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Meeting the Energy Code with Centrifugal Chillers

The purpose of this white paper is to explain the energy code requirements for water cooled centrifugal chillers.

I often get requests to send IPLV ratings for a centrifugal chiller to prove energy code compliance. However, unless the chiller is designed to operate at AHRI standard conditions (2.4 GPM/ton of chilled water leaving at 44°F and 3.0 GPM/ton of condenser water entering at 85°F), this is an invalid request. Figure 1 below from the 2015 WA State Energy Code establishes the rules for determining minimum efficiency levels for centrifugal chillers designed to operate at non AHRI Standard 550/590 conditions. Oregon uses ASHRAE 90.1-2016 which contains the same requirement. However, the baseline chiller efficiencies are slightly different in Oregon (see page 5).

C403.2.3.1 Water-cooled centrifugal chilling package. Equipment not designed for operation at AHRI Standard 550/590 test conditions of 44°F (7°C) leaving chilled-water temperature and 2.4 gpm/ton evaporator fluid flow and 85°F (29°C) entering condenser water temperature with 3 gpm/ton (0.054 L/s x kW) condenser water flow shall have maximum full-load kW/ton (*FL*) and part-load ratings adjusted using Equations 4-7 and 4-8.

$$FL_{adj} = FL/K_{adj} \quad \text{(Equation 4-7)}$$

$$PLV_{adj} = IPLV/K_{adj} \quad \text{(Equation 4-8)}$$

Where:

$$K_{adj} = A \times B$$

FL = Full-load kW/ton values as specified in Table C403.3.2(7)

FL_{adj} = Maximum full-load kW/ton rating, adjusted for nonstandard conditions

IPLV = Values as specified in Table C403.3.2(7)

PLV_{adj} = Maximum NPLV rating, adjusted for nonstandard conditions.

$$A = 0.00000014592 \times (\text{LIFT})^4 - 0.0000346496 \times (\text{LIFT})^3 + 0.00314196 \times (\text{LIFT})^2 - 0.147199 \times \text{LIFT} + 3.9302$$

$$B = 0.0015 \times L_{vg}^{Evap} (\text{°F}) + 0.934$$

$$\text{LIFT} = L_{vg}^{Cond} - L_{vg}^{Evap}$$

L_{vg}^{Cond} = Full-load condenser leaving fluid temperature (°F)

L_{vg}^{Evap} = Full-load evaporator leaving temperature (°F)

The FL_{adj} and PLV_{adj} values are only applicable for centrifugal chillers meeting all of the following full-load design ranges:

1. Minimum evaporator leaving temperature: 36°F.
2. Maximum condenser leaving temperature: 115°F.
3. LIFT is not less than 20°F and not greater than 80°F.

Figure 1 Energy Requirements for Non-Standard Conditions

The reason for this is a centrifugal compressor is optimized at a specific mass flow rate (capacity) and lift (pressure differential across the compressor). Asking a centrifugal chiller to be optimized at one set of conditions and then forcing it to show energy code compliance at another set of conditions makes little sense. This is analogous to selecting a fan or a pump at a specific flow rate and head pressure, then modeling them at a completely different set of operating conditions to show code compliance.

In the state energy code, equation 4-7 establishes the required full load efficiency by applying a correction factor (K_{adj}) to the tabulated energy code value (see page 3). Equation 4-8 applies the same correction factor to the tabulated IPLV to arrive at a minimum NPLV (non standard part load value) rating.

As you can see, the equation is quite complicated and time consuming. However, I have put together a simple spreadsheet to help with this calculation. The spreadsheet can be found in the Engineering White Paper folders on the shared drives for each office.

2015 WA STATE ENERGY CODE			
Full Load Capacity (Tons)	500.0		Instructions: Fill in the grey shaded cells.
Condenser LWT (°F)	86.0		
Evaporator LWT (°F)	42.0		
	PATH A	PATH B	
Full load kW/ton from Table Table C403.2.3(7)	0.560	0.585	
IPLV from Table Table C403.2.3(7)	0.500	0.380	
LIFT (°F)	44.0		
A	1.13		
B	1.00		
$K_{adj} = A \times B$	1.13		
Adjusted maximum full load kW/ton rating	0.496	0.519	
Adjusted maximum NPLV rating	0.443	0.337	

Figure 2 Energy Code Spreadsheet

To use the spreadsheet, simply enter the capacity, leaving condenser water temperature and leaving evaporator water temperature in the grey cells. The yellow cells automatically calculate the required efficiencies.

For this particular 500 ton chiller with 86°F leaving condenser water and 42°F leaving chilled water, you can show compliance by either meeting path A (≤ 0.496 kW/ton at full load with an NPLV ≤ 0.443 kW/ton) or path B (≤ 0.519 kW/ton at full load with an NPLV ≤ 0.337 kW/ton).

When the 2018 WA State Energy Code goes into effect in November of this year, the equation stays the same but the tabulated efficiency requirements are slightly different (see page 4). I have written a spreadsheet for the 2018 code and saved that to the H: drive as well. The Oregon code has it's own spreadsheet.

If there are any questions or concerns, please feel free to contact the engineering department.

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TABLE C403.2.3(7)
MINIMUM EFFICIENCY REQUIREMENTS:
WATER CHILLING PACKAGES^a

EQUIPMENT TYPE	SIZE CATEGORY	UNITS	AS OF 1/1/2015b				TEST PROCEDURE ^c
			PATH A		PATH B		
			FULL LOAD	IPLV	FULL LOAD	IPLV	
Air-cooled chillers	< 150 tons	EER	EER	EER	EER	EER	AHRI 550/590
	≥150 tons	EER	EER	EER	EER	EER	
Air cooled without condenser, electrical operated	All capacities	EER	Air-cooled chillers without condensers shall be rated with matching condensers and comply with the air-cooled chiller efficiency requirements				
Water cooled, electrically operated, reciprocating	All capacities	kW/ton	Reciprocating units shall comply with water cooled positive displacement efficiency requirements				
Water cooled, electrically operated, positive displacement	< 75 tons	kW/ton	≤ 0.750	≤ 0.600	≤ 0.780	≤ 0.500	
	≥75 tons and < 150 tons	kW/ton	≤ 0.720	≤ 0.560	≤ 0.750	≤ 0.490	
	≥ 150 tons and < 300 tons	kW/ton	≤ 0.660	≤ 0.540	≤ 0.680	≤ 0.440	
	≥ 300 tons and < 600 tons	kW/ton	≤ 0.610	≤ 0.520	≤ 0.625	≤ 0.410	
	≥ 600 tons	kW/ton	≤ 0.560	≤ 0.500	≤ 0.585	≤ 0.380	
Water cooled, electrically operated, centrifugal	< 150 tons	kW/ton	≤ 0.610	≤ 0.660	≤ 0.695	≤ 0.440	
	≥ 150 tons and < 300 tons	kW/ton					
	≥300 tons and < 400 tons	≤0.560	≤ 0.560	≤ 0.520	≤ 0.595	≤ 0.390	
	≥400 tons	≤0.560	≤ 0.560	≤ 0.500	≤ 0.585	≤ 0.380	
Air cooled, absorption single effect	All capacities	COP	≥ 0.600	NR	NA	NA	AHRI 560
Water cooled, absorption single effect	All capacities	COP	≥ 0.700	NR	NA	NA	
Absorption double effect, indirect fired	All capacities	COP	≥ 1.000	≥ 1.050	NA	NA	
Absorption double effect, direct fired	All capacities	COP	≥ 1.000	≥ 1.000	NA	NA	

For SI: 1 ton = 3517 W, 1 British thermal unit per hour = 0.2931 W, °C = [(°F) - 32]/1.8.

NA = Not applicable, not to be used for compliance; NR = No requirement.

- a. The centrifugal chiller equipment requirements, after adjustment in accordance with Section C403.2.3.1 or Section C403.2.3.2, do not apply to chillers used in low-temperature applications where the design leaving fluid temperature is less than 36°F. The requirements do not apply to positive displacement chillers with leaving fluid temperatures less than or equal to 32°F. The requirements do not apply to absorption chillers with design leaving fluid temperatures less than 40°F.
- b. Compliance with this standard can be obtained by meeting the minimum requirements of Path A or B. However, both the full load and IPLV shall be met to fulfill the requirements of Path A or B.
- c. Chapter 6 of the referenced standard contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.

Ec = Combustion efficiency (100 percent less flue losses). Et = Thermal efficiency. See referenced standard document for detailed information.

- a. These requirements apply to boilers with rated input of 8,000,000 Btu/h or less that are not packaged boilers and to all packaged boilers. Minimum efficiency requirements for boilers cover all capacities of packaged boilers.
- b. Maximum capacity – minimum and maximum ratings as provided for and allowed by the unit’s controls.
- c. Includes oil-fired (residual).
- d. Boilers shall not be equipped with a constant burning ignition pilot.
- e. A boiler not equipped with a tankless domestic water heating coil shall be equipped with an automatic means for adjusting the temperature of the water such that an incremental change in inferred heat load produces a corresponding incremental change in the temperature of the water supplied.

TABLE C403.3.2(6) RESERVED

TABLE C403.3.2(7) MINIMUM EFFICIENCY REQUIREMENTS: WATER CHILLING PACKAGES^{a, b}

EQUIPMENT TYPE	SIZE CATEGORY	UNITS	PATH A		PATH B		TEST PROCEDURE ^c
			FULL LOAD	IPLV	FULL LOAD	IPLV	
Air-cooled chillers	< 150 tons	EER	≥ 10.100	≥ 13.700	≥ 9.700	≥ 15.800	AHRI 550/590
	≥ 150 tons	EER	≥ 10.100	≥ 14.000	≥ 9.700	≥ 16.100	
Air cooled without condenser, electrical operated	All capacities	EER	Air-cooled chillers without condensers shall be rated with matching condensers and comply with the air-cooled chiller efficiency requirements				
Water cooled, electrically operated, positive displacement	< 75 tons	kW/ton	≤ 0.750	≤ 0.600	≤ 0.780	≤ 0.500	
	≥75 tons and < 150 tons	kW/ton	≤ 0.720	≤ 0.560	≤ 0.750	≤ 0.490	
	≥ 150 tons and < 300 tons	kW/ton	≤ 0.660	≤ 0.540	≤ 0.680	≤ 0.440	
	≥ 300 tons and < 600 tons	kW/ton	≤ 0.610	≤ 0.520	≤ 0.625	≤ 0.410	
	≥ 600 tons	kW/ton	≤ 0.560	≤ 0.500	≤ 0.585	≤ 0.380	
Water cooled, electrically operated, centrifugal	< 150 tons	kW/ton	≤ 0.610	≤ 0.550	≤ 0.695	≤ 0.440	
	≥ 150 tons and < 300 tons	kW/ton	≤ 0.610	≤ 0.550	≤ 0.695	≤ 0.440	
	≥300 tons and < 400 tons	≤0.560	≤ 0.560	≤ 0.520	≤ 0.595	≤ 0.390	
	≥400 tons	≤0.560	≤ 0.560	≤ 0.500	≤ 0.585	≤ 0.380	
Air cooled, absorption single effect	All capacities	COP	≥ 0.600	NR	NA	NA	AHRI 560
Water cooled, absorption single effect	All capacities	COP	≥ 0.700	NR	NA	NA	
Absorption double effect, indirect fired	All capacities	COP	≥ 1.000	≥ 1.050	NA	NA	
Absorption double effect, direct fired	All capacities	COP	≥ 1.000	≥ 1.000	NA	NA	

For SI: 1 ton = 3517 W, 1 British thermal unit per hour = 0.2931 W, °C = [(°F) - 32]/1.8.

NA = Not applicable, not to be used for compliance; NR = No requirement.

- a. The centrifugal chiller equipment requirements, after adjustment in accordance with Section C403.3.2.2 or Section C403.3.2.3, do not apply to chillers used in low-temperature applications where the design leaving fluid temperature is less than 36°F. The requirements do not apply to positive displacement chillers with leaving fluid temperatures less than or equal to 32°F. The requirements do not apply to absorption chillers with design leaving fluid temperatures less than 40°F.
- b. Compliance with this standard can be obtained by meeting the minimum requirements of Path A or B. However, both the full load and IPLV shall be met to fulfill the requirements of Path A or B.
- c. Chapter 12 of the referenced standard contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.

6 Heating, Ventilating, and Air Conditioning

Table 6.8.1-3 Water-Chilling Packages—Minimum Efficiency Requirements^{a,b,e}

EQUIPMENT TYPE	SIZE CATEGORY	UNITS	PATH A	PATH B	TEST PROCEDURE ^c
Air-cooled chillers	< 150 tons	EER (Btu/Wh)	≥ 10.100 FL	≥ 9.700 FL	AHRI 550/590
			≥ 13.700 IPLV.IP	≥ 15.800 IPLV.IP	
	≥ 150 tons		≥ 10.100 FL	≥ 9.700 FL	
	≥ 14.000 IPLV.IP		≥ 16.100 IPLV.IP		
Air cooled without condenser, electrical operated	All capacities	EER (Btu/Wh)	Air-cooled chillers without condensers shall be rated with matching condensers and comply with the air-cooled chiller efficiency requirements		AHRI 550/590
Water cooled, electrically operated, positive displacement	< 75 tons	kW/ton	≤ 0.750 FL	≤ 0.780 FL	AHRI 550/590
	≥ 75 tons and < 150 tons		≤ 0.600 IPLV.IP	≤ 0.500 IPLV.IP	
			≤ 0.720	≤ 0.750 FL	
	≥ 150 tons and < 300 tons		≤ 0.560 IPLV.IP	≤ 0.490 IPLV.IP	
			≤ 0.660 FL	≤ 0.680 FL	
	≥ 300 tons and < 600 tons		≤ 0.540 IPLV.IP	≤ 0.4420 IPLV.IP	
	≥ 600 tons		≤ 0.610 FL	≤ 0.625 FL	
≤ 0.520 IPLV.IP		≤ 0.410 IPLV.IP			
Water cooled, electrically operated, centrifugal	< 150 tons	kW/ton	≤ 0.560 FL	≤ 0.585 FL	AHRI 550/590
			≤ 0.500 IPLV.IP	≤ 0.380 IPLV.IP	
			≤ 0.610 FL	≤ 0.695 FL	
			≤ 0.550 IPLV.IP	≤ 0.440 IPLV.IP	
	≥ 300 tons and < 400 tons		≤ 0.610 FL	≤ 0.635 FL	
			≤ 0.550 IPLV.IP	≤ 0.400 IPLV.IP	
	≥ 400 tons and < 600 tons		≤ 0.560 FL	≤ 0.595 FL	
			≤ 0.520 IPLV.IP	≤ 0.390 IPLV.IP	
≥ 600 tons	≤ 0.560 FL	≤ 0.585 FL			
≤ 0.500 IPLV.IP	≤ 0.380 IPLV.IP				
Air cooled, absorption single effect	All capacities	COP (W/W)	≥ 0.600 FL	NA ^d	AHRI 560
Water cooled, absorption single effect	All capacities	COP (W/W)	≥ 0.700 FL	NA ^d	AHRI 560
Absorption double effect, indirect fired	All capacities	COP (W/W)	≥ 1.000	NA ^d	AHRI 560
			≥ 1.050 IPLV.IP		
Absorption double effect, direct fired	All capacities	COP (W/W)	≥ 1.000	NA ^d	AHRI 560
			1≥ .000 IPLV		

- The requirements for centrifugal chillers shall be adjusted for nonstandard rating conditions per Section 6.4.1.2.1 and are only applicable for the range of conditions listed there. The requirements for air-cooled, water-cooled positive displacement and absorption chillers are at standard rating conditions defined in the reference test procedure.
- Both the full-load and IPLV.IP requirements must be met or exceeded to comply with this standard. When there is a Path B, compliance can be with either Path A or Path B for any application.
- Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.
- NA means the requirements are not applicable for Path B, and only Path A can be used for compliance.
- FL is the full-load performance requirements, and IPLV.IP is for the part-load performance requirements.