Table of Contents

EnergyPlus Testing with HVAC Equipment Component Tests

EnergyPlus Version 8.3.0-b45b06b780
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1 Test Objectives and Overview

1.1 Test Type: Comparative - HVAC

The EnergyPlus HVAC Component Test checks the accuracy of EnergyPlus 8.3.0-b45b06b780 component simulation results compared to manufacturer catalog data, when available. The test procedure makes use of ANSI/ASHRAE Standard 140 procedures for generating hourly equipment loads and ASHRAE Standard 140 weather files. The test suites described within this report are for testing of the EnergyPlus electric chiller referred to within EnergyPlus by the object name Chiller:Electric:EIR and the EnergyPlus hot water boiler referred to within EnergyPlus by the object name Boiler:HotWater.

1.2 Test Suite: EnergyPlus HVAC Component Test Description

The EnergyPlus HVAC Component Test makes use of the basic test building geometry and envelope described as Case CE100 in Section 5.3.1 of ANSI/ASHRAE Standard 140-2011, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer* Programs.

1.2.1 Base Case Building Description

The basic test building (Figure 1) is a rectangular 48 m^2 single zone (8 m wide x 6 m long x 2.7 m high) with no interior partitions and no windows. The building is intended as a near-adiabatic cell with cooling or heating load driven by user specified internal gains. Material properties are described below. For further details on building geometry and building envelope thermal properties refer to Section 5.3.1 of ANSI/ASHRAE Standard 140.

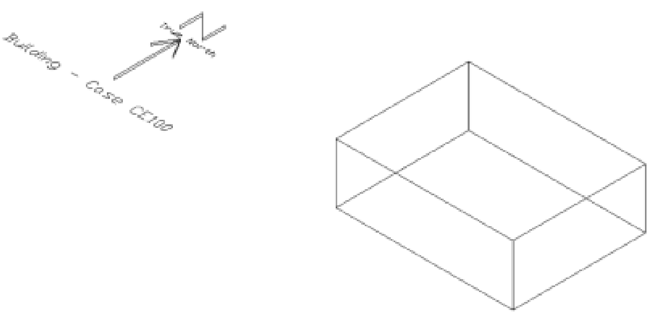


Figure 1 Base Building Geometry - Isometric View of Southeast Corner

Wall, Roof and Floor Construction:

Element	k ($\frac{W}{mK}$)	Thickness (m)	U ($\frac{W}{m^2K}$)	R ($\frac{m^2K}{W}$)
Int. Surface Coeff.			8.290	0.121
Insulation	0.010	1.000	0.010	100.000
Ext. Surface Coeff.			29.300	0.034
Overall, air-to-air			0.010	100.155

Opaque Surface Radiative Properties:

	Interior Surface	Exterior Surface
Solar Absorptance	0.6	0.1
Infrared Emittance	0.9	0.9

Infiltration: None

Depending upon whether type of cooling equipment or heating equipment that is being tested, the internal loads, HVAC systems and plant equipment for the base building will change appropriately as described below.

1.2.2 Adiabatic Surfaces

An opaque exterior surface can be made adiabatic in EnergyPlus by specifying the outside face environment of the exterior surface to be an “OtherZoneSurface” and then setting the object of the outside face environment to be the exterior surface itself. In other words, the surface is forced to see itself. As an example, the input stream for specifying the east facing exterior wall as an adiabatic surface is as follows:

```
BuildingSurface:Detailed,
 ZONE SURFACE EAST, !- Name
 WALL, !- Surface Type
 LTWALL, !- Construction Name
 ZONE ONE, !- Zone Name
 Surface, !- Outside Boundary Condition
 ZONE SURFACE EAST, !- Outside Boundary Condition Object
 NoSun, !- Sun Exposure
 NoWind, !- Wind Exposure
 0.0, !- View Factor to Ground
 4, !- Number of Vertices
 8.00, 0.00, 2.70, !- X,Y,Z ==> Vertex 1 {m}
 8.00, 0.00, 0.00, !- X,Y,Z ==> Vertex 2 {m}
 8.00, 6.00, 0.00, !- X,Y,Z ==> Vertex 3 {m}
 8.00, 6.00, 2.70; !- X,Y,Z ==> Vertex 4 {m}
```

This approach was used on all 6 exterior surfaces of the of the Base Case building to make the building exterior adiabatic and ensure that the resulting cooling or heating load in the space was always exactly equal to the total of the internal space gains.

1.3 EIR Chiller Test

1.3.1 Internal Loads

In order to create a cooling load for the cooling equipment, a sensible internal gain ranging from 8,400 W to 13,000 W is imposed on the building interior space according to a fixed schedule which holds the internal load constant throughout any one day but varies by day of the simulation. The sensible gains are assumed to be 100% convective. Latent internal loads are always 0.0 W. Table 1 further describes the internal load schedule by day of the simulation. Zone sensible internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat that are not related to the operation of the mechanical cooling system or its air distribution fan. The reason for the range of internal sensible loads is to ensure that there will be at least one day during the simulation period when a chiller part load ratio of 1.0 (PLR=1.0) will occur for the combinations of leaving chiller water temperatures and entering condenser water temperatures that are to be tested. The chiller cooling capacity is set to 10,000 W.

Another series of tests are required to determine the chiller's performance over a range of part loads varying from 5% to 100% in 5% increments. To perform these part load tests the internal load schedule described in Table 2 is used.

1.3.2 Air Distribution System

A simple and ideal air distribution system is used with the following characteristics to provide whatever cooling the space needs in order to maintain the setpoint temperature:

- 100% convective air system
- 100% efficient with no duct losses and no capacity limitation, no latent heat extraction
- Zone air is perfectly mixed
- No outside air; no exhaust air
- Indoor circulating fan uses no power (W = 0.0) and adds no heat to the air stream
- Non-proportional-type thermostat, heat always off, cooling on if zone air temperature >22.2°C (72°F)

Table 1 Schedule of Internal Loads for Full Load Tests

Day	Hours	Sensible Watts	Latent Watts
1-Jan	1 - 24	8,000	0
2-Jan	1 - 24	8,100	0
3-Jan	1 - 24	8,200	0
4-Jan	1 - 24	8,300	0
5-Jan	1 - 24	8,400	0
6-Jan	1 - 24	8,500	0
7-Jan	1 - 24	8,600	0
8-Jan	1 - 24	8,700	0
9-Jan	1 - 24	8,800	0
10-Jan	1 - 24	8,900	0
11-Jan	1 - 24	9,000	0
12-Jan	1 - 24	9,100	0
13-Jan	1 - 24	9,200	0
14-Jan	1 - 24	9,300	0
15-Jan	1 - 24	9,400	0
16-Jan	1 - 24	9,500	0
17-Jan	1 - 24	9,600	0
18-Jan	1 - 24	9,700	0
19-Jan	1 - 24	9,800	0
20-Jan	1 - 24	9,900	0
21-Jan	1 - 24	10,000	0
22-Jan	1 - 24	10,100	0
23-Jan	1 - 24	10,200	0
24-Jan	1 - 24	10,300	0
25-Jan	1 - 24	10,400	0
26-Jan	1 - 24	10,500	0
27-Jan	1 - 24	10,600	0
28-Jan	1 - 24	10,700	0
29-Jan	1 - 24	10,800	0
30-Jan	1 - 24	10,900	0
31-Jan	1 - 24	11,000	0
1-Feb	1 - 24	11,100	0
2-Feb	1 - 24	11,200	0
3-Feb	1 - 24	11,300	0
4-Feb	1 - 24	11,400	0
5-Feb	1 - 24	11,500	0
6-Feb	1 - 24	11,600	0
7-Feb	1 - 24	11,700	0
8-Feb	1 - 24	11,800	0
9-Feb	1 - 24	11,900	0
10-Feb	1 - 24	12,000	0
11-Feb	1 - 24	12,100	0
12-Feb	1 - 24	12,200	0
13-Feb	1 - 24	12,300	0
14-Feb	1 - 24	12,400	0
15-Feb	1 - 24	12,500	0
16-Feb	1 - 24	12,600	0
17-Feb	1 - 24	12,700	0
18-Feb	1 - 24	12,800	0
19-Feb	1 - 24	12,900	0
20-Feb	1 - 24	13,000	0

Table 2 Schedule of Internal Loads for Part Load Tests

Day	Hours	Sensible Watts	Latent Watts
1-Jan	1 - 24	500	0
2-Jan	1 - 24	1,000	0
3-Jan	1 - 24	1,500	0
4-Jan	1 - 24	2,000	0
5-Jan	1 - 24	2,500	0
6-Jan	1 - 24	3,000	0
7-Jan	1 - 24	3,500	0
8-Jan	1 - 24	4,000	0
9-Jan	1 - 24	4,500	0
10-Jan	1 - 24	5,000	0
11-Jan	1 - 24	5,500	0
12-Jan	1 - 24	6,000	0
13-Jan	1 - 24	6,500	0
14-Jan	1 - 24	7,000	0
15-Jan	1 - 24	7,500	0
16-Jan	1 - 24	8,000	0
17-Jan	1 - 24	8,500	0
18-Jan	1 - 24	9,000	0
19-Jan	1 - 24	9,500	0
20-Jan	1 - 24	10,000	0

1.3.3 Central Cooling Plant

To perform the component test, cooling is provided by a water cooled electric water chiller whose full load performance is described by a York Model YCWZ33AB0 water cooled reciprocating chiller as indicated below in Table 3 where data are in English units. Although the performance data shown in Table 3 is for a chiller of specific rated cooling capacity (56.5 tons), it is assumed that a set of capacity and electric consumption performance curves normalized to the standard rated conditions of 44°F (6.67°C) leaving chilled water temperature and 95°F (29.44°C) entering condenser water temperature can be developed and used to simulate the full load and part load conditions of a similar chiller of this type and any cooling capacity rating.

Table 3 Performance Data for Model Water Cooled Electric Reciprocating Chiller (York)

MODEL YCWZ33AB0

IPLV = 17.3

LCWT °F	LEAVING CONDENSER WATER TEMPERATURE (°F)																			
	85.0				90.0				95.0				100.0				105.0			
	TONS	KW	MBH	EER	TONS	KW	MBH	EER	TONS	KW	MBH	EER	TONS	KW	MBH	EER	TONS	KW	MBH	EER
40.0	55.3	45.7	820	14.5	53.8	47.8	809	13.5	52.3	49.8	797	12.6	50.7	51.8	785	11.7	49.1	53.8	773	11.0
42.0	57.5	46.0	846	15.0	55.9	48.2	835	13.9	54.4	50.3	824	13.0	52.8	52.4	812	12.1	51.2	54.4	799	11.3
44.0	59.7	46.3	874	15.5	58.1	48.5	863	14.4	56.5	50.7	851	13.4	54.9	52.9	839	12.5	53.2	55.0	826	11.6
45.0	60.8	46.4	888	15.7	59.2	48.7	876	14.6	57.6	50.9	865	13.6	56.0	53.1	852	12.6	54.3	55.3	840	11.8
46.0	61.9	46.5	902	16.0	60.3	48.8	890	14.8	58.7	51.1	878	13.8	57.0	53.4	866	12.8	55.3	55.6	853	12.0
48.0	64.2	46.8	930	16.5	62.6	49.1	918	15.3	60.9	51.5	907	14.2	59.2	53.8	894	13.2	57.5	56.1	881	12.3
50.0	66.6	47.0	959	17.0	64.9	49.4	947	15.8	63.2	51.8	935	14.6	61.5	54.3	923	13.6	59.7	56.6	910	12.7

> TONS = total cooling capacity, 12,000 Btu/Hr
> KW = electric input, kilowatts
> MBH = condenser heat rejection rate, 1000 Btu/Hr
> EER = energy efficiency ratio, Btu/W

Water chiller performance data shown in Table 3 is for a 10°F range on both the chilled water and condenser water temperatures. Other simulation assumptions included:

- Ideal chilled water and condenser water pumps are assumed to consume no electricity and add no heat to the chilled water or condenser water loops.
- Chilled water and condenser water loop piping are assumed to be perfectly insulated such that the entire amount of cooling provided by the chiller during each time increment goes completely to cool the space.
- Chilled water and condenser water flows are assumed to be constant.

1.3.4 Weather Data

A three-month long (January – March) TMY format weather file developed previously as part of ANSI/ASHRAE Standard 140-2011 with the file name of CE200A.TM2 was used for the simulations required as part of this component test series. The outdoor dry-bulb temperature of 35.0°C is constant for every hour of the three-month long period.

1.3.5 Summary of Test Cases

A set of 54 test cases are used to test the water chiller's full load performance over a range of combinations of leaving chilled water temperatures and entering condenser water temperatures. The objective of each test is to determine the chiller's cooling capacity and electric consumption for the defined set of operating temperature pairs at the full load condition (PLR=1.0). Table 4 summarizes the various test cases and parameters that are varied between cases.

In addition, 6 additional tests are used to test the chiller's part load performance at the standard condition of 6.67°C leaving chilled water temperature and varying entering condenser water temperatures. The conditions for these tests are described in Table 4 as Cases TC-PL1 through TC-PL6.

1.3.6 Simulation and Reporting Period

Simulations for all cases were run for the period from January 1 through February 20 which covers the full range of internal loads.

1.3.7 Output Data Requirements

For chiller full load performance Tests TC-1A through TC-9F

- Steady state hourly cooling capacity in Wh for PLR=1.0
- Steady state hourly electric consumption in Wh for PLR=1.0
- Calculated coefficient of performance (COP) (dimensionless)

For chiller part load performance Tests TC-PL1 through TC-PL5

- Steady state hourly electric consumption in Wh for PLR=1.0
- Calculated coefficient of performance (COP) (dimensionless)

For each of the full load performance tests, the hourly results file is searched for the first hour where the chiller PLR=1.0. The chiller cooling capacity, electric consumption and COP for this hour then represent the data that is plotted on the charts that are presented in Section 2.3 of this report. For most cases the range of scheduled internal loads does not produce an hour when the PLR of the chiller is exactly 1.0. In those cases then it is necessary to interpolate between hours to determine what the cooling capacity and electric consumption of the chiller is at a PLR=1.0.

Table 4 HVAC Component Test Case Descriptions

Case #	Zone			Weather	Water Chiller Operating Temperatures	
	Internal Gains		Setpoint	ODB ('C)	Leaving Chilled Water Temp ('C)	Entering Condenser Water Temp ('C)
	Sensible(W)	Latent (W)	IDB ('C)			
TC-1A	8,000 - 13,000	0	22.2	35.0	3.33	23.89
TC-1B	8,000 - 13,000	0	22.2	35.0	3.33	26.67
TC-1C	8,000 - 13,000	0	22.2	35.0	3.33	29.44
TC-1D	8,000 - 13,000	0	22.2	35.0	3.33	32.22
TC-1E	8,000 - 13,000	0	22.2	35.0	3.33	35.00
TC-1F	8,000 - 13,000	0	22.2	35.0	3.33	37.78
TC-2A	8,000 - 13,000	0	22.2	35.0	4.44	23.89
TC-2B	8,000 - 13,000	0	22.2	35.0	4.44	26.67
TC-2C	8,000 - 13,000	0	22.2	35.0	4.44	29.44
TC-2D	8,000 - 13,000	0	22.2	35.0	4.44	32.22
TC-2E	8,000 - 13,000	0	22.2	35.0	4.44	35.00
TC-2F	8,000 - 13,000	0	22.2	35.0	4.44	37.78
TC-3A	8,000 - 13,000	0	22.2	35.0	5.56	23.89
TC-3B	8,000 - 13,000	0	22.2	35.0	5.56	26.67
TC-3C	8,000 - 13,000	0	22.2	35.0	5.56	29.44
TC-3D	8,000 - 13,000	0	22.2	35.0	5.56	32.22
TC-3E	8,000 - 13,000	0	22.2	35.0	5.56	35.00
TC-3F	8,000 - 13,000	0	22.2	35.0	5.56	37.78
TC-4A	8,000 - 13,000	0	22.2	35.0	6.67	23.89
TC-4B	8,000 - 13,000	0	22.2	35.0	6.67	26.67
TC-4C	8,000 - 13,000	0	22.2	35.0	6.67	29.44
TC-4D	8,000 - 13,000	0	22.2	35.0	6.67	32.22
TC-4E	8,000 - 13,000	0	22.2	35.0	6.67	35.00
TC-4F	8,000 - 13,000	0	22.2	35.0	6.67	37.78
TC-5A	8,000 - 13,000	0	22.2	35.0	7.22	23.89
TC-5B	8,000 - 13,000	0	22.2	35.0	7.22	26.67
TC-5C	8,000 - 13,000	0	22.2	35.0	7.22	29.44
TC-5D	8,000 - 13,000	0	22.2	35.0	7.22	32.22
TC-5E	8,000 - 13,000	0	22.2	35.0	7.22	35.00
TC-5F	8,000 - 13,000	0	22.2	35.0	7.22	37.78
TC-6A	8,000 - 13,000	0	22.2	35.0	7.78	23.89
TC-6B	8,000 - 13,000	0	22.2	35.0	7.78	26.67
TC-6C	8,000 - 13,000	0	22.2	35.0	7.78	29.44
TC-6D	8,000 - 13,000	0	22.2	35.0	7.78	32.22
TC-6E	8,000 - 13,000	0	22.2	35.0	7.78	35.00

TC-6F	8,000 - 13,000	0	22.2	35.0	7.78	37.78
Abbreviations:		IDB = indoor dry-bulb temperature				
		ODB = outdoor dry-bulb temperature				

Table 4 HVAC Component Test Case Descriptions (Cont'd)

Case #	Zone			Weather	Water Chiller Operating Temperatures	
	Internal Gains		Setpoint	ODB ('C)	Leaving Chilled Water Temp ('C)	Entering Condenser Water Temp ('C)
	Sensible(W)	Latent (W)	IDB ('C)			
TC-7A	8,000 - 13,000	0	22.2	35.0	8.89	23.89
TC-7B	8,000 - 13,000	0	22.2	35.0	8.89	26.67
TC-7C	8,000 - 13,000	0	22.2	35.0	8.89	29.44
TC-7D	8,000 - 13,000	0	22.2	35.0	8.89	32.22
TC-7E	8,000 - 13,000	0	22.2	35.0	8.89	35.00
TC-7F	8,000 - 13,000	0	22.2	35.0	8.89	37.78
TC-8A	8,000 - 13,000	0	22.2	35.0	10.00	23.89
TC-8B	8,000 - 13,000	0	22.2	35.0	10.00	26.67
TC-8C	8,000 - 13,000	0	22.2	35.0	10.00	29.44
TC-8D	8,000 - 13,000	0	22.2	35.0	10.00	32.22
TC-8E	8,000 - 13,000	0	22.2	35.0	10.00	35.00
TC-8F	8,000 - 13,000	0	22.2	35.0	10.00	37.78
TC-9A	8,000 - 13,000	0	22.2	35.0	11.11	23.89
TC-9B	8,000 - 13,000	0	22.2	35.0	11.11	26.67
TC-9C	8,000 - 13,000	0	22.2	35.0	11.11	29.44
TC-9D	8,000 - 13,000	0	22.2	35.0	11.11	32.22
TC-9E	8,000 - 13,000	0	22.2	35.0	11.11	35.00
TC-9F	8,000 - 13,000	0	22.2	35.0	11.11	37.78
TC-PL1	500 - 10,000	0	22.2	35.0	6.67	23.89
TC-PL2	500 - 10,000	0	22.2	35.0	6.67	26.67
TC-PL3	500 - 10,000	0	22.2	35.0	6.67	29.44
TC-PL4	500 - 10,000	0	22.2	35.0	6.67	32.22
TC-PL5	500 - 10,000	0	22.2	35.0	6.67	35.00
TC-PL6	500 - 10,000	0	22.2	35.0	6.67	37.78
Abbreviations:		IDB = indoor dry-bulb temperature				
		ODB = outdoor dry-bulb temperature				

1.4 Hot Water Boiler Test

1.4.1 Internal Loads

In order to create a heating load for the heating plant equipment, a sensible internal gain ranging from -500 W to -12,000 W is imposed on the building interior space according to a fixed schedule which holds the internal load constant throughout any one day but varies by day of the simulation. The sensible gains are assumed to be 100% convective. Latent internal loads are always 0.0 W. Table 5 further describes the internal load schedule by day of the simulation. Zone sensible internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated loads that are not related to the operation of the mechanical heating system or its air distribution fan. The reason for the range of internal sensible loads is to exercise the part load on the heating equipment throughout its entire load range, i.e. PLR from 0.05 to 1.2. Other than the boiler full load heating efficiency, the part load ratio is the only other parameter that effects the part load performance of the boiler. The boiler heating capacity is set to 10,000 W and the full load heating efficiency is assumed to be 80%.

Table 5 Schedule of Internal Loads for Hot Water Boiler Tests

Day	Hours	Sensible Watts	Latent Watts
1-Jan	1 - 24	-500	0
2-Jan	1 - 24	-1000	0
3-Jan	1 - 24	-1500	0
4-Jan	1 - 24	-2000	0
5-Jan	1 - 24	-2500	0
6-Jan	1 - 24	-3000	0
7-Jan	1 - 24	-3500	0
8-Jan	1 - 24	-4000	0
9-Jan	1 - 24	-4500	0
10-Jan	1 - 24	-5000	0
11-Jan	1 - 24	-5500	0
12-Jan	1 - 24	-6000	0
13-Jan	1 - 24	-6500	0
14-Jan	1 - 24	-7000	0
15-Jan	1 - 24	-7500	0
16-Jan	1 - 24	-8000	0
17-Jan	1 - 24	-8500	0
18-Jan	1 - 24	-9000	0
19-Jan	1 - 24	-9500	0
20-Jan	1 - 24	-10000	0
21-Jan	1 - 24	-10500	0
22-Jan	1 - 24	-11000	0
23-Jan	1 - 24	-11500	0
24-Jan	1 - 24	-12000	0

1.4.2 Central Heating Plant

To perform the component heating test, heating is provided by a hot water gas-fired boiler whose full load heating efficiency is assumed to be 80%. In the absence of actual part load performance data from a manufacturer's catalog, a part load performance curve was taken from the DOE-2.1E Equipment-Quad Default Curves data base. The part load performance curve for a hot water boiler is referred to as HW-BOILER-HIR-FPLR in the DOE-2.1E documentation (DOE-2 1993b) and is described as:

> HW-BOILER-HIR-FPLR = $a * PLR + b * PLR + c * PLR * PLR$
>
> where
>
> HW-BOILER-HIR-FPLR is the heat input at a given part load ratio divided by the full load heat input (PLR = 1.0).
>
> PLR is the part load ratio which is the load on the boiler divided by the full load capacity of the boiler
>
> - a = 0.082597
> - b = 0.996764
> - c = -0.079361

Other simulation assumptions for the heating plant included:

- Ideal hot water pump are assumed to consume no electricity and add no heat to the hot water loop.
- Hot water loop piping is assumed to be perfectly insulated such that the entire amount of heating provided by the boiler during each time increment goes completely to heat the space.
- Hot water flow is assumed to be constant.

1.4.3 Weather Data

Since the test building is near adiabatic and the hot water boiler performance is independent of outdoor weather conditions, the weather file used with this test is irrelevant but the test was performed using the same CE200A.TM2 weather file described previously in Section 1.3.4.

1.4.4 Summary of Test Cases

As described in Table 5, only one test case was used to test the hot water boiler's performance over its full part load range of operation.

1.4.5 Output Data Requirements

To compare the EnergyPlus simulation results for the hot water boiler to the reference performance data, the following output variables are required:

- Steady state hourly heating load in Wh
- Steady-state hourly energy consumption in Wh

The hourly PLR for the hot water boiler is the hourly heating load divided by the rated heating capacity of the boiler.

2 Modeler Report

2.1 Modeling Methodology

2.1.1 Base Building HVAC System

To simulate the ideal air distribution system for the base case building, the EnergyPlus ZoneHVAC:FourPipeFanCoil object was used. Cooling and heating was scheduled to be continuously available as needed. Outside air quantity was set to 0.0 m3/s. The zone thermostat was modeled as a ThermostatSetpoint:SingleHeatingOrCooling type with a cooling setpoint of 22.2°C and a heating setpoint 20.0°C throughout the simulation period. The air distribution fan delta pressure was set to 0.0 Pa in order to zero out the possibility of any motor heat being added to the air stream.

2.1.2 Central Plant EIR Chiller

To simulate the Chiller:Electric:EIR model in EnergyPlus requires three performance curves:

1. **Cooling Capacity Function of Temperature Curve** - The total cooling capacity modifier curve (function of temperature) is a bi-quadratic curve with two independent variables: leaving chilled water temperature and entering condenser fluid temperature. The output of this curve is multiplied by the design capacity to give the total cooling capacity at specific temperature operating conditions (i.e., at temperatures different from the design temperatures). The curve has a value of 1.0 at the design temperatures.
2. **Energy Input to Cooling Output Ratio Function of Temperature** - The energy input ratio (EIR) modifier curve (function of temperature) is a bi-quadratic curve with two independent variables: leaving chilled water temperature and entering condenser fluid temperature. The output of this curve is multiplied by the design EIR (inverse of the COP) to give the EIR at specific temperature operating conditions (i.e., at temperatures different from the design temperatures). The curve has a value of 1.0 at the design temperatures.
3. **Electric Input to Cooling Output Ratio Function of Part Load Ratio** - The energy input ratio (EIR) modifier curve (function of part load ratio) is a quadratic curve that parameterizes the variation of the energy input ratio (EIR) as a function of part load ratio.. The EIR is the inverse of the COP, and the part load ratio is the actual cooling load divided by the chiller's available cooling capacity. The output of this curve is multiplied by the design EIR and the Energy Input to Cooling Output Ratio Function of Temperature Curve to give the EIR at the specific temperatures and part-load ratio at which the chiller is operating. The curve has a value of 1.0 when the part-load ratio equals 1.0.

Before the curve fitting of the performance data could be done the performance data as available from the manufacturer's catalog (see Table 2) which is in IP units was converted to SI units. A least squares curve fit was then performed using the Excel LINEST function to determine the coefficients of the curves. Appendix A presents the details of this exercise for the first two curves. The following results were obtained:

1. **Cooling Capacity Function of Temperature Curve**
   - Form: Bi-quadratic curve

     > $$curve = a + b * tchwl + c * tchwl^2 + d * tcnwe + e * tcnwe^2 + f * tchwl * tcnwe$$

   - Independent variables: tchwl, leaving chilled water temperature, and tcnwe, entering condenser water temperature.

     > - a = 1.018907198 Adjusted a = 1.018707198
     > - b = 0.035768388
     > - c = 0.000335718
     > - d = -0.006886487
     > - e = -3.51093E-05
     > - f = -0.00019825

   The resulting R^2 for this curve fit of the catalog data was 0.999. The value of the a-coefficient was adjusted by -0.0002 so that the value given by the quadratic curve would exactly equal the catalog value at rated conditions.
2. **Energy Input to Cooling Output Ratio Function of Temperature**
   - Form: Bi-quadratic curve

     > $$curve = a + b * tchwl + c * tchwl^2 + d * tcnwe + e * tcnwe^2 + f * tchwl * tcnwe$$

- Independent variables: tchwl, leaving chilled water temperature, and tcnwe, entering condenser water temperature. The value of the a-coefficient was adjusted by -0.0021 so that the value given by the quadratic curve would exactly equal the catalog value at rated conditions.

> - a = 0.54807728 Adjusted a = 0.54597728
> - b = -0.020497
> - c = 0.000456
> - d = 0.015890
> - e = 0.000218
> - f = -0.000440

The resulting R^2 for this curve fit of the catalog data was 0.999.

3. **Electric Input to Cooling Output Ratio Function of Part Load Ratio**

   - Form: Quadratic curve

   > $$curve = a + b * plr + c * plr^2$$

   - Independent variable: part load ratio (sensible cooling load/steady state sensible cooling capacity)

     Since part load performance as required by EnergyPlus was not available from the catalog for this piece of equipment, the part load curve from the DOE-2 program for a hermetic reciprocating chiller was used. The coefficients for the DOE-2 curve specified as EIRPLR4 in the DOE-2 documentation (DOE-2 1993a) are as follows:

   > - a = 0.88065
   > - b = 1.137742
   > - c = -0.225806

Some additional inputs required by EnergyPlus included:

- Design capacity (W), set at 10,000 W for this series of tests
- Design COP, set at 3.926 based on catalog data at rated conditions of 6.67°C leaving chilled water temperature and 29.44°C entering condenser water temperature
- Design leaving chilled water temperature (°C), set at 6.67°C (44°F)
- Design entering condenser water temperature (°C), set at 29.44°C (85°F)
- Design evaporator volumetric water flow rate ($\frac{m^3}{s}$), parameter set to “autosized”
- Design condenser volumetric water flow rate ($\frac{m^3}{s}$), parameter set to “autosized”
- Minimum part-load ratio, left to default to 0.1
- Maximum part-load ratio, set at 1.2

2.1.3 Central Plant Hot Water Boiler

To simulate the Boiler:HotWater model in EnergyPlus requires that a fuel use/part load ratio curve be defined. EnergyPlus uses the following equation to calculate fuel use.

> $$FuelUsed = \frac{TheoreticalFuelUsed}{C1 + C2 \cdot OperatingPartLoadRatio + C3 \cdot OperatingPartLoadRatio\ ^2}$$

where

> $$TheoreticalFuelUse = \frac{BoilerLoad}{BoilerEfficiency}$$

User inputs include the Boiler Efficiency and the coefficients C1, C2 and C3. The EnergyPlus model of the Boiler:HotWater determines the Boiler Load and Operating Part Load Ratio for each simulated time increment. The Operating Part Load is calculated as the Boiler Load divided by the Boiler Rated Heating Capacity. For the hot water boiler component test described here the Boiler Heating Capacity was set to 10,000 W and the

Boiler Efficiency was set to 80%.

The Fuel Used equation which describes the part load performance of the hot water boiler was taken from the DOE-2.1E equipment library (DOE-2 1993b) where the part load performance curve for a hot water boiler is identified as HW-BOILER-HIR-FPLR and has coefficient values of:

> C1 = 0.082597
> C2 = 0.996764
> C3 = -0.079361

Some additional input parameters required by EnergyPlus included:

- Design boiler water outlet temperature, parameter left to default to 81°C
- Maximum design boiler water flow rate, parameter set to "autosize"
- Minimum part load ratio, parameter left to default to 0.0
- Maximum part load ratio, parameter set to 1.2
- Boiler flow mode, parameter set to "constant flow"
- Parasitic electric load, parameter set to 0.0W

2.2 Modeling Difficulties

2.2.1 Building Envelope Construction

The specification for the building envelope indicates that the exterior walls, roof and floor are made up of one opaque layer of insulation (R=100) with differing radiative properties for the interior surface and exterior surface (ref. Table 24 of Standard 140). To allow the surface radiative properties to be set at different values, the exterior wall, roof and floor had to be simulated as two insulation layers, each with an R=50. The EnergyPlus description for this construction was as follows:

```
INSULATION-EXT, ! Name
 VerySmooth, ! Roughness
 50.00, ! Thermal Resistance {m2-K/W}
 0.9000, ! Thermal Absorptance
 0.1000, ! Solar Absorptance
 0.1000; ! Visible Absorptance

Material:NoMass,
 INSULATION-INT, ! Name
 VerySmooth, ! Roughness
 50.00, ! Thermal Resistance {m2-K/W}
 0.9000, ! Thermal Absorptance
 0.6000, ! Solar Absorptance
 0.6000; ! Visible Absorptance

Construction,
 LTWALL, ! Name
 INSULATION-EXT, !- Outside layer
 INSULATION-INT; !- Layer 2
```

2.3 Software Errors Discovered

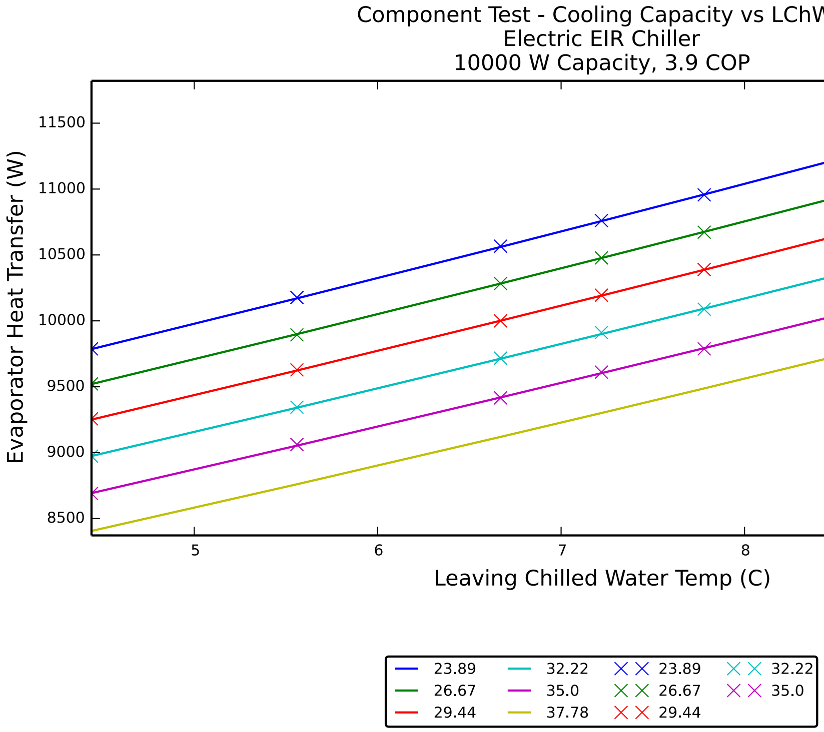
During the initial testing of EnergyPlus with the new chiller test suite, two software errors were discovered as part of the testing which was subsequently corrected:

- When the chiller was specified as "constant flow" as part of the Chiller:Electric:EIR object input, the chiller delivered more than capacity with no additional energy use (corrected in EnergyPlus version 1.2.3.031, CR# 6766)
- When the max PLR was greater than 1.0, the PLR was getting clipped at 1.0 but chiller was delivering load up to the max PLR with no increase in electric consumption (corrected in EnergyPlus version 1.3.0.008, CR# 6921)
- Plant solver routines were reworked which caused minor changes (<0.1%) in Chiller:Electric:EIR electric consumption and COP results (changed in EnergyPlus version 7.0.0.036)

2.4 Results

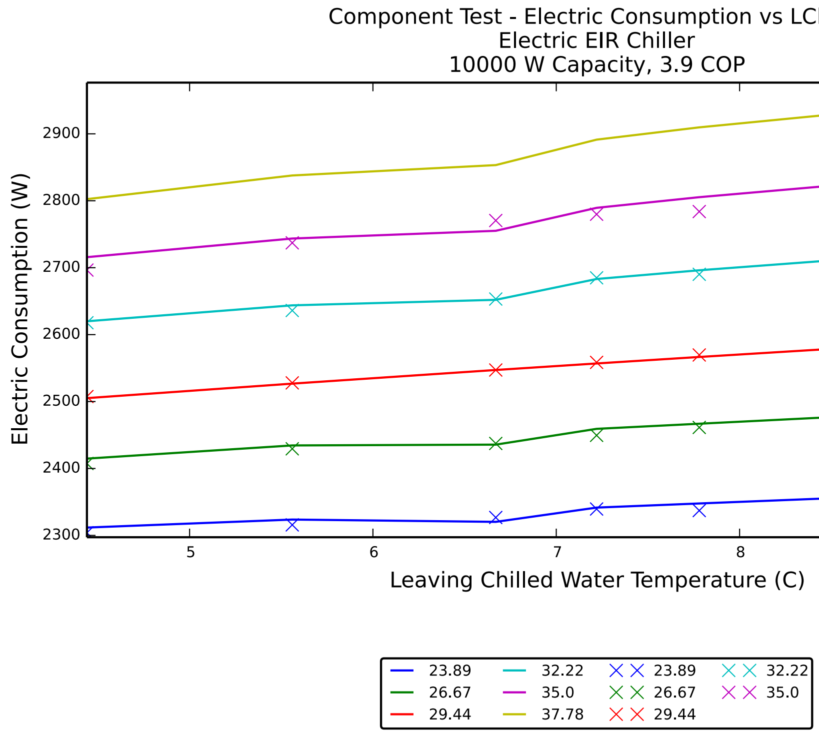
2.4.1 EIR Electric Chiller

Results from running the Chiller:Electric:EIR component test suite with EnergyPlus 8.3.0-b45b06b780 are depicted graphically in Figures 2 through 8.



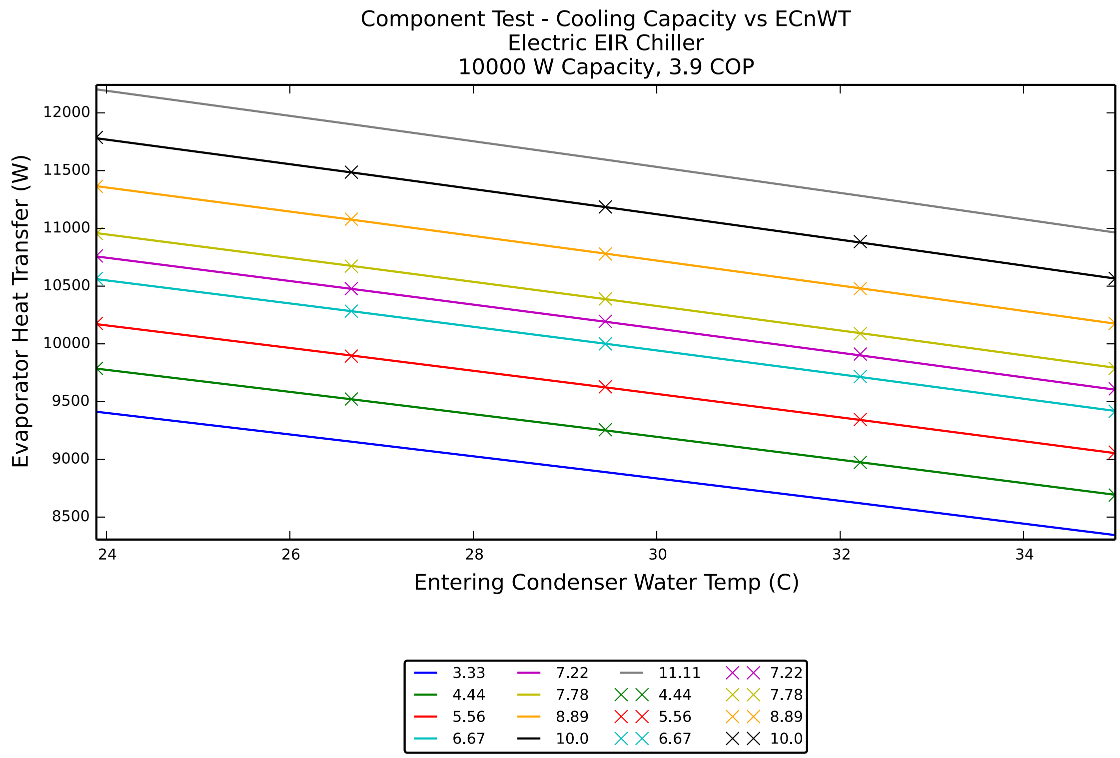
Notes: Legend Values: Entering Condenser Water Temp (C)
Solid Line = Simulated Data; Marker = Catalog Data

Figure 2 Chiller Cooling Capacity Versus Leaving Chilled Water Temperature – EnergyPlus Model Versus Manufacturer Data



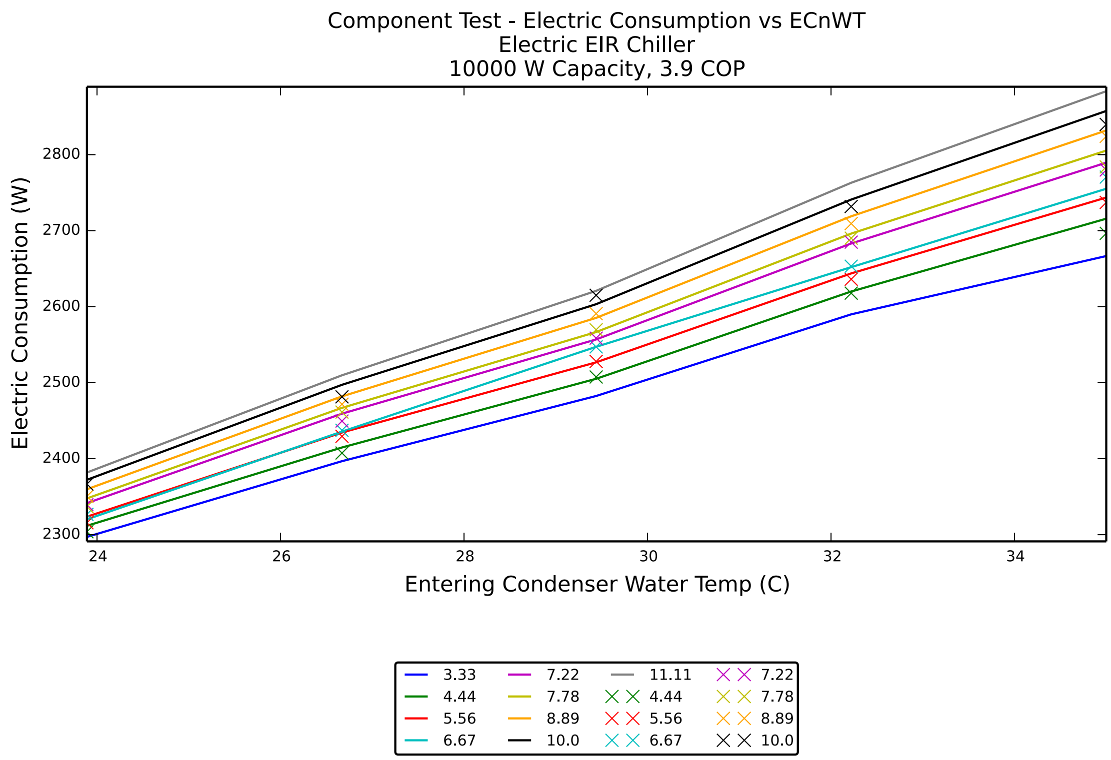
Notes: Legend Values: Entering Condenser Water Temp (C)
Solid Line = Simulated Data; Marker = Catalog Data

Figure 3 Chiller Electric Consumption Versus Leaving Chilled Water Temperature – EnergyPlus Model Versus Manufacturer Data



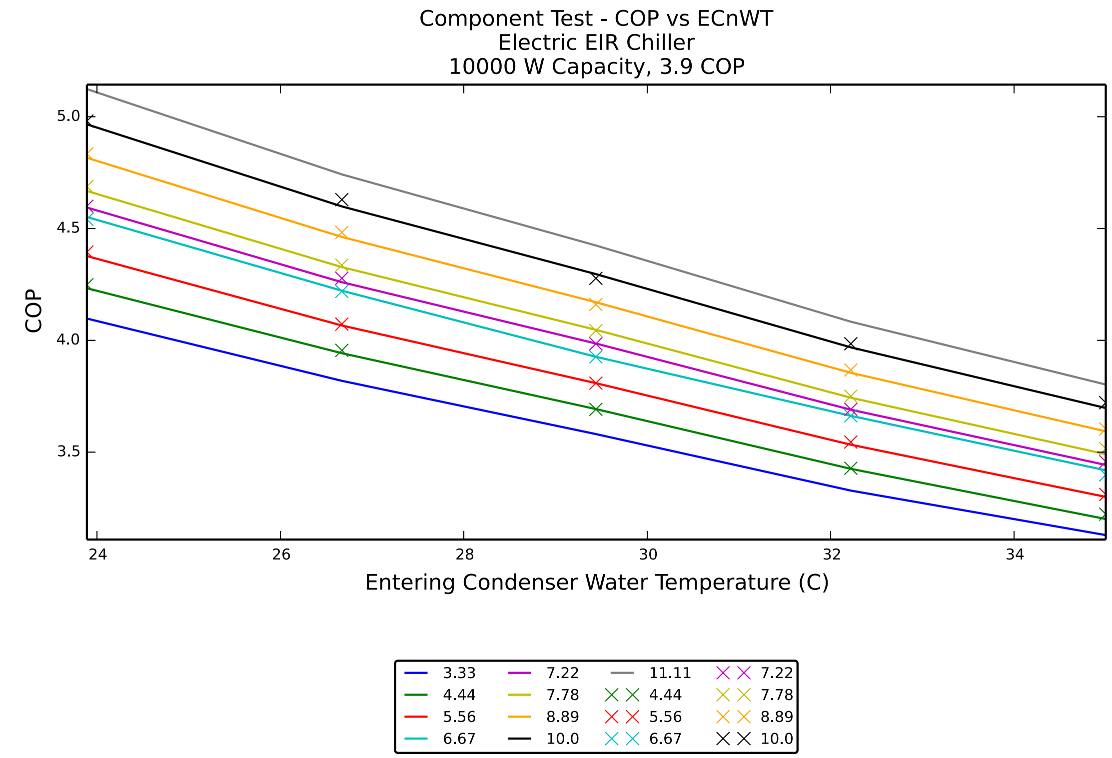
Notes: Legend Values: Leaving Chilled Water Temp (C)
Solid Line = Simulated Data; Marker = Catalog Data

Figure 4 Chiller Cooling Capacity Versus Entering Condenser Water Temperature – EnergyPlus Model Versus Manufacturer Data



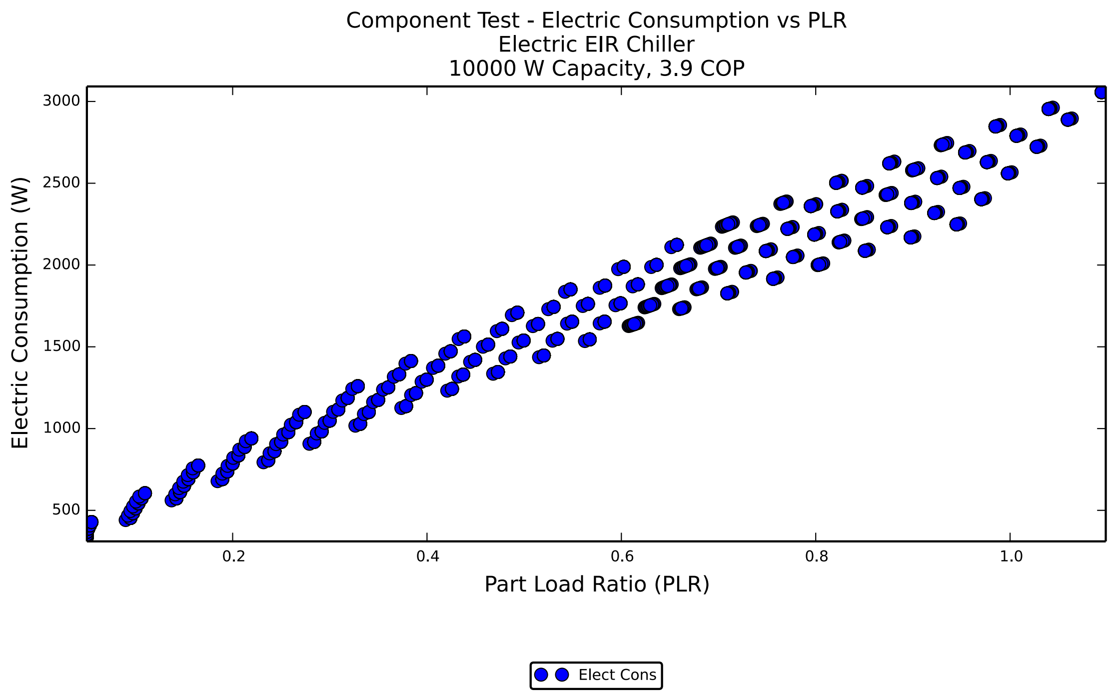
Notes: Legend Values: Leaving Chilled Water Temp (C)
Solid Line = Simulated Data; Marker = Catalog Data

Figure 5 Chiller Electric Consumption Versus Entering Condenser Water Temperature – EnergyPlus Model Versus Manufacturer Data



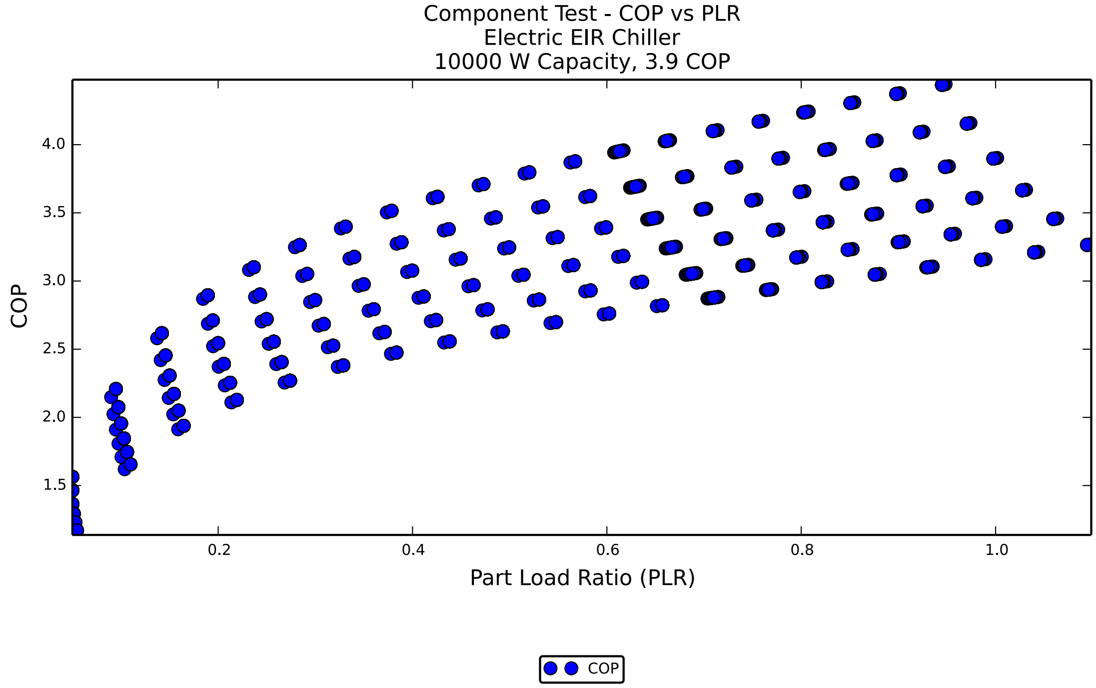
Notes: Legend Values: Leaving Chilled Water Temp (C)
Solid Line = Simulated Data; Marker = Catalog Data

Figure 6 Chiller COP Versus Entering Condenser Water Temperature



Notes: Constant Leaving Chilled Water Temperature = 6.67 C Varying Entering Condenser Water Temperatures
Data series from top to bottom: 37.8C, 35.0C, 32.2C, 29.4C, 26.7C, 23.9C
Entering Condenser Water Temp (C)

Figure 7 Chiller Electric Consumption Versus Part Load Ratio



Notes: Constant Leaving Chilled Water Temperature = 6.67 C Varying Entering Condenser Water Temperatures
Data series from top to bottom: 23.9C, 26.7C, 29.4C, 32.2C, 35.0C, 37.8C
Entering Condenser Water Temp (C)

Figure 8 Chiller COP Versus Part Load Ratio

Figures 2 through 6 show how the simulated results (represented by lines) compare to catalog data. The EnergyPlus Chiller:Electric:EIR model was simulated for higher and lower leaving chilled water temperatures and entering condenser water temperatures than were available with the catalog data to show that the curve fitted performance data behaves well even beyond the limits of the curve fitted data. Good agreement was obtained between the simulated data and the catalog data although there is some small variations.

Figures 7 and 8 are also provided to give an indication of how the electric consumption and COP varies with the part load ratio. No catalog data was available to include with these charts.

The three tables below summarize the percent differences between the EnergyPlus results and catalog data for the chiller cooling capacity, chiller electric consumption and chiller COP.

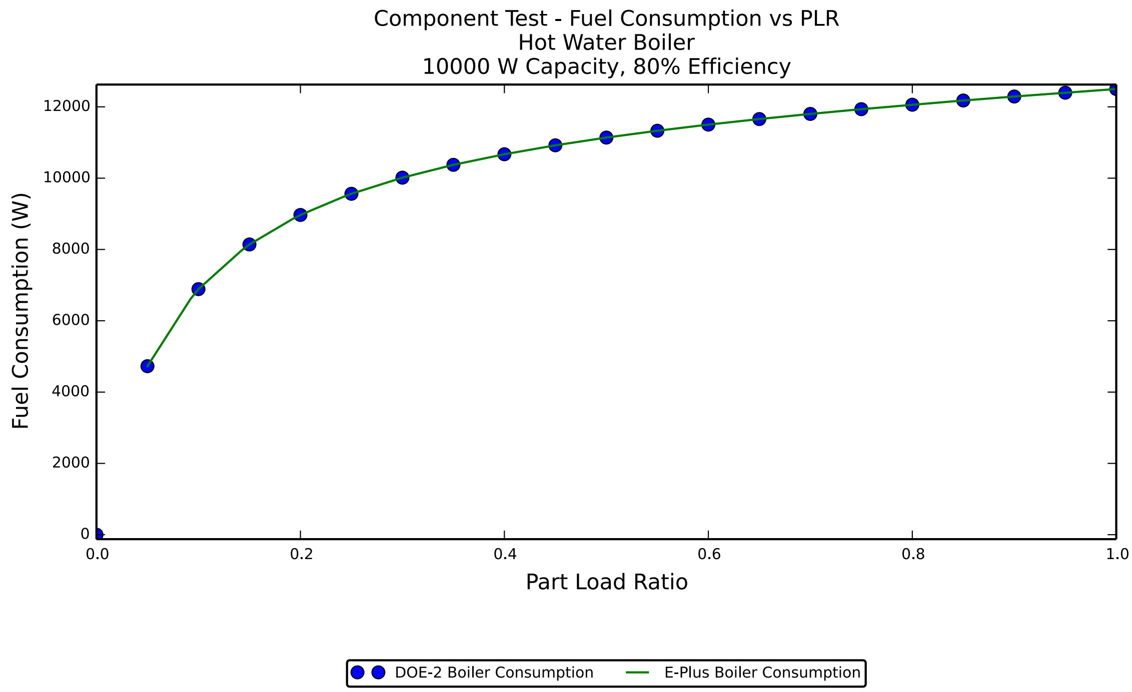
CAPACITY %Difference (E-Plus - Catalog)/Catalog					
Leaving Chilled Water Temp. (C)	**Entering Condenser Water Temp. (C)**				
	23.890000	**26.670000**	**29.440000**	**32.220000**	**35.00**
4.44	-0.02%	-0.02%	-0.07%	0.01%	0.03%
5.56	-0.06%	0.05%	-0.05%	-0.04%	-0.09%
6.67	-0.05%	-0.00%	0.01%	-0.04%	0.03%
7.22	-0.04%	-0.01%	-0.03%	-0.12%	-0.08%
7.78	0.03%	0.03%	-0.02%	0.04%	0.05%
8.89	0.02%	-0.03%	0.03%	0.03%	-0.02%
10.00	-0.06%	-0.02%	-0.01%	-0.07%	-0.01%

CONSUMPTION %Difference (E-Plus - Catalog)/Catalog					
Leaving Chilled Water Temp. (C)	Entering Condenser Water Temp. (C)				
	23.890000	**26.670000**	**29.440000**	**32.220000**	**35.00**
4.44	0.34%	0.30%	-0.09%	0.08%	0.71%
5.56	0.34%	0.21%	-0.05%	0.29%	0.24%
6.67	-0.28%	-0.07%	0.00%	-0.05%	-0.56%
7.22	0.09%	0.40%	-0.06%	-0.07%	0.34%
7.78	0.45%	0.23%	-0.12%	0.22%	0.77%
8.89	0.39%	0.42%	-0.21%	0.35%	0.28%
10.00	0.23%	0.64%	-0.45%	0.34%	0.63%

COP %Difference (E-Plus - Catalog)/Catalog					
Leaving Chilled Water Temp. (C)	Entering Condenser Water Temp. (C)				
	23.890000	**26.670000**	**29.440000**	**32.220000**	**35.000000**
4.44	-0.36%	-0.32%	0.03%	-0.07%	-0.68%
5.56	-0.40%	-0.15%	-0.01%	-0.33%	-0.33%
6.67	0.23%	0.07%	0.01%	0.00%	0.59%
7.22	-0.13%	-0.41%	0.03%	-0.05%	-0.42%
7.78	-0.42%	-0.20%	0.10%	-0.18%	-0.71%
8.89	-0.37%	-0.45%	0.24%	-0.32%	-0.30%
10.00	-0.29%	-0.65%	0.44%	-0.40%	-0.63%

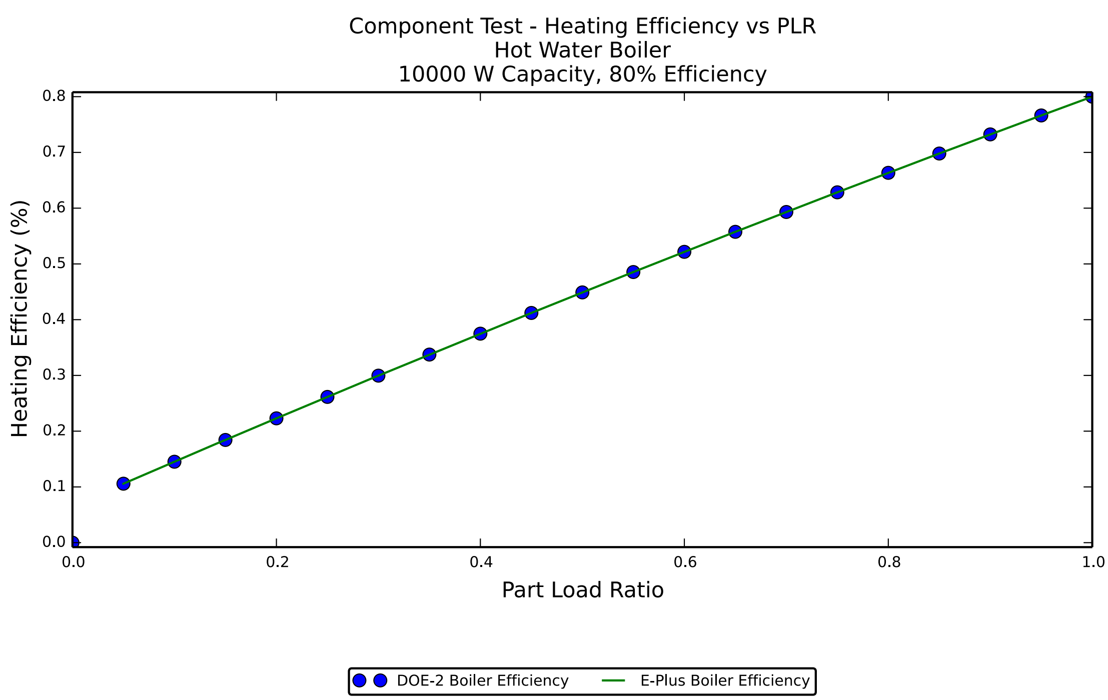
2.4.2 Hot Water Boiler

Results from running the Boiler:HotWater component test with EnergyPlus 8.3.0-b45b06b780 are shown graphically in Figure 9 and 10. Very good agreement (max 0.31% difference) was obtained between the EnergyPlus predicted fuel consumption and the fuel consumption of the boiler when using the DOE-2 hot water boiler part load curve which was used as a surrogate for catalog data. Similarly, very good agreement (max 0.14% difference) between the two also resulted when comparing boiler heating efficiency versus the part load ratio.



Notes: Solid Line = Catalog Data (represented by DOE-2 performance data) Dashed Line = EnergyPlus Simulated Data

Figure 9 Hot Water Boiler Fuel Consumption Versus Part Load Ratio – EnergyPlus Model Versus DOE-2 Performance Curve



Notes: Solid Line = Catalog Data (represented by DOE-2 performance data) Dashed Line = EnergyPlus Simulated Data

Figure 10 Hot Water Boiler Heating Efficiency Versus Part Load Ratio – EnergyPlus Model Versus DOE-2 Performance Curve

3 Conclusions

3.1 EIR Chiller Test

EnergyPlus version 8.3.0-b45b06b780 was used to model the operation of an electric chiller with the EnergyPlus object called Chller:Electric:EIR over a range of leaving chiller water and entering condenser water temperatures and part load ratios. Results were compared to manufacturer catalog data which were curve fit for modeling in EnergyPlus. The HVAC Component Test suite as described in this report makes use of the basic test building geometry and envelope described as Case E100 in Section 5.3.1 of ANSI/ASHRAE Standard 140-2011, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer* Programs to generate a set of controlled cooling loads on the chiller. The ability of EnergyPlus to model the cooling capacity, electric consumption and part load operation of an electric chiller was tested using 54 test cases which were run for varying internal loads and fixed outdoor conditions.

Curve fits of the catalog data for cooling capacity and electric consumption normalized to rated conditions using the least squares method gave an R^2 of 0.999. When these curve fits were used in EnergyPlus to simulate the modeled electric chiller over a range of leaving chilled water and entering condenser water temperatures, the EnergyPlus results agreed to within a maximum of 0.12% of the catalog data for cooling capacity and to within a maximum of 0.77% of the catalog data for electric consumption and to within a maximum of 0.71% of the catalog based calculated COP. The EIR charts (Figures 3 and 5) do not produce a smooth curve when the simulated data points are connected as might be expected. It should be noticed however that the catalog data on these charts also jumps around and the resulting EIR curve fit of the catalog data attempts to emulate this behavior.

3.2 Hot Water Boiler Test

EnergyPlus version 8.3.0-b45b06b780 was also used to model the operation of a hot water boiler with the EnergyPlus object called Boiler:HotWater over a range of part loads from 5% to 100%. Results were compared to the specified performance data taken from the DOE-2 program part load performance curve for the same type of equipment. Excellent agreement between the EnergyPlus model and the specified performance data was achieved with a max resulting 0.31% difference for fuel consumption and 0.14% heating efficiency.

4 References

ANSI/ASHRAE 2011. Standard 140-2011, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.

DOE-2 1993a. “DOE-2 Supplement, Version 2.1E,” Section 4 –Plant, page 4.81. LBL-34947. November 1993.

DOE-2 1993b. “DOE-2 Supplement, Version 2.1E,” Section 4 –Plant, page 4.82. LBL-34947. November 1993.

EnergyPlus 2014. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies. www.energyplus.gov

York, “Millennium Liquid Chillers, Water Cooled Chiller & Remote Condenser Models, 60 to 250 Tons, Models YCWZ, YCRZ, YCWJ and YCRJ, Engineering Guide,” Form 150.24-EG2(899).

5 Appendix A

Curve Fitting of Manufacturer Catalog Data for York Model YCWZ33AB0 Millennium Water Cooled Chiller

Performance Curves

Manufacturer:	York
Class:	Reciprocating Water Chiller
Type:	Water-Cooled, Electric
Source of Data:	YORK Millennium Liquid Chillers, 60 to 250 tons, Form 150.24-EG2 (899)

EnergyPlus Curve: RecipCapFt   CHWS=Chilled Water Supply Temperature (F)   CWS=Entering Condenser Water Temperature (F)

English Units

Manufacturer	Model	CHWS	CHWS**2	CWS	CWS**2	CHWS*CWS	Capacity (tons)	Normalized CAP	CAP-FT From Curve	% Diff
York	YCWZ33AB0	40	1600	75	5625	3000	55.3	0.979	0.9787	0.00%
York	YCWZ33AB0	42	1764	75	5625	3150	57.5	1.018	1.0169	-0.08%
York	YCWZ33AB0	44	1936	75	5625	3300	59.7	1.057	1.0560	-0.06%
York	YCWZ33AB0	45	2025	75	5625	3375	60.8	1.076	1.0758	-0.03%
York	YCWZ33AB0	46	2116	75	5625	3450	61.9	1.096	1.0958	0.02%
York	YCWZ33AB0	48	2304	75	5625	3600	64.2	1.136	1.1365	0.02%
York	YCWZ33AB0	50	2500	75	5625	3750	66.6	1.179	1.1781	-0.06%
York	YCWZ33AB0	40	1600	80	6400	3200	53.8	0.952	0.9522	0.00%
York	YCWZ33AB0	42	1764	80	6400	3360	55.9	0.989	0.9898	0.04%
York	YCWZ33AB0	44	1936	80	6400	3520	58.1	1.028	1.0282	-0.01%
York	YCWZ33AB0	45	2025	80	6400	3600	59.2	1.048	1.0478	0.00%
York	YCWZ33AB0	46	2116	80	6400	3680	60.3	1.067	1.0675	0.02%
York	YCWZ33AB0	48	2304	80	6400	3840	62.6	1.108	1.1076	-0.04%
York	YCWZ33AB0	50	2500	80	6400	4000	64.9	1.149	1.1485	-0.02%
York	YCWZ33AB0	40	1600	85	7225	3400	52.3	0.926	0.9252	-0.05%
York	YCWZ33AB0	42	1764	85	7225	3570	54.4	0.963	0.9621	-0.07%
York	YCWZ33AB0	44	1936	85	7225	3740	56.5	1.000	1.0000	0.00%
York	YCWZ33AB0	45	2025	85	7225	3825	57.6	1.019	1.0192	-0.03%
York	YCWZ33AB0	46	2116	85	7225	3910	58.7	1.039	1.0386	-0.03%
York	YCWZ33AB0	48	2304	85	7225	4080	60.9	1.078	1.0781	0.02%
York	YCWZ33AB0	50	2500	85	7225	4250	63.2	1.119	1.1184	-0.02%
York	YCWZ33AB0	40	1600	90	8100	3600	50.7	0.897	0.8976	0.02%
York	YCWZ33AB0	42	1764	90	8100	3780	52.8	0.935	0.9339	-0.06%
York	YCWZ33AB0	44	1936	90	8100	3960	54.9	0.972	0.9711	-0.06%
York	YCWZ33AB0	45	2025	90	8100	4050	56	0.991	0.9901	-0.11%
York	YCWZ33AB0	46	2116	90	8100	4140	57	1.009	1.0092	0.03%
York	YCWZ33AB0	48	2304	90	8100	4320	59.2	1.048	1.0480	0.02%
York	YCWZ33AB0	50	2500	90	8100	4500	61.5	1.088	1.0877	-0.07%
York	YCWZ33AB0	40	1600	95	9025	3800	49.1	0.869	0.8694	0.05%
York	YCWZ33AB0	42	1764	95	9025	3990	51.2	0.906	0.9052	-0.11%
York	YCWZ33AB0	44	1936	95	9025	4180	53.2	0.942	0.9418	0.02%
York	YCWZ33AB0	45	2025	95	9025	4275	54.3	0.961	0.9604	-0.07%
York	YCWZ33AB0	46	2116	95	9025	4370	55.3	0.979	0.9792	0.05%
York	YCWZ33AB0	48	2304	95	9025	4560	57.5	1.018	1.0175	-0.02%
York	YCWZ33AB0	50	2500	95	9025	4750	59.7	1.057	1.0565	-0.01%

CAP-FT

	f	e	d	c	b	a	Adjusted a
	-6.11884E-05	-1.08362E-05	-0.001174282	0.000103617	0.015197888	0.537801492	0.537601492
	3.53229E-06	1.88809E-06	0.000358351	7.82061E-06	0.000765626	0.024830849	
r2	0.999966506	0.000467278	#N/A	#N/A	#N/A	#N/A	

Metric Units

CHWS=Chilled Water Supply Temperature (C)   CWS=Entering Condenser Water Temperature (C)

Manufacturer	Model	CHWS	CHWS**2	CWS	CWS**2	CHWS*CWS	Capacity (kW)	Normalized CAP	CAP-FT From Curve	% Diff
York	YCWZ33AB0	4.4	19.8	23.9	570.7	106.2	194.4	0.98	0.9787	0.00%
York	YCWZ33AB0	5.6	30.9	23.9	570.7	132.7	202.2	1.02	1.0169	-0.08%
York	YCWZ33AB0	6.7	44.4	23.9	570.7	159.3	209.9	1.06	1.0560	-0.06%
York	YCWZ33AB0	7.2	52.2	23.9	570.7	172.5	213.8	1.08	1.0758	-0.03%
York	YCWZ33AB0	7.8	60.5	23.9	570.7	185.8	217.6	1.10	1.0958	0.02%
York	YCWZ33AB0	8.9	79.0	23.9	570.7	212.3	225.7	1.14	1.1365	0.02%
York	YCWZ33AB0	10.0	100.0	23.9	570.7	238.9	234.2	1.18	1.1781	-0.06%
York	YCWZ33AB0	4.4	19.8	26.7	711.1	118.5	189.2	0.95	0.9522	0.00%
York	YCWZ33AB0	5.6	30.9	26.7	711.1	148.1	196.5	0.99	0.9898	0.04%
York	YCWZ33AB0	6.7	44.4	26.7	711.1	177.8	204.3	1.03	1.0282	-0.01%
York	YCWZ33AB0	7.2	52.2	26.7	711.1	192.6	208.1	1.05	1.0478	0.00%
York	YCWZ33AB0	7.8	60.5	26.7	711.1	207.4	212.0	1.07	1.0675	0.02%
York	YCWZ33AB0	8.9	79.0	26.7	711.1	237.0	220.1	1.11	1.1076	-0.04%
York	YCWZ33AB0	10.0	100.0	26.7	711.1	266.7	228.2	1.15	1.1485	-0.02%
York	YCWZ33AB0	4.4	19.8	29.4	867.0	130.9	183.9	0.93	0.9252	-0.05%
York	YCWZ33AB0	5.6	30.9	29.4	867.0	163.6	191.3	0.96	0.9621	-0.07%
York	YCWZ33AB0	6.67	44.4	29.44	867.0	196.3	198.7	1.00	1.0000	0.00%
York	YCWZ33AB0	7.2	52.2	29.4	867.0	212.7	202.5	1.02	1.0192	-0.03%
York	YCWZ33AB0	7.8	60.5	29.4	867.0	229.0	206.4	1.04	1.0386	-0.03%
York	YCWZ33AB0	8.9	79.0	29.4	867.0	261.7	214.1	1.08	1.0781	0.02%
York	YCWZ33AB0	10.0	100.0	29.4	867.0	294.4	222.2	1.12	1.1184	-0.02%
York	YCWZ33AB0	4.4	19.8	32.2	1038.3	143.2	178.3	0.90	0.8976	0.02%
York	YCWZ33AB0	5.6	30.9	32.2	1038.3	179.0	185.6	0.93	0.9339	-0.06%
York	YCWZ33AB0	6.7	44.4	32.2	1038.3	214.8	193.0	0.97	0.9711	-0.06%
York	YCWZ33AB0	7.2	52.2	32.2	1038.3	232.7	196.9	0.99	0.9901	-0.11%
York	YCWZ33AB0	7.8	60.5	32.2	1038.3	250.6	200.4	1.01	1.0092	0.03%
York	YCWZ33AB0	8.9	79.0	32.2	1038.3	286.4	208.1	1.05	1.0480	0.02%
York	YCWZ33AB0	10.0	100.0	32.2	1038.3	322.2	216.2	1.09	1.0877	-0.07%
York	YCWZ33AB0	4.4	19.8	35.0	1225.0	155.6	172.6	0.87	0.8694	0.05%
York	YCWZ33AB0	5.6	30.9	35.0	1225.0	194.4	180.0	0.91	0.9052	-0.11%
York	YCWZ33AB0	6.7	44.4	35.0	1225.0	233.3	187.0	0.94	0.9418	0.02%
York	YCWZ33AB0	7.2	52.2	35.0	1225.0	252.8	190.9	0.96	0.9604	-0.07%
York	YCWZ33AB0	7.8	60.5	35.0	1225.0	272.2	194.4	0.98	0.9792	0.05%
York	YCWZ33AB0	8.9	79.0	35.0	1225.0	311.1	202.2	1.02	1.0175	-0.02%
York	YCWZ33AB0	10.0	100.0	35.0	1225.0	350.0	209.9	1.06	1.0565	-0.01%

CAP-FT

	f	e	d	c	b	a	Adjusted a
	-0.00019825	-3.51093E-05	-0.006886487	0.000335718	0.035768388	1.018907198	1.018707198
	1.14446E-05	6.1174E-06	0.000370154	2.53388E-05	0.000499536	0.005921788	
r2	0.999966506	0.000467278	#N/A	#N/A	#N/A	#N/A	

CHWS	CWS 21.5	23.9	26.7	29.4	32.2	35.0
3.2	0.9587	0.9369	0.9111	0.8847	0.8578	0.8304
4.4	1.0011	0.9787	0.9522	0.9252	0.8976	0.8694
5.6	1.0398	1.0169	0.9898	0.9621	0.9339	0.9052
6.7	1.0794	1.0560	1.0282	1.0000	0.9711	0.9418
7.2	1.0995	1.0758	1.0478	1.0192	0.9901	0.9604
7.8	1.1198	1.0958	1.0675	1.0386	1.0092	0.9792
8.9	1.1610	1.1365	1.1076	1.0781	1.0480	1.0175
10.0	1.2031	1.1781	1.1485	1.1184	1.0877	1.0565
11.2	1.2494	1.2238	1.1936	1.1628	1.1315	1.0997

Performance Curves

Manufacturer:	York
Class:	Reciprocating Water Chiller
Type:	Water-Cooled, Electric
Source of Data:	YORK Millennium Liquid Chillers, 60 to 250 tons, Form 150.24-EG2 (899)

EnergyPlus Curve: RecipEIRFt CHWS=Chilled Water Supply Temperature (F) CWS=Entering Condenser Water Temperature (F)

English Units

EER includes compressor power

EIR = 3.413/EER

Manufacturer	Model	CHWS	CHWS**2	CWS	CWS**2	CHWS*CWS	Capacity (tons)	Total Unit EER BTU/Watt	EIR	Normalized EIR	EIR-FT From Curve	% Diff
York	YCWZ33AB0	40	1600	75	5625	3000	55.3	14.5	0.24	0.92	0.9211	-0.33%
York	YCWZ33AB0	42	1764	75	5625	3150	57.5	15.0	0.23	0.89	0.8917	-0.18%
York	YCWZ33AB0	44	1936	75	5625	3300	59.7	15.5	0.22	0.86	0.8634	-0.13%
York	YCWZ33AB0	45	2025	75	5625	3375	60.8	15.7	0.22	0.85	0.8497	-0.45%
York	YCWZ33AB0	46	2116	75	5625	3450	61.9	16.0	0.21	0.84	0.8363	-0.15%
York	YCWZ33AB0	48	2304	75	5625	3600	64.2	16.5	0.21	0.81	0.8103	-0.23%
York	YCWZ33AB0	50	2500	75	5625	3750	66.6	17.0	0.20	0.79	0.7854	-0.37%
York	YCWZ33AB0	40	1600	80	6400	3200	53.8	13.5	0.25	0.99	0.9904	-0.22%
York	YCWZ33AB0	42	1764	80	6400	3360	55.9	13.9	0.25	0.96	0.9596	-0.46%
York	YCWZ33AB0	44	1936	80	6400	3520	58.1	14.4	0.24	0.93	0.9300	-0.06%
York	YCWZ33AB0	45	2025	80	6400	3600	59.2	14.6	0.23	0.92	0.9156	-0.24%
York	YCWZ33AB0	46	2116	80	6400	3680	60.3	14.8	0.23	0.91	0.9015	-0.43%
York	YCWZ33AB0	48	2304	80	6400	3840	62.6	15.3	0.22	0.88	0.8741	-0.19%
York	YCWZ33AB0	50	2500	80	6400	4000	64.9	15.8	0.22	0.85	0.8479	-0.03%
York	YCWZ33AB0	40	1600	85	7225	3400	52.3	12.6	0.27	1.06	1.0631	-0.04%
York	YCWZ33AB0	42	1764	85	7225	3570	54.4	13.0	0.26	1.03	1.0309	0.02%
York	YCWZ33AB0	44	1936	85	7225	3740	56.5	13.4	0.25	1.00	1.0000	0.00%
York	YCWZ33AB0	45	2025	85	7225	3825	57.6	13.6	0.25	0.99	0.9849	-0.04%
York	YCWZ33AB0	46	2116	85	7225	3910	58.7	13.8	0.25	0.97	0.9701	-0.10%
York	YCWZ33AB0	48	2304	85	7225	4080	60.9	14.2	0.24	0.94	0.9414	-0.24%
York	YCWZ33AB0	50	2500	85	7225	4250	63.2	14.6	0.23	0.92	0.9137	-0.44%
York	YCWZ33AB0	40	1600	90	8100	3600	50.7	11.7	0.29	1.15	1.1391	-0.54%
York	YCWZ33AB0	42	1764	90	8100	3780	52.8	12.1	0.28	1.11	1.1056	-0.16%
York	YCWZ33AB0	44	1936	90	8100	3960	54.9	12.5	0.27	1.07	1.0733	0.12%
York	YCWZ33AB0	45	2025	90	8100	4050	56	12.6	0.27	1.06	1.0575	-0.56%
York	YCWZ33AB0	46	2116	90	8100	4140	57	12.8	0.27	1.05	1.0420	-0.46%
York	YCWZ33AB0	48	2304	90	8100	4320	59.2	13.2	0.26	1.02	1.0119	-0.32%
York	YCWZ33AB0	50	2500	90	8100	4500	61.5	13.6	0.25	0.99	0.9830	-0.24%
York	YCWZ33AB0	40	1600	95	9025	3800	49.1	11.0	0.31	1.22	1.2185	0.02%
York	YCWZ33AB0	42	1764	95	9025	3990	51.2	11.3	0.30	1.19	1.1836	-0.19%
York	YCWZ33AB0	44	1936	95	9025	4180	53.2	11.6	0.29	1.16	1.1499	-0.45%
York	YCWZ33AB0	45	2025	95	9025	4275	54.3	11.8	0.29	1.14	1.1335	-0.18%
York	YCWZ33AB0	46	2116	95	9025	4370	55.3	12.0	0.28	1.12	1.1174	0.06%
York	YCWZ33AB0	48	2304	95	9025	4560	57.5	12.3	0.28	1.09	1.0859	-0.32%
York	YCWZ33AB0	50	2500	95	9025	4750	59.7	12.7	0.27	1.06	1.0556	0.04%

EIR-FT

	f	e	d	c	b	a	Adjusted a
	-0.00013587	6.72502E-05	0.008871755	0.000140632	-0.016039968	0.703719087	0.701619
	1.5715E-05	8.40004E-06	0.001594294	3.47937E-05	0.003406248	0.110471781	
r2	0.999709348	0.002078905	#N/A	#N/A	#N/A	#N/A	

Metric Units

Manufacturer	Model	CHWS	CHWS**2	CWS	CWS**2	CHWS*CWS	Capacity (tons)	Total Unit EER BTU/Watt	EIR	Normalized EIR	EIR-FT From Curve	% Diff
York	YCWZ33AB0	4.4	19.8	23.9	570.7	106.2	55.3	14.5	0.24	0.92	0.9211	-0.33%
York	YCWZ33AB0	5.6	30.9	23.9	570.7	132.7	57.5	15.0	0.23	0.89	0.8917	-0.18%
York	YCWZ33AB0	6.7	44.4	23.9	570.7	159.3	59.7	15.5	0.22	0.86	0.8634	-0.13%
York	YCWZ33AB0	7.2	52.2	23.9	570.7	172.5	60.8	15.7	0.22	0.85	0.8497	-0.45%
York	YCWZ33AB0	7.8	60.5	23.9	570.7	185.8	61.9	16.0	0.21	0.84	0.8363	-0.15%
York	YCWZ33AB0	8.9	79.0	23.9	570.7	212.3	64.2	16.5	0.21	0.81	0.8103	-0.23%
York	YCWZ33AB0	10.0	100.0	23.9	570.7	238.9	66.6	17.0	0.20	0.79	0.7854	-0.37%
York	YCWZ33AB0	4.4	19.8	26.7	711.1	118.5	53.8	13.5	0.25	0.99	0.9904	-0.22%
York	YCWZ33AB0	5.6	30.9	26.7	711.1	148.1	55.9	13.9	0.25	0.96	0.9596	-0.46%
York	YCWZ33AB0	6.7	44.4	26.7	711.1	177.8	58.1	14.4	0.24	0.93	0.9300	-0.06%
York	YCWZ33AB0	7.2	52.2	26.7	711.1	192.6	59.2	14.6	0.23	0.92	0.9156	-0.24%
York	YCWZ33AB0	7.8	60.5	26.7	711.1	207.4	60.3	14.8	0.23	0.91	0.9015	-0.43%
York	YCWZ33AB0	8.9	79.0	26.7	711.1	237.0	62.6	15.3	0.22	0.88	0.8741	-0.19%
York	YCWZ33AB0	10.0	100.0	26.7	711.1	266.7	64.9	15.8	0.22	0.85	0.8479	-0.03%
York	YCWZ33AB0	4.4	19.8	29.4	867.0	130.9	52.3	12.6	0.27	1.06	1.0631	-0.04%
York	YCWZ33AB0	5.6	30.9	29.4	867.0	163.6	54.4	13.0	0.26	1.03	1.0309	0.02%
York	YCWZ33AB0	6.7	44.4	29.4	867.0	196.3	56.5	13.4	0.25	1.00	1.0000	0.00%
York	YCWZ33AB0	7.2	52.2	29.4	867.0	212.7	57.6	13.6	0.25	0.99	0.9849	-0.04%
York	YCWZ33AB0	7.8	60.5	29.4	867.0	229.0	58.7	13.8	0.25	0.97	0.9701	-0.10%
York	YCWZ33AB0	8.9	79.0	29.4	867.0	261.7	60.9	14.2	0.24	0.94	0.9414	-0.24%
York	YCWZ33AB0	10.0	100.0	29.4	867.0	294.4	63.2	14.6	0.23	0.92	0.9137	-0.44%
York	YCWZ33AB0	4.4	19.8	32.2	1038.3	143.2	50.7	11.7	0.29	1.15	1.1391	-0.54%
York	YCWZ33AB0	5.6	30.9	32.2	1038.3	179.0	52.8	12.1	0.28	1.11	1.1056	-0.16%
York	YCWZ33AB0	6.7	44.4	32.2	1038.3	214.8	54.9	12.5	0.27	1.07	1.0733	0.12%
York	YCWZ33AB0	7.2	52.2	32.2	1038.3	232.7	56	12.6	0.27	1.06	1.0575	-0.56%
York	YCWZ33AB0	7.8	60.5	32.2	1038.3	250.6	57	12.8	0.27	1.05	1.0420	-0.46%
York	YCWZ33AB0	8.9	79.0	32.2	1038.3	286.4	59.2	13.2	0.26	1.02	1.0119	-0.32%
York	YCWZ33AB0	10.0	100.0	32.2	1038.3	322.2	61.5	13.6	0.25	0.99	0.9830	-0.24%
York	YCWZ33AB0	4.4	19.8	35.0	1225.0	155.6	49.1	11.0	0.31	1.22	1.2185	0.02%
York	YCWZ33AB0	5.6	30.9	35.0	1225.0	194.4	51.2	11.3	0.30	1.19	1.1836	-0.19%
York	YCWZ33AB0	6.7	44.4	35.0	1225.0	233.3	53.2	11.6	0.29	1.16	1.1499	-0.45%
York	YCWZ33AB0	7.2	52.2	35.0	1225.0	252.8	54.3	11.8	0.29	1.14	1.1335	-0.18%
York	YCWZ33AB0	7.8	60.5	35.0	1225.0	272.2	55.3	12.0	0.28	1.12	1.1174	0.06%
York	YCWZ33AB0	8.9	79.0	35.0	1225.0	311.1	57.5	12.3	0.28	1.09	1.0859	-0.32%
York	YCWZ33AB0	10.0	100.0	35.0	1225.0	350.0	59.7	12.7	0.27	1.06	1.0556	0.04%

EIR-FT

	f	e	d	c	b	a	Adjusted a
	-0.000440218	0.000217891	0.015890292	0.000455648	-0.020497212	0.54807728	0.545977
	5.09167E-05	2.72161E-05	0.001646805	0.000112732	0.002222422	0.026345877	
r2	0.999709348	0.002078905	#N/A	#N/A	#N/A	#N/A	

COP=EER/3.413= 3.926164665