The description of the proposed Chiller Part-Load Curve needs to be added in the existing Engineering Reference (in Section "Simulation Models – Encyclopedic Reference > Chillers > Electric ChillerModel Based on Condenser Leaving Temperature", around Page 1834). Modifications are shown below using Track Changes.\_\_\_Rongpeng Zhang, Feb. 19, 2015

### Electric Chiller Model Based on Condenser Leaving Temperature

#### Overview

This model (object name Chiller:Electric:ReformulatedEIR) simulates the thermal performance of an electric liquid chiller and the power consumption of its compressor(s). The model, developed by Hydeman et al. (2002) as part of the CoolTools™ project sponsored by Pacific Gas and Electric Company (PG&E), is an empirical model similar to EnergyPlus’ Chiller:Electric:EIR model. The model uses performance information at reference conditions along with three curve fits for cooling capacity and efficiency to determine chiller operation at off-reference conditions. The model has the same capabilities as the Chiller:Electric:EIR model, but can potentially provide significant accuracy improvement over the Chiller:Electric:EIR model for chillers with variable-speed compressor motor drives and/or variable condenser water flow applications.

Chiller performance curves can be generated by fitting manufacturer’s catalog data or measured data. Performance curves developed primarily from manufacturer’s performance data are provided in the EnergyPlus Reference DataSets (Chillers.idf and AllDataSets.idf). This chiller model can be used to predict the performance of various chiller types (e.g., reciprocating, screw, scroll, and centrifugal) with water-cooled condensers. The model does not simulate the thermal performance or the power consumption of associated pumps or cooling towers. This auxiliary equipment must be modeled using other EnergyPlus models (e.g. CoolingTower:SingleSpeed).

The main difference between this model and the Chiller:Electric:EIR model is the condenser fluid temperature used in the associated performance curves: the Chiller:Electric:ReformulatedEIR model uses the LEAVING condenser water temperature while the Chiller:Electric:EIR model uses the ENTERING condenser water temperature. In addition, the Energy Input to Cooling Output Function of Part Load Ratio curve for this reformulated EIR chiller model includes the condenser leaving water temperature as an independent variable in addition to part-load ratio. Since the leaving condenser water temperature is a function of load, chiller performance, and condenser entering water temperature, EnergyPlus must iterate to converge on a solution for each simulation time step.

#### Model Description

The chiller model uses user-supplied performance information at reference conditions along with three performance curves (curve objects) for cooling capacity and efficiency to determine chiller operation at off-reference conditions. The three performance curves are:

1. Cooling Capacity Function of Temperature Curve
2. Energy Input to Cooling Output Ratio Function of Temperature Curve
3. Energy Input to Cooling Output Ratio Function of Part Load Ratio Curve

* The cooling capacity function of temperature curve is a biquadratic performance curve with two independent variables: the leaving chilled water temperature and the leaving condenser water temperature. The output of this curve is multiplied by the reference capacity to give the full-load cooling capacity at specific temperature operating conditions (i.e., at temperatures different from the reference temperatures). The curve should have a value of 1.0 at the reference temperatures and flow rates specified in the input data file by the user. The biquadratic curve should be valid for the range of water temperatures anticipated for the simulation (otherwise the program issues warning messages).



where

*ChillerCapFTemp* = Cooling capacity factor, equal to 1 at reference conditions

*Tcw,l* = leaving chilled water temperature, ˚C

*Tcond,l*= leaving condenser water temperature, ˚C. This will be the water temperature entering the condenser loop (e.g., entering the cooling tower). If the chiller is a heat recovery chiller,then the condenser leaving temperature is adjusted to account for both fluid streams as described in the section above on heat recovery chillers.

* The energy input to cooling output ratio function of temperature curve is a biquadratic performance curve that parameterizes the variation of the energy input to cooling output ratio (EIR) as a function of the leaving chilled water temperature and the leaving condenser water temperature. The EIR is the inverse of the COP. The output of this curve is multiplied by the reference EIR (inverse of the reference COP) to give the full-load EIR at specific temperature operating conditions (i.e., at temperatures different from the reference temperatures). The curve should have a value of 1.0 at the reference temperatures and flow rates specified in the input data file by the user. The biquadratic curve should be valid for the range of water temperatures anticipated for the simulation (otherwise the program issues warning messages).

where

*ChillerEIRFTemp* = Energy input to cooling output factor, equal to 1 at reference conditions

*Tcw,l* = leaving chilled water temperature, ˚C

*Tcond,l*= leaving condenser water temperature, ˚C. This will be the water temperature entering the condenser loop (e.g., entering the cooling tower). If the chiller is a heat recovery chiller,then the condenser leaving temperature is adjusted to account for both fluid streams as described in the section above on heat recovery chillers.

* The energy input to cooling output ratio function of part-load ratio curve parameterizes the variation of the energy input ratio (EIR). The output of this curve is multiplied by the reference EIR (inverse of the reference COP) and the Energy Input to Cooling Output Ratio Function of Temperature Curve to give the EIR at the specific temperatures and part-load ratio at which the chiller is operating. This curve should have a value of 1.0 at the reference leaving condenser water temperature with part-load ratio equal to 1.0. It is recommended that this performance curve be developed using both full- and part-load performance data. The bicubic curve should be valid for the range of condenser water temperatures and part-load ratios anticipated for the simulation (otherwise the program issues warning messages). Either of the following two types of curves can be used.

The first type is a bicubic performance curve that parameterizes the variation of the chiller input power ratio as a function of the leaving condenser water temperature and the part-load ratio. The part-load ratio is the actual cooling load divided by the chiller’s available cooling capacity.





where

*ChillerEIRFPLR* = Energy input to cooling output factor, equal to 1 at the reference leaving condenser water temperature and PLR = 1.0

*Tcond,l*= leaving condenser water temperature, ˚C. This will be the water temperature entering the condenser loop (e.g., entering the cooling tower). If the chiller is a heat recovery chiller,then the condenser leaving temperature is adjusted to account for both fluid streams as described in the section above on heat recovery chillers.

*PLR* = Part load ratio = (cooling load) / (chiller’s available cooling capacity)

*Pchiller =* chiller power at specific PLR

*Pref = /COPref*

Note: Although a bicubic curve requires 10 coefficients (ref. Curve:Bicubic), coefficients 7, 9 and 10 are typically not used in the performance curve described here and should be entered as 0 unless sufficient performance data and regression accuracy exist to justify the use of these terms of the bicubic curve.

The second type is a Chiller Part Load Custom Curve that parameterizes the variation of EIR as a function of the normalized dT, normalized Tdev and the PLR.

*ChillerEIRFPLR = a + b(dT\*) + c(dT\*)2 + d ×* *PLR + e×PLR2 + f× (dT\*)×PLR + g× (dT\*)3 + h×PLR3 + i× (dT\*)2×PLR + j× (dT\*)×PLR2 + k× (dT\*)2×PLR2 + l× (Tdev\*)×PLR3*

*dT\* = dT / dTref*

*Tdev\* = Tdev/ dTref*

where

*dT* = the delta of temperature across the leaving condenser water temperature and leaving evaporator water temperature of a chiller (lift)

*dT\** = the normalized fractional lift

*dTref* = the lift under the reference condition

*PLR* = the part load ratio

*Tdev*  = the deviation of leaving chilled water temperature from the reference condition

*Tdev\** = the normalized Tdev term

All three of the performance curves are accessed through EnergyPlus’ built-in performance curve equation manager (curve:biquadratic, curve:bicubic, and urve:ChillerPartLoadWithLift). Note that the above three performance curves use the leaving condenser water temperature as an independent variable, instead of the entering condenser water temperature used in the performance curves for the Chiller:Electric:EIR model. Since the leaving condenser water temperature is calculated based on the condenser heat transfer rate, which is a function of the load to be met by the chiller, chiller compressor power, and the false loading (detailed calculations are given below), iterative calculations are required to determine the actual (converged) leaving condenser water temperature. The program uses the leaving condenser water temperature from the previous iteration to calculate values for each of the three performance curves described above. After obtaining the condenser heat transfer rate, the leaving condenser water temperature is recalculated. When the difference between the leaving condenser water temperature calculated on successive iterations is less than 0.0001°C, the solution is assumed to have converged. Warning messages are issued if the calculated solution for leaving condenser water temperature and/or part-load ratio falls outside the valid range specified for the chiller’s performance curves. If these warnings are issued, the user may choose to extend the range for the performance curves (only if a small extension is required since model extrapolation may produce significant errors) or a different chiller and associated performance curves with extended performance range can be located and used for the simulation.

Note: Chiller:Electric:ReformulatedEIR objects and their associated performance curve objects are developed using performance information for a specific chiller and should almost always be used together for an EnergyPlus simulation. Changing the object input values, or swapping performance curves between chillers, should be done with extreme caution. For example, if the user wishes to model a chiller size that is different from the reference capacity, it is highly recommended that the reference flow rates be scaled proportionately to the change in reference capacity. Although this model can provide more accurate prediction than the Chiller:Electric:EIR model, it requires more performance data to develop the associated performance curves (at least 12 points from full-load performance and 7 points from part-load performance).

Although performance curve data sets for 160 chillers are provided in the EnergyPlus Reference DataSets (Chillers.idf and AllDataSets.idf), they may not meet the requirements for specific applications. One can develop performance curves from performance data using two available techniques (Hydeman and Gillespie 2002). The first technique is called the Least-squares Linear Regression method and is used when sufficient performance data exist to employ standard least-square linear regression techniques. The second technique is called Reference Curve Method and is used when insufficient performance data exist to apply linear regression techniques. A detailed description of both techniques can be found in the reference mentioned above.

For any simulation time step, the chiller’s available cooling capacity is calculated as follows:



where

 = chiller capacity at reference conditions (reference temperatures and flow rates defined by the user), W

 = available chiller capacity adjusted for current water temperatures, W

The model then calculates the evaporator heat transfer rate required to bring the entering chilled water temperature down to the leaving chilled water setpoint temperature (established using a SetpointManager object and referenced in the PlantLoop object). If this calculated heat transfer rate is greater than the heat transfer rate being requested by the plant equipment operation scheme, then the evaporator heat transfer rate is reset to the requested cooling rate.

The evaporator heat transfer rate is then compared to the available capacity. If the available chiller capacity is sufficient to meet the evaporator heat transfer rate, the leaving chilled water temperature is set equal to the chilled water setpoint temperature. If the requested evaporator heat transfer rate is larger than the available capacity the chilled water leaving the evaporator is allowed to float upward. For this case, the exiting chilled water temperature is calculated based on the water temperature entering the evaporator, the available cooling capacity, and the evaporator mass flow rate as follows:



where

*Tcw,l* = water temperature leaving the evaporator, ˚C

*Tcw,e* = water temperature entering the evaporator, ˚C

 = evaporator mass flow rate, kg/s

*Cp,evap* = specific heat of water entering evaporator at *Tcw,e*, J/kg-˚C

The part-load ratio is then calculated as the ratio of the evaporator heat transfer rate to the available chiller capacity. The part-load ratio is not allowed to be greater than the maximum part-load ratio specified by the user or less than zero as follows:



where

*PLR* = part-load ratio

 = load to be met by the chiller, W

*PLRmax* = maximum part-load ratio (specified by the user in the input data file)

Note that the maximum part-load ratio (PLRmax, specified in the Chiller:Electric:ReformulatedEIR object) used in the equation should be less than or equal to the maximum part-load ratio specified in the “Energy Input to Cooling Output Ratio Function of Part-Load Ratio” performance curve object.

The model assumes that the cooling load is met through chiller unloading down to the minimum unloading ratio. False loading (e.g. hot-gas bypass) is assumed to occur between the minimum unloading ratio and the minimum part-load ratio yielding constant electrical power consumption under these conditions. Below the minimum part-load ratio, the chiller cycles on/off to meet very small loads and the power consumption during the on cycle is the same as when the chiller is operating at the minimum part load ratio. When the chiller part-load ratio is less than the minimum part-load ratio, the on-off cycling ratio of the chiller is calculated as follows and is available as an output variable.



To properly account for chiller electric power consumption when PLR is less than the minimum unloading ratio, the PLR is reset to the greater of the PLR calculated above and the PLR at the minimum unloading ratio. The result is available as the output variable Chiller Part Load Ratio.



This revised PLR accounts for the “false loading” (e.g., hot-gas bypass) that is assumed to occur whenever the PLR (based on cooling load divided by available capacity) is less than the minimum unloading ratio specified. The amount of false loading on the chiller is calculated using this revised PLR and is reported as an output variable as follows:



The electrical power consumption for the chiller compressor(s) for any simulation time step is then calculated using the following equation:

where

*Pchiller* = Chiller compressor power, W

*COPref* = Reference coefficient of performance, W/W

Heat rejected by the chiller condenser includes the heat transferred in the evaporator plus a portion or all of the compressor electrical energy consumption. For electric chillers with hermetic compressors, all compressor energy consumption is rejected by the condenser (compressor motor efficiency = *effmotor* = 1.0). For chillers with semi-hermetic or open compressors, only a portion of the compressor energy use is rejected by the condenser. The heat transfer rate for the chiller condenser is calculated as follows:



where

 = condenser heat transfer rate, W

 = compressor motor efficiency = fraction of compressor electrical energy consumption rejected as condenser heat

The above curve values are calculated based on the leaving condenser water temperature found through iteration. After obtaining the condenser heat transfer rate, the final leaving condenser water temperature is then calculated as:



where:

*Tcond,l* = water temperature leaving the condenser, ˚C

*Tcond,e* = water temperature entering the condenser, ˚C

 = mass flow rate through the condenser, kg/s

 = specific heat of water entering the condenser at *Tcond,e*, J/kg-˚C

The final calculations determine the total heat transfer energy for the condenser and evaporator, as well as the total electric energy consumed by the chiller compressor motor(s) and condenser fan(s). The results are available as output variables.









where

*Qcond* = chiller condenser heat transfer energy, J

*Qevap* = chiller evaporator cooling energy, J

*Echiller* = chiller (compressor) electric energy, J

*Econd* = chiller condenser fan electric energy, J

*TimeStepSys* = HVAC system simulation time step, hr

 = conversion factor, sec/hr

#### Electric Reformulated EIR Chiller with Heat Recovery Option

Heat from the electric reformulated EIR chiller condenser may be recovered. The heat recovery water flow rate is specified by the user along with the input and output nodes connected to the heat recovery loop. The algorithms are identical to those used for Chiller:Electric and Chiller:Electric:EIR. Refer to the section entitled Chillers with Plant Heat Recovery for details.

#### Standard Rating (Integrated Part Load Value)

Integrated Part Laod Value (IPLV) calculations for Reformulated EIR chiller are similar to what are described above for EIR chillers. The only difference with Reformulated EIR chiller is that it calls an iterative subroutine (SolveRegulaFalsi) to obtain a condenser water outlet temperature which corresponds to condenser inlet temperature at reduced capacity conditions as outlined in Table 51 above. SolveRegulaFalsi is a general utility routine for finding the zero of a function. In this case it finds the condenser inlet temperature that will zero the residual function – the difference between calculated condenser inlet temperature and desired condenser inlet temperature per ANSI/AHRE 550/590, 2011 (table 42 above) divided by desired condenser inlet temperature.

#### References

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