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6.8 HVAC Primary Systems

6.8.1 Boilers

Boiler Name	
Applicability	All boilers
Definition	A unique descriptor for each boiler, heat pump, central heating heat-exchanger or heat recovery device.
Units	None
Input Restrictions	User entry. Where applicable, this should match the tags that are used on the plans for the proposed design.
Baseline Rules	Boilers are only designated in the baseline model if the Baseline System is of type 1 (PTAC), type 5 (Packages VAV with Reheat) or type 7 (VAV with Reheat).

Boiler Fuel	
Applicability	All boilers
Definition	The fuel source for the central heating equipment. The choices are: • Gas • Oil • Electricity
Units	List (see above)
Input Restrictions	As designed
Baseline Rules	Same fuel as the proposed design

Boiler Type	
Applicability	All boilers
Definition	The boiler type. Choices include: • Steam Boiler • Hot Water Boiler • Heat-Pump Water Heater
Units	List (see above)
Input Restrictions	As designed
Baseline Rules	The boiler type will be a hot water boiler for baseline systems 1, 5 and 7, according to the baseline system descriptions from Table G3.1.1B. All other system types do not have a boiler.

Boiler Draft Type	
Applicability	All boilers
Definition	How combustion airflow is drawn through the boiler. Choices are: • Natural (sometimes called atmospheric) • Mechanical Natural draft boilers use natural convection to draw air for combustion through the boiler. Natural draft boilers are subject to outside air conditions and the temperature of the flue gases. Mechanical draft boilers enhance the air flow in one of three ways: 1) Induced draft, which uses ambient air, a steam jet, or a fan to induce a negative pressure which pulls flow through the exhaust stack; 2) Forced draft, which uses a fan and ductwork to create a positive pressure that forces air into the furnace, and 3) Balanced draft, which uses both induced draft and forced draft methods to bring air through the furnace, usually keeping the pressure slightly below atmospheric.
Units	List (see above)
Input Restrictions	As designed. Default is natural draft.
Baseline Rules	The baseline boiler is always assumed to be a natural draft boiler. (G3.1.3.2)

Number of Identical Boiler Units	
Applicability	All boilers

Definition The number of identical units for staging

Units Numeric: integer

Input Restrictions As designed. Default is 1.

Baseline Rules The number of boilers in the baseline case is set as follows (G3.1.3.2). The baseline building has one boiler when it serves an area less than or equal to 15,000 ft². For larger service areas, the baseline building shall have two equally sized boilers.

Boiler Heat Loss

Applicability All boilers

Definition The boiler or heat-exchanger heat loss expressed as a percentage of full load output capacity. This loss only occurs when the boiler is firing.

Units Percent (%)

Input Restrictions Default is 2% for electric boilers and heat-exchangers and 0% for fuel-fired boilers. If the user overrides the default, supporting documentation is required.

Baseline Rules Prescribed at 2% for electric boilers and heat-exchangers. Prescribed at 0% for fuel-fired boilers, since this loss is already incorporated into the overall thermal efficiency, combustion efficiency or AFUE of the boiler.

Boiler Design Capacity

Applicability All boilers

Definition The heating capacity at design conditions

Units Btu/h

Input Restrictions Unmet load hours shall not exceed 300. If they do, the proposed boiler capacity shall be increased incrementally until the unmet loads are reduced to 300 or less.

Baseline Rules

The boiler is sized to be 25% larger than the peak loads of the baseline building. Baseline boilers shall be sized using weather files containing 99.6% heating design temperatures and 1% dry-bulb and 1% wet-bulb cooling design temperatures.

The unmet load hours of the proposed case shall also not exceed the unmet load hours of the baseline design by more than 50 hours. If they do, then the capacity of the baseline boiler shall be decreased incrementally until this difference is less than 50 hours.

Boiler Efficiency Type

Applicability All boilers

Definition The full load efficiency of a boiler is expressed as one of the following:

- *Annual Fuel Utilization Efficiency* (AFUE) is a measure of the boiler's efficiency over a predefined heating season.
- *Thermal Efficiency* (E_t) is the ratio of the heat transferred to the water divided by the heat input of the fuel.
- *Combustion Efficiency* (E_c) is the measure of how much energy is extracted from the fuel and is the ratio of heat transferred to the combustion air divided by the heat input of the fuel.

Units List (see above)

Input Restrictions

Annual Fuel Utilization Efficiency (AFUE), for all gas and oil-fired boilers with less than 300,000 Btu/h capacity.

Thermal Efficiency (E_t), for all gas and oil-fired boilers with capacities between 300,000 and 2,500,000 Btu/h.

Combustion Efficiency (E_c), for all gas and oil-fired boilers with capacities above 2,500,000 Btu/h.

Baseline Rules Same as proposed design

Boiler Efficiency

Applicability All boilers

Definition

The full load efficiency of a boiler at rated conditions (see efficiency type above) expressed as a dimensionless ratio of output over input. The software must accommodate input in either *Thermal Efficiency* (E_t) or *Annual Fuel Utilization Efficiency* (AFUE). Where AFUE is provided, E_t shall be calculated as follows:

(6.8.1-1)

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All electric boilers will have an efficiency of 100%.

Units	Ratio
Input Restrictions	As designed
Baseline Rules	Boilers for the baseline design are assumed to have the minimum efficiency as listed in Table 6.8.1F from ASHRAE Standard 90.1-2007 or Table 6.2.1F from ASHRAE Standard 90.1-2001.

Boiler Part-Load Performance Curve

Applicability All boilers

Definition

An adjustment factor that represents the percentage full load fuel consumption as a function of the percentage full load capacity. This curve shall take the form of a quadratic equation as follows:

(6.8.1-2)

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where

FHeatPLC	The Fuel Heating Part Load Efficiency Curve
$\mathbf{Fuel}_{partload}$	The fuel consumption at part load conditions (Btu/h)
$\mathbf{Fuel}_{design}$	The fuel consumption at design conditions (Btu/h)
$\mathbf{Q}_{partload}$	The boiler capacity at part load conditions (Btu/h)
$\mathbf{Q}_{rated}$	The boiler capacity at design conditions (Btu/h)
a	Constant, 0.082597
b	Constant, 0.996764
c	Constant, -0.079361

Units	Ratio
Input Restrictions	As designed. If the user does not use the default curve, supporting documentation is required. The software may auto-generate curves for other boiler types from descriptive type information such as boiler type, core, full or partial condensing, combustion air control, minimum unloading or staging, and return water temperature.
Baseline Rules	The baseline building uses the default

Boiler Minimum Unloading Ratio

Applicability All boilers

Definition

The minimum unloading capacity of a boiler expressed as a percentage of the rated capacity. Below this level the boiler must cycle to meet the load.

Table 6.8.1-1: *"Default Minimum Unloading Ratios"*

Boiler Type	Default Unloading Ratio
Electric Steam	1%
Electric Hot Water	1%
Fuel-Fired Steam	25%
Fuel-Fired Hot Water	25%

Units	Percent (%)
Input Restrictions	As designed. If the user does not use the default curve the software must indicate that supporting documentation is required on the output forms.
Baseline Rules	Use defaults.

Hot Water Supply Temperature

Applicability	All boilers
Definition	The temperature of the water produced by the boiler and supplied to the hot water loop
Units	Degrees Fahrenheit (°F)
Input Restrictions	As designed
Baseline Rules	Use 180°F for baseline boiler (G3.1.3.3).

Hot Water Return Temperature

Applicability	All boilers
Definition	The temperature of the water returning to the boiler from the hot water loop
Units	Degrees Fahrenheit (°F)

Input Restrictions As designed

Baseline Rules Use 130°F for baseline boiler design.

Hot Water Supply Temperature Reset

Applicability All boilers

Definition Variation of the hot water supply temperature with outdoor air temperature.

Units Degrees Fahrenheit (°F)

Input Restrictions As designed

Baseline Rules The hot water supply temperature should vary according to the following:

- 180°F when outside air is < 20°F
- ramp linearly between 180°F & 150°F when outdoor air is between 20°F and 50°F
- 150°F when outdoor air is > 50°F

6.8.2 Chillers

Chiller Name

Applicability All chillers

Definition A unique descriptor for each chiller

Units Text, unique

Input Restrictions User entry. Where applicable, this should match the tags that are used on the plans.

Baseline Rules Chillers are only designated when the baseline system is of type 7 (VAV with reheat) or 8 (VAV with PFP Boxes) (see Table G3.1.1B).

Chiller Type

Applicability All chillers

Definition The type of chiller, either a vapor-compression chiller or an absorption chiller.

Vapor compression chillers operate on the reverse-Rankine cycle, using mechanical energy to compress the refrigerant, and include:

- Reciprocating – uses pistons for compression
- Screw – uses two counter rotating screws for compression
- Scroll – uses two interlocking spirals or scrolls to perform the compression
- Centrifugal – uses rotating impeller blades to compress the air
- Absorption chillers – use heat to vaporize a working fluid (usually either ammonia or lithium bromide)
- Single Effect Absorption – use a single generator & condenser
- Double Effect Absorption – use two generators/concentrators and condensers, one at a lower temperature and the other at a higher temperature. It is more efficient than the single effect, but it must use a higher temperature heat source.

Units List (see above)

Input Restrictions As designed

Baseline Rules

The baseline building chiller is based on the design capacity of the proposed design as follows from ASHRAE 90.1 Appendix G:

Table 6.8.2-1: *"Type and Number of Chillers"*

Building Peak Cooling Load	Number and Type of Chillers (s)
*TeX Embedding failed!*300 tons	1 water-cooled screw chiller
>300 tons, <600 tons	2 water-cooled screw chillers sized equally
*TeX Embedding failed!*600 tons	2 water-cooled centrigugal chillers minimum with chillers added so that no chiller is larger than 800 tons, all sized equally

Number of Identical Chiller Units

Applicability All chillers

Definition The number of identical units for staging.

Units None

Input Restrictions As designed. Default is 1.

Baseline Rules From Table 6.8.2-1 [1] above, there is one chiller if the cooling load is 300 tons or less and two equally sized chillers for loads between 300 and 600 tons. For loads above 600 tons, two or more chillers of equal size are used, with no chiller larger than 800 tons.

Chiller Fuel

Applicability All chillers

Definition The fuel source for the chiller. The choices are:

- Electricity (for all vapor-compression chillers)
- Gas (Absorption units only, designated as direct-fired units)
- Oil (Absorption units only, designated as direct-fired units)
- Hot Water (Absorption units only, designated as indirect-fired units)
- Steam (Absorption units only, designated as indirect-fired units)

Units List (see above)

Input Restrictions As designed.

Baseline Rules Electricity

Chiller Rated Capacity

Applicability All chillers

Definition The cooling capacity of a piece of heating equipment at rated conditions.

Units Btu/h or tons

Input Restrictions As designed. If unmet load hours are greater than 300, the chiller may have to be made larger.

Baseline Rules Determine loads for baseline building and oversize by 15%.

Chiller Rated Efficiency

Applicability All chillers

Definition The Coefficient of Performance (COP) at ARI rated conditions.

Units Ratio

Input Restrictions As designed

Baseline Rules With the ASHRAE Standard 90.1-2007 baseline, use the minimum values of efficiency from either Table 6.8.1C for various types of chillers or the values from Tables 6.8.1H, 6.8.1I or 6.8.1J for centrifugal chillers. With the ASHRAE Standard 90.1-2001 baseline, use the minimum values of efficiency from either Table 6.2.1C for various types of chillers, or the values from Tables 6.2.1H, 6. 2.1I or 6. 2.1J for centrifugal chillers.

Chiller Minimum Unloading Ratio

Applicability All chillers

Definition

The minimum unloading capacity of a chiller expressed as a fraction of the rated capacity. Below this level the chiller must cycle to meet the load.

Table 6.8.2-2: *"Default Minimum Unloading Ratios"*

Chiller Type	Default Unloading Ratio
Reciprocating	25%
Screw	15%
Centrifugal	10%
Scroll	25%
Single Effect Absorption	10%
Double Effect Absorption	10%

Units Percent (%)

Input Restrictions As designed. If the user does not employ the default values, supporting documentation is required.

Baseline Rules Use defaults listed above.

Chiller Cooling Capacity Adjustment Curve

Applicability All chillers

Definition

A curve or group of curves or other functions that represent the available total cooling capacity as a function of evaporator and condenser conditions and perhaps other operating conditions. The default curves are given as follows:

(6.8.2-1)

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For air-cooled chillers:

(6.8.2-2)

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For water-cooled chillers:

(6.8.2-3)

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where

$\mathbf{Q}_{available}$	Available cooling capacity at present evaporator and condenser conditions (MBH)
$\mathbf{t}_{chws}$	The chilled water supply temperature (°F)
$\mathbf{t}_{cws}$	The condenser water supply temperature (°F)
$\mathbf{t}_{odb}$	The outside air dry-bulb temperature (°F)
$\mathbf{Q}_{rated}$	Rated capacity at ARI conditions (MBH)

Note: If an air-cooled unit employs an evaporative condenser, t_{odb} is the effective dry-bulb temperature of the air leaving the evaporative cooling unit.

Table 6.8.2-3: *"Default Capacity Coefficients – Electric Air-Cooled Chillers"*

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.40070684	0.57617295	-0.09464899	N/A
b	0.01861548	0.02063133	0.03834070	N/A
c	0.00007199	0.00007769	-0.00009205	N/A
d	0.00177296	-0.00351183	0.00378007	N/A
e	-0.00002014	0.00000312	-0.00001375	N/A
f	-0.00008273	-0.00007865	-0.00015464	N/A

Table 6.8.2-4: *"Default Capacity Coefficients – Electric Water-Cooled Chillers"*

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.36131454	0.58531422	0.33269598	-0.29861976
b	0.01855477	0.01539593	0.00729116	0.02996076
c	0.00003011	0.00007296	-0.00049938	-0.00080125
d	0.00093592	-0.00212462	0.01598983	0.01736268
e	-0.00001518	-0.00000715	-0.00028254	-0.00032606
f	-0.00005481	-0.00004597	0.00052346	0.00063139

Table 6.8.2-5: *"Default Capacity Coefficients – Fuel- & Steam-Source Water-Cooled Chillers"*

Coefficient	Single Stage Absorption	Double Stage Absorption	Direct-Fired Absorption	Engine Driven Chiller
a	0.723412	-0.816039	1.000000	0.573597
b	0.079006	-0.038707	0.000000	0.0186802
c	-0.000897	0.000450	0.000000	0.000000
d	-0.025285	0.071491	0.000000	-0.00465325
e	-0.000048	-0.000636	0.000000	0.000000
f	0.000276	0.000312	0.000000	0.000000

Units Data structure

Input Restrictions User may input curves, other appropriate functions, or use default curves. If the default curves are overridden, supporting documentation is required.

Baseline Rules Use default curves.

Electric Chiller Cooling Efficiency Adjustment Curves

Applicability All chillers

Definition

A curve or group of curves that varies the cooling efficiency of an electric chiller as a function of evaporator conditions, condenser conditions and part-load ratio. The default curves are given as follows:

(6.8.2-4)

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where

PLR	Part load ratio based on available capacity (not rated capacity)
$\mathbf{Q}_{\text{operating}}$	Present load on chiller (Btu/h)
$\mathbf{Q}_{\text{available}}$	Chiller available capacity at present evaporator and condenser conditions (Btu/h)
$\mathbf{t}_{\text{chws}}$	The chilled water supply temperature (°F)
$\mathbf{t}_{\text{cws}}$	The condenser water supply temperature (°F)
$\mathbf{t}_{\text{odb}}$	The outside air dry-bulb temperature (°F)
$\mathbf{P}_{\text{rated}}$	Rated power draw at ARI conditions (kW)
$\mathbf{P}_{\text{operating}}$	Power draw at specified operating conditions (kW)

Note: If an air-cooled chiller employs an evaporative condenser, t_{odb} is the effective dry-bulb temperature of the air leaving the evaporative cooling unit.

Table 6.8.2-6: *"Default Efficiency EIR-FT Coefficients – Air-Cooled Chillers"*

Coefficient	Scroll	Reciprocating	Screw	Centrifugal
a	0.99006553	0.66534403	0.13545636	N/A
b	-0.00584144	-0.01383821	0.02292946	N/A
c	0.00016454	0.00014736	-0.00016107	N/A
d	-0.00661136	0.00712808	-0.00235396	N/A
e	0.00016808	0.00004571	0.00012991	N/A
f	-0.00022501	-0.00010326	-0.00018685	N/A

Table 6.8.2-7: *"Default Efficiency EIR-FT Coefficients – Water-Cooled Chiller"*

Coefficient	Scroll	Reciprocating	Screw	Centrifugal
a	1.00121431	0.46140041	0.66625403	0.51777196
b	-0.01026981	-0.00882156	0.00068584	-0.00400363
c	0.00016703	0.00008223	0.00028498	0.00002028
d	-0.00128136	0.00926607	-0.00341677	0.00698793
e	0.00014613	0.00005722	0.00025484	0.00008290
f	-0.00021959	-0.00011594	-0.00048195	-0.00015467

Table 6.8.2-8: *"Default Efficiency EIR-FPLR Coefficients – Air-Cooled Chillers"*

Coefficient	Scroll	Reciprocating	Screw	Centrifugal
a	0.06369119	0.11443742	0.03648722	N/A
b	0.58488832	0.54593340	0.73474298	N/A
c	0.35280274	0.34229861	0.21994748	N/A

Table 6.8.2-9: *"Default Efficiency EIR-FPLR Coefficients – Water-Cooled Chillers"*

Coefficient	Scroll	Reciprocating	Screw	Centrifugal
a	0.04411957	0.08144133	0.33018833	0.17149273
b	0.64036703	0.41927141	0.23554291	0.58820208
c	0.31955532	0.49939604	0.46070828	0.23737257

Units Data structure

Input Restrictions User may input curves or use default curves. If defaults are overridden, supporting documentation is required.

Baseline Rules Use default curves.

Fuel and Steam Chiller Cooling Efficiency Adjustment Curves

Applicability All chillers

Definition

A curve or group of curves that varies the cooling efficiency of a fuel-fired or steam chiller as a function of evaporator conditions, condenser conditions, and part-load ratio. The default curves are given as follows:
Default Curves for Steam-Driven Single and Double Effect Absorption Chillers

(6.8.2-5)

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Default Curves for Direct-Fired Double Effect Absorption Chillers

(6.8.2-6)

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The default curves for engine driven chillers are the same format as those for the Steam-Driven Single and Double Effect Absorption Chillers but there are three sets of curves for different ranges of operation based on the engine speed.

where

PLR	Part load ratio based on available capacity (not rated capacity)
FIR-FPLR	A multiplier on the fuel input ratio (FIR) to account for part load conditions
FIR-FT	A multiplier on the fuel input ratio (FIR) to account for the chiller water supply temperature and the condenser water temperature
FIR-FT1	A multiplier on the fuel input ratio (FIR) to account for chilled water supply temperature
FIR-FT2	A multiplier on the fuel input ratio (FIR) to account for condenser water supply temperature
CAP-FT	A multiplier on the capacity of the chiller (see Equation (6.8.2-2))
$\mathbf{Q}_{operating}$	Present load on chiller (in Btu/h)
$\mathbf{Q}_{available}$	Chiller available capacity at present evaporator and condenser conditions (in Btu/h)
$\mathbf{t}_{chws}$	The chilled water supply temperature (in °F)
$\mathbf{t}_{cws}$	The condenser water supply temperature (in °F)
$\mathbf{t}_{odb}$	The outside air dry-bulb temperature (°F)
$Fuel_{rated}$	Rated fuel consumption at ARI conditions (in Btu/h)
$Fuel_{partload}$	Fuel consumption at specified operating conditions (in Btu/h)

Table 6.8.2-10: *"Default FIR-FPLR coefficients – Fuel- & Steam-Source Water-Cooled Absorption Chillers"*

Coefficient	Single Stage Absorption	Double Stage Absorption	Direct-Fired Absorption
a	0.098585	0.013994	0.13551150
b	0.583850	1.240449	0.61798084
c	0.560658	-0.914883	0.24651277
d	-0.243093	0.660441	0.00000000

Table 6.8.2-11: *"Default FIR-FPLR coefficients – Engine Driven Chillers"*

Coefficient	%Speed*TeX Embedding failed!*Min.	%Speed>Min. %Speed<60%	%Speed>60%
a	0.3802	1.14336	1.38861
b	2.3609	0.022889	-0.388614
c	0.0000	0.0000	0.0000
d	0.0000	0.0000	0.000

Table 6.8.2-12: *"Default FIR-FT coefficients – Fuel- & Steam-Source Water-Cooled Absorption Chillers"*

Coefficient	Single Stage Absorption	Double Stage Absorption	Direct-Fired Absorption
a	0.652273	1.658750	4.42871284
b	0.000000	0.000000	-0.13298607
c	0.000000	0.000000	0.00125331
d	-0.000545	-0.290000	0.86173749
e	0.000055	0.000250	-0.00708917
f	0.000000	0.000000	0.0010251

Table 6.8.2-13: *"Default FIR-FT coefficients – Engine Driven Chillers"*

Coefficient	%Speed*TeX Embedding failed!*Min.	%Speed>Min. %Speed<60%	%Speed>60%
a	1.0881500	1.2362400	1.2362400
b	0.0141064	0.0168923	0.0168923
c	0.0000000	0.0000000	0.0000000
d	-0.00833912	-0.0115235	-0.0115235
e	0.0000000	0.0000000	0.0000000
f	0.0000000	0.0000000	0.0000000

Units Data structure

Input Restrictions User may input curves or use default curves. If defaults are overridden, supporting documentation is required.

Baseline Rules Use default curves.

Chilled Water Supply Temperature

Applicability All chillers

Definition The chilled water supply temperature of the chiller at design conditions

Units Degrees Fahrenheit (°F)

Input Restrictions As designed

Baseline Rules The baseline chilled water supply temperature is set to 44°F.

Chilled Water Return Temperature

Applicability All chillers

Definition The chilled water return temperature setpoint

Units Degrees Fahrenheit (°F)

Input Restrictions As designed

Baseline Rules The baseline chilled water return temperature is set to 56°F.

Chilled Water Supply Temperature Reset

Applicability All chillers

Definition The reset schedule for the chilled water supply temperature. The chilled water setpoint may be reset based on demand or outdoor air temperature.

Units Degrees Fahrenheit (°F)

Input Restrictions As designed. The default is Figure 6.8.2-1 [2].

Baseline Rules The baseline chilled water supply temperature is reset from 44°F to 54°F based on outdoor air temperature as shown in the figure below.

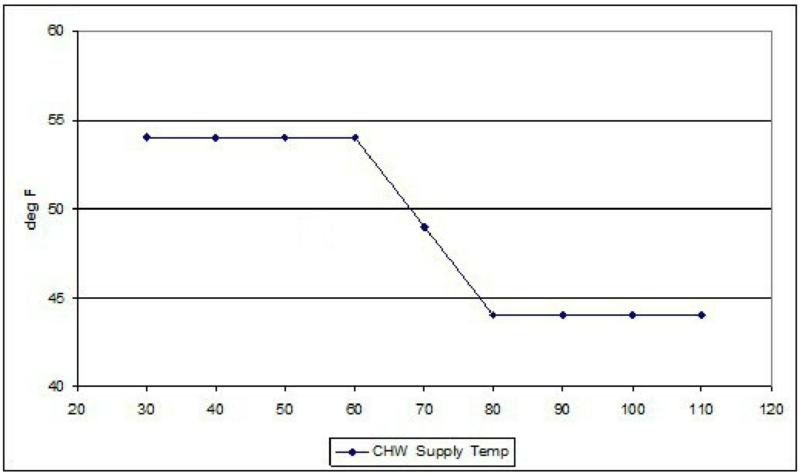

Figure 6.8.2-1: *"Chilled Water Supply Temperature Reset Schedule"*

Condenser Type

Applicability All chillers

Definition The type of condenser for a chiller. The choices are:

- Air-Cooled
- Water-Cooled
- Evaporatively-Cooled

Air-cooled chillers use air to cool the condenser coils. Water-cooled chillers use cold water to cool the condenser and additionally need either a cooling tower or a local source of cold water. Evaporatively-cooled chillers are similar to air-cooled chillers, except they use a water mist to cool the condenser coil which makes them more efficient.

Units List (see above)

Input Restrictions	As designed
Baseline Rules	The baseline chiller is always assumed to have a water-cooled condenser, although the chiller type will change depending on the design capacity. If the chiller size is less than 600 tons, the baseline chiller is a water-cooled screw; if the capacity is greater than or equal to 600 tons, the baseline chiller is a water-cooled centrifugal chiller.

Air-Cooled Condenser Power

Applicability	All chillers
Definition	The energy usage of the condenser fan(s) at design conditions on an air-cooled chiller. This unit should only be used for chillers composed of separate evaporator and condenser sections where the fan energy is not part of the chiller COP.
Units	Kilowatts (kW)
Input Restrictions	As designed. The user must enter data for remote air-cooled condensing units.
Baseline Rules	Not applicable, since all baseline chillers have water-cooled condensers.

6.8.3 Cooling Towers

Baseline Building Summary. Baseline building systems 7 and 8 have one or more cooling towers. One tower is assumed to be matched to each baseline building chiller. The number of baseline building chillers is determined in 6.8.2. Each baseline building chiller has its own condenser water pump that operates when the chiller is brought into service. The range between the condenser water return (CWR) and condenser water supply (CWS) is 10 F so the condenser water flow is a constant 2.5 gpm per cooling ton[1] when the chiller is in service. The baseline building pumping energy is assumed to be 19 W/gpm. The baseline building cooling tower is assumed to have a two-speed fan that is controlled to provide a CWS of 70 F when weather permits. The tower fan cycles to one-speed or off to maintain a CWS of 70 F at low wetbulb conditions. Under cooling conditions closer to design conditions, the CWS floats up to a maximum of 85 F (the design condition).

Cooling Tower Name

Applicability	All cooling towers
Definition	A unique descriptor for each cooling tower
Units	Text, unique
Input Restrictions	User entry. Where applicable, this should match the tags that are used on the plans.
Baseline Rules	Descriptive name that keys the baseline building plant

Cooling Tower Type

Applicability	All cooling towers
Definition	The type of cooling tower employed. The choices are: • Open tower, centrifugal fan • Open tower, axial fan • Closed tower, centrifugal fan • Closed tower, axial fan Open cooling towers collect the cooled water from the tower and pump it directly back to the cooling system. Closed towers circulate the evaporated water over a heat exchanger to indirectly cool the system fluid.
Units	List (see above)
Input Restrictions	As designed
Baseline Rules	The baseline cooling tower is an open tower axial fan device with a two-speed fan (See PRM G3.1.3.11)

Cooling Tower Capacity

Applicability	All cooling towers
Definition	The tower thermal capacity per cell adjusted to CTI (Cooling Technology Institute) rated conditions of 95 F condenser water return, 85 F condenser water supply, and 78 F wetbulb with a 3 gpm/nominal ton water flow. The default cooling tower curves below are at unity at these conditions.
Units	Btu/h
Input Restrictions	As designed
Baseline Rules	The baseline building chiller is autosized and increased by 15%. The tower is sized to deliver 85 F condenser water supply at design conditions for the oversized chiller.

Cooling Tower Number of Cells

Applicability	All cooling towers
Definition	The number of cells in the cooling tower. Each cell will be modeled as equal size. Cells are subdivisions in cooling towers into individual cells, each with their own fan and water flow, and allow the cooling system to respond more efficiently to lower load conditions.
Units	Numeric: integer
Input Restrictions	As designed
Baseline Rules	One cell per tower and one tower per chiller.

Cooling Tower Total Fan Horse Power

Applicability	All cooling towers

Definition	The sum of the nameplate rated horsepower (hp) of all fan motors on the cooling tower. Pony motors should not be included.
Units	Horsepower (hp)
Input Restrictions	As designed. For minimum compliance with ASHRAE Standard 90.1-2007, must be at least 38.2 gpm/hp for an axial fan cooling tower and at least 20.0 gpm/hp for a centrifugal fan cooling tower. (Table 6.8.1G)
Baseline Rules	Not applicable since pump power is specified as 19 watts/gpm.

Cooling Tower Design Wet-Bulb

Applicability	All cooling towers
Definition	The design wet-bulb temperature that was used for selection and sizing of the cooling tower.
Units	Degrees Fahrenheit (°F)
Input Restrictions	As designed.
Baseline Rules	Same as proposed design

Cooling Tower Design Entering Water Temperature

Applicability	All cooling towers
Definition	The design condenser water supply temperature (leaving tower) that was used for selection and sizing of the cooling tower.
Units	Degrees Fahrenheit (°F)
Input Restrictions	As designed. Default to 85°F.
Baseline Rules	85°F or 10°F above the design wet-bulb temperature, whichever is lower (Table 6.8.1G)

Cooling Tower Design Return Water Temperature

Applicability	All cooling towers
Definition	The design condenser water return temperature (entering tower) that was used for selection and sizing of the cooling tower.
Units	Degrees Fahrenheit (°F)
Input Restrictions	As designed. Default to 95°F.
Baseline Rules	Set to 95°F for a range of 10 F. (Table 6.8.1G)

Cooling Tower Capacity Adjustment Curve(s)

Applicability All cooling towers

Definition

A curve or group of curves that represent the available total cooling capacity as a function of outdoor air wet-bulb, condenser water supply and condenser water return temperatures. The default curves are given as follows:

(6.8.3-1)

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where

$\mathbf{Q}_{available}$	Available cooling capacity at present outside air and condenser water conditions (MBH)
$\mathbf{Q}_{rated}$	Rated cooling capacity at CTI test conditions (MBH)
$\mathbf{t}_{cws}$	The condenser water supply temperature (in °F)
$\mathbf{t}_{cwr}$	The condenser water return temperature (in °F)
$\mathbf{t}_{owb}$	The outside air wet-bulb temperature (°F)
$\mathbf{t}_{R}$	The tower range (in °F)
$\mathbf{t}_{A}$	The tower approach (in °F)
FRA	An intermediate capacity curve based on range and approach
FWB	The ratio of available capacity to rated capacity (gpm/gpm).

Table 6.8.3-1: *"Default Capacity Coefficients – Cooling Towers"*

Coefficient	FRA	FWB
a	-2.22888899	0.60531402
b	0.16679543	-0.03554536
c	-0.01410247	0.00804083
d	0.03222333	-0.02860259
e	0.18560214	0.00024972
f	0.24251871	0.00490857

Units Data structure

Input Restrictions User may input curves or use default curves. If defaults are overridden, the rating software must indicate that supporting documentation is required on the output forms.

Baseline Rules Use default curves.

Cooling Tower Set Point Control

Applicability All cooling towers

Definition The type of control for the condenser water supply. The choices are:

- Fixed
- Wet-bulb reset

A fixed control will modulate the tower to provide the design supply water temperature at all times. A wet-bulb reset control will reset according to the following control scheme:

(6.8.3-2)

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where

t_{cws}	The condenser water supply setpoint (in °F)
t_{owb}	The outside air wet-bulb temperature (°F)
t_{dwb}	The design outside air wet-bulb temperature (°F).
t_A	The tower design approach (in °F).
RR	The reset ratio (default is 0.29)

A reset ratio (RR) of 0 will force the tower to always attempt a fixed approach to the outdoor wet-bulb temperature. A reset ratio (RR) of 1 will cause the system to perform as if it had fixed condenser water controls.

Units List (see above)

Input Restrictions As designed. If the user does not use the default curve, supporting documentation is required.

Baseline Rules Fixed at 70°F

Cooling Tower Capacity Control

Applicability All cooling towers

Definition Describes the modulation control employed in the cooling tower. Choices include:

- **Fluid Bypass** provides a parallel path to divert some of the condenser water around the cooling tower at part-load conditions
- **Fan Cycling** is a simple method of capacity control where the tower fan is cycled on and off. This is and is often used on multiple-cell installations.
- **Two-Speed Fan/Pony Motor.** From an energy perspective, these are the same. A lower horsepower pony motor is an alternative to a two-speed motor; the pony motor runs at part-load conditions (instead of the full sized motor) and saves fan energy when the tower load is reduced. Additional buildling descriptors are triggered when this method of capacity control is selected.
- **Variable Speed Fan.** A variable frequency drive is installed for the tower fan so that the speed can be modulated.

Units List (see above)

Input Restrictions As designed.

Baseline Rules Two-speed fan

Cooling Tower Low-Speed Airflow Ratio

Applicability All cooling towers with two-speed or pony motors

Definition The percentage full load airflow that the tower has at low speed or with the pony motor operating. This is equivalent to the percentage full load capacity when operating at low speed.

Units Ratio

Input Restrictions As designed.

Baseline Rules 0.50

Cooling Tower Low-Speed kW Ratio

Applicability All cooling towers

Definition The percentage full load power that the tower fans draw at low speed or with the pony motor operating

Units Ratio

Input Restrictions As designed.

Baseline Rules 0.30

Cooling Tower Power Adjustment Curve

Applicability All cooling towers with VSD control

Definition A curve that varies the cooling tower fan energy usage as a function of part-load ratio for cooling towers with variable speed fan control. The default curve is given as follows:

(6.8.3-3)

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where

PLR	Part load ratio based on available capacity (not rated capacity)
$\mathbf{Q}_{operating}$	Present load on tower (in Btu/h)
$\mathbf{Q}_{available}$	Tower available capacity at present range, approach, and outside wet-bulb conditions (in Btu/h).
$\mathbf{t}_{\mathrm{owb}}$	The outside air wet-bulb temperature (°F)
$\mathbf{t}_{\mathrm{R}}$	The tower range (°F)
$\mathbf{t}_{\mathrm{A}}$	The tower approach (°F)
$\mathbf{P}_{\mathrm{rated}}$	Rated power draw at CTI conditions (kW)
$\mathbf{P}_{\mathrm{operating}}$	Power draw at specified operating conditions (kW)

Table 6.8.3-2: *"Default Efficiency TWR-FAN-FPLR Coefficients – VSD on Cooling Tower Fan"*

Coefficient	TWR-FAN-FPLR
a	0.33162901
b	-0.88567609
c	0.60556507

Units Data structure

Input Restrictions User may input curves or use default curves. If defaults are overridden, supporting documentation is required.

Baseline Rules Use default curves from DOE 2, given above.

Cooling Tower Minimum Speed

Applicability All cooling towers with a VSD control

Definition The minimum fan speed setting of a VSD controlling a cooling tower fan expressed as a ratio of full load speed.

Units Ratio

Input Restrictions As designed. The default is 0.40.

Baseline Rules Not applicable

1. Cooling capacity is related to flow and delta-T through the equation Q = 500 * GPM * Delta-T. When Q is one ton (12,000 Btu/h), GPM = 24 / Delta-T and Delta-T = 24 / GPM

6.8.4 Water-side Economizers

Baseline Building Summary. None of the baseline building systems use a water-side economizer.

Water-Side Economizer Name

Applicability All water-side economizers

Definition The name of a water-side economizer for a cooling system

Units Text, unique

Input Restrictions Descriptive reference to the construction documents. The default is no water-side economizer.

Baseline Rules No water economizer

Water Economizer Type

Applicability All water-side economizers

Definition The type of water-side economizer. Choices include:

- None
- Heat exchanger in parallel with chillers. This would be used with an open cooling tower is often referred to as a non-integrated economizer, because the chillers are locked out when the plant is in economizer mode.
- Heat exchanger in series with chillers. This would be used with an open cooling tower and is often referred to as an integrated, because the chillers can operate simultaneously with water economizer operation.
- Direct water economizer. This would be used with a closed cooling tower. In this case, a heat exchanger is not needed. This type works only as a non-integrated economizer.

needed. This type works only as a non-integrated economizer.

- Thermo-cycle (also known as refrigerant migration). With thermo-cycle, bypass valves allow for the flow to vapor refrigerant to the condenser and allow gravity flow of liquid refrigerant to the evaporator without use of the compressor. Only some chillers have this capability and capacity may be limited under this mode. There is no additional piping; the cooler water from the tower is brought directly to the chiller(s) and the chiller(s) respond by shutting down the compressor and relying on thermal forces to drive the refrigerant. This method is also known as "thermosiphon" since thermal gradients passively move refrigerant between the evaporator and condenser.

Units	List (see above)
Input Restrictions	As designed
Baseline Rules	No water economizer

Water-Side Economizer HX Effectiveness

Applicability	Water-side economizers with an open cooling tower
Definition	The effectiveness of a water-side heat exchanger at design conditions. This is defined as:

(6.8.4-1)

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where

WSE_{eff}	The effectiveness of the water-side economizer coil
t_{ea}	The entering coil air dry-bulb temperature (°F)
t_{la}	The leaving coil air dry-bulb temperature (°F)
t_{ea}	The entering coil water temperature (°F)

Units	Ratio
Input Restrictions	As designed. The default is 60 %.
Baseline Rules	No water economizer

Water-Side Economizer Maximum T_{db}

Applicability	All water-side economizers
Definition	The control temperature (outside air dry-bulb temperature) above which the water-side economizer is disabled.
Units	Degrees Fahrenheit (°F)
Input Restrictions	As designed. Defaults to 65°F.
Baseline Rules	No water economizer

Water-Side Economizer Maximum CWS

Applicability	All water-side economizers
Definition	The control temperature (condenser water supply temperature) above which the water-side economizer is disabled.
Units	Degrees Fahrenheit (°F)
Input Restrictions	As designed. Defaults to 50°F.
Baseline Rules	No water economizer

Water-Side Economizer CWS Setpoint

Applicability	All water-side economizers
Definition	The design condenser water supply temperature for the cooling tower in economizer mode.
Units	Degrees Fahrenheit (°F)
Input Restrictions	As designed. Defaults to 45°F or 40°F for "Thermo Cycle."
Baseline Rules	No water economizer

Water-Side Economizer Availability Schedule

Applicability	All water-side economizers
Definition	A schedule which represents the availability of the water-side economizer
Units	Data structure: schedule, on/off
Input Restrictions	As designed
Baseline Rules	No water economizer

Water-Side Economizer Auxiliary kW

Applicability	Water-side economizers with an open tower
Definition	The electrical input (pumps and auxiliaries) for a dedicated pump for the chilled water side of the heat exchanger. This power is in excess of the condenser water pumps and cooling tower fans for the system during water-side economizer operation.
Units	KW or kW/ton
Input Restrictions	As designed
Baseline Rules	No water economizer

6.8.5 Pumps

Baseline Building Summary. Hot water pumping in the baseline building (systems 1, 5, and 7) shall be modeled as a variable flow primary only system. When the spaces served by the hot water system are greater than or equal to 120,000 ft², the pump shall have a variable speed drive, otherwise, the pump "rides the curve". Pumping energy shall be assumed to be 19 W/gpm. Two-way valves are assumed at the heating coils with a modulating bypass valve at the end of the loop. The bypass valve shall open as necessary to maintain minimum flow through the boiler when the system is activated. This will establish the minimum flow through the system.

Chilled water pumping in the baseline building (systems 7 and 8) is a primary/secondary system. Each chiller has its own primary and condenser water pumps that operate when the chiller is activated. All primary and secondary pumps shall be assumed to be 22 W/gpm and the condenser water pump is assumed to be 19 W/gpm. For plants less than or equal to 300 tons, the secondary pump "rides the curve" for larger plants, the pump has a variable speed drive.

General Notes. The building descriptors in this section are repeated for each pumping system. See the Pump Service building descriptor for a list of common pump services.

Pump Name

Applicability	All pumps
Definition	A unique descriptor for each pump
Units	Text, unique
Input Restrictions	User entry. Where applicable, this should match the tags that are used on the plans.
Baseline Rules	Same as the proposed design. If there is no equivalent in the proposed design, assign a sequential tag to each piece of equipment. The sequential tags should indicate the pump service as part of the descriptor (e.g. CW for condenser water, CHW for chilled water, or HHW for heating hot water).

Pump Service

Applicability	All pumps
Definition	The service for each pump. Choices include: • Chilled water • Chilled water (primary) • Chilled water (secondary) • Heating water • Heating water (primary) • Heating water (secondary) • Service hot water • Condenser water • Loop water (for hydronic heat pumps)
Units	List (see above)
Input Restrictions	As designed
Baseline Rules	As needed by the baseline building system

Number of Pumps

Applicability	All pumps
Definition	The number of identical pumps in service in a particular loop, e.g. the heating hot water loop, chilled water loop, or condenser water loop
Units	Numeric: integer
Input Restrictions	As designed
Baseline Rules	There will be one heating hot water pump for each boiler, one chilled water pump, and one condenser water pump for each chiller.

Water Loop Design

Applicability	All pumps
Definition	The heating and cooling delivery systems can consist of a simple primary loop system, or more complicated primary/secondary loops or primary/secondary/tertiary loops.
Units	List (see above)
Input Restrictions	As designed
Baseline Rules	Assume primary loops only for heating hot water. For chilled water loops, a primary-secondary loop design is assumed.

Pump Motor Modeling Method

Applicability	All pumps
Definition	Software commonly models fans in one of two ways: The simple method is for the user to enter the electric power per unit of flow (W/gpm). This method is commonly used for smaller systems. A more detailed method requires a specification of the pumping head, impeller efficiency, motor efficiency, and other inputs.
Units	List: Power-Per-Unit-Flow or Detailed
Input Restrictions	Either method may be used, as appropriate.
Baseline Rules	Power-Per-Unit-Flow

Baseline Rules Power Per Unit Flow

Pump Motor Power-Per-Unit-Flow

Applicability All baseline building pumps and proposed design pumps that use the Power-Per-Unit-Flow method.

Definition The electric power of the pump divided by the flow at design conditions.

Units W/gpm

Input Restrictions As designed

Baseline Rules Prescribed to be 19 W/gpm for condenser and heating hot water pumps and 22 W/gpm for primary and secondary chilled water pumps.

Impeller Efficiency

Applicability All pumps in proposed design that use the detailed modeling method

Definition The full load efficiency of the impeller

Units Ratio

Input Restrictions As designed

Baseline Rules Not applicable

Motor Efficiency

Applicability All pumps in proposed design that use the detailed modeling method

Definition The full load efficiency of the pump motor

Units Ratio

Input Restrictions As designed

Baseline Rules Not applicable

Pump Design Head

Applicability All pumps in proposed design that use the detailed modeling method

Definition The design pressure for the pump

Units Feet of water (or feet of head)

Input Restrictions As designed

Baseline Rules Not applicable

Pump Minimum Speed

Applicability All two-speed or variable-speed pumps

Definition The minimum pump speed for a two-speed for variable-speed pump. For two-speed pumps this is typically 0.67 or 0.5. Note that the pump minimum speed is not necessarily the same as the minimum flow ratio, since the system head may change.

Units Ratio

Input Restrictions As designed

Baseline Rules The secondary chilled water pumps for baseline building systems 7 and 8 have variable speed drives when the size of the cooling plant is greater than 300 tons. In these cases the Pump Minimum Speed shall be 0.10.

Pump Design Flow (GPM)

Applicability All pumps

Definition The flow rate of the pump at design conditions. This is derived from the load, and the design supply and return temperatures.

Units gpm or gpm/ton for condenser and primary chilled water pumps

Input Restrictions Not a user input

Baseline Rules The temperature change on the evaporator side of the chillers is 12 F (56 F less 44 F) and this equates to a flow of 2 gpm/ton. The temperature change on the condenser side of the chillers is 10 F, which equates to a flow of 2.5 gpm/ton. The flow for secondary chilled water pumps varies with cooling demand, since there are two-way valves at the coils. The flow for primary only heating varies with demand down to the minimum required for flow through the boiler. A VSD is required for heating pumps when the service area is greater than or equal to 120,000 ft².

Pump Control Type

Applicability All pumps

Definition The type of control for the pump. Choices are:

- Fixed speed, fixed flow
- Fixed speed, variable flow (the default, with flow control via a valve)
- Two-speed
- Variable speed, variable flow

Units None

Input Restrictions As designed. The default is “Fixed Speed, Variable Flow” which models the action of a constant speed pump riding the curve against 2-way control valves.

Baseline Rules The hot water and condenser water loops shall be primary loops only. When the hot water system serves less than 120,000 ft², the hot water pump shall be modeled as a fixed speed, variable flow pump (riding the pump curve). When the hot water system serves more than 120,000 ft², the hot water pump shall be modeled as a variable speed pump on a primary loop. The chilled water pumping for systems 7 and 8 is primary/secondary with variable flow. When the chilled water system has a capacity of less than 300 tons, the secondary system pumps shall ride the pump curve. When the chilled water system has a capacity of more than 300 tons, the secondary chilled water pumps shall be variable speed. Chilled water pumps used in the primary loop shall be fixed speed, fixed flow. Condenser water pumps shall be modeled as fixed speed, fixed flow.

Pump Operation

Applicability	All pumps
Definition	The type of pump operation can be either On-Demand, Standby or Scheduled. On-Demand operation means the pumps are only pumping when their associated equipment is cycling, so chiller and condenser pumps are on when the chiller is on and the heating hot water pump operates when its associated boiler is cycling. Standby operation allows hot or chilled water to circulate through the primary loop of a primary/secondary loop system or through a reduced portion of a primary-only system, assuming the system has appropriate 3-way valves. Scheduled operation means that the pumps and their associated equipment are turned completely off according to occupancy schedules, time of year, or outside conditions. Under scheduled operation, when the systems are on they are assumed to be in On-Demand mode.
Units	List (see above)
Input Restrictions	As designed
Baseline Rules	The baseline system pumps are assumed to operate in On-Demand mode. The chilled water and condenser pumps are tied to the chiller operation, cycling on and off with the chiller, and the heating hot water pumps are tied to the boiler operation.

Pump Part Load Curve

Applicability All pumps

Definition

A part-load power curve for the pump

(6.8.5-1)

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(6.8.5-2)

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where

PLR	Part load ratio (the ratio of operating flow rate in gpm to design flow rate in gpm)
$\mathbf{P}_{pump}$	Pump power draw at part-load conditions (W)
$\mathbf{P}_{design}$	Pump power draw at design conditions (W)

Table 6.8.5-1: *"Default Part-Load CIRC-PUMP-FPLR Coefficients – VSD on Circulation Pump"*

Coefficient	CIRC-PUMP-FPLR
a	0.0015303
b	0.0052081
c	1.1086242
d	-0.1163556

Units	Data structure
Input Restrictions	As designed. Default is curve above.
Baseline Rules	Use the defaults described above.

6.8.6 Thermal Storage

There are multiple ways to model thermal storage in the proposed design. The baseline building does not have thermal storage.

6.8.7 Heat Recovery Equipment

Heat Recovery Name

Applicability	All heat recovery systems
Definition	A name assigned to a heat recovery system. This would provide a link to the construction documents.
Units	Text, unique
Input Restrictions	As designed
Baseline Rules	No heat recovery systems

Heat Recovery Device Type

Applicability All heat recovery systems

Definition The type of heat recovery equipment. Choices include:

- Double-Bundled Chiller

- Generator
- Engine-Driven Chiller
- Air Conditioning Unit
- Refrigerated Casework

Units	List (see above)
Input Restrictions	As designed
Baseline Rules	Heat recovery systems are not included in the baseline system.

Heat Recovery Loads

Applicability	All heat recovery systems
Definition	The loads met by the heat recovery system. Choices include: • Service water heating • Space heating • Process heating More than one load may be selected.
Units	List (see above)
Input Restrictions	As designed
Baseline Rules	Not required in the baseline system.

6.8.8 Plant Management

Plant management is a method of sequencing equipment. Separate plant management schemes may be entered for chilled water systems, hot water systems, etc.

Equipment Type Managed

Applicability	All plant systems
Definition	The type of equipment under a plant management control scheme. Choices include: • Chilled water cooling • Hot water space heating • Condenser water heat rejection • Service water heating • Electrical generation
Units	None
Input Restrictions	As designed
Baseline Rules	Same as the proposed design

Equipment Schedule

Applicability	All plant equipment
Definition	A schedule which identifies when the equipment is in service.
Units	Data structure
Input Restrictions	As designed
Baseline Rules	Where multiple equipment is used, they shall be staged in operation.

Equipment Operation

Applicability	All plant equipment
Definition	Equipment operation can be either On-Demand or Always-On. On-Demand operation means the equipment cycles on when it is scheduled to be in service and when it is needed to meet building loads, otherwise it is off. Always-On means that equipment runs continuously when it scheduled to be in service.
Units	None
Input Restrictions	As designed; the default is On-Demand.
Baseline Rules	Assume On-Demand operation

Source URL: http://www.comnet.org/mgp/content/68-hvac-primary-systems

Links:
[1] http://www.comnet.org/mgp/content/chillers#type-and-number-of-chillers
[2] http://www.comnet.org/mgp/content/chillers#chilled-water-supply-temperature-reset-schedule