EnergyPlus Testing with Global Energy Balance Test

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1 TEST OBJECTIVES AND OVERVIEW

1.1 Test Type: Comparative

The EnergyPlus Global Energy Balance Test checks the accuracy of EnergyPlus in regards to energy balances at various boundary volumes when simulating the operation of HVAC systems and equipment. The test procedure makes use of ANSI/ASHRAE Standard 140-2007 procedures for generating hourly equipment loads and ASHRAE Standard 140-2007 weather files. The test suites described within this report are for testing of:

a) EnergyPlus DX cooling system referred to within EnergyPlus by the object named ZoneHVAC:WindowAirConditioner with electric baseboard heat (ZoneHVAC:Baseboard:Convective:Electric)

b) EnergyPlus hydronic heating/cooling system which utilizes chilled water, hot water and condenser water loops along with an electric chiller (Chiller:Electric:EIR), cooling tower (CoolingTower:SingleSpeed), and gas-fired boiler (Boiler:HotWater) to provide cooling and heating to a 4-pipe fan coil system (ZoneHVAC:FourPipeFanCoil).

1.2 Test Suite: EnergyPlus Global Energy Balance Test Description

The EnergyPlus Global Energy Balance Test makes use of the basic test building geometry and envelope described as Case E100 in Section 5.3.1 of ANSI/ASHRAE Standard 140-2007, *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 as specified in Standard 140 is intended as a near-adiabatic cell with cooling and heating loads driven by user specified internal gains. For Global Energy Balance Test purposes, the building envelope is made totally adiabatic so that the cooling or heating load in the space during any hour of the simulation is solely due to internal loads. How this was done in EnergyPlus is discussed further in Section 1.2.2. Material properties for the building envelope as specified in Standard 140 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.

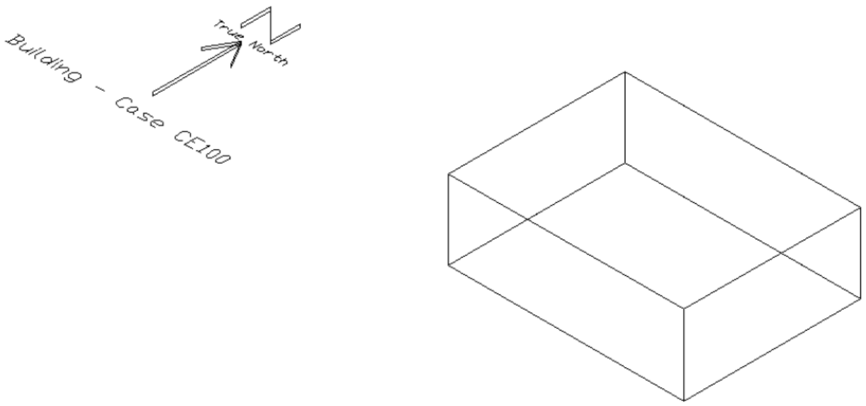


Figure 1 Base Building Geometry - Isometric View of Southeast Corner

Wall, Roof and Floor Construction:

Element	k (W/m-K)	Thickness (m)	U (W/m^2-K)	R (m^2-K/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

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 another surface 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 load or heating load in the space each hour was always exactly equal to the total of the internal space gains.

1.3 Window Air Conditioner Global Energy Balance Test

1.3.1 Internal Loads

Two different types of tests were conducted with varying internal loads: a limited daily comparison test with cooling only and an annual comparison test with cooling and heating.

1.3.1.1 Daily Comparison Test

In order to create a cooling load for the cooling system, various internal gain scenarios are imposed on the building interior space according to a fixed schedule which holds the internal load constant throughout a certain test duration. Five types of internal loads (lights, electric equipment, other equipment, gas equipment and steam equipment) which can be modeled by EnergyPlus are tested for sensible, latent, radiant, convective, etc. fractions to test the program's ability to properly transfer these space loads to the HVAC system. Table 1 describes eight test cases (A through H), each of two day duration, and the internal load schedule by day of the simulation. The first day of each case is simulated to allow steady state to be achieved. Energy balances are then done for the second day of each test case. Zone 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.

1.3.1.2 Annual Comparison Test

A second test was also performed with internal loads that created either a heating load or cooling load in the space for each month over a 12 month period. A constant space cooling load of 1,000 W/hr was scheduled for the cooling season which ran from May 1st through September 30th. A constant space heating load of –1,000 W/hr was scheduled for the heating season which ran from January 1st through April 30th and October 1st through December 31st. Zone 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. Table 2 describes the internal load schedules used for each month of the test (Test Cases I through T).

Table 1 Schedule of Internal Loads for Daily Test Cases – Window AC System

Case	Day	Hours	Electric Light Level (W)	Electric Equip. Level (W)	Other Equip. Level (W)	Gas Equip. Level (W)	Steam Equip. Level (W)	Internal Load Fraction Latent	Internal Load Fraction Radiant
	1-Jan	1 - 24	0	0	0	0	0	0.0	0.0
A	2-Jan	1 - 24	0	0	0	0	0	0.0	0.0
	3-Jan	1 - 24	1,000	0	0	0	0	0.0	0.0
B	4-Jan	1 - 24	1,000	0	0	0	0	0.0	0.0
	5-Jan	1 - 24	1,000	1,000	0	0	0	0.0	0.0
C	6-Jan	1 - 24	1,000	1,000	0	0	0	0.0	0.0
	7-Jan	1 - 24	1,000	1,000	1,000	0	0	0.0	0.0
D	8-Jan	1 - 24	1,000	1,000	1,000	0	0	0.0	0.0
	9-Jan	1 - 24	1,000	1,000	1,000	1,000	0	0.0	0.0
E	10-Jan	1 - 24	1,000	1,000	1,000	1,000	0	0.0	0.0
	11-Jan	1 - 24	1,000	1,000	1,000	1,000	1,000	0.0	0.0
F	12-Jan	1 - 24	1,000	1,000	1,000	1,000	1,000	0.0	0.0
	13-Jan	1 - 24	0	0	1,000	0	0	0.0	0.2
G	14-Jan	1 - 24	0	0	1,000	0	0	0.0	0.2
	15-Jan	1 - 24	0	0	1,000	0	0	0.3	0.0
H	16-Jan	1 - 24	0	0	1,000	0	0	0.3	0.0

Table 2 Schedule of Internal Loads for Annual Test Case – Window AC System with Baseboard Heat

Case	Month	Other Equip. Level (W)	Internal Load Amount Convective (%)
I	Jan	-1,000	100.0
J	Feb	-1,000	100.0
K	Mar	-1,000	100.0
L	Apr	-1,000	100.0
M	May	1,000	100.0
N	Jun	1,000	100.0
O	Jul	1,000	100.0
P	Aug	1,000	100.0
Q	Sep	1,000	100.0
R	Oct	-1,000	100.0
S	Nov	-1,000	100.0
T	Dec	-1,000	100.0

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

- Zone air is perfectly mixed
- Supply air fan has the following characteristics
  Cycles on when compressor operates
  Flow rate = 0.425 m3/s
  Located in the air stream and adds heat to the air stream
  Fan efficiency = 0.5
  Delta pressure = 10 Pa
  Motor efficiency = 0.9
- No outside air; no exhaust air
- Non-proportional-type thermostat, heat always off, cooling on if zone air temperature >22.2°C (72°F)

1.3.3 HVAC Cooling System

The mechanical cooling system specified in Standard 140 is a simple unitary vapor compression cooling system with air cooled condenser and indoor evaporator coil, 100% convective air system, no outside air or exhaust air, single speed, draw-through air distribution fan, indoor and outdoor fans cycle on/off with compressor, no cylinder unloading, no hot gas bypass, crankcase heater and other auxiliary energy = 0. Performance characteristics at ARI rating conditions of 35.0°C outdoor dry-bulb, 26.7°C cooling coil entering dry-bulb and 19.4°C cooling coil entering wet-bulb as presented in Table 26c of Standard 140 is:

Gross Total Capacity	8,818	W
Airflow	0.425	m3/s
Compressor Power	1858	W
Outdoor Fan Power	108	W
Indoor Fan Power	230	W
COP (includes outdoor fan)	4.16	

1.3.4 Zone Heating System

For the annual comparison test, an electric baseboard convective heating system was added to the zone to provide any hourly heating that the zone required. The heating capacity of the baseboard was set to 1100 W and was assumed to be 100% efficient.

1.3.5 Weather Data

1.3.5.1 Daily Comparison Test

A three-month long (January – March) TMY format weather file provided as part of ANSI/ASHRAE Standard 140-2007 with the file name of CE100A.TM2 was used for the daily test case simulations. The outdoor dry-bulb temperature of 46.1°C is constant for every hour of the three-month long period.

1.3.5.2 Annual Comparison Test

For the 12 month annual simulation test case, a TMY2 format weather file for Chicago O'hare converted to EnergyPlus epw format (IL_Chicago_TMY2.epw) was used for the simulation.

1.3.6 Summary of Test Cases

Eight test cases (A through H) as summarized in Table 1 are designed to test the accuracy of the EnergyPlus Window AC system to handle internal space gains and the ability of the cooling system to satisfy these loads. Twelve additional test cases (I through T) as summarized in Table 2 perform a similar series of tests but for a one year period.

1.3.7 Simulation and Reporting Period

A 16 day simulation period from January 1 through January 16 was used to cover the full range of scheduled internal loads as described in Table 1. The 12 month annual simulation period which used the internal load schedule described in Table 2 was January 1 through December 31.

1.3.8 Output Data Requirements

The following hourly output data as a minimum are required to test the accuracy of EnergyPlus using the Global Energy Balance Test:

- Hourly internal load (sensible, latent and total) for each type of internal space gain which is present in Wh
- Hourly space cooling load (sensible, latent and total) in Wh
- Hourly amount of cooling performed by the DX cooling coil (sensible, latent and total) in Wh
- Hourly HVAC system cooling (sensible, latent and total) delivered to the space in Wh
- Hourly resulting space temperature in C
- Hourly electric cooling energy used by the HVAC system
- Hourly electric energy used by the HVAC system supply fan

1.4 Hydronic Heating/Cooling System Global Energy Balance Test

Similar to the Global Energy Balance Test described in Section 1.3 for the Window Air Conditioner, a limited daily comparison test and annual comparison test with varying internal space loads are also prescribed for a typical hydronic heating/cooling system as further described below which contains:

- Hot water loop containing
  - Simple hot water boiler
  - Hot water pump

- Chilled water loop containing
  - Water chiller
  - Chilled water pump

- Condenser water loop containing
  - Single speed cooling tower
  - Condenser water pump

- Air loop containing
  - Four-pipe fan coil unit serving one zone
  - Constant speed fan
  - Water heating coil
  - Water cooling coil.

1.4.1 Internal Loads

Two different types of tests were conducted with varying internal loads: a limited daily comparison test and an annual comparison test.

1.4.1.1 Daily Comparison Test

The same eight internal load schedules that were used for the Window Air Conditioner global energy test (see Section 1.3.1.1) are also used here for the limited daily comparison test for the hydronic heating/cooling system except that the magnitude of the internal load is increased to a constant 10,000 W each hour. Table 3 describes Test Cases A through H.

1.4.1.2 Annual Comparison Test

A constant space cooling load of 10,000 W/hr was scheduled for the cooling season which ran from May 1st through September 30th. A constant space heating load of –10,000 W/hr was scheduled for the heating season which ran from January 1st through April 30th and October 1st through December 31st. Zone internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of cooling and heating that are not related to the operation of the mechanical heating or cooling equipment or the 4-pipe fan coil HVAC system. Table 4 describes the internal load schedules used for each month of the test (Test Cases I through T).

Table 3 Schedule of Internal Loads for Daily Test Cases – Hydronic Heating/Cooling System

Case	Day	Hours	Electric Light Level (W)	Electric Equip. Level (W)	Other Equip. Level (W)	Gas Equip. Level (W)	Steam Equip. Level (W)	Internal Load Fraction Latent	Internal Load Fraction Radiant
A	1-Jan	1 - 24	0	0	-10,000	0	0	0.0	0.0
	2-Jan	1 - 24	0	0	-10,000	0	0	0.0	0.0
B	3-Jan	1 - 24	10,000	0	0	0	0	0.0	0.0
	4-Jan	1 - 24	10,000	0	0	0	0	0.0	0.0
C	5-Jan	1 - 24	10,000	10,000	0	0	0	0.0	0.0
	6-Jan	1 - 24	10,000	10,000	0	0	0	0.0	0.0
D	7-Jan	1 - 24	10,000	10,000	10,000	0	0	0.0	0.0
	8-Jan	1 - 24	10,000	10,000	10,000	0	0	0.0	0.0
E	9-Jan	1 - 24	10,000	10,000	10,000	10,000	0	0.0	0.0
	10-Jan	1 - 24	10,000	10,000	10,000	10,000	0	0.0	0.0
F	11-Jan	1 - 24	10,000	10,000	10,000	10,000	10,000	0.0	0.0
	12-Jan	1 - 24	10,000	10,000	10,000	10,000	10,000	0.0	0.0
G	13-Jan	1 - 24	0	0	10,000	0	0	0.0	0.2
	14-Jan	1 - 24	0	0	10,000	0	0	0.0	0.2
H	15-Jan	1 - 24	0	0	10,000	0	0	0.3	0.0
	16-Jan	1 - 24	0	0	10,000	0	0	0.3	0.0

Table 4 Schedule of Internal Loads for Annual Test Case – Hydronic Heating/Cooling System

Case	Month	Other Equip. Level (W)	Internal Load Amount Convective (%)
I	Jan	-10,000	100.0
J	Feb	-10,000	100.0
K	Mar	-10,000	100.0
L	Apr	-10,000	100.0
M	May	10,000	100.0
N	Jun	10,000	100.0
O	Jul	10,000	100.0
P	Aug	10,000	100.0
Q	Sep	10,000	100.0
R	Oct	-10,000	100.0
S	Nov	-10,000	100.0
T	Dec	-10,000	100.0

1.4.2 Air Distribution System

A simple air distribution system was modeled as a 4-pipe fan coil HVAC system (EnergyPlus object ZoneHVAC:FourPipeFanCoil) with the following characteristics to provide whatever heating or 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
- Zone air is perfectly mixed
- No outside air; no exhaust air

- Indoor circulating fan autosized based on heating and cooling design day conditions (total efficiency = 50%) which operates against a 100 Pa delta pressure and has its motor (motor efficiency = 90%) located in the air stream
- Non-proportional-type single heating/cooling setpoint thermostat set at a temperature of 22.2°C (72°F)
- Heating provided by hot water heating coil and cooling provided by chilled water cooling coil, both of which are autosized based on heating and cooling design conditions.

1.4.3 Central Plant Heating Equipment

The central plant heating equipment was a constant flow natural gas-fired hot water boiler (EnergyPlus object Boiler:HotWater) whose full load heating efficiency is assumed to be 80%. The boiler was autosized by EnergyPlus based on winter design day conditions. Hot water is supplied to a hot water loop which includes the HVAC system heating coil.

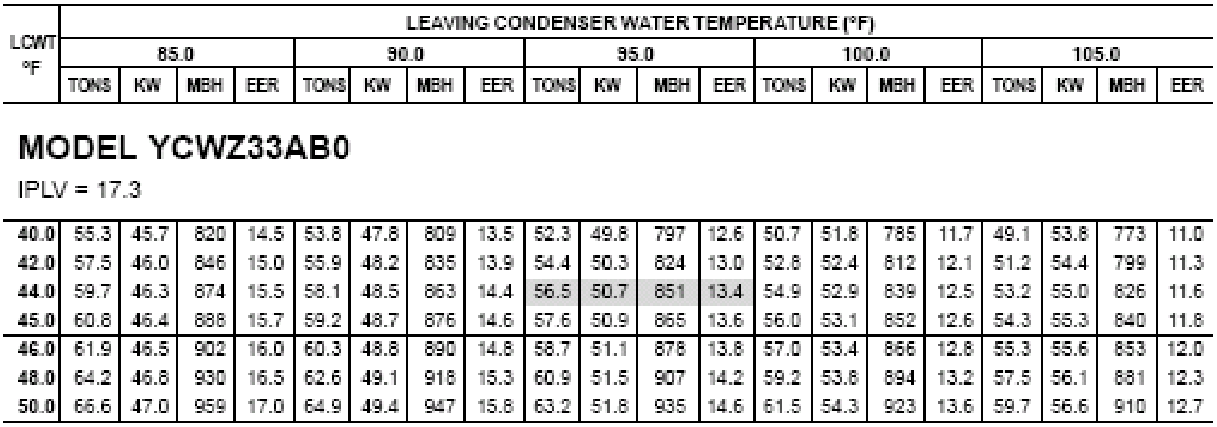
Other simulation assumptions for the heating plant included:

- Hot water pump with a motor efficiency of 90% was autosized to operate against a 500,000 Pa head. Motor located outside of fluid and adds no heat to fluid..
- Hot water loop piping is assumed to be perfectly insulated such that the entire amount of heating provided by the boiler plus the pump heat during each time increment goes completely to heat the space.
- Hot water flow is assumed to be constant.
- Boiler was oversized by 10%.

1.4.4 Central Plant Cooling Equipment

Cooling was 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 5 where data are in English units. Although the performance data shown in Table 5 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. The water chiller provides chilled water to a chilled water loop which includes the HVAC system cooling coil. Condenser water is supplied to the chiller condenser from a condenser water loop which includes a cooling tower.

Table 5 Performance Data for Model Water Cooled Electric Reciprocating Chiller (York)



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
MODEL YCWZ33AB0																				
IPLV = 17.3																				
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 5 is for a 10°F range on both the chilled water and condenser water temperatures. Other simulation assumptions included:

- Chilled water and condenser water pumps are autosized by EnergyPlus using summer design day conditions with chilled water pump operating against a 500,000 Pa head and the condenser water pump operating against a 500,000 Pa head. Motors located outside of fluid and add no heat to the fluid.
- Chilled water and condenser water loop piping are assumed to be perfectly insulated such that the entire amount of cooling provided by the chiller, less any heat added by the chilled water pump during each time increment, goes completely to cool the space.
- Chilled water and condenser water flows are assumed to be constant.
- Water chiller was oversized by 10%.

1.4.5 Weather Data

1.4.5.1 Design Day Conditions

Chicago design day weather conditions were used to size the heating and cooling equipment for both of the daily and annual comparison tests. Those conditions are as follows:

Location: CHICAGO-OHARE
Latitude: 41.98 deg
Longitude: -87.9 deg
Time Zone: -6.0
Elevation: 201.0 m

Annual Heating 99% Design Conditions DB

-17.3	Maximum Dry-Bulb Temperature {C}
0.0	Daily Temperature Range {deltaC}
99063.	Barometric Pressure {Pa}
4.9	Wind Speed {m/s}
270	Wind Direction {deg}
0.0	Sky Clearness
21	Day Of Month
1	Month

Annual Cooling 1% Design Conditions DB/MCWB

31.5	Maximum Dry-Bulb Temperature {C}
10.7	Daily Temperature Range {deltaC}
23.0	Humidity Indicating Conditions (wet-bulb) at Max Dry-Bulb
99063.	Barometric Pressure {Pa}
5.3	Wind Speed {m/s}
230	Wind Direction {deg}
1.0	Sky Clearness
21	Day Of Month
7	Month

1.4.5.2 Daily Comparison Test

A three-month long (January – March) TMY2 format weather file provided as part of ANSI/ASHRAE Standard 140-2007 with the file name of CE100A.TM2 was used for the daily test case simulations. The numeric code that is part of the file name represents the outdoor dry-bulb temperature (without the decimal) used in the weather file. The outdoor dry-bulb temperature of 46.1°C is constant for every hour of the three-month long period.

1.4.5.3 Annual Comparison Test

A TMY2 format weather file for Chicago O'Hare converted to EnergyPlus epw format (IL_Chicago_TMY2.epw) was used for the simulations required as part of this 12-month test series.

1.4.6 Summary of Test Cases

The eight test cases (A through H), as summarized in Table 3, are designed to test the accuracy of an EnergyPlus hydronic heating/cooling system with four pipe fan coil HVAC system to handle internal space gains and the ability of the heating and cooling equipment to satisfy these loads. Twelve additional test cases (I through T), as summarized in Table 4, perform a similar series of tests but for a one year period.

1.4.7 Simulation and Reporting Period

A 16 day simulation period from January 1 through January 16 was used to cover the full range of scheduled internal loads as described in Table 3. The 12 month annual simulation period which used the internal load schedule described in Table 4 was January 1 through December 31.

1.4.8 Output Data Requirements

The following hourly output data as a minimum are required to test the accuracy of EnergyPlus using this Global Energy Balance Test:

- Hourly internal load (sensible, latent and total) for each type of internal space gain which is present in Wh
- Hourly space cooling or heating load (sensible, latent and total) in Wh
- Hourly amount of cooling performed by the cooling coil (sensible, latent and total) in Wh
- Hourly amount of heating performed by the heating coil in Wh
- Hourly HVAC system cooling (sensible, latent and total) delivered to the space in Wh
- Hourly HVAC system heating delivered to the space in Wh
- Hourly electric consumption of the HVAC fan and amount of fan heat added to the air stream in Wh
- Hourly resulting space temperature in C
- Hourly resulting space humidity ratio
- Hourly cooling output by the central plant water chiller
- Hourly heating output by the central plant hot water boiler
- Hourly cooling load on the cooling tower in Wh
- Hourly electric consumption of the water chiller in Wh
- Hourly electric consumption of the chilled water pump, hot water pump and condenser water pump and amount of heat added to water loop in Wh

2 MODELER REPORT

2.1 Modeling Methodology

2.1.1 Window Air Conditioner

The EnergyPlus Window Air Conditioner model is a simple unitary vapor compression cooling system. This system is specified in EnergyPlus as ZoneHVAC:WindowAirConditioner and consists of three modules for which specifications can be entered: DX cooling coil, indoor fan and outside air mixer. The outside air quantity was set to 0.0 m3/s. The indoor fan delta pressure was set to 0.0 Pa in order to zero out the possibility of any fan motor heat being added to the air stream. EnergyPlus has several DX cooling coil models to select from. The Coil:Cooling:DX:SingleSpeed model was used for this test. The performance characteristics of this DX coil model were set as described below in accordance with performance characteristics presented in Standard 140. The zone thermostat was modeled as a ThermostatSetpoint:SingleHeatingOrCooling type with a constant setting of 22.2°C throughout the simulation period.

The building internal loads are simulated each hour to determine the zone load that the mechanical HVAC system must satisfy. The DX coil model then uses performance information at rated conditions along with curve fits for variations in total capacity, energy input ratio and part load fraction to determine performance at part load conditions. Sensible/latent capacity splits are determined by the rated sensible heat ratio (SHR) and the apparatus dewpoint/bypass factor approach.

Five performance curves are required by the EnergyPlus window air conditioner model as described below. Performance data for a range of operating conditions as presented in Table 26c of Standard 140 was used along with the Excel LINEST function to perform a least squares curve fit of the performance data and determine the coefficients of the curves.

1) The **total cooling capacity modifier curve (function of temperature)** is a bi-quadratic curve with two independent variables: wet bulb temperature of the air entering the cooling coil, and dry bulb temperature of the air entering the air-cooled condenser. The output of this curve is multiplied by the rated total cooling capacity to give the total cooling capacity at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures).

   CoolCapFT = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
   where
   wb = wet-bulb temperature of air entering the cooling coil
   edb = dry-bulb temperature of the air entering the air-cooled condenser
   a = 0.43863482
   b = 0.04259180
   c = 0.00015024
   d = 0.00100248

e = -0.00003314
f = -0.00046664

Data points were taken from first three columns of Table 26c of Standard 140. CoolCap data was normalized to ARI rated net capacity of 8,181 W, i.e. CoolCapFT = 1.0 at 19.4 C wb and 35.0 C edb.

2) The **energy input ratio (EIR) modifier curve (function of temperature)** is a bi-quadratic curve with two independent variables: wet bulb temperature of the air entering the cooling coil, and dry bulb temperature of the air entering the air-cooled condenser. The output of this curve is multiplied by the rated EIR (inverse of the rated COP) to give the EIR at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures).

   EIRFT = a + b*wb + c*wb**2 + d*edb + e*edb**2 + f*wb*edb
   where:
   wb = wet-bulb temperature of air entering the cooling coil
   edb = dry-bulb temperature of the air entering the air-cooled condenser
   a = 0.77127580
   b = -0.02218018
   c = 0.00074086
   d = 0.01306849
   e = 0.00039124
   f = -0.00082052

   edb and wb data points were taken from the first two columns of Table 26c of Standard 140. Energy input data points for corresponding pairs of edb and wb were taken from column labeled “Compressor Power” in Table 26c of Standard 140 with an additional 108 W added to them for outdoor fan power. EIR is energy input ratio [(compressor + outdoor fan power)/cooling capacity] normalized to ARI rated conditions, i.e. EIRFT = 1.0 at 19.4 C wb and 35.0 C edb.

3) The **total cooling capacity modifier curve (function of flow fraction)** is a quadratic curve with one independent variable: ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total cooling capacity and the total cooling capacity modifier curve (function of temperature) to give the total cooling capacity at the specific temperature and air flow conditions at which the coil is operating.

   CAPFFF = a + b*ff + c*ff**2
   where:
   ff = fraction of full load flow

   Since the indoor fan always operates at constant volume flow, the modifier will be 1.0, therefore:
   a = 1.0
   b = 0.0
   c = 0.0

4) The **energy input ratio (EIR) modifier curve (function of flow fraction)** is a quadratic curve with one independent variable: ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated EIR (inverse of the rated COP) and the EIR modifier curve (function of temperature) to give the EIR at the specific temperature and airflow conditions at which the coil is operating.

   EIRFFF = a + b*ff + c*ff**2
   where:
   ff = fraction of full load flow

   Since the indoor fan always operates at constant volume flow, the modifier will be 1.0, therefore:
   a = 1.0
   b = 0.0
   c = 0.0

5) The **part load fraction correlation (function of part load ratio)** is a quadratic curve with one independent variable: part load ratio (sensible cooling load / steady-state sensible cooling capacity). The output of this curve is used in combination with the rated EIR and EIR modifier curves to give the "effective" EIR for a given simulation time step. The part load fraction correlation accounts for efficiency losses due to compressor cycling.

   PLFFPLR = a + b*PLR + c*PLR**2
   where:
   PLR = part load ratio

   Part load performance was specified in Figure 10 of Standard 140, therefore:

   a = 0.771
   b = 0.229
   c = 0.0

2.1.2 Hydronic Heating/Cooling System

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

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

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 described here the Boiler Heating Capacity was autosized based on winter design day conditions and the Boiler Efficiency was set to 80%. The resulting boiler and hot water pump capacities and flows were as follows:

- For Daily Comparison Test

Boiler capacity	10,996 W
Hot water pump flow rate	0.000239 m3/s
Hot water pump size	170.3 W

- For Annual Comparison Test

Boiler capacity	10,996 W
Hot water pump flow rate	0.000239 m3/s
Hot water pump size	170.3 W

The boiler capacity is the same for both tests since the maximum heating load for each test plus a 10% oversize factor results in the same design load (see Tables 3 and 4).

The Fuel Used equation which describes the part load performance of the hot water boiler has coefficient values of:

C1 = 0.97
C2 = 0.0633
C3 = -0.0333

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 1.1
- Boiler flow mode, parameter set to "constant flow"
- Parasitic electric load, parameter set to 0.0 W

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 to “autosize”
- 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 (m3/s), parameter set to “autosize”
- Design condenser volumetric water flow rate (m3/s), parameter set to “autosize”
- Minimum part-load ratio, left to default to 0.1
- Maximum part-load ratio, set at 1.2

The cooling tower was modeled using the EnergyPlus object CoolingTower:SingleSpeed. All size related parameters were left to autosize.

The resulting chiller, cooling tower, chilled water pump and condenser water pump capacities and flows were as follows:

- For Daily Comparison Test

Chiller capacity	55,005 W
Chilled water pump flow rate	0.00197 m3/s
Chilled water pump size	1,405.2 W
Cooling tower fan size	724.7 W
Cooling tower fan flow rate	1.907 m3/s
Condenser water pump size	2,100 W
Condenser water pump flow rate	0.00295 m3/s

- For Annual Comparison Test

Chiller capacity	11,005 W
Chilled water pump flow rate	0.000395 m3/s
Chilled water pump size	281.1 W
Cooling tower fan size	144.9 W
Cooling tower fan flow rate	0.390 m3/s
Condenser water pump size	420.1 W
Condenser water pump flow rate	0.000590 m3/s

The chiller capacity for the daily comparison test is five times greater than that for the annual comparison test because of the difference in internal load schedules (see Tables 3 and 4). A 10% oversize factor was also included when calculating the cooling design load for each test.

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. In addition, the wall layers were defined using the Material feature of EnergyPlus. The wall, roof and floor constructions described in Section 5.3.1 from Standard 140 are massless and typically these constructions would be defined using the Material:NoMass feature of EnergyPlus where only the thermal resistance of the material layer along with surface absorptances are required. When this approach was used however, EnergyPlus generated a severe warning as indicated below:

```
** Severe  ** This building has no thermal mass which can cause an unstable solution.
**   ~~~   ** Use Material for all opaque material types except very light
              insulation layers.
```

To avoid this possible severe error, the wall, roof and floor materials were defined using the construction as follows:

```
Material,
```

```
        INSULATION-EXT,          !- Name
        VeryRough,               !- Roughness
        1.0,                     !- Thickness {m}
        3.9999999E-02,           !- Conductivity {w/m-K}
        32.03,                   !- Density {kg/m3}
        830.0,                   !- Specific Heat {J/kg-K}
        0.0000001,               !- Thermal Emittance
        0.0000001,               !- Solar Absorptance
        0.0000001;               !- Visible Absorptance
    Material,
        INSULATION-INT,          !- Name
        VeryRough,               !- Roughness
        1.0,                     !- Thickness {m}
        3.9999999E-02,           !- Conductivity {w/m-K}
        32.03,                   !- Density {kg/m3}
        830.0,                   !- Specific Heat {J/kg-K}
        0.0000001,               !- Thermal Emittance
        0.0000001,               !- Solar Absorptance
        0.0000001;               !- Visible Absorptance
    Construction,
        LTWALL,                  ! Construction Name
        INSULATION-EXT,          !- Outside layer
        INSULATION-INT;          !- Layer 2
```

2.3 Software Errors Discovered

During the initial testing of EnergyPlus with the new global energy balance test suite, one software error was discovered as part of the testing which was subsequently corrected:

- The sensible and latent cooling coil loads did not agree with the sensible and latent cooling loads reported by the Window AC HVAC system. There was agreement however with the total cooling load. This discrepancy was corrected in EnergyPlus version 1.4.0.020.

- Plant solver routines were reworked which caused minor changes in some results (changed in EnergyPlus version 7.0.0.036)

2.4 Results

2.4.1 Window Air Conditioner

For the Window AC Global Energy Balance Test energy balances were performed at the following boundary volumes:

- Zone boundary
- Coil boundary
- HVAC system boundary

At each level all energy flows into and out of the boundary volume are assessed using standard output variables and node values to determine energy balances. Before such energy balances are performed, the results of the simulation are first examined to ensure that the space temperature setpoint is maintained for all hours and space humidity ratios are constant for all hours indicating that all space loads have been met.

2.4.1.1 Daily Comparison Test

Daily comparison results from running the Global Energy Balance Test with EnergyPlus 7.0.0.036 for the one-zone building described in Section 1 which is cooled by an EnergyPlus Window AC system are shown in spreadsheet format on the following three pages for:

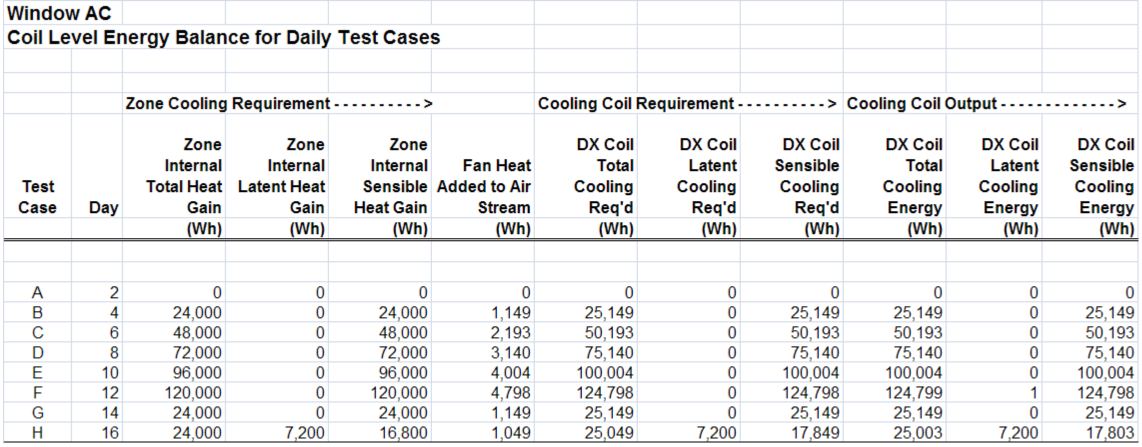
- Zone Level Energy Balance
- Coil Level Energy Balance
- HVAC Cooling System Energy Balance
- Equipment Performance Summary

Window AC

Zone Level Energy Balance For Daily Test Cases

		Zone Energy Input -->											
Test Case	Day	Daily Lights Consump. (Wh)	Daily Electric Equipment Consump. (Wh)	Daily Other Equipment Consump. (Wh)	Daily Gas Equipment Consump. (Wh)	Daily Steam Equipment Consump. (Wh)	Internal Loads % Latent	Internal Loads % Radiant	Daily Total Internal Consump. (Wh)	Zone Air Temp. Min (C)	Zone Air Temp. Max (C)	Zone Air Humidity Ratio Min ( )	Zone Air Humidity Ratio Max ( )
	1	0	0	0	0	0	0	0	0	22.0	22.0	0.00969	0.00969
A	2	0	0	0	0	0	0	0	0	22.0	22.0	0.00969	0.00969
	3	24,000	0	0	0	0	0	0	24,000	22.2	22.2	0.00747	0.00897
B	4	24,000	0	0	0	0	0	0	24,000	22.2	22.2	0.00747	0.00747
	5	24,000	24,000	0	0	0	0	0	48,000	22.2	22.2	0.00747	0.00747
C	6	24,000	24,000	0	0	0	0	0	48,000	22.2	22.2	0.00747	0.00747
	7	24,000	24,000	24,000	0	0	0	0	72,000	22.2	22.2	0.00747	0.00747
D	8	24,000	24,000	24,000	0	0	0	0	72,000	22.2	22.2	0.00747	0.00747
	9	24,000	24,000	24,000	24,000	0	0	0	96,000	22.2	22.2	0.00747	0.00747
E	10	24,000	24,000	24,000	24,000	0	0	0	96,000	22.2	22.2	0.00747	0.00747
	11	24,000	24,000	24,000	24,000	24,000	0	0	120,000	22.2	22.2	0.00747	0.00747
F	12	24,000	24,000	24,000	24,000	24,000	0	0	120,000	22.2	22.2	0.00747	0.00747
	13	0	0	24,000	0	0	0	20	24,000	22.2	22.2	0.00746	0.00747
G	14	0	0	24,000	0	0	0	20	24,000	22.2	22.2	0.00746	0.00746
	15	0	0	24,000	0	0	30	0	24,000	22.2	22.2	0.00844	0.01065
H	16	0	0	24,000	0	0	30	0	24,000	22.2	22.2	0.01065	0.01065

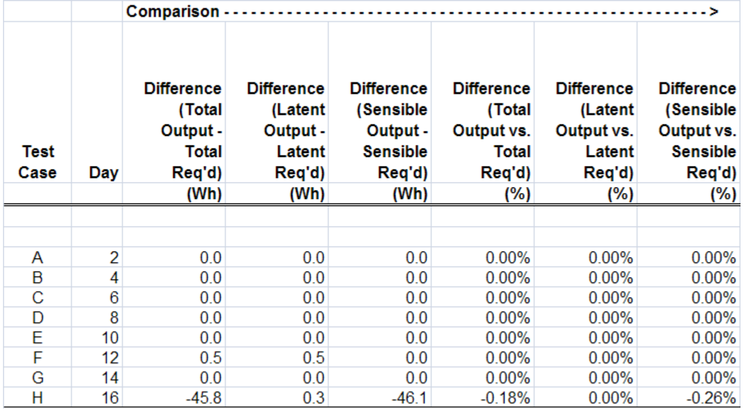
		Zone Energy Output ---------------->				Comparison ----------->	
Test Case	Day	Zone Internal Total Heat Gain (Wh)	Zone Internal Latent Heat Gain (Wh)	Zone Internal Sensible Heat Gain (Wh)		Difference (Total Output - Total Input) (Wh)	Difference (Total Output vs. Total Input) (%)
	1	0	0	0		0	0.00%
A	2	0	0	0		0	0.00%
	3	24,000	0	24,000		0	0.00%
B	4	24,000	0	24,000		0	0.00%
	5	48,000	0	48,000		0	0.00%
C	6	48,000	0	48,000		0	0.00%
	7	72,000	0	72,000		0	0.00%
D	8	72,000	0	72,000		0	0.00%
	9	96,000	0	96,000		0	0.00%
E	10	96,000	0	96,000		0	0.00%
	11	120,000	0	120,000		0	0.00%
F	12	120,000	0	120,000		0	0.00%
	13	24,000	0	24,000		0	0.00%
G	14	24,000	0	24,000		0	0.00%
	15	24,000	7,200	16,800		0	0.00%
H	16	24,000	7,200	16,800		0	0.00%



Window AC

Coil Level Energy Balance for Daily Test Cases

		Zone Cooling Requirement ---------->				Cooling Coil Requirement ---------->			Cooling Coil Output ------------->		
Test Case	Day	Zone Internal Total Heat Gain (Wh)	Zone Internal Latent Heat Gain (Wh)	Zone Internal Sensible Heat Gain (Wh)	Fan Heat Added to Air Stream (Wh)	DX Coil Total Cooling Req'd (Wh)	DX Coil Latent Cooling Req'd (Wh)	DX Coil Sensible Cooling Req'd (Wh)	DX Coil Total Cooling Energy (Wh)	DX Coil Latent Cooling Energy (Wh)	DX Coil Sensible Cooling Energy (Wh)
A	2	0	0	0	0	0	0	0	0	0	0
B	4	24,000	0	24,000	1,149	25,149	0	25,149	25,149	0	25,149
C	6	48,000	0	48,000	2,193	50,193	0	50,193	50,193	0	50,193
D	8	72,000	0	72,000	3,140	75,140	0	75,140	75,140	0	75,140
E	10	96,000	0	96,000	4,004	100,004	0	100,004	100,004	0	100,004
F	12	120,000	0	120,000	4,798	124,798	0	124,798	124,799	1	124,798
G	14	24,000	0	24,000	1,149	25,149	0	25,149	25,149	0	25,149
H	16	24,000	7,200	16,800	1,049	25,049	7,200	17,849	25,003	7,200	17,803



		Comparison -->					
Test Case	Day	Difference (Total Output - Total Req'd) (Wh)	Difference (Latent Output - Latent Req'd) (Wh)	Difference (Sensible Output - Sensible Req'd) (Wh)	Difference (Total Output vs. Total Req'd) (%)	Difference (Latent Output vs. Latent Req'd) (%)	Difference (Sensible Output vs. Sensible Req'd) (%)
A	2	0.0	0.0	0.0	0.00%	0.00%	0.00%
B	4	0.0	0.0	0.0	0.00%	0.00%	0.00%
C	6	0.0	0.0	0.0	0.00%	0.00%	0.00%
D	8	0.0	0.0	0.0	0.00%	0.00%	0.00%
E	10	0.0	0.0	0.0	0.00%	0.00%	0.00%
F	12	0.5	0.5	0.0	0.00%	0.00%	0.00%
G	14	0.0	0.0	0.0	0.00%	0.00%	0.00%
H	16	-45.8	0.3	-46.1	-0.18%	0.00%	-0.26%

		Zone Cooling Requirement - - - - - - - - - - - >				Cooling Delivered to Zone - - - - - - - - - - >		
Test Case	Day	Zone Internal Total Heat Gain (Wh)	Zone Internal Latent Heat Gain (Wh)	Zone Internal Sensible Heat Gain (Wh)		Window AC Total Zone Cooling Energy (Wh)	Window AC Latent Zone Cooling Energy (Wh)	Window AC Sensible Zone Cooling Energy (Wh)
A	2	0	0	0		0	0	0
B	4	24,000	0	24,000		24,000	0	24,000
C	6	48,000	0	48,000		48,000	0.00000000	48,000
D	8	72,000	0	72,000		72,000	0.00000000	72,000
E	10	96,000	0	96,000		96,000	0	96,000
F	12	120,000	0	120,000		120,001	1	120,000
G	14	24,000	0	24,000		24,000	0	24,000
H	16	24,000	7,200	16,800		23,954	7,200	16,754

		Comparison - >					
Test Case	Day	Difference (Total Deliv'd - Total Req'd) (Wh)	Difference (Latent Deliv'd - Latent Req'd) (Wh)	Difference (Sensible Deliv'd - Sensible Req'd) (Wh)	Difference (Total Deliv'd vs. Total Req'd) (%)	Difference (Latent Deliv'd vs. Latent Req'd) (%)	Difference (Sensible Deliv'd vs. Sensible Req'd) (%)
A	2	0.0	0.0	0.0	0.00%	0.00%	0.00%
B	4	0.0	0.0	0.0	0.00%	0.00%	0.00%
C	6	0.0	0.0	0.0	0.00%	0.00%	0.00%
D	8	0.0	0.0	0.0	0.00%	0.00%	0.00%
E	10	0.0	0.0	0.0	0.00%	0.00%	0.00%
F	12	0.5	0.5	0.0	0.00%	0.00%	0.00%
G	14	0.0	0.0	0.0	0.00%	0.00%	0.00%
H	16	-45.8	0.3	-46.1	-0.19%	0.00%	-0.27%

Window AC

Equipment Performance Summary for Daily Test Cases

Test Case	Day	HVAC Cooling Electric Consump. (Wh)	HVAC System Total Cooling (Wh)	HVAC System Average COP	Supply Fan Electric Consump. (Wh)
A	2	0	0		0
B	4	12,166	24,000	1.97	1,149
C	6	23,215	48,000	2.07	2,193
D	8	33,240	72,000	2.17	3,140
E	10	42,394	96,000	2.26	4,004
F	12	50,813	120,001	2.36	4,798
G	14	12,168	24,000	1.97	1,149
H	16	11,317	23,954	2.12	1,049

The following is observed from examining the results:

- Zone Level Energy Balance

  a) For each hour of the second day of each test case the zone setpoint temperature of 22.2 C was maintained and the zone humidity level remained constant

  b) 100% of the internal loads showed up as sensible and latent cooling loads in the space, therefore energy balance at the zone level was achieved.

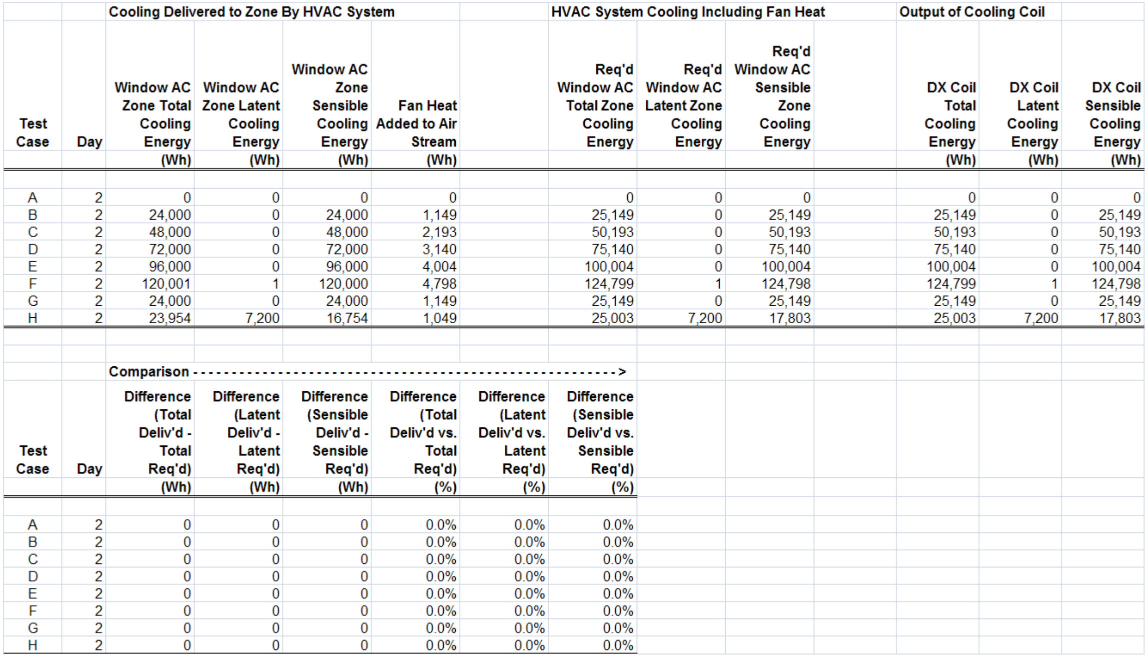
- Coil Level Energy Balance

  a) For all test cases the amount of sensible cooling performed by the cooling coil was equal to the zone sensible cooling requirement plus fan heat except for Case H where there was a very small difference of 0.26%. Sensible energy balance was therefore achieved for all cases except Case H.

  b) For Case H when space latent gains did occur within the space, the amount of latent cooling performed by the cooling coil was less than that required by 0.01% while the total cooling by the cooling coil was differing by only 0.18%. For Case H the internal load is 30% latent and surface temperatures did not reach steady state condition until late in the second day.

- HVAC Cooling System Energy Balance

  a) When comparing the HVAC system cooling delivered to the zone versus the cooling required by the zone, energy balance was achieved for all cases as shown below.



		Cooling Delivered to Zone By HVAC System				HVAC System Cooling Including Fan Heat			Output of Cooling Coil		
Test Case	Day	Window AC Zone Total Cooling Energy (Wh)	Window AC Zone Latent Cooling Energy (Wh)	Window AC Zone Sensible Cooling Energy (Wh)	Fan Heat Added to Air Stream (Wh)	Req'd Window AC Total Zone Cooling Energy	Req'd Window AC Latent Zone Cooling Energy	Req'd Window AC Sensible Zone Cooling Energy	DX Coil Total Cooling Energy (Wh)	DX Coil Latent Cooling Energy (Wh)	DX Coil Sensible Cooling Energy (Wh)
A	2	0	0	0	0	0	0	0	0	0	0
B	2	24,000	0	24,000	1,149	25,149	0	25,149	25,149	0	25,149
C	2	48,000	0	48,000	2,193	50,193	0	50,193	50,193	0	50,193
D	2	72,000	0	72,000	3,140	75,140	0	75,140	75,140	0	75,140
E	2	96,000	0	96,000	4,004	100,004	0	100,004	100,004	0	100,004
F	2	120,001	1	120,000	4,798	124,799	1	124,798	124,799	1	124,798
G	2	24,000	0	24,000	1,149	25,149	0	25,149	25,149	0	25,149
H	2	23,954	7,200	16,754	1,049	25,003	7,200	17,803	25,003	7,200	17,803

		Comparison - >					
Test Case	Day	Difference (Total Deliv'd - Total Req'd) (Wh)	Difference (Latent Deliv'd - Latent Req'd) (Wh)	Difference (Sensible Deliv'd - Sensible Req'd) (Wh)	Difference (Total Deliv'd vs. Total Req'd) (%)	Difference (Latent Deliv'd vs. Latent Req'd) (%)	Difference (Sensible Deliv'd vs. Sensible Req'd) (%)
A	2	0	0	0	0.0%	0.0%	0.0%
B	2	0	0	0	0.0%	0.0%	0.0%
C	2	0	0	0	0.0%	0.0%	0.0%
D	2	0	0	0	0.0%	0.0%	0.0%
E	2	0	0	0	0.0%	0.0%	0.0%
F	2	0	0	0	0.0%	0.0%	0.0%
G	2	0	0	0	0.0%	0.0%	0.0%
H	2	0	0	0	0.0%	0.0%	0.0%

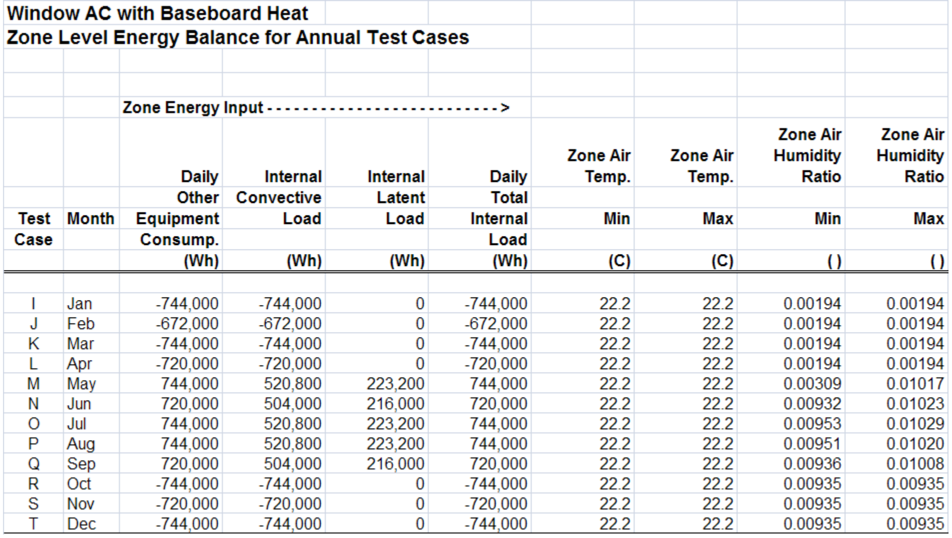
In previous versions of EnergyPlus there were differences between the sensible and latent cooling coil loads versus the sensible and latent cooling loads indicated for the Window AC system for all cases. This error was corrected in EnergyPlus 1.4.0.025.

- Equipment Performance Summary

  a) The Window AC system average COP during each of the test cases ranged from 1.97 to 2.36 while the outdoor drybulb temperature remained constant at 46.1°C. Entering coil wet-bulb temperature for Tests B through F when there was no latent load was about 14°C (dry coil). Full load COP and gross cooling capacity at these conditions for this equipment are 6,250 kW and 2.81. During Test B when the hourly space sensible load was held constant at 1,000 kW and the hourly fan heat was 48 W (PLR = 0.16), the COP degradation factor according to Standard 140 is 0.81. It is expected that the resulting COP during these tests would then be 2.81 x 0.81 = 2.27 which falls within the range of COPs reported above.

2.4.1.2 Annual Comparison Test

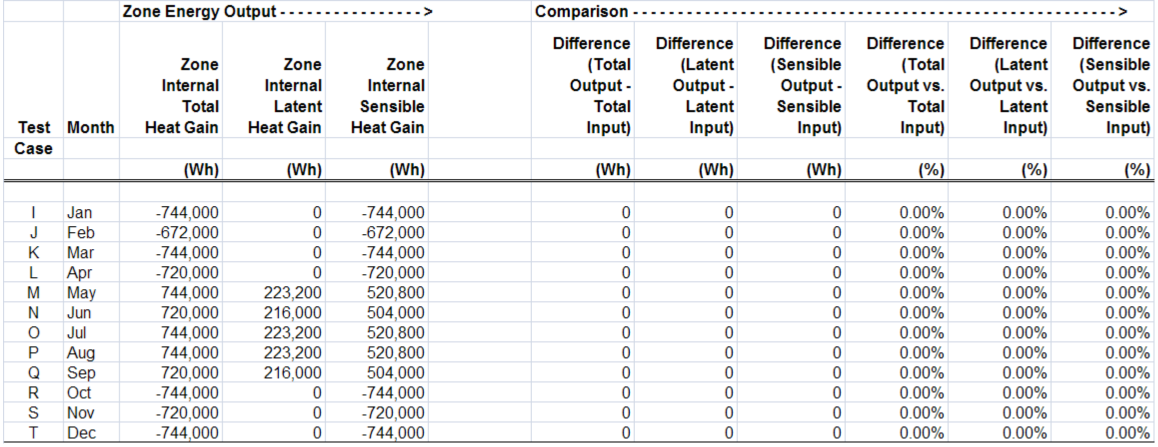
Monthly comparison results from running the Global Energy Balance Test with EnergyPlus 7.0.0.036 for the one-zone building described in Section 1 which is cooled by an EnergyPlus Window AC system and heated by electric baseboard are shown in spreadsheet format on the following four pages for:



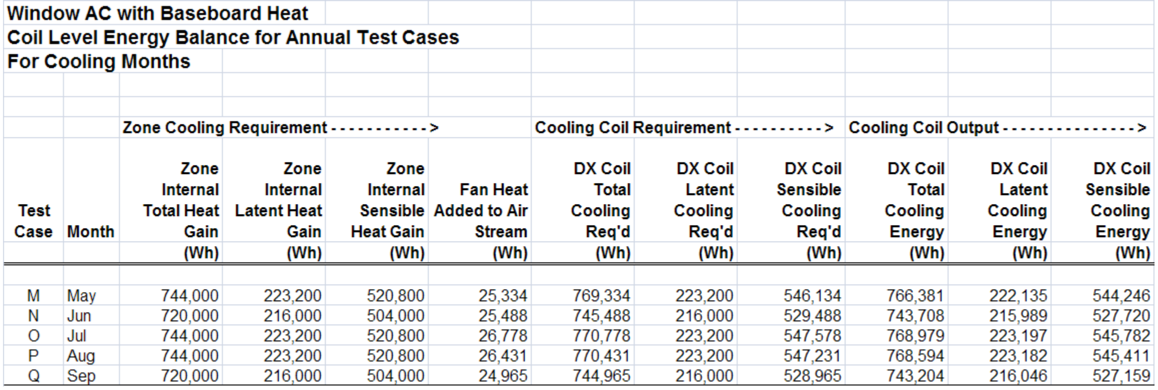
Window AC with Baseboard Heat

Zone Level Energy Balance for Annual Test Cases

Test Case	Month	Zone Energy Input - > Daily Other Equipment Consump. (Wh)	Internal Convective Load (Wh)	Internal Latent Load (Wh)	Daily Total Internal Load (Wh)	Zone Air Temp. Min (C)	Zone Air Temp. Max (C)	Zone Air Humidity Ratio Min ( )	Zone Air Humidity Ratio Max ( )
I	Jan	-744,000	-744,000	0	-744,000	22.2	22.2	0.00194	0.00194
J	Feb	-672,000	-672,000	0	-672,000	22.2	22.2	0.00194	0.00194
K	Mar	-744,000	-744,000	0	-744,000	22.2	22.2	0.00194	0.00194
L	Apr	-720,000	-720,000	0	-720,000	22.2	22.2	0.00194	0.00194
M	May	744,000	520,800	223,200	744,000	22.2	22.2	0.00309	0.01017
N	Jun	720,000	504,000	216,000	720,000	22.2	22.2	0.00932	0.01023
O	Jul	744,000	520,800	223,200	744,000	22.2	22.2	0.00953	0.01029
P	Aug	744,000	520,800	223,200	744,000	22.2	22.2	0.00951	0.01020
Q	Sep	720,000	504,000	216,000	720,000	22.2	22.2	0.00936	0.01008
R	Oct	-744,000	-744,000	0	-744,000	22.2	22.2	0.00935	0.00935
S	Nov	-720,000	-720,000	0	-720,000	22.2	22.2	0.00935	0.00935
T	Dec	-744,000	-744,000	0	-744,000	22.2	22.2	0.00935	0.00935

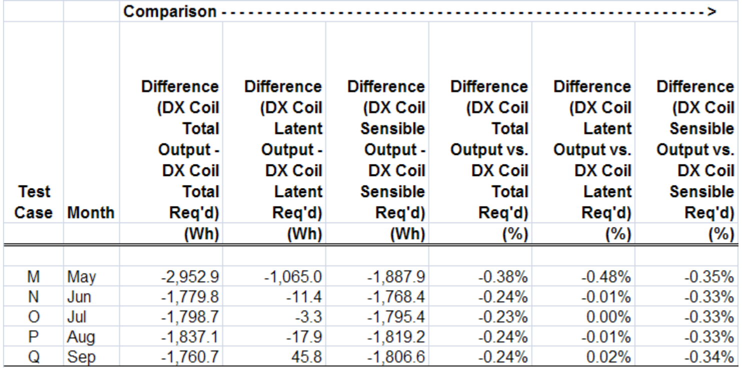


Test Case	Month	Zone Energy Output - - - - - - - - - - - - - - - - > Zone Internal Total Heat Gain (Wh)	Zone Internal Latent Heat Gain (Wh)	Zone Internal Sensible Heat Gain (Wh)	Comparison - > Difference (Total Output - Total Input) (Wh)	Difference (Latent Output - Latent Input) (Wh)	Difference (Sensible Output - Sensible Input) (Wh)	Difference (Total Output vs. Total Input) (%)	Difference (Latent Output vs. Latent Input) (%)	Difference (Sensible Output vs. Sensible Input) (%)
I	Jan	-744,000	0	-744,000	0	0	0	0.00%	0.00%	0.00%
J	Feb	-672,000	0	-672,000	0	0	0	0.00%	0.00%	0.00%
K	Mar	-744,000	0	-744,000	0	0	0	0.00%	0.00%	0.00%
L	Apr	-720,000	0	-720,000	0	0	0	0.00%	0.00%	0.00%
M	May	744,000	223,200	520,800	0	0	0	0.00%	0.00%	0.00%
N	Jun	720,000	216,000	504,000	0	0	0	0.00%	0.00%	0.00%
O	Jul	744,000	223,200	520,800	0	0	0	0.00%	0.00%	0.00%
P	Aug	744,000	223,200	520,800	0	0	0	0.00%	0.00%	0.00%
Q	Sep	720,000	216,000	504,000	0	0	0	0.00%	0.00%	0.00%
R	Oct	-744,000	0	-744,000	0	0	0	0.00%	0.00%	0.00%
S	Nov	-720,000	0	-720,000	0	0	0	0.00%	0.00%	0.00%
T	Dec	-744,000	0	-744,000	0	0	0	0.00%	0.00%	0.00%

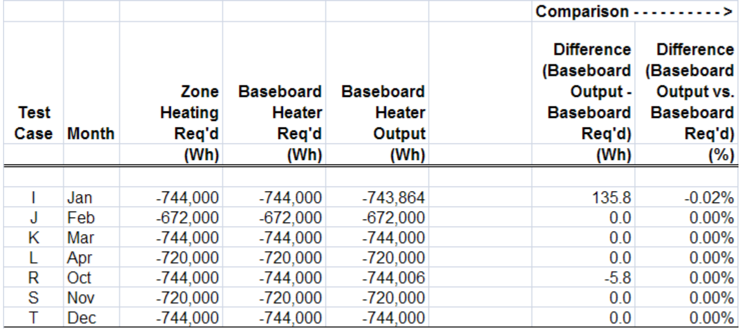


Window AC with Baseboard Heat
Coil Level Energy Balance for Annual Test Cases
For Cooling Months

		Zone Cooling Requirement - - - - - - - - - - - >				Cooling Coil Requirement - - - - - - - - - - >			Cooling Coil Output - - - - - - - - - - - - - - - >		
Test Case	Month	Zone Internal Total Heat Gain (Wh)	Zone Internal Latent Heat Gain (Wh)	Zone Internal Sensible Heat Gain (Wh)	Fan Heat Added to Air Stream (Wh)	DX Coil Total Cooling Req'd (Wh)	DX Coil Latent Cooling Req'd (Wh)	DX Coil Sensible Cooling Req'd (Wh)	DX Coil Total Cooling Energy (Wh)	DX Coil Latent Cooling Energy (Wh)	DX Coil Sensible Cooling Energy (Wh)
M	May	744,000	223,200	520,800	25,334	769,334	223,200	546,134	766,381	222,135	544,246
N	Jun	720,000	216,000	504,000	25,488	745,488	216,000	529,488	743,708	215,989	527,720
O	Jul	744,000	223,200	520,800	26,778	770,778	223,200	547,578	768,979	223,197	545,782
P	Aug	744,000	223,200	520,800	26,431	770,431	223,200	547,231	768,594	223,182	545,411
Q	Sep	720,000	216,000	504,000	24,965	744,965	216,000	528,965	743,204	216,046	527,159



		Comparison - >					
Test Case	Month	Difference (DX Coil Total Output - DX Coil Total Req'd) (Wh)	Difference (DX Coil Latent Output - DX Coil Latent Req'd) (Wh)	Difference (DX Coil Sensible Output - DX Coil Sensible Req'd) (Wh)	Difference (DX Coil Total Output vs. DX Coil Total Req'd) (%)	Difference (DX Coil Latent Output vs. DX Coil Latent Req'd) (%)	Difference (DX Coil Sensible Output vs. DX Coil Sensible Req'd) (%)
M	May	-2,952.9	-1,065.0	-1,887.9	-0.38%	-0.48%	-0.35%
N	Jun	-1,779.8	-11.4	-1,768.4	-0.24%	-0.01%	-0.33%
O	Jul	-1,798.7	-3.3	-1,795.4	-0.23%	0.00%	-0.33%
P	Aug	-1,837.1	-17.9	-1,819.2	-0.24%	-0.01%	-0.33%
Q	Sep	-1,760.7	45.8	-1,806.6	-0.24%	0.02%	-0.34%



						Comparison - - - - - - - - - - >	
Test Case	Month	Zone Heating Req'd (Wh)	Baseboard Heater Req'd (Wh)	Baseboard Heater Output (Wh)		Difference (Baseboard Output - Baseboard Req'd) (Wh)	Difference (Baseboard Output vs. Baseboard Req'd) (%)
I	Jan	-744,000	-744,000	-743,864		135.8	-0.02%
J	Feb	-672,000	-672,000	-672,000		0.0	0.00%
K	Mar	-744,000	-744,000	-744,000		0.0	0.00%
L	Apr	-720,000	-720,000	-720,000		0.0	0.00%
R	Oct	-744,000	-744,000	-744,006		-5.8	0.00%
S	Nov	-720,000	-720,000	-720,000		0.0	0.00%
T	Dec	-744,000	-744,000	-744,000		0.0	0.00%

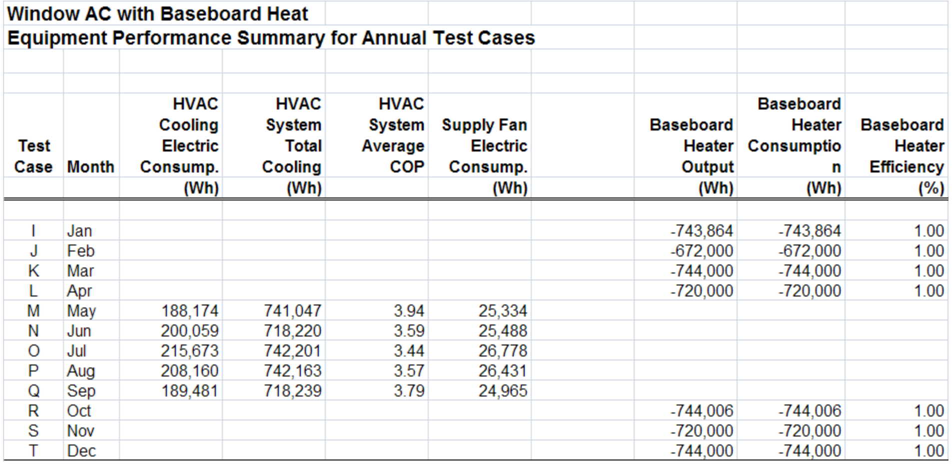
Window AC with Baseboard Heat
HVAC System Level Energy Balance for Annual Test Cases
For Cooling Months

		Zone Cooling Requirement ----------->				Cooling Delivered to Zone --------->		
Test Case	**Month**	**Zone Internal Total Heat Gain (Wh)**	**Zone Internal Latent Heat Gain (Wh)**	**Zone Internal Sensible Heat Gain (Wh)**		**Window AC Total Zone Cooling Energy (Wh)**	**Window AC Latent Zone Cooling Energy (Wh)**	**Window AC Sensible Zone Cooling Energy (Wh)**
M	May	744,000	223,200	520,800		741,047	222,135	518,912
N	Jun	720,000	216,000	504,000		718,220	215,989	502,232
O	Jul	744,000	223,200	520,800		742,201	223,197	519,005
P	Aug	744,000	223,200	520,800		742,163	223,182	518,981
Q	Sep	720,000	216,000	504,000		718,239	216,046	502,193

		Comparison --->					
Test Case	**Month**	**Difference (Total Deliv'd - Total Req'd) (Wh)**	**Difference (Latent Deliv'd - Latent Req'd) (Wh)**	**Difference (Sensible Deliv'd - Sensible Req'd) (Wh)**	**Difference (Total Deliv'd vs. Total Req'd) (%)**	**Difference (Latent Deliv'd vs. Latent Req'd) (%)**	**Difference (Sensible Deliv'd vs. Sensible Req'd) (%)**
M	May	-2,953	-1,065	-1,888	-0.40%	-0.48%	-0.36%
N	Jun	-1,780	-11	-1,768	-0.25%	-0.01%	-0.35%
O	Jul	-1,799	-3	-1,795	-0.24%	0.00%	-0.34%
P	Aug	-1,837	-18	-1,819	-0.25%	-0.01%	-0.35%
Q	Sep	-1,761	46	-1,807	-0.24%	0.02%	-0.36%

Window AC with Baseboard Heat
HVAC System Level Energy Balance for Annual Test Cases
For Heating Months

					Comparison ---------->	
Test Case	**Month**	**Zone Internal Total Heat Gain (Wh)**	**Baseboard Heater Output (Wh)**		**Difference (Baseboard Heat Deliv'd - Zone Heat Req'd) (Wh)**	**Difference (Baseboard Heat Deliv'd vs. Zone Heat Req'd) (%)**
I	Jan	-744,000	-743,864		136	-0.02%
J	Feb	-672,000	-672,000		0	0.00%
K	Mar	-744,000	-744,000		0	0.00%
L	Apr	-720,000	-720,000		0	0.00%
R	Oct	-744,000	-744,006		-6	0.00%
S	Nov	-720,000	-720,000		0	0.00%
T	Dec	-744,000	-744,000		0	0.00%



Window AC with Baseboard Heat

Equipment Performance Summary for Annual Test Cases

Test Case	Month	HVAC Cooling Electric Consump. (Wh)	HVAC System Total Cooling (Wh)	HVAC System Average COP	Supply Fan Electric Consump. (Wh)		Baseboard Heater Output (Wh)	Baseboard Heater Consumption (Wh)	Baseboard Heater Efficiency (%)
I	Jan						-743,864	-743,864	1.00
J	Feb						-672,000	-672,000	1.00
K	Mar						-744,000	-744,000	1.00
L	Apr						-720,000	-720,000	1.00
M	May	188,174	741,047	3.94	25,334				
N	Jun	200,059	718,220	3.59	25,488				
O	Jul	215,673	742,201	3.44	26,778				
P	Aug	208,160	742,163	3.57	26,431				
Q	Sep	189,481	718,239	3.79	24,965				
R	Oct						-744,006	-744,006	1.00
S	Nov						-720,000	-720,000	1.00
T	Dec						-744,000	-744,000	1.00

- Zone Level Energy Balance
- Coil Level Energy Balance
- HVAC Cooling and Heating System Energy Balance.
- Equipment Performance Summary

The following is observed from examining the results:

- Zone Level Energy Balance

  a) For each month of the simulation the zone setpoint temperature of 22.2 C was maintained.

  b) During the summer cooling months the HVAC system did not maintain constant humidity ratios in the space. The largest difference occurred during May when the latent cooling load occurred for the first time and several hours were required during the first day in May for semi steady-state humidity conditions to be achieved.

  c) 100% of the internal loads were showing up as sensible and latent cooling loads in the space, therefore energy balance at the zone level was achieved.

- Coil Level Energy Balance for Cooling Months

  a) For all five of the cooling months there were very small differences between the amount of sensible cooling performed by the cooling coil and the zone sensible cooling requirement plus fan heat. The percentage difference was less than 0.35% for these months.

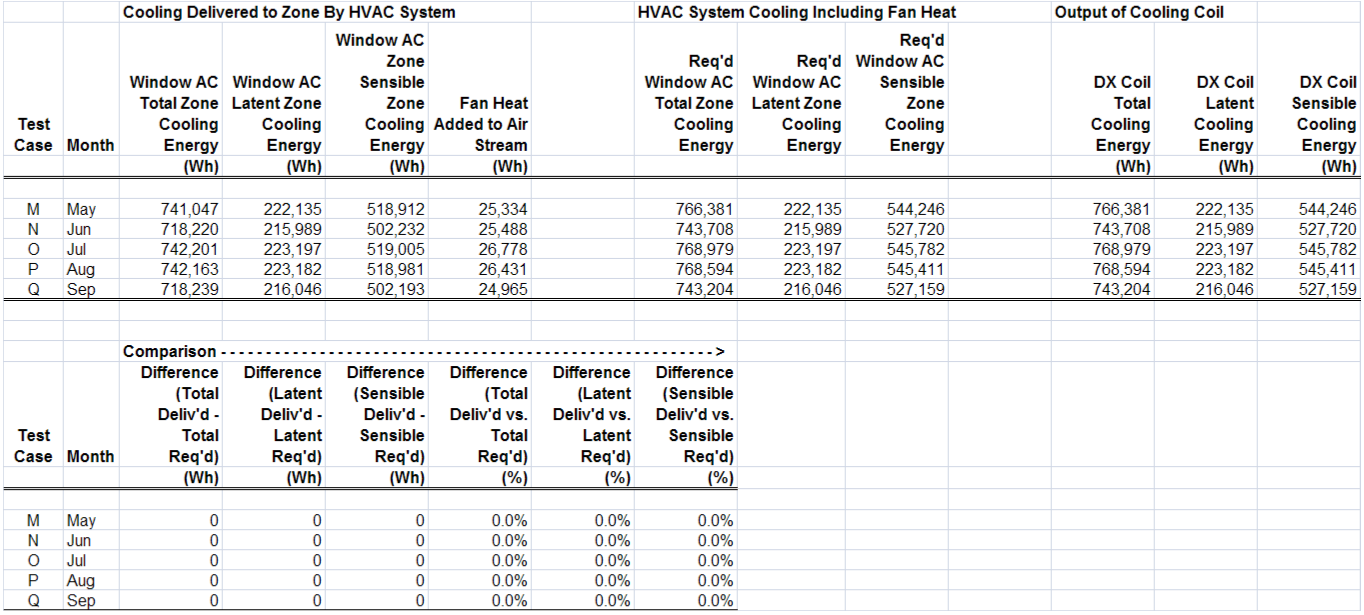
  b) For each of the cooling months when latent cooling loads were present, the amount of latent cooling performed by the cooling coil was less than that required by as much as 0.48% while the total cooling by the cooling coil was differing by as much as 0.38%.

- Coil Level Energy Balance for Heating Months

  a) During the heating months the baseboard heater output equaled the space heating requirement except for January and October where small differences occurred (0.05% or less).

- HVAC Cooling System Energy Balance

  a) When comparing the HVAC system cooling delivered to the zone versus the cooling required by the zone, energy balance was achieved for all cases as shown below.



		Cooling Delivered to Zone By HVAC System				HVAC System Cooling Including Fan Heat			Output of Cooling Coil		
Test Case	Month	Window AC Total Zone Cooling Energy (Wh)	Window AC Latent Zone Cooling Energy (Wh)	Window AC Zone Sensible Zone Cooling Energy (Wh)	Fan Heat Added to Air Stream (Wh)	Req'd Window AC Total Zone Cooling Energy	Req'd Window AC Latent Zone Cooling Energy	Req'd Window AC Sensible Zone Cooling Energy	DX Coil Total Cooling Energy (Wh)	DX Coil Latent Cooling Energy (Wh)	DX Coil Sensible Cooling Energy (Wh)
M	May	741,047	222,135	518,912	25,334	766,381	222,135	544,246	766,381	222,135	544,246
N	Jun	718,220	215,989	502,232	25,488	743,708	215,989	527,720	743,708	215,989	527,720
O	Jul	742,201	223,197	519,005	26,778	768,979	223,197	545,782	768,979	223,197	545,782
P	Aug	742,163	223,182	518,981	26,431	768,594	223,182	545,411	768,594	223,182	545,411
Q	Sep	718,239	216,046	502,193	24,965	743,204	216,046	527,159	743,204	216,046	527,159

		Comparison --->					
Test Case	Month	Difference (Total Deliv'd - Total Req'd) (Wh)	Difference (Latent Deliv'd - Latent Req'd) (Wh)	Difference (Sensible Deliv'd - Sensible Req'd) (Wh)	Difference (Total Deliv'd vs. Total Req'd) (%)	Difference (Latent Deliv'd vs. Latent Req'd) (%)	Difference (Sensible Deliv'd vs. Sensible Req'd) (%)
M	May	0	0	0	0.0%	0.0%	0.0%
N	Jun	0	0	0	0.0%	0.0%	0.0%
O	Jul	0	0	0	0.0%	0.0%	0.0%
P	Aug	0	0	0	0.0%	0.0%	0.0%
Q	Sep	0	0	0	0.0%	0.0%	0.0%

In previous versions of EnergyPlus there were differences between the sensible and latent cooling coil loads versus the sensible and latent cooling loads indicated for the Window AC system for all cases. This error was corrected in EnergyPlus 1.4.0.025.

- Equipment Performance Summary

  a) The Window AC system average COP during each of the test cases ranged from 3.57 to 3.94 with varying outdoor drybulb temperature. Nominal cooling capacity and full load COP for the system at ARI conditions is 8,181 W and 4.16. The average PLR for the cooling system which had an hourly cooling load of 1,000 kW plus hourly fan heat of 34 W is 0.13. The corresponding COP degradation factor is 0.80 resulting in an operating COP of 4.16 x 0.80 = 3.33. Outdoor temperatures in Chicago during the cooling season would typically be less than the 35 °C ARI condition and therefore COPs higher than the nominal would be expected as was the case.

2.4.2 Hydronic Heating/Cooling System

For the hydronic heating/cooling system Global Energy Balance Test energy balances were performed for the following:

- Zone Level Energy Balance
- Coil Level Energy Balance
- Hot Water Loop Energy Balance
- Chilled Water Loop Energy Balance
- Condenser Water Loop Energy Balance
- Equipment Performance Summary

For each heating/cooling coil, HVAC system and water loop energy flows into and out of the boundary volume are assessed using standard output variables and node values to determine energy balances. Before such energy balances are performed, the results of the simulation are first examined to ensure that the space temperature setpoint is maintained for all hours and space humidity ratios are constant for all hours indicating that all space loads have been met.

2.4.2.1 Daily Comparison Test

Daily comparison results from running the Global Energy Balance Test with EnergyPlus 7.0.0.036 for the one-zone building described in Section 1 which is cooled by an EnergyPlus four-pipe fan coil system with water supplied to the coils by a water chiller and hot water boiler are shown in spreadsheet format on the following five pages.

The following is observed from examining the results:

- Zone Level Energy Balance

  a) For each hour of the second day of each test case the zone setpoint temperature of 22.2 C was maintained and the zone humidity level remained constant

  b) 100% of the internal loads showed up as sensible and latent cooling loads in the space, therefore energy balance at the zone level was achieved.

Hydronic Heating/Cooling System
Zone Level Energy Balance for Daily Test Cases

		Zone Energy Input --->											
Test Case	Day	Daily Lights Consump. (kWh)	Daily Electric Equipment Consump. (kWh)	Daily Other Equipment Consump. (kWh)	Daily Gas Equipment Consump. (kWh)	Daily Steam Equipment Consump. (kWh)	Internal Loads % Latent	Internal Loads % Radiant	Daily Total Internal Consump. (kWh)	Zone Air Temp. Min (C)	Zone Air Temp. Max (C)	Zone Air Humidity Ratio Min ( )	Zone Air Humidity Ratio Max ( )
	1	0	0	-240	0	0	0	0	-240	22.2	22.2	0.0101	0.0101
A	2	0	0	-240	0	0	0	0	-240	22.2	22.2	0.0101	0.0101
	3	240	0	0	0	0	0	0	240	22.2	22.2	0.0101	0.0101
B	4	240	0	0	0	0	0	0	240	22.2	22.2	0.0101	0.0101
	5	240	240	0	0	0	0	0	480	22.2	22.2	0.0101	0.0101
C	6	240	240	0	0	0	0	0	480	22.2	22.2	0.0101	0.0101
	7	240	240	240	0	0	0	0	720	22.2	22.2	0.0101	0.0101
D	8	240	240	240	0	0	0	0	720	22.2	22.2	0.0101	0.0101
	9	240	240	240	240	0	0	0	960	22.2	22.2	0.0101	0.0102
E	10	240	240	240	240	0	0	0	960	22.2	22.2	0.0102	0.0102
	11	240	240	240	240	240	0	0	1,200	22.2	22.2	0.0092	0.0097
F	12	240	240	240	240	240	0	0	1,200	22.2	22.2	0.0091	0.0092
	13	0	0	240	0	0	0	20	240	22.2	22.2	0.0091	0.0091
G	14	0	0	240	0	0	0	20	240	22.2	22.2	0.0091	0.0091
	15	0	0	240	0	0	30	0	240	22.2	22.2	0.0095	0.0158
H	16	0	0	240	0	0	30	0	240	22.2	22.2	0.0158	0.0158

		Zone Energy Output -------------------->			Comparison ------------->	
Test Case	Day	Zone Internal Total Heat Gain (kWh)	Zone Internal Latent Heat Gain (kWh)	Zone Internal Sensible Heat Gain (kWh)	Difference (Total Output - Total Input) (kWh)	Difference (Total Output vs. Total Input) (kWh)
	1	-240	0	-240	0	0.00%
A	2	-240	0	-240	0	0.00%
	3	240	0	240	0	0.00%
B	4	240	0	240	0	0.00%
	5	480	0	480	0	0.00%
C	6	480	0	480	0	0.00%
	7	720	0	720	0	0.00%
D	8	720	0	720	0	0.00%
	9	960	0	960	0	0.00%
E	10	960	0	960	0	0.00%
	11	1200	0	1,200	0	0.00%
F	12	1200	0	1,200	0	0.00%
	13	240	0	240	0	0.00%
G	14	240	0	240	0	0.00%
	15	240	72	168	0	0.00%
H	16	240	72	168	0	0.00%

Hydronic Heating/Cooling System
Cooling Coil Level Energy Balance for Daily Test Cases

		Zone Cooling Requirement - - - - - - - - - - - - - - - >				Cooling Coil Requirement - - - - - - - - - - - - - - - >			Cooling Coil Output - - - - - - - - - - - - - - - - - - - >		
Test Case	Day	Zone Internal Total Heat Gain (kWh)	Zone Internal Latent Heat Gain (kWh)	Zone Internal Sensible Heat Gain (kWh)	Fan Heat Added to Air Stream (kWh)	Cooling Coil Total Cooling Req'd) (kWh)	Cooling Coil Latent Cooling Req'd (kWh)	Cooling Coil Sensible Cooling Req'd (kWh)	Cooling Coil Total Cooling Energy (kWh)	Cooling Coil Latent Cooling Energy (kWh)	Cooling Coil Sensible Cooling Energy (kWh)
B	4	240	0	240	26	266	0	266	266	0	266
C	6	480	0	480	26	506	0	506	506	0	506
D	8	720	0	720	26	746	0	746	746	0	746
E	10	960	0	960	26	986	0	986	986	0	986
F	12	1200	0	1,200	26	1,226	0	1,226	1227	0	1226
G	14	240	0	240	26	266	0	266	265	0	265
H	16	240	72	168	26	266	72	194	267	71	196

		Comparison - >					
Test Case	Day	Difference (Total Output - Total Req'd) (kWh)	Difference (Latent Output - Latent Req'd) (kWh)	Difference (Sensible Output - Sensible Req'd) (kWh)	Difference (Total Output vs. Total Req'd) (%)	Difference (Latent Output vs. Latent Req'd) (%)	Difference (Sensible Output vs. Sensible Req'd) (%)
B	4	0.0	0.0	0.0	0.01%	0.00%	0.01%
C	6	0.0	0.0	0.0	0.00%	0.00%	0.00%
D	8	0.0	0.0	0.0	0.00%	0.00%	0.00%
E	10	0.0	0.0	0.0	0.00%	0.00%	0.00%
F	12	0.4	0.4	0.0	0.03%	0.00%	0.00%
G	14	-1.3	0.0	-1.3	-0.47%	0.00%	-0.47%
H	16	0.5	-1.2	1.7	0.20%	-1.64%	0.88%

Hydronic Heating/Cooling System
Heating Coil Level Energy Balance for Daily Test Cases

		Zone Heating Requirement - - - - - - - - - - - - - - - - >							Comparison - - - - - - - >	
Test Case	Day	Zone Internal Total Heat Gain (kWh)	Zone Internal Latent Heat Gain (kWh)	Zone Internal Sensible Heat Gain (kWh)	Fan Heat Added to Air Stream (kWh)	Heating Coil Total Heating Req'd) (kWh)	Heating Coil Total Heating Energy Output (kWh)		Difference (Total Output - Total Req'd) (kWh)	Difference (Total Output vs. Total Req'd) (%)
A	2	-240	0	-240	26	-214	-214		0.0	-0.01%

Hydronic Heating/Cooling System
Hot Water Loop Energy Balance for Daily Test Cases

Test Case	Month	Zone/Sys Daily Average Temp (C)	Zone/Sys Daily Heating Req'd (kWh)	Heating Coil Daily Output (kWh)	Daily Fan Heat to Air Stream (kWh)	Fan Coil Daily Heating Output Delivered to Zone (kWh)	Hot Water Pump Daily Electric Consumption (kWh)	Daily Hot Water Pump Heat to Fluid (kWh)	Daily Boiler Load (kWh)	Daily Boiler Load Should = Heating Coil Output - Pump Heat to Fluid (kWh)	Daily Boiler Load Should = Zone Heating Req'd -Fan Heat - Pump Heat to Fluid (kWh)
A	2	22.2	240	214	26	240	4.2	3.7	209.6	210.1	210.1

		Comparison - >			
Test Case	Day	Difference (Daily Boiler Load vs. Heating Coil Output - Pump Heat to Fluid) (kWh)	Difference (Daily Boiler Load vs. Zone Heating Req'd -Fan Heat - Pump Heat to Fluid) (kWh)	Difference (Daily Boiler Load vs. Heating Coil Output - Pump Heat to Fluid) (%)	Difference (Daily Boiler Load vs. Zone Heating Req'd -Fan Heat - Pump Heat to Fluid) (%)
A	2	0	0	0.21%	0.21%

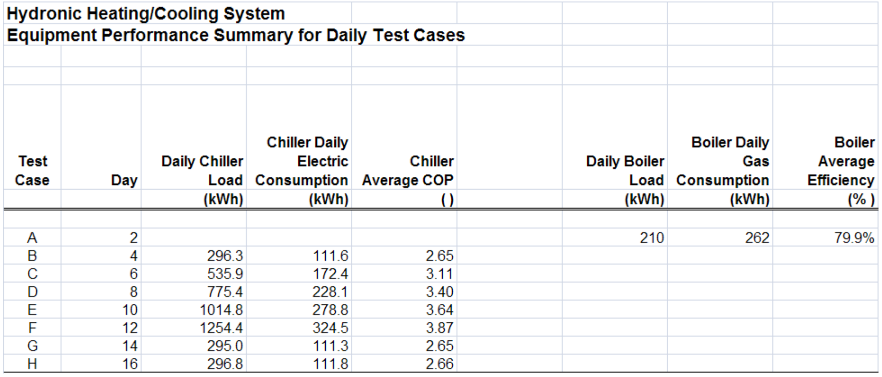
Hydronic Heating/Cooling System
Chilled Water Loop Energy Balance for Daily Test Cases

Test Case	Day	Zone/Sys Daily Average Temp (C)	Zone/Sys Daily Cooling Req'd (kWh)	Cooling Coil Daily Output (kWh)	Daily Fan Heat to Air Stream (kWh)	Fan Coil Daily Cooling Output Delivered to Zone (kWh)	Chilled Water Pump Daily Electric Consumption (kWh)	Daily Chilled Water Pump Heat to Fluid (kWh)	Daily Chiller Load (kWh)	Daily Chiller Load Should = Cooling Coil Output + CHW Pump Heat (kWh)	Daily Chiller Load Should = Zone Cooling Req'd + Fan Heat + CHW Pump Heat to Fluid (kWh)
B	4	22.2	240	266	26	240	33.6	30.2	296.3	296.4	296.4
C	6	22.2	480	506	26	480	33.6	30.2	535.9	536.4	536.4
D	8	22.2	720	746	26	720	33.6	30.2	775.4	776.4	776.4
E	10	22.2	960	986	26	960	33.6	30.2	1014.8	1016.4	1016.4
F	12	22.2	1200	1227	26	1200	33.6	30.2	1254.4	1256.8	1256.4
G	14	22.2	240	265	26	239	33.6	30.2	295.0	295.1	296.4
H	16	22.2	240	267	26	241	33.6	30.2	296.8	296.9	296.4

		Comparison --->			
Test Case	Day	Difference (Daily Chiller Load vs. Cooling Coil Output + CHW Pump Heat) (kWh)	Difference (Daily Chiller Load vs. Zone Cooling Req'd + Fan Heat + CHW Pump Heat to Fluid) (kWh)	Difference (Daily Chiller Load vs. Cooling Coil Output + CHW Pump Heat) (%)	Difference (Daily Chiller Load vs. Zone Cooling Req'd + Fan Heat + CHW Pump Heat to Fluid) (%)
B	4	0.1	0.1	0.04%	0.04%
C	6	0.5	0.4	0.09%	0.08%
D	8	1.0	1.0	0.12%	0.12%
E	10	1.6	1.6	0.16%	0.16%
F	12	2.4	2.0	0.19%	0.16%
G	14	0.1	1.4	0.05%	0.47%
H	16	0.1	-0.4	0.04%	-0.13%

Hydronic Heating/Cooling System
Condenser Water Loop Energy Balance for Daily Test Cases

							Comparison ------------->	
Test Case	Day	Chiller Daily Electric Consumption (kWh)	Condenser Water Pump Daily Electric Consumption (kWh)	Daily Condenser Water Pump Heat to Fluid (kWh)	Daily Cooling Tower Load (kWh)	Daily Cooling Tower Load Should = Chiller Load + Chiller Electric Consumption + CNW Pump Heat (kWh)	Difference(Daily Colling Tower Load vs. Chiller Load + Chiller Electric Consumption + CNW Pump Heat) (kWh)	Difference(Daily Colling Tower Load vs. Chiller Load + Chiller Electric Consumption + CNW Pump Heat) (%)
B	4	111.6	50.4	45.4	453	453	0	0.00%
C	6	172.4	50.4	45.4	754	754	0	0.00%
D	8	228.1	50.4	45.4	1049	1049	0	0.00%
E	10	278.8	50.4	45.4	1339	1339	0	0.00%
F	12	324.5	50.4	45.4	1624	1624	0	0.00%
G	14	111.3	50.4	45.4	452	452	0	0.00%
H	16	111.8	50.4	45.4	454	454	0	0.00%



Hydronic Heating/Cooling System
Equipment Performance Summary for Daily Test Cases

Test Case	Day	Daily Chiller Load (kWh)	Chiller Daily Electric Consumption (kWh)	Chiller Average COP ( )		Daily Boiler Load (kWh)	Boiler Daily Gas Consumption (kWh)	Boiler Average Efficiency (%)
A	2					210	262	79.9%
B	4	296.3	111.6	2.65				
C	6	535.9	172.4	3.11				
D	8	775.4	228.1	3.40				
E	10	1014.8	278.8	3.64				
F	12	1254.4	324.5	3.87				
G	14	295.0	111.3	2.65				
H	16	296.8	111.8	2.66				

- Coil Level Energy Balance

  a) For the test cases where cooling was required (Cases B through H) there were small amounts of differences between the sensible, latent and total cooling performed by the cooling coil versus what was required for some cases with the maximum difference being 1.65%.

  b) For the heating test case (Case A), the output of the heating coil was 0.03% greater than that required.

- Hot Water Loop Energy Balance

  a) For Case A where the zone had a heating requirement, energy balance was achieved when comparing the heating output of the boiler to the heating coil output less the monthly hot water pump heat added to the hot water loop.

  b) For Case A where the zone had a heating requirement, energy balance was also achieved when comparing the heating output of the boiler to the zone monthly heating requirement less the monthly fan heat added to the air stream less the hot water pump heat added to the hot water loop.

- Chilled Water Loop Energy Balance

  a) For each Case B through H where zone cooling was required, energy balance was achieved when comparing the cooling output of the chiller to the monthly total cooling coil output plus the chilled water pump heat added to the chilled water loop.

  b) Very small energy balance differences (0.42% or less) occurred for four out of seven cooling cases when comparing the cooling output of the chiller to the monthly zone total cooling requirement plus the fan heat added to the air stream plus the chilled water pump heat added to the chilled water loop.

- Condenser Water Loop Energy Balance

  a) For each of the seven cooling cases, energy balance was achieved when comparing the monthly cooling tower load to the monthly chiller load plus the chiller electric consumption plus the condenser water pump heat added to the condenser water loop.

- Equipment Performance Summary

  a) For the heating day (Case A) the boiler average efficiency was 79.9% comparing favorably to the rated steady state efficiency of 80%.

  b) During the seven cooling cases (Cases B through H) the average chiller COP ranged from 2.65 to 3.87. The rated cooling capacity and COP of the chiller at ARI conditions is 55,005 W and 3.926. The chiller entering condenser water temperature and leaving chilled water temperature was held constant at the ARI standard conditions of 29.44 °C and 6.67 °C for all test cases. For Case B where the hourly chiller load was 10,000 W space load plus 1,090 W fan heat plus 1,265 W pump heat for a total cooling load of 12,355 W, the PLR is 0.22. The EIRfPLR at this PLR is 0.332. The COP at this PLR is therefore 12,355 / (0.332 * 55,005/3.926) = 2.65 which is the resulting average COP for Test B.

2.4.2.2 Annual Comparison Test

The following is observed from examining the results (see following five pages) of the hydronic heating/cooling energy balance test performed with the annual comparison tests:

- Zone Level Energy Balance

  a) For each month of each test case the zone setpoint temperature of 22.2 C was maintained and the zone humidity level remained constant except for Case I

  b) 100% of the internal loads showed up in the space, therefore energy balance at the zone level was achieved.

- Coil Level Energy Balance for Cooling Months

  a) For all five of the cooling months the amount of sensible cooling performed by the cooling coil equaled the zone sensible cooling requirement plus fan heat. Energy balance was therefore achieved at the cooling coil level.

- Coil Level Energy Balance for Heating Months

  a) During each of the heating months the heating coil output equaled the space heating requirement less the fan heat, therefore, energy balance at the heating coil level was achieved.

- Hot Water Loop Energy Balance

  a) For each month of the seven month heating season, energy balance was achieved when comparing the heating output of the boiler to the heating coil output less the monthly hot water pump heat added to the hot water loop.

  b) For each month of the seven month heating season, energy balance was also achieved when comparing the heating output of the boiler to the zone monthly heating requirement less the monthly fan heat added to the air stream less the hot water pump heat added to the hot water loop.

- Chilled Water Loop Energy Balance

  a) For each month of the five month cooling season, energy balance was achieved when comparing the cooling output of the chiller to the monthly total cooling coil output plus the chilled water pump heat added to the chilled water loop.

  b) For each month of the five month cooling season, energy balance was also achieved when comparing the cooling output of the chiller to the monthly zone total cooling requirement plus the fan heat added to the air stream plus the chilled water pump heat added to the chilled water loop.

- Condenser Water Loop Energy Balance

  a) For each month of the five month cooling season, energy balance was achieved when comparing the monthly cooling tower load to the monthly chiller load plus the chiller electric consumption plus the condenser water pump heat added to the condenser water loop

- Equipment Performance Summary

  a) For the heating months (Cases I throughL and R through T) the boiler average efficiency was 80.0% each month matching the rated steady state efficiency of 80%.

  b) During the five cooling cases (Cases M through Q) the average chiller COP was 3.87. The rated cooling capacity and COP of the chiller at ARI conditions is 11,005 W and 3.926. The chiller entering condenser water temperature and leaving chilled water temperature was held constant at the ARI standard conditions of 29.44 °C and 6.67 °C for all test cases. For each cooling month the hourly chiller load was 10,000 W space load plus 223 W fan heat plus 253 W pump heat for a total cooling load of 10,476 W, the PLR is 0.95. The EIRfPLR at this PLR is 0.966. The COP at this PLR is therefore 10,476 / (0.966 * 11,005 / 3.926) = 3.87 which is the resulting average COP for each of the cooling months.

Hydronic Heating/Cooling System
Zone Level Energy Balance for Annual Test Cases

		Zone Energy Input - >							
Test Case	Month	Daily Other Equipment Consump. (kWh)	Internal Convective Load (kWh)	Internal Latent Load (kWh)	Daily Total Internal Load (kWh)	Zone Air Temp. Min (C)	Zone Air Temp. Max (C)	Zone Air Humidity Ratio Min ( )	Zone Air Humidity Ratio Max ( )
I	Jan	-7440	-7440	0	-7440	22.2	22.2	0.00084	0.00941
J	Feb	-6720	-6720	0	-6720	22.2	22.2	0.00194	0.00194
K	Mar	-7440	-7440	0	-7440	22.2	22.2	0.00194	0.00194
L	Apr	-7200	-7200	0	-7200	22.2	22.2	0.00194	0.00194
M	May	7440	7440	0	7440	22.2	22.2	0.00194	0.00194
N	Jun	7200	7200	0	7200	22.2	22.2	0.00194	0.00194
O	Jul	7440	7440	0	7440	22.2	22.2	0.00194	0.00194
P	Aug	7440	7440	0	7440	22.2	22.2	0.00194	0.00194
Q	Sep	7200	7200	0	7200	22.2	22.2	0.00194	0.00194
R	Oct	-7440	-7440	0	-7440	22.2	22.2	0.00194	0.00194
S	Nov	-7200	-7200	0	-7200	22.2	22.2	0.00194	0.00194
T	Dec	-7440	-7440	0	-7440	22.2	22.2	0.00194	0.00194

		Zone Energy Output - - - - - - - - - - - - - - - - >				Comparison - - - - - - - - - - - - - >	
Test Case	Month	Zone Internal Total Heat Gain (kWh)	Zone Internal Latent Heat Gain (kWh)	Zone Internal Sensible Heat Gain (kWh)		Difference (Total Output - Total Input) (kWh)	Difference (Total Output vs. Total Input) (%)
I	Jan	-7440	0	-7440		0	0.00%
J	Feb	-6720	0	-6720		0	0.00%
K	Mar	-7440	0	-7440		0	0.00%
L	Apr	-7200	0	-7200		0	0.00%
M	May	7440	0	7440		0	0.00%
N	Jun	7200	0	7200		0	0.00%
O	Jul	7440	0	7440		0	0.00%
P	Aug	7440	0	7440		0	0.00%
Q	Sep	7200	0	7200		0	0.00%
R	Oct	-7440	0	-7440		0	0.00%
S	Nov	-7200	0	-7200		0	0.00%
T	Dec	-7440	0	-7440		0	0.00%

Hydronic Heating/Cooling System
Coil Level Energy Balance for Annual Test Cases
For Cooling Months

		Zone Cooling Requirement - - - - - - - - - - - - - - - >				Cooling Coil Requirement - - - - - - - - - - - - -			Cooling Coil Output - - - - - - - - - - - - - - - - - -		
Test Case	Month	Zone Internal Total Heat Gain (kWh)	Zone Internal Latent Heat Gain (kWh)	Zone Internal Sensible Heat Gain (kWh)	Fan Heat Added to Air Stream (kWh)	Cooling Coil Total Cooling Req'd) (kWh)	Cooling Coil Latent Cooling Req'd (kWh)	Cooling Coil Sensible Cooling Req'd (kWh)	Cooling Coil Total Cooling Energy (kWh)	Cooling Coil Latent Cooling Energy (kWh)	Cooling Coil Sensible Cooling Energy (kWh)
M	May	7440	0	7440	166	7,606	0	7,606	7606	0	7606
N	Jun	7200	0	7200	161	7,361	0	7,361	7361	0	7361
O	Jul	7440	0	7440	166	7,606	0	7,606	7606	0	7606
P	Aug	7440	0	7440	166	7,606	0	7,606	7606	0	7606
Q	Sep	7200	0	7200	161	7,361	0	7,361	7361	0	7361

		Comparison - >					
Test Case	Month	Difference (Coil Total Output - Coil Total Req'd) (Wh)	Difference (Coil Latent Output - Coil Latent Req'd) (Wh)	Difference (Coil Sensible Output - Coil Sensible Req'd) (Wh)	Difference (Coil Total Output vs. Coil Total Req'd) (%)	Difference (Coil Latent Output vs. Coil Latent Req'd) (%)	Difference (Coil Sensible Output vs. Coil Sensible Req'd) (%)
M	May	0.0	0.0	0.0	0.00%	0.00%	0.00%
N	Jun	0.0	0.0	0.0	0.00%	0.00%	0.00%
O	Jul	0.0	0.0	0.0	0.00%	0.00%	0.00%
P	Aug	0.0	0.0	0.0	0.00%	0.00%	0.00%
Q	Sep	0.0	0.0	0.0	0.00%	0.00%	0.00%

Hydronic Heating/Cooling System
Coil Level Energy Balance for Annual Test Cases
For Heating Months

		Zone Heating Requirement - - - - - - - - - - - - - - - - >							Comparison - - - - - - - >	
Test Case	Month	Zone Internal Total Heat Gain (kWh)	Zone Internal Latent Heat Gain (kWh)	Zone Internal Sensible Heat Gain (kWh)	Fan Heat Added to Air Stream (kWh)	Heating Coil Total Heating Req'd) (kWh)	Heating Coil Total Heating Energy Output (kWh)		Difference (Total Output - Total Req'd) (kWh)	Difference (Total Output vs. Total Req'd) (%)
I	Jan	7440	0	7440	166	7274	7274		0	0.00%
J	Feb	6720	0	6720	150	6570	6570		0	0.00%
K	Mar	7440	0	7440	166	7274	7274		0	0.00%
L	Apr	7200	0	7200	161	7039	7039		0	0.00%
R	Oct	7440	0	7440	166	7274	7274		0	0.00%
S	Nov	7200	0	7200	161	7039	7039		0	0.00%
T	Dec	7440	0	7440	166	7274	7274		0	0.00%

Hydronic Heating/Cooling System

Hot Water Loop Energy Balance for Annual Test Cases

Test Case	Month	Zone/Sys Monthly Average Temp (C)	Zone/Sys Monthly Heating Req'd (kWh)	Heating Coil Monthly Output (kWh)	Monthly Fan Heat to Air Stream (kWh)	Fan Coil Monthly Heating Output Delivered to Zone (kWh)	Hot Water Pump Monthly Electric Consumption (kWh)	Monthly Hot Water Pump Heat to Fluid (kWh)	Monthly Boiler Load (kWh)	Monthly Boiler Load Should = Heating Coil Output - Pump Heat to Fluid (kWh)	Monthly Boiler Load Should = Zone Heating Req'd -Fan Heat - Pump Heat to Fluid (kWh)
I	Jan	22.2	7440	7274	166	7440	129	116	7142	7158	7158
J	Feb	22.2	6720	6570	150	6720	116	105	6451	6465	6465
K	Mar	22.2	7440	7274	166	7440	129	116	7142	7158	7158
L	Apr	22.2	7200	7039	161	7200	125	112	6912	6927	6927
R	Oct	22.2	7440	7274	166	7440	129	116	7142	7158	7158
S	Nov	22.2	7200	7039	161	7200	125	112	6912	6927	6927
T	Dec	22.2	7440	7274	166	7440	129	116	7142	7158	7158

		Comparison ------------------------------------			
Test Case	Month	Difference (Monthly Boiler Load vs. Heating Coil Output - Pump Heat to Fluid) (kWh)	Difference (Monthly Boiler Load vs. Zone Heating Req'd -Fan Heat - Pump Heat to Fluid) (kWh)	Difference (Monthly Boiler Load vs. Heating Coil Output - Pump Heat to Fluid) (%)	Difference (Monthly Boiler Load vs. Zone Heating Req'd -Fan Heat - Pump Heat to Fluid) (%)
I	Jan	16	16	0.23%	0.23%
J	Feb	15	15	0.23%	0.23%
K	Mar	16	16	0.23%	0.23%
L	Apr	16	16	0.23%	0.23%
R	Oct	16	16	0.23%	0.23%
S	Nov	16	16	0.23%	0.23%
T	Dec	16	16	0.23%	0.23%

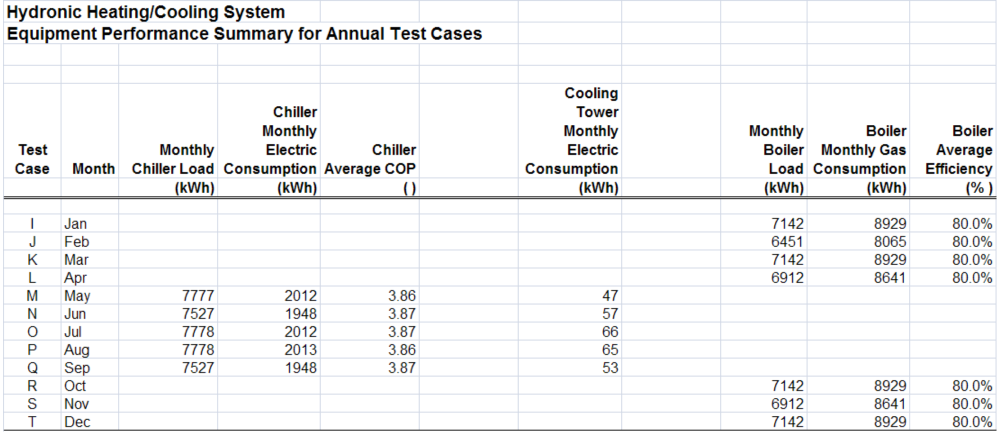
Hydronic Heating/Cooling System
Chilled Water Loop Energy Balance for Annual Test Cases

Test Case	Month	Zone/Sys Monthly Average Temp (C)	Zone/Sys Monthly Cooling Req'd (kWh)	Cooling Coil Monthly Output (kWh)	Monthly Fan Heat to Air Stream (kWh)	Fan Coil Monthly Cooling Output Delivered to Zone (kWh)	Chilled Water Pump Monthly Electric Consumption (kWh)	Monthly Chilled Water Pump Heat to Fluid (kWh)	Monthly Chiller Load (kWh)	Monthly Chiller Load Should = Cooling Coil Output + CHW Pump Heat (kWh)	Chiller Load Should = Zone Cooling Req'd + Fan Heat + CHW Pump Heat to (kWh)
M	May	22.20	7440	7606	166	7440	208	187	7777	7793	7793
N	Jun	22.20	7200	7361	161	7200	202	181	7527	7542	7542
O	Jul	22.20	7440	7606	166	7440	208	187	7778	7793	7793
P	Aug	22.20	7440	7606	166	7440	208	187	7778	7793	7793
Q	Sep	22.20	7200	7361	161	7200	202	181	7527	7542	7542

		Comparison -			
Test Case	Month	Difference (Monthly Chiller Load vs. Cooling Coil Output + CHW Pump Heat) (kWh)	Difference (Monthly Chiller Load vs. Zone Cooling Req'd + Fan Heat + CHW Pump Heat to Fluid) (kWh)	Difference (Monthly Chiller Load vs. Cooling Coil Output + CHW Pump Heat) (%)	Difference (Monthly Chiller Load vs. Zone Cooling Req'd + Fan Heat + CHW Pump Heat to Fluid) (%)
M	May	17	17	0.21%	0.21%
N	Jun	15	15	0.19%	0.19%
O	Jul	15	15	0.19%	0.19%
P	Aug	15	15	0.19%	0.19%
Q	Sep	15	15	0.19%	0.19%

Hydronic Heating/Cooling System
Condenser Water Loop Energy Balance for Annual Test Cases

Test Case	Month	Chiller Monthly Electric Consumption (kWh)	Condenser Water Pump Monthly Electric Consumption (kWh)	Monthly Condenser Water Pump Heat to Fluid (kWh)	Monthly Cooling Tower Load (kWh)	Monthly Cooling Tower Load Should = Chiller Load + Chiller Electric Consumption + CNW Pump Heat (kWh)	Difference (Monthly Cooling Tower Load vs. Chiller Load + Chiller Electric Consumption + CNW Pump Heat) (kWh)	(Monthly Cooling Tower Load vs. Chiller Load + Chiller Electric Consumption + CNW Pump Heat) (%)
M	May	2012	313	281	10068	10070	2	0.02%
N	Jun	1948	302	272	9747	9747	0	0.00%
O	Jul	2012	313	281	10072	10072	0	0.00%
P	Aug	2013	313	281	10073	10072	0	0.00%
Q	Sep	1948	302	272	9747	9747	0	0.00%



Hydronic Heating/Cooling System

Equipment Performance Summary for Annual Test Cases

Test Case	Month	Monthly Chiller Load (kWh)	Chiller Monthly Electric Consumption (kWh)	Chiller Average COP ( )		Cooling Tower Monthly Electric Consumption (kWh)		Monthly Boiler Load (kWh)	Boiler Monthly Gas Consumption (kWh)	Boiler Average Efficiency (%)
I	Jan							7142	8929	80.0%
J	Feb							6451	8065	80.0%
K	Mar							7142	8929	80.0%
L	Apr							6912	8641	80.0%
M	May	7777	2012	3.86		47				
N	Jun	7527	1948	3.87		57				
O	Jul	7778	2012	3.87		66				
P	Aug	7778	2013	3.86		65				
Q	Sep	7527	1948	3.87		53				
R	Oct							7142	8929	80.0%
S	Nov							6912	8641	80.0%
T	Dec							7142	8929	80.0%

3 CONCLUSIONS

EnergyPlus version 7.0.0.036 was used to model the operation of a DX cooling system and hydronic heating/cooling system and perform global energy balances across various energy boundaries to determine how accurately energy was being transferred between the building space being cooled and various components of the HVAC system and equipment for various types of internal loads. The Global Energy Balance 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 140-2007, *Standard Method of Test for the Evaluation of Building Energy Analysis Computer* Programs to generate a set of controlled heating and cooling loads on the HVAC system. The global energy balance test was performed for the DX cooling system in EnergyPlus referred to as ZoneHVAC:WindowAirConditioner. Energy balances and flows into and out of three boundary volumes were performed for the zone boundary, coil boundary and HVAC system boundary for both daily comparison cases and annual comparison cases with the following results.

- Zone Level Energy Balance – exact agreement was obtained between the internal loads generated within the space and the resulting cooling load in the space

- Coil Level Energy Balance – sensible cooling coil energy balance was achieved between the sensible cooling performed by the cooling coil and the zone sensible cooling requirement plus fan heat. Small differences (1.36% or less) occurred when comparing the amount of latent cooling performed by the cooling coil versus what was required. Small differences (0.02%) also occurred when comparing the sensible cooling performed by the cooling coil versus what was required.

- HVAC Cooling System Level Energy Balance – energy balance was achieved when comparing the HVAC system cooling provided to the zone to the cooling coil output.

- Equipment Performance Summary – the resulting cooling system COPs and heating system efficiencies were within range of expected results.

The global energy balance test was also performed for a hydronic heating/cooling system which utilized chilled water, hot water and condenser water loops, electric chiller, gas-fired hot water boiler, cooling tower and 4-pipe fan coil HVAC system. Energy balances performed for each of the three water loops for both daily comparison cases and annual comparison cases yielded the following results:

- Zone Level Energy Balance – exact agreement was obtained between the internal loads generated within the space and the resulting cooling load in the space

- Coil Level Energy Balance – small differences (1.65% or less) occurred when comparing the amount of sensible or latent cooling performed by the cooling coil versus what was required. Heating coil energy output compared favorably with the space required heating.

- Hot Water Loop Energy Balance – for each day or month when heating was required exact agreement was obtained between the heating required and delivered to the space by the hot water loop and the boiler after accounting for pump heat added to the hot water loop

- Chilled Water Loop Energy Balance – for each day or month during the both the daily and annual comparison tests when cooling was required exact agreement was obtained between the cooling required and delivered to the space by the chilled water loop and water chiller after accounting for pump heat added to the chilled water loop. Small differences (0.42% or less) when comparing the chiller output to the zone cooling load plus fan heat plus chilled water pump heat.

- Condenser Water Loop Energy Balance - for each day or month when cooling was required, exact agreement was obtained between the cooling performed by the cooling tower and that required by the water chiller condenser and condenser water pump.

- Equipment Performance Summary – the resulting chiller COPs and heating system efficiencies were within range of expected results.

As a result of the testing several discrepancies were uncovered that need to be investigated:

- differences between amount of sensible and latent cooling done by water cooling coils versus that required by the zone (-1.65% to 0.88%)

- differences between the amount of cooling provided by the chilled water loop versus the zone cooling plus fan heat plus chilled water pump heat added to the fluid (-0.18% to 0.42%)

- differences between the amount of heating done by water heating coils versus that required by the zone (-0.03 to 0.0%)

As discussed in this report, one discrepancy, the difference between the sensible and latent loads reported for the DX cooling coil versus the sensible and latent cooling loads reported for the Window AC system, was discovered and corrected.

4 REFERENCES

ANSI/ASHRAE 2007. Standard 140-2007, Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.

EnergyPlus 2011. 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).

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