					0	22.68%	43.11%	34.21%

E - Economizer operation
M - Mechanical refrigeration cooling

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Supersedes: Nothing