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# Overview

### Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed

#### Overview

The latest technology for commercial air conditioners and air-to-air heat pumps can utilize a variable speed compressor with a variable speed indoor blower and outdoor fan. Integrated heat pumps are multi-functional units, capable of space conditioning and water heating. And thus, variable-speed water heating is usually a function provided by an air-source (ASIHP) or water-source integrated heat pump (WSIHP). Variable-speed water heating withdraws source energy from the outdoor air for ASIHP, or from a conditioned zone for both ASIHP and WSIHP. The control system adjusts the compressor speed, in response to the water heating demand; for example, if there is a water-draw request in the water tank, the compressor runs at the highest speed to heat the water for minimizing electric resistance heat use; if there is not a water-draw request, the heat pump may run at a reduced speed to maintain the tank water temperature, with a better efficiency. The air flow rate entering the evaporator coil is usually a function of the compressor speed. Refrigerant mass flow rate is a function of compressor speed as well as the water temperature entering the condenser, and the air dry bulb or wet bulb temperature entering the evaporator coil.

The compressor, fan and blower speeds are not discrete values and can be considered to vary infinitesimally between the minimum and maximum compressor speeds. At the minimum compressor speed, for a continuous fan, the supply airflow is fixed and the unit will have to cycle for reduced part loads below this point. For a cycling fan, the fan will cycle with the compressor.

To simulate the variable-speed water heating coil, the number of speed levels and the corresponding curve sets will be expanded up to ten. The number of speed levels is selectable by the user. The user can provide speed levels at any number from 1 to 10. In the case that the number of given speed levels are above 1, the model would do linear interpolation between neighboring speeds. The more curves, the more accurate. Furthermore, using linear interpolation, and inputting air and water flow rates at individual speed levels facilitates arbitrary relationships of flow rates as a function of the compressor speed.

The Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed object will simulate the performance of a variable-speed water heating coil. It fits into the parent object of WaterHeater:HeatPump, to be connected other components, i.e. water heater tank, evaporator fan, etc. The user can replace an existing single-speed water heating coil by switching to the name and object type of a variable-speed water heating coil, i.e. Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed vs. Coil:WaterHeating:AirToWaterHeatPump in the same parent object.

#### Model Description

The Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed object is modeled similar to Coil:WaterHeating:AirToWaterHeatPump. Of course, rather than including one set of performance curves, the new coil object is able to include ten sets of performance curves and interpolate performance between speed levels. If a VS water heating coil object (Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed) contains only set of performance curves, it would have the same functionality as the object of Coil:WaterHeating:AirToWaterHeatPump.

The user needs to input Rated Water Heating Capacity, Rated Evaporator Air Flow Rate, and Rated Water Flow Rate at a selected nominal speed level. They are used to scale the performances of a specific unit and correlate with the actual loop flow rates. Except these three fields, all other capacity and flow rate inputs at individual speed levels should be directly obtained from Reference Unit catalog data, specific to an actual unit.

The Rated Water Heating Capacity at a Selected Nominal Speed Level contains the rated capacity. The rated heating capacity is used to determine a capacity scaling factor, as compared to the Reference Unit capacity at the nominal speed level.

And then, this scaling factor is used to determine capacities at rated conditions for other speed levels, as below:

The Rated Volumetric Air Flow Rate is used to determine an internal scaling factor, and calculate the air flow rates in the parent objects, as follows:

And the loop volumetric air flow rates at various speed levels in the parent object are calculated as below:

If the volumetric air flow rate at one speed level is higher than the flow rate allowed by the fan in the parent object, the flow rate will be set back to the fan flow rate.

This Rated Volumetric Water Flow Rate is used to determine an internal scaling factor, and calculate the loop water flow rates.

And the required volumetric water flow rates in the parent object are calculated as below,

If and are equal to unity, the loop flow rates become the design flow rates of the Reference Unit (after scaled by the rated heating capacity). The Rated Volumetric Air Flow Rate and Rated Volumetric Water Flow Rate are introduced here to correlate with the actual flow rates in the air and water loops, in case that these differ from the design specification. Certainly, it is recommended that the Rated Volumetric Air Flow Rate and Rated Volumetric Water Flow Rate are selected in the way that and are unity, so as to get more accurate representations from the performance curves.

Performance curves:

This object includes 7 curve objects at each individual speed level.

1) Heating capacity modifier curve (function of temperature).

2) Heating capacity modifier curve (function of air flow fraction).

3) Heating capacity modifier curve (function of water flow fraction).

4) COP modifier curve (function of temperature).

5) COP modifier curve (function of air flow fraction).

6) COP modifier curve (function of water flow fraction).

7) Part load fraction correlation (function of part load ratio) .

The flow fraction modifier curves, i.e. Curves 2), 3), 5) and 6), are used as placeholders, to account for off-design flow rates if needed. If the manufacturer doesn’t provide off-design performances, we can simply use a default modification multiplier of 1.0. At the lowest speed, Curve 7) will be used to account for the part-load condition.

1) Heating capacity modifier curve (function of temperature)

The heating capacity modifier as a function of temperature curve is a biquadratic curve with two independent variables: water temperature entering the condenser coil, and the air dry bulb or wet bulb temperature entering the evaporator. The output of this curve is multiplied by the rated heating capacity at the speed, to give the heating capacity at the specific entering air and water temperatures at which the water heating unit is operating (i.e., at temperatures different from the rating point temperatures).

where

= dry-bulb or wet-bulb temperature of air entering the evaporator coil, °C

= entering water temperature, °C

a-f = regression curve-fit coefficients

2) Heating capacity modifier curve (function of air flow fraction)

where

= actual air mass flow rate/design air mass flow rate, at one speed level

a-d = regression curve-fit coefficients, if no data available for the correction, the user can simply put a = 1.0, and the other coefficients as 0.0.

3) Heating capacity modifier curve (function of water flow fraction)

where

= actual water mass flow rate/design water mass flow rate, at one speed level

a-d = regression curve-fit coefficients, if no data available for the correction, the user can simply put a = 1.0, and the other coefficients as 0.0.

4) COP modifier curve (function of temperature)

The COP modifier curve as a function of temperature is a biquadratic curve with two independent variables: dry-bulb or wet bulb temperature of air entering the evaporator coil and entering water temperature to the condenser. The output of this curve is multiplied by the rated COP at the speed, to give the COP at the specific entering air and water temperatures at which the water heating coil unit is operating (i.e. at temperatures different from the rating point temperatures).

where

= dry-bulb or wet-bulb temperature of air entering the evaporator coil, °C

= entering water temperature, °C

a-f = regression curve fit coefficients.

5) COP modifier curve (function of air flow fraction)

where

a-d = regression curve-fit coefficients, if no data available for correction, the user can simply put a = 1.0, and the other coefficients as 0.0.

6) COP modifier curve (function of water flow fraction)

where

a-d = regression curve fit coefficients, if no data available for the correction, the user can simply put a = 1.0, and the other coefficients as 0.0.

7) Part load fraction correlation (function of part load ratio)

This field defines the name of a quadratic or cubic performance curve (Ref: Performance Curves) that parameterizes the variation of electrical power input to the unit as a function of the part load ratio (PLR, heating load/steady-state heating capacity for Speed 1),

And

RTF = (PLR/PartLoadFrac) = runtime fraction of the heating coil

The part load fraction (PLF) correlation accounts for efficiency losses due to compressor cycling. 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 runs continuously for the simulation timestep). For PLR values between 0 and 1 (0 <= PLR < 1), the following rules apply:

PLF >= 0.7 and PLF >= PLR

If PLF < 0.7, 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, the runtime fraction of the coil is limited to 1.0. A typical part load fraction correlation would be:

Lowest Speed Operation:

The lowest speed operation of a VS water heating coil is similar to a single speed water heating coil. The heating capacity of the unit is calculated as follows:

And the COP is calculated as:

And the power consumption is,

The heating capacity calculated above may or may not include the impact of pump heat. For this reason, the user input Condenser Pump Heat Included in Rated Heating Capacity and Rated COP is used to determine the total water heating capacity including pump heat.

Compressor power (electricity consumption rate) is then calculated based on two additional inputs provided by the user. The first input specifies if the condenser pump heat is included in the rated heating capacity and rated COP. If the condenser pump heat is included in the rated heating capacity and COP, then condenser pump power must be subtracted from the water heating coil power calculated above to determine the compressor power. is the pump power consumption at the lowest compressor speed. The second of these inputs specifies if the evaporator fan power is included in the rated heating COP. If evaporator fan power is included in the rated COP, then fan power must also be subtracted from the water heating coil power to determine the compressor power as follows:

The model assumes that all the compressor power is rejected as heat via the DX heating coil. Therefore, the evaporator total cooling capacity at the current operating conditions is determined depending on the user input for pump heat:

The fraction of the actual air mass flow to the design air mass flow rate is calculated:

The fraction of the actual water mass flow to the design water mass flow rate is calculated:

The runtime fraction of the DX coil compressor is calculated as the ratio of the compressor part load ratio to the part load fraction correlation entered by the user. The part load ratio of the DX coil is determined by the heat pump water heater compound object (Ref. WaterHeater:HeatPump) and is used by the DX coil to determine the run time fraction of the compressor.

Calculations of the sensible heat transfer ratio, latent and sensible cooling capacities are the same as Coil:WaterHeating:AirToWaterHeatPump.

Higher Speed Operation:

At the speed level between the lowest and the highest, there is no part-load loss, i.e. RTF= 1.0. A parameter of speed ratio (SpeedRatio) is used to define the capacity partition between Speed x-1 and Speed x.

The design air and water flow rate at the speed ratio are given as following:

And the fractions of air flow and water flow are given:

= = actual air mass flow rate/DesignAirFlowRateSpeedRatio

= = actual water mass flow rate/DesignWaterFlowRateSpeedRatio

The heating capacities and COPs at Speed x-1 and Speed x are given:

The heating capacity at the corresponding speed ratio is:

And the power consumption is

If the speed reaches the highest level, the speed ratio becomes 1.0, and Speed x represents the highest speed.

For the higher speeds, calculations of the total water side heating capacity, evaporator cooling capacity and compressor power, i.e. how to add or subtract the pump and fan power, are the same as the lowest speed. The power power is interpolated between the two neighboring speed levels, and the fan power is obtained from a parent object.

Finally, the condenser water outlet temperature is calculated based on the total water heating capacity of the DX coil and the actual condenser water mass flow rate.

This evaporator cooling capacity is used to calculate the air-side performance of the heat pump water heater (HPWH) DX coil. The crankcase heater power, and the exiting air conditions for the HPWH DX coil are calculated the same way as they are for the DX cooling coil model (cycling fan, cycling coil).

Calculation of sensible heat ratio at off-rated conditions uses the ADP/BF approach described for the variable-speed, water-source cooling coil object, i.e. Coil:Cooling:WaterToAirHeatPump:VariableSpeedEquationFit. It is assumed that the Ao (effective surface area in the BF correlation) parameter mainly depends on the compressor speed. In the IDF file, the user needs to input SHRs at individual compressor speeds. And then, within the VS water heating coil module, the Ao parameter is calculated, specific to each compressor speed at the design air flow rate, and then do linear interpolation of Ao between neighboring compressor speeds. For calculating SHRs in energy simulations, the module first calculates the Ao parameter related to the actual compressor speed, and then uses the simulated Ao parameter in the original BF correlation to correlate the effect of varied indoor air flow rate.

The effective surface area in the correlations of BF factor, between speed levels, is calculated as below:

Using Ao,SpeedRatio in the same BF and SHR calculation procedure as the single speed DX cooling coil, one can get BFSpeedRatio, and SHRSpeedRatio. And the sensible cooling capacity is calculated:

The latent cooling capacity is calculated:

### Coil:WaterHeating:AirToWaterHeatPump:VariableSpeed Sizing

For the variable-speed air source water heating coil, a nominal speed level is specified. During the sizing calculation, the Rated Water Heating Capacity at the Selected Nominal Speed Level should be given by the user, i.e. can’t be autosized. The default nominal speed level will be the highest speed. However, the model allows the user to select a nominal speed level rather than the highest. If the user chooses to autosize the Rated Air and Water Volume Flow Rates, the flow rates, as compared to the Rated Water Heating Capacity, is sized to have the same ratio as the air and water volume flow rates to the water heating capacity at the nominal speed, of the Reference Unit.