EnergyPlus  
Engineering Reference

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

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### Humidifier Sizing

The rated power, or nominal electric power input of an Electric Steam Humidifier (Humidifier:Steam:Electric) is calculated from user specified rated capacity (m3/s) and the enthalpy change of the water from a reference temperature (20.0°C) to saturated steam at 100.0°C. Autosizing procedure assumes that electrical heating element in the humidifier heat the water from the reference temperature and generate saturated steam at 100°C, and electric to thermal energy conversion efficiency of 100.0%.

#### Rated Power



where

*Cp,w is the specific heat of water at average temperature ((100+20)/2 = 60.0 °C), (J/kgK);*

*ρw is the density of water at standard conditions (5.05 °C);*

*ΔTw is the sensible temperature rise of water (100.0 – 20.0=80.0 °C);*

* is the rated capacity of the humidifier in volumetric flow rate.*

*hfg is the latent heat of vaporization of water at 100.0°C, (J/kg);*

### Gas Fired Humidifier Sizing

The rated power, or nominal gas use rate of a gas steam humidifier (Humidifier:Steam:Gas) is calculated from user specified rated volumetric capacity (m3/s) and the enthalpy change of the water from a reference temperature of 20.0°C to a saturated steam at 100.0°C. Autosizing procedure assumes that gas heater in the humidifier convert the water from the reference temperature and generate saturated steam at 100°C, using gas to thermal energy conversion rated thermal efficiency.

#### Rated Gas Use Rate

The rated or nominal gas use rate is given by:



Where,

*Cp,w specific heat of water at average temperature ((100+20)/2 = 60.0 °C), (J/kgK);*

*ρw density of water at standard condition (5.05 °C);*

*ΔTw*  *sensible temperature rise of water (100.0 – 20.0=80.0 °C);*

* rated or nominal capacity of the humidifier, (m3/s)*

*hfg* *latent heat of vaporization of water at 100.0°C, (J/kg);*

*ηrated thermal efficiency at rated condition;*

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## Air System Humidifiers

### Overview

Air system humidifiers are components that add moisture to the supply air stream. They fall into 2 broad categories: spray type humidifiers which act like direct evaporative coolers, cooling the supply air as well as humidifying it; and dry steam humidifiers, which humidify the supply air stream while causing almost no change to the supply air stream temperature. The EnergyPlus electric and gas fired steam humidifier uses electrical energy and thermal energy, respectively, to convert ordinary tap water to steam which it then injects into the supply air stream by means of a blower fan. The actual electric dry steam unit might be an electrode-type humidifier or a resistance-type humidifier.

### Electric and Gas Steam Humidifier

The electric and gas fired steam humidifier model (object names: Humidifier:Steam:Electric and Humidifier:Steam:Gas) are based on moisture and enthalpy balance equations plus standard psychrometric relationships. The approach is similar to that taken in the ASHRAE HVAC 2 Toolkit, page 4-112 (ASHRAE 1993). EnergyPlus contains its own module of psychrometric routines; the psychrometric theory and relations are given in the 2001 edition of ASHRAE Fundamentals, Chapter 6 (ASHRAE 2001). The model contains both an ideal controller and the component. The control model assumes that there is a minimum humidity setpoint on the component air outlet node. This setpoint is established by a setpoint manager described elsewhere.

#### Model

The component model is a forward model: its inputs are its inlet conditions; its outputs are its outlet conditions and its energy consumption. The inputs are the temperature, humidity ratio, and mass flow rate of the inlet air stream, which are known; and the water addition rate (kg/s) which is determined by the controller. The moisture mass balance and psychometric calculations are identical for both gas and electric dry steam humidifiers. The only difference is how a heat source (electric or gas) is used to generate the steam.

#### Controller

The controller first decides whether the humidifier is on or off. For the humidifier to be on:

* the humidifier schedule value must be nonzero;
* the inlet air mass flow must be greater than zero;
* the inlet air humidity ratio must be less than the minimum humidity ratio setpoint.

If the humidifier is off, the water addition rate is set to zero. If the humidifier is on, the water addition rate needed to meet the humidity setpoint is calculated.



where

 = the air mass flow rate [kg/s]

= the inlet air humidity ratio [kg/kg]

 = water addition rate needed to meet the setpoint [kg/s]

= the humidity ratio setpoint [kg/kg]

Equation is the moisture balance equation for the component. It is solved for  (the other variables are known) which is passed to the humidifier component model as its desired inlet water addition rate.

#### Component

The inputs to the component model are the air inlet conditions and mass flow rate and the water addition rate set by the controller. The outputs are the air outlet conditions. First the desired water addition rate is checked against component capacity.



where

 = the humidifier nominal capacity [kg/s], a user input.

If  is zero, the outlet conditions are set to the inlet conditions and the water addition rate is set to zero. If the humidifier is scheduled on the component power consumption is set to the standby power consumption: . Otherwise  = 0.

If  > 0, then the moisture and enthalpy balance equations





with  set equal to  are solved for  and . Here

 = the air mass flow rate [kg/s]

= the inlet air humidity ratio [kg/kg]

 = the inlet water addition rate [kg/s]

 = the outlet air humidity ratio [kg/kg]

 = the inlet air specific enthalpy [J/kg]

 = the steam specific enthalpy = 2676125. [J/kg] at 100 oC

 = the outlet air specific enthalpy [J/kg]

The outlet temperature is obtained from



where

 = outlet air temperature [oC],

 is an EnergyPlus psychrometric function.

The humidity ratio at saturation at the outlet temperature is



where

 = the barometric pressure [Pa],

1.0 is the relative humidity at saturation,

 is an EnergyPlus psychrometric function.

IF  then the outlet condition is below the saturation curve and the desired moisture addition rate can be met.  is set to  and the calculation of outlet conditions is done. But if  then it is assumed that this condition will be detected and the steam addition rate throttled back to bring the outlet conditions back to the saturation condition. We need to find the point where the line drawn between state 1 (inlet) and state 2 (our desired outlet) crosses the saturation curve. This will be the new outlet condition. Rather than iterate to obtain this point, we find it approximately by solving for the point where 2 lines cross: the first drawn from state 1 to state 2, the second from ,  to , ; where

 is the inlet temperature [oC],

 is the humidity ratio at saturation at temperature  [kg/kg],

 is the desired outlet temperature [oC],

 is the humidity ratio at saturation at temperature  [kg/kg].

The 2 lines are given by the equations:





Solving for the point (state 3) where the lines cross:





This point isn't quite on the saturation curve since we made a linear approximation of the curve, but the temperature should be very close to the correct outlet temperature. We will use this temperature as the outlet temperature and move to the saturation curve for the outlet humidity and enthalpy. Thus we set  =  and





where  is an EnergyPlus psychrometric function. The water addition rate is set to



We now have the outlet conditions and the adjusted steam addition rate for the case where the desired outlet humidity results in an outlet state above the saturation curve. The energy consumption of the electric and gas steam humidifiers is calculated separately.

The electric steam humidifier electric consumption is given by



where

 = nominal fan power [W], a user input,

 = standby power [W], a user input.

The gas steam humidifier performance calculation is done for fixed and variable entering water temperature. The calculation procedure for fixed and variable entering water temperature are as follows.

***Fixed Inlet WaterTemperature:***

The gas steam humidifier gas consumption rate for fixed entering water temperature is given by:



The actual gas use rate accounting for gas fired humidifier thermal efficiency variation with part load ratio is given by:







where,

 = thermal efficiency modifier curve value as function of part load ratio. This curve is generated from manufacturer’s part load performance data.

 = part load ratio, (-).

 = nominal or rated gas use rate, (Watts).

 = actual gas use rate, (Watts).

 = nominal or rated thermal efficiency of gas fired steam humidifier, (-)

 = actual thermal efficiency of gas fired steam humidifier accounting for part load

performance, (-).

***Variable Inlet WaterTemperature****:*

The gas use rate is determined from the theoretical gas input rate and actual thermal efficiency. The actual thermal efficiency is the rated thermal efficiency corrected for part load ratio operation. At steady state the gas use rate is given by:









where,

 = temperature of water entering the gas steam humidifier, °C. This value depends on the water source.

If the rated gas use rated input field is not autosized, then user specified thermal efficiency will be overriden with a value calculated from user specified rated gas use rate, nominal capacity (m3/s) and design conditions as follows:



The gas steam humidifier requires electric power input to the blower fan and associated control units. The auxiliary electric power input rate of the gas steam humidifier is given by:



where

 = nominal fan power [W], a user input,

 = control electric power [W], a user input.

The water consumption rate in m3/s for electric and steam humidifier at a reference temperature of 5.05 °C is given by:



where

 = the water consumption rate [m3],

 = water density (998.2 kg/m3).

#### References

ASHRAE. 1993. HVAC 2 Toolkit: A Toolkit for Secondary HVAC System Energy Calculations. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 2001. 2001 ASHRAE Handbook Fundamentals. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

## Zone Internal Gains