EnergyPlus  
Engineering Reference

The Reference to EnergyPlus Calculations  
(in case you want or need to know)

### Single-Speed Electric DX Air Cooling Coil

#### Overview

This model (object names Coil:Cooling:DX:SingleSpeed and Coil:Cooling:DX:TwoStageWithHumidityControlMode, with CoilPerformance:DX:Cooling) simulates the performance of an air-cooled or evaporative-cooled direct expansion (DX) air conditioner. The model uses performance information at rated conditions along with curve fits for variations in total capacity, energy input ratio and part-load fraction to determine the performance of the unit at part-load conditions (Henderson et al. 1992, ASHRAE 1993). Sensible/latent capacity splits are determined by the rated sensible heat ratio (SHR) and the apparatus dewpoint (ADP)/bypass factor (BF) approach. This approach is analogous to the NTU-effectiveness calculations used for sensible-only heat exchanger calculations, extended to a cooling and dehumidifying coil.

This model simulates the thermal performance of the DX cooling coil and the power consumption of the outdoor condensing unit (compressor, fan, crankcase heater and evap condenser water pump). The total amount of heat rejected by the condenser is also calculated and stored for use by other waste heat recovery models (e.g., Coil:Heating:Desuperheater). The performance of the indoor supply air fan varies widely from system to system depending on control strategy (e.g., constant fan vs. AUTO fan, constant air volume vs. variable air volume, etc.), fan type, fan motor efficiency and pressure losses through the air distribution system. Therefore, this DX system model does not account for the thermal effects or electric power consumption of the indoor supply air fan. EnergyPlus contains separate models for simulating the performance of various indoor fan configurations, and these models can be easily linked with the DX system model described here to simulate the entire DX air conditioner being considered (e.g., see AirLoopHVAC:Unitary:Furnace:HeatCool, AirLoopHVAC:UnitaryHeatCool, ZoneHVAC:WindowAirConditioner or AirLoopHVAC:UnitaryHeatPump:AirToAir).

#### Model Description

The user must input the total cooling capacity, sensible heat ratio (SHR), coefficient of performance (COP) and the volumetric air flow rate across the cooling coil at rated conditions. The capacity, SHR and COP inputs should be “gross” values, excluding any thermal or energy impacts due to the indoor supply air fan. The rated conditions are considered to be air entering the cooling coil at 26.7°C drybulb/19.4°C wetbulb and air entering the outdoor condenser coil at 35°C drybulb/23.9°C wetbulb. The rated volumetric air flow should be between 0.00004027 m3/s and 0.00006041 m3/s per watt of rated total cooling capacity (300 – 450 cfm/ton). The rated volumetric air flow to total cooling capacity ratio for 100% dedicated outdoor air (DOAS) application DX cooling coils should be between 0.00001677 (m3/s)/W (125 cfm/ton) and 0.00003355 (m3/s)/W (250 cfm/ton).

The user must also input five performance curves or performance tables that describe the change in total cooling capacity and efficiency at part-load conditions:

1. Total cooling capacity modifier curve or table (function of temperature)
2. Total cooling capacity modifier curve or table (function of flow fraction)
3. Energy input ratio (EIR) modifier curve or table (function of temperature)
4. Energy input ratio (EIR) modifier curve or table (function of flow fraction)
5. Part load fraction correlation curve or table (function of part load ratio)

* The total cooling capacity modifier curve (function of temperature) is a curve with two independent variables: wet-bulb temperature of the air entering the cooling coil, and dry-bulb temperature of the air entering the air-cooled condenser coil (wet-bulb temperature if modeling an evaporative-cooled condenser). The output of this curve is multiplied by the rated total cooling capacity to give the total cooling capacity at the specific entering air temperatures at which the DX coil unit is operating (i.e., at temperatures different from the rating point temperatures). This curve is typically a biquadratic but any curve or table with two independent variables can be used.

Note: The data used to develop the total cooling capacity modifier curve (function of temperature) should represent performance when the cooling coil is ‘wet’ (i.e., coil providing sensible cooling and at least some dehumidification). Performance data when the cooling coil is ‘dry’ (i.e., not providing any dehumidification) should **not** be included when developing this modifier curve. This model automatically detects and adjusts for ‘dry coil’ conditions (see section “Dry Coil Conditions” below).



where

 = x values = wet-bulb temperature of the air entering the cooling coil, °C

 = y values = dry-bulb temperature of the air entering an air-cooled condenser or wet-bulb

temperature of the air entering an evaporative-cooled condenser, °C

* The total cooling capacity modifier curve (function of flow fraction) is a curve with one the independent variable being the ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated total cooling capacity and the total cooling capacity modifier curve (function of temperature) to give the total cooling capacity at the specific temperature and air flow conditions at which the DX unit is operating. This curve is typically a quadratic or cubic but any curve or table with one independent variable can be used.



where

= x value

**Note:** The actual volumetric air flow rate through the cooling coil for any simulation time step where the DX unit is operating must be between 0.00002684 m3/s and .00006713 m3/s per watt of rated total cooling capacity (200 - 500 cfm/ton). The simulation will issue a warning message if this air flow range is exceeded.

* The energy input ratio (EIR) modifier curve (function of temperature) is a curve with two independent variables: wet-bulb temperature of the air entering the cooling coil, and dry-bulb temperature of the air entering the air-cooled condenser coil (wet-bulb temperature if modeling an evaporative-cooled condenser). The output of this curve is multiplied by the rated EIR (inverse of the rated COP) to give the EIR at the specific entering air temperatures at which the DX coil unit is operating (i.e., at temperatures different from the rating point temperatures). This curve is typically a biquadratic but any curve or table with two independent variables can be used.

Note: The data used to develop the energy input ratio (EIR) modifier curve (function of temperature) should represent performance when the cooling coil is ‘wet’ (i.e., coil providing sensible cooling and at least some dehumidification). Performance data when the cooling coil is ‘dry’ (i.e., not providing any dehumidification) should **not** be included when developing this modifier curve. This model automatically detects and adjusts for ‘dry coil’ conditions (see section “Dry Coil Conditions” below).



where

 = x values = wet-bulb temperature of the air entering the cooling coil, °C

 = y values = dry-bulb temperature of the air entering an air-cooled condenser or wet-bulb

temperature of the air entering an evaporative-cooled condenser, °C

* The energy input ratio (EIR) modifier curve (function of flow fraction) is a curve with one independent variable being the ratio of the actual air flow rate across the cooling coil to the rated air flow rate (i.e., fraction of full load flow). The output of this curve is multiplied by the rated EIR (inverse of the rated COP) and the EIR modifier curve (function of temperature) to give the EIR at the specific temperature and air flow conditions at which the DX unit is operating. This curve is typically a quadratic or cubic but any curve or table with one independent variable can be used.



where

 = x values.

* The part load fraction correlation (function of part load ratio) is a curve with one independent variable being part load ratio (sensible cooling load / steady-state sensible cooling capacity). The output of this curve is used in combination with the rated EIR and EIR modifier curves to give the “effective” EIR for a given simulation time step. The part load fraction (PLF) correlation accounts for efficiency losses due to compressor cycling. This curve is typically a linear, quadratic or cubic but any curve or table with one independent variable can be used.



where

 = x values

The part-load fraction correlation should be normalized to a value of 1.0 when the part load ratio equals 1.0 (i.e., no efficiency losses when the compressor(s) run continuously for the simulation time step). For PLR values between 0 and 1 (0 <= PLR < 1), the following rules apply:

PLF >= 0.7 and PLF >= PLR

If PLF < 0.7 a warning message is issued, the program resets the PLF value to 0.7, and the simulation proceeds. The runtime fraction of the coil is defined as PLR/PLF. If PLF < PLR, then a warning message is issued and the runtime fraction of the coil is limited to 1.0.

A typical part load fraction correlation for a conventional, single-speed DX cooling coil (e.g., residential or small commercial unit) would be:

PLF = 0.85 + 0.15(PLR)

All five part-load curves are accessed through EnergyPlus’ built-in performance curve equation manager (curve: quadratic, curve:cubic and curve:biquadratic). It is not imperative that the user utilize all coefficients shown in equations (464) through (468) if their performance equation has fewer terms (e.g., if the user’s PartLoadFrac performance curve is linear instead of quadratic, simply enter the values for a and b, and set coefficient c equal to zero).

For any simulation time step, the total (gross) cooling capacity of the DX unit is calculated as follows:



In a similar fashion, the electrical power consumed by the DX unit (compressors plus outdoor condenser fans) for any simulation time step is calculated using the following equation:



where

= Total cooling capacity, W -- ref. equation (470)



 = Coefficient of performance at rated conditions (user input)



The total amount of heat rejected by the condenser is then calculated and stored for use by other waste heat recovery models (e.g., Coil:Heating:Desuperheater).



where

 = total amount of heat rejected by the condenser (W)

The crankcase heater is assumed to operate when the cooling coil’s compressor is OFF and the outdoor dry-bulb temperature is below the maximum outdoor temperature for crankcase heater operation. The average crankcase heater power for the simulation time step is calculated as follows:



where

 = DX cooling coil crankcase heater power, W

= crankcase heater capacity, W

If this cooling coil is used as part of an air-to-air heat pump (Ref. AirLoopHVAC:UnitaryHeatPump:AirToAir), the crankcase heater defined for this DX cooling coil is disregarded and the associated output variable is omitted. Instead, the crankcase heater defined for the DX heating coil (Coil:Heating:DX:SingleSpeed) is enabled during the time that the compressor is not running for either heating or cooling. In this instance, RTF in the above equations would be the runtime fraction of the heat pump’s heating coil or cooling coil, whichever is greater.

In addition to calculating the total cooling capacity provided by the DX air conditioner, it is important to properly determine the break down of total cooling capacity into its sensible (temperature) and latent (dehumidification) components. The model computes the sensible/ latent split using the rated SHR and the ADP/BF approach (Carrier et al. 1959). When the DX coil model is initially called during an EnergyPlus simulation, the rated total capacity and rated SHR are used to calculate the coil bypass factor (BF) at rated conditions. The rated total capacity and rated SHR are first used to determine the ratio of change in air humidity ratio to air dry-bulb temperature:



where

*ωin*= humidity ratio of the air entering the cooling coil at rated conditions, kg/kg

*ωout*= humidity ratio of the air leaving the cooling coil at rated conditions, kg/kg

*Tdb,in*= dry-bulb temperature of the air entering the cooling coil at rated conditions, °C

*Tdb,out*= dry-bulb temperature of the air leaving the cooling coil at rated conditions, °C

Along with the rated entering air conditions, the algorithm then searches along the saturation curve of the psychrometric chart until the slope of the line between the point on the saturation curve and the inlet air conditions matches *SlopeRated*. Once this point, the apparatus dewpoint, is found on the saturation curve the coil bypass factor at rated conditions is calculated as follows:



where

*hout,rated* = enthalpy of the air leaving the cooling coil at rated conditions, J/kg

*hin,rated* = enthalpy of the air entering the cooling coil at rated conditions, J/kg

*hADP* = enthalpy of saturated air at the coil apparatus dewpoint, J/kg

The coil bypass factor is analogous to the “ineffectiveness” (1-ε) of a heat exchanger, and can be described in terms of the number of transfer of unit (NTU).



For a given coil geometry, the bypass factor is only a function of air mass flow rate. The model calculates the parameter Ao in equation (475) based on BFrated and the rated air mass flow rate. With Ao known, the coil BF can be determined for non-rated air flow rates.

For each simulation time step when the DX air conditioner operates to meet a cooling load, the total cooling capacity at the actual operating conditions is calculated using equation (470) and the coil bypass factor is calculated based on equation (475). The coil bypass factor is used to calculate the operating sensible heat ratio (SHR) of the cooling coil using equations (476) and (477).





where

 = enthalpy of the air entering the cooling coil, J/kg

 = enthalpy of air at the apparatus dewpoint condition, J/kg

 = enthalpy of air at the entering coil dry-bulb temperature and humidity ratio at ADP, J/kg

 = air mass flow rate, kg/s

With the SHR for the coil at the current operating conditions, the properties of the air leaving the cooling coil are calculated using the following equations:









where

 = enthalpy of the air leaving the cooling coil, J/kg

 = enthalpy of air at the entering coil dry-bulb temperature and leaving air humidity ratio, J/kg

 = leaving air humidity ratio, kg/kg

 = leaving air dry-bulb temperature, °C

*PsyWFnTdbH* = EnergyPlus psychrometric function, returns humidity ratio given dry-bulb temperature and enthalpy

*PsyTdbFnHW* = EnergyPlus psychrometric function, returns dry-bulb temperature given enthalpy and humidity ratio

#### Dry Coil Conditions

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#### ANSI/ASHRAE 127 - Standard Ratings of Single-Speed DX Cooling Coils

For computer and data processing room unitary air conditioners single-speed direct expansion (DX) cooling coils, the standard ratings net total cooling capacity and total cooling electric power inputs are calculated according to ANSI/AHRI Standard 127 (ASHRAE 2012). These ratings apply to unitary air conditioners with air-cooled. If the single-speed DX cooling coil is specified with an evaporatively-cooled condenser, then no standard ratings are output from EnergyPlus at this time. These standard ratings are not direct inputs to the model. However, these standard ratings can be calculated using user-entered information for the Coil:Cooling:DX:SingleSpeed object. These standard rating values are provided in the eplusout.eio output file and also in the predefined tabular output reports (Output:Table:SummaryReports object, Equipment Summary).

Note: The standard ratings described in this section require that the DX cooling coil model be evaluated at sixteen different test conditions (i.e., specific wet-bulb temperatures for air entering the cooling coil and dry-bulb temperatures for air entering the air-cooled [outdoor] condenser) for each of the four standard tests and four application classes (ASHRAE – 2012). The four test conditions: A, B, C and D are provided in the ANSI/ASHRAE Standard 127. And the test conditions are different for each application classes described in the standard. In total sixteen performance data of net cooling capacity and total electric power inputs are reported. The total cooling electric power includes the supply fan power.

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| --- | --- | --- | --- | --- | --- |
|  |  | Rated Cooling Tests | | | |
|  | Application Class | A | B | C | D |
| Tdb, Indoor | Class 1 | 23.9°C(75.0°F) | 23.9°C(75.0°F) | 23.9°C(75.0°F) | 23.9°C(75.0°F) |
| Class 2 | 29.4°C(85.0°F) | 29.4°C(85.0°F) | 29.4°C(85.0°F) | 29.4°C(85.0°F) |
| Class 3 | 35.0°C(95.0°F) | 35.0°C(95.0°F) | 35.0°C(95.0°F) | 35.0°C(95.0°F) |
| Class 4 | 40.5°C(105°F) | 40.5°C(105°F) | 40.5°C(105°F) | 40.5°C(105°F) |
| Tdp, Indoor | | 35.0°C(95.0°F) | 26.7°C(80.0°F) | 18.3°C(65.0°F) | 4.4°C(40.0°F) |
| Tdb, Outdoor | | 35.0°C(95.0°F) | 26.7°C(80.0°F) | 18.3°C(65.0°F) | 4.4°C(40.0°F) |

The standard rating net total cooling capacity is calculated as follows:



where,

 = Standard Rating (Net) Cooling Capacity (W)

 = Rated Total (Gross) Cooling Capacity, user input (W)

= Total Cooling Capacity Function of Temperature Curve evaluated at wet-bulb temperature of air entering the cooling coil and dry-bulb temperature of air entering the air-cooled (outdoor) condenser (dimensionless)

= Total Cooling Capacity Function of Flow Fraction Curve evaluated at a flow fraction of 1.0 (dimensionless)

= Rated Evaporator Fan Power Per Volume Flow Rate, user input ( W/(m3/s) )

= Rated Air Volume Flow Rate, user input (m3/s)

The standard rating net total cooling electric power input is calculated as follows:



where,

*EER* = Energy efficiency ratio at wet-bulb temperature of air entering the cooling coil, dry-bulb temperature of air entering the air-cooled (outdoor) condenser, and rated air volume flow through the cooling coil (W/W)

 = Total Cooling Capacity Function of Temperature Curve evaluated at the test condition of wet-bulb temperature of air entering the cooling coil and dry-bulb temperature of air entering the air-cooled (outdoor) condenser (dimensionless)

 = Total electric power (compressors, condenser fans and evaporator fan) at the test conditions of wet-bulb temperature of air entering the cooling coil, and dry-bulb temperature of air entering the air-cooled (outdoor) condenser, and rated air volume flow through the cooling coil (W)

 = Coefficient of Performance at Rated Conditions, user input (W/W)

 = Energy Input Ratio Function of Temperature Curve evaluated at the test condition of wet-bulb temperature of air entering the cooling coil and dry-bulb temperature of air entering the air-cooled (outdoor) condenser (dimensionless)

= Energy Input Ratio Function of Flow Fraction Curve evaluated at a flow fraction of 1.0 (dimensionless).

Reference:

ASHRAE 2012. ANSI/ASHRAE Standard 127-2012 Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners.