EnergyPlus Testing with IEA BESTEST Mechanical Equipment & Control Strategies for a Chilled Water and a Hot Water System

EnergyPlus Version 7.1.0.012

June 2012

Prepared for:

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Office of Building Technologies
Washington, D.C.

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This work was supported by the Department of Energy and the National Renewable Energy Laboratory (NREL) through the University of Central Florida. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the sponsor. Earlier work was supported by the Ernest Orlando Lawrence Berkeley National Laboratory and by the National Energy Technology Laboratory by subcontract through the University of Central Florida/Florida Solar Energy Center.

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1 TEST OBJECTIVES AND OVERVIEW

1.1 Introduction

This report describes the modeling methodology and results for comparative testing done for the *IEA Mechanical Equipment & Control Strategies for a Chilled Water and a Hot Water System,* (Felsmann 2008) which were simulated using the EnergyPlus software. Although both empirical and comparative test cases are described for a chilled water system and hot water system, only the comparative tests for the chilled water coil and hot water coil were performed. The specifications for these tests are described in Part I. Chilled Water System, Section 4.4 Cooling Coil Comparative Test and in Part II. Heating Water System, Section 4.5 Heating Coil Comparative Test of that report. The results of EnergyPlus are compared with results for other whole building energy simulation programs (Table 1) which simulated all of the same test cases.

Table 1 Participating Programs and Organizations

Simulation Program	Implemented by	Abbreviation
EnergyPlus	GARD Analytics, Inc., United States	EnergyPlus
EES	University of Liege, Belgium	ESP-r/ESRU
TRNSYS-TUD	Technical University Dresden, Germany	TRNSYS-TUD
Matlab/Simulink	ITG Dresden, Germany	Matlab/Simulink
VA114	VABI Software BV, Delft, The Netherlands	VABI

1.2 Test Type: Comparative

Comparative tests compare a program to itself or to other simulation programs. This type of testing accomplishes results on two different levels, both validation and debugging.

From a validation perspective, comparative tests will show that EnergyPlus is computing solutions that are reasonable compared to other energy simulation programs. This is a very powerful method of assessment, but it is no substitute for determining if the program is absolutely correct since it may be just as equally incorrect as the benchmark program or programs. The biggest strength of comparative testing is the ability to compare any cases that two or more programs can model. This is much more flexible than analytical tests when only specific solutions exist for simple models, and much more flexible than empirical tests when only specific data sets have been collected for usually a very narrow band of operation.

Comparative testing is also useful for field-by-field input debugging. Energy simulation programs have so many inputs and outputs that the results are often difficult to interpret. To ascertain if a given test passes or fails, engineering judgment or hand calculations are often needed. Field by field comparative testing eliminates any calculational requirements for the subset of fields that are equivalent in two or more simulation programs. The equivalent fields are exercised using equivalent inputs and relevant outputs are directly compared.

1.3 Test Suite: IEA Mechanical Equipment & Control Strategies for a Chilled Water and a Hot Water System

The tests described in Part I. Section 4.4 Cooling Coil Comparative Test and Part II. Section 4.5 Heating Coil Comparative Test (Felsmann 2008) of the referenced IEA final report were performed using EnergyPlus. Although additional empirical tests are also described for the chiller, chilled water coil, chilled water hydraulic circuit, boiler, hot water coil and hot water hydraulic circuit, these empirical tests and certain comparative tests could not be run with EnergyPlus because internal code changes would have to be made to accommodate the field test data or because:

1. Only water can currently be modeled as the chilled water fluid. The ability to model glycol solutions has not yet been added to chillers and chilled water coils in EnergyPlus

2. Varying water supply temperatures to cooling coils and heating coils with constant water flow rates cannot currently be modeled by EnergyPlus

The test cases are designed for testing the capability of building energy simulation programs to predict the performance of the mechanical equipment of buildings including their control systems.

1.3.1 Cooling Coil Comparative Tests

There are in general two methods for controlling the performance or discharge air temperature coming off of a chilled water coil:

1. Variable water flow rate with constant water inlet temperature (m_{var})
   Constant temperature chilled water is supplied to the cooling coil. Control of the desired leaving air temperature is achieved by bypassing a portion of the supply water around the cooling coil and thereby varying the chilled water flow rate (m_{var}) through the coil (see Figure 1).

2. Constant water flow rate with a variable water inlet temperature (T_{var})
   Constant chilled water flow rate is maintained through the cooling coil while the chiller supply water is mixed with warm coil return water to achieve the required coil inlet water temperature (T_{var}) in order to maintain the desired leaving discharge air temperature (see Figure 2).

For each of the flow configurations described above there are 8 test cases which are to be simulated for different air flow arrangements, water mixtures and discharge air temperature setpoints as described in Table 2.

The cooling coil nominal performance data as provided by the manufacturer is shown in Table 3. The EnergyPlus chilled water coil model required some of this data as input.

The following additional requirements were provided by the specification in regards to modeling the cooling coil comparative tests:

- For test cases with a variable water flow rate and constant water inlet temperature, the maximum water flow rate is 1.77 l/s

- For test cases with a constant water flow rate and variable water inlet temperature the water flow rate is fixed at 1.77 l/s.

- For test cases with constant air volume (CAS), the air flow rate is fixed at 3000 m3/h at all times

- For test cases with quasi-variable flow volume (VAV), the air flow switches between 2000 m3/h (6 PM to 7 AM) and 5000 m3/h (7 AM to 6 PM)

- Cases are run for two discharge air temperatures: 13°C, which cause the cooling coil to operate in the wet regime and 18°C which should cause the cooling coil to operate predominately in the dry regime. Discharge air temperatures are held constant throughout the entire simulation

- For all test cases the chilled water supply temperature and entering coil water temperature is held constant at 6°C

- The cooling coil is processing 100% outside air with no recirculation through the coil

- A TMY2 weather file for Des Moines, Iowa was provided for use in simulating all test cases

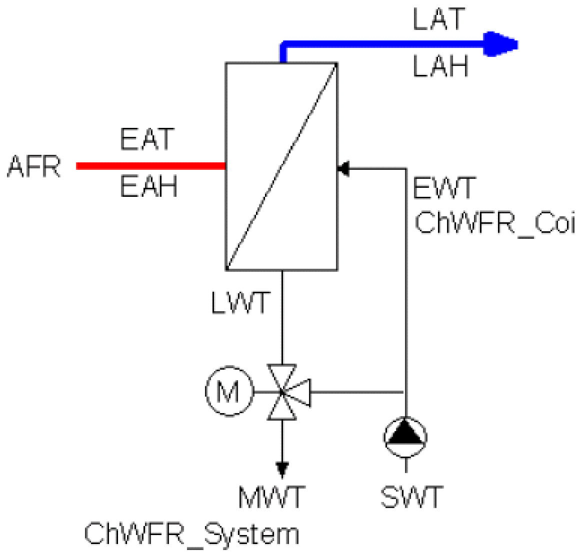


Figure 1 – Schematic Diagram of Cooling Coil with Variable Water Flow Rate (Part I - Figure 4-7, Felsmann 2008)

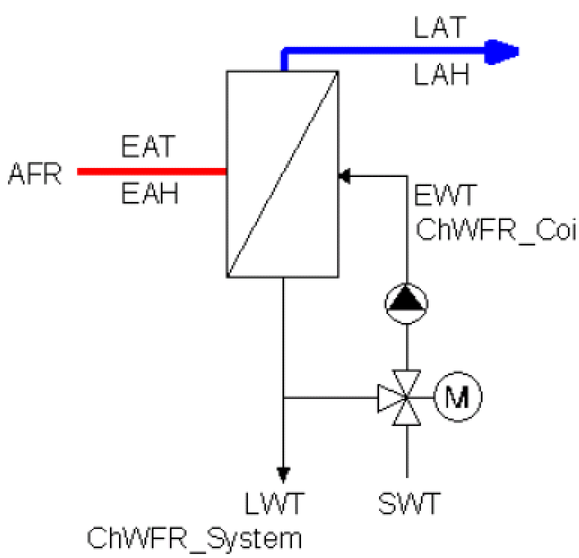


Figure 2 – Schematic Diagram of Cooling Coil with Constant Water Flow Rate (Part I - Figure 4-8, Felsmann 2008)

Table 2 – Cooling Coil Comparative Test Cases
(Part I - Table 4-3, Felsmann 2008)

Test Case	Control Configuration	Air Flow	Fluid	Discharge Air Temperature Setpoint (C)
CC100	m_{var}	Constant Air Volume	35% Ethylene Glycol	13
CC120				18
CC140			18% Propylene Glycol	13
CC160				18
CC200		Variable Air Volume	35% Ethylene Glycol	13
CC220				18
CC240			18% Propylene Glycol	13
CC260				18
CC300	T_{var}	Constant Air Volume	35% Ethylene Glycol	13
CC320				18
CC340			18% Propylene Glycol	13
CC360				18
CC400		Variable Air Volume	35% Ethylene Glycol	13
CC420				18
CC440			18% Propylene Glycol	13
CC460				18

Table 3 – Cooling Coil Nominal Performance Data
(Part I - Table 4-2, Felsmann 2008)

Cooling Coil Performance		
Barometric pressure*)	kPa	101.3
Entering Air Temperature	°C Dry bulb °C Wet bulb	27.8 19.2
Entering Air Relative Humidity*)	%	44.4
Entering Air Moisture*)	kg/kg	0.0104
Leaving Air Temperature	°C Dry bulb °C Wet bulb	12.5 12.2
Leaving Air Relative Humidity*)	%	96.9
Leaving Air Moisture*)	kg/kg	0.0087
Leaving Air Density	kg/m³	1.23
Air Flow Rate at leaving air conditions *)	m³/h	5430
Air Pressure Drop	kPa	0.194
Entering Liquid Temp.	°C	6.7
Leaving Liquid Temp.	°C	12.1
Liquid Flow	l/s	1.8
Liquid Pressure Drop	kPa	22.4
Total Cooling Capacity	kW	35.8
Latent Cooling Capacity*)	kW	7.3

Data marked with an (*) were calculated from manufacturer's data

The following outputs are to be provided for each simulation time increment:

EAT	Entering air dry-bulb temperature, °C
EArH	Entering air relative humidity, %
EAH	Entering air humidity ratio, kg/kg
LAT	Discharge/Leaving air dry-bulb temperature, °C
LArH	Discharge/Leaving air relative humidity, %
LAH	Discharge/Leaving air humidity ratio, kg/kg
AFR	Air flow rate, m3/h
EWT	Chilled water coil entering water temperature, °C
LWT	Chilled water coil leaving water temperature, °C
ChWFRcoil	Chilled water flow rate through the coil, l/s
UA	Overall UA-value of the coil, kW/K
CLT	Total cooling load, kW
CLS	Sensible cooling load, kW
CLL	Latent cooling load, kW

The Overall UA was to be calculated as:

$$UA = CLS / \Delta T_m$$

where

$$\Delta T_m = \frac{(LWT - EAT) - (EWT - LAT)}{ln\dfrac{LWT - EAT}{EWT - LAT}}$$

1.3.2 Heating Coil Comparative Tests

Similar to the cooling coil comparative tests, there are in general two methods for controlling the performance or discharge air temperature coming off of a hot water heating coil:

1. Variable water flow rate with constant water inlet temperature (m_{var})
   Constant temperature hot water is supplied to the heating coil. Control of the desired leaving air temperature is achieved by bypassing a portion of the supply water around the heating coil and thereby varying the hot water flow rate (m_{var}) through the coil (see Figure 3).

2. Constant water flow rate with a variable water inlet temperature (T_{var})
   Constant hot water flow rate is maintained through the heating coil while the boiler supply water is mixed with cooler coil return water to achieve the required coil inlet water temperature (T_{var}) in order to maintain the desired leaving air discharge temperature (see Figure 4).

For each of the flow configurations described above there are 4 test cases which are to be simulated for different air flow arrangements and discharge air temperature setpoints as described in Table 4.

The heating coil nominal performance data as provided by the manufacturer is shown in Table 5. The EnergyPlus heating water coil model required some of this data as input.

The following additional requirements were provided by the specification in regards to modeling the heating coil comparative tests:

- For test cases with a variable water flow rate and constant water inlet temperature, the maximum water flow rate is 1.33 l/s

- For test cases with a constant water flow rate and variable water inlet temperature the water flow rate is fixed at 1.33 l/s.

- For test cases with constant air volume (CAS), the air flow rate is fixed at 4500 m3/h at all times

- For test cases with quasi-variable flow volume (VAV), the air flow switches between 2000 m3/h (6 PM to 7 AM) and 5000 m3/h (7 AM to 6 PM)

- Cases are run for two discharge air temperatures: 13°C and 18°C and are held constant during the entire simulation

- For all test cases the heating water supply temperature is held constant at 70°C

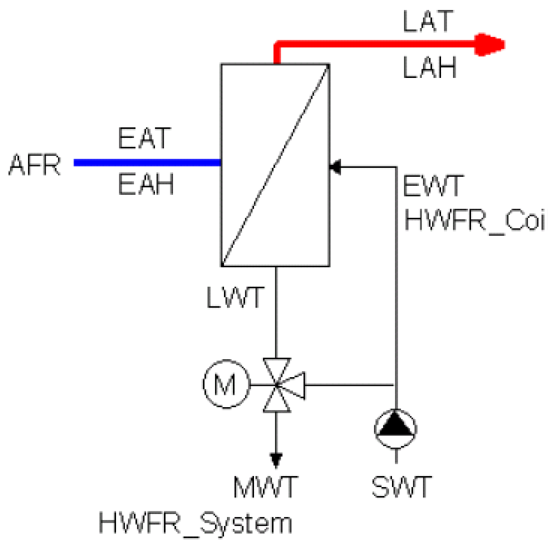


Figure 3 – Schematic Diagram of Heating Coil with Variable Water Flow Rate (Part II - Figure 4-5, Felsmann 2008)

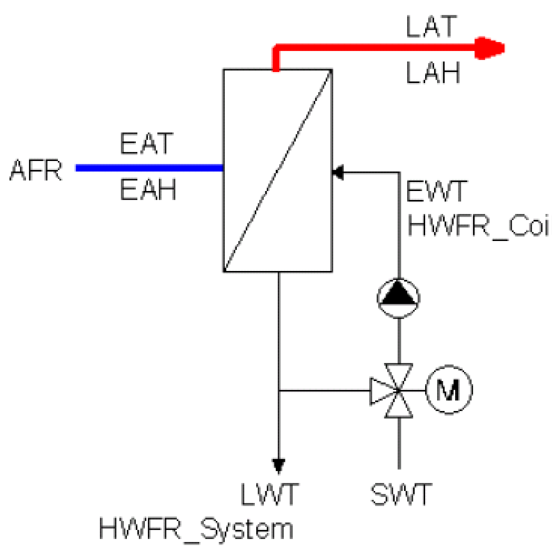


Figure 4 – Schematic Diagram of Heating Coil with Constant Water Flow Rate (Part II - Figure 4-6, Felsmann 2008)

Table 4 – Heating Coil Comparative Test Cases
(Part II - Table 4-3, Felsmann 2008)

Test Case	Control Configuration	Air Flow	Discharge Air Temperature Setpoint (C)
HX100	m_{var}	Constant Air Volume	13
HX120			18
HX200		Variable Air Volume	13
HX220			18
HX300	T_{var}	Constant Air Volume	13
HX320			18
HX400		Variable Air Volume	13
HX420			18

Table 5 – Heating Coil Nominal Performance Data
(Part II - Table 4-2, Felsmann 2008)

Heating Coil Performance		
Barometric pressure *)	kPa	101.3
Entering Air Temperature	°C Dry bulb	4.44
Entering Air Relative Humidity *)	%	50
Entering Air Moisture *)	kg/kg	0.00259
Entering Air Density *)	kg/m³	1.27
Leaving Air Temperature	°C Dry bulb	37.78
Leaving Air Moisture *)	kg/kg	0.0026
Leaving Air Density *)	kg/m³	1.13
Air Flow Rate at coil leaving air conditions *)	m³/h	5780
Air Pressure Drop	kPa	0.0498
Entering Liquid Temp.	°C	82.28
Leaving Liquid Temp.	°C	71.06
Liquid Flow	l/s	1.33
Liquid Pressure Drop	kPa	3.67
Total Heating Capacity	kW	61

Data marked with an (*) were calculated from manufacturer's data

- The heating coil is processing 100% outside air with no recirculation through the coil
- A TMY2 weather file for Des Moines, Iowa was provided for use in simulating all test cases

The following outputs are to be provided for each simulation time increment:

EAT	Entering air dry-bulb temperature, °C
EArH	Entering air relative humidity, %
EAH	Entering air humidity ratio, kg/kg
LAT	Discharge/Leaving air dry-bulb temperature, °C
LArH	Discharge/Leaving air relative humidity, %
LAH	Discharge/Leaving air humidity ratio, kg/kg
AFR	Air flow rate, m3/h
EWT	Heating water coil entering water temperature, °C
LWT	Heating water coil leaving water temperature, °C
HWFRcoil	Heating water flow rate through the coil, l/s
UA	Overall UA-value of the coil, kW/K
HLT	Total heating load, kW
HLS	Sensible heating load, kW

The Overall UA was to be calculated as:

$$UA = CLS / \Delta T_m$$

where

$$\Delta T_m = \frac{(LWT - EAT) - (EWT - LAT)}{ln \frac{LWT - EAT}{EWT - LAT}}$$

2 RESULTS AND DISCUSSION

2.1 Modeling Methodology

In order to generate the required cooling coil and heating coil load each hour of the simulation period as required by the specification, the EnergyPlus user must model a thermal zone, HVAC system including cooling coil and heating coil, and plant equipment including chilled water cooling equipment and hot water heating equipment. For this test suite, a one zone building was modeled with an adiabatic building shell, no windows and no internal loads.

2.1.1 Cooling Coil Tests

Since the specification for the comparative cooling coil tests requires that the air handling system be VAV for some cases, the HVAC system was modeled as a variable volume system using the AirTerminal:SingleDuct:VAV:NoReheat object in EnergyPlus with input parameters set as shown below:

```
AirTerminal:SingleDuct:VAV:NoReheat,
  ZONE ONE VAV Reheat,          !- Name
  COMPACT HVAC-ALWAYS 1,        !- Availability Schedule Name
  ZONE ONE Supply Inlet,        !- Air Outlet Node Name
  ZONE ONE Zone Equip Inlet,    !- Air Inlet Node Name
  0.8333,                       !- Maximum Air Flow Rate {m3/s}
  Constant,                     !- Zone Minimum Air Flow Input Method
  1.;                           !- Zone Minimum Air Flow Fraction
```

The VAV system as described in the specification is not a typical fully variable volume air flow system but is referred to in Section 4.4.2 of the specification as “Quasi-Variable Air Volume” since the air flow rate was either 2000 m3/h or 5000 m3/h depending on the time of day. The VAV system modeled in EnergyPlus was therefore forced to operate as a constant volume system by setting the zone minimum air flow fraction to 1.0. For Cases CC100 and CC120 the maximum air flow rate was set to 3000 m3/h (0.8333 m3/s). For Cases CC200 and CC220 where supply air flow changed from 2000 m3/h (0.5555 m3/s) to 5000 m3/h (1.3889 m3/s) depending on time of day, two separate simulations were performed, one at the high flow rate and one at the low flow rate for the entire simulation period, and then the appropriate results were linked into the results spreadsheet. The supply fan heat added to the air stream was forced to be 0.0 by setting the fan delta pressure to 0.0. The VAV system supply air flow was set to 100% outdoor air as follows with the min and max flow rates set accordingly for each test case:

```
Controller:OutdoorAir,
  SYSTEM-1 OA Controller,       !- Name
  SYSTEM-1 Relief Air Outlet,   !- Relief Air Outlet Node Name
  SYSTEM-1 Air Loop Inlet,      !- Return Air Node Name
  SYSTEM-1 Mixed Air Outlet,    !- Mixed Air Node Name
```

```
  SYSTEM-1 Outside Air Inlet,        !- Actuator Node Name
  0.8333,                            !- Minimum Outdoor Air Flow Rate {m3/s}
  0.8333,                            !- Maximum Outdoor Air Flow Rate {m3/s}
  NoEconomizer,                      !- Economizer Control Type
  ModulateFlow,                      !- Economizer Control Action Type
  ,                                  !- Economizer Maximum Limit Dry-Bulb Temp. {C}
  ,                                  !- Economizer Maximum Limit Enthalpy {J/kg}
  ,                                  !- Economizer Maximum Limit Dewpoint Temp. {C}
  ,                                  !- Electronic Enthalpy Limit Curve Name
  ,                                  !- Economizer Minimum Limit Dry-Bulb Temp. {C}
  NoLockout,                         !- Lockout Type
  ProportionalMinimum,               !- Minimum Limit Type
  COMPACT SYSTEM-1 Outside Air Sched;    !- Minimum Outdoor Air Schedule Name
```

The cooling coil was modeled using the Coil:Cooling:Water object in EnergyPlus with input parameters set as shown below:

```
Coil:Cooling:Water,
  SYSTEM-1 Cooling Coil,             !- Name
  COMPACT HVAC-ALWAYS 1,             !- Availability Schedule Name
  0.00177,                           !- Design Water Flow Rate {m3/s}
  1.54778,                           !- Design Air Flow Rate {m3/s}
  6.67,                              !- Design Inlet Water Temperature {C}
  27.78,                             !- Design Inlet Air Temperature {C}
  12.50,                             !- Design Outlet Air Temperature {C}
  0.0104,                            !- Design Inlet Air Humidity Ratio {kg-H2O/kg-air}
  0.0087,                            !- Design Outlet Air Humidity Ratio {kg-H2O/kg-air}
  SYSTEM-1 Cooling Coil ChW Inlet,   !- Water Inlet Node Name
  SYSTEM-1 Cooling Coil ChW Outlet,  !- Water Outlet Node Name
  SYSTEM-1 Supply Fan Outlet,        !- Air Inlet Node Name
  SYSTEM-1 Cooling Coil Outlet,      !- Air Outlet Node Name
  DetailedAnalysis,                  !- Type of Analysis
  CrossFlow,                         !- Heat Exchanger Configuration
  ;                                  !- Condensate Collection Water Storage Tank Name
```

The coil design parameters were taken from Table 2 in Section 1 of this report.

EnergyPlus has two models available for simulating a water cooling coil:

a) Coil:Cooling:Water
   This coil model has the ability to give detailed output with simplified inputs. Inputs for complicated coil geometry are not required. Instead, the coil requires thermodynamic inputs such as temperatures, mass flow rates and humidity ratios. This model uses the NTU-effectiveness approach to model heat transfer and has two types of flow arrangements, cross-flow and counter-flow. For this test series the CROSSFLOW arrangement was used. This EnergyPlus cooling coil model allows the user to choose between a Simple Analysis method or Detailed Analysis method. The difference

between the two methods being, the Simple Analysis assumes that the coil is either all-dry or all-wet while the Detailed Analysis method checks for part-wet and part-dry operation and reports the surface area wet fraction of the coil. Both the Simple Analysis and Detailed Analysis options were simulated for this test series.

b) Coil:Cooling:Water:DetailedGeometry
This model requires the user to input the detailed coil geometry in terms of tube outside and inside surface area, coil depth, fin diameter and thickness, tube inside and outside diameter, tube and fin thermal conductivity, fin spacing, tube depth spacing, and number of tube rows. Since none of these details were available for the cooling coil from the specification, this cooling coil model was not used for these tests.

2.1.2 Heating Coil Tests

The air handling system for the comparative heating coil tests were structured in a manner similar to the cooling coil tests except that for the constant volume air flow cases (Cases HX100 and HX120) the air flow rate was 4500m3/h (1.25 m3/s). This required that the HVAC system object and the outside air controller object be changed as indicated below.

```
AirTerminal:SingleDuct:VAV:NoReheat,
  ZONE ONE VAV Reheat,            !- Name
  COMPACT HVAC-ALWAYS 1,          !- Availability Schedule Name
  ZONE ONE Supply Inlet,          !- Air Outlet Node Name
  ZONE ONE Zone Equip Inlet,      !- Air Inlet Node Name
  1.25,                           !- Maximum Air Flow Rate {m3/s}
  Constant,                       !- Zone Minimum Air Flow Input Method
  1.;                             !- Zone Minimum Air Flow Fraction

Controller:OutdoorAir,
  SYSTEM-1 OA Controller,         !- Name
  SYSTEM-1 Relief Air Outlet,     !- Relief Air Outlet Node Name
  SYSTEM-1 Air Loop Inlet,        !- Return Air Node Name
  SYSTEM-1 Mixed Air Outlet,      !- Mixed Air Node Name
  SYSTEM-1 Outside Air Inlet,     !- Actuator Node Name
  1.25,                           !- Minimum Outdoor Air Flow Rate {m3/s}
  1.25,                           !- Maximum Outdoor Air Flow Rate {m3/s}
  NoEconomizer,                   !- Economizer Control Type
  ModulateFlow,                   !- Economizer Control Action Type
  ,                               !- Economizer Maximum Limit Dry-Bulb Temp. {C}
  ,                               !- Economizer Maximum Limit Enthalpy {J/kg}
  ,                               !- Economizer Maximum Limit Dewpoint Temp. {C}
  ,                               !- Electronic Enthalpy Limit Curve Name
  ,                               !- Economizer Minimum Limit Dry-Bulb Temp. {C}
  NoLockout,                      !- Lockout Type
  ProportionalMinimum,            !- Minimum Limit Type
  COMPACT SYSTEM-1 Outside Air Sched;   !- Minimum Outdoor Air Schedule Name
```

To model the heating coil, the following EnergyPlus object was used with input parameters set as shown below.

```
Coil:Heating:Water,
  SYSTEM-1 Heating Coil,              !- Name
  COMPACT HVAC-BOILER,                !- Availability Schedule Name
  autosize,                           !- U-Factor Times Area Value {W/K}
  0.00133,                            !- Maximum Water Flow Rate {m3/s}
  SYSTEM-1 Heating Coil HW Inlet,     !- Water Inlet Node Name
  SYSTEM-1 Heating Coil HW Outlet,    !- Water Outlet Node Name
  SYSTEM-1 Supply Fan Outlet,         !- Air Inlet Node Name
  SYSTEM-1 Heating Coil Outlet,       !- Air Outlet Node Name
  UFactorTimesAreaAndDesignWaterFlowRate,   !- Performance Input Method
  autosize,                           !- Rated Capacity {W}
  82.28,                              !- Rated Inlet Water Temperature {C}
  4.44,                               !- Rated Inlet Air Temperature {C}
  71.22,                              !- Rated Outlet Water Temperature {C}
  37.78;                              !- Rated Outlet Air Temperature {C}
```

The rated coil parameters were taken from Table 4 in Section 1 of this report.

The input object Coil:Heating:Water provides a model that uses an NTU–effectiveness model of a static heat exchanger. The model is an inlet – outlet model: given the inlet conditions and flow rates and the UA, the effectiveness is calculated using the formula for the effectiveness of a cross-flow heat exchanger with both fluid streams unmixed. The effectiveness then allows the calculation of the outlet conditions from the inlet conditions.

The inputs to the model are: (1) the current inlet temperatures and flow rates of the air and water fluid streams and (2) the UA of the coil. The design UA of the coil was calculated by EnergyPlus using the heating coil performance data provided in Table 4 of Section 1 as 1.1108 kW/K. The resulting hourly UA of the heating coil which was calculated directly in the results spreadsheet using the heating coil output and the air and water inlet and outlet water temperatures for each hour varies around the design UA depending on the air and water flow rates but being more sensitive to the air flow rate.

There are 2 alternative user inputs for the component: the user may input the design water volumetric flow rate and the UA directly; or the user may choose to input the more familiar design heating capacity plus design inlet and outlet temperatures and let the program calculate the design UA. The latter method was used for the tests described here.

2.2 Modeling Difficulties

2.2.1 Cooling Coil Tests

Only eight of the Cooling Coil Comparative Test cases (CC100, CC120, CC140, CC160, CC200, CC220, CC240 and CC260) described in Section 1.3.1 could be modeled by EnergyPlus. The other cooling coil comparative cases (cases CC300 through CC460) and the Cooling Coil Empirical Test could not be modeled by EnergyPlus due to the following reason:

a) They required the use a varying water supply temperature to the cooling coils with the water flow rate remaining constant. EnergyPlus will allow different water supply temperatures but currently cannot <u>control</u> the supply temperature of the water entering the coil to meet the load.

Prior to EnergyPlus version 7.0.0.026, EnergyPlus did not have the capability to model glycol solutions as part of the chilled water loops and therefore an approximation using water as the chilled water fluid was used by adjusting the cooling loop water flow rate. The use of a 35% Ethylene Glycol solution was approximated in the simulations by adjusting the input design water flow rate of the cooling coil based on the ratio of specific heats and densities of water and the glycol solution using the data provided in Table 2-4 of Part I of the specification. This was arrived at as follows:

0.00177 m3/s * (3.5543 kJ/(kgK) * 1054.08 kg/m3) / (4.180 kJ/(kgK) * 998.2 kg/m3)
= 0.001589 m3/s

One of the new features of EnergyPlus version 7.0.0.036 release was the ability to simulate chilled water loops the use either ethylene glycol or propylene glycol mixtures so the above approximation is no longer needed. An additional feature added the EnergyPlus version 7.0.0.036 was the ability to model variable UA conditions for the cooling coil.

Cases CC200, CC220, CC240 and CC260 all required that the supply air flow rate be fixed at two different values depending on the time of day: 2000 m3/h from 6 p.m. to 7 a.m. and 5000 m3/h from 7 a.m. to 6 p.m. This was modeled in EnergyPlus by two separate simulations, one at 2000 m3/h for the full simulation period and one at 5000 m3/h for the full simulation period. The results summarized in the spreadsheet then linked to the proper hourly results from the two separate EnergyPlus runs. This does not introduce errors at the transitions because the cooling coil input air stream was always 100% outdoor air and not affected by the zone conditions.

2.2.2 Heating Coil Tests

Only four of the Heating Coil Comparative Test cases (HX100, HX120, HX200 and HX220) described in Part II, Section 4.5 of the specification were able to be modeled by EnergyPlus, and these were modeled with water as the heating fluid. The other heating coil comparative cases could not be modeled by EnergyPlus due to the following reason:

a) They required the use a varying water supply temperature to the heating coils with the water flow rate remaining constant. EnergyPlus will allow different water supply temperatures but currently cannot control the supply temperature of the water entering the coil to meet the load.

Cases HX200 and HX220 both required that the supply air flow rate be fixed at two different values depending on the time of day: 2000 m3/h from 6 p.m. to 7 a.m. and 5000 m3/h from 7 a.m. to 6 p.m. This was modeled in EnergyPlus by two separate simulations, one at 2000 m3/h for the full simulation period and one at 5000 m3/h for the full simulation period. The results summarized in the spreadsheet then linked to the proper hourly results from the two separate EnergyPlus runs. This does not introduce errors at the transitions because the heating coil input air stream was always 100% outdoor air and not affected by the zone conditions.

2.3 Results for Cooling Coil Tests

2.3.1 Cooling Coil Test Results as Reported in IEA Final Report

EnergyPlus 2.2.0.023 results for the cooling coil comparative tests that were submitted as part of the final round of testing and which are reported in the IEA final report are presented in Table 6 – Results of Cooling Coil Tests. Figures 5 through 7 are reproductions of charts from the IEA final report showing the amount of total, sensible and latent cooling energy predicted by the various programs for the period from May through September to maintain the air leaving the cooling coil at the given set point temperature. Deviations between programs were normally less than 10%. EnergyPlus results are shown for only test cases CC100, CC120, CC200 and CC220 and were within the range of other program results except for test case CC200 latent cooling where EnergyPlus is setting the upper boundary of results.

When comparing hourly results between programs for specific day types, e.g., test case CC100 on a hot dry day where the cooling load is less than the nominal load for the cooling coil (Figure 8), the agreement between programs is very good. For test case CC200 however, on a hot humid day (Figure 9) where the air flow rate is increased and the coil is required to operate outside the nominal performance of the cooling coil, the range of results between programs is much greater. Under these conditions the leaving air set point temperature cannot be maintained. These variations between programs are probably due to the differences in the coil models used by the various programs. Other major differences between the program coil models are evident when comparing the volume of chilled water circulated through the cooling coil during the simulation period (Figure 10) and comparing hourly water flow rates for specific days (Figures 11 and 12). Another indication of variation in models is indicated by the mean leaving water temperature as indicated in Figure 13. In the case of EnergyPlus where the water flow rates are lower and leaving water temperatures are higher than other programs, this indicates that the EnergyPlus coil model has calculated a higher design UA value for the coil than the other programs.

Table 6 Results of Cooling Coil Tests with EnergyPlus Version 2.2.0.023

IEA Mechanical Equipment and Control Strategies - Chilled Water System

Results of Cooling Coil Comparative Test - Simple Coil Solution
Simulation Program: **Energy Plus 2.2.0.023**
Date: **4/22/2008**

Fixed Simulation Conditions

Simulation Period: May 1 thru Sep 30
100% outside air with conditions taken from 14933.tm2 weather file
Constant chilled water supply temperature to cooling coil = 6C
Variable chilled water supply flow to cooling coil
Maximum chilled water supply flow rate = 1.505 l/s = 0.001505 m3/s
Coil Water Flow changed from 0.00177 m3/s to 0.001589 m3/s in proportion to water and 35% Ethylene Glycol specific heats and densities

Case CC100

Constant air flow = 3000 m3/h = 0.8333 m3/s
Constant air discharge temperature from coil = 13C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	3000	1.7	6.0	6.0	0.00	0	0	0
Max	3000	13.0	6.0	22.1	0.97	54	23	32
Average	3000	12.8	6.0	15.8	0.27			
Sum						45402	28634	16768

Case CC120

Constant air flow = 3000 m3/h = 0.8333 m3/s
Constant air discharge temperature from coil = 18C

Case CC120	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	3000	1.7	6.0	6.0	0.00	0	0	0
Max	3000	18.0	6.0	26.3	0.52	40	18	23
Average	3000	16.7	6.0	14.7	0.09			
Sum						18152	14207	3945

Case CC200

Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 13C

Case CC200	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	2000	1.7	6.0	6.0	0.00	0	0	0
Max	5000	14.8	6.0	23.0	1.77	82	39	49
Average	3375	12.8	6.0	15.3	0.38			
Sum						56769	36240	20529

Case CC220

Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 18C

Case CC220	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	2000	1.7	6.0	6.0	0.00	0	0	0
Max	5000	18.0	6.0	26.6	1.03	67	31	39
Average	3375	16.7	6.0	14.6	0.12			
Sum						24429	19109	5320

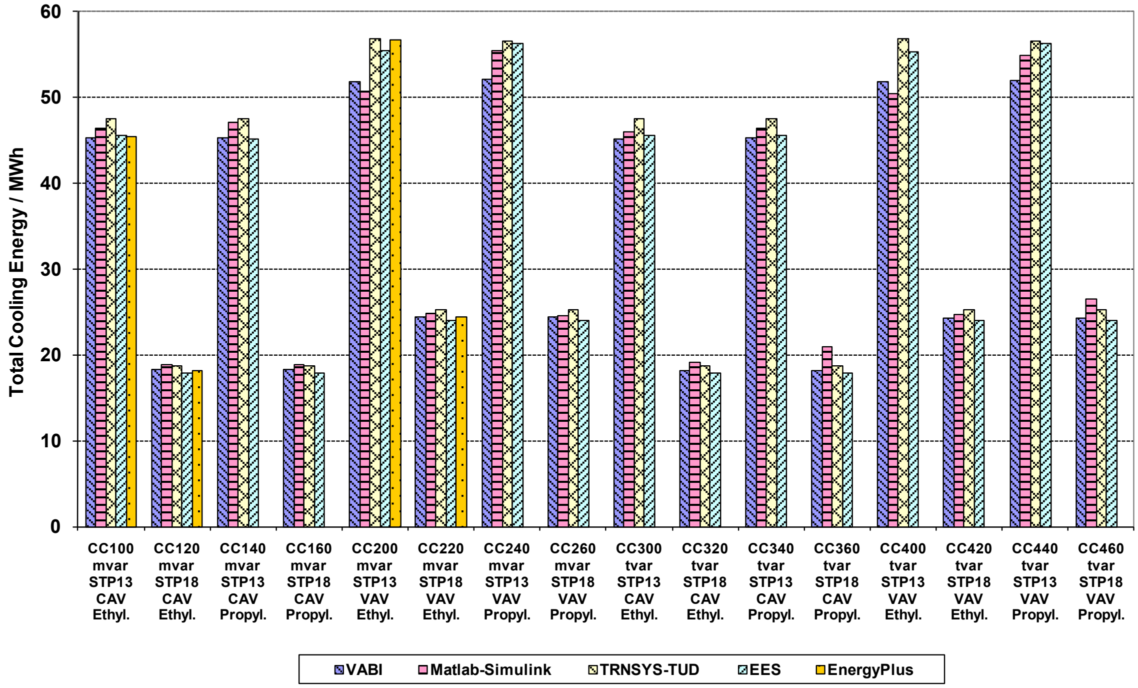


Figure 5 – Cooling Coil Comparative Tests – Total Cooling Energy EnergyPlus v2.2.0.23 (Part I - Figure 6-35, Felsmann 2008)

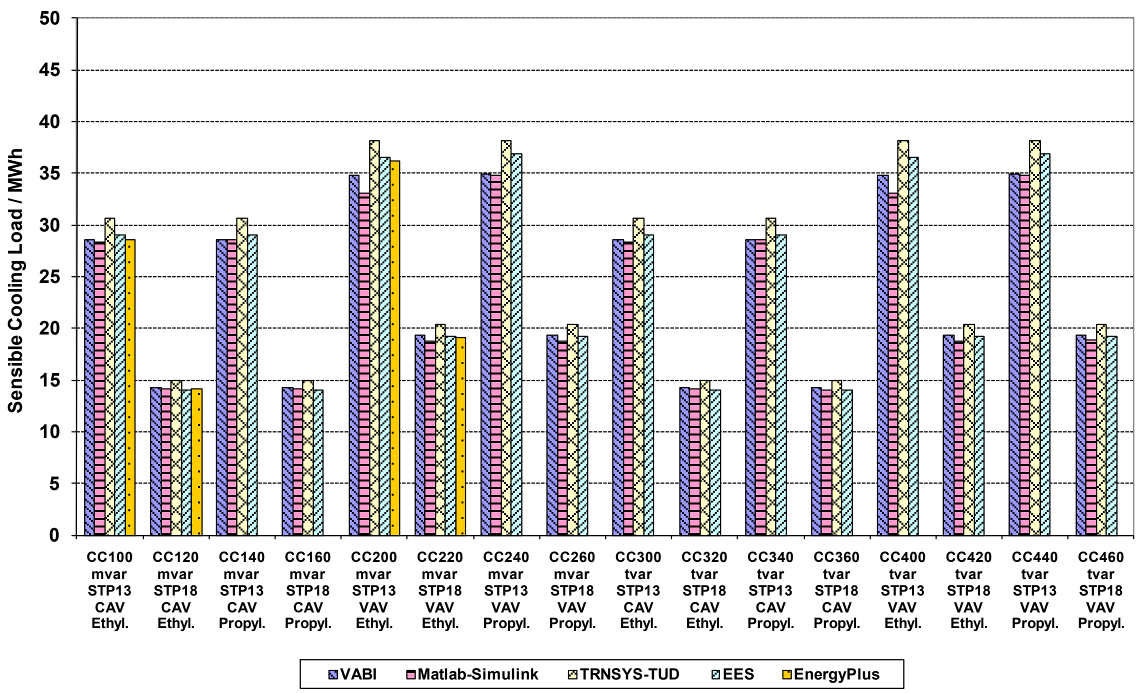


Figure 6 – Cooling Coil Comparative Tests – Sensible Cooling Energy EnergyPlus v2.2.0.23 (Part I - Figure 6-38, Felsmann 2008)

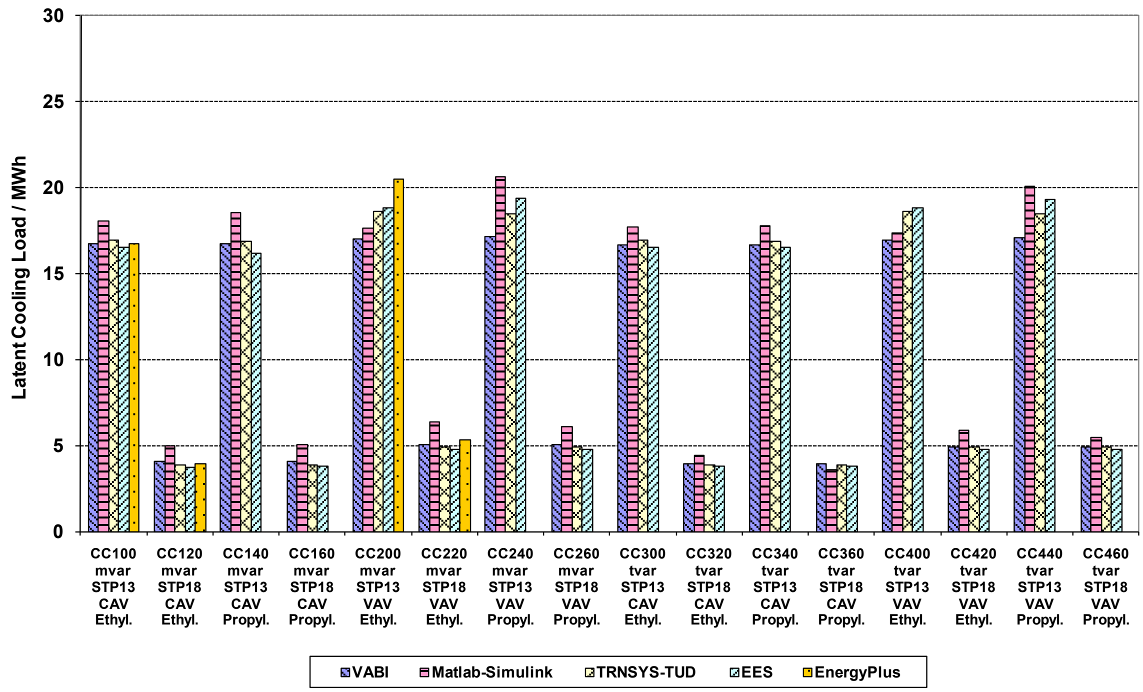


Figure 7 – Cooling Coil Comparative Tests – Latent Cooling Energy
EnergyPlus v2.2.0.23 (Part I - Figure 6-39, Felsmann 2008)

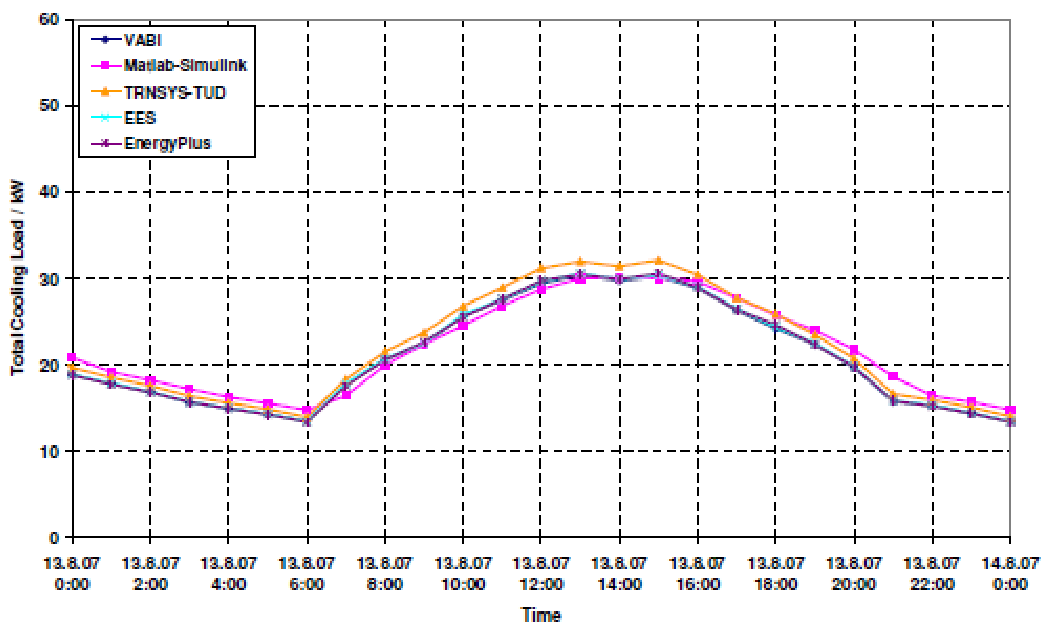


Figure 8 – Cooling Coil Comparative Test CC100 – Total Cooling Load
August 13 (hot-dry)
EnergyPlus v2.2.0.23 (Part I - Figure 6-36, Felsmann 2008)

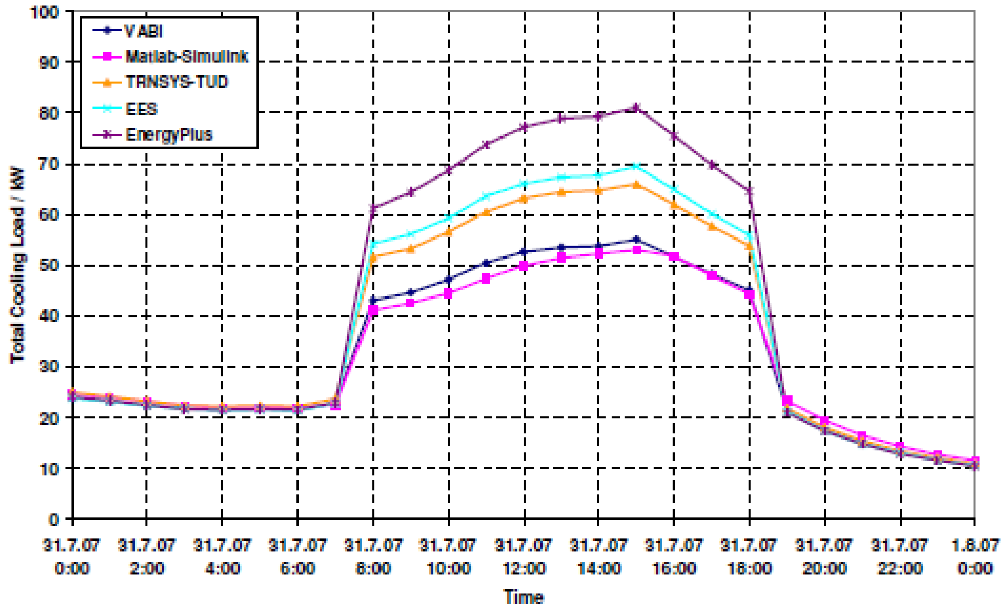


Figure 9 – Cooling Coil Comparative Test CC200 – Total Cooling Load July 31 (hot-humid) EnergyPlus v2.2.0.23 (Part I - Figure 6-37, Felsmann 2008)

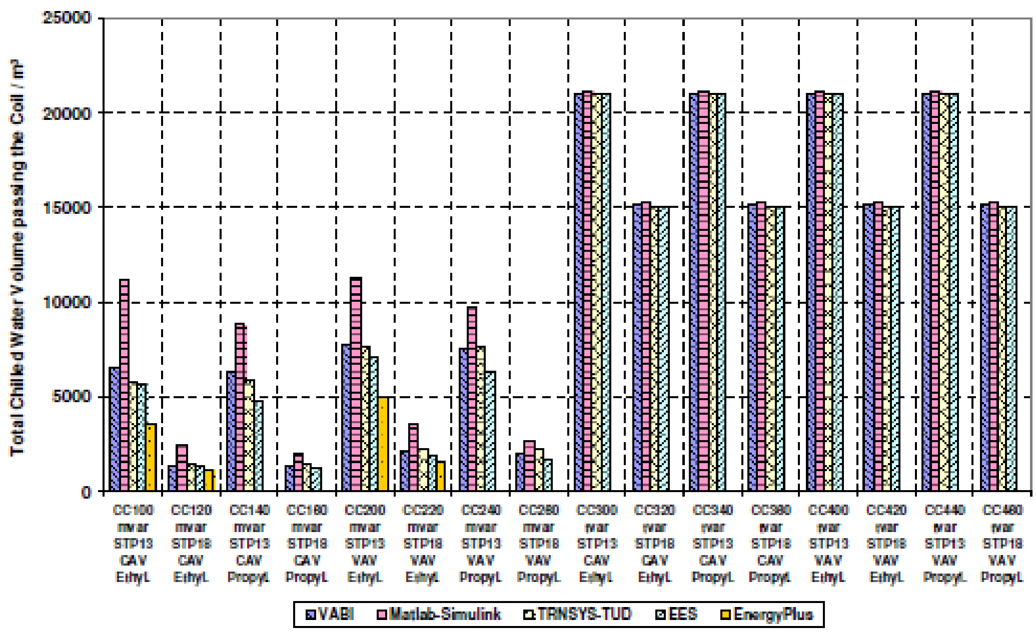


Figure 10 – Cooling Coil Comparative Tests – Chilled Water Volume Circulated EnergyPlus v2.2.0.23 (Part I - Figure 6-41, Felsmann 2008)

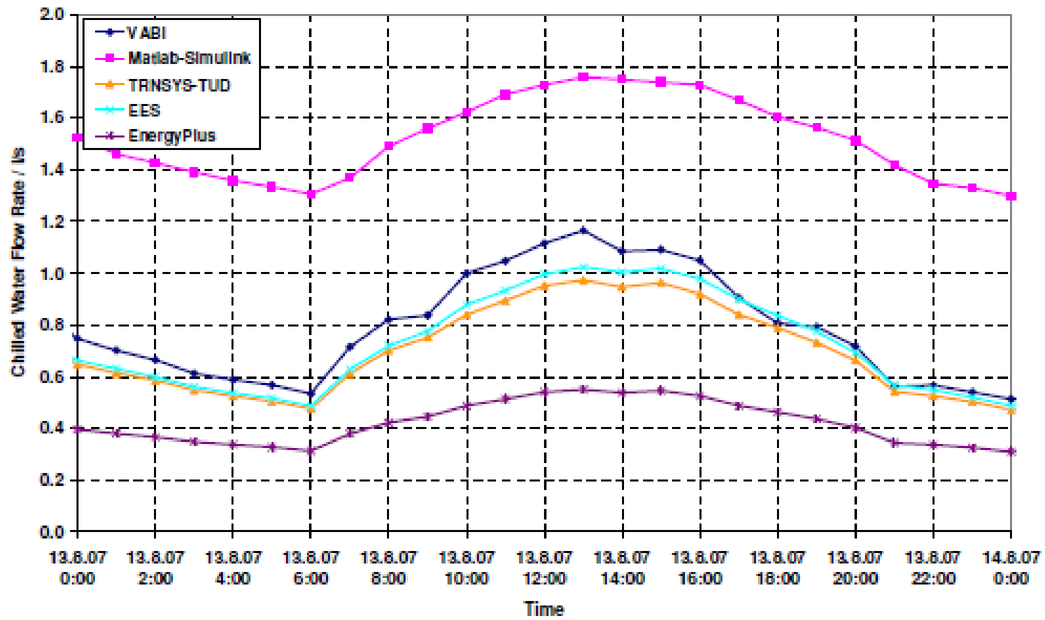


Figure 11 – Cooling Coil Comparative Test CC100 – Chilled Water Flow Rate
August 13 (hot-dry)
EnergyPlus v2.2.0.23 (Part I - Figure 6-42, Felsmann 2008)

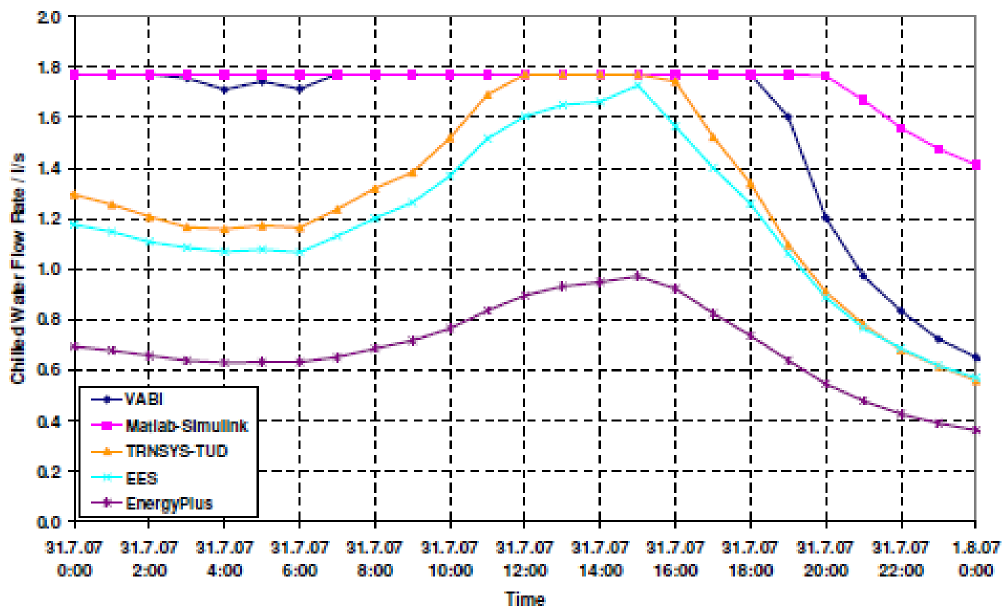


Figure 12 – Cooling Coil Comparative Test CC100 – Chilled Water Flow Rate
July 31 (hot-humid)
EnergyPlus v2.2.0.23 (Part I - Figure 6-43, Felsmann 2008)

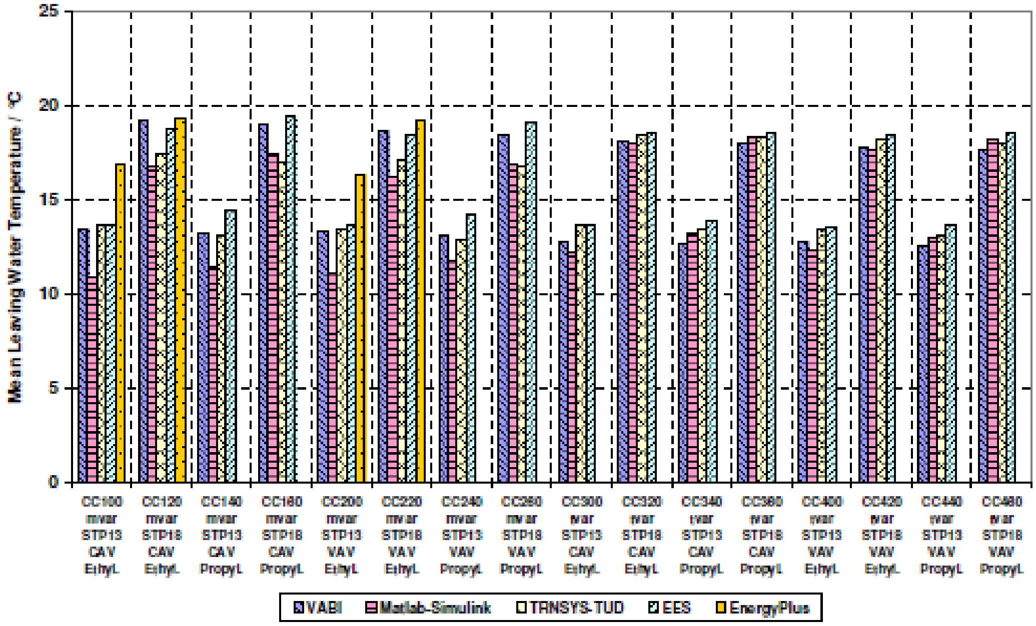


Figure 13 – Cooling Coil Comparative Tests – Mean Leaving Water Temperature EnergyPlus v2.2.0.23 (Part I - Figure 6-45, Felsmann 2008)

2.3.2 Cooling Coil Test Results with Latest Version of EnergyPlus

The results obtained for the cooling coil tests when simulated with the latest release of EnergyPlus, version 7.1.0.012, are shown in Tables 7 (35% Ethylene Glycol) and 8 (18% Propylene Glycol) and Figures 14 through 22. Coil loads increased slightly compared to those for EnergyPlus version 2.2.0.023 but EnergyPlus results are still within the range of other programs except for the latent load of Case CC200 which is still setting the upper boundary. With the addition of the variable UA feature to EnergyPlus version 7.0.0.036, the chilled water flow rates changed significantly and now are in range of the other programs. Numerous other charts comparing EnergyPlus v7.1.0.012 results with other programs are included in Appendix A

Table 7 Results of Cooling Coil Tests with EnergyPlus Version 7.1.0.012 Cases with 35% Ethylene Glycol Mixture

IEA Mechanical Equipment and Control Strategies - Chilled Water System

Results of Cooling Coil Comparative Test - Simple Coil Solution

Simulation Program: **Energy Plus 7.1.0.012**

Date: **6/20/2012**

Fixed Simulation Conditions

Simulation Period: May 1 thru Sep 30
100% outside air with conditions taken from 14933.tm2 weather file
Constant chilled water supply temperature to cooling coil = 6C
Variable chilled water supply flow to cooling coil
Maximum chilled water supply flow rate = 1.77 l/s = 0.00177 m3/s

35% Ethylene Glycol

Case CC100

Constant air flow = 3000 m3/h = 0.8333 m3/s
Constant air discharge temperature from coil = 13C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	3000	1.7	6.0	6.0	0.00	0	0	0
Max	3000	14.1	6.0	14.9	1.87	51	23	30
Average	3000	12.8	6.0	12.4	0.50			
Sum						46399	28629	17770

Case CC120

Constant air flow = 3000 m3/h = 0.8333 m3/s
Constant air discharge temperature from coil = 18C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	3000	1.7	6.0	6.0	0.00	0	0	0
Max	3000	18.0	6.0	20.4	0.97	40	18	24
Average	3000	16.7	6.0	13.4	0.12			
Sum						18689	14207	4482

Case CC200

Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 13C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	2000	1.7	6.0	6.0	0.00	0	0	0
Max	5000	17.7	6.0	16.5	1.87	69	37	41
Average	3375	12.9	6.0	12.4	0.61			
Sum						55933	35609	20324

Case CC220

Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 18C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	2000	1.7	6.0	6.0	0.00	0	0	0
Max	5000	18.0	6.0	19.9	1.77	67	31	40
Average	3375	16.7	6.0	13.3	0.17			
Sum						25171	19223	5945

Table 8 Results of Cooling Coil Tests with EnergyPlus Version 7.1.0.012
Cases with 18% Propylene Glycol Mixture

IEA Mechanical Equipment and Control Strategies - Chilled Water System
Results of Cooling Coil Comparative Test - Simple Coil Solution
Simulation Program: **Energy Plus 7.1.0.012**
Date: **6/20/2012**

Fixed Simulation Conditions
Simulation Period: May 1 thru Sep 30
100% outside air with conditions taken from 14933.tm2 weather file
Constant chilled water supply temperature to cooling coil = 6C
Variable chilled water supply flow to cooling coil
Maximum chilled water supply flow rate = 1.77 l/s = 0.00177 m3/s
18% Propylene Glycol

Case CC140
Constant air flow = 3000 m3/h = 0.8333 m3/s
Constant air discharge temperature from coil = 13C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	3000	1.7	6.0	6.0	0.00	0	0	0
Max	3000	14.1	6.0	14.3	1.81	51	23	30
Average	3000	12.8	6.0	12.1	0.48			
Sum						46541	28628	17913

Case CC160
Constant air flow = 3000 m3/h = 0.8333 m3/s
Constant air discharge temperature from coil = 18C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	3000	1.7	6.0	6.0	0.00	0	0	0
Max	3000	18.0	6.0	19.8	0.93	40	18	24
Average	3000	16.7	6.0	13.1	0.11			
Sum						18772	14207	4565

Case CC240
Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 13C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	2000	1.7	6.0	6.0	0.00	0	0	0
Max	5000	17.6	6.0	15.6	1.81	69	37	41
Average	3375	12.9	6.0	12.1	0.58			
Sum						56106	35590	20516

Case CC260
Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 18C

Case CC100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Chilled Water Flow Rate ChWFR (l/s)	Total Cooling Load CLT (kW)	Sensible Cooling Load CLS (kW)	Latent Cooling Load CLL (kW)
Min	2000	1.7	6.0	6.0	0.00	0	0	0
Max	5000	18.0	6.0	19.5	1.70	67	31	40
Average	3375	16.7	6.0	13.0	0.16			
Sum						25299	19223	6073

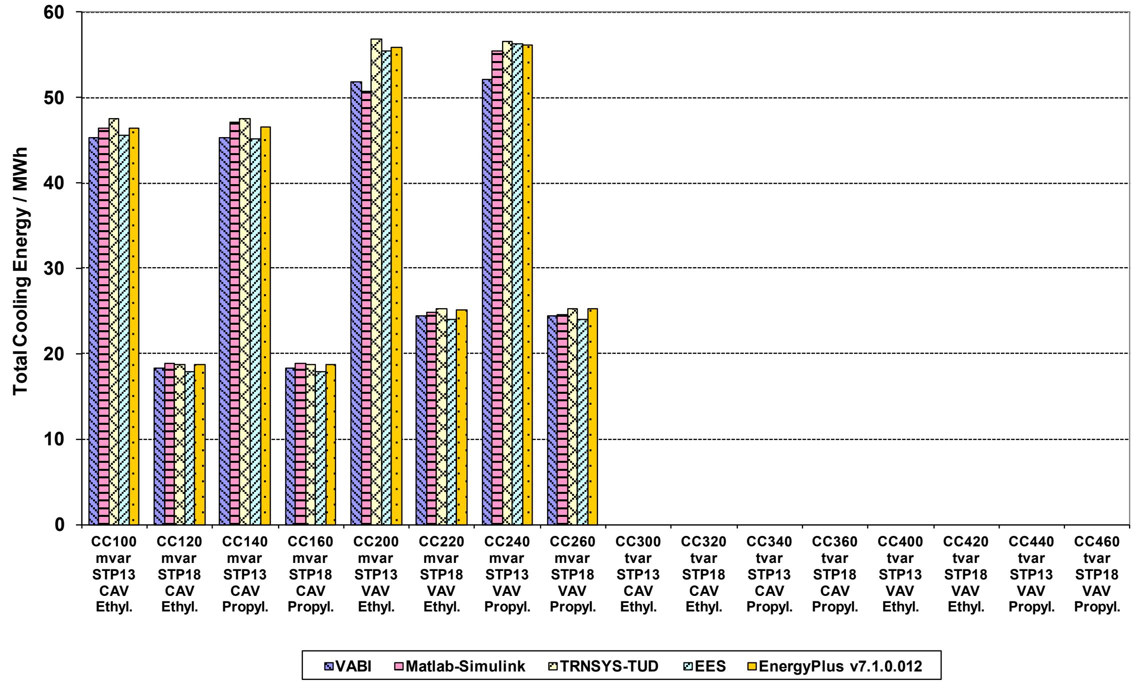


Figure 14 – Cooling Coil Comparative Tests – Total Cooling Energy EnergyPlus v7.1.0.012

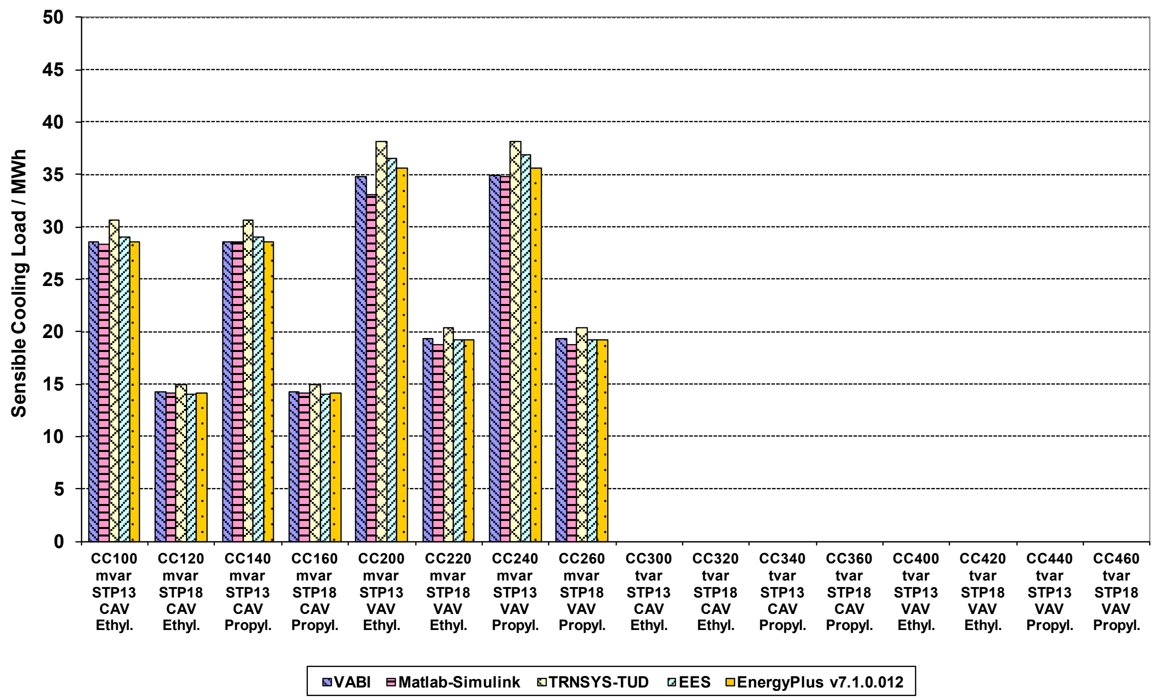


Figure 15 – Cooling Coil Comparative Tests – Sensible Cooling Energy EnergyPlus v7.1.0.012

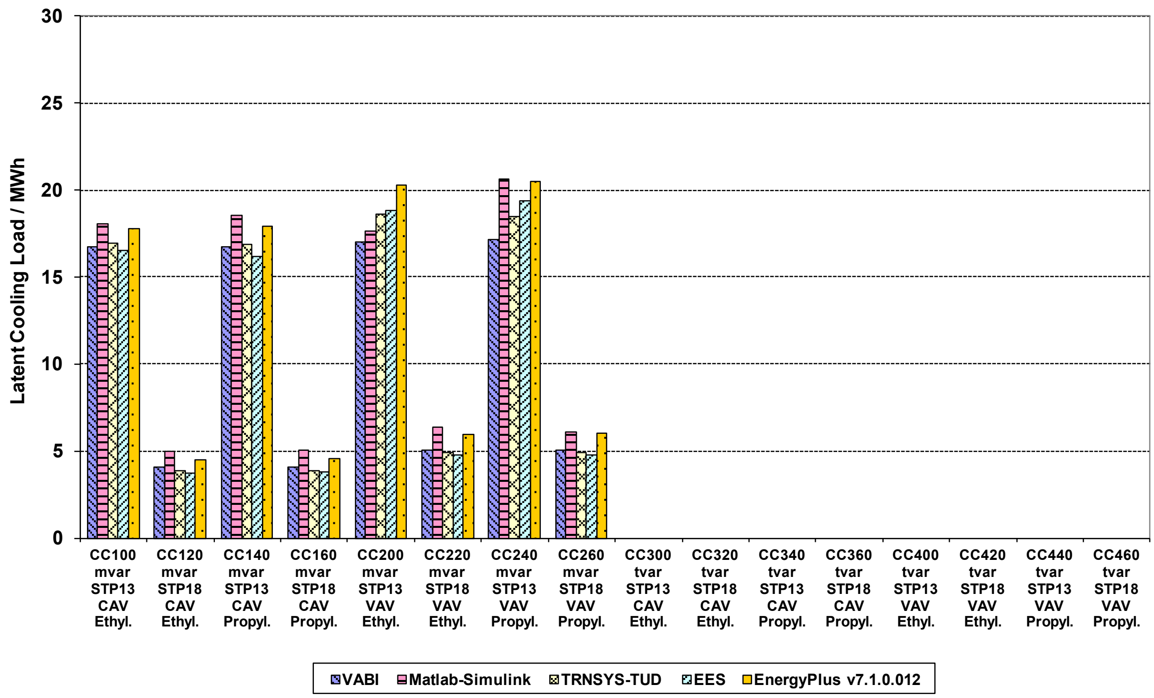


Figure 16 – Cooling Coil Comparative Tests – Latent Cooling Energy EnergyPlus v7.1.0.012

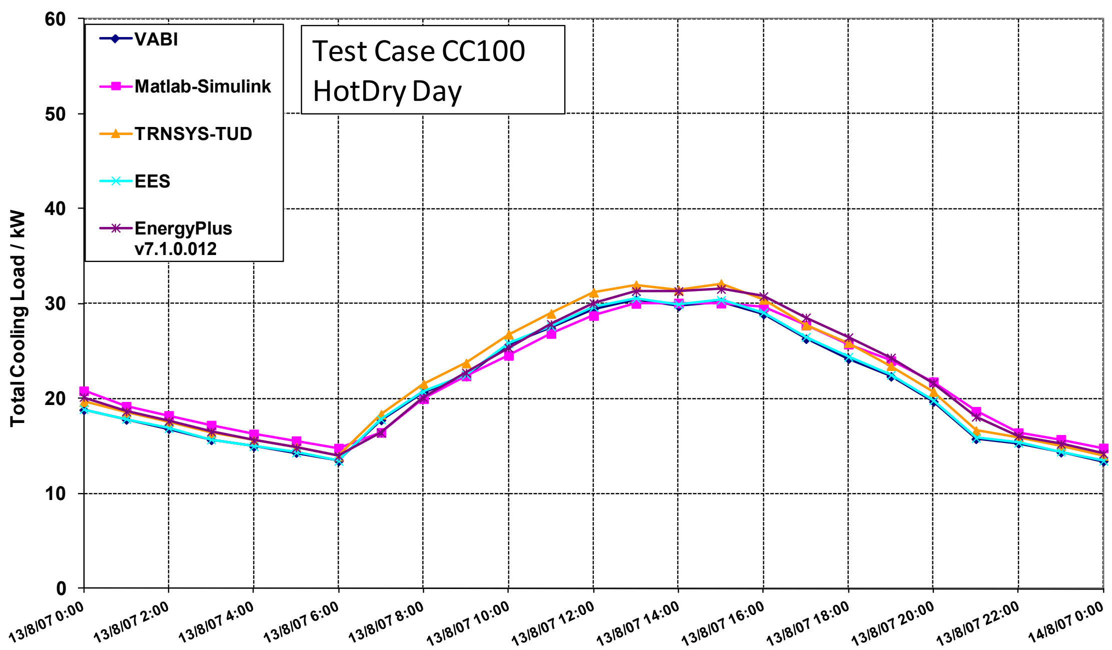


Figure 17 – Cooling Coil Comparative Test CC100 – Total Cooling Load August 13 (hot-dry) EnergyPlus v7.1.0.012

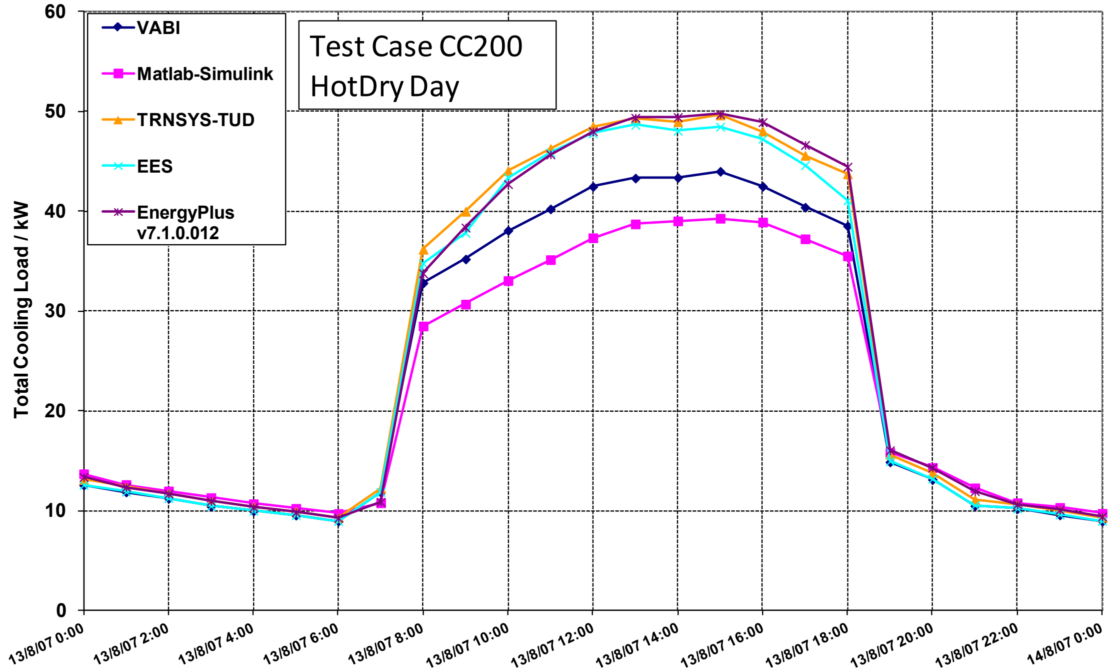


Figure 18 – Cooling Coil Comparative Test CC200 – Total Cooling Load
July 31 (hot-humid)
EnergyPlus v7.1.0.012

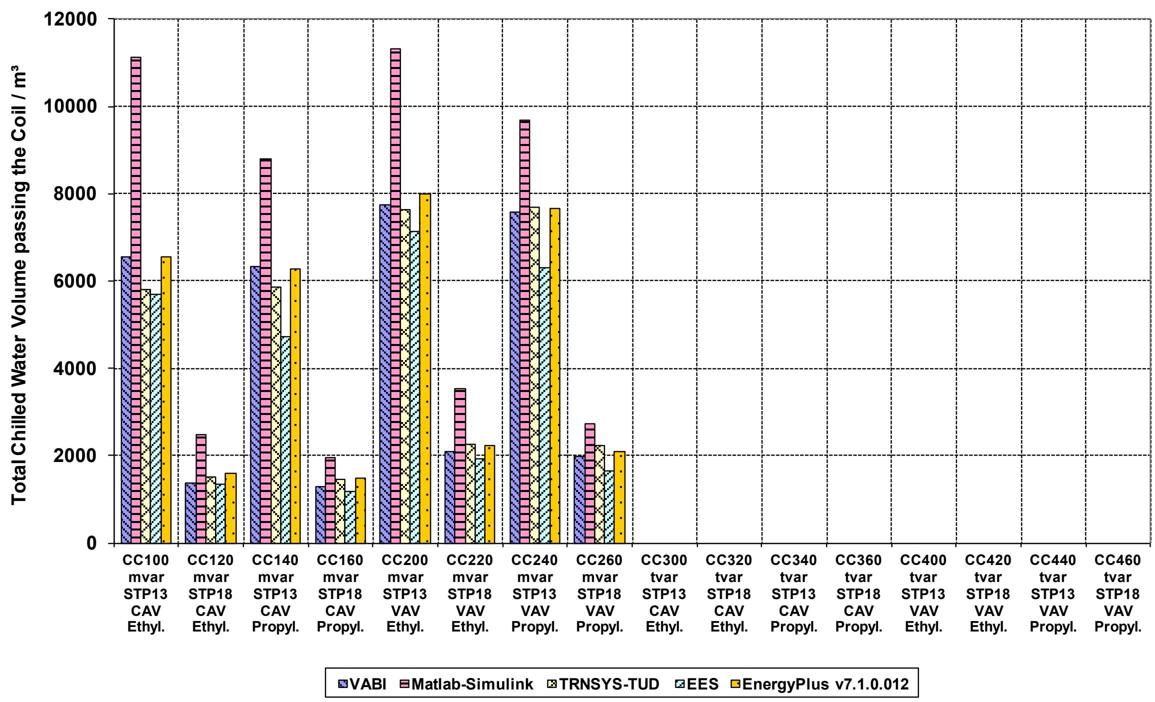


Figure 19 – Cooling Coil Comparative Tests – Chilled Water Volume Circulated
EnergyPlus v7.1.0.012

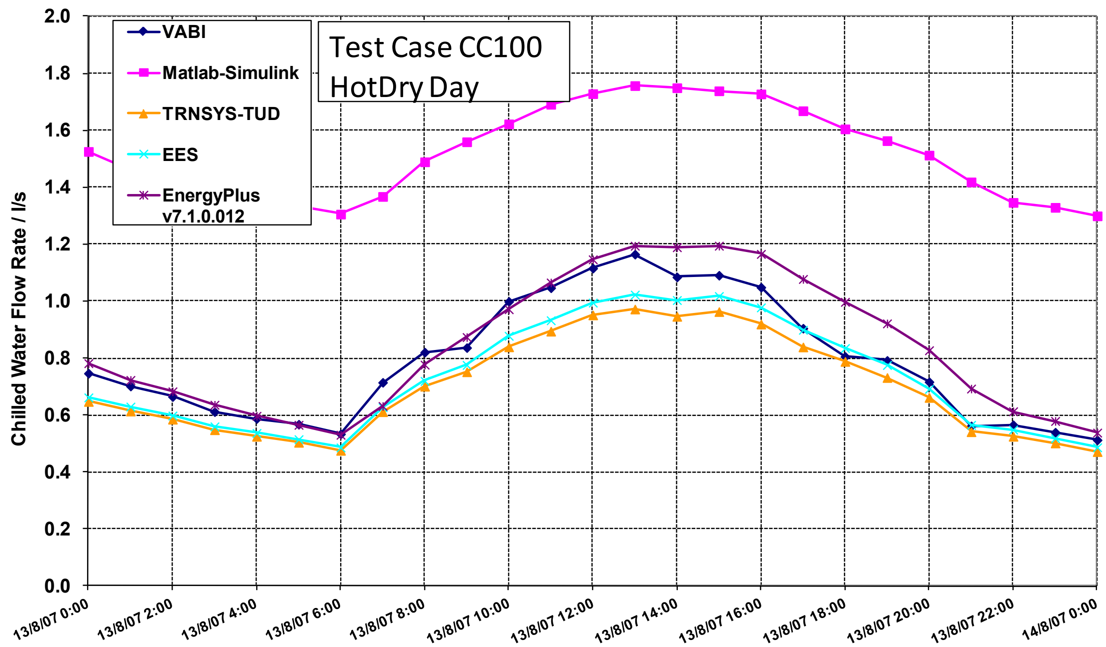


Figure 20 – Cooling Coil Comparative Test CC100 – Chilled Water Flow Rate
August 13 (hot-dry)
EnergyPlus v7.1.0.012

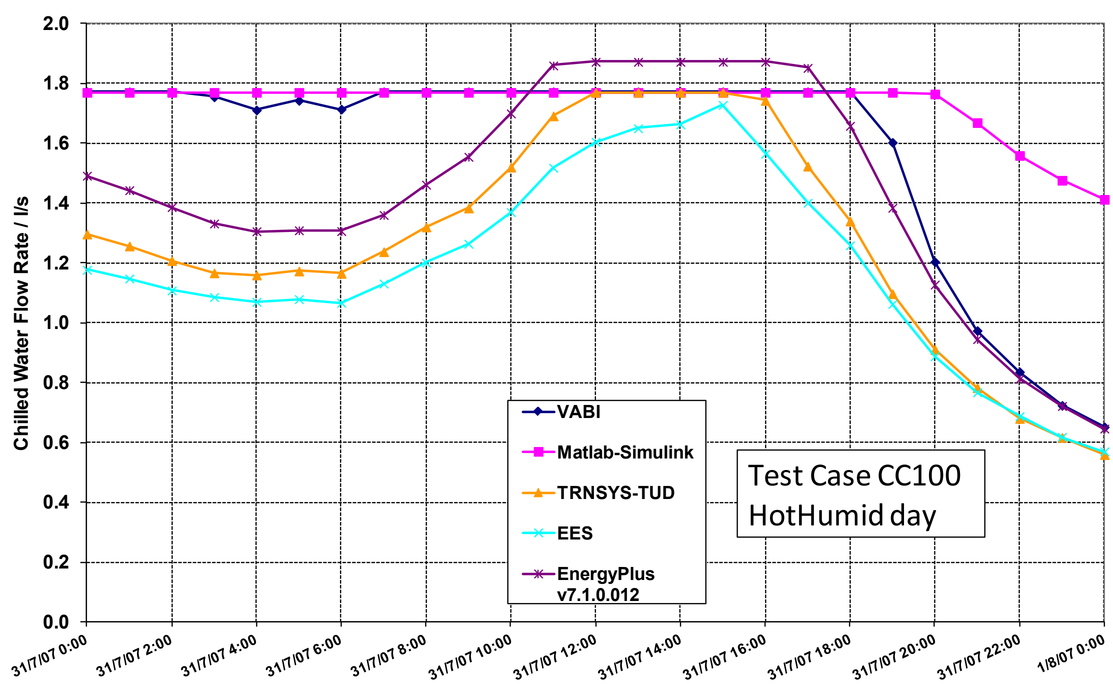


Figure 21 – Cooling Coil Comparative Test CC100 – Chilled Water Flow Rate
July 31 (hot-humid)
EnergyPlus v7.1.0.012

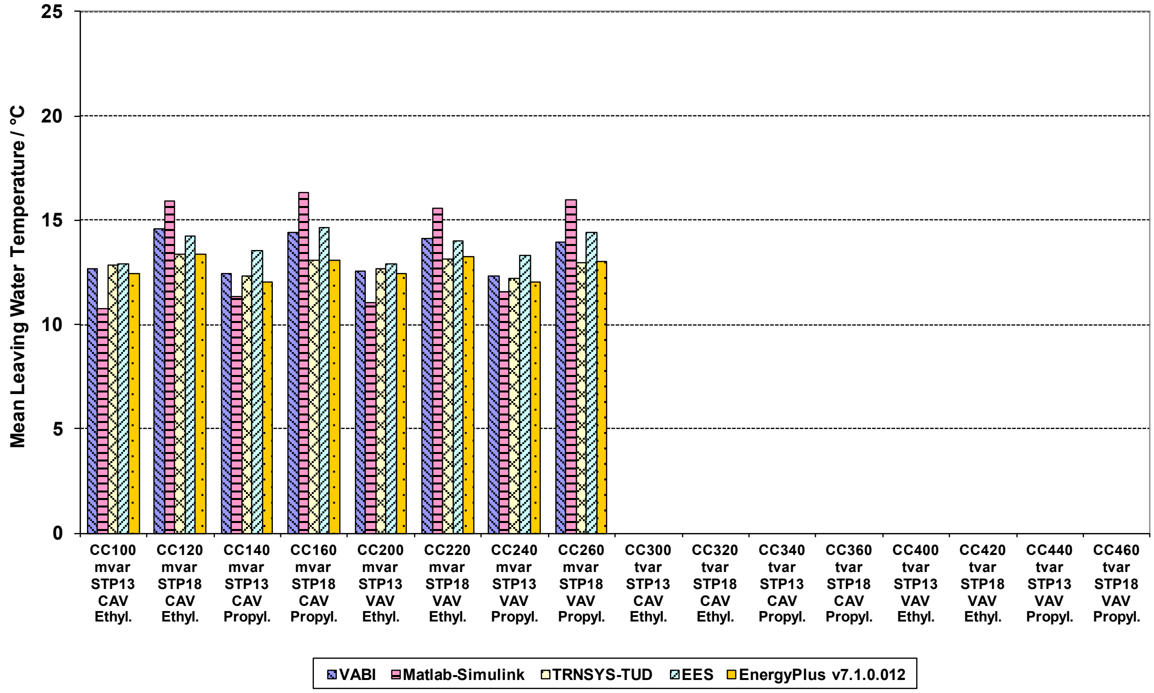


Figure 22 – Cooling Coil Comparative Tests – Mean Leaving Water Temperature EnergyPlus v7.1.0.012

2.4 Results for Heating Coil Tests

2.4.1 Heating Coil Test Results as Reported in IEA Final Report

EnergyPlus 2.2.0.023 results for the heating coil comparative tests that were submitted as part of the final round of testing and which are reported in the IEA final report are presented in Table 9 – Results of Heating Coil Tests. Figure 23 is a reproduction of a chart from the IEA final report showing the amount of total heating energy predicted by the various programs for the period from October through April to maintain the air leaving the heating coil at the given set point temperature. Deviations between programs were normally less than 5% indicating good agreement between programs. Figures 24 – 25 show hourly results for test cases HX100 and HX200 for the coldest day during the simulation. Here again the results of the various programs are very similar.

Major differences between programs can be seen when looking at the control variable hot water mass flow rate. Figure 26 shows the total hot water volume circulated through the heating coil during the simulation period while Figures 27 and 28 show the hourly hot water flow rate through the heating coil for test cases HX100 and HX200. EnergyPlus hot water flow is always much less than for other programs even though Figure 23 indicates that EnergyPlus supplied about the same amount of heating load and maintained the same mean discharge air temperature (Figure 29) and mean entering water temperature (Figure 30) compared to other programs. This occurred because the EnergyPlus coil model calculated a higher design UA (Figure 32) than the other programs which is reflected in the lower mean leaving water temperature as indicated in Figure 31.

Table 9 Results of Heating Coil Tests with EnergyPlus Version 2.2.0.023

IEA Mechanical Equipment and Control Strategies - Hot Water System

Results of Heating Coil Comparative Test
Simulation Program: Energy Plus 2.2.0.023
Date: 4/22/2008

Fixed Simulation Conditions

Simulation Period: Oct 1 thru Apr 30
100% outside air with conditions taken from 14933.tm2 weather file
Constant hot water supply temperature to heating coil = 70C
Variable hot water supply flow to heating coil
Maximum hot water supply flow rate = 1.33 l/s = 0.00133 m3/s

Case HX100

Constant air flow = 4500 m3/h = 1.25 m3/s
Constant air discharge temperature from coil = 13C

Case HX100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	4500	13.0	70.0	3.6	0.00	0
Max	4500	29.1	70.0	70.0	0.38	59
Average	4500	13.7	70.0	15.8	0.07	
Sum						86322

Case HX120

Constant air flow = 4500 m3/h =1.25 m3/s
Constant air discharge temperature from coil = 18C

Case HV120	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	4500	18.0	70.0	9.4	0.00	0
Max	4500	29.1	70.1	70.1	0.73	67
Average	4500	18.2	70.0	17.6	0.11	
Sum						120145

Case HX200

Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 13C

Case HX200	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	2000	13.0	70.0	-14.3	0.00	0
Max	5000	29.1	70.3	70.2	0.56	65
Average	3375	13.7	70.0	13.2	0.05	
Sum						61776

Case HX220

Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 18C

Case HX220	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	2000	17.4	70.0	-8.0	0.00	0
Max	5000	29.1	70.4	70.4	1.33	72
Average	3375	18.2	70.0	12.5	0.08	
Sum						86663

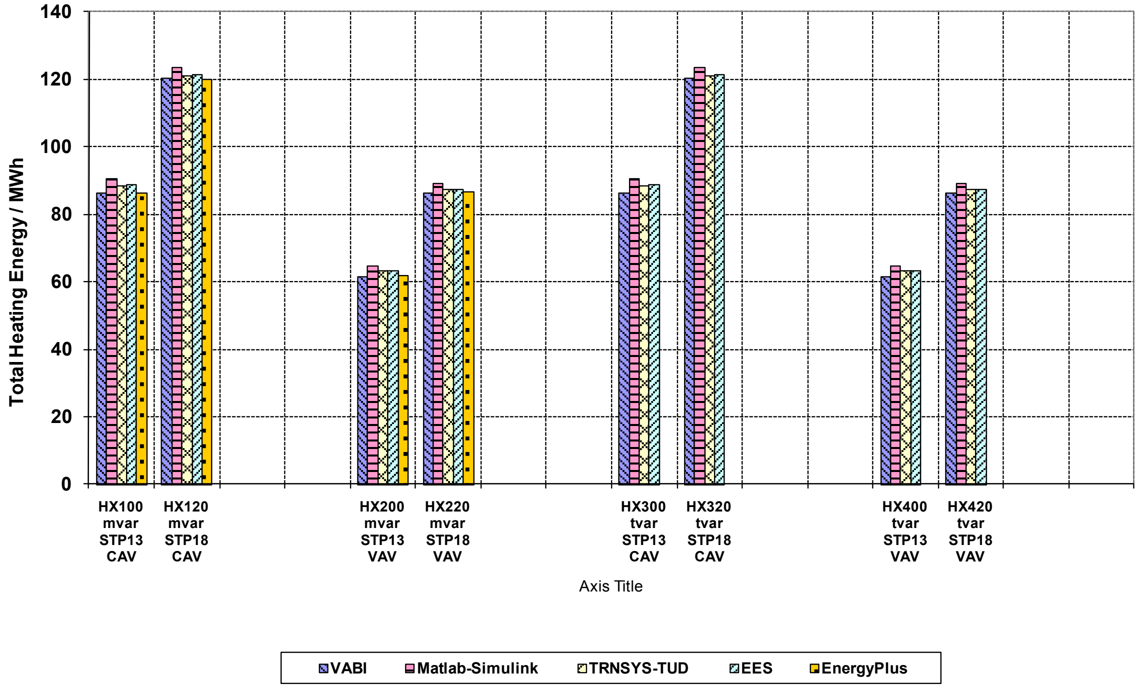


Figure 23 – Heating Coil Comparative Tests – Total Heating Energy EnergyPlus v2.2.0.23 (Part II - Figure 6-11, Felsmann 2008)

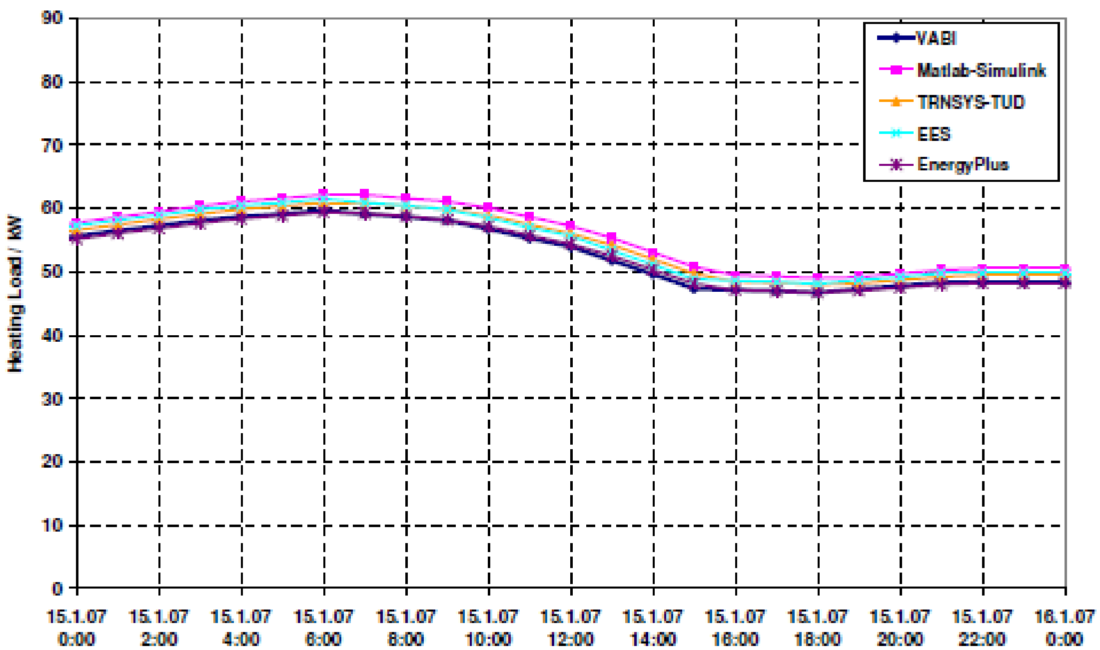


Figure 24 – Heating Coil Comparative Test HX100 – Heating Load Jan 15 (coldest day) EnergyPlus v2.2.0.23 (Part II - Figure 6-12, Felsmann 2008)

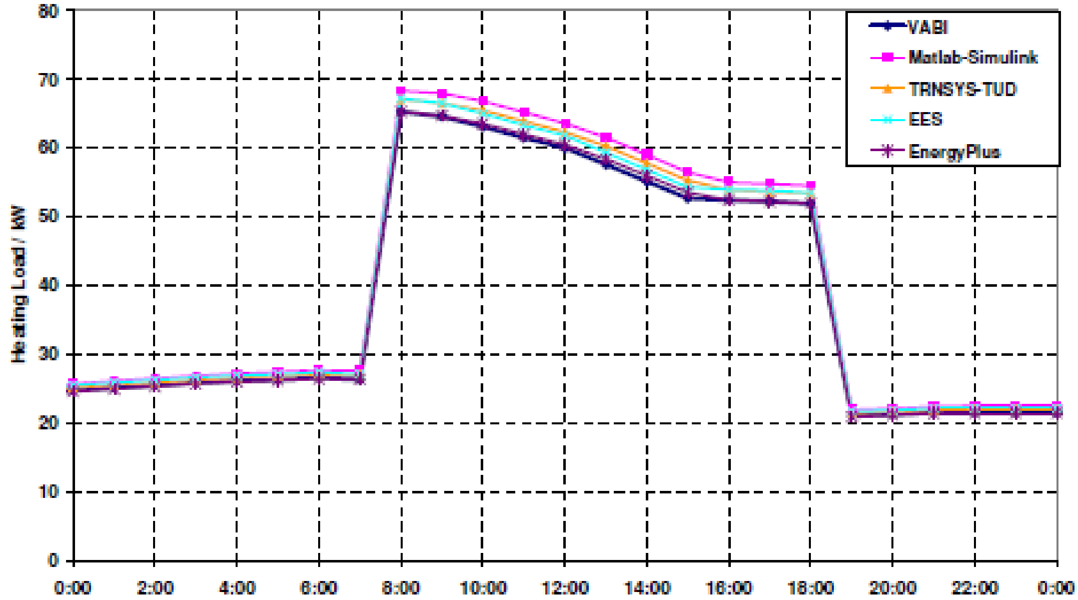


Figure 25 – Heating Coil Comparative Test HX200 – Heating Load Jan 15 (coldest day) EnergyPlus v2.2.0.23 (Part II - Figure 6-13, Felsmann 2008)

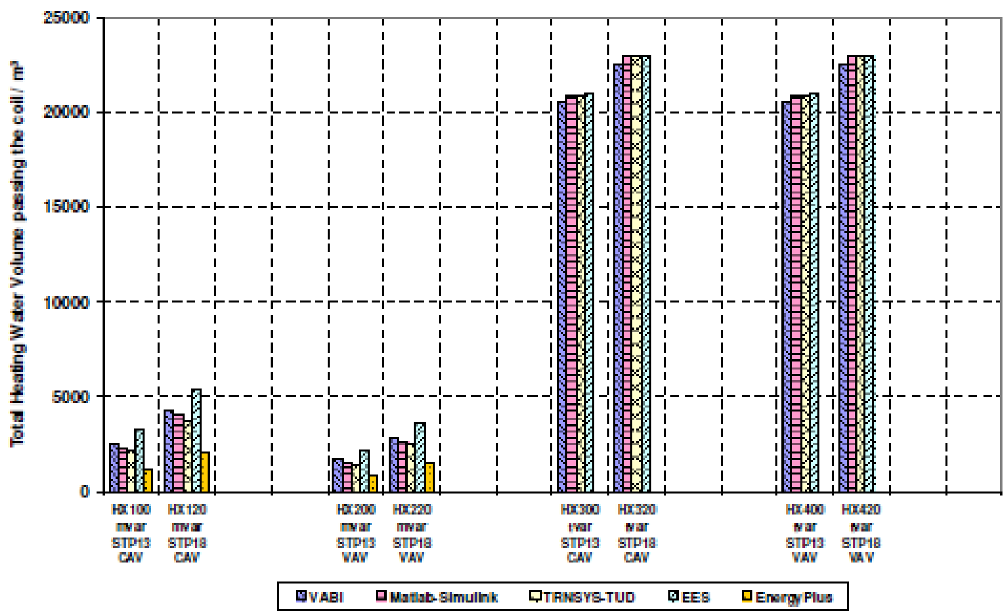


Figure 26 – Heating Coil Comparative Test – Hot Water Volume Circulated EnergyPlus v2.2.0.23 (Part II - Figure 6-14, Felsmann 2008)

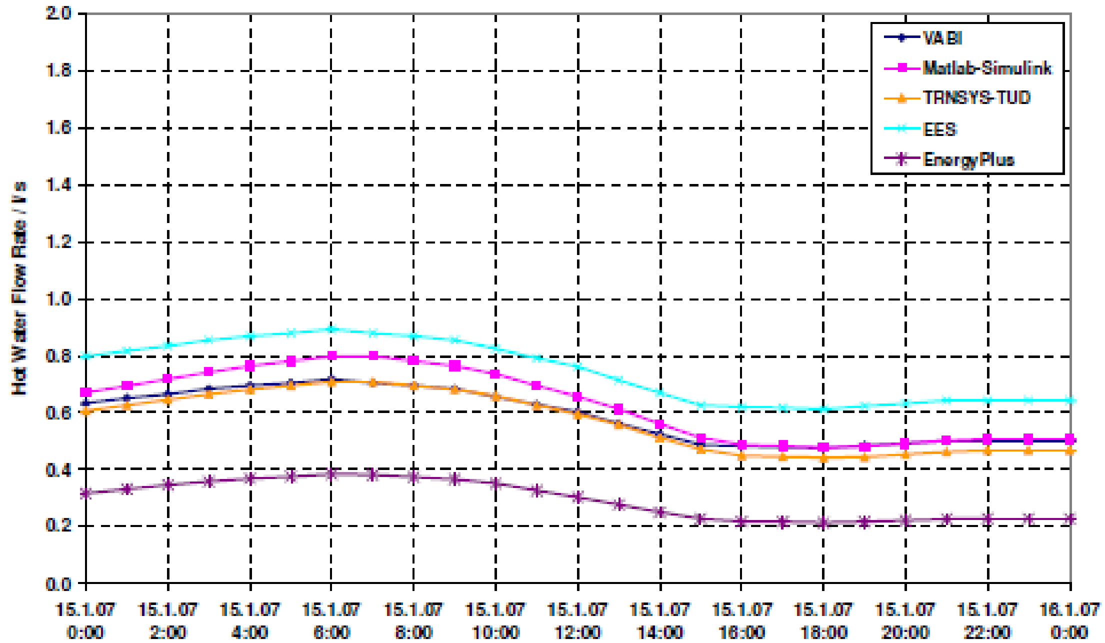


Figure 27 – Heating Coil Comparative Test HX100– Hot Water Flow Rate
Jan 15 (coldest day)
EnergyPlus v2.2.0.23 (Part II - Figure 6-15, Felsmann 2008)

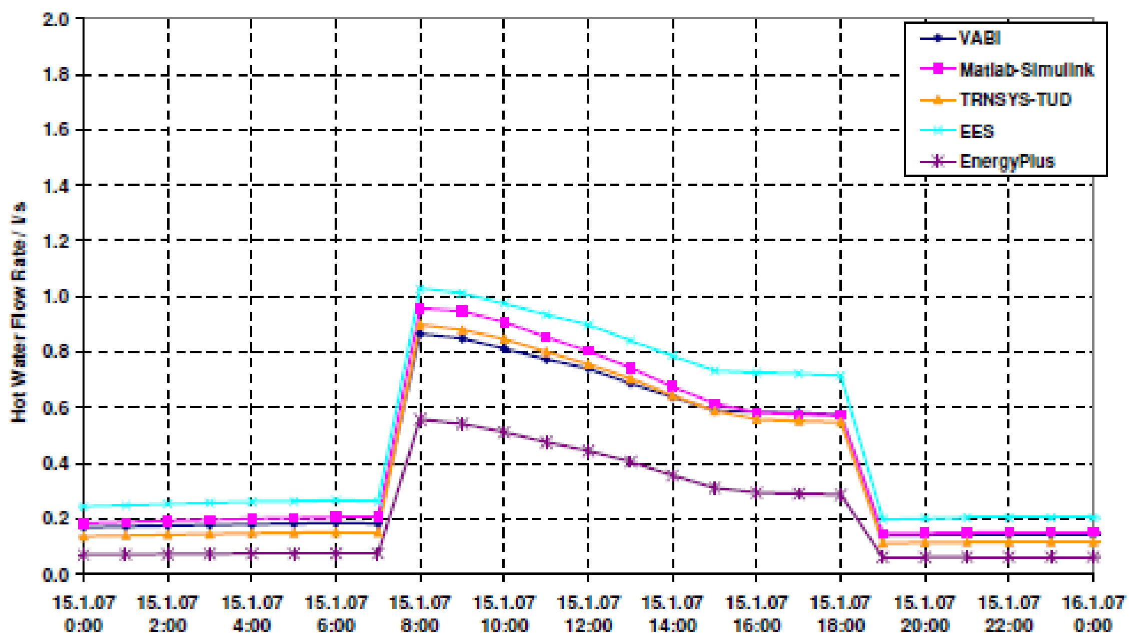


Figure 28 – Heating Coil Comparative Test HX200– Hot Water Flow Rate
Jan 15 (coldest day)
EnergyPlus v2.2.0.23 (Part II - Figure 6-16, Felsmann 2008)

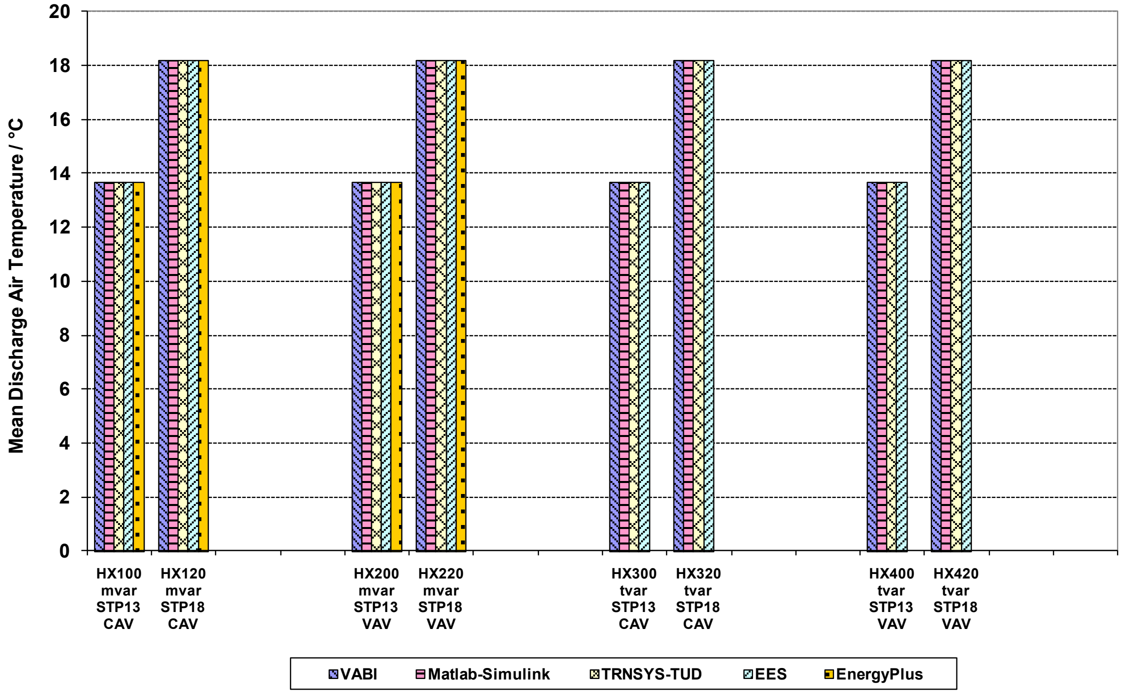


Figure 29 – Heating Coil Comparative Tests – Mean Discharge Air Temperature EnergyPlus v2.2.0.23 (Felsmann 2008)

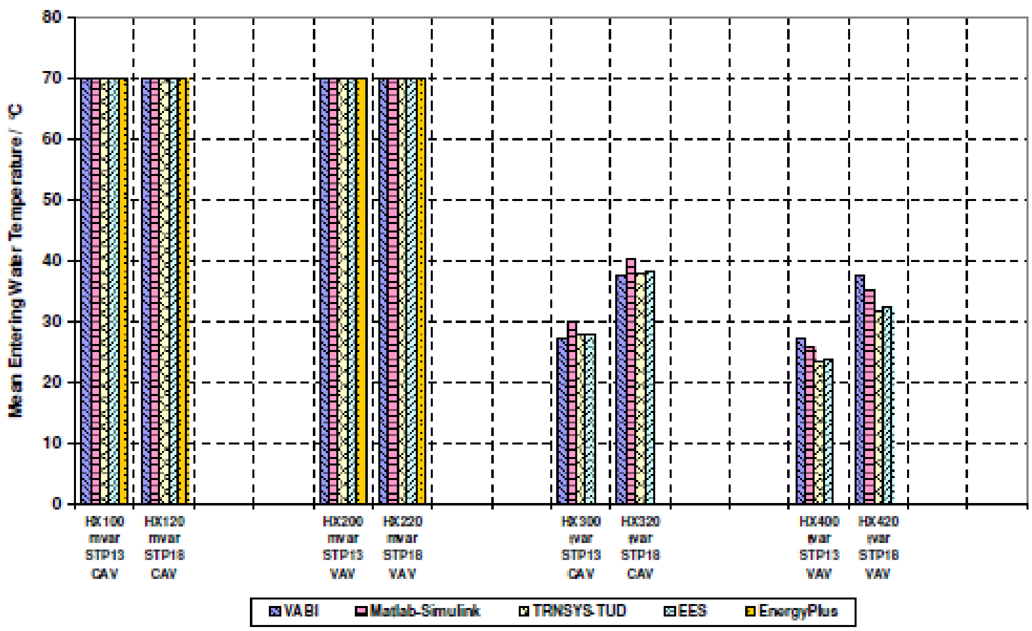


Figure 30 – Heating Coil Comparative Tests– Mean Entering Water Temperature EnergyPlus v2.2.0.23 (Part II - Figure 6-17, Felsmann 2008)

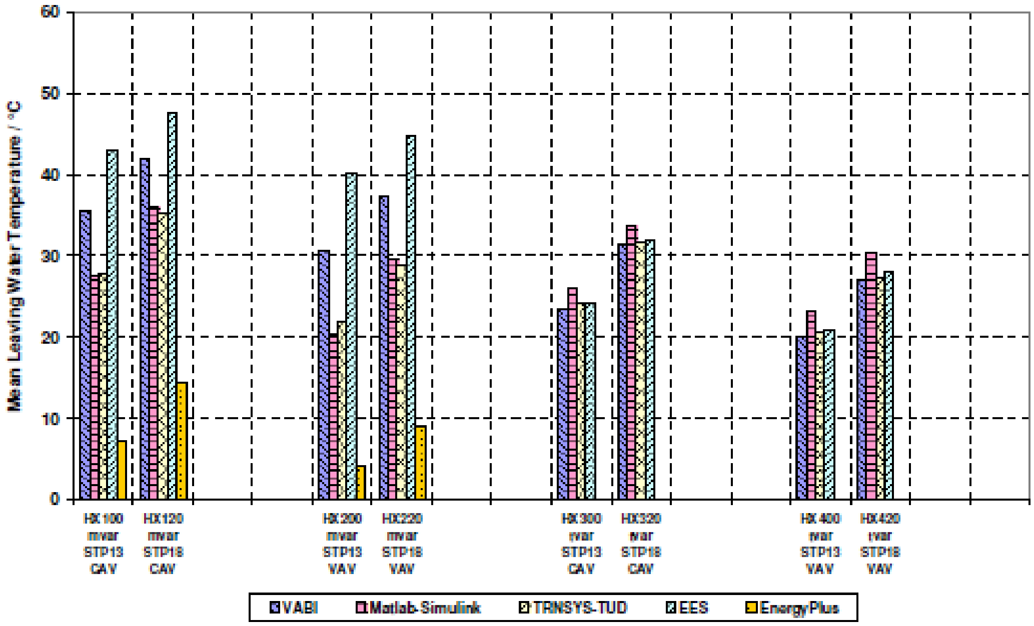


Figure 31 – Heating Coil Comparative Tests– Mean Leaving Water Temperature EnergyPlus v2.2.0.23 (Part II - Figure 6-18, Felsmann 2008)

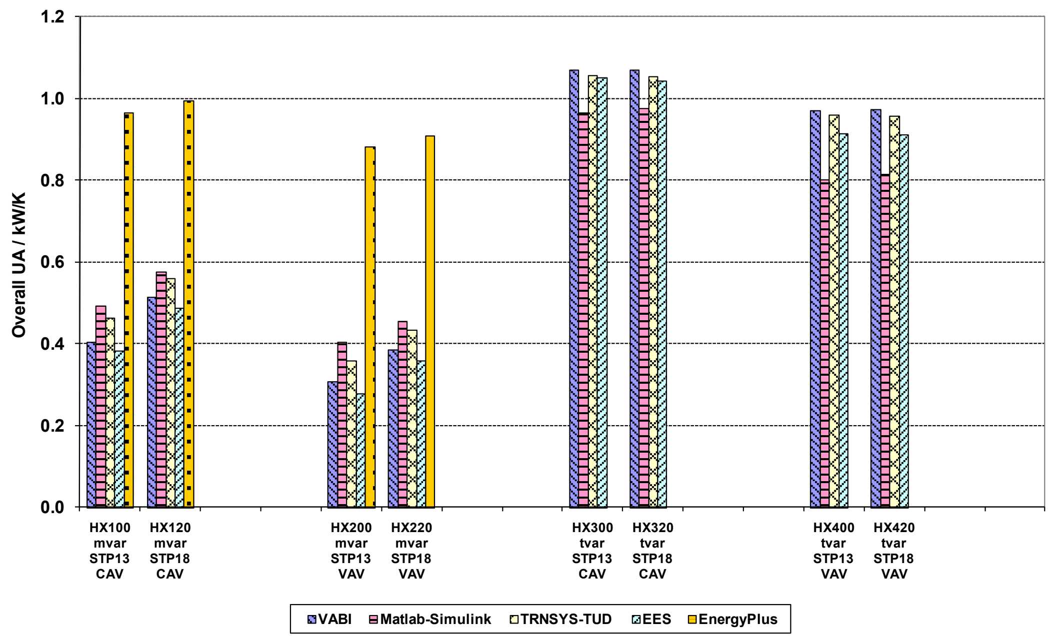


Figure 32 – Heating Coil Comparative Tests– Overall UA EnergyPlus v2.2.0.23 (Felsmann 2008)

2.4.2 Heating Coil Test Results with latest Version of EnergyPlus

The results obtained for the heating coil tests when simulated with the latest release of EnergyPlus, version 7.1.0.012, are shown in Table 10 and Figures 33 through 42. Although there were only small changes in the heating coil annual loads compared to EnergyPlus v2.2.0.023 results, there were significant improvements in Overall UA as seen in Figure 42 which brought EnergyPlus results more closely into the range of other programs. This change in UA results were due to changes to the EnergyPlus heating coil model in EnergyPlus version 6.0.0.023 which incorporated variable UA simulations. Significant changes also occurred in annual mean leaving water temperature and annual mean hot water flow as shown in Figures 36 through 41 where EnergyPlus results are above the other programs. Numerous other charts comparing EnergyPlus v7.1.0.012 results with other programs are included in Appendix B

Table 10   Results of Heating Coil Tests with EnergyPlus Version 7.1.0.012

IEA Mechanical Equipment and Control Strategies - Hot Water System
Results of Heating Coil Comparative Test
Simulation Program: **Energy Plus 7.1.0.012**
Date: **6/20/2012**

Fixed Simulation Conditions
Simulation Period: Oct 1 thru Apr 30
100% outside air with conditions taken from 14933.tm2 weather file
Constant hot water supply temperature to heating coil = 70C
Variable hot water supply flow to heating coil
Maximum hot water supply flow rate = 1.33 l/s = 0.00133 m3/s

Case HX100
Constant air flow = 4500 m3/h = 1.25 m3/s
Constant air discharge temperature from coil = 13C

Case HX100	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	4500	13.0	70.0	23.9	0.00	0
Max	4500	29.1	70.0	70.0	0.98	59
Average	4500	13.7	70.0	46.4	0.17	
Sum						86322

Case HX120
Constant air flow = 4500 m3/h =1.25 m3/s
Constant air discharge temperature from coil = 18C

Case HV120	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	4500	16.5	70.0	28.2	0.00	0
Max	4500	29.1	70.4	70.3	1.33	65
Average	4500	18.2	70.0	48.7	0.29	
Sum						120129

Case HX200
Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 13C

Case HX200	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	2000	13.0	70.0	21.7	0.00	0
Max	5000	29.1	70.4	70.4	1.28	65
Average	3375	13.7	70.0	43.3	0.12	
Sum						61776

Case HX220
Constant air flow = 2000 m3/h = 0.5555 m3/s from 6PM to 7AM
Constant air flow = 5000 m3/h = 1.3889 m3/s from 7AM to 6PM
Constant air discharge temperature from coil = 18C

Case HX220	Air Flow Rate AFR (m3/h)	Leaving Air Temp. LAT (C)	Entering Water Temp. EWT (C)	Leaving Water Temp. LWT (C)	Hot Water Flow Rate HWFR (l/s)	Sensible Heating Load HLS (kW)
Min	2000	13.4	70.0	26.1	0.00	0
Max	5000	29.1	70.7	70.7	1.33	66
Average	3375	18.2	70.0	45.0	0.19	
Sum						86575

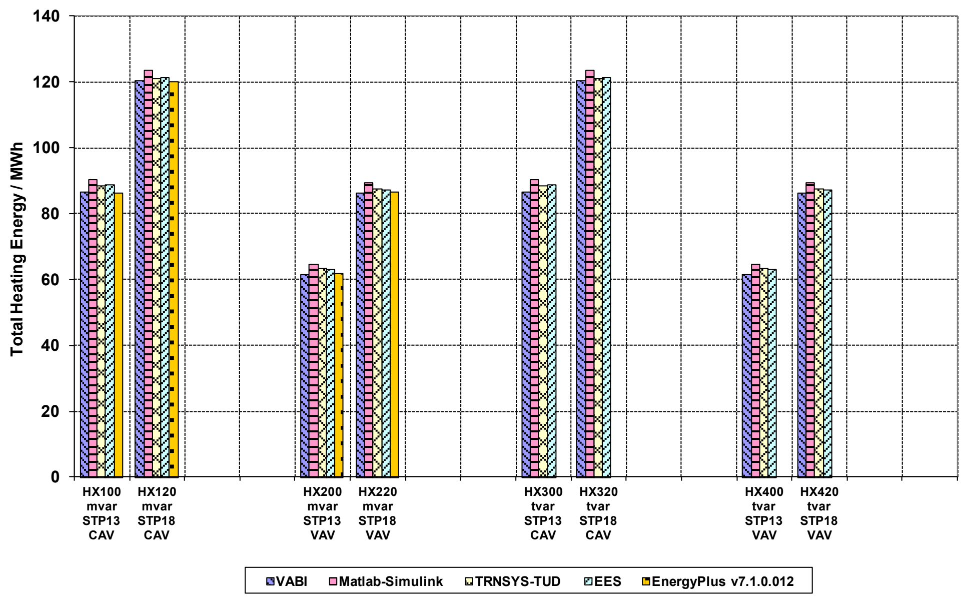


Figure 33 – Heating Coil Comparative Tests – Total Heating Energy EnergyPlus v7.1.0.012

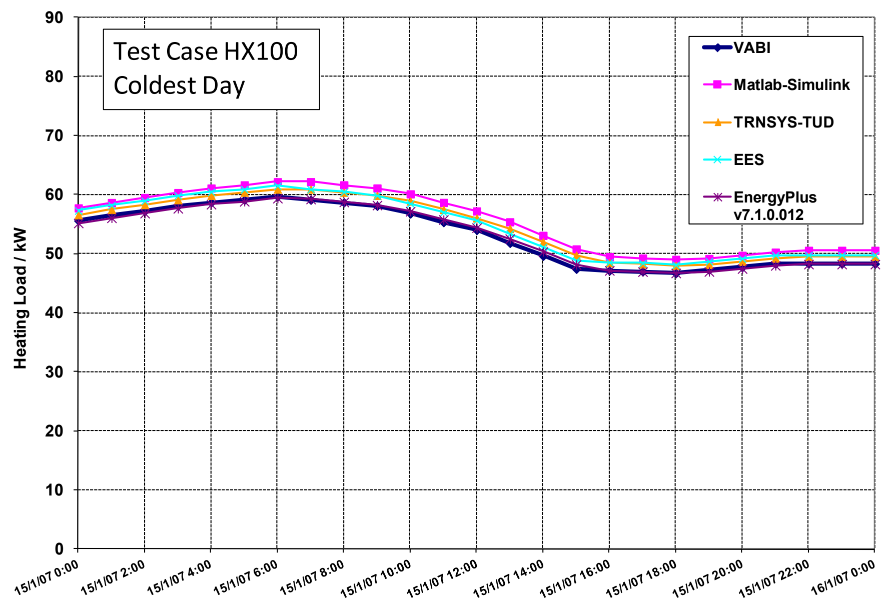


Figure 34 – Heating Coil Comparative Test HX100 – Heating Load Jan 15 (coldest day) EnergyPlus v7.1.0.012

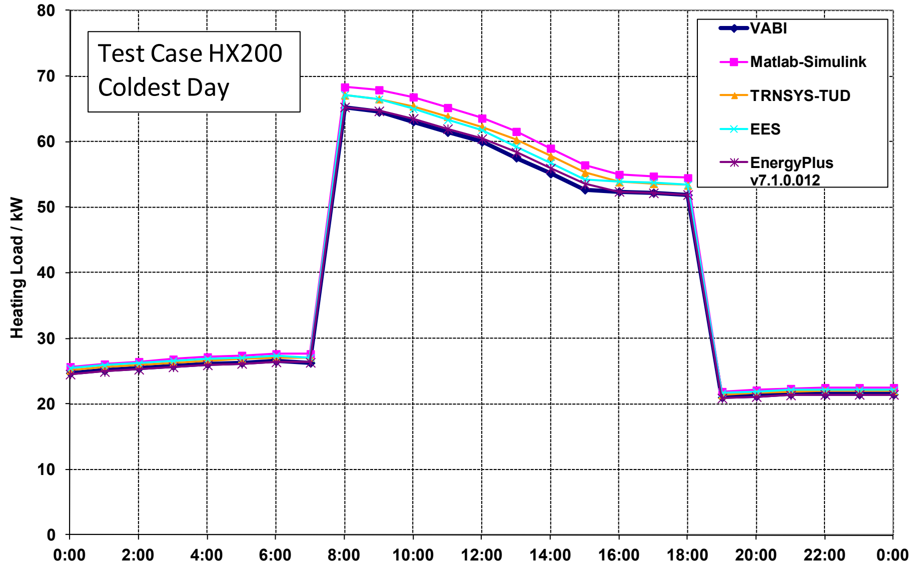


Figure 35 – Heating Coil Comparative Test HX200 – Heating Load Jan 15 (coldest day) EnergyPlus v7.1.0.012

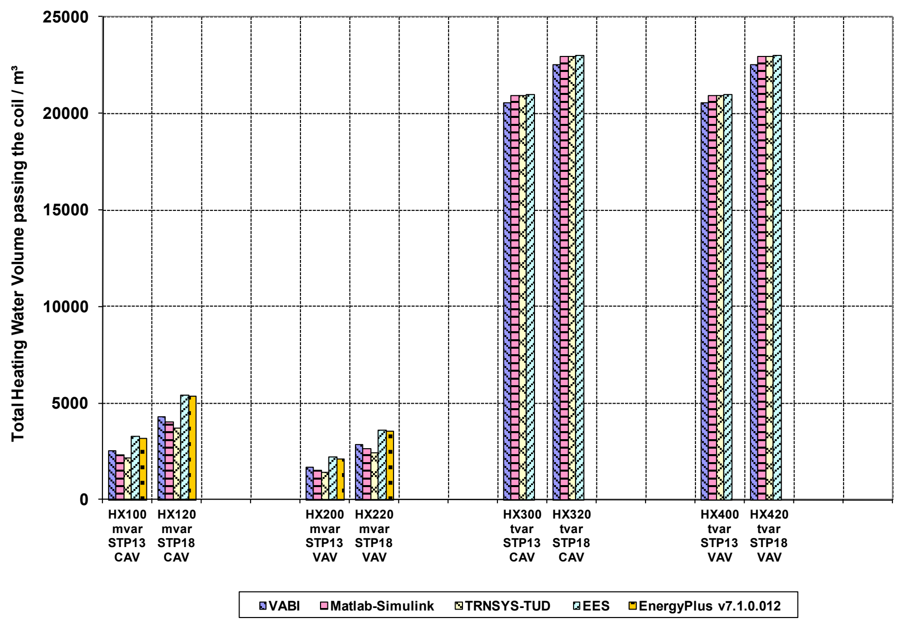


Figure 36 – Heating Coil Comparative Test – Hot Water Volume Circulated EnergyPlus v7.1.0.012

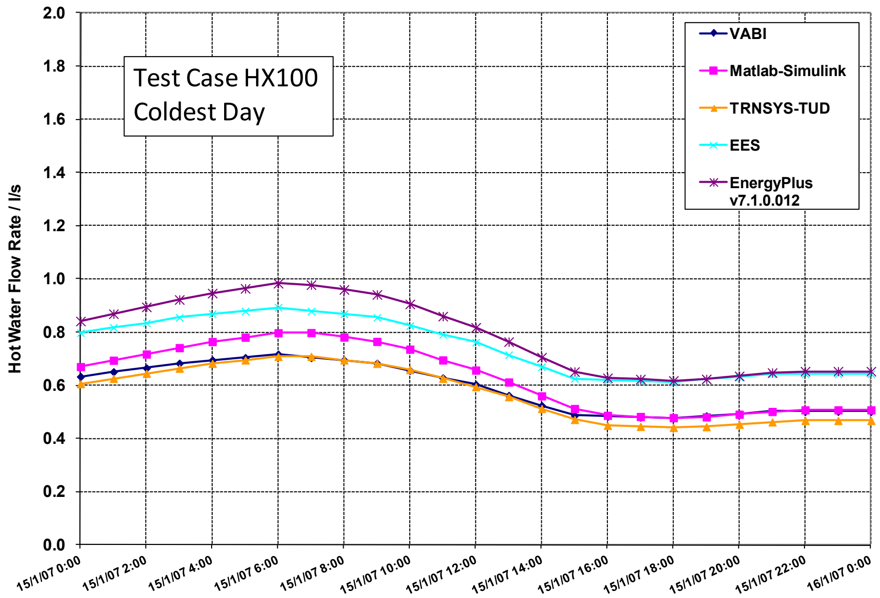


Figure 37 – Heating Coil Comparative Test HX100– Hot Water Flow Rate
Jan 15 (coldest day)
EnergyPlus v7.1.0.012

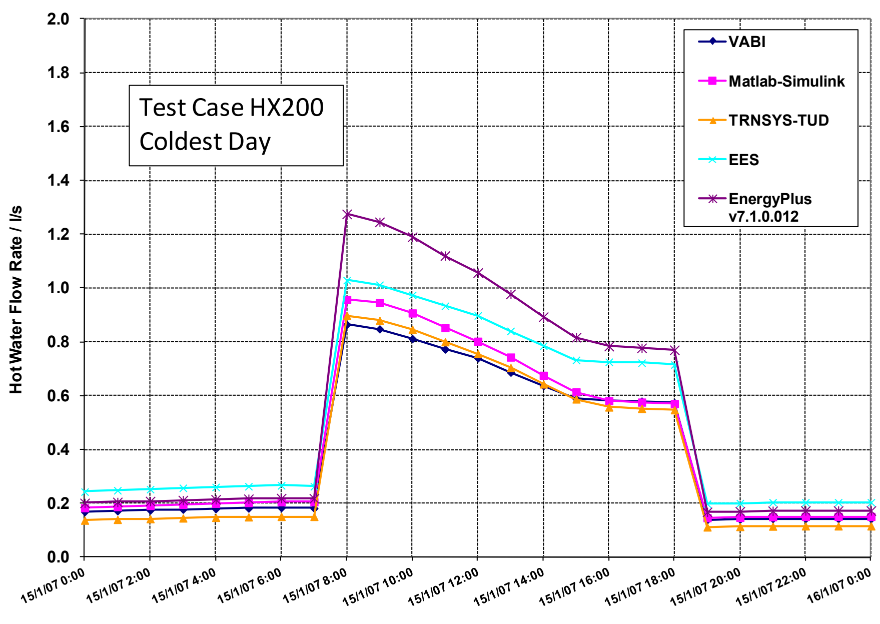


Figure 38 – Heating Coil Comparative Test HX200– Hot Water Flow Rate
Jan 15 (coldest day)
EnergyPlus v7.1.0.012

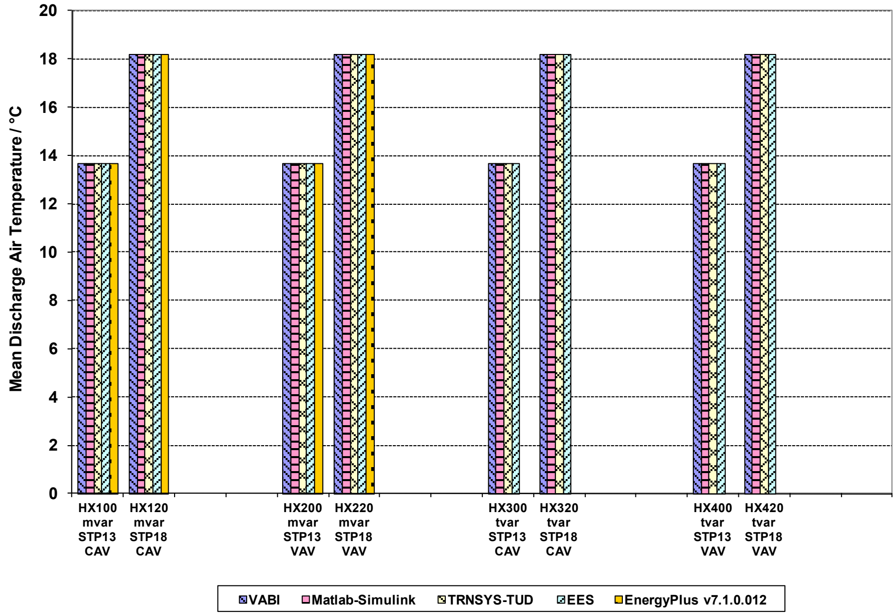


Figure 39 – Heating Coil Comparative Tests – Mean Discharge Air Temperature EnergyPlus v7.1.0.012

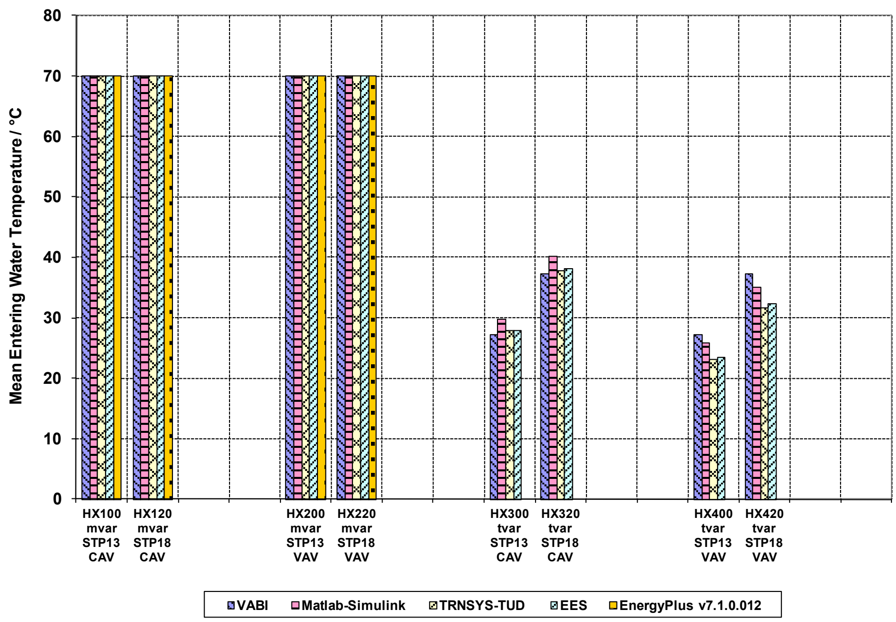


Figure 40 – Heating Coil Comparative Tests– Mean Entering Water Temperature EnergyPlus v7.1.0.012

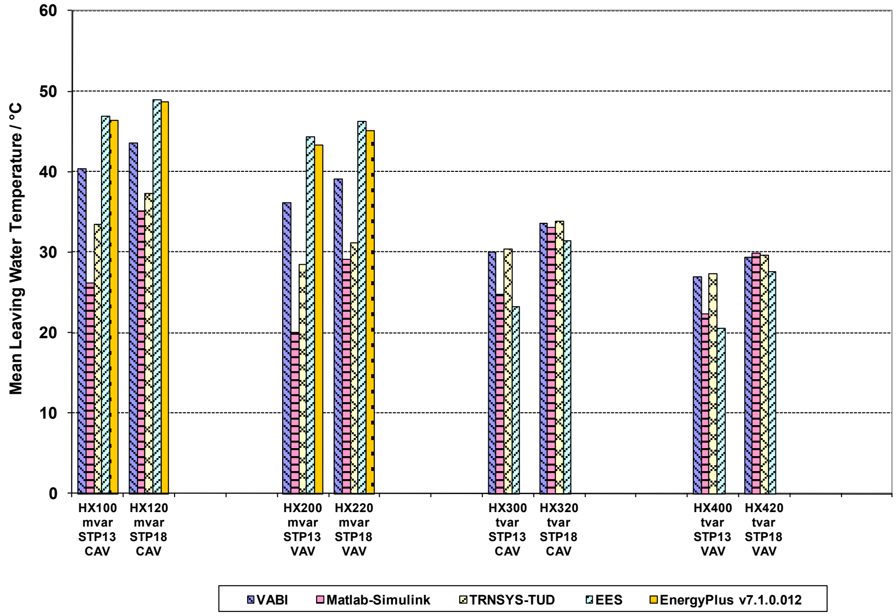


Figure 41 – Heating Coil Comparative Tests– Mean Leaving Water Temperature EnergyPlus v7.1.0.012

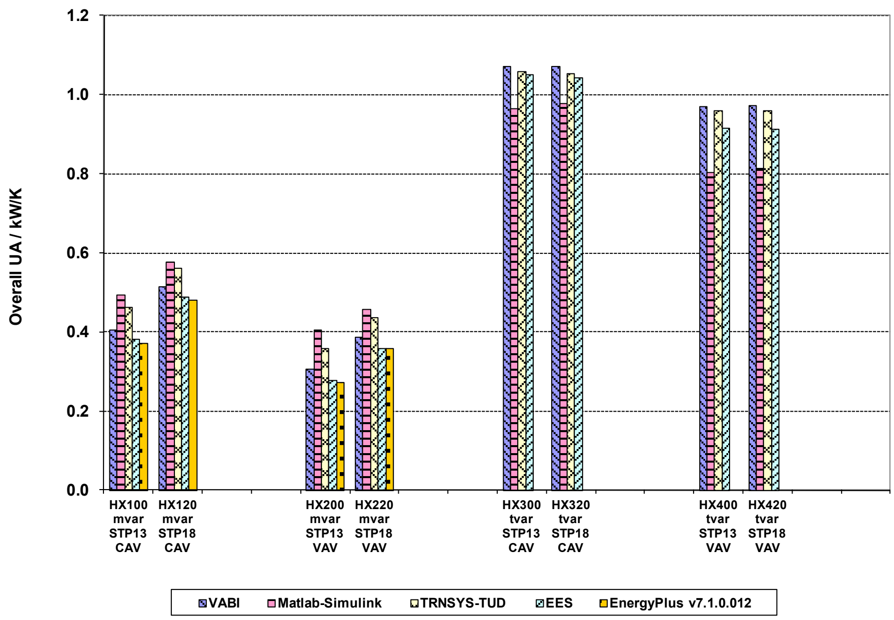


Figure 42 – Heating Coil Comparative Tests– Overall UA EnergyPlus v7.1.0.012

2.5 Summary of Changes that Occurred Between Versions of EnergyPlus

This section documents modifications that were made to the EnergyPlus code or changes that were made in the modeling approach. Since the first reporting of EnergyPlus results for the IEA Mechanical Equipment Control Strategies for a Chilled Water and a Hot Water System with EnergyPlus version 2.2.0.023 back in June 2008, further capabilities and improvements have been added to EnergyPlus with new releases beginning in November 2008 (Version 3.0.0.028) and continuing through the current release in June 2012 (version 7.1.0.012). The table below summarizes pertinent input file and code changes that were made as the testing progressed with each new release of EnergyPlus.

Summary of Pertinent EnergyPlus Changes that were Implemented Since Original Testing with Version 2.2.0.023

Version	Input File Changes	Code Changes
6.0.0.023		Changed hot water heating coil model to variable UA
6.0.0.023		Changed the default for hot water heating coil ratio value from 1.0 to 0.5
6.0.0.023		Corrected error in Coil:Cooling:Water object where equation Q = UA * LMTD was unbalanced
7.0.0.036		Changed chilled water cooling coil model to variable UA (CR8530)
7.0.0.036		Added feature to model water cooling coils with glycol mixtures

The changes as summarized in the table above for the hot water heating coil resulted in only very small changes in the heating coil sensible load but did cause significant changes in hot water flow rates and hot water leaving temperatures as can be seen in Figures 26, 27, 28 and 31 .

The change in the water cooling coil algorithm reduced the annual cooling coil loads with the biggest impact on the annual latent cooling load which decreased by as much 3.2% for Case CC200. Other significant changes also occurred in with the chilled water flow rate and leaving coil water temperature.

3 CONCLUSIONS

EnergyPlus Version 7.1.0.012 was used to model a range of water cooling coil and water heating coil tests specified in *IEA Mechanical Equipment & Control Strategies for a Chilled Water and a Hot Water System* (Felsmann 2008). The ability of EnergyPlus to model a chilled water cooling coil and hot water heating coil and predict resultant loads discharge air and water temperatures were tested using a suite of 8 chilled water coil tests and 4 hot water coil tests which included variable water flow rates, constant and variable air flow rates and two different discharge air set point temperatures. The results predicted by EnergyPlus were compared to the results from 4 other programs that participated in an International Energy Agency project which was completed in 2008.

For the eight chilled water coil tests, EnergyPlus results for total, sensible and latent annual cooling loads were within the range of results of other programs. When comparing hourly results for a hot dry day and hot humid day, coil water flow rates and leaving water temperatures are now within bounds when compared to other programs as is the mean UA value for the coil compared to other programs.

For the four hot water coil tests, the results for total heating between the 5 programs varied by less than 5% overall. Major differences between programs did occur however when looking at the control variable hot water mass flow rate. EnergyPlus hot water flow was always higher than for other programs even though EnergyPlus supplied about the same amount of heating load and maintained the same mean discharge air temperature and mean entering water temperature compared to other programs. This occurred because the EnergyPlus coil model calculated a higher design UA than the other programs which is reflected in a lower mean leaving water temperature.

Work is in progress to fully support glycol solutions in all EnergyPlus plant components.

4 REFERENCES

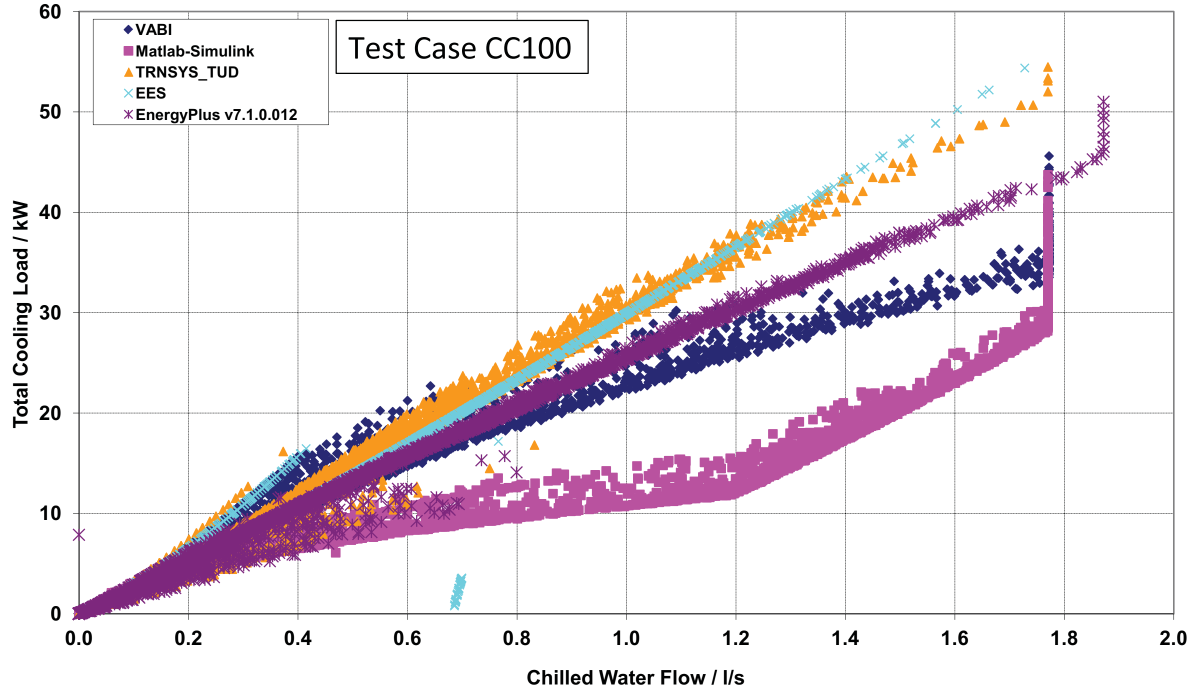
EnergyPlus 2012. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technologies. www.energyplus.gov

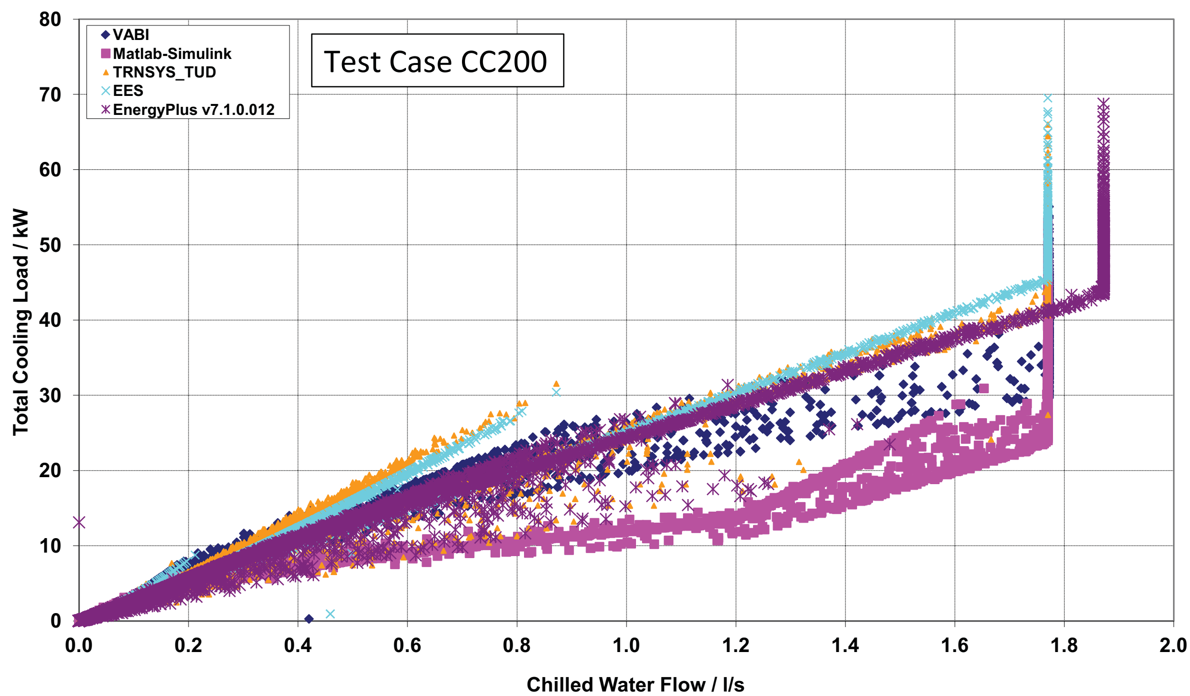
Felsmann 2008. *IEA Mechanical Equipment & Control Strategies for a Chilled Water and a Hot Water System*, Technical University of Dresden, Germany, June 18, 2008. www.iea-shc.org/publications/task.aspx?Task=34

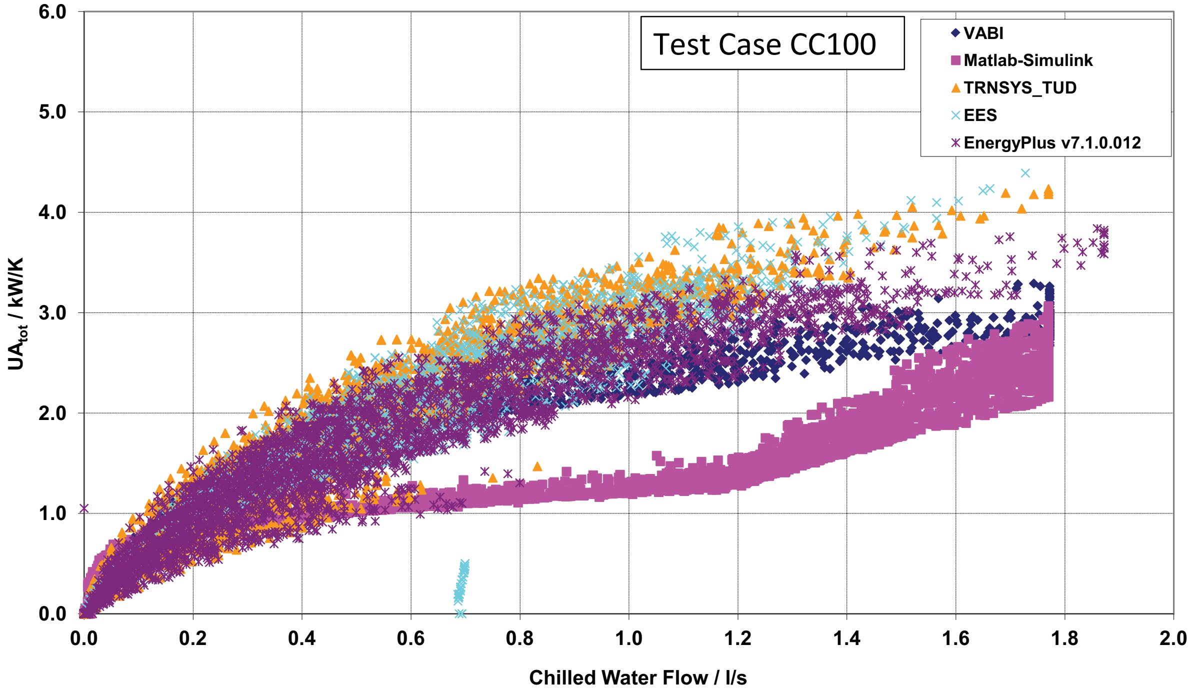
Appendix A

Charts Comparing EnergyPlus 7.1.0.012 Results with Other Whole Building Energy Simulation Programs for Chilled Water Coil Tests

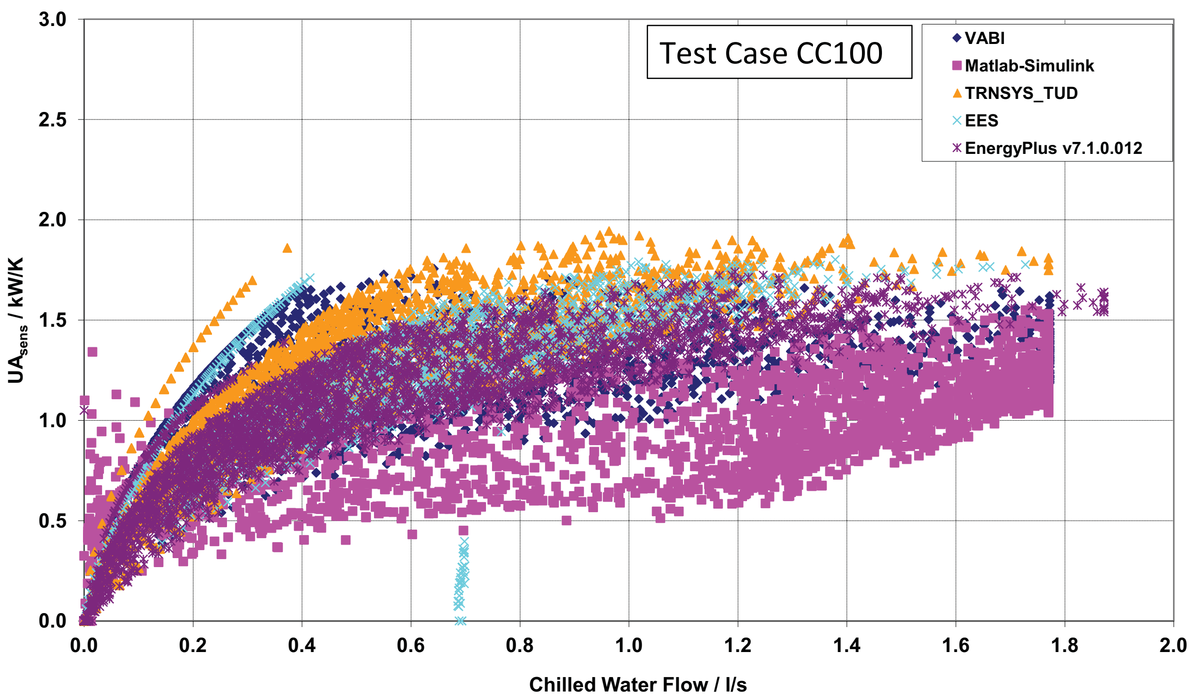
(Excerpted from files provided as part of Felsmann 2008 and updated with EnergyPlus 7.1.0.012 results)


Test Case CC100
VABI
Matlab-Simulink
TRNSYS_TUD
EES
EnergyPlus v7.1.0.012
Total Cooling Load / kW
Chilled Water Flow / l/s
0
10
20
30
40
50
60
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

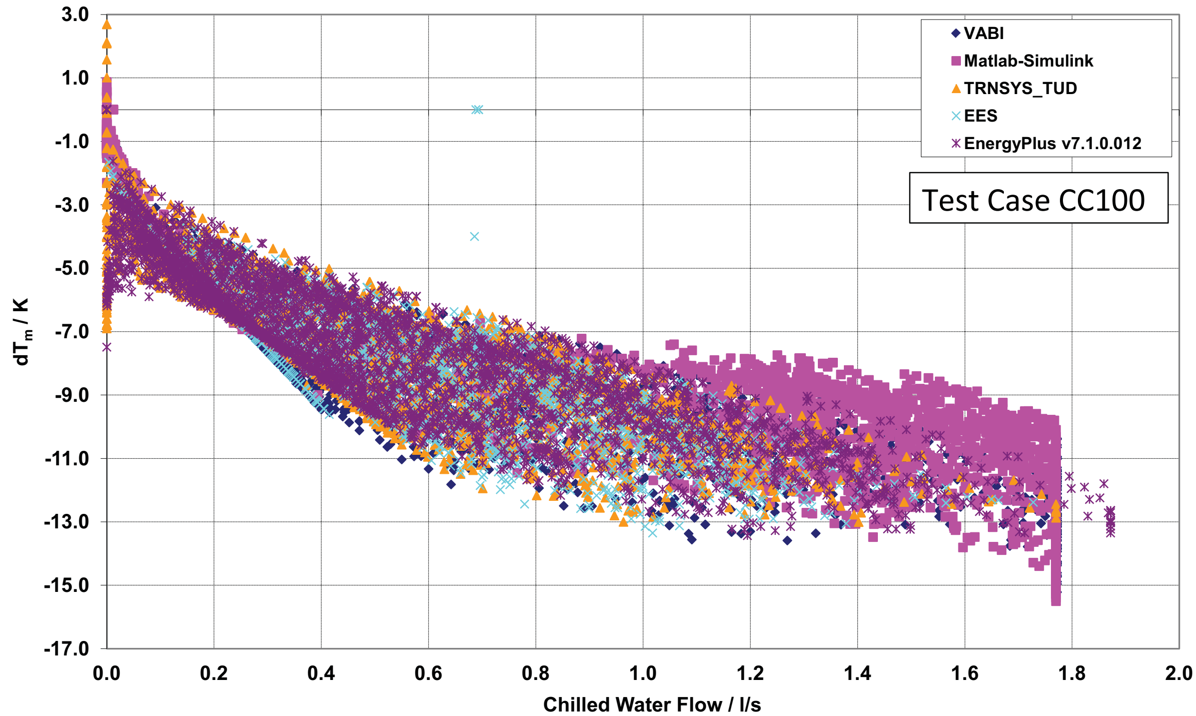

Test Case CC200
VABI
Matlab-Simulink
TRNSYS_TUD
EES
EnergyPlus v7.1.0.012
Total Cooling Load / kW
Chilled Water Flow / l/s
0
10
20
30
40
50
60
70
80
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0



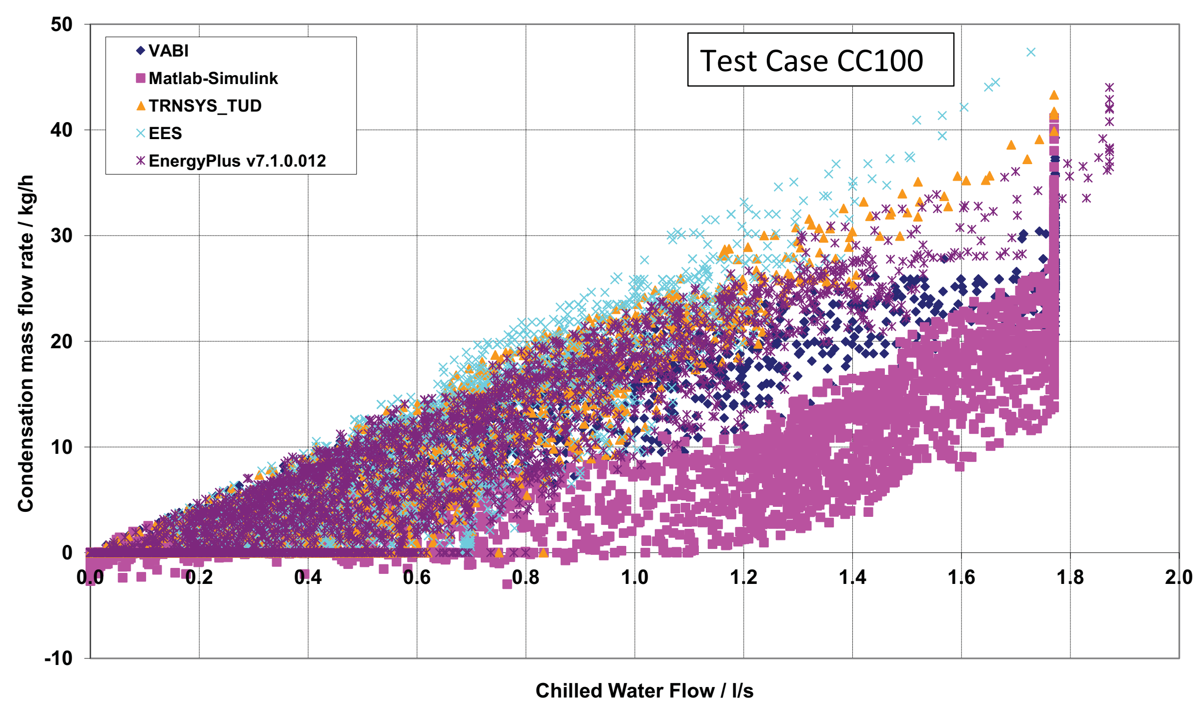
Test Case CC100
VABI
Matlab-Simulink
TRNSYS_TUD
EES
EnergyPlus v7.1.0.012
6.0
5.0
4.0
3.0
2.0
1.0
0.0
UAtot / kW/K
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Chilled Water Flow / l/s



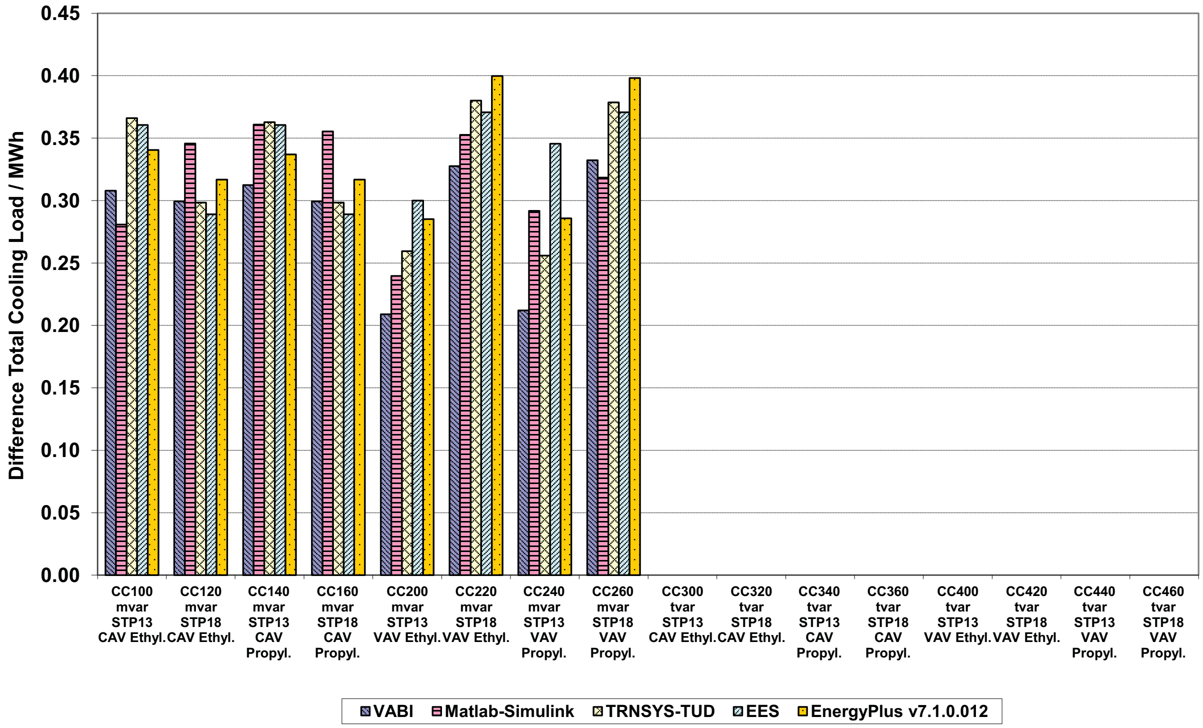
Test Case CC100
VABI
Matlab-Simulink
TRNSYS_TUD
EES
EnergyPlus v7.1.0.012
3.0
2.5
2.0
1.5
1.0
0.5
0.0
UAsens / kW/K
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Chilled Water Flow / l/s

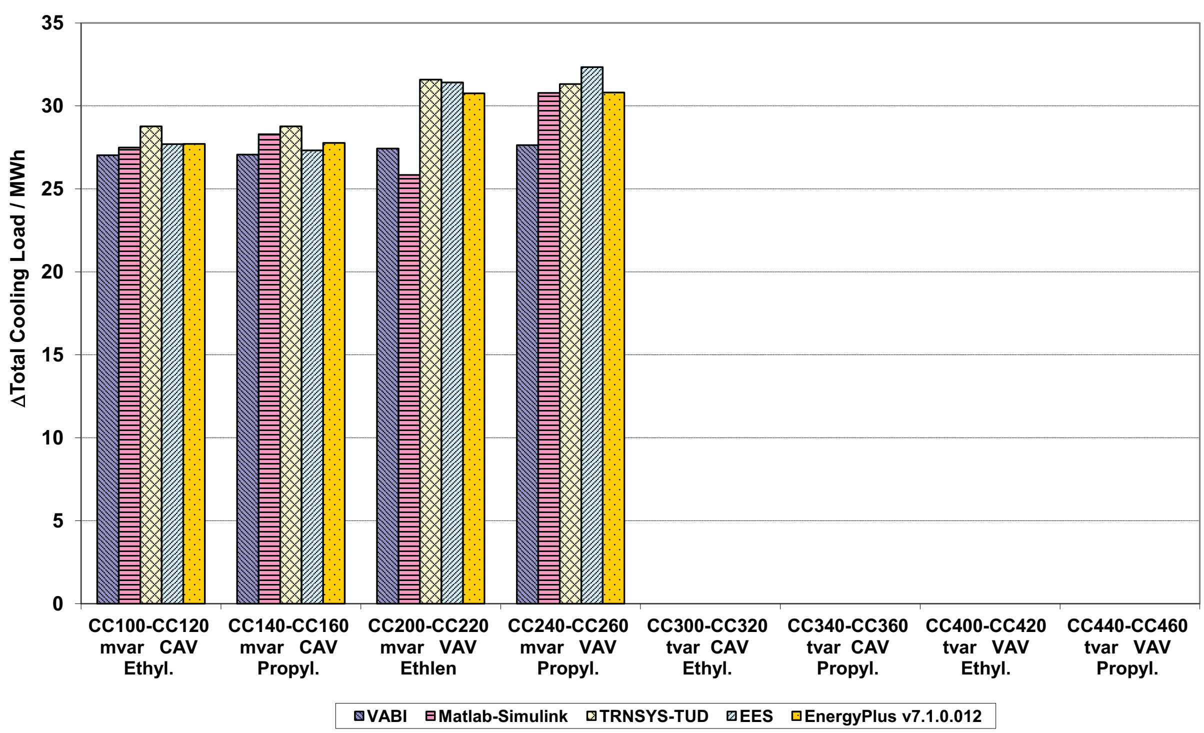


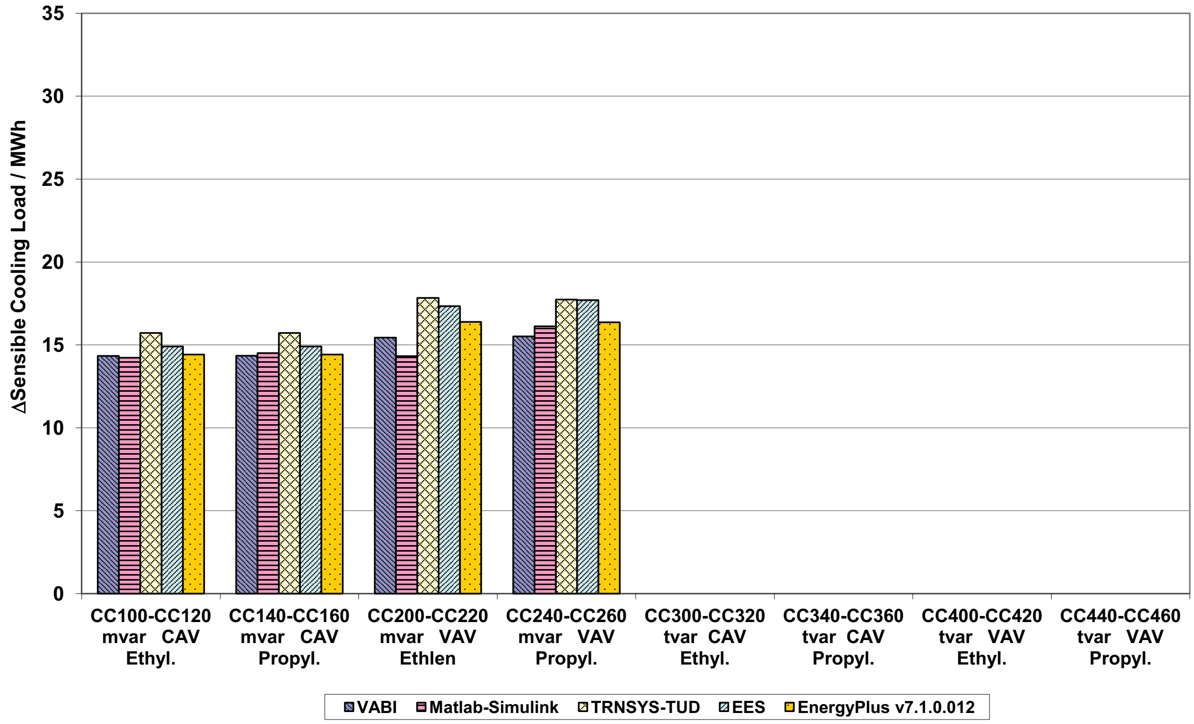
3.0
1.0
-1.0
-3.0
-5.0
-7.0
-9.0
-11.0
-13.0
-15.0
-17.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
dT_m / K
Chilled Water Flow / l/s
VABI
Matlab-Simulink
TRNSYS_TUD
EES
EnergyPlus v7.1.0.012
Test Case CC100



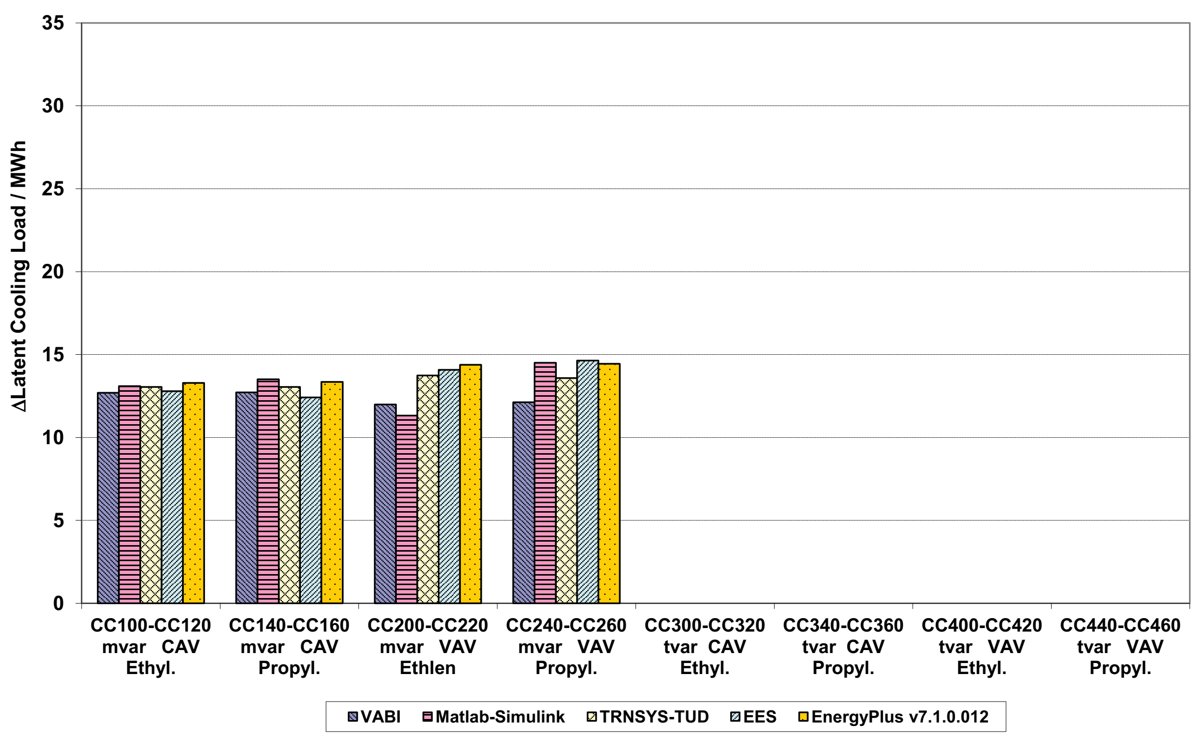
50
40
30
20
10
0
-10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Condensation mass flow rate / kg/h
Chilled Water Flow / l/s
VABI
Matlab-Simulink
TRNSYS_TUD
EES
EnergyPlus v7.1.0.012
Test Case CC100


Difference Total Cooling Load / MWh
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

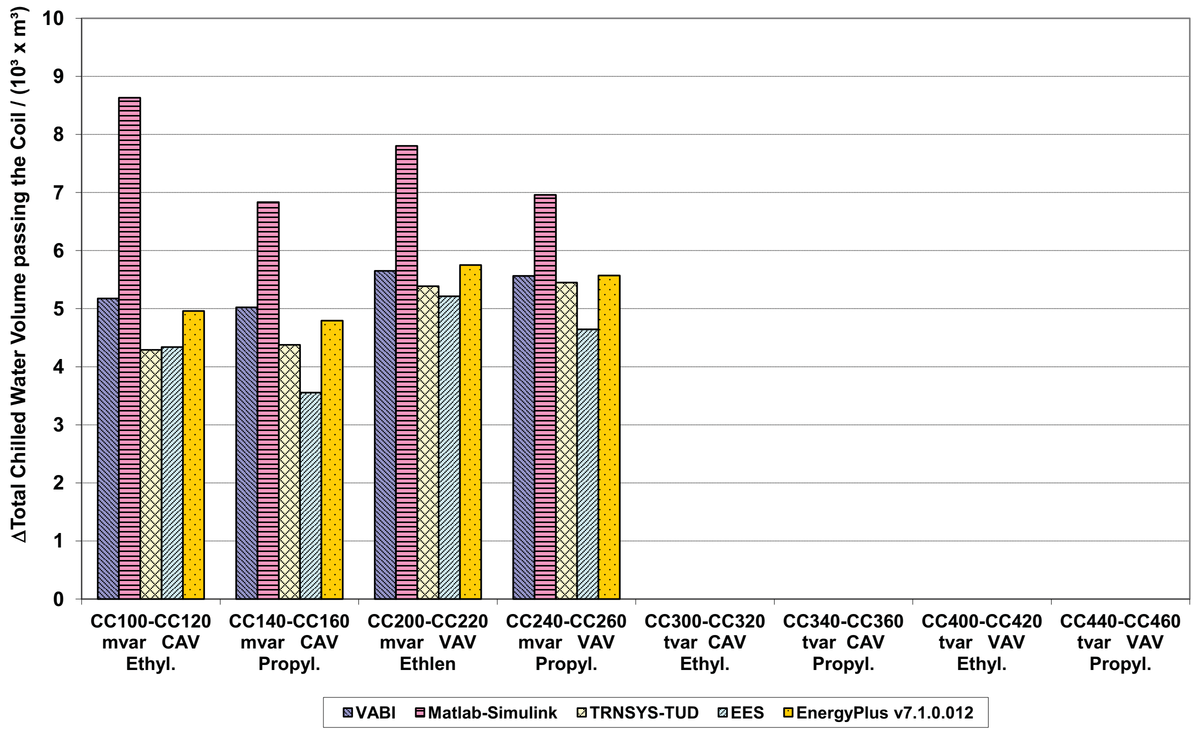

ΔTotal Cooling Load / MWh
35
30
25
20
15
10
5
0
CC100-CC120 mvar CAV Ethyl.
CC140-CC160 mvar CAV Propyl.
CC200-CC220 mvar VAV Ethlen
CC240-CC260 mvar VAV Propyl.
CC300-CC320 tvar CAV Ethyl.
CC340-CC360 tvar CAV Propyl.
CC400-CC420 tvar VAV Ethyl.
CC440-CC460 tvar VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

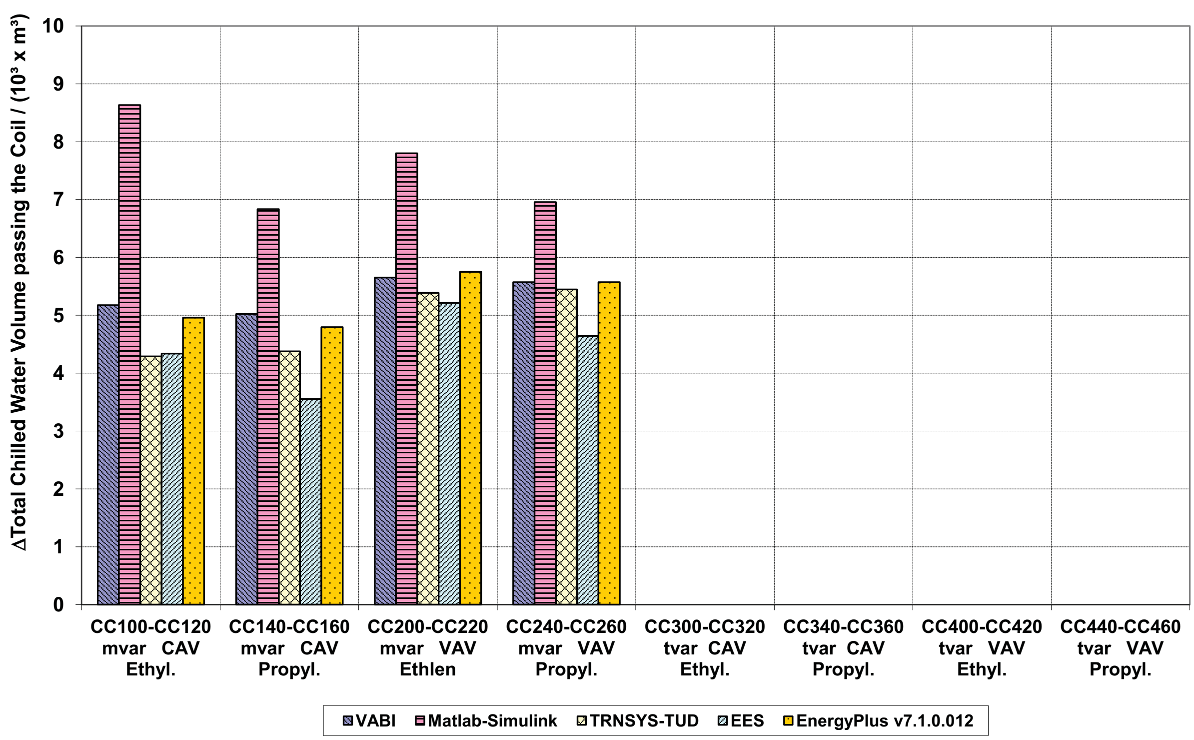


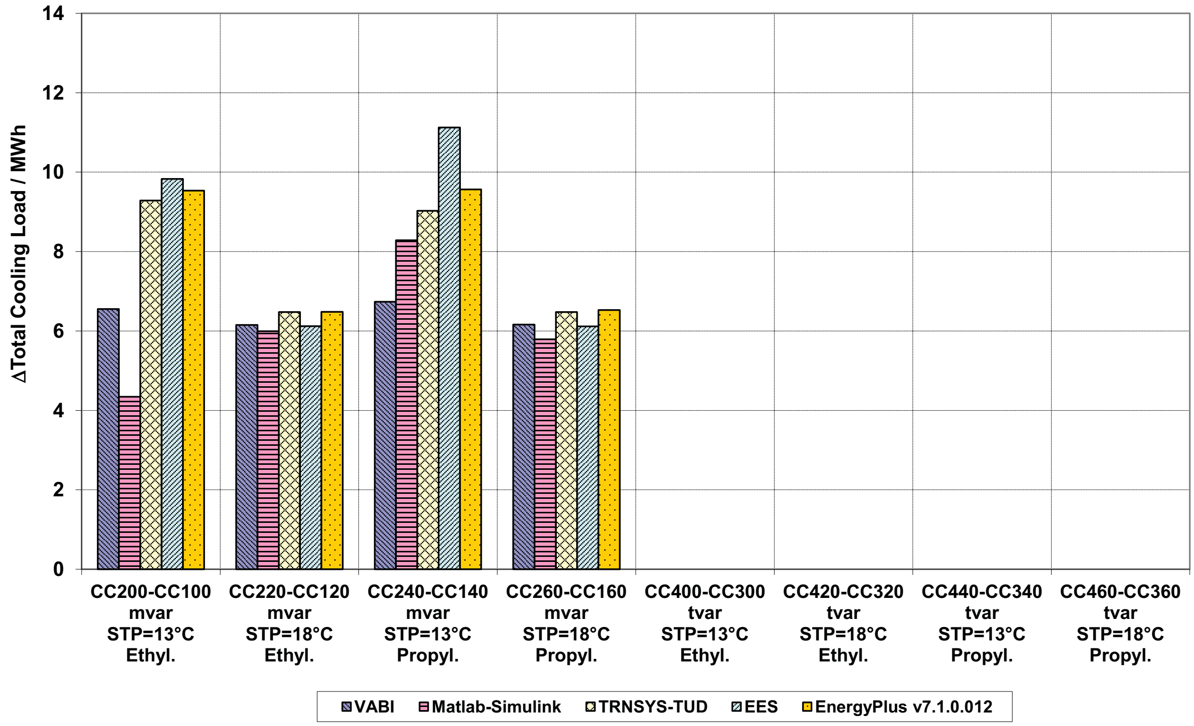
ΔSensible Cooling Load / MWh
35
30
25
20
15
10
5
0
CC100-CC120 mvar CAV Ethyl.
CC140-CC160 mvar CAV Propyl.
CC200-CC220 mvar VAV Ethlen
CC240-CC260 mvar VAV Propyl.
CC300-CC320 tvar CAV Ethyl.
CC340-CC360 tvar CAV Propyl.
CC400-CC420 tvar VAV Ethyl.
CC440-CC460 tvar VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



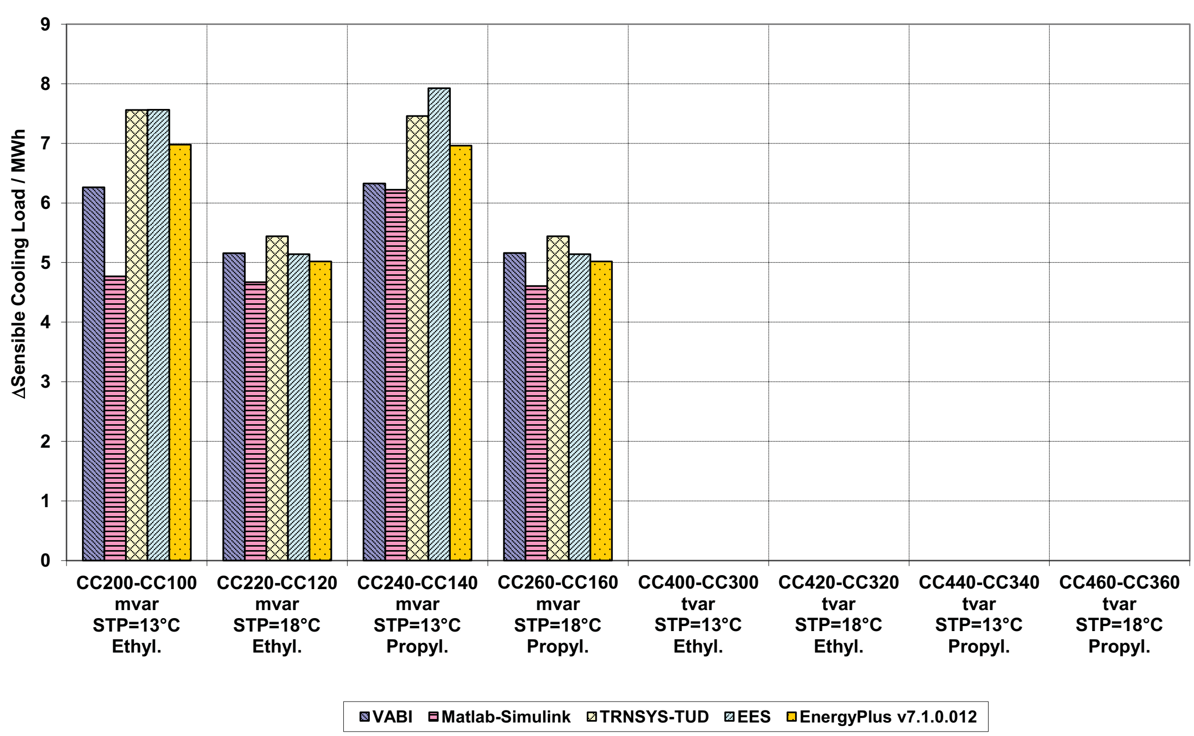
ΔLatent Cooling Load / MWh
35
30
25
20
15
10
5
0
CC100-CC120 mvar CAV Ethyl.
CC140-CC160 mvar CAV Propyl.
CC200-CC220 mvar VAV Ethlen
CC240-CC260 mvar VAV Propyl.
CC300-CC320 tvar CAV Ethyl.
CC340-CC360 tvar CAV Propyl.
CC400-CC420 tvar VAV Ethyl.
CC440-CC460 tvar VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


ΔTotal Chilled Water Volume passing the Coil / (10³ x m³)
10
9
8
7
6
5
4
3
2
1
0
CC100-CC120 mvar CAV Ethyl.
CC140-CC160 mvar CAV Propyl.
CC200-CC220 mvar VAV Ethlen
CC240-CC260 mvar VAV Propyl.
CC300-CC320 tvar CAV Ethyl.
CC340-CC360 tvar CAV Propyl.
CC400-CC420 tvar VAV Ethyl.
CC440-CC460 tvar VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

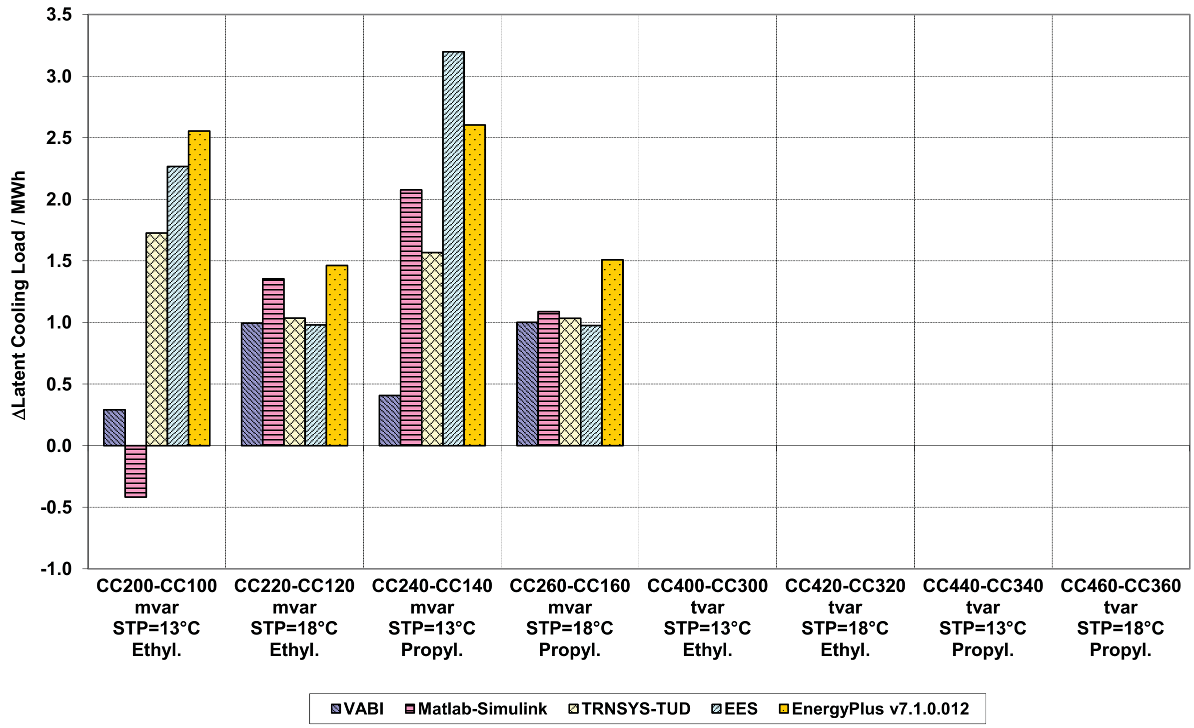

ΔTotal Chilled Water Volume passing the Coil / (10³ x m³)
10
9
8
7
6
5
4
3
2
1
0
CC100-CC120 mvar CAV Ethyl.
CC140-CC160 mvar CAV Propyl.
CC200-CC220 mvar VAV Ethlen
CC240-CC260 mvar VAV Propyl.
CC300-CC320 tvar CAV Ethyl.
CC340-CC360 tvar CAV Propyl.
CC400-CC420 tvar VAV Ethyl.
CC440-CC460 tvar VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



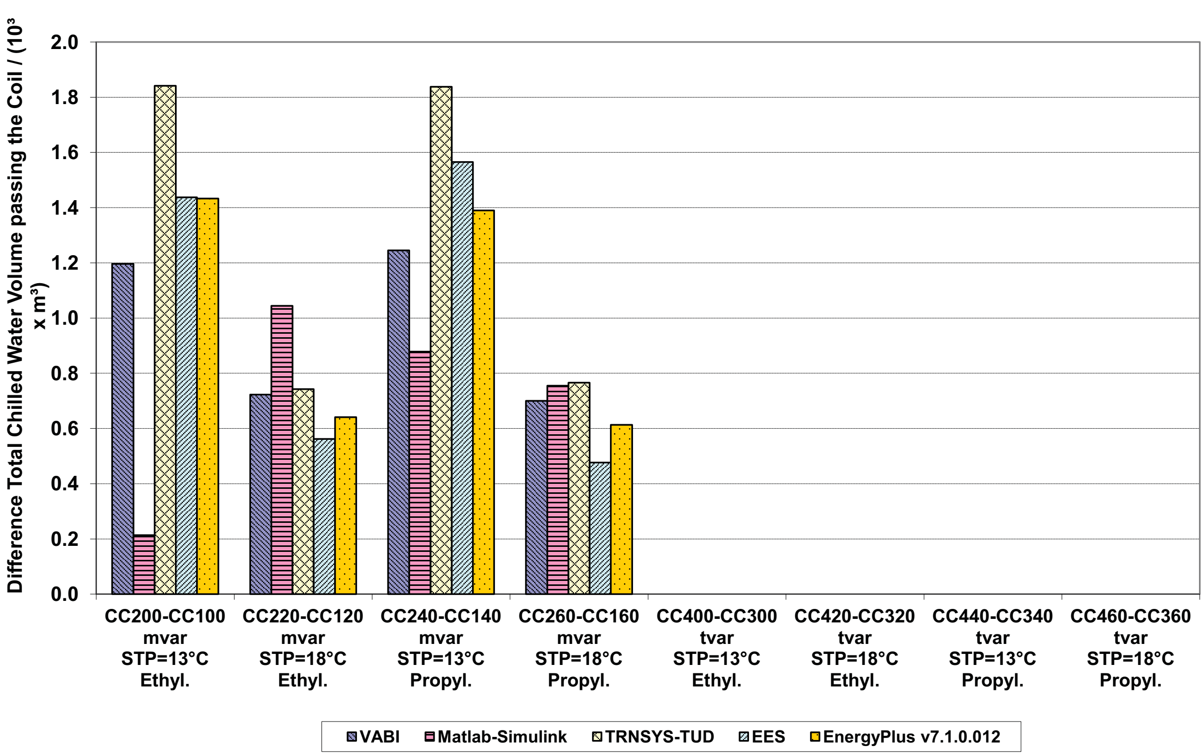
14
12
10
8
6
4
2
0
ΔTotal Cooling Load / MWh
CC200-CC100 mvar STP=13°C Ethyl.
CC220-CC120 mvar STP=18°C Ethyl.
CC240-CC140 mvar STP=13°C Propyl.
CC260-CC160 mvar STP=18°C Propyl.
CC400-CC300 tvar STP=13°C Ethyl.
CC420-CC320 tvar STP=18°C Ethyl.
CC440-CC340 tvar STP=13°C Propyl.
CC460-CC360 tvar STP=18°C Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



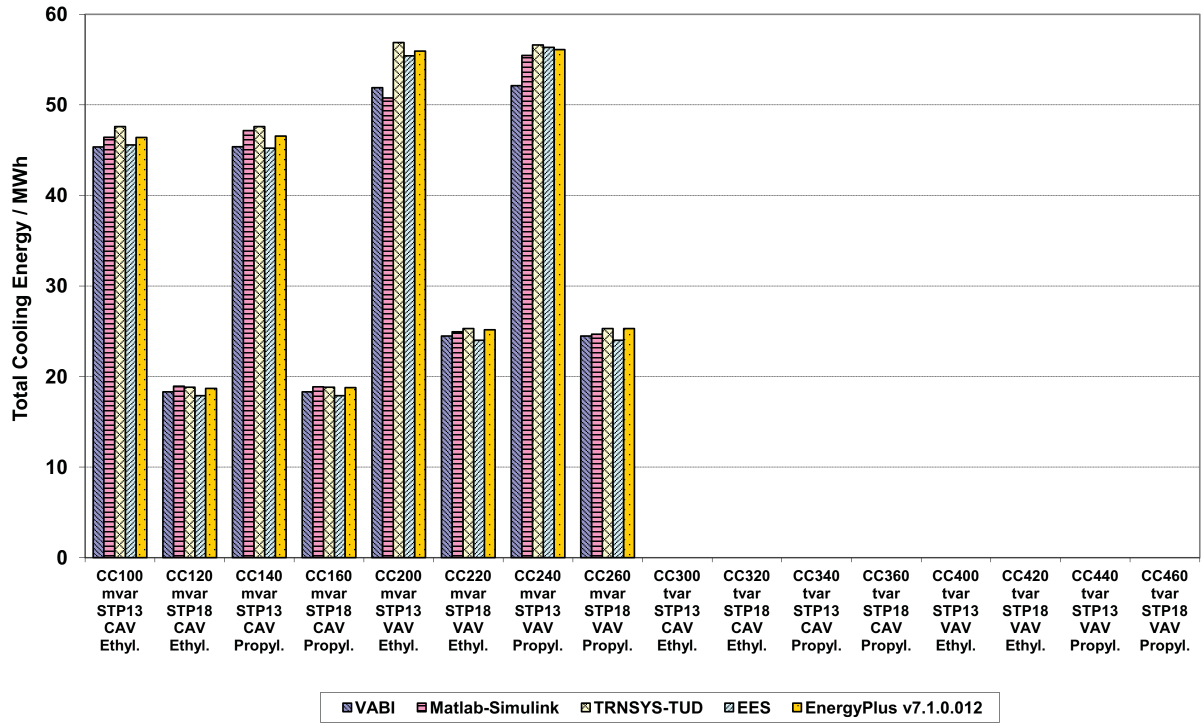
9
8
7
6
5
4
3
2
1
0
ΔSensible Cooling Load / MWh
CC200-CC100 mvar STP=13°C Ethyl.
CC220-CC120 mvar STP=18°C Ethyl.
CC240-CC140 mvar STP=13°C Propyl.
CC260-CC160 mvar STP=18°C Propyl.
CC400-CC300 tvar STP=13°C Ethyl.
CC420-CC320 tvar STP=18°C Ethyl.
CC440-CC340 tvar STP=13°C Propyl.
CC460-CC360 tvar STP=18°C Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



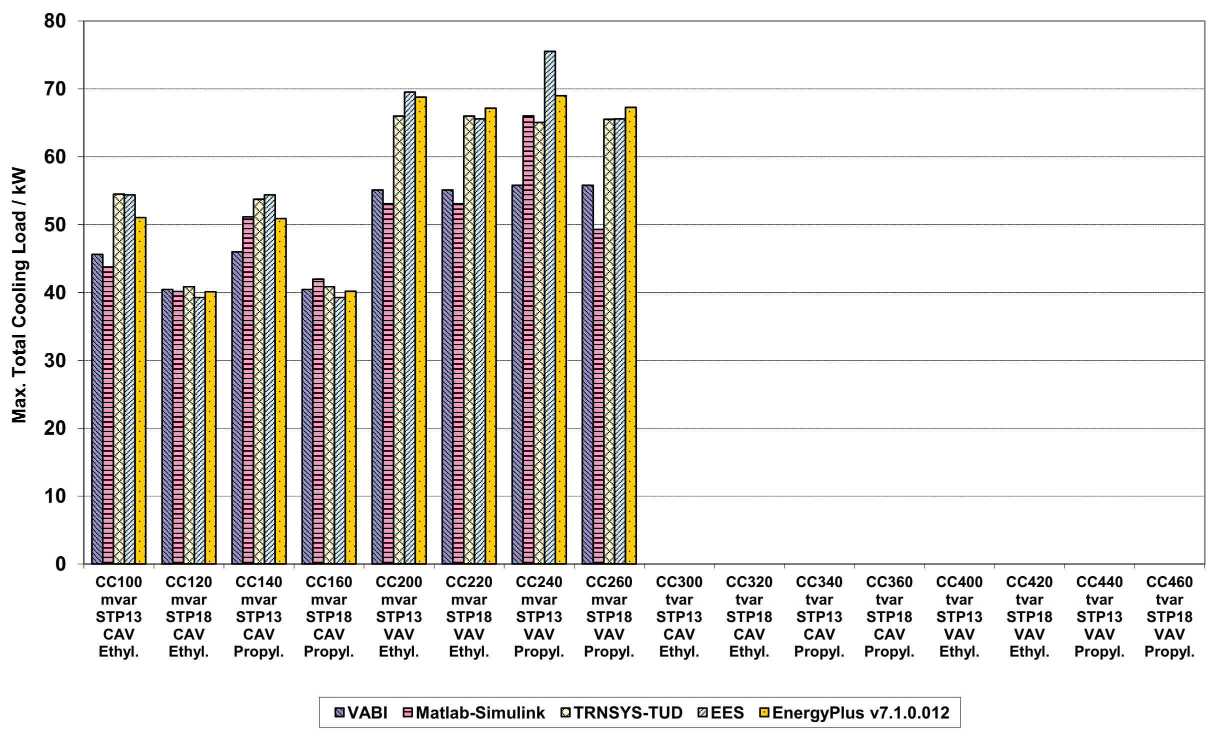
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
ΔLatent Cooling Load / MWh
CC200-CC100 mvar STP=13°C Ethyl.
CC220-CC120 mvar STP=18°C Ethyl.
CC240-CC140 mvar STP=13°C Propyl.
CC260-CC160 mvar STP=18°C Propyl.
CC400-CC300 tvar STP=13°C Ethyl.
CC420-CC320 tvar STP=18°C Ethyl.
CC440-CC340 tvar STP=13°C Propyl.
CC460-CC360 tvar STP=18°C Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



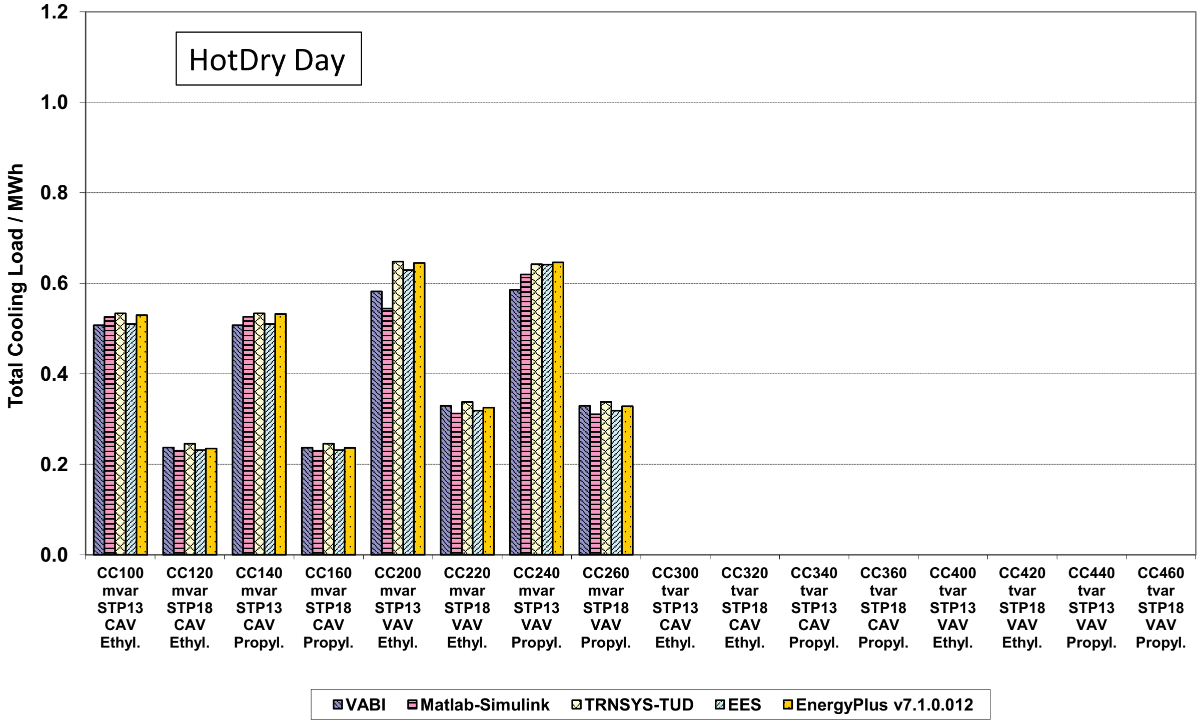
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Difference Total Chilled Water Volume passing the Coil / (10³ x m³)
CC200-CC100 mvar STP=13°C Ethyl.
CC220-CC120 mvar STP=18°C Ethyl.
CC240-CC140 mvar STP=13°C Propyl.
CC260-CC160 mvar STP=18°C Propyl.
CC400-CC300 tvar STP=13°C Ethyl.
CC420-CC320 tvar STP=18°C Ethyl.
CC440-CC340 tvar STP=13°C Propyl.
CC460-CC360 tvar STP=18°C Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

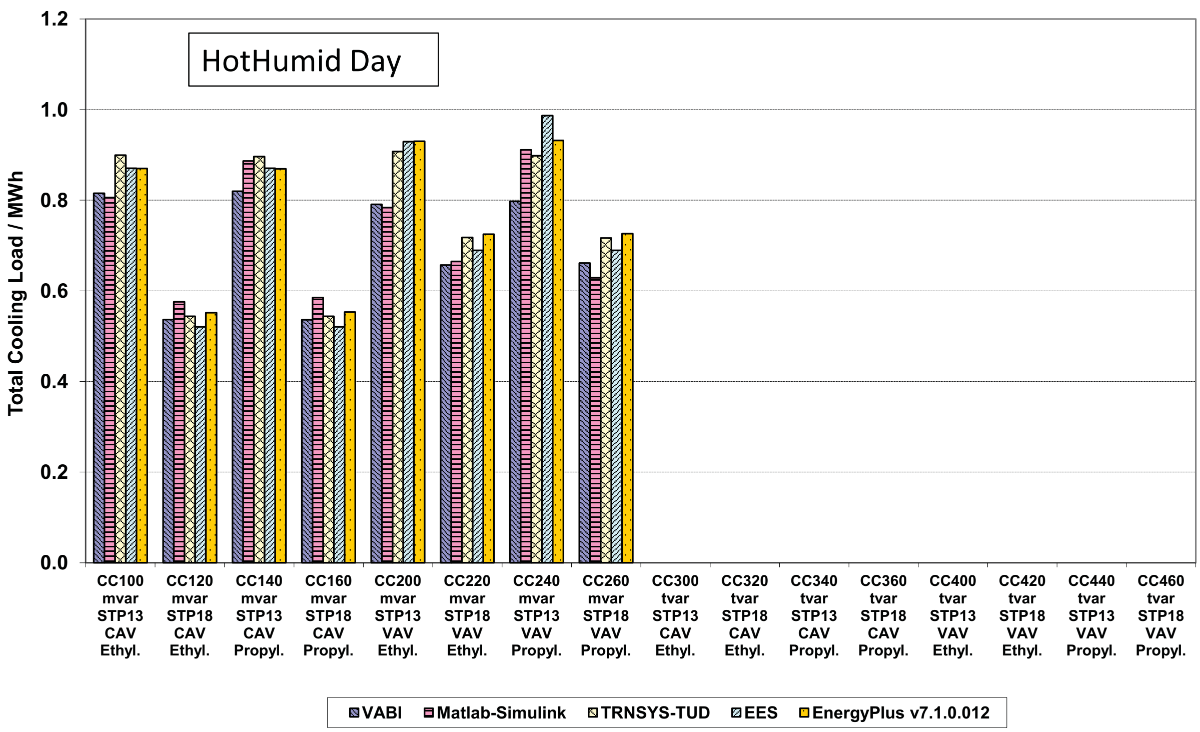


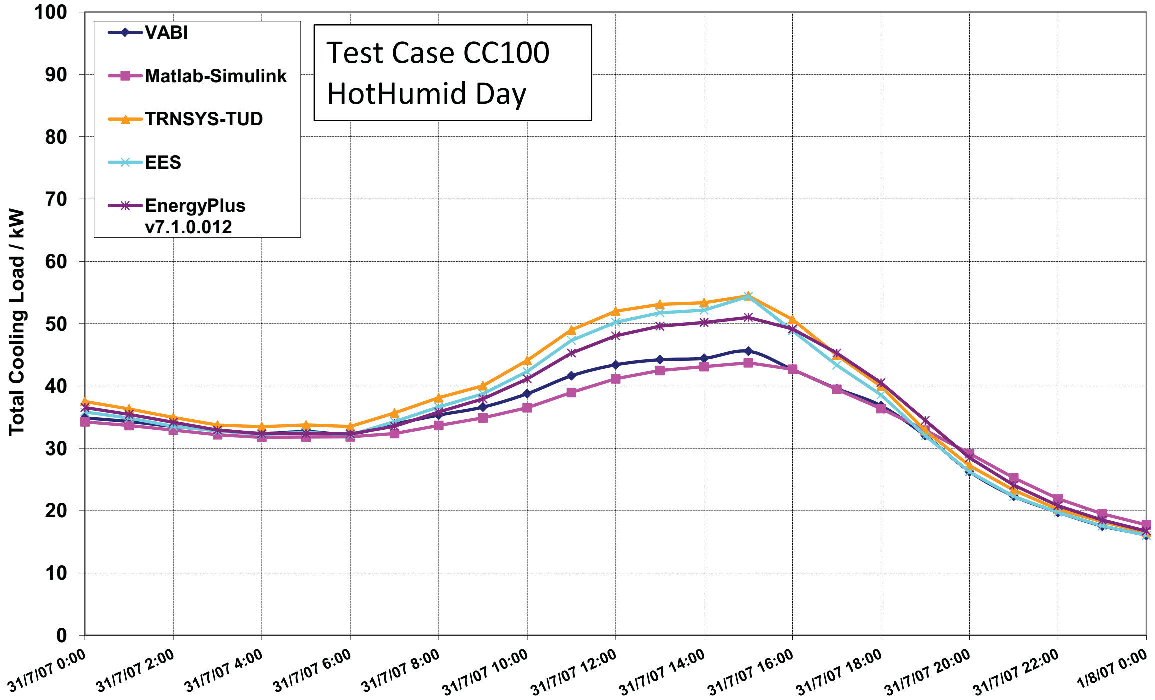
Total Cooling Energy / MWh
60
50
40
30
20
10
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



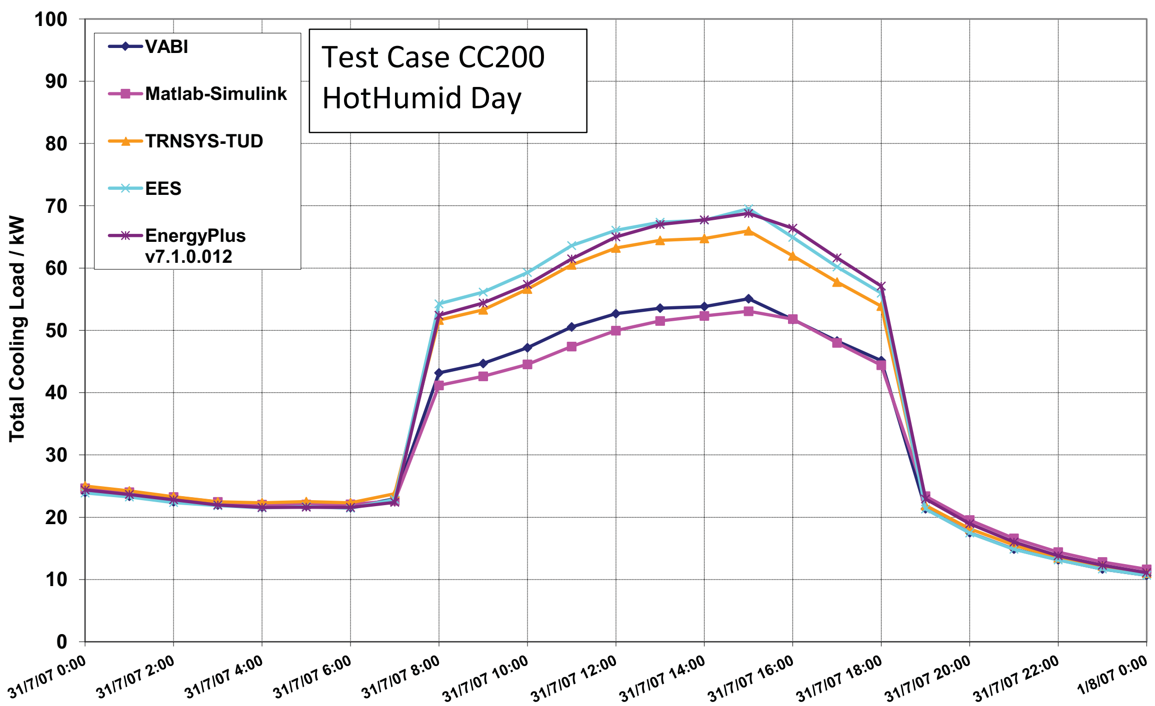
Max. Total Cooling Load / kW
80
70
60
50
40
30
20
10
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


HotDry Day
Total Cooling Load / MWh
1.2
1.0
0.8
0.6
0.4
0.2
0.0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


HotHumid Day
Total Cooling Load / MWh
1.2
1.0
0.8
0.6
0.4
0.2
0.0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



Test Case CC100
HotHumid Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Total Cooling Load / kW
0
10
20
30
40
50
60
70
80
90
100
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
31/7/07 16:00
31/7/07 18:00
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00



Test Case CC200
HotHumid Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Total Cooling Load / kW
0
10
20
30
40
50
60
70
80
90
100
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
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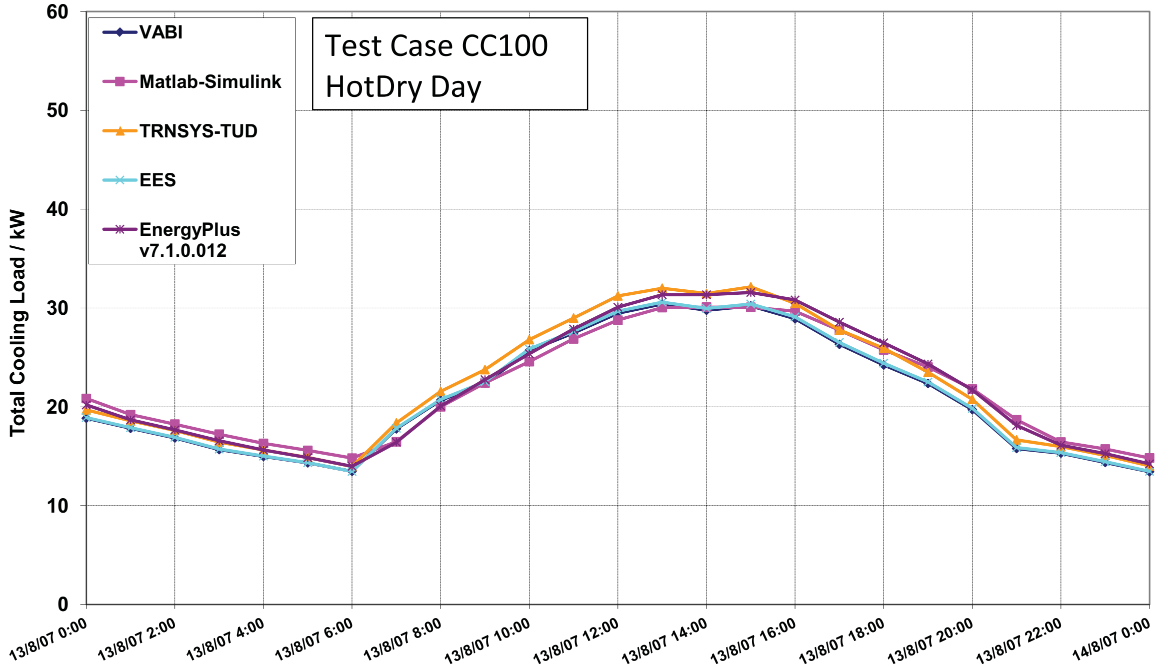
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00



Test Case CC100
HotDry Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Total Cooling Load / kW
0
10
20
30
40
50
60
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
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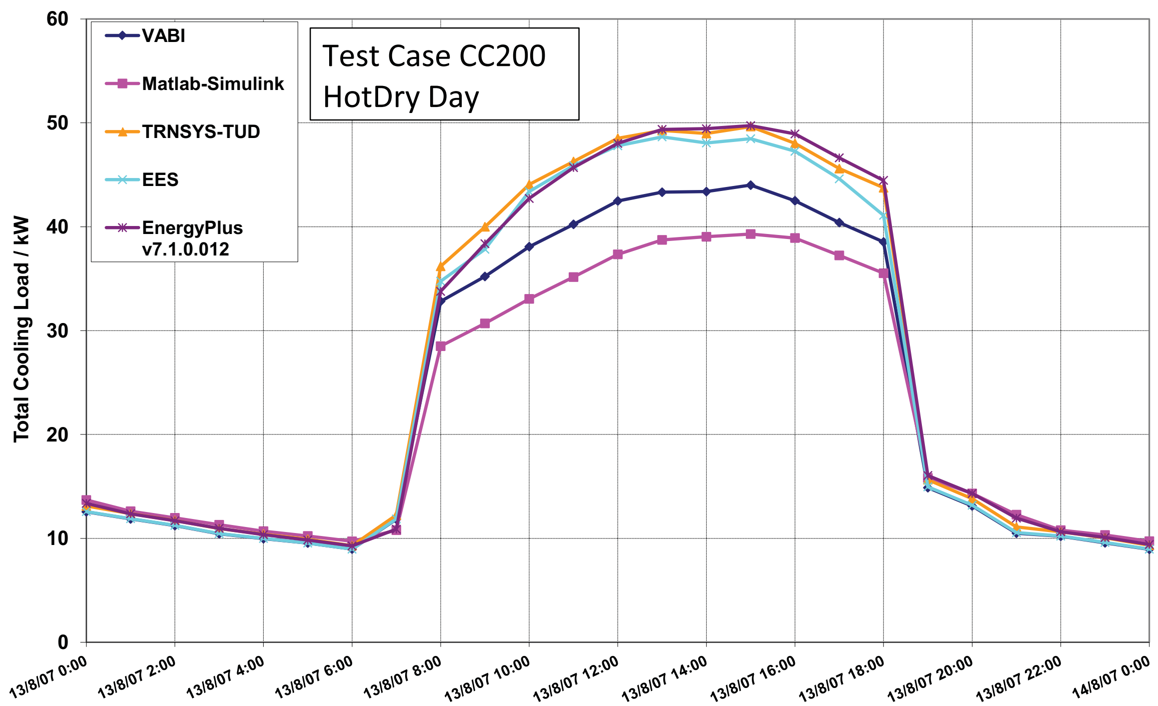
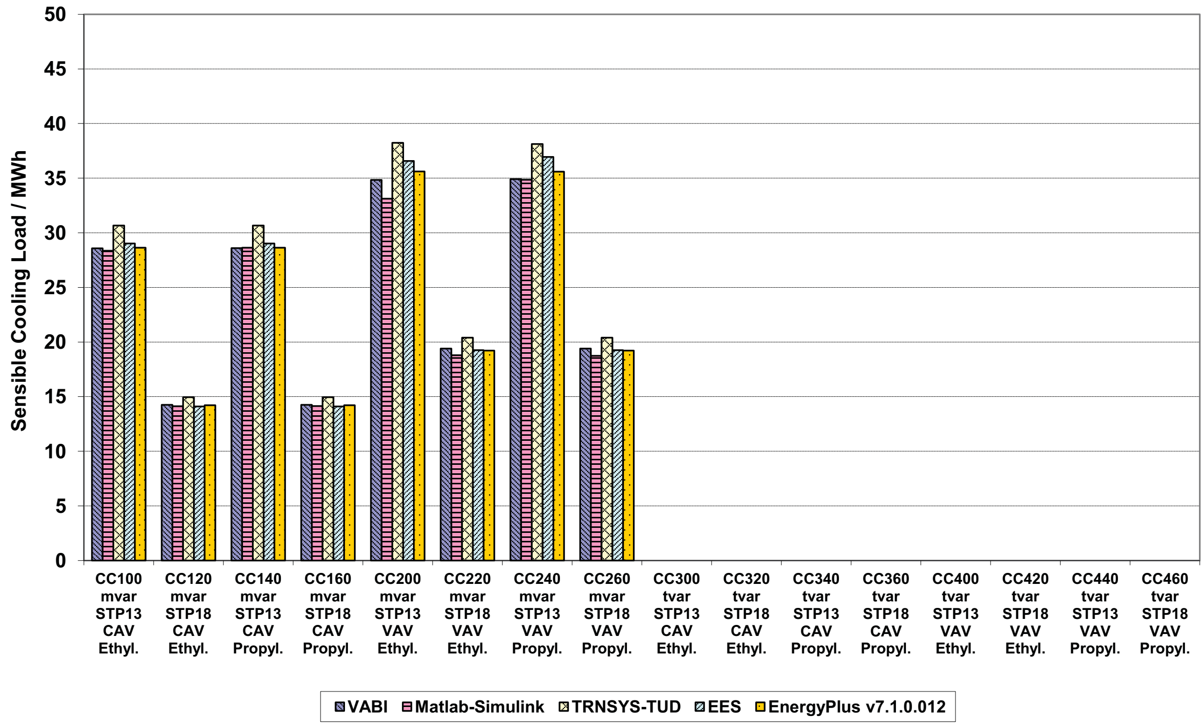
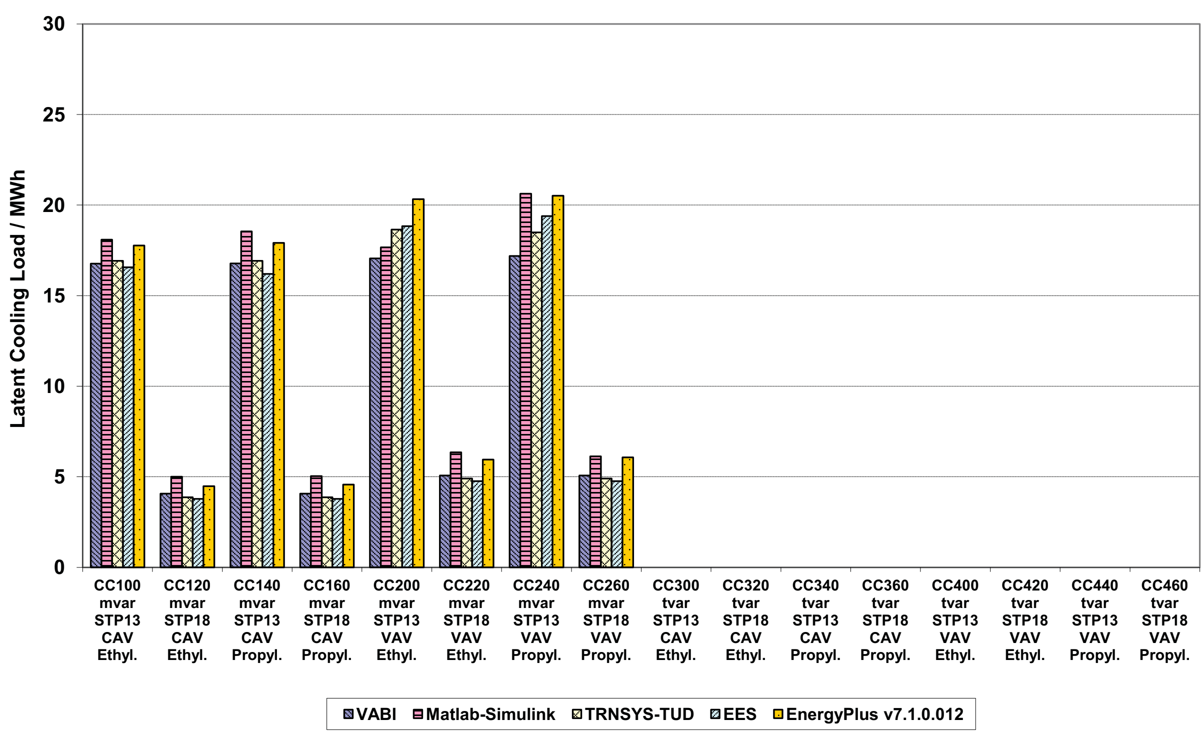
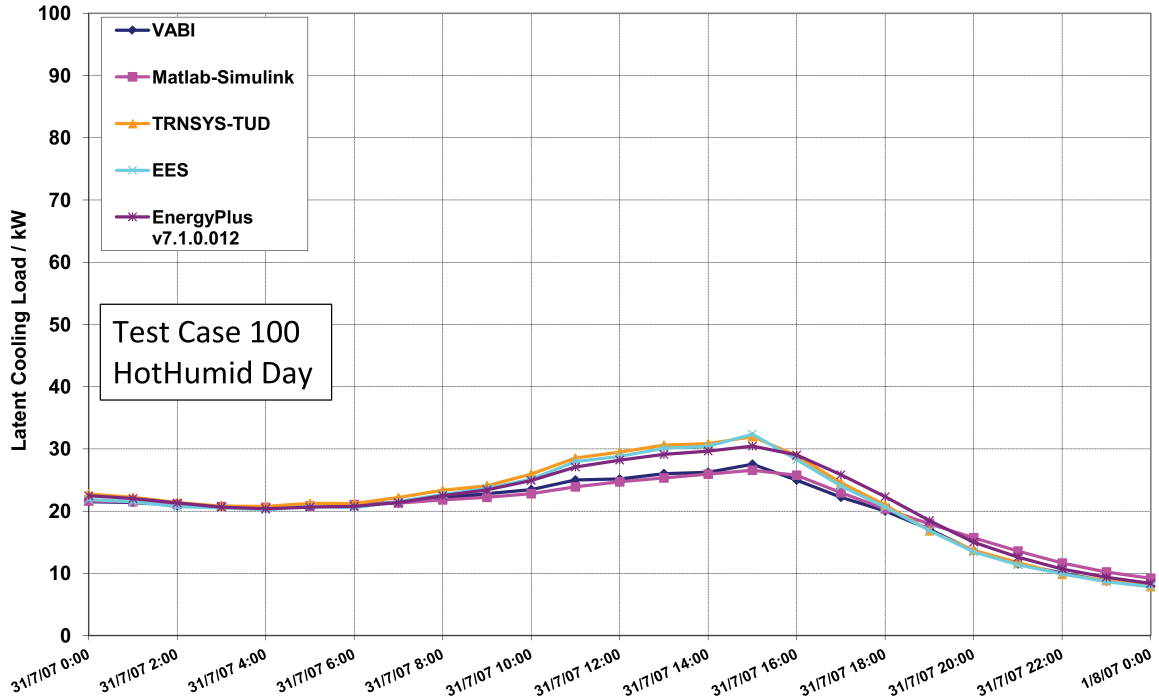
13/8/07 22:00
14/8/07 0:00



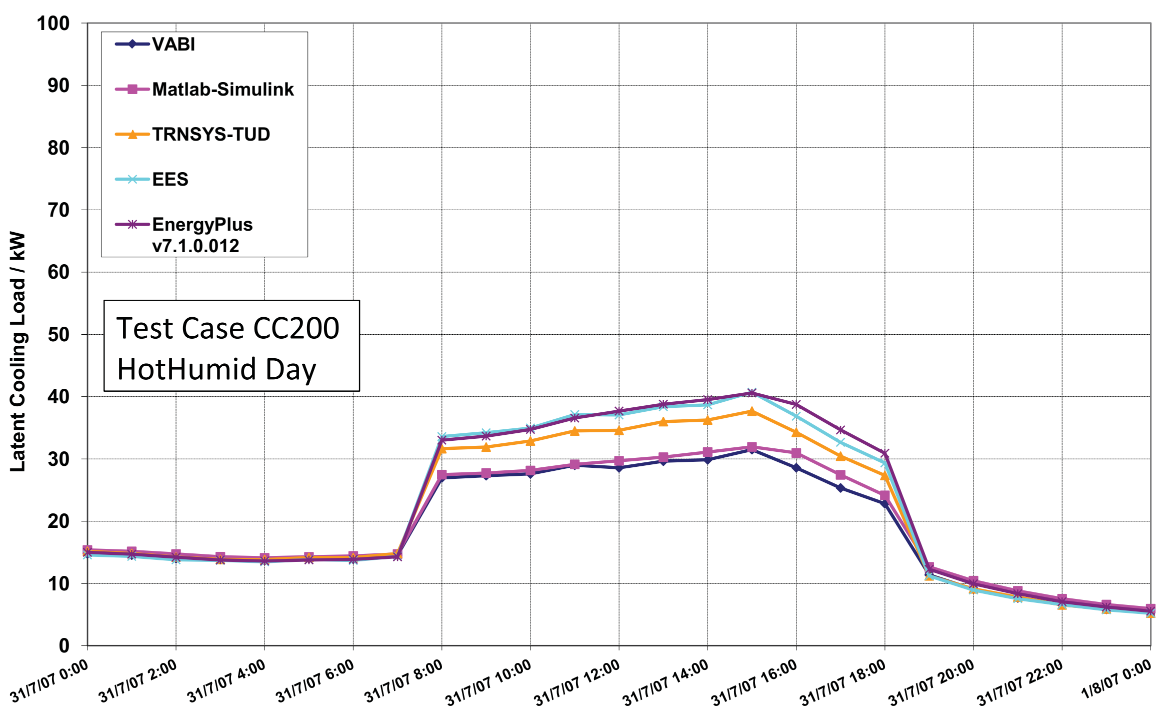
Test Case CC200
HotDry Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Total Cooling Load / kW
0
10
20
30
40
50
60
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
13/8/07 16:00
13/8/07 18:00
13/8/07 20:00
13/8/07 22:00
14/8/07 0:00


Sensible Cooling Load / MWh
0
5
10
15
20
25
30
35
40
45
50
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

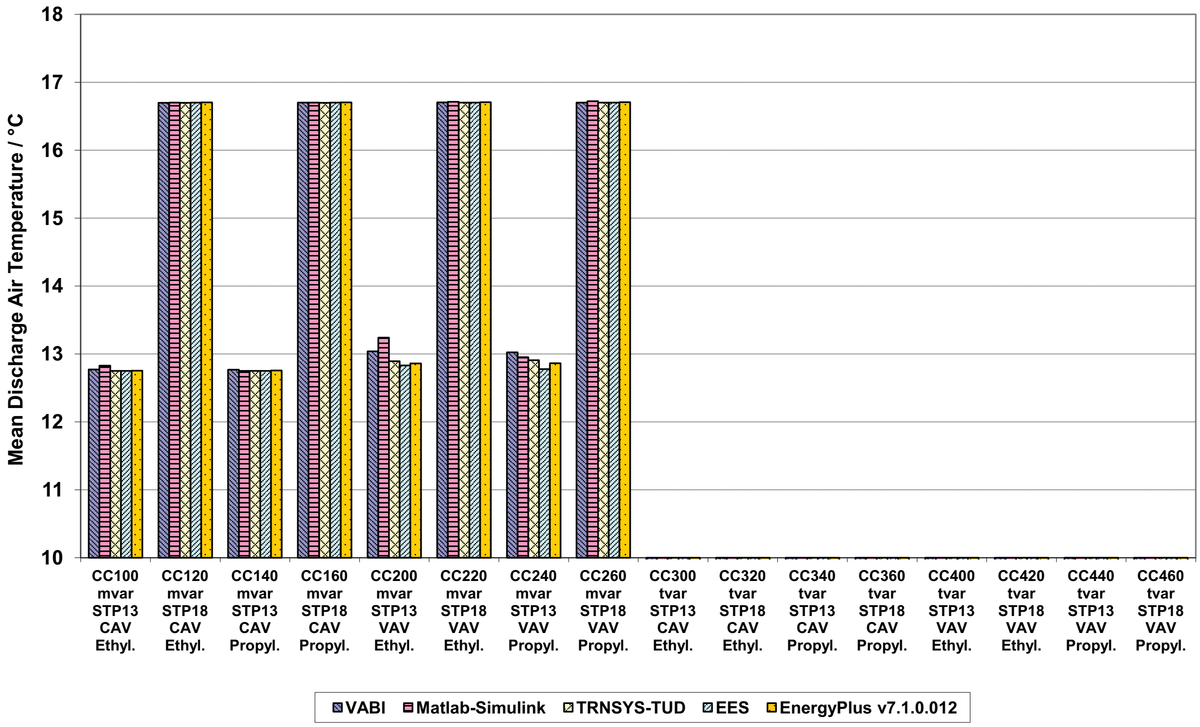

Latent Cooling Load / MWh
0
5
10
15
20
25
30
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

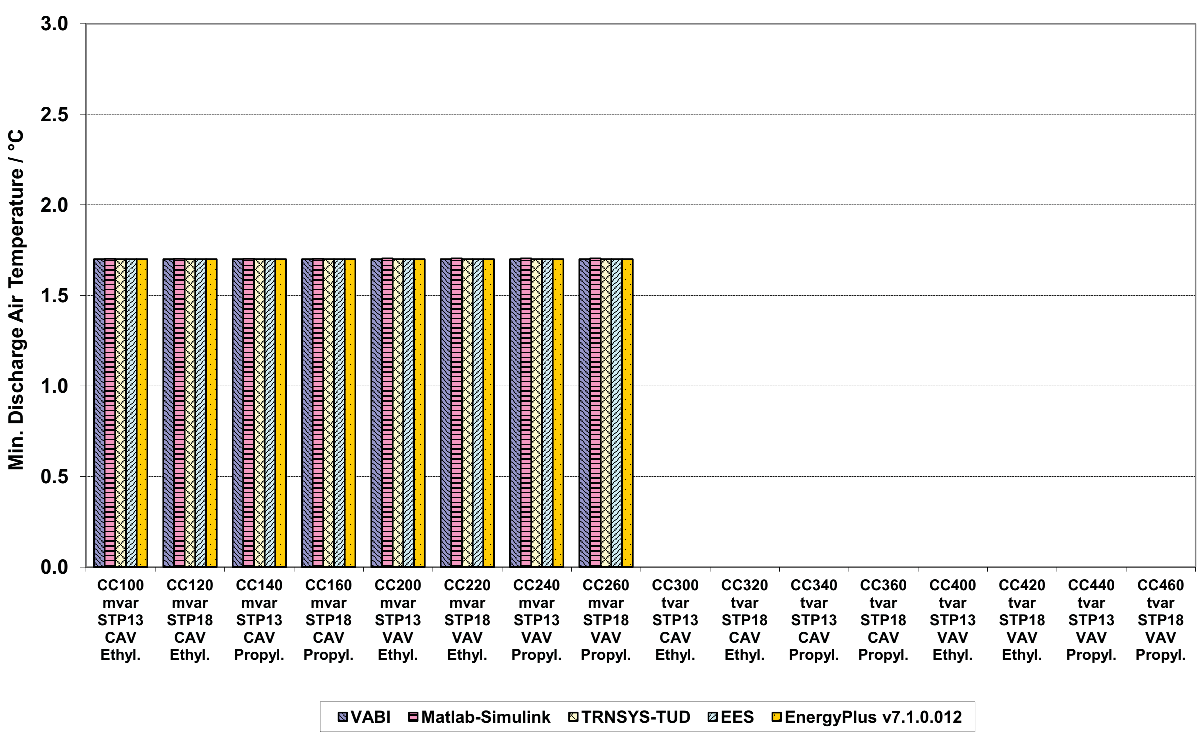


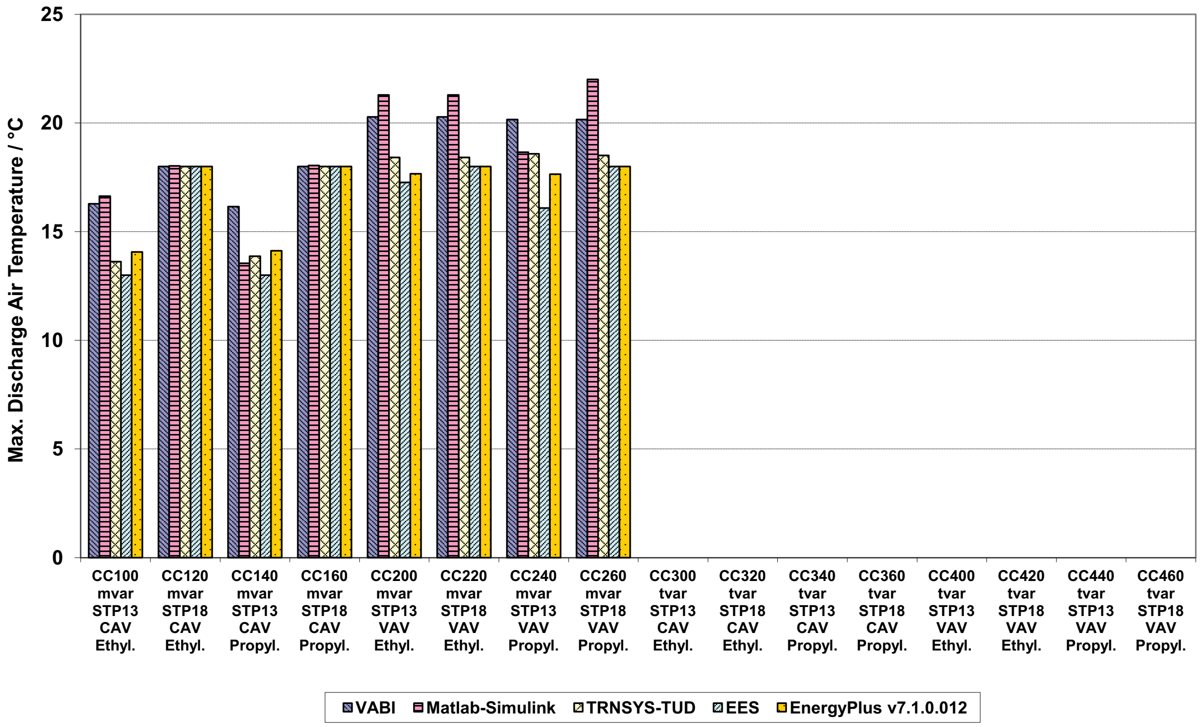
Latent Cooling Load / kW
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Test Case 100
HotHumid Day
100
90
80
70
60
50
40
30
20
10
0
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
31/7/07 16:00
31/7/07 18:00
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00

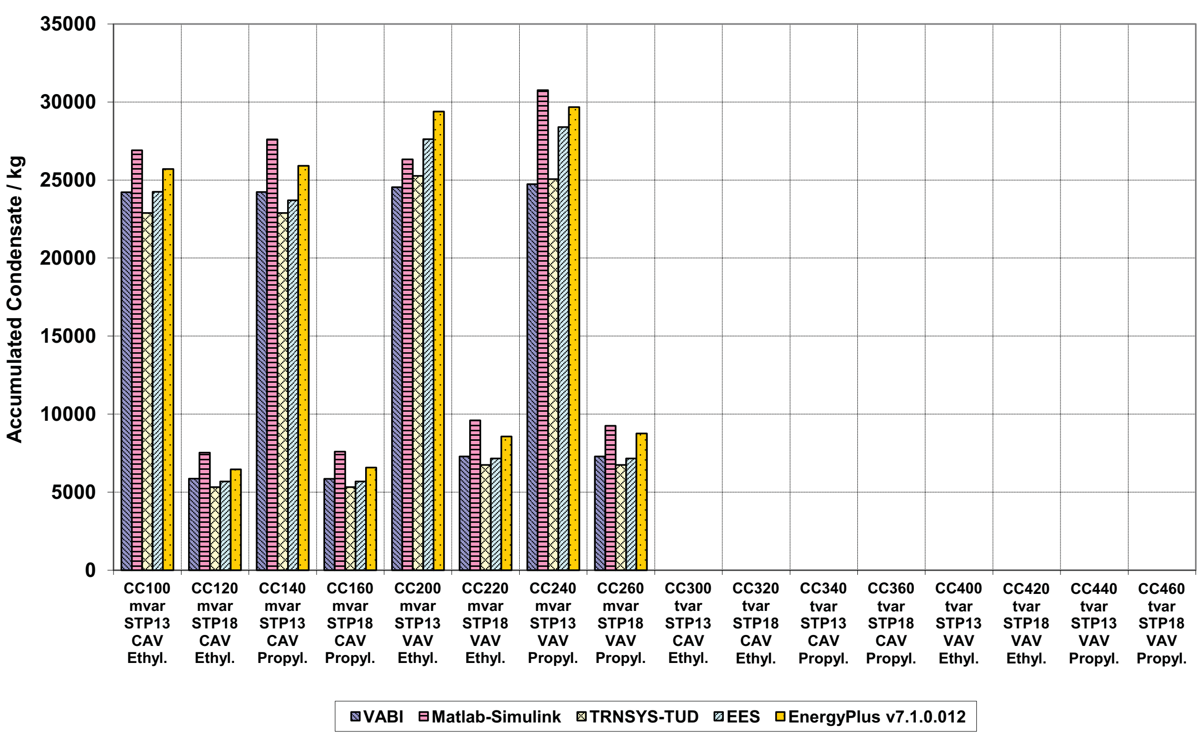


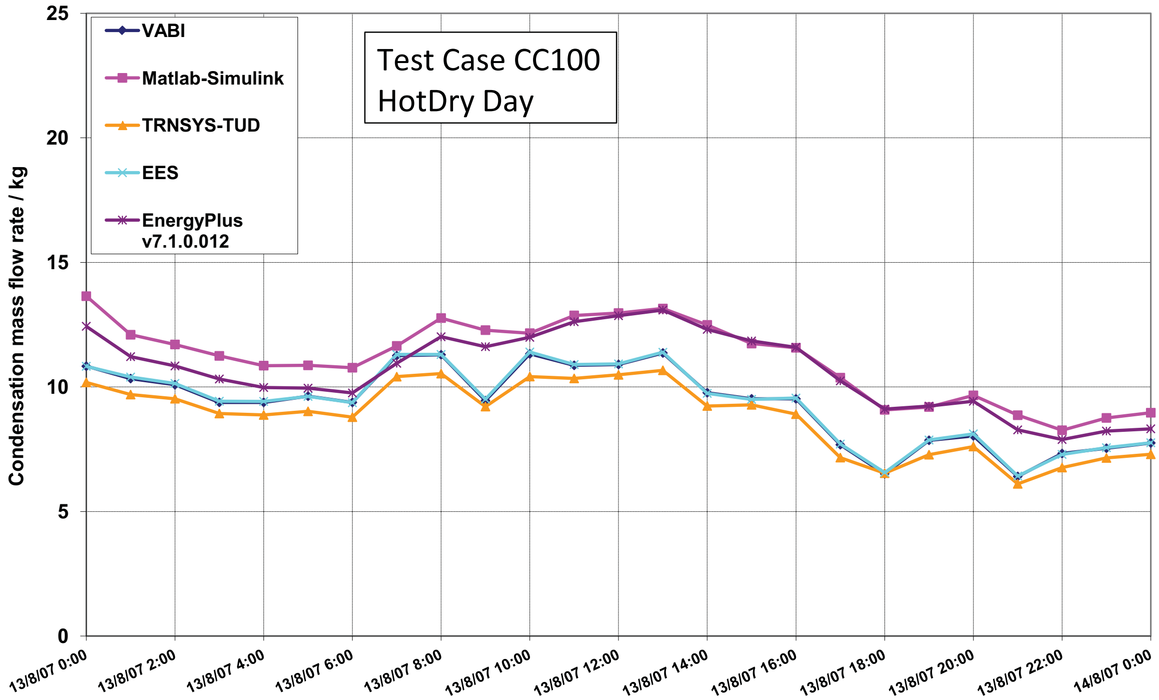
Latent Cooling Load / kW
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Test Case CC200
HotHumid Day
100
90
80
70
60
50
40
30
20
10
0
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
31/7/07 16:00
31/7/07 18:00
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00


Mean Discharge Air Temperature / °C
18
17
16
15
14
13
12
11
10
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

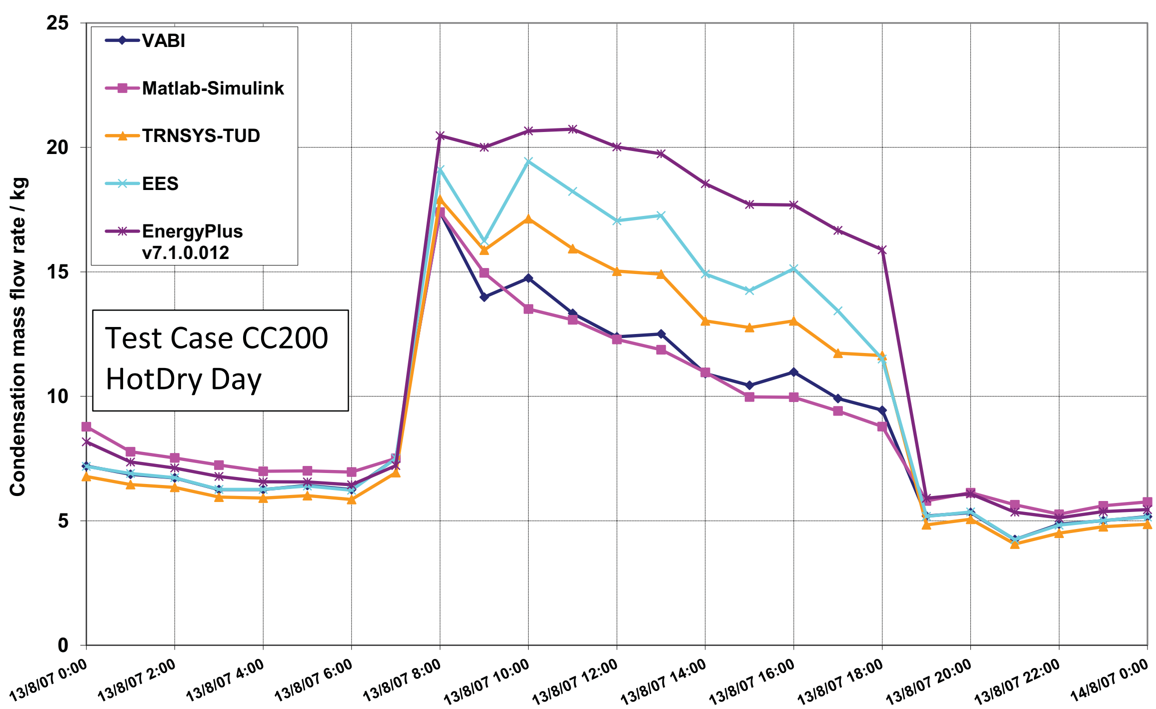

Min. Discharge Air Temperature / °C
3.0
2.5
2.0
1.5
1.0
0.5
0.0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


25
20
15
10
5
0
Max. Discharge Air Temperature / °C
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

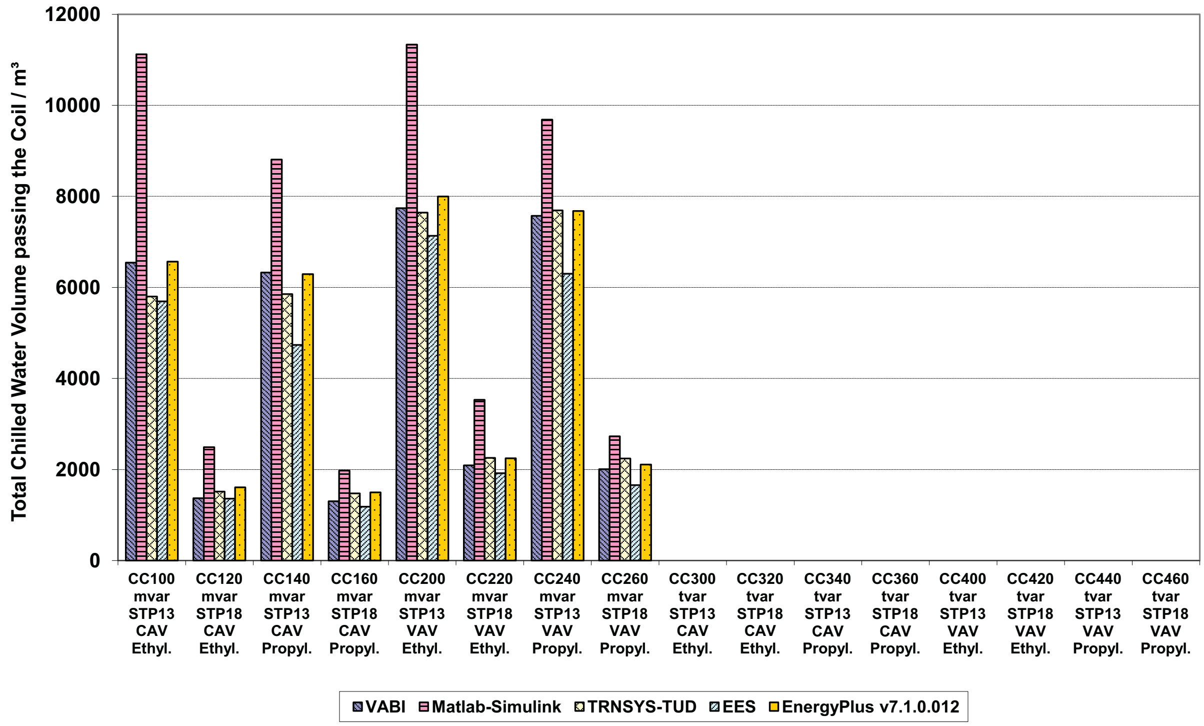

35000
30000
25000
20000
15000
10000
5000
0
Accumulated Condensate / kg
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



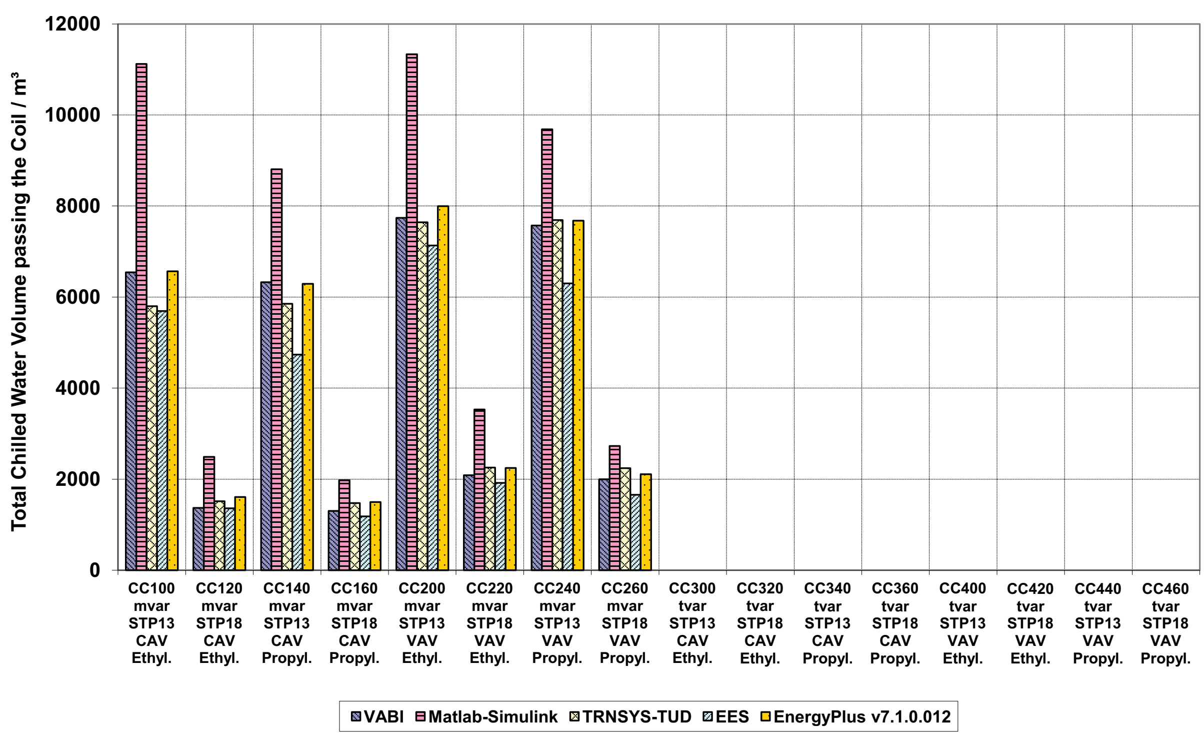
Test Case CC100
HotDry Day
Condensation mass flow rate / kg
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
0
5
10
15
20
25
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
13/8/07 16:00
13/8/07 18:00
13/8/07 20:00
13/8/07 22:00
14/8/07 0:00



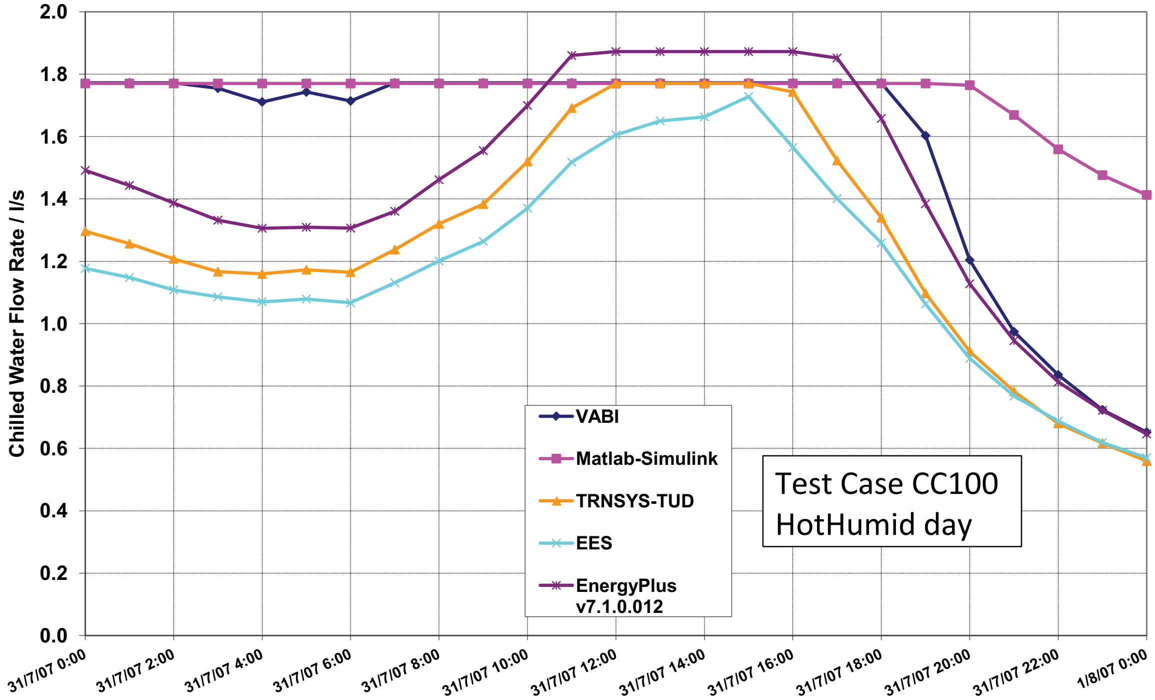
Test Case CC200
HotDry Day
Condensation mass flow rate / kg
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
0
5
10
15
20
25
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
13/8/07 16:00
13/8/07 18:00
13/8/07 20:00
13/8/07 22:00
14/8/07 0:00



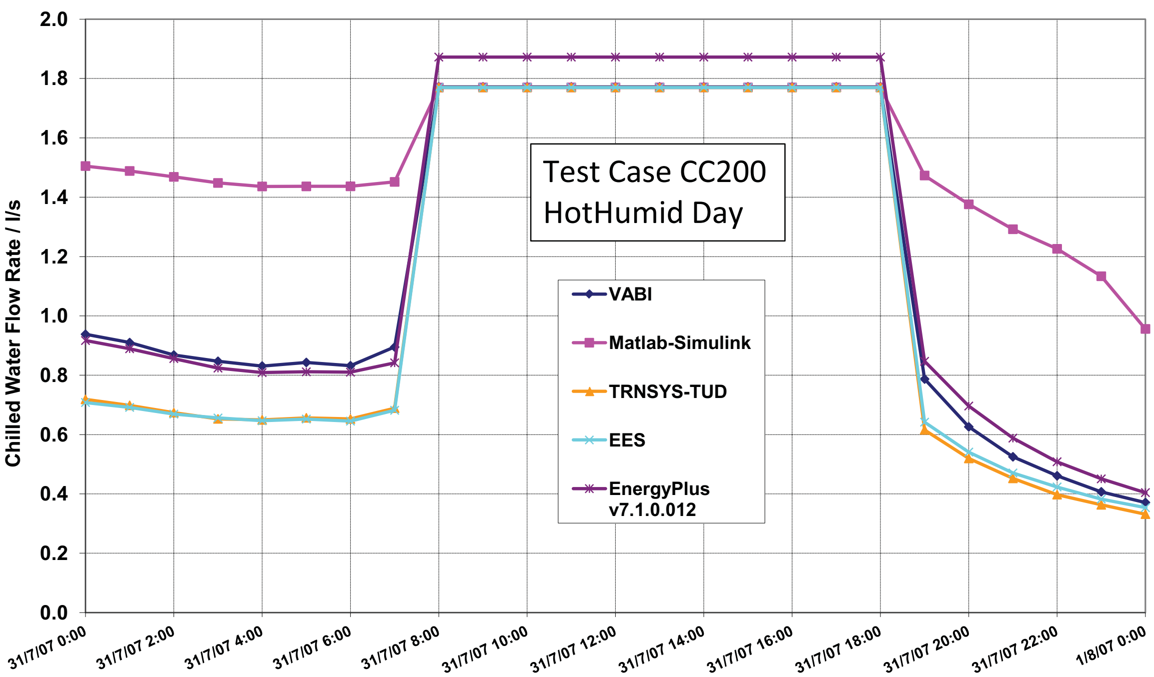
Total Chilled Water Volume passing the Coil / m³
12000
10000
8000
6000
4000
2000
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



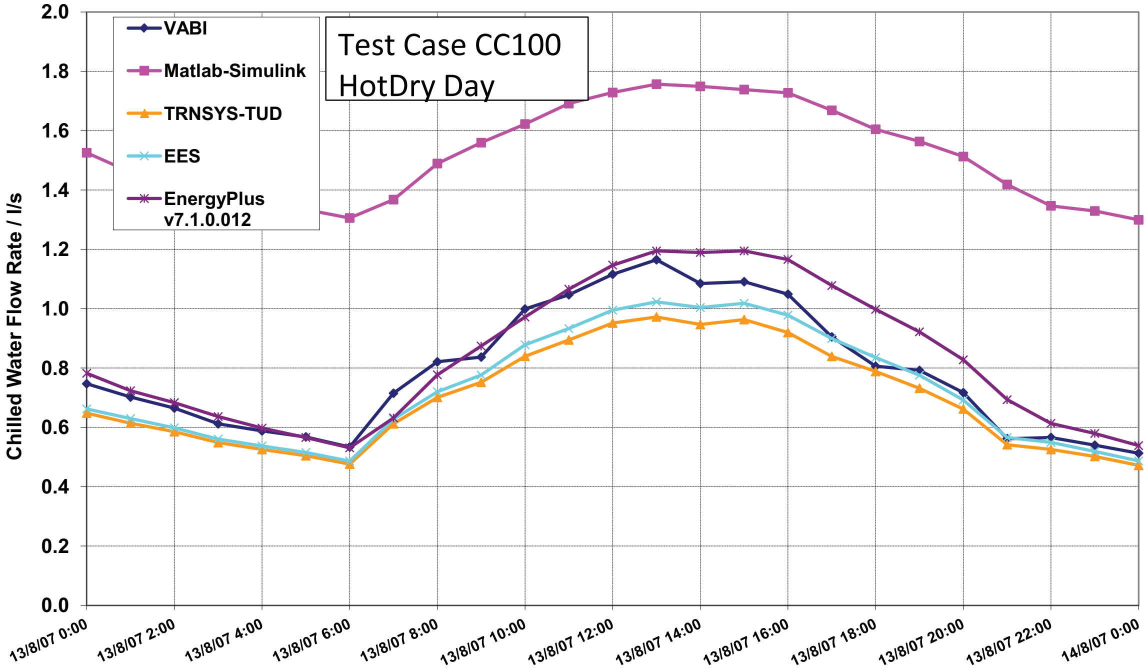
Total Chilled Water Volume passing the Coil / m³
12000
10000
8000
6000
4000
2000
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

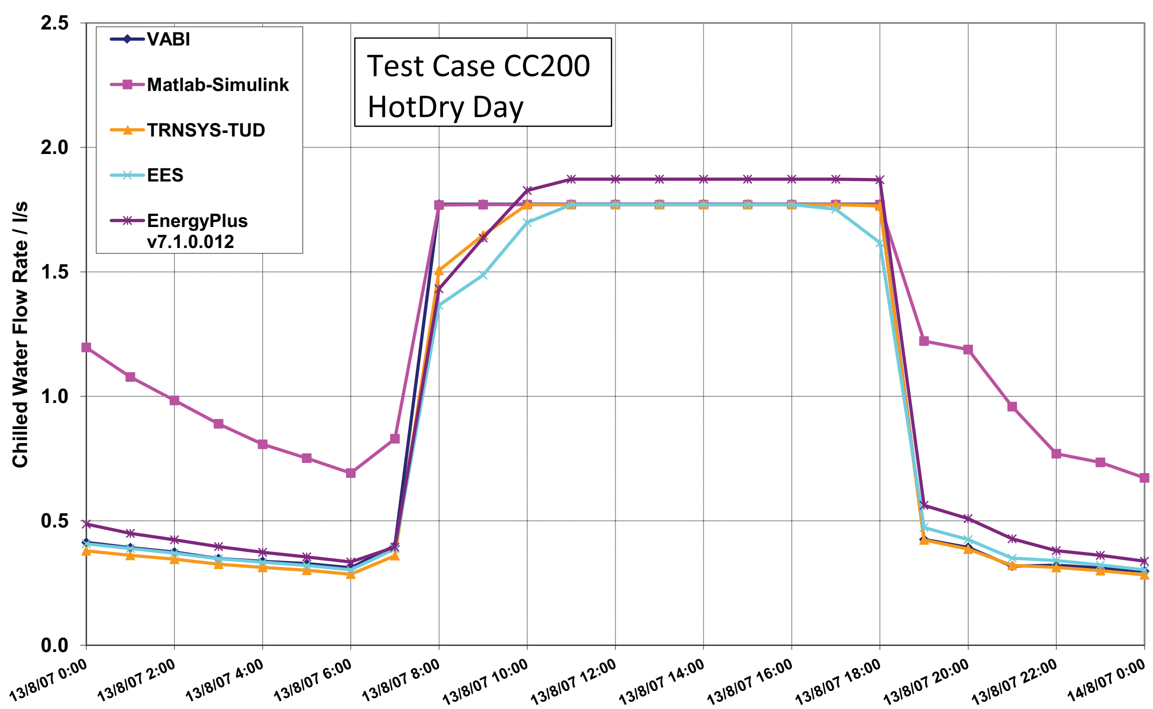


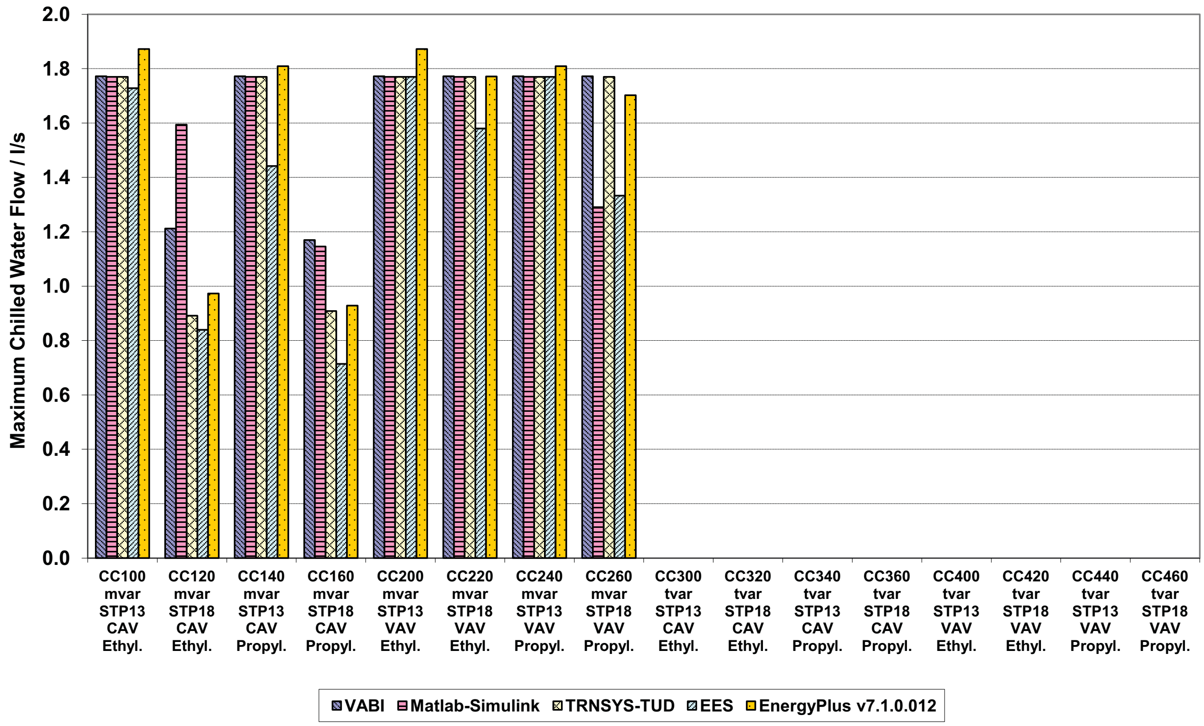
Chilled Water Flow Rate / l/s
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
31/7/07 16:00
31/7/07 18:00
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Test Case CC100
HotHumid day

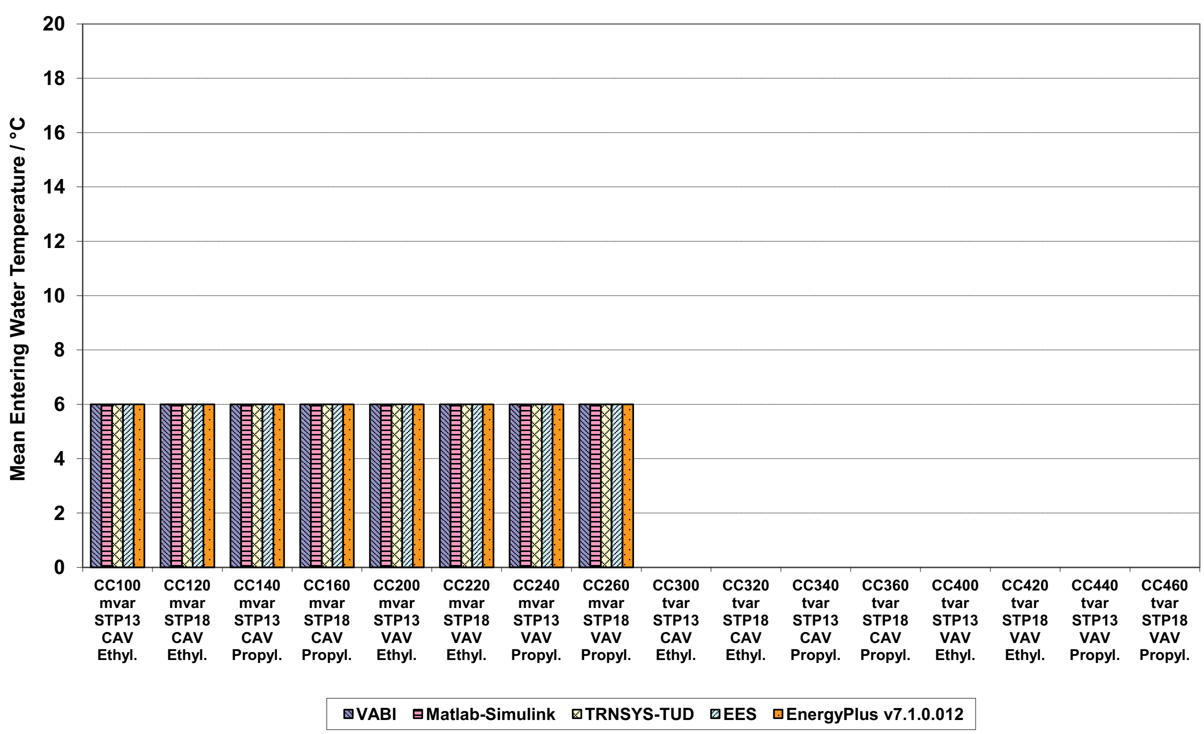


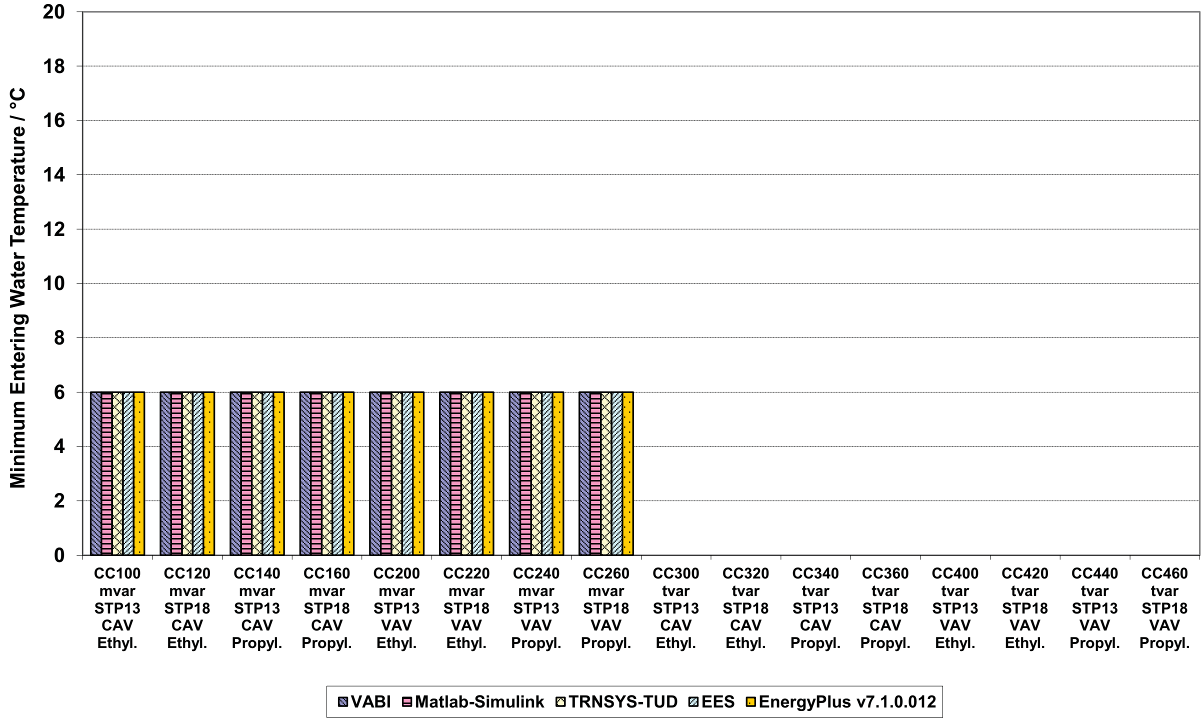
Chilled Water Flow Rate / l/s
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
31/7/07 16:00
31/7/07 18:00
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00
Test Case CC200
HotHumid Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

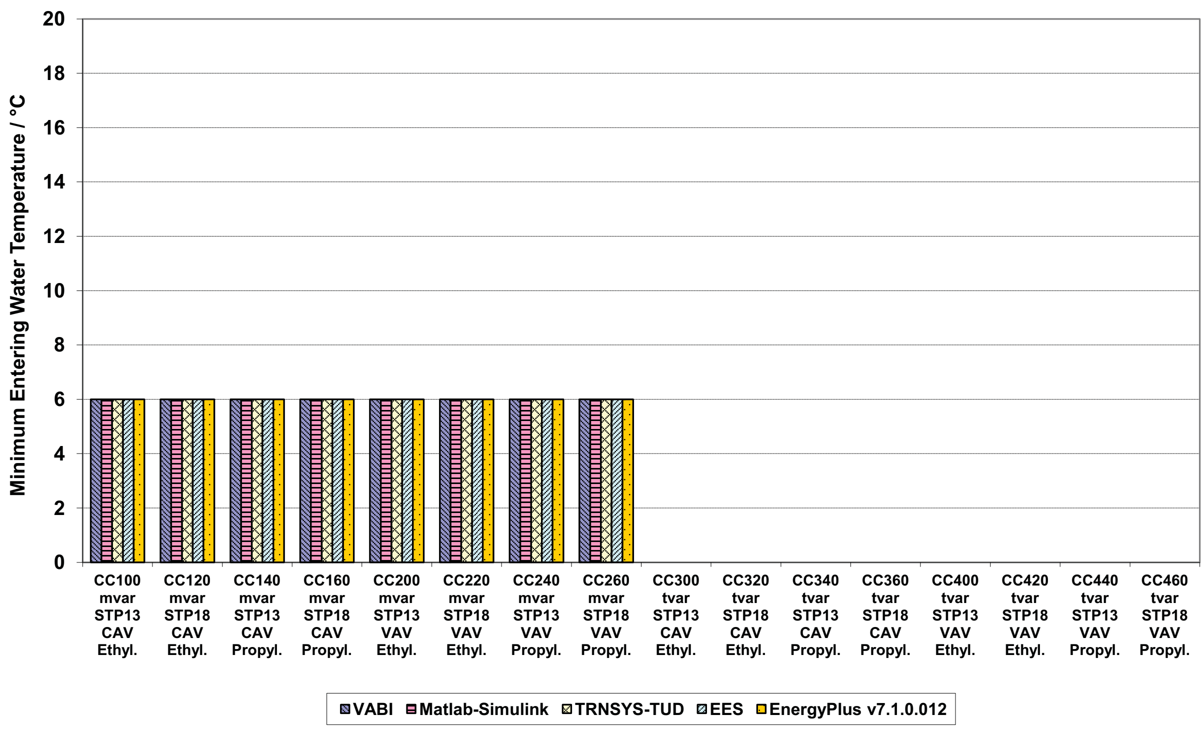

Test Case CC100
HotDry Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Chilled Water Flow Rate / l/s
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
13/8/07 16:00
13/8/07 18:00
13/8/07 20:00
13/8/07 22:00
14/8/07 0:00

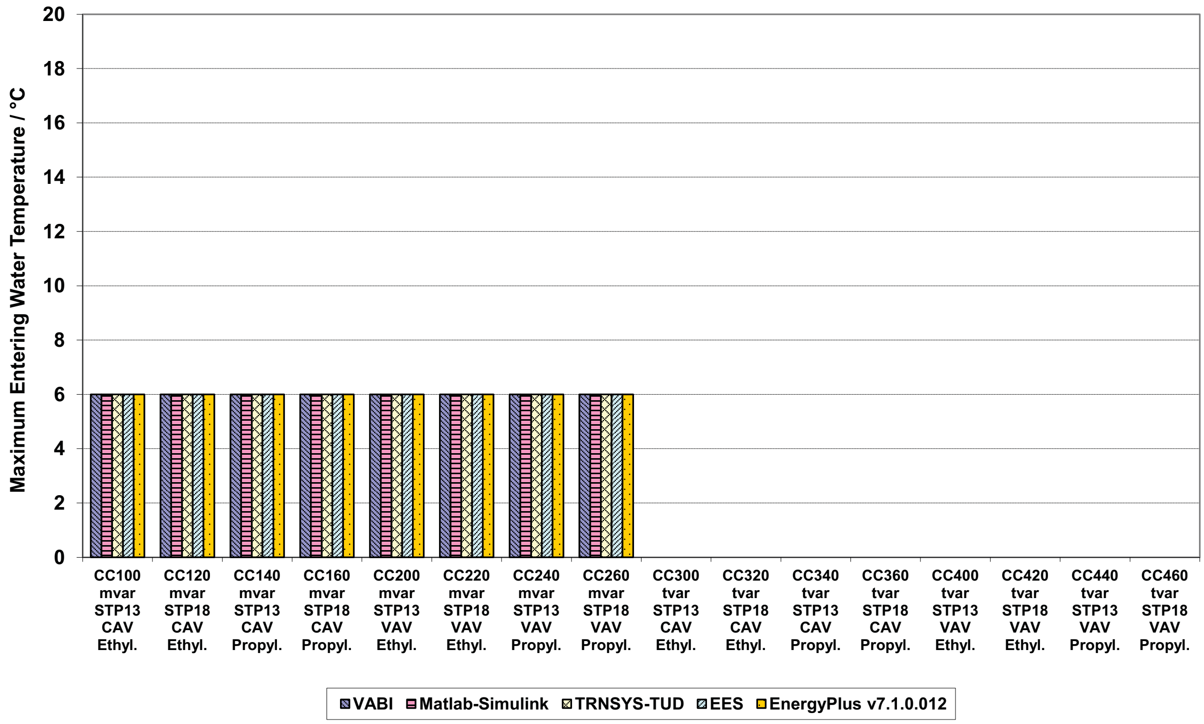

Test Case CC200
HotDry Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Chilled Water Flow Rate / l/s
2.5
2.0
1.5
1.0
0.5
0.0
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
13/8/07 16:00
13/8/07 18:00
13/8/07 20:00
13/8/07 22:00
14/8/07 0:00

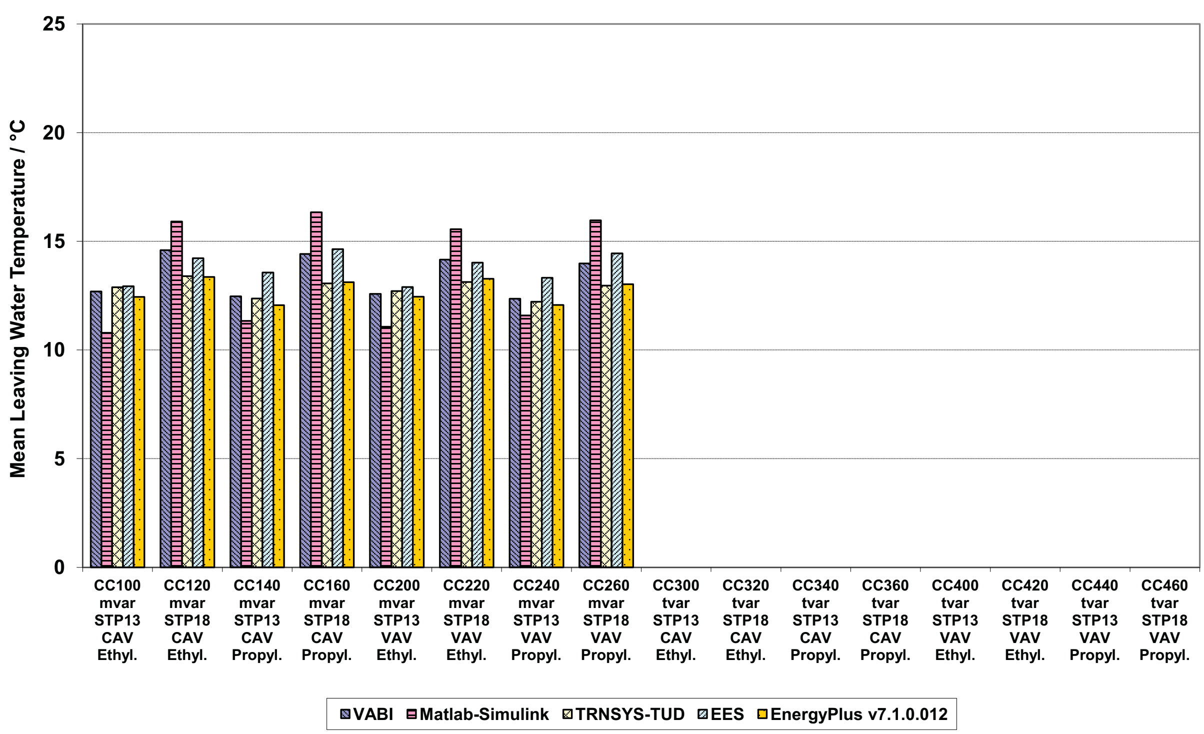

Maximum Chilled Water Flow / l/s
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

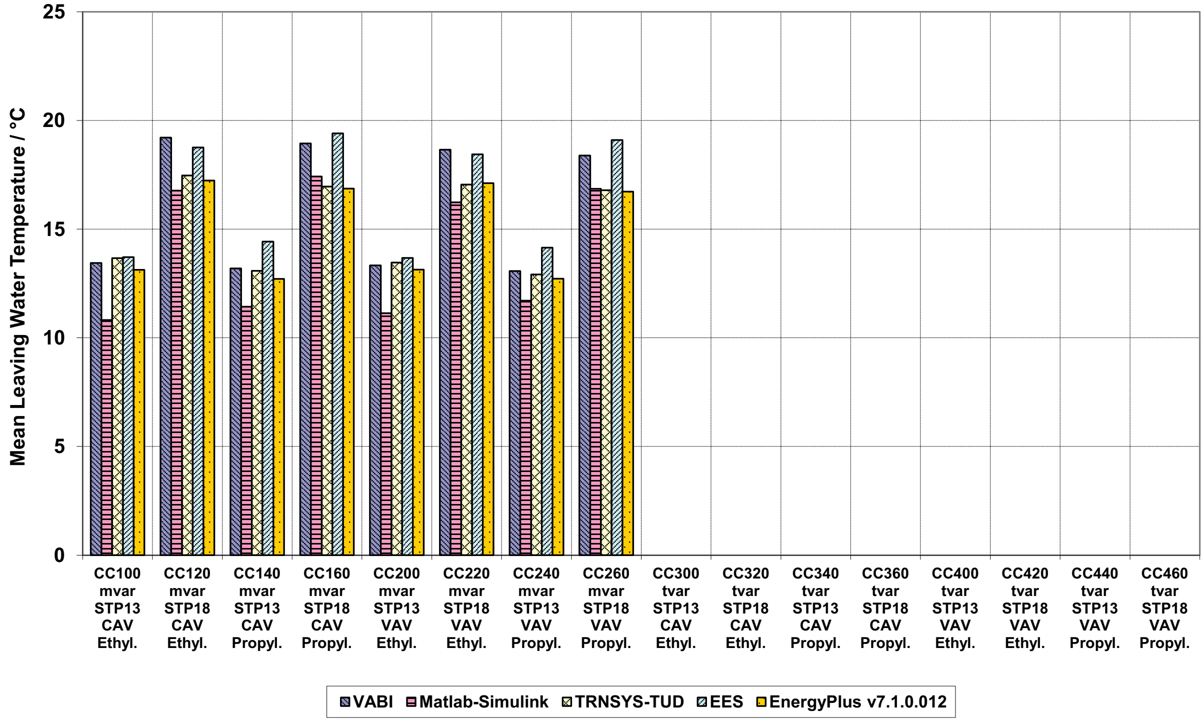

Mean Entering Water Temperature / °C
20
18
16
14
12
10
8
6
4
2
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


Minimum Entering Water Temperature / °C
20
18
16
14
12
10
8
6
4
2
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

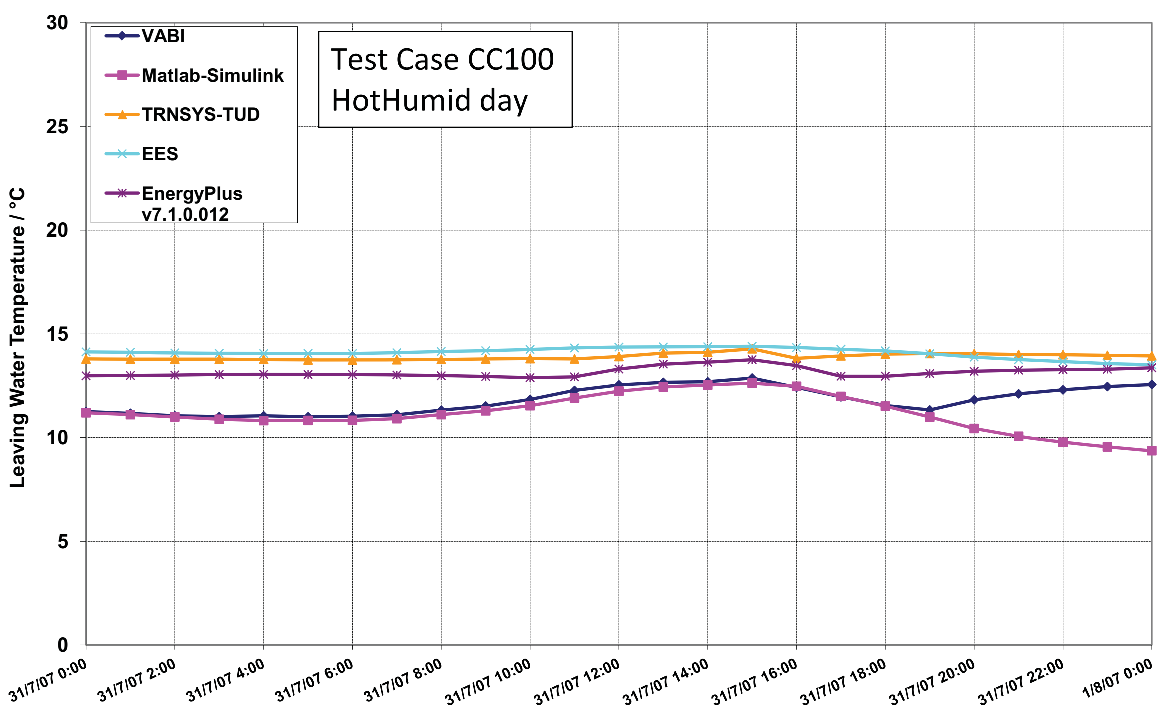

Minimum Entering Water Temperature / °C
20
18
16
14
12
10
8
6
4
2
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


Maximum Entering Water Temperature / °C
20
18
16
14
12
10
8
6
4
2
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

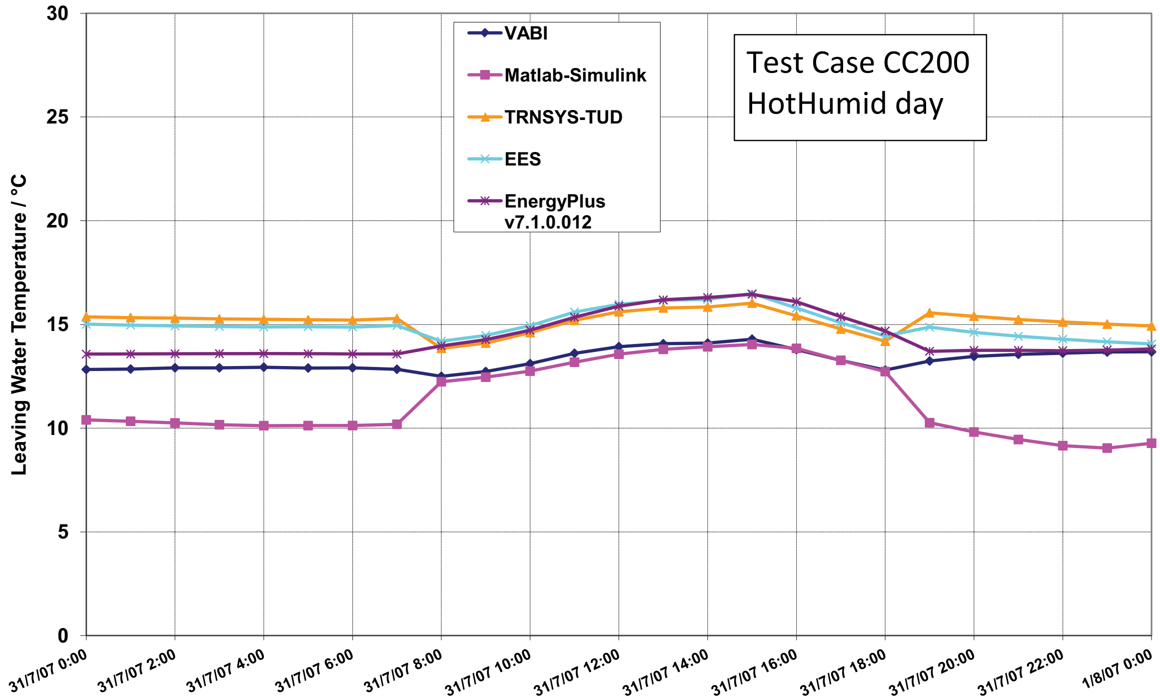

Mean Leaving Water Temperature / °C
25
20
15
10
5
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



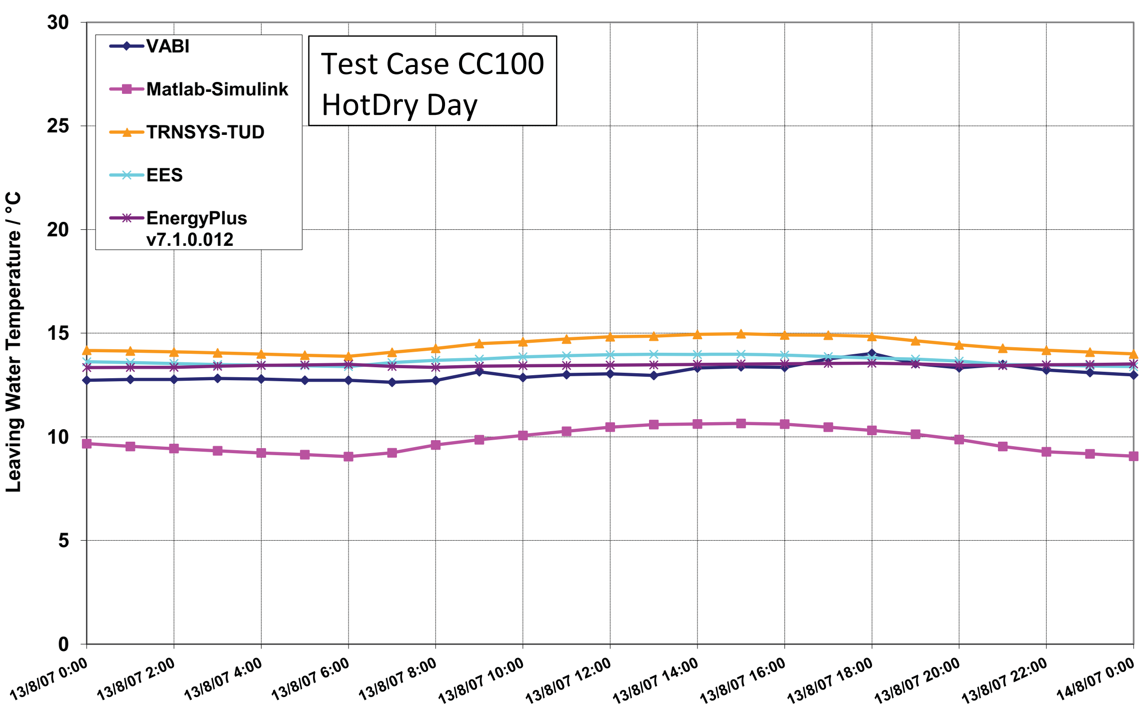
Mean Leaving Water Temperature / °C
25
20
15
10
5
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



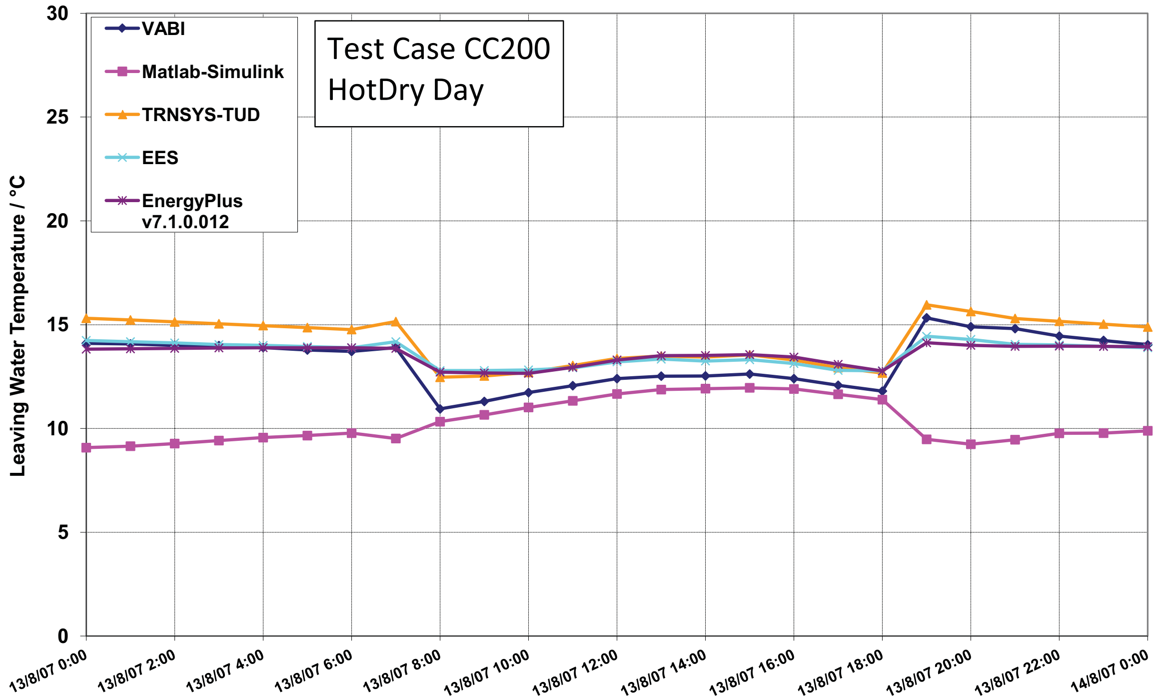
Leaving Water Temperature / °C
30
25
20
15
10
5
0
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Test Case CC100
HotHumid day
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
31/7/07 16:00
31/7/07 18:00
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00



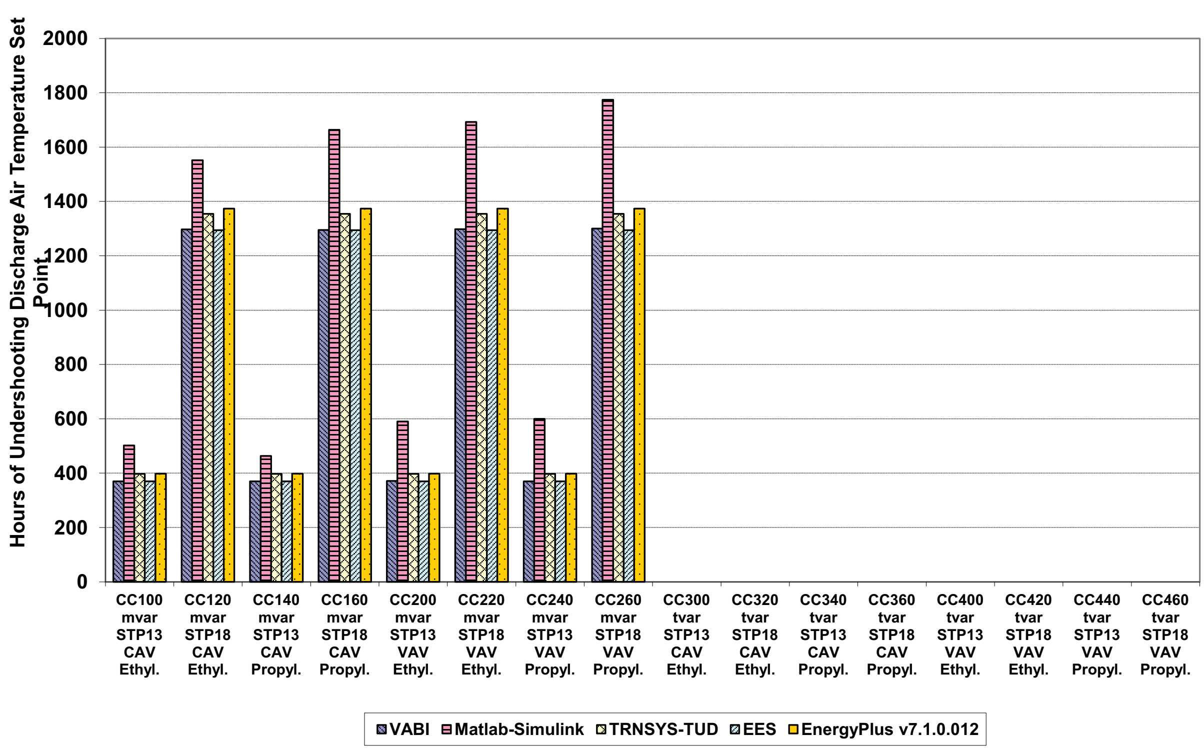
Test Case CC200
HotHumid day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Leaving Water Temperature / °C
30
25
20
15
10
5
0
31/7/07 0:00
31/7/07 2:00
31/7/07 4:00
31/7/07 6:00
31/7/07 8:00
31/7/07 10:00
31/7/07 12:00
31/7/07 14:00
31/7/07 16:00
31/7/07 18:00
31/7/07 20:00
31/7/07 22:00
1/8/07 0:00



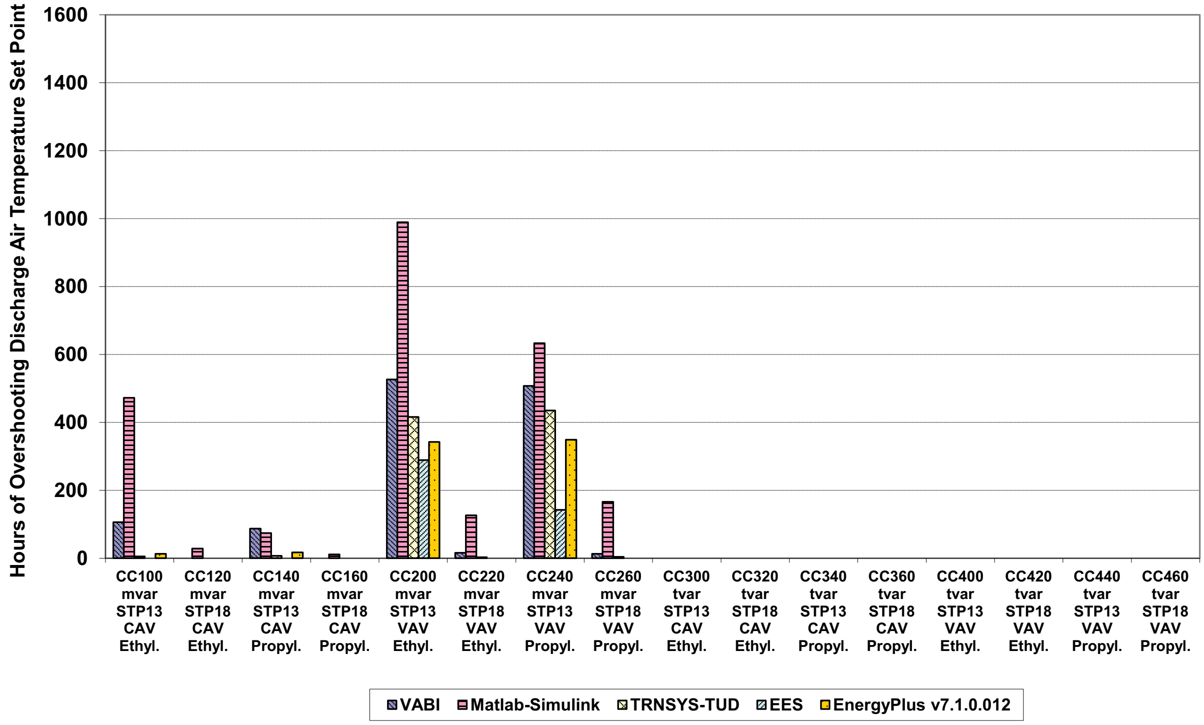
Test Case CC100
HotDry Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Leaving Water Temperature / °C
30
25
20
15
10
5
0
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
13/8/07 16:00
13/8/07 18:00
13/8/07 20:00
13/8/07 22:00
14/8/07 0:00

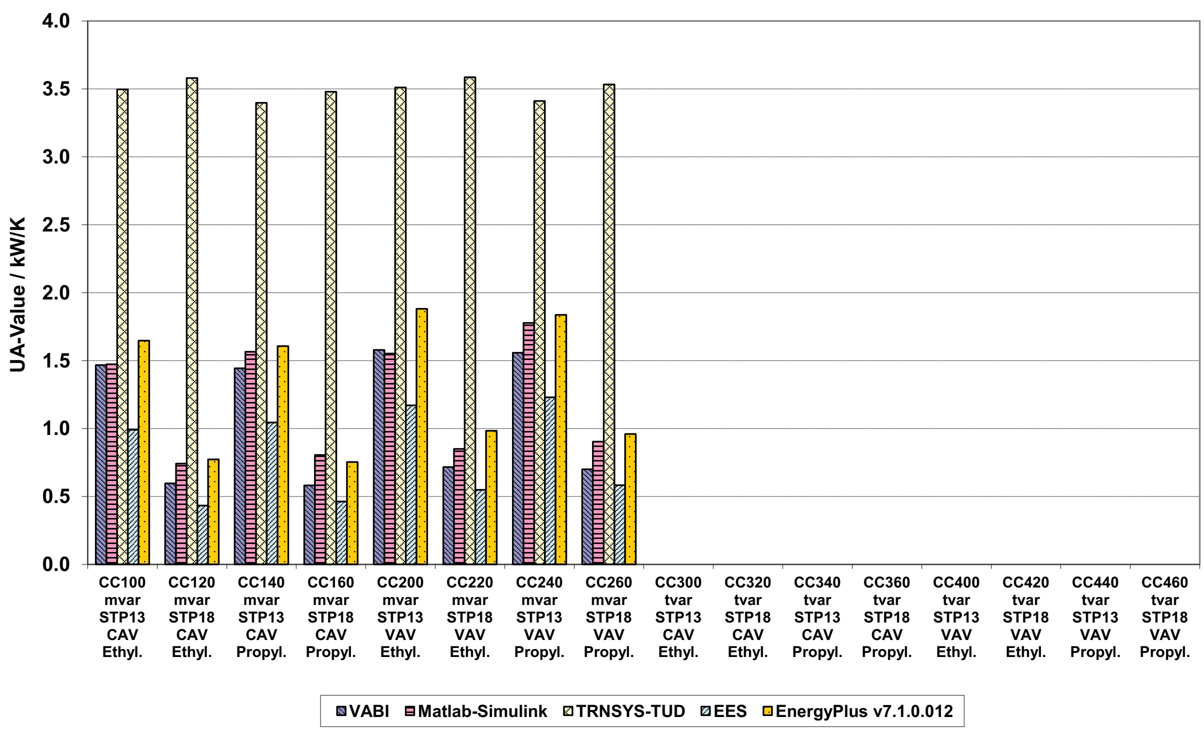


Test Case CC200
HotDry Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Leaving Water Temperature / °C
30
25
20
15
10
5
0
13/8/07 0:00
13/8/07 2:00
13/8/07 4:00
13/8/07 6:00
13/8/07 8:00
13/8/07 10:00
13/8/07 12:00
13/8/07 14:00
13/8/07 16:00
13/8/07 18:00
13/8/07 20:00
13/8/07 22:00
14/8/07 0:00



Hours of Undershooting Discharge Air Temperature Set Point
2000
1800
1600
1400
1200
1000
800
600
400
200
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

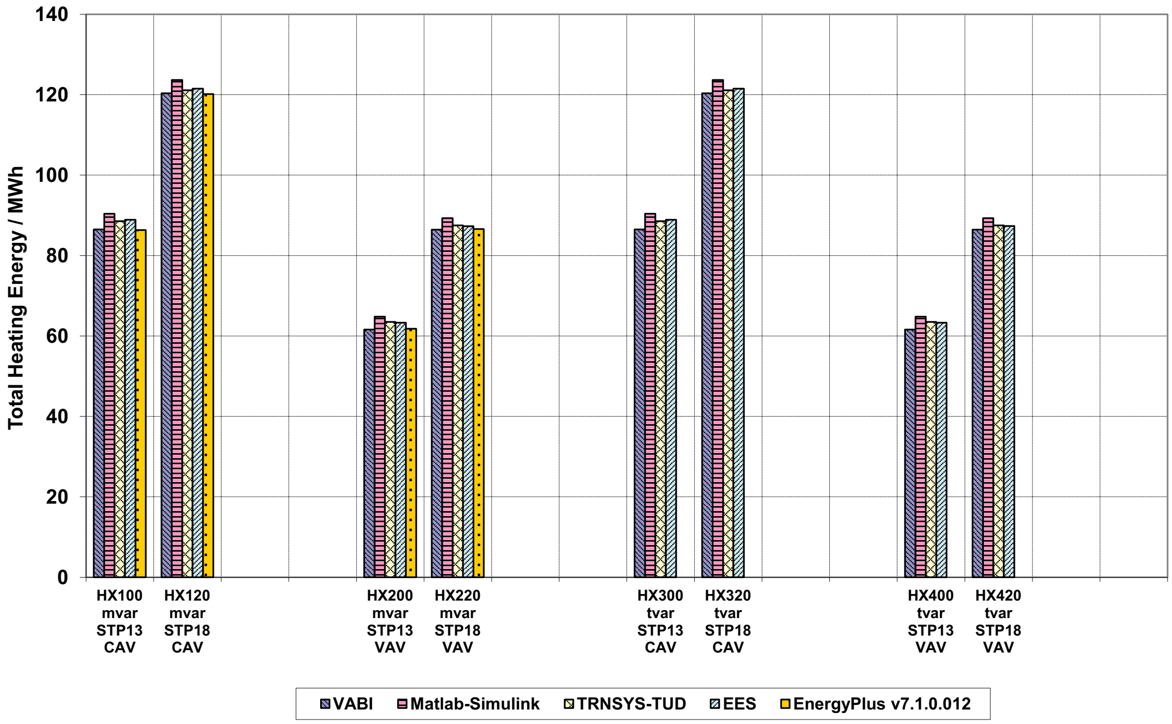

Hours of Overshooting Discharge Air Temperature Set Point
1600
1400
1200
1000
800
600
400
200
0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


UA-Value / kW/K
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
CC100 mvar STP13 CAV Ethyl.
CC120 mvar STP18 CAV Ethyl.
CC140 mvar STP13 CAV Propyl.
CC160 mvar STP18 CAV Propyl.
CC200 mvar STP13 VAV Ethyl.
CC220 mvar STP18 VAV Ethyl.
CC240 mvar STP13 VAV Propyl.
CC260 mvar STP18 VAV Propyl.
CC300 tvar STP13 CAV Ethyl.
CC320 tvar STP18 CAV Ethyl.
CC340 tvar STP13 CAV Propyl.
CC360 tvar STP18 CAV Propyl.
CC400 tvar STP13 VAV Ethyl.
CC420 tvar STP18 VAV Ethyl.
CC440 tvar STP13 VAV Propyl.
CC460 tvar STP18 VAV Propyl.
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

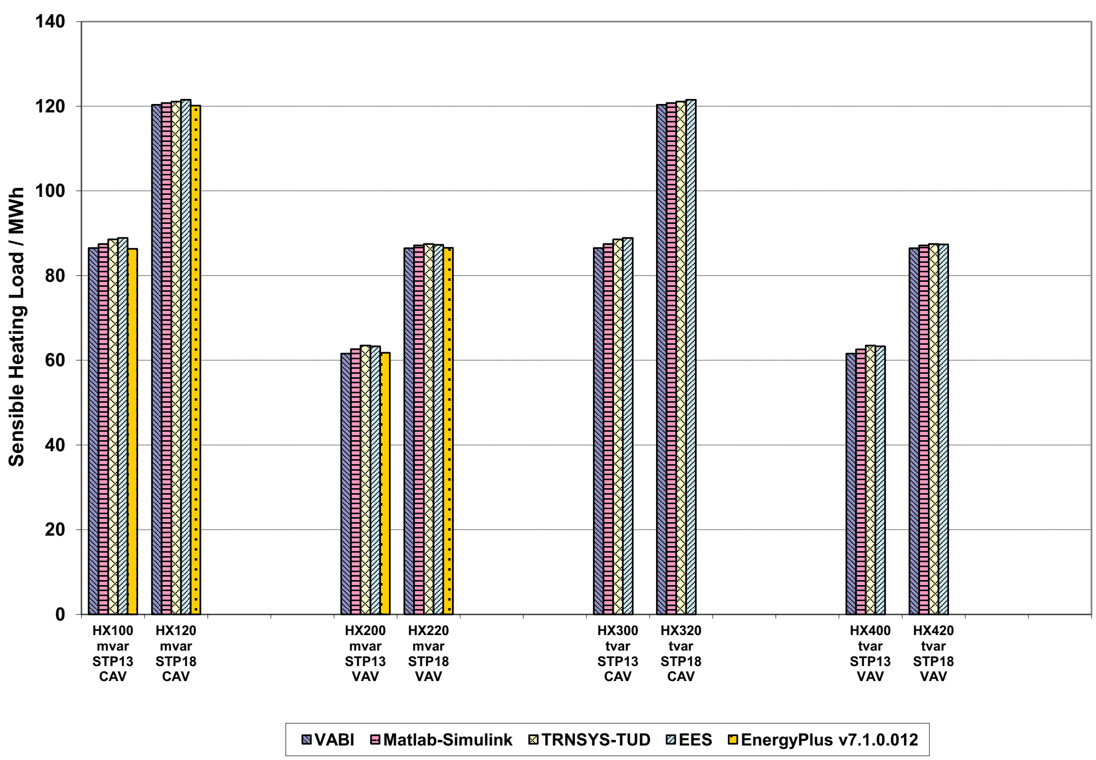
Appendix B

Charts Comparing EnergyPlus 7.1.0.012 Results with Other Whole Building Energy Simulation Programs for Hot Water Coil Tests

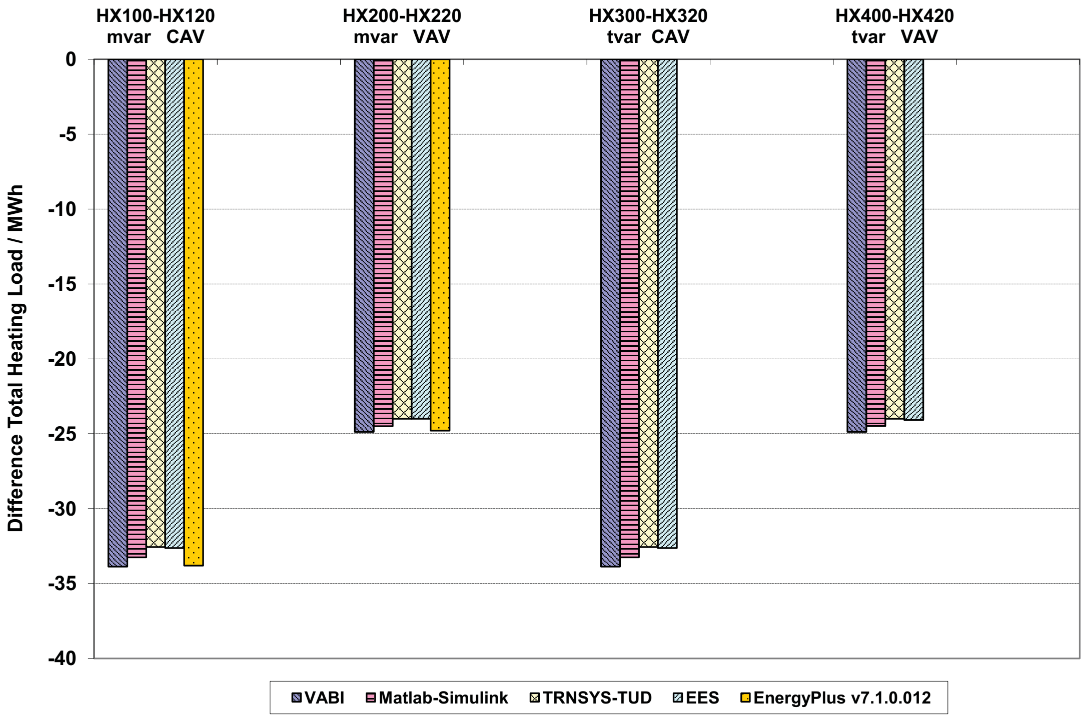
(Excerpted from files provided as part of Felsmann 2008 and updated with EnergyPlus 7.1.0.012 results)



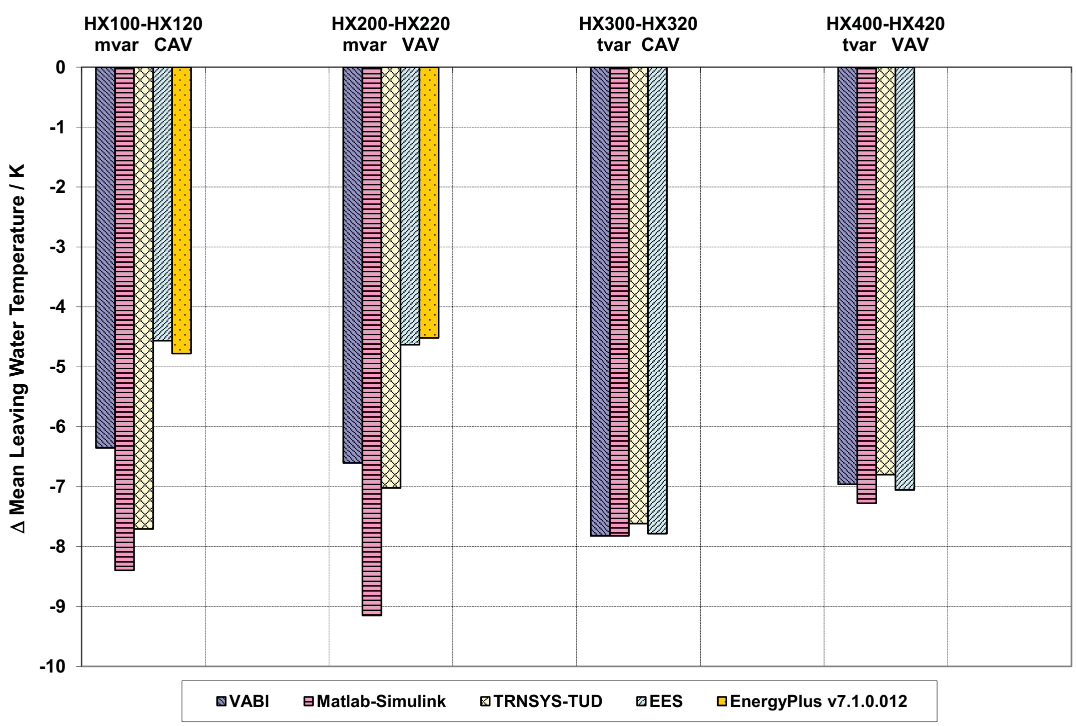
Total Heating Energy / MWh
140
120
100
80
60
40
20
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



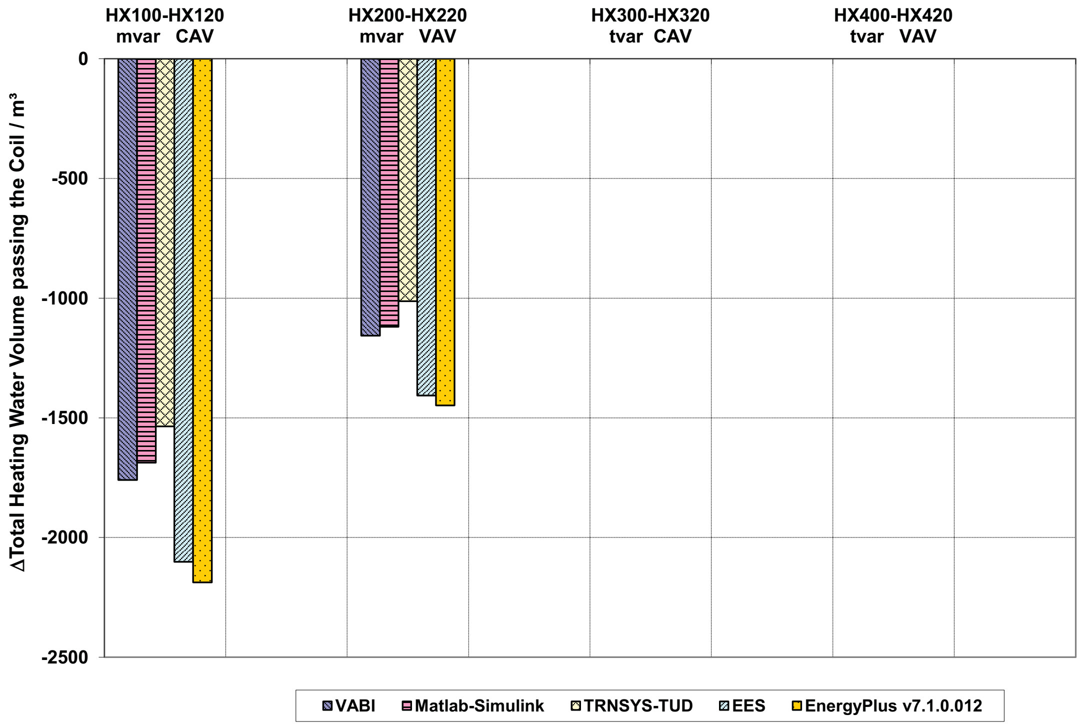
Sensible Heating Load / MWh
140
120
100
80
60
40
20
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

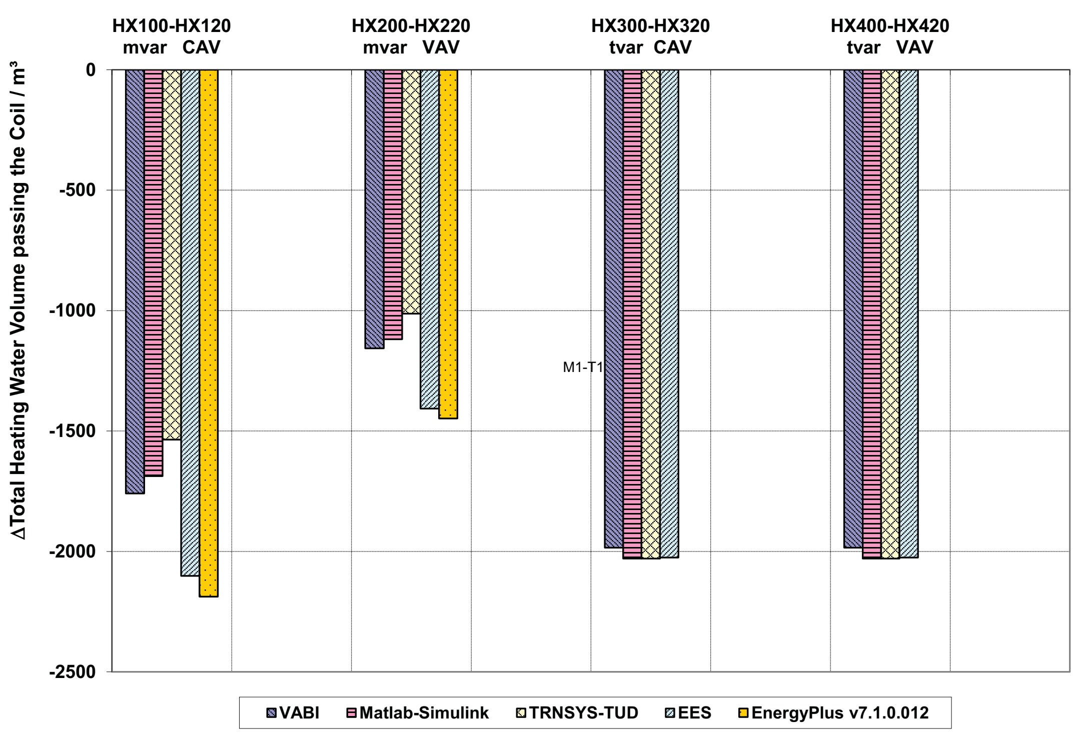


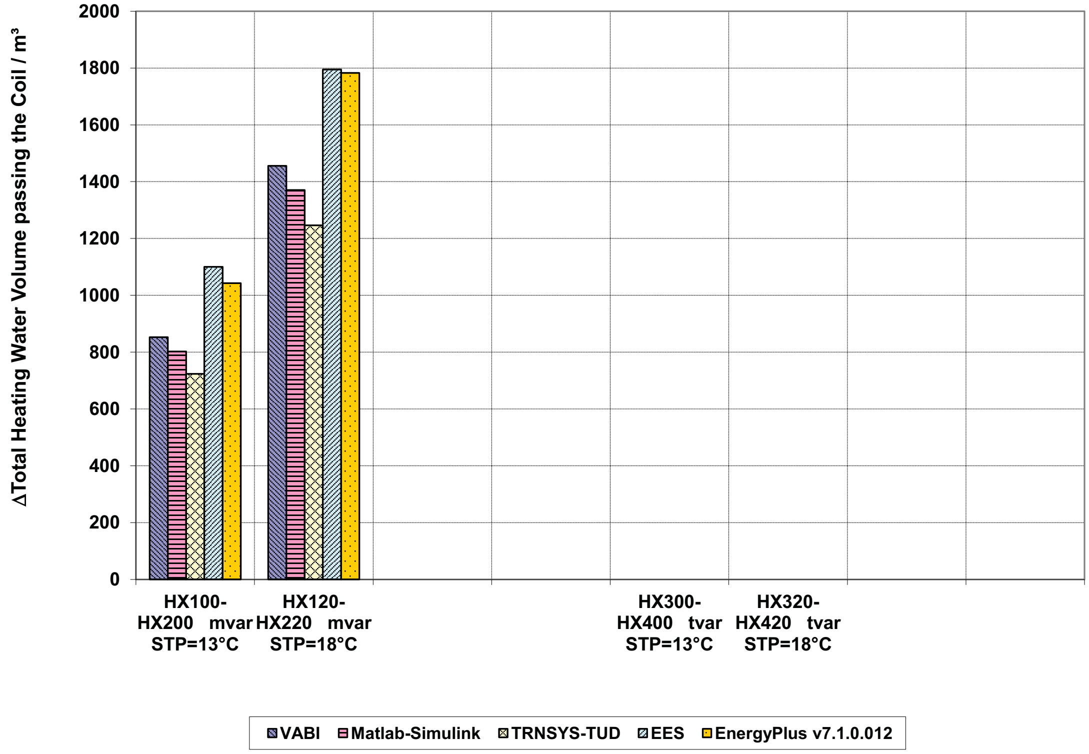
HX100-HX120
mvar CAV
HX200-HX220
mvar VAV
HX300-HX320
tvar CAV
HX400-HX420
tvar VAV
Difference Total Heating Load / MWh
0
-5
-10
-15
-20
-25
-30
-35
-40
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



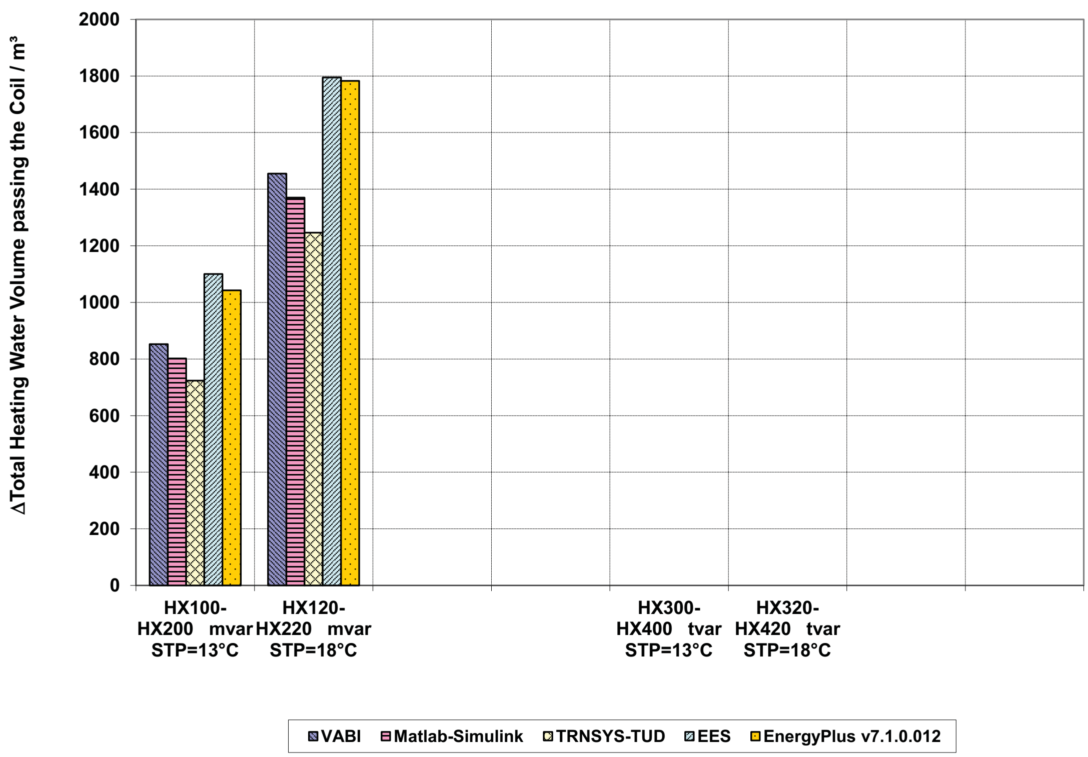
HX100-HX120
mvar CAV
HX200-HX220
mvar VAV
HX300-HX320
tvar CAV
HX400-HX420
tvar VAV
Δ Mean Leaving Water Temperature / K
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


HX100-HX120
mvar CAV
HX200-HX220
mvar VAV
HX300-HX320
tvar CAV
HX400-HX420
tvar VAV
0
-500
-1000
-1500
-2000
-2500
ΔTotal Heating Water Volume passing the Coil / m³
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

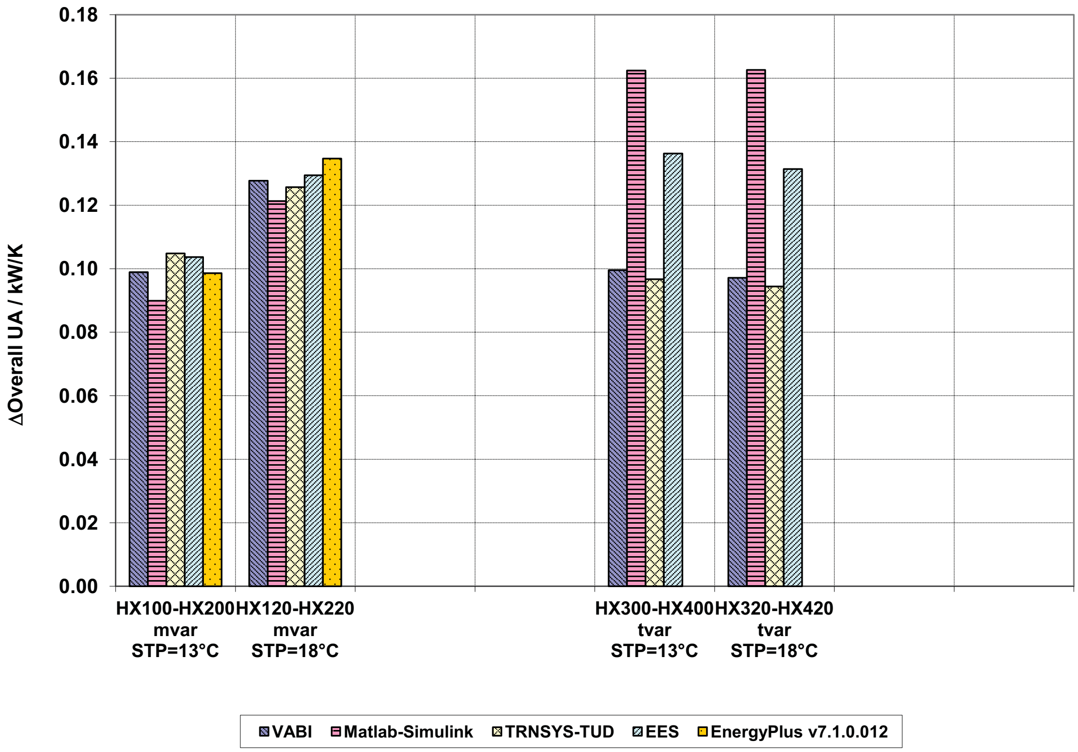

HX100-HX120
mvar CAV
HX200-HX220
mvar VAV
HX300-HX320
tvar CAV
HX400-HX420
tvar VAV
0
-500
-1000
-1500
-2000
-2500
ΔTotal Heating Water Volume passing the Coil / m³
M1-T1
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



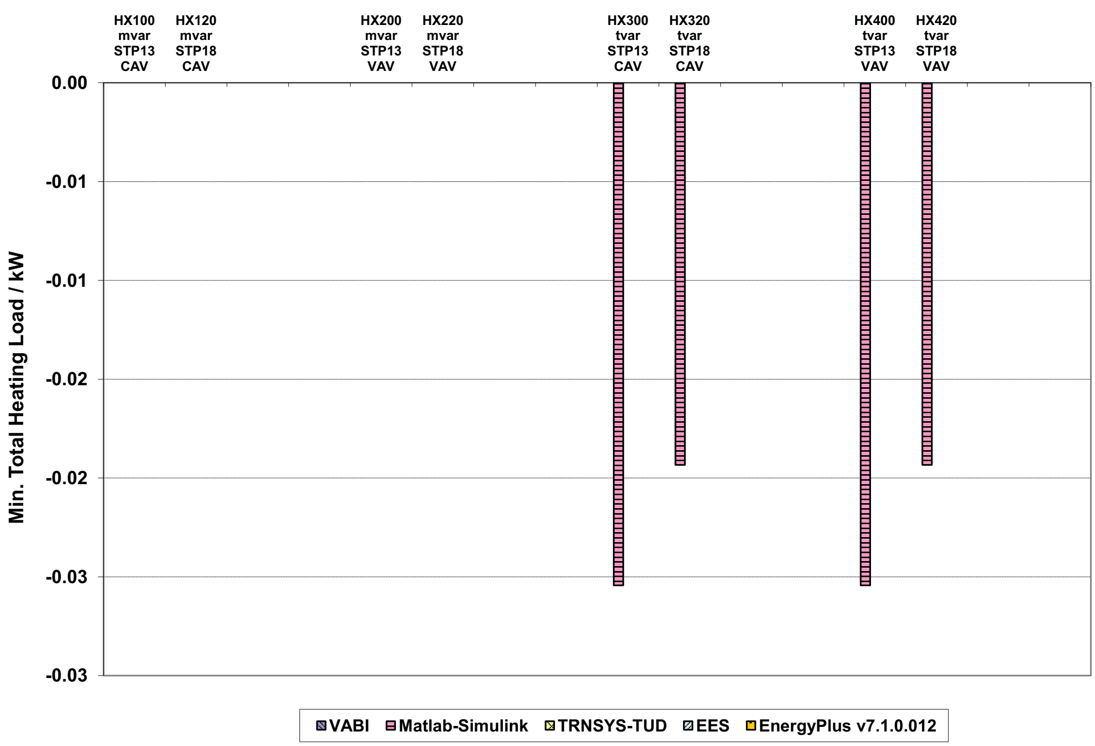
ΔTotal Heating Water Volume passing the Coil / m³
2000
1800
1600
1400
1200
1000
800
600
400
200
0
HX100-HX200 mvar STP=13°C
HX120-HX220 mvar STP=18°C
HX300-HX400 tvar STP=13°C
HX320-HX420 tvar STP=18°C
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



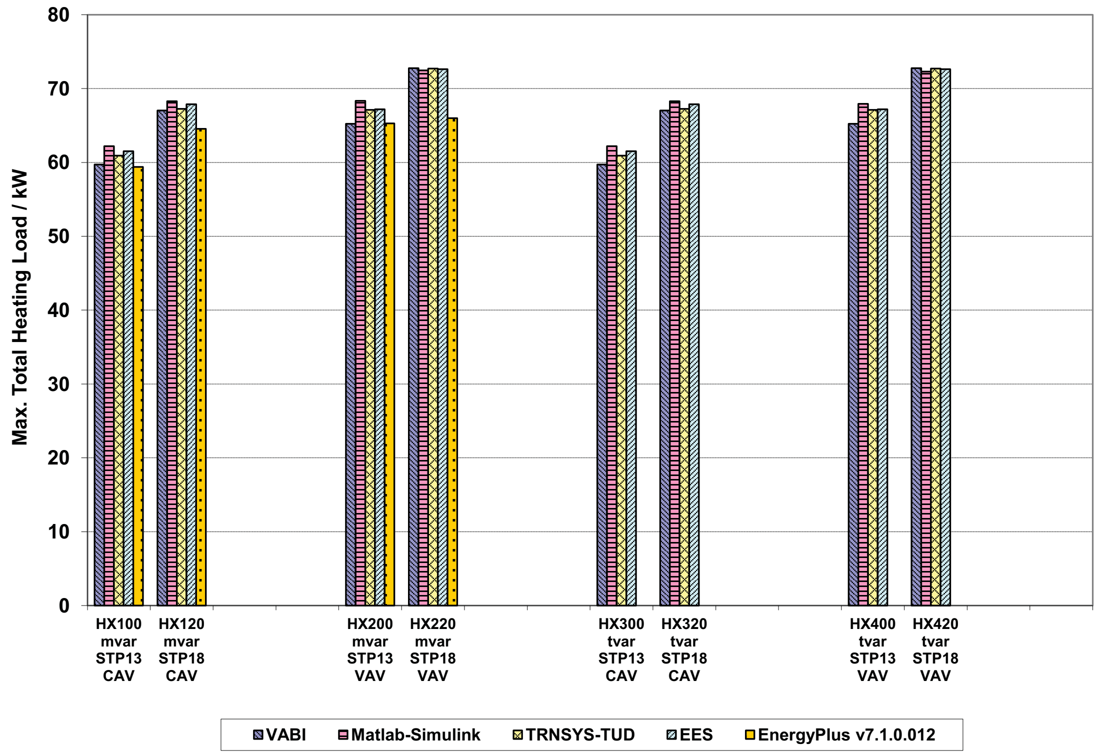
ΔTotal Heating Water Volume passing the Coil / m³
2000
1800
1600
1400
1200
1000
800
600
400
200
0
HX100-HX200 mvar STP=13°C
HX120-HX220 mvar STP=18°C
HX300-HX400 tvar STP=13°C
HX320-HX420 tvar STP=18°C
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

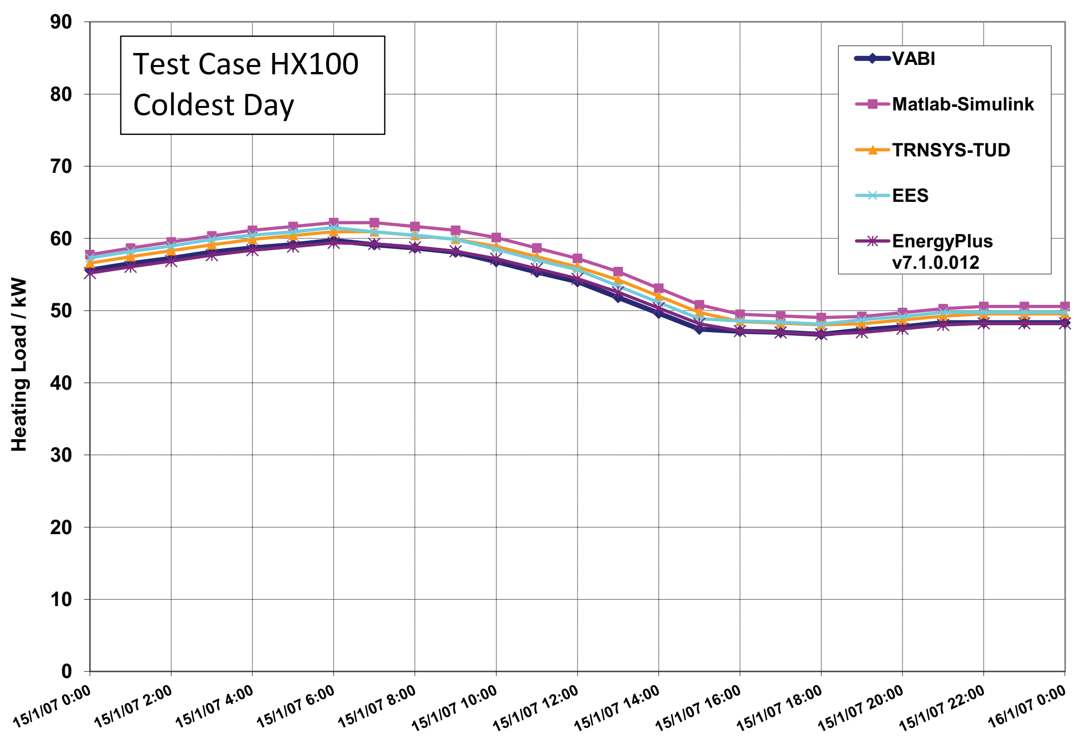


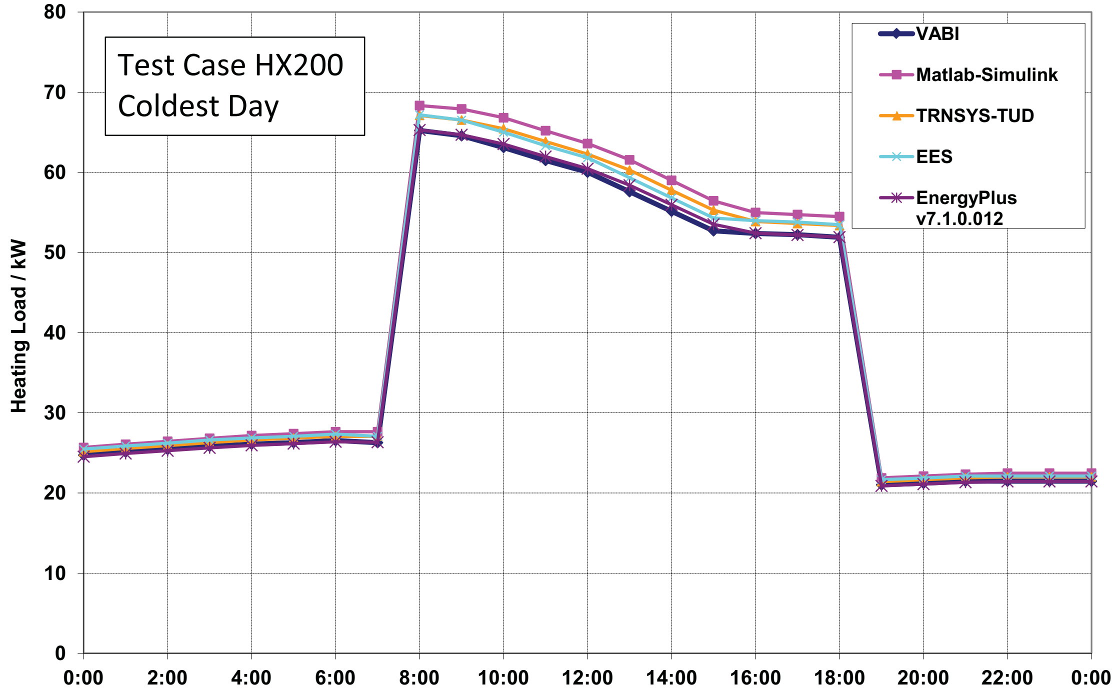
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
ΔOverall UA / kW/K
HX100-HX200 mvar STP=13°C
HX120-HX220 mvar STP=18°C
HX300-HX400 tvar STP=13°C
HX320-HX420 tvar STP=18°C
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

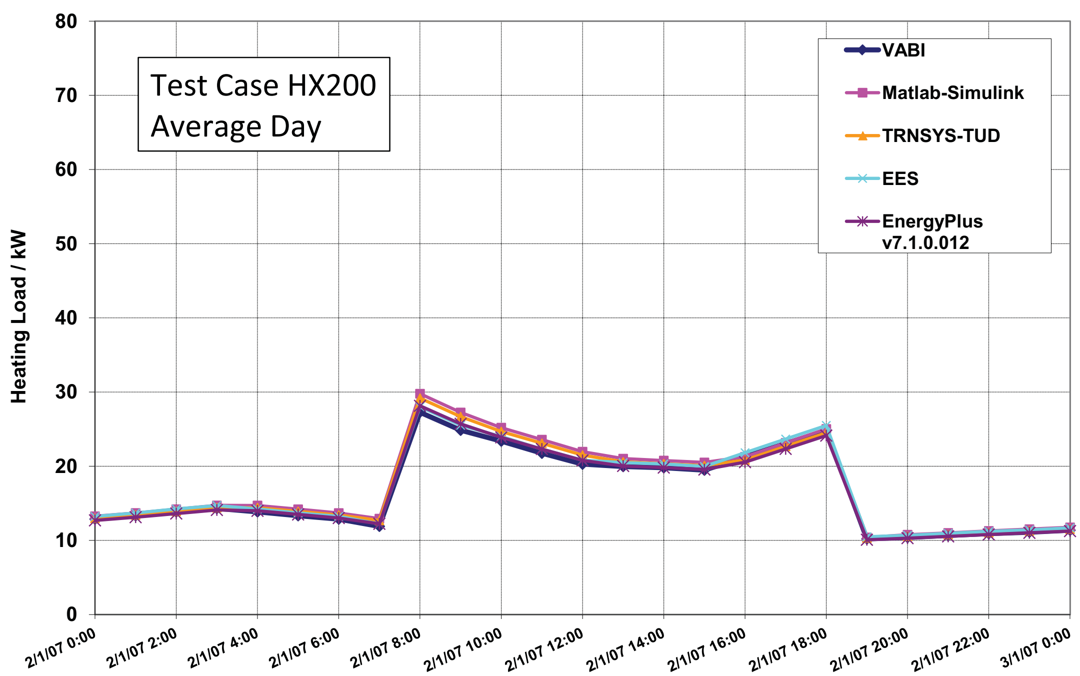


HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
0.00
-0.01
-0.01
-0.02
-0.02
-0.03
-0.03
Min. Total Heating Load / kW
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


Max. Total Heating Load / kW
0
10
20
30
40
50
60
70
80
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


Test Case HX100
Coldest Day
Heating Load / kW
0
10
20
30
40
50
60
70
80
90
15/1/07 0:00
15/1/07 2:00
15/1/07 4:00
15/1/07 6:00
15/1/07 8:00
15/1/07 10:00
15/1/07 12:00
15/1/07 14:00
15/1/07 16:00
15/1/07 18:00
15/1/07 20:00
15/1/07 22:00
16/1/07 0:00
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


Test Case HX200
Coldest Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Heating Load / kW
80
70
60
50
40
30
20
10
0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00


Test Case HX200
Average Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Heating Load / kW
80
70
60
50
40
30
20
10
0
2/1/07 0:00
2/1/07 2:00
2/1/07 4:00
2/1/07 6:00
2/1/07 8:00
2/1/07 10:00
2/1/07 12:00
2/1/07 14:00
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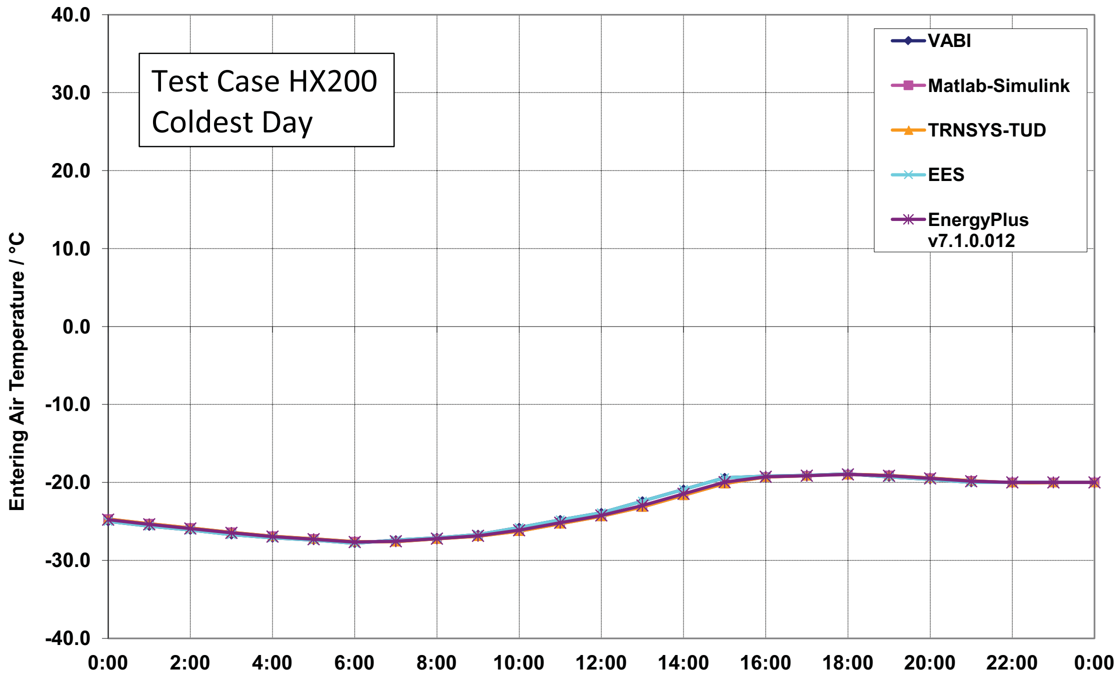
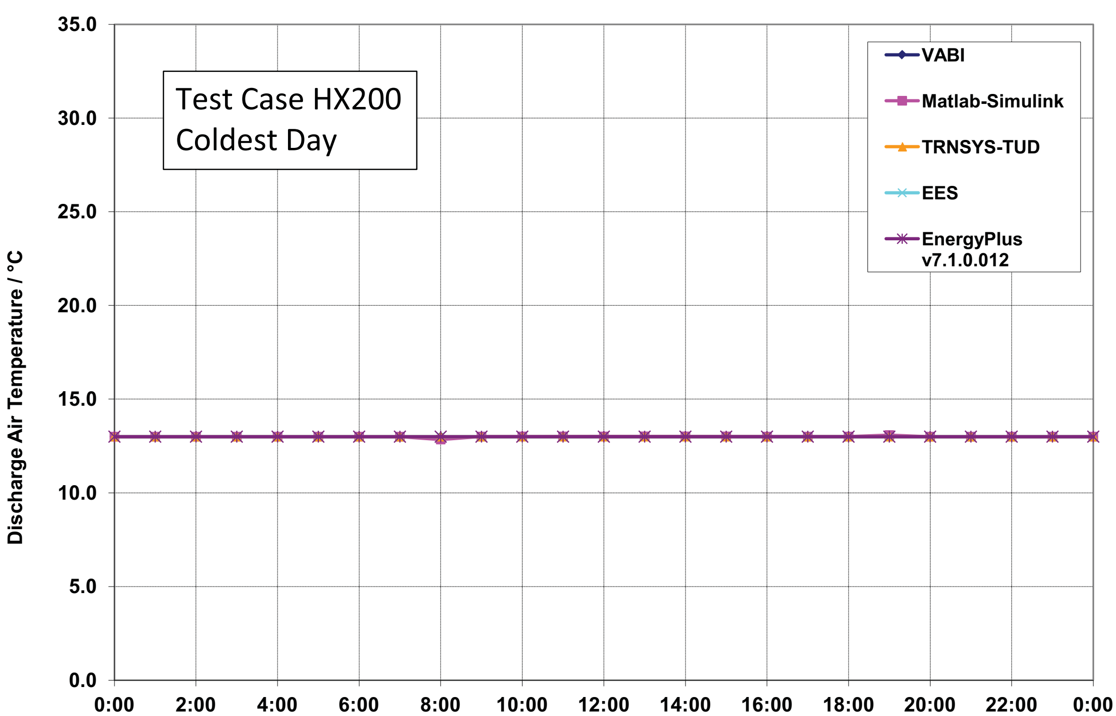
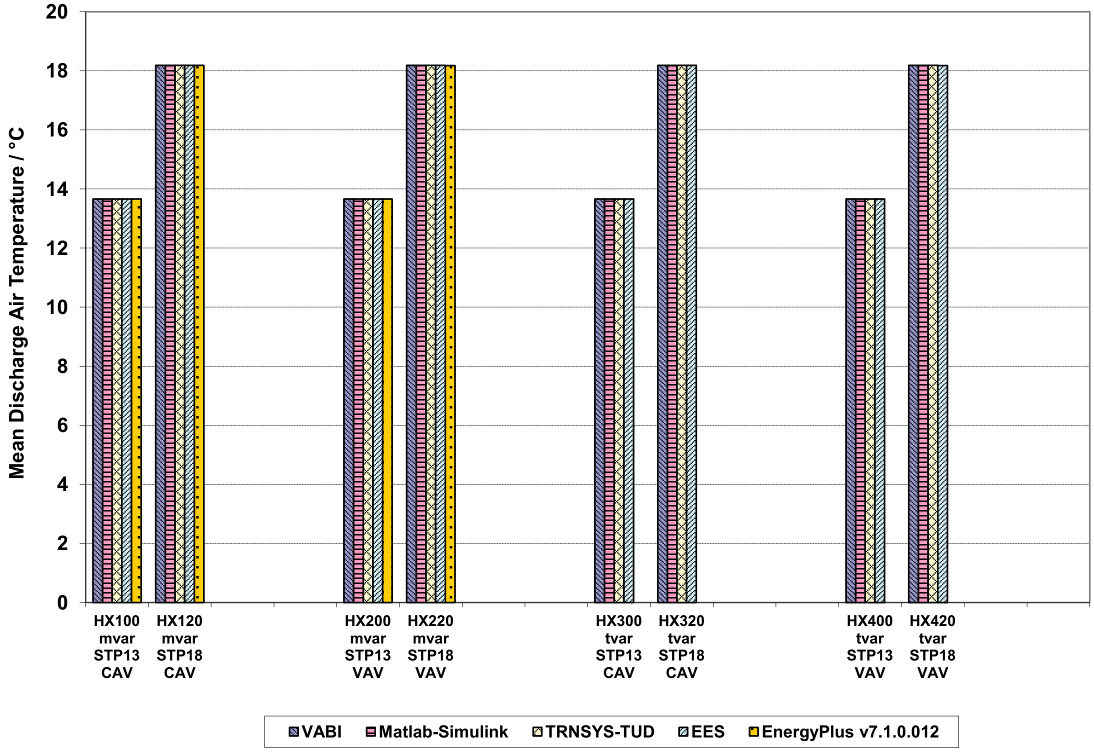
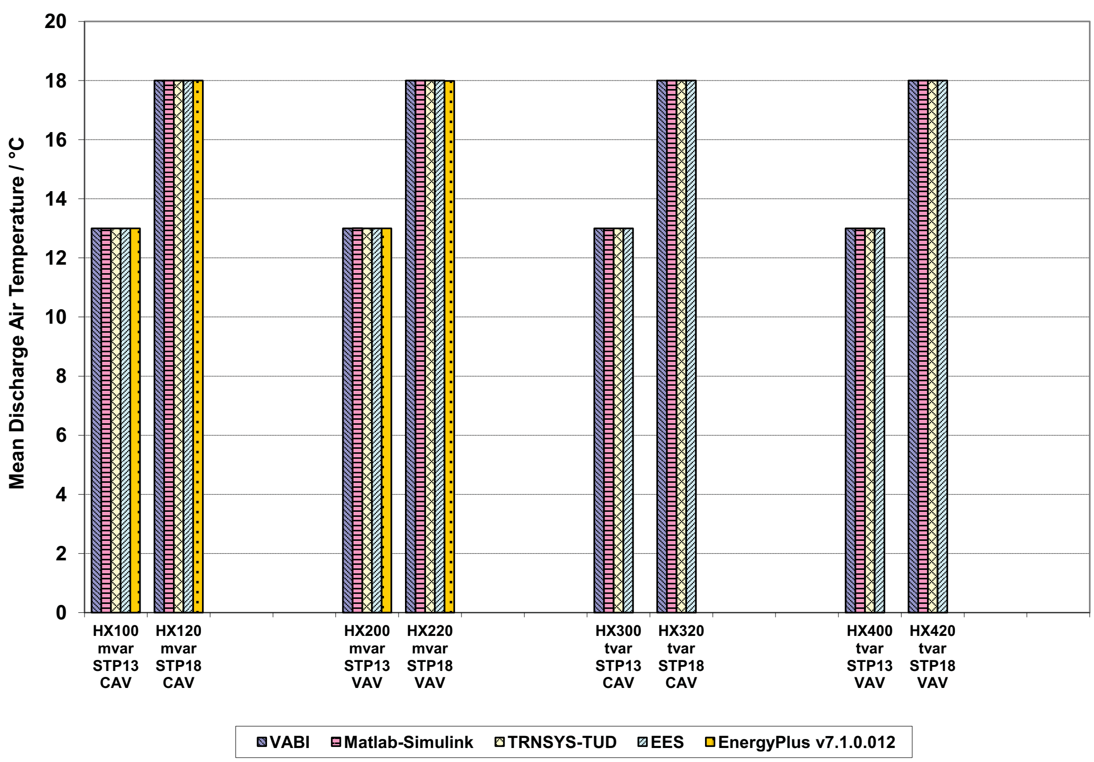
2/1/07 18:00
2/1/07 20:00
2/1/07 22:00
3/1/07 0:00


Test Case HX200
Coldest Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Entering Air Temperature / °C
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00

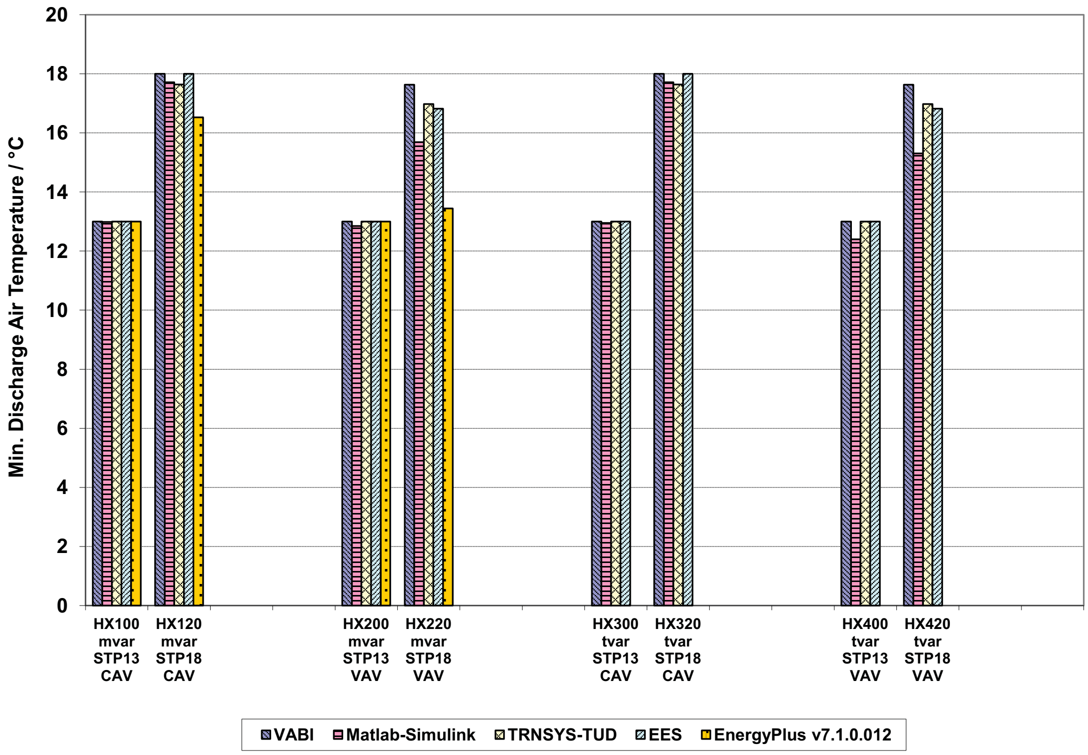

Test Case HX200
Coldest Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Discharge Air Temperature / °C
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00



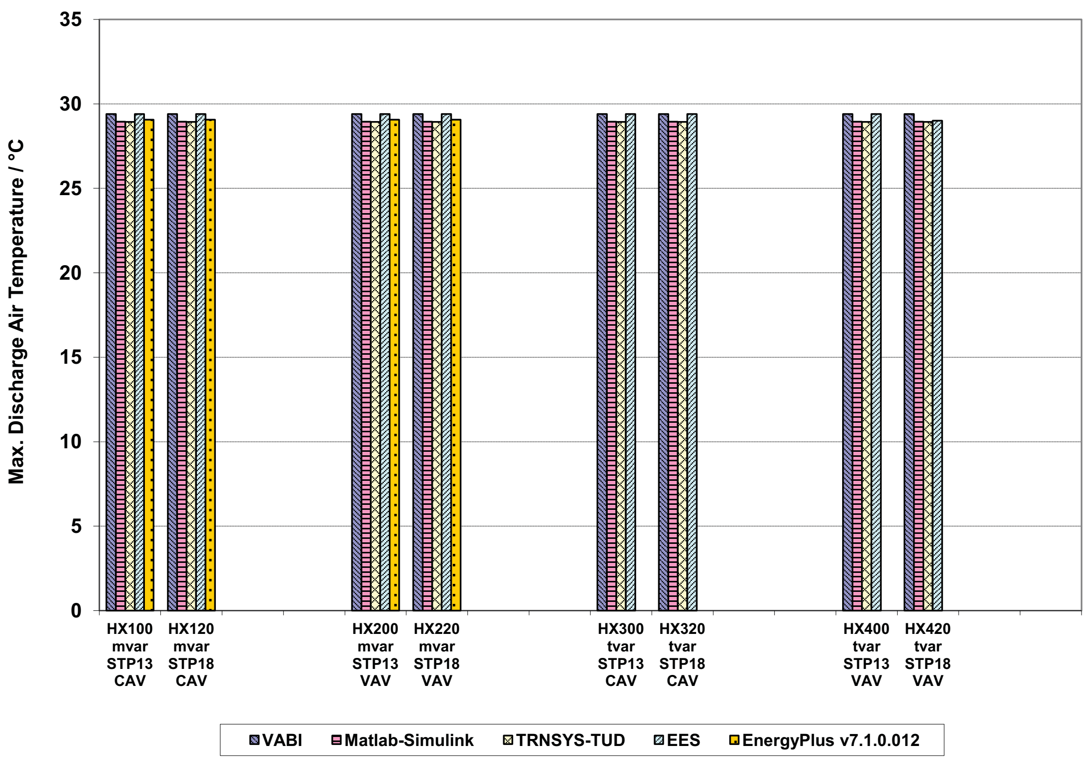
Mean Discharge Air Temperature / °C
20
18
16
14
12
10
8
6
4
2
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



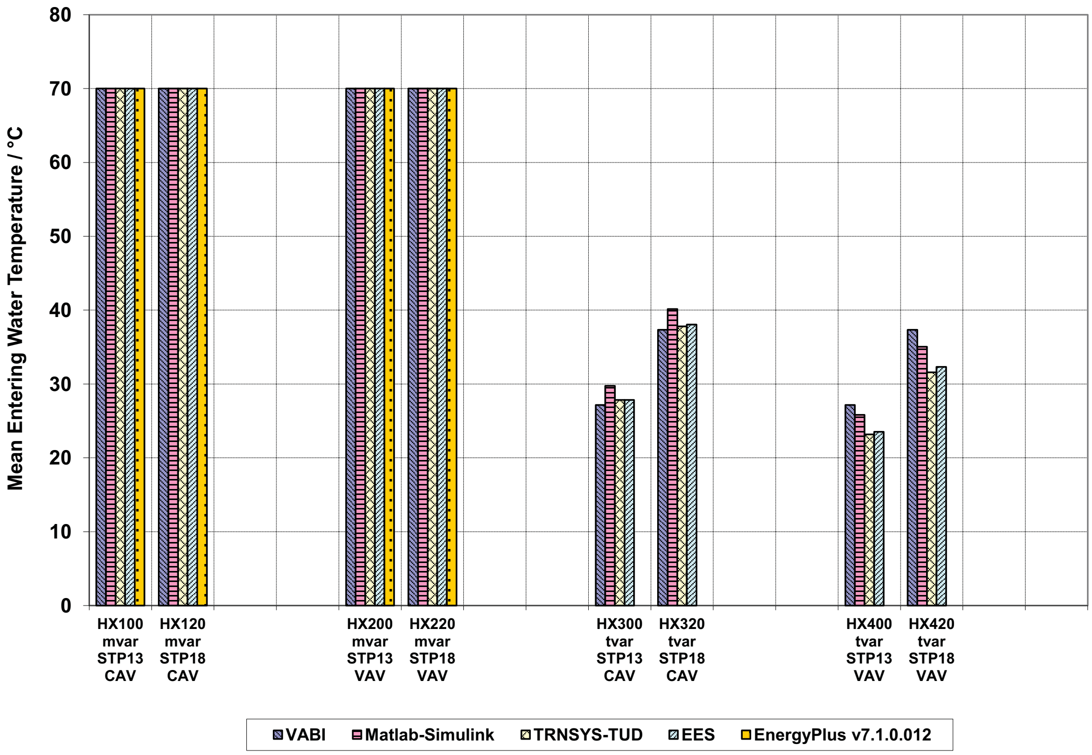
Mean Discharge Air Temperature / °C
20
18
16
14
12
10
8
6
4
2
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



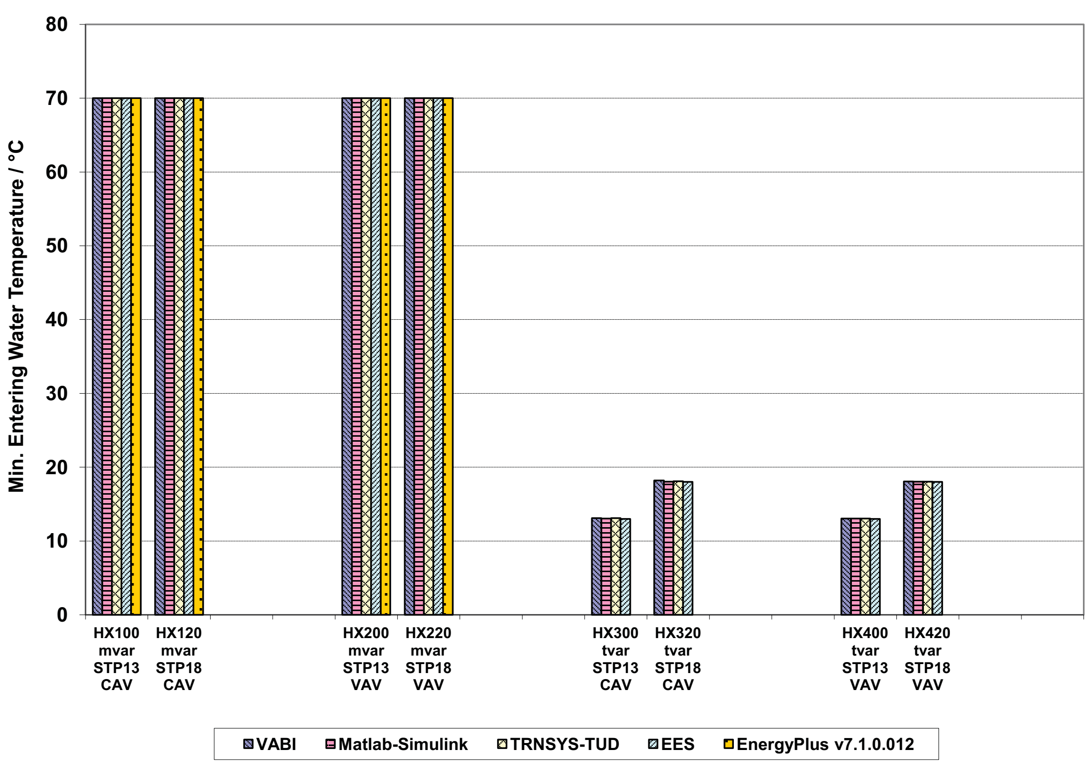
Min. Discharge Air Temperature / °C
0
2
4
6
8
10
12
14
16
18
20
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



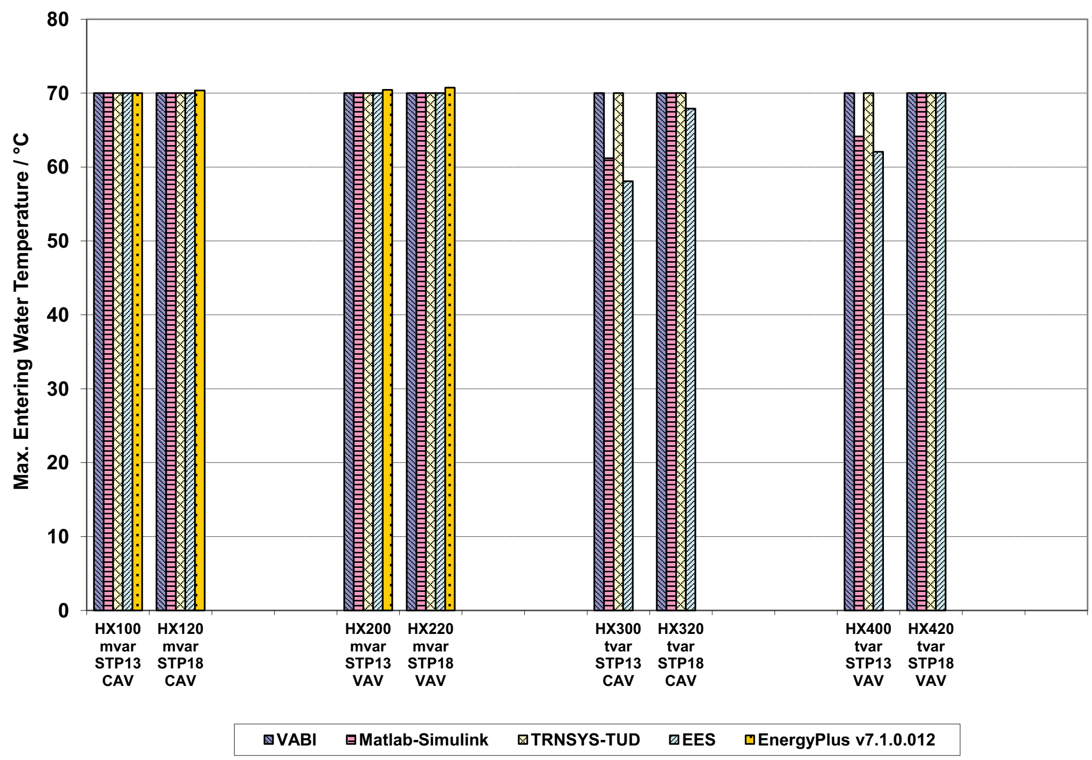
Max. Discharge Air Temperature / °C
0
5
10
15
20
25
30
35
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



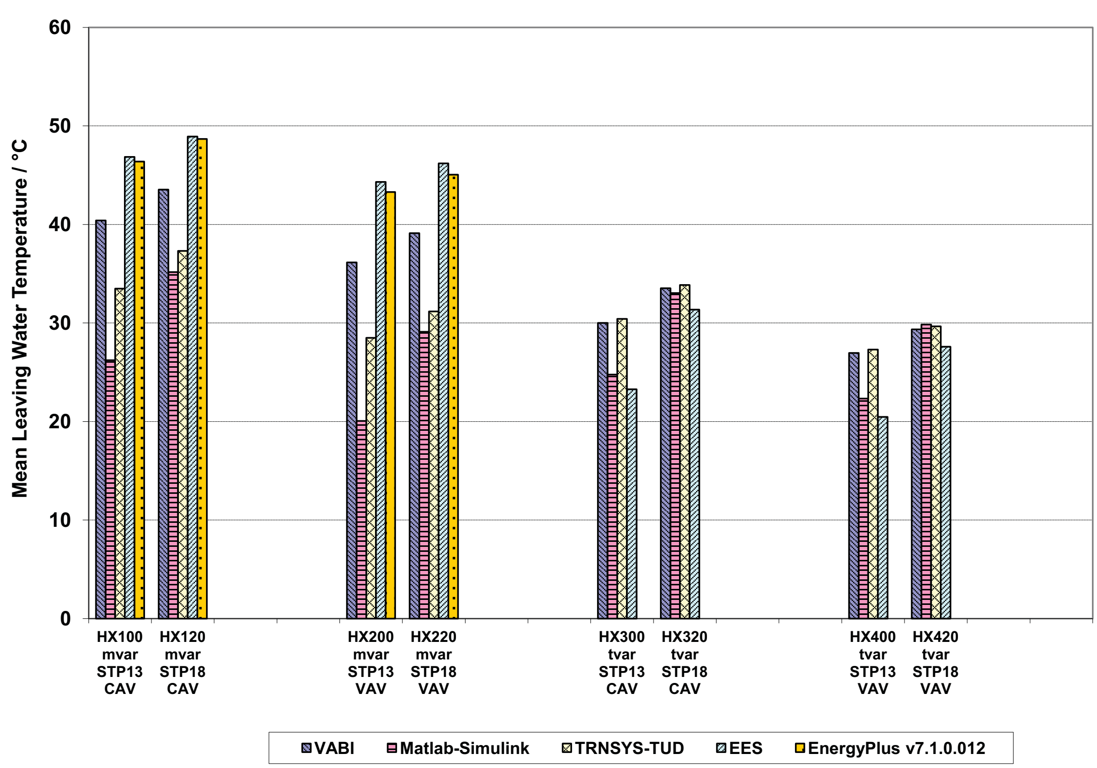
80
70
60
50
40
30
20
10
0
Mean Entering Water Temperature / °C
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



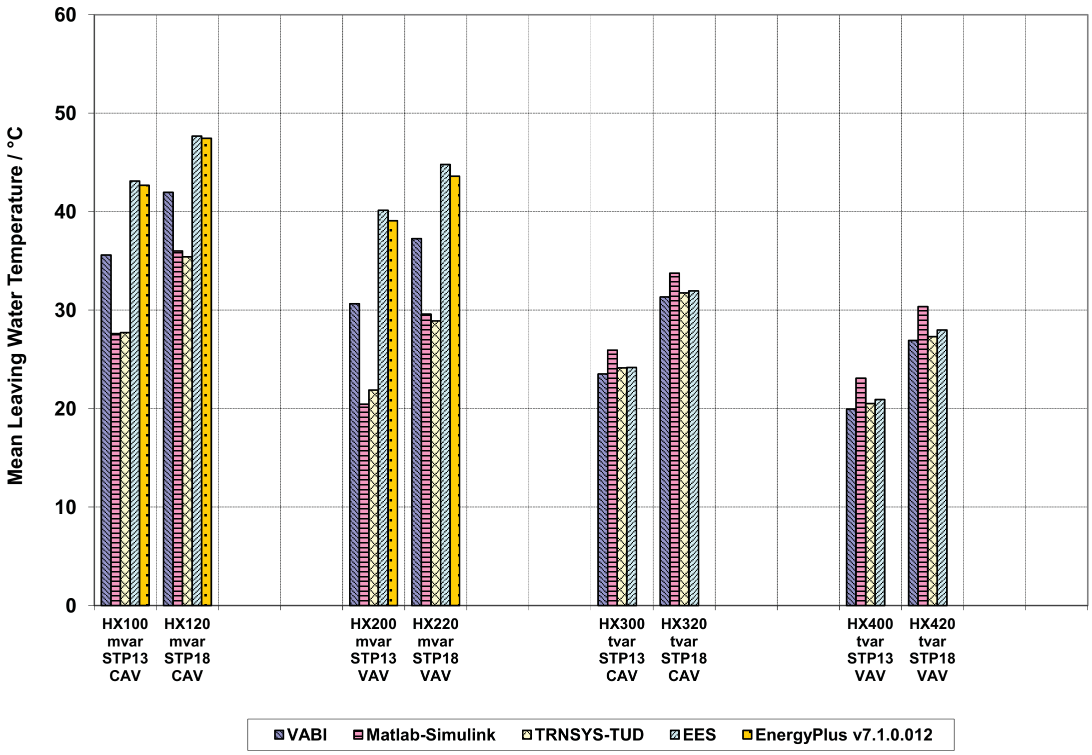
80
70
60
50
40
30
20
10
0
Min. Entering Water Temperature / °C
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



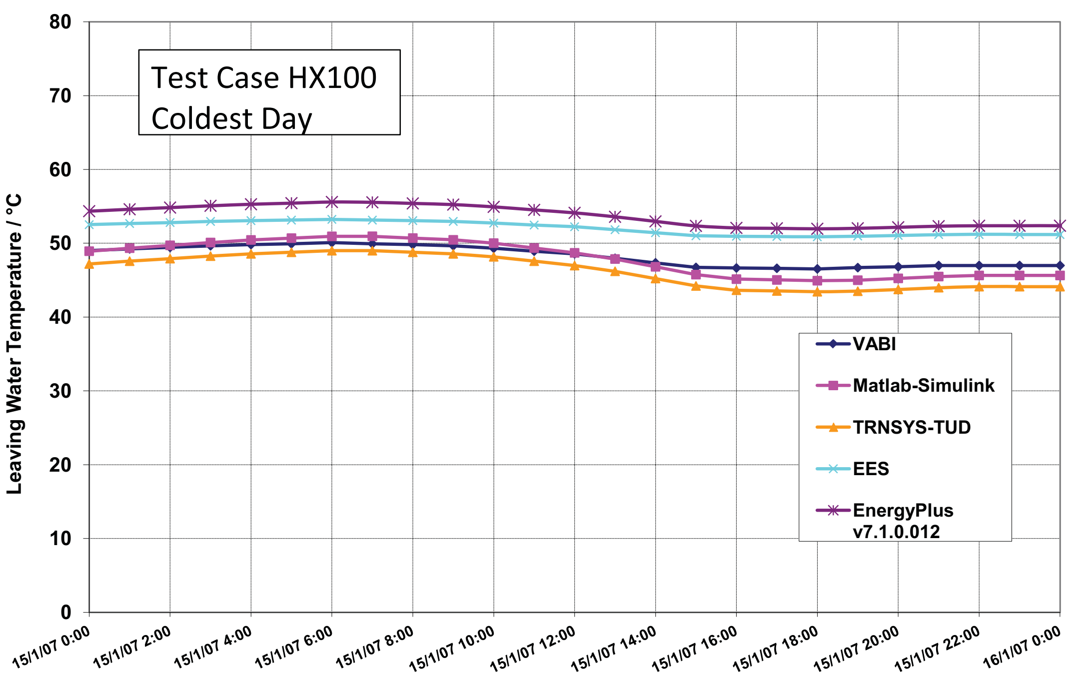
Max. Entering Water Temperature / °C
0
10
20
30
40
50
60
70
80
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



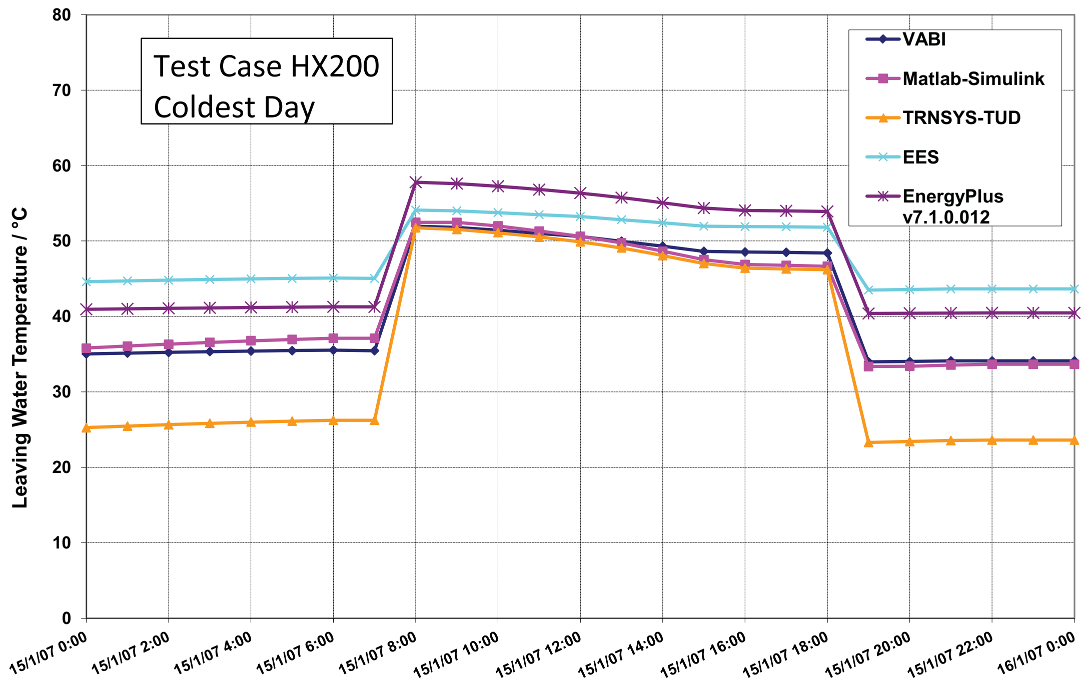
Mean Leaving Water Temperature / °C
0
10
20
30
40
50
60
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

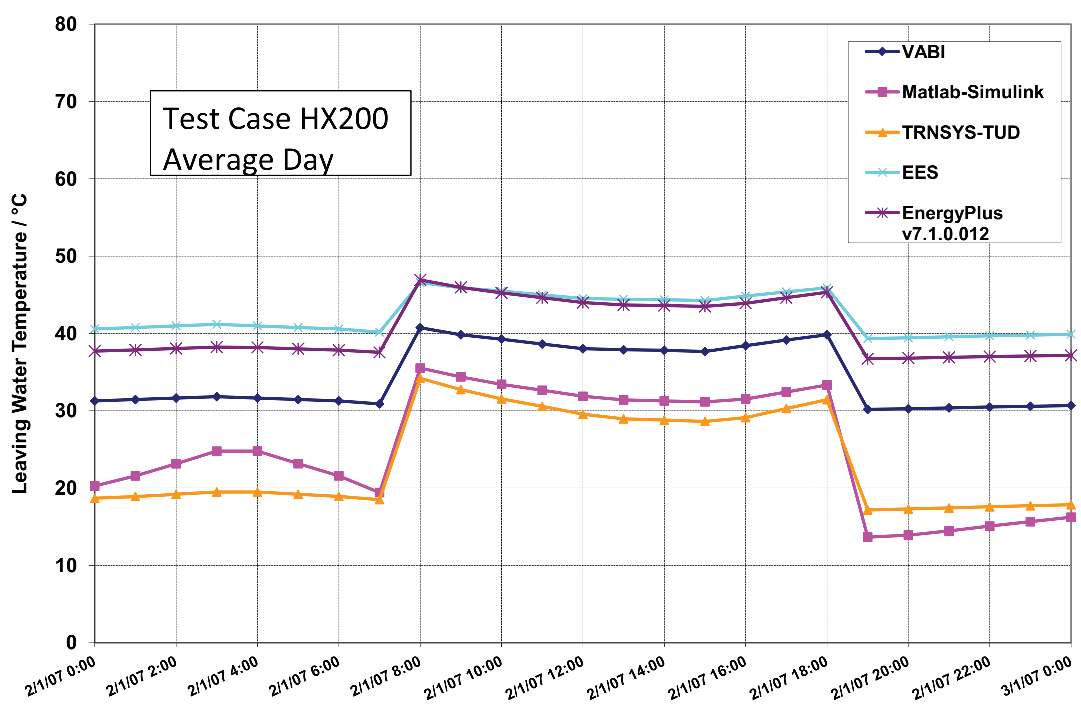


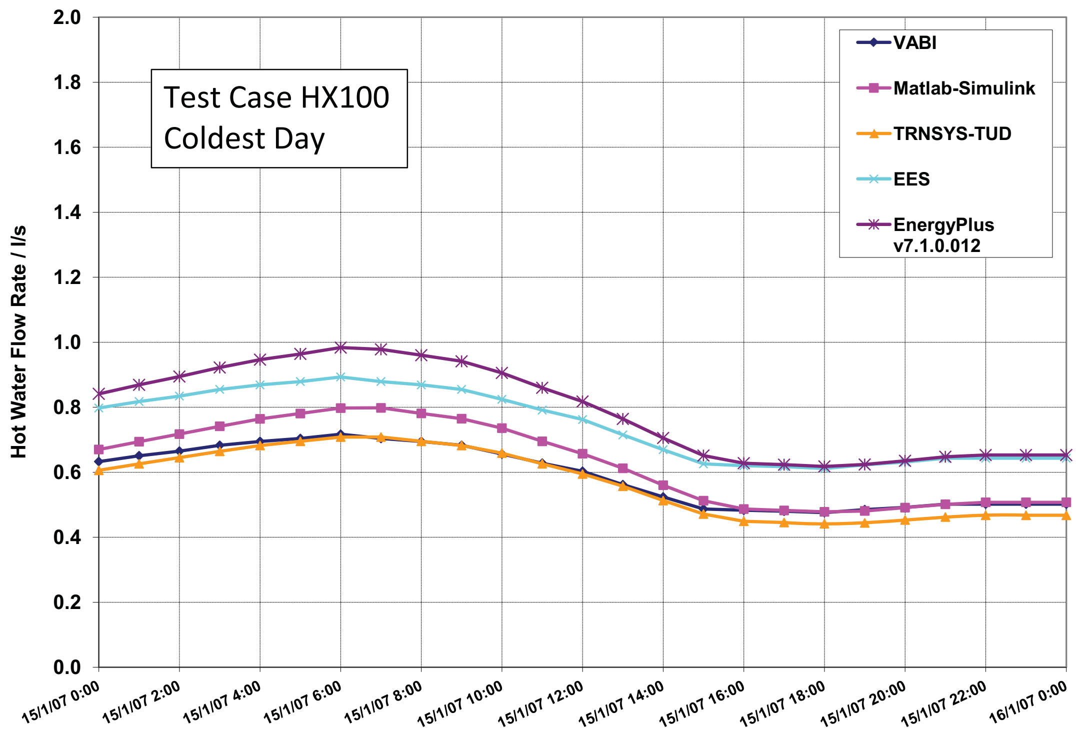
Mean Leaving Water Temperature / °C
0
10
20
30
40
50
60
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

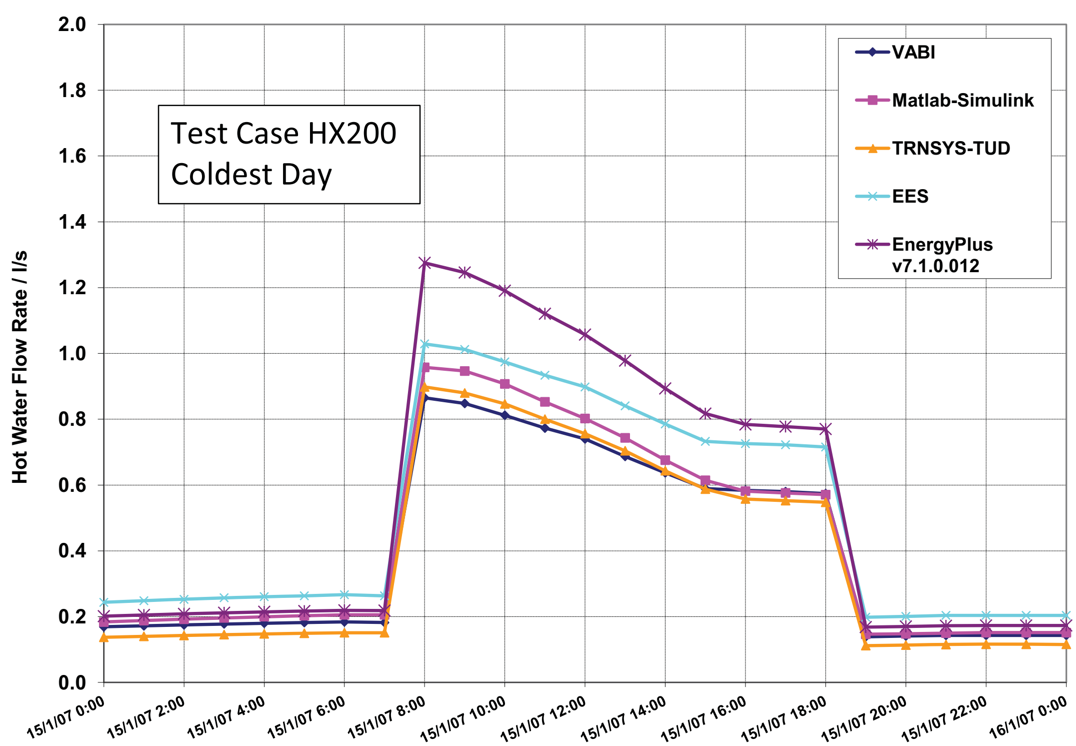


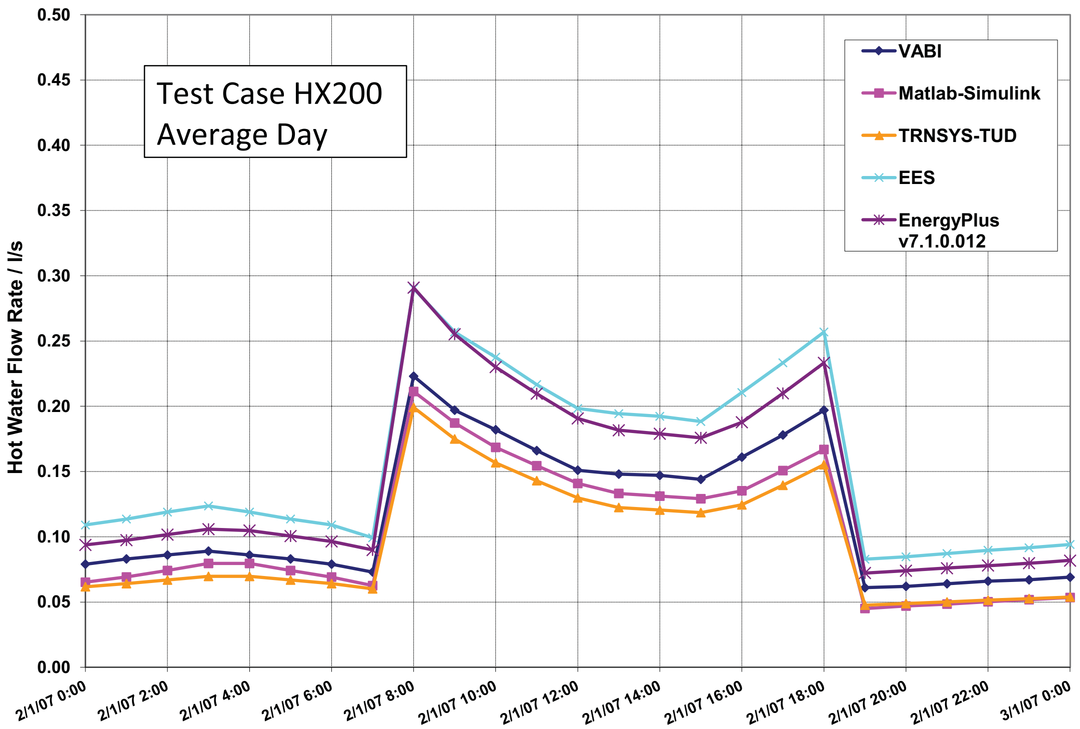
Test Case HX100
Coldest Day
Leaving Water Temperature / °C
0
10
20
30
40
50
60
70
80
15/1/07 0:00
15/1/07 2:00
15/1/07 4:00
15/1/07 6:00
15/1/07 8:00
15/1/07 10:00
15/1/07 12:00
15/1/07 14:00
15/1/07 16:00
15/1/07 18:00
15/1/07 20:00
15/1/07 22:00
16/1/07 0:00
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

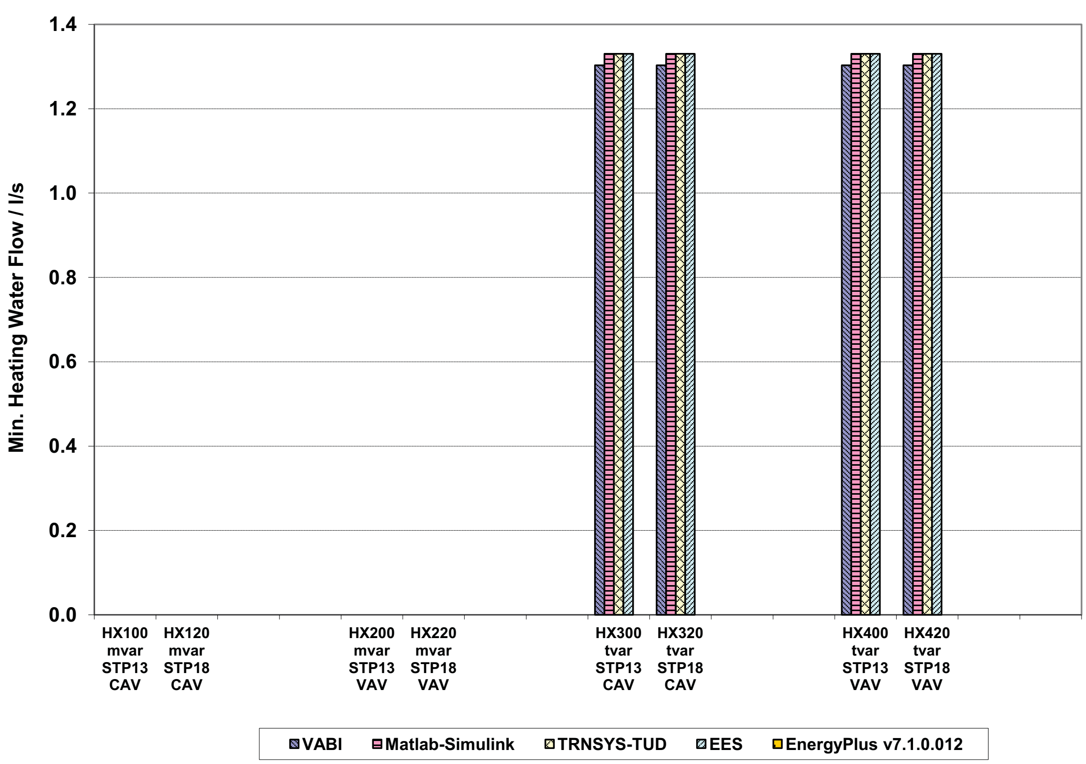

Test Case HX200
Coldest Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Leaving Water Temperature / °C
0
10
20
30
40
50
60
70
80
15/1/07 0:00
15/1/07 2:00
15/1/07 4:00
15/1/07 6:00
15/1/07 8:00
15/1/07 10:00
15/1/07 12:00
15/1/07 14:00
15/1/07 16:00
15/1/07 18:00
15/1/07 20:00
15/1/07 22:00
16/1/07 0:00

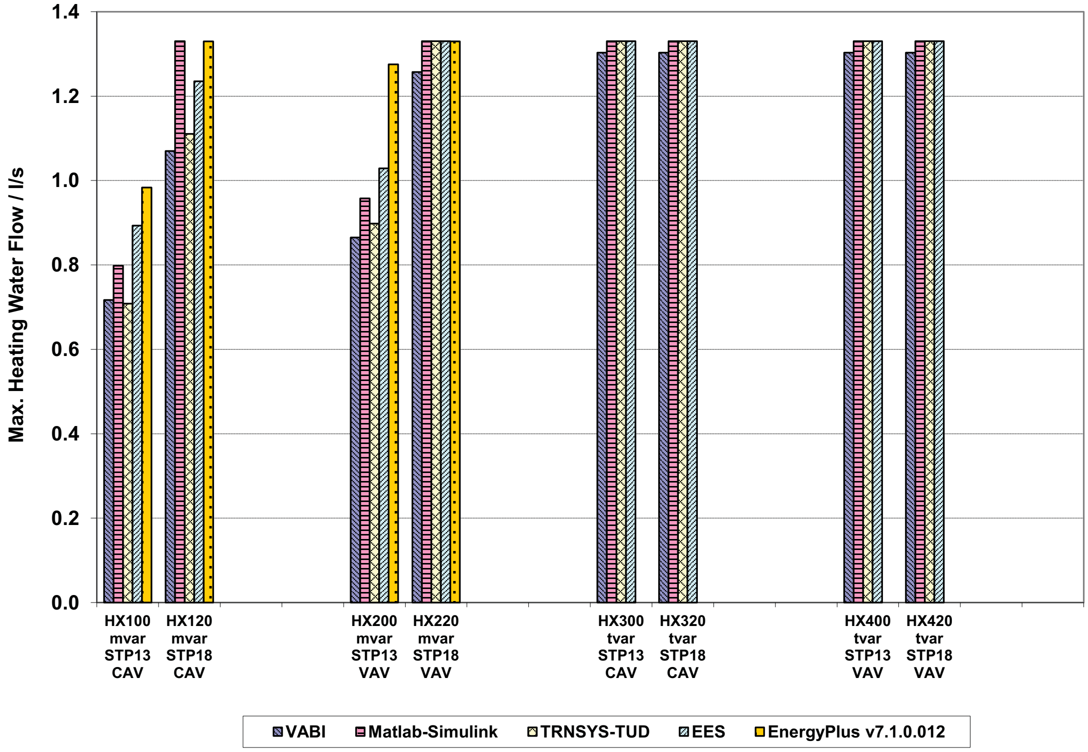

Test Case HX200
Average Day
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Leaving Water Temperature / °C
0
10
20
30
40
50
60
70
80
2/1/07 0:00
2/1/07 2:00
2/1/07 4:00
2/1/07 6:00
2/1/07 8:00
2/1/07 10:00
2/1/07 12:00
2/1/07 14:00
2/1/07 16:00
2/1/07 18:00
2/1/07 20:00
2/1/07 22:00
3/1/07 0:00


Test Case HX100
Coldest Day
Hot Water Flow Rate / l/s
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
15/1/07 0:00
15/1/07 2:00
15/1/07 4:00
15/1/07 6:00
15/1/07 8:00
15/1/07 10:00
15/1/07 12:00
15/1/07 14:00
15/1/07 16:00
15/1/07 18:00
15/1/07 20:00
15/1/07 22:00
16/1/07 0:00

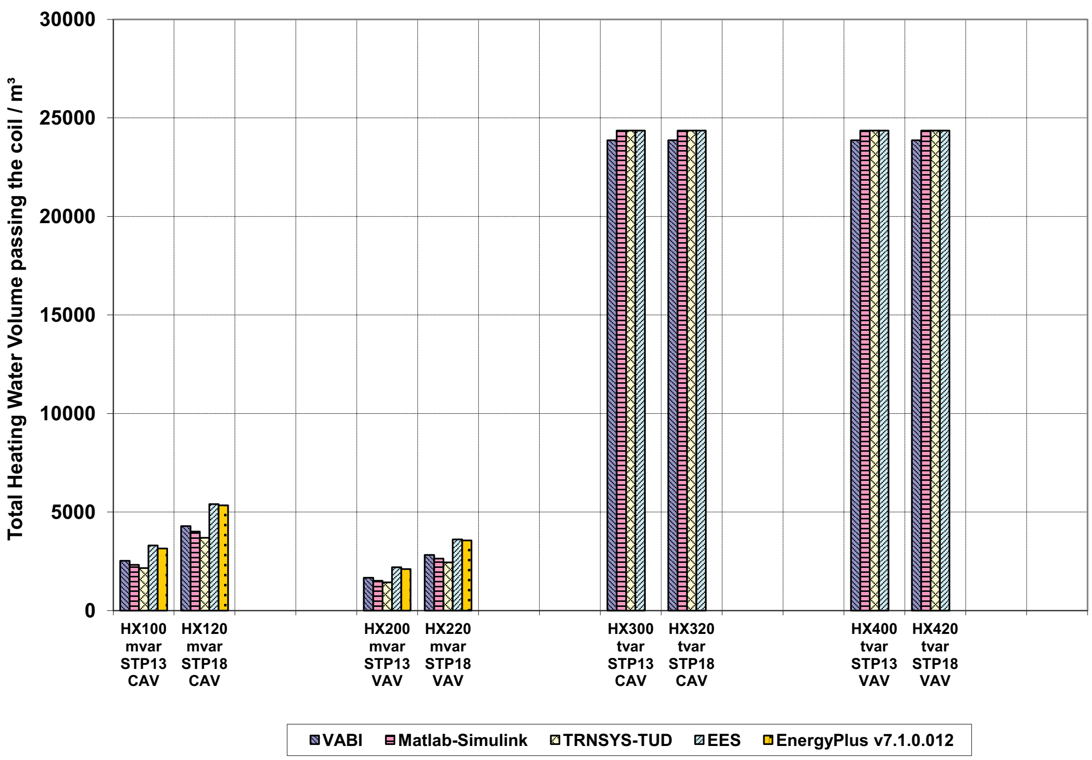

Test Case HX200
Coldest Day
Hot Water Flow Rate / l/s
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
15/1/07 0:00
15/1/07 2:00
15/1/07 4:00
15/1/07 6:00
15/1/07 8:00
15/1/07 10:00
15/1/07 12:00
15/1/07 14:00
15/1/07 16:00
15/1/07 18:00
15/1/07 20:00
15/1/07 22:00
16/1/07 0:00


Test Case HX200
Average Day
Hot Water Flow Rate / l/s
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2/1/07 0:00
2/1/07 2:00
2/1/07 4:00
2/1/07 6:00
2/1/07 8:00
2/1/07 10:00
2/1/07 12:00
2/1/07 14:00
2/1/07 16:00
2/1/07 18:00
2/1/07 20:00
2/1/07 22:00
3/1/07 0:00
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

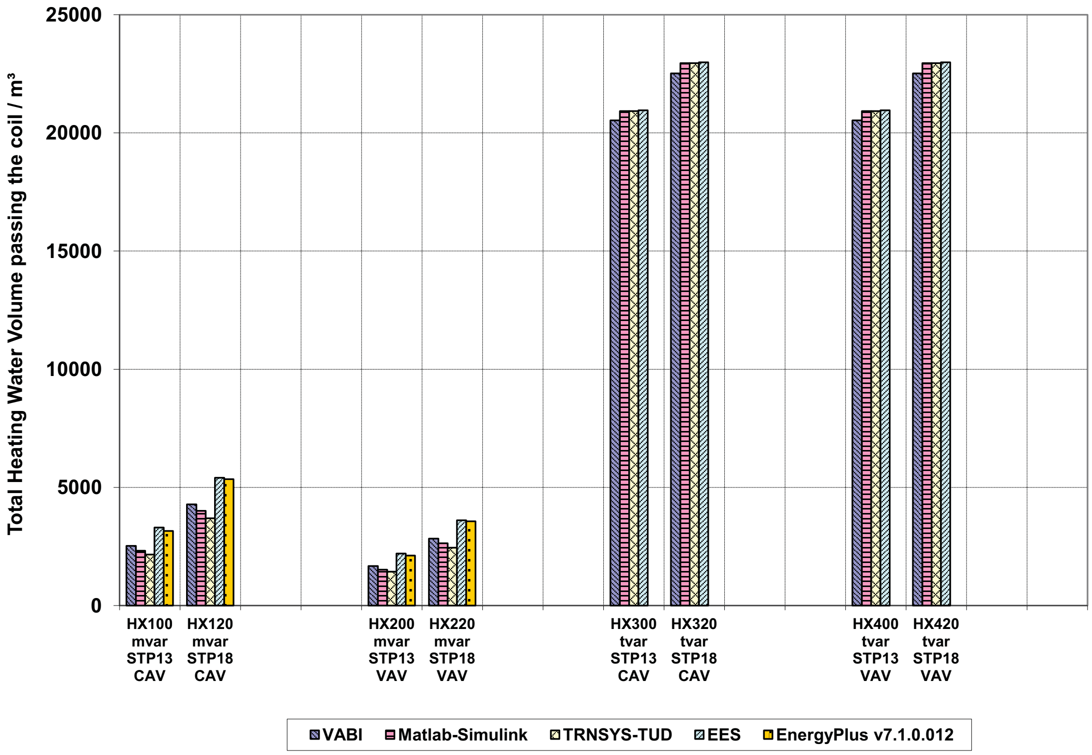

Min. Heating Water Flow / l/s
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



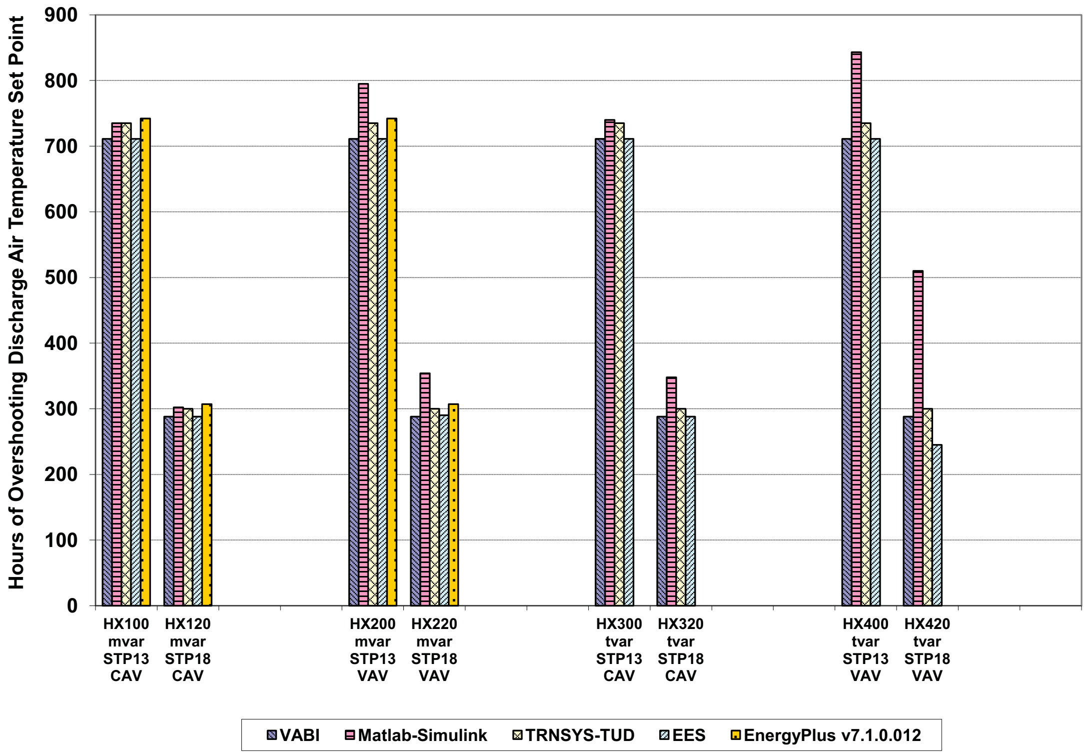
Max. Heating Water Flow / l/s
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



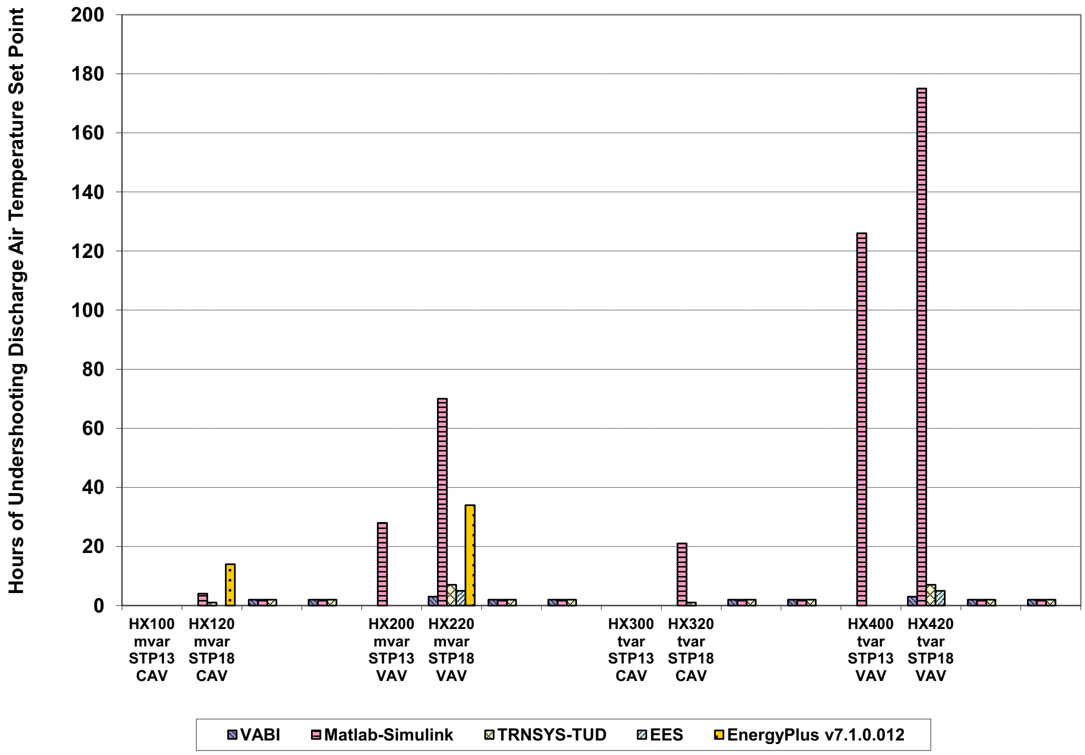
Total Heating Water Volume passing the coil / m³
30000
25000
20000
15000
10000
5000
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



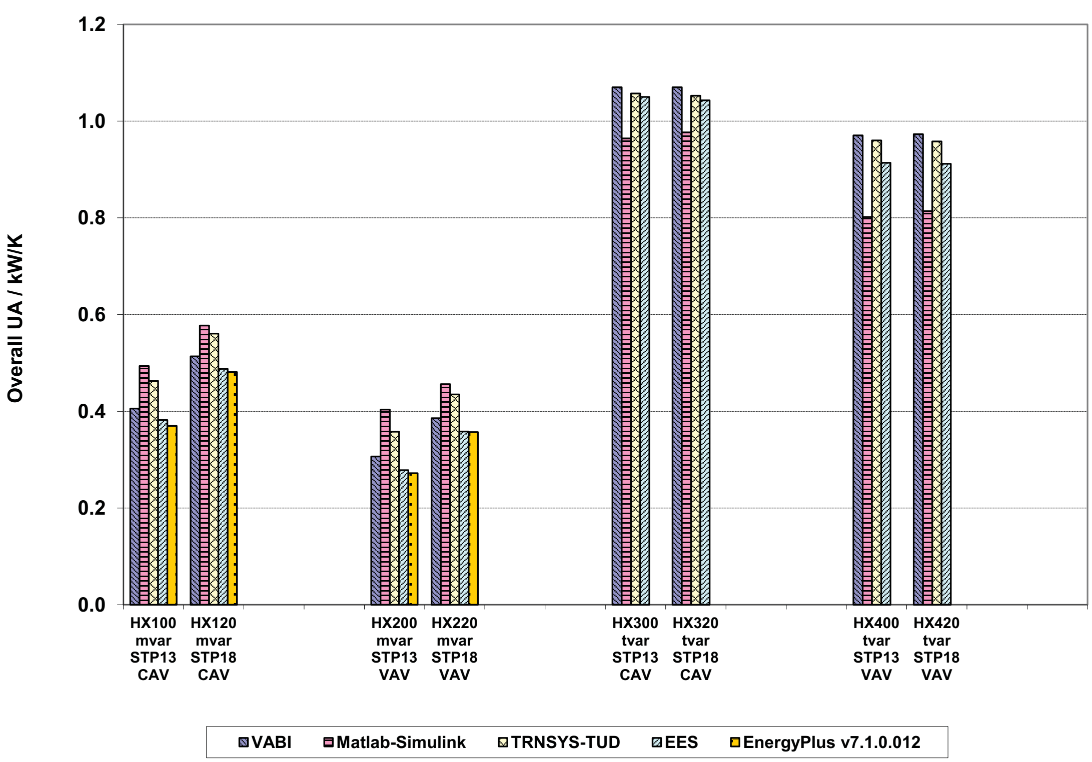
Total Heating Water Volume passing the coil / m³
25000
20000
15000
10000
5000
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



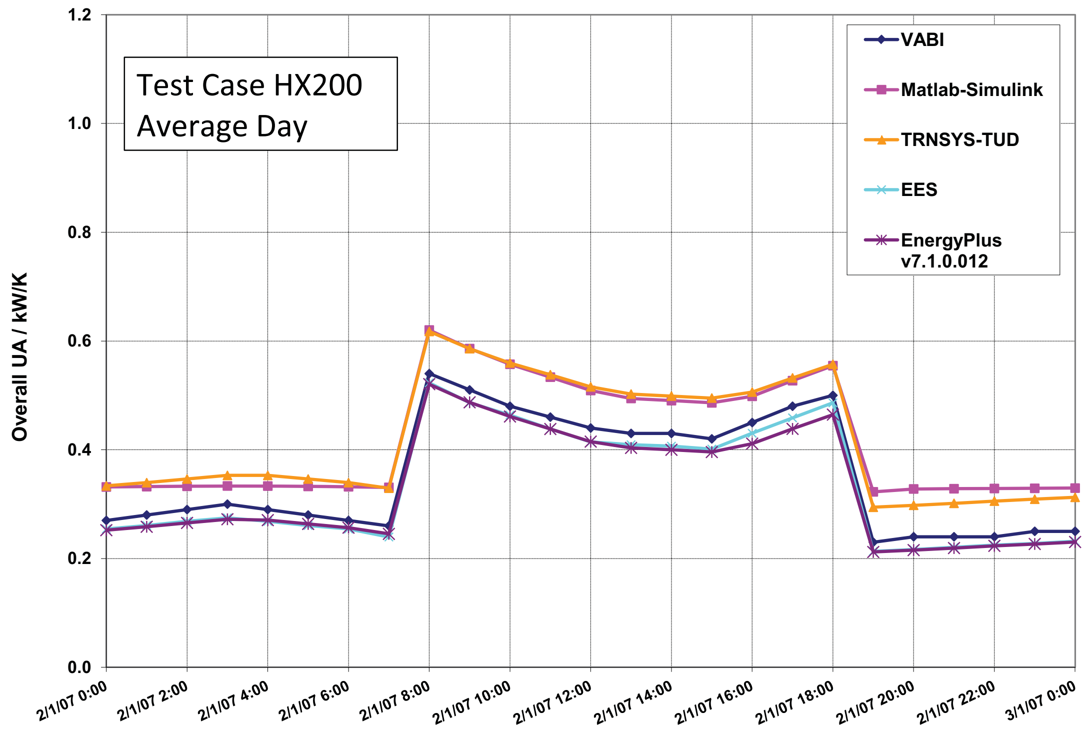
Hours of Overshooting Discharge Air Temperature Set Point
900
800
700
600
500
400
300
200
100
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012

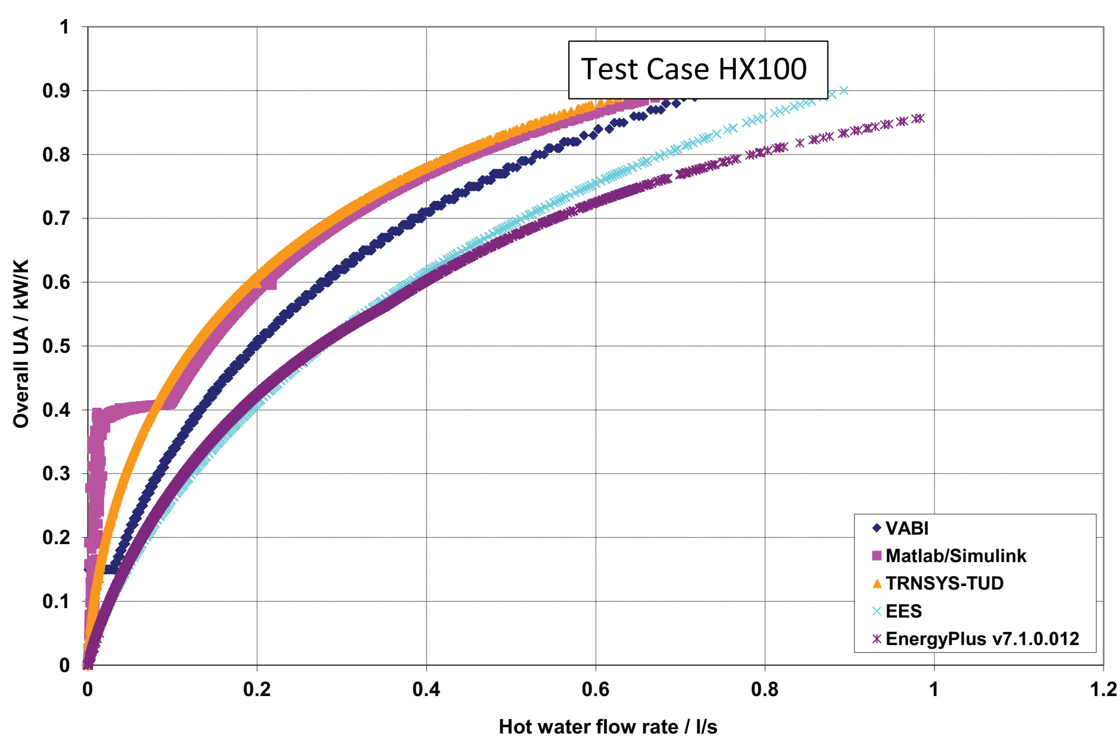


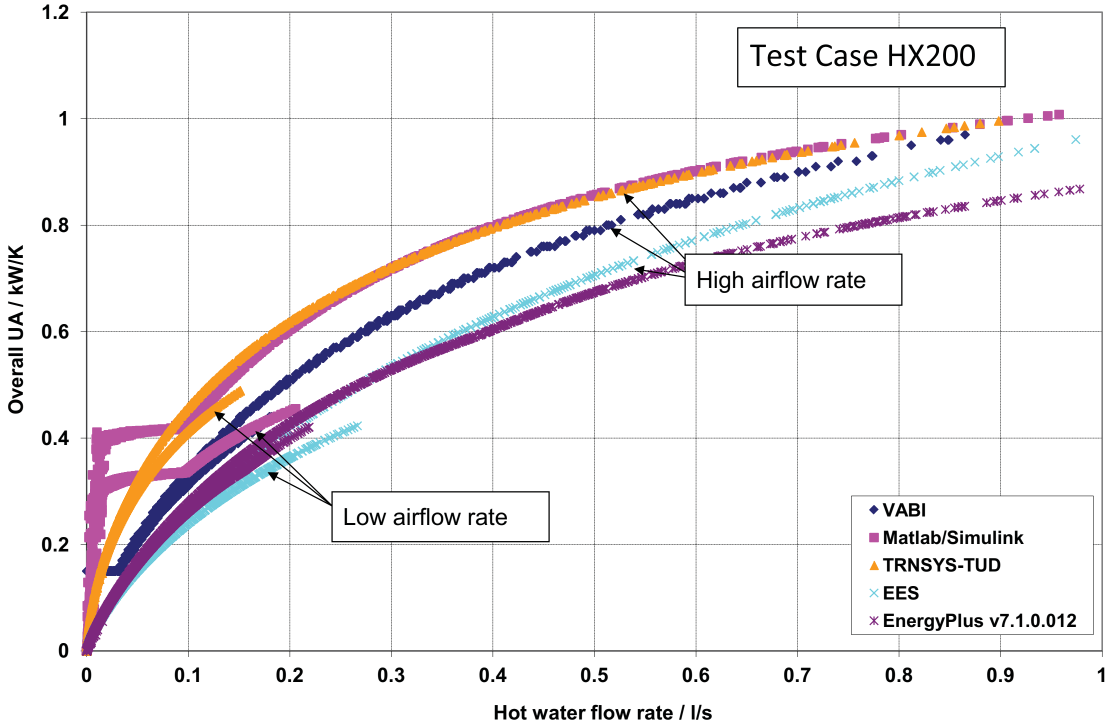
Hours of Undershooting Discharge Air Temperature Set Point
200
180
160
140
120
100
80
60
40
20
0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012



Overall UA / kW/K
1.2
1.0
0.8
0.6
0.4
0.2
0.0
HX100 mvar STP13 CAV
HX120 mvar STP18 CAV
HX200 mvar STP13 VAV
HX220 mvar STP18 VAV
HX300 tvar STP13 CAV
HX320 tvar STP18 CAV
HX400 tvar STP13 VAV
HX420 tvar STP18 VAV
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012


Test Case HX200
Average Day
Overall UA / kW/K
VABI
Matlab-Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2/1/07 0:00
2/1/07 2:00
2/1/07 4:00
2/1/07 6:00
2/1/07 8:00
2/1/07 10:00
2/1/07 12:00
2/1/07 14:00
2/1/07 16:00
2/1/07 18:00
2/1/07 20:00
2/1/07 22:00
3/1/07 0:00


Test Case HX100
Overall UA / kW/K
Hot water flow rate / l/s
VABI
Matlab/Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2


Test Case HX200
High airflow rate
Low airflow rate
VABI
Matlab/Simulink
TRNSYS-TUD
EES
EnergyPlus v7.1.0.012
Overall UA / kW/K
Hot water flow rate / l/s
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1