TYPE 753: HEATING COIL WITH VARIOUS CONTROL MODES

General Description

Type753 models a heating coil using one of three control modes. The heating coil is modeled using a bypass approach in which the user specifies a fraction of the air stream that bypasses the coil. The remainder of the air stream is assumed to exit the coil at the average temperature of the fluid in the coil. The air stream passing through the coil is then remixed with the air stream that bypassed the coil. In its unrestrained (uncontrolled) mode of operation, the coil heats the air stream as much as possible given the inlet conditions of both the air and the fluid streams. The model is alternatively able to internally bypass air around the coil so as to maintain the outlet air dry bulb temperature above a user specified minimum, or to maintain the fluid outlet temperature above a user specified minimum.

Nomenclature

P_{out}	[atm]	Air outlet pressure
P_{in}	[atm]	Air inlet pressure
ΔP	[atm]	Air pressure drop through the coil.
$\dot{m}_{cond}$	[kg/hr]	Flow rate of condensate draining from the coil.
$\dot{m}_{fluid}$	[kg/hr]	Total flow rate of fluid through the coil (includes bypassed fluid).
$\dot{m}_{air}$	[kg/hr]	Total flow rate of air through the coil (includes bypassed air).
$f_{AirBypass}$	[0..1]	Fraction of air bypassed around the coil (user defined)
$f_{FluidBypass}$	[0..1]	Fraction of fluid bypassed around the coil (calculated by this model)
$\omega_{air,out}$	[kgH_2O/kgAir]	Absolute humidity ratio of air exiting the coil after mixing
$\omega_{air,in}$	[kgH_2O/kgAir]	Absolute humidity ratio of air entering the coil.
$\omega_{air,CoilOut}$	[kgH_2O/kgAir]	Absolute humidity ratio of air exiting the coil before remixed with bypassed air.
$h_{air,CoilOut}$	[kJ/kg]	Enthalpy of air exiting the coil before mixing
$h_{air,in}$	[kJ/kg]	Enthalpy of air entering the coil.
$h_{air,out}$	[kJ/kg]	Enthalpy of air exiting the coil remixed with bypassed air.
$\dot{Q}_{fluid}$	[kJ/hr]	Energy transferred from the air stream to the fluid stream.
$\dot{Q}_{air}$	[kJ/hr]	Energy transferred from the fluid stream to the air stream.
Cp_{fluid}	[kJ/kg.K]	Specific heat of coil fluid
$T_{fluid,CoilOut}$	[ºC]	Temperature of fluid exiting the coil (before remixing with bypassed fluid)
$T_{fluid,out}$	[ºC]	Temperature of fluid exiting the coil (after remixing with bypassed fluid)
$T_{fluid,in}$	[ºC]	Temperature of fluid entering the coil.
$T_{air,in}$	[ºC]	Temperature of air entering the coil.
$T_{guess,new}$	[ºC]	An updated coil fluid outlet temperature guess
$T_{guess,old}$	[ºC]	The previous coil fluid outlet temperature guess.

Detailed Description

A heating coil is a device that heats air by passing it in proximity to tubes containing a hot liquid. Energy is transferred from the hotter liquid to the cooler air. In order to maintain the desired outlet condition, the air stream is split between a stream that passes across the coil, exiting at the coil average fluid temperature and a part that does not come into any contact with the coil but is bypassed around the coil at its inlet state. It is then remixed with the fraction of the air stream that did pass through the coil. Figure 1 shows a schematic diagram of the technique used to model heating coils.

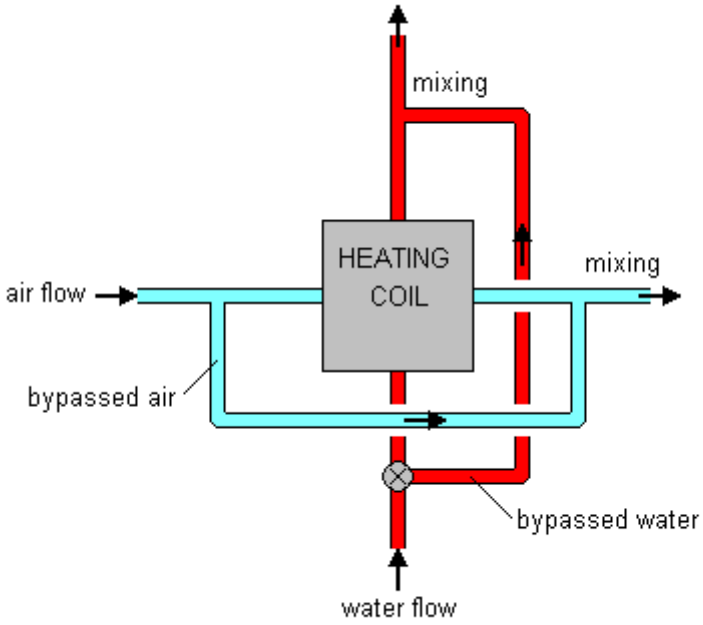


Figure 1: Heating Coil Model Schematic

Each time Type753 is accessed, it fully determines the air inlet state by making a call to the TRNSYS Psychrometrics routine with inlet air pressure, dry bulb temperature, and depending upon the value of parameter 1 either absolute humidity ratio or relative humidity. If Psychrometrics is given a humidity ratio condition that results in saturated, the routine warns the user and resets the humidity ratio to the saturation value for that dry bulb temperature.

No Flow Condition

If there is a zero flow on either the fluid or the air side of the heating coil, Type753 sets the air outlet pressure to its inlet value minus the air side pressure drop as indicated by equation 753.1.

$$P_{out} = P_{in} - \Delta P \qquad \text{(Eq. 753.1)}$$

The air outlet humidity ratio and enthalpy are set to the corresponding inlet conditions and the Psychrometrics routine is called to fully determine the air outlet state. Because of the air side pressure drop, the air may exit the device saturated in which case the flow rate of condensate is given by equation 753.2

$$\dot{m}_{cond} = \dot{m}_{air}\left(\omega_{air,in} - \omega_{air,out}\right) \qquad \text{(Eq. 753.2)}$$

The temperature of the condensate flow is set to the outlet air temperature. Under the no flow condition, the fluid outlet temperature is assumed to exit at its inlet temperature and all energy transfer rates are set to zero. The fluid bypass fraction under no flow conditions is also set to zero. The air bypass fraction is defined by the user as an input to the model.

Flow Condition Special Cases

Three special cases are checked by Type753. In the first of these cases, there may be flow in both the water and the air sides of the device but the coil inlet temperature is lower than the air temperature. Under this circumstance, no matter what the device set points, the coil is unable to heat the air to any degree and the entire fluid stream is bypassed around the coil. The air exits at the pressure given by equation 753.1, at its inlet enthalpy and at its inlet humidity ratio. A call is made to Psychrometrics and again, the humidity ratio may be reset to saturation conditions if appropriate. The flow rate of condensate is given by 753.2 and again its temperature is set to the outlet air temperature returned by Psychrometrics.

In the second special case scenario, the air outlet temperature is being controlled but the inlet air temperature is already higher than the desired outlet temperature. Regardless of coil conditions, air should not be further heated and so fluid is bypassed around the coil. The outlet states are set in the same manner as they were in the first special flow case.

The third special flow case is much the same as the second only the fluid outlet temperature is being controlled to stay below a user defined maximum and the desired fluid outlet temperature is already higher than the fluid inlet temperature. Under this circumstance any contact that the fluid has with the air stream will only heat up the fluid stream and so again the fluid is completely bypassed around the coil.

Normal Flow Conditions

When fluid and air are flowing through the device and either the device is in its "free float" case or if the air and fluid temperature set points have not been exceeded then Type753 initiates an iterative process to balance the quantity of energy that is removed from the air stream with the quantity of energy that is added to the fluid stream all the while insuring that the air exits the coil (before remixing) at the average coil temperature, which is not known but must be guessed. In the iteration, a coil fluid outlet temperature is guessed and it is first assumed that the entire fluid stream flows through the coil (in other words the bypass fraction of the fluid is 0). The air is assumed to exit at the coil fluid average temperature, at its inlet humidity ratio, and at the outlet pressure given by 753.1. The energy transferred from the fluid and to the air stream is therefore:

$$\dot{Q}_{fluid} = \dot{m}_{air}\left(1 - f_{AirBypass}\right)\left(h_{air,CoilOut} - h_{air,in}\right) \qquad \text{(Eq. 753.3)}$$

The fluid outlet temperature is then calculated as

$$T_{fluid,CoilOut} = T_{fluid,in} - \frac{\dot{Q}_{fluid}}{\dot{m}_{fluid}\ Cp_{fluid}} \qquad \text{(Eq. 753.4)}$$

Physically, the fluid cannot exit the heating coil at a temperature lower than the entering air temperature. Thus Type753 checks to make sure that the outlet fluid temperature is lower than the air inlet

temperature. If it is not, then it is automatically set equal to the air inlet temperature and the energy added to the fluid stream is recalculated based on equation 753.5.

$$\dot{Q}_{fluid} = \dot{m}_{fluid}\ Cp_{fluid}\left(T_{fluid,in} - T_{air,in}\right) \qquad \text{(Eq. 753.5)}$$

This same amount of energy must be removed from the air stream. Thus the air outlet enthalpy can be calculated

$$h_{air,CoilOut} = h_{air,in} + \frac{\dot{Q}_{fluid}}{\dot{m}_{air}\left(1 - f_{AirBypass}\right)} \qquad \text{(Eq. 753.6)}$$

The air outlet humidity ratio is assumed not to change from its inlet value and the outlet pressure is given by equation 753.1 before making a call to Psychrometrics to fully determine the air outlet state.

At this point the difference between the initially guessed fluid outlet temperature and the most recently calculated fluid outlet temperature is calculated. If the difference falls within a tolerance that is specified within the Fortran code, the guess was appropriate. If the difference is greater than the tolerance, a new temperature is guessed and the process begins again. The new temperature guessed is given by equation 753.7

$$T_{guess,new} = T_{guess,old} + \frac{T_{fluid,CoilOut} - T_{guess,old}}{4} \qquad \text{(Eq. 753.7)}$$

Once the energy transfers have balanced, the bypassed air stream is mixed with the air stream coming off the coil. The humidity ratio of air before mixing is stored for later use when determining whether condensation will occur during mixing. The mixing equations for enthalpy and humidity ratio are given as equations 753.8a and 753.8b.

$$h_{air,out} = \left(1 - f_{AirBypass}\right) h_{air,CoilOut} + f_{AirBypass}\ h_{air,in} \qquad \text{(Eq. 753.8a)}$$

$$\omega_{air,out} = \left(1 - f_{AirBypass}\right) \omega_{air,CoilOut} + f_{AirBypass}\ \omega_{air,in} \qquad \text{(Eq. 753.8b)}$$

Psychrometrics is called with the outlet conditions and a check is made to see whether condensation has occurred when mixing the air streams. If it is, the condensate flows out at the air outlet temperature.

We have, at this point assumed that the coil is not being controlled and that all of the fluid flow passes through the coil. During later iterations or when the coil is being controlled, it is necessary to mix the fluid stream that passes through the coil back into the fluid stream that has been bypassed around the coil. The mixing equation is

$$T_{fluid,out} = \dot{m}_{fluid}\left(1 - f_{FluidBypass}\right) T_{fluid,CoilOut} + \dot{m}_{fluid}\ f_{FluidBypass}\ T_{fluid,in} \qquad \text{(Eq. 753.9)}$$

The energy transferred to the air stream is given by equation 753.10.

$$\dot{Q}_{air} = \dot{m}_{air}\left(h_{air,out} - h_{air,in}\right) \qquad \text{(Eq. 753.10)}$$

If the heating coil is unrestrained (not being controlled) then the model has completed all its calculations at this point. If, however, the outlet air temperature is being controlled not to fall below a certain user defined temperature, the outlet temperature is next checked against the set point. If the air outlet temperature is below the set point having assumed that all of the fluid passes through the coil, then there are no modifications that can be made to further heat the air. If, on the other hand, the air is above its set point temperature, then fluid can be bypassed around the coil so that the air temperature comes down to its set point. A new fluid bypass fraction is guessed and the entire iteration process, beginning with guessing a coil fluid outlet temperature begins again.

Likewise, if the outlet fluid temperature is being controlled to stay above a minimum temperature and the mixed fluid temperature is already above the set point temperature then bypassing fluid will not help. If, however, the fluid is coming out colder than desired, bypassing fluid around the coil may bring the outlet fluid temperature up. A higher bypass fraction is guessed and iteration begins again.