TYPE 757: INDIRECT EVAPORATIVE COOLER

General Description

Type757 models an evaporative cooling device for which the user supplies the inlet air conditions of a primary and secondary air stream and the device effectiveness as a function of primary stream inlet air dry bulb temperature and secondary stream inlet air wet bulb temperature. The model calculates outlet air conditions and assumes that the secondary air stream process is a constant wet bulb temperature process meaning that air enters and exits at the same wet bulb temperature. The device is not equipped with controls that monitor the conditions of the outlet air. When the device is ON (based on a user supplied control signal value), Type757 cools the primary air stream as much as it can given the entering conditions and the device effectiveness.

Nomenclature

$P_{primary,in}$	[atm]	The absolute pressure of air entering the primary side of the device
$P_{primary,out}$	[atm]	The absolute pressure of air exiting the primary side of the device
$P_{sec,in}$	[atm]	The absolute pressure of air entering the secondary side of the device
$P_{sec,out}$	[atm]	The absolute pressure of air exiting the secondary side of the device
$\Delta P_{primary}$	[atm]	The pressure drop of air flowing through the primary side of the device
ΔP_{sec}	[atm]	The pressure drop of air flowing through the secondary side of the device
$\dot{m}_{cond}$	[kg/hr]	The flow rate of condensate draining from the primary side of the device.
$\dot{m}_{primary}$	[kg/hr]	The mass flow rate of dry air flowing through the primary side of the device.
$\dot{m}_{sec}$	[kg/hr]	The mass flow rate of dry air flowing through the secondary side of the device.
$\omega_{primary,in}$	[kgH_2O/kgAir]	The absolute humidity ratio of air entering the primary side of the device
$\omega_{primary,out}$	[kgH_2O/kgAir]	The absolute humidity ratio of air exiting the primary side of the device
$\omega_{sec,in}$	[kgH_2O/kgAir]	The absolute humidity ratio of air entering the secondary side of the device
$\omega_{sec,out}$	[kgH_2O/kgAir]	The absolute humidity ratio of air exiting the secondary side of the device
$T_{primary,in}$	[ºC]	The dry bulb temperature of air entering the primary side of the device
$T_{primary,out}$	[ºC]	The dry bulb temperature of air exiting the primary side of the device
$T_{sec,in}$	[ºC]	The dry bulb temperature of air entering the secondary side of the device
$T_{sec,out}$	[ºC]	The dry bulb temperature of air exiting the secondary side of the device
$h_{primary,in}$	[kJ/kg]	The enthalpy of air entering the primary side of the device
$h_{primary,out}$	[kJ/kg]	The enthalpy of air exiting the primary side of the device
$h_{sec,in}$	[kJ/kg]	The enthalpy of air entering the secondary side of the device
$h_{sec,out}$	[kJ/kg]	The enthalpy of air exiting the secondary side of the device
$WB_{primary,in}$	[ºC]	The wet bulb temperature of air entering the primary side of the device
$WB_{primary,out}$	[ºC]	The wet bulb temperature of air exiting the primary side of the device
$WB_{sec,in}$	[ºC]	The wet bulb temperature of air entering the secondary side of the device

$WB_{sec,out}$	[ºC]	The wet bulb temperature of air exiting the secondary side of the device
$\dot{Q}_{up}$	[kJ/hr]	The energy transferred from the primary air stream to the secondary air stream
$\dot{Q}_{evap}$	[kJ/hr]	The energy of evaporation in the secondary air stream.
$\dot{Q}_{max}$	[kJ/hr]	The maximum amount of energy that can be absorbed by the secondary air stream.
ERR	[kJ/hr]	The energy balance error between air exiting the primary stream and energy absorbed in the secondary air stream.
Cp_{sec}	[kJ/kg.K]	The specific heat of air in the secondary air stream.
ε	[0..1]	The device effectiveness.

Detailed Description

A direct evaporative cooler (sometimes called a swamp cooler) is a device that cools air by passing it across a wet medium. Such devices can be found in many configurations ranging from those in which air is passed across a solid matrix that contains water (such as a wet sponge or filter) or in which air passes directly over an open tray of water. As hot air passes over the wet media, some of its energy goes to evaporating water from the media. The air comes out of the other side of the device having given up some of its energy and consequently, exits at a lower temperature and a higher humidity. In an indirect evaporative cooler, the stream being cooled does not actually come into physical contact with the wetted medium as it does in a direct evaporative cooler. In an indirect evaporative cooler, a secondary air stream passes over a wetted surface, evaporating some of the moisture from that surface and cooling it. The primary air stream is also in contact with the evaporatively cooled surface and gives up some of its energy to that surface. Figure 1 shows a schematic diagram of a possible indirect evaporative cooler configuration.

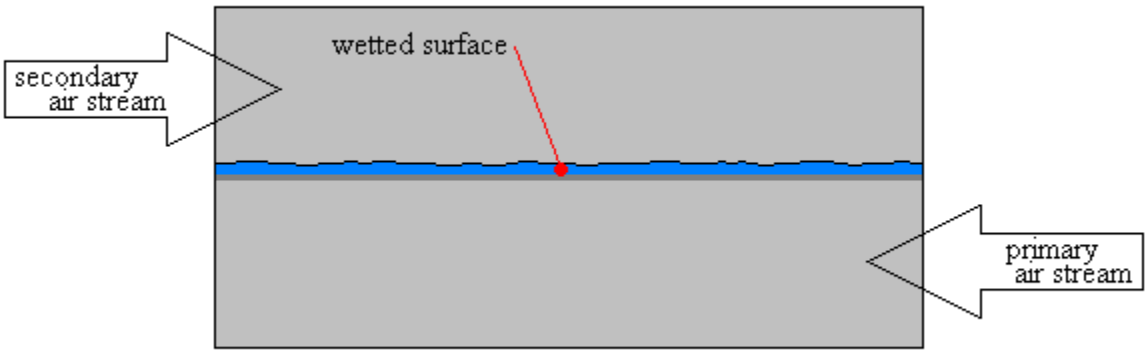


Figure 1: Indirect Evaporative Cooler Schematic

Evaporative cooling devices may either be controlled or uncontrolled. In an uncontrolled device such as this component models, secondary stream air passes across the wetted media and primary stream air passes across the cooled surface at rate set by one or more fans. The flow rate is not modulated in any way and the air comes out at a state determined entirely by the inlet air conditions and the effectiveness of the device.

Type757 performs an energy balance on the liquid in the secondary air stream. The energy balance is shown in Figure 2.

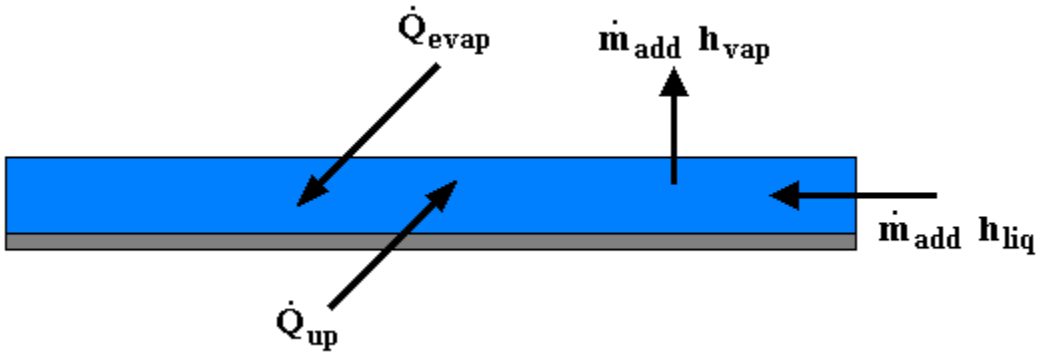


Figure 2: Wetted Surface Energy Balance

At each time step, Type757 fully determines the air inlet state of both the primary and secondary air streams by performing a call to the TRNSYS Psychrometrics routine. Depending upon the Type757 mode of operation, the user must specify inlet air pressure, dry bulb temperature, and either relative humidity or humidity ratio for each of the two air streams. The Psychrometrics routine returns the inlet air wet bulb temperatures and enthalpies. If the inlet conditions sent to Psychrometrics were such that the inlet air is saturated, the returned wet bulb temperature, relative humidity and humidity ratio will correspond to the saturated air condition at the inlet dry bulb temperature. If this situation arises and Psychrometrics modifies the inlet air condition, the user will find a warning printed in the simulation log and list files.

No Flow Conditions

When either the secondary or the primary air stream flow rate is zero or if the entering primary stream dry bulb temperature is lower than the entering secondary stream wet bulb temperature then the device cannot transfer energy. The outlet air stream pressures are set according to equation 757.1a and 757.1b.

$$P_{\text{sec},out} = P_{\text{sec},in} - \Delta P_{\text{sec}} \quad \text{(Eq. 757.1a)}$$

$$P_{primary,out} = P_{primary,in} - \Delta P_{primary} \quad \text{(Eq. 757.1b)}$$

The outlet air stream enthalpies and humidity ratios are set to their corresponding inlet values and Psychrometrics is called to fully determine the air outlet states. Again, Psychrometrics may reset the exiting primary air stream humidity ratio if the pressure drop has caused condensation to occur. The mass flow rate of condensate is calculated using equation 757.2.

$$\dot{m}_{cond} = \dot{m}_{primary}\left(\omega_{primary,in} - \omega_{primary,out}\right) \quad \text{(Eq. 757.2)}$$

Flow Conditions

When Type757 is able to transfer energy between the primary and secondary air streams, it first performs a call to the TRNSYS Data Reading routine with the user defined primary air stream inlet dry bulb temperature and the secondary air stream inlet wet bulb temperature. The Data Reading routine returns the device effectiveness, which is defined by equation 757.3

$$\varepsilon = \frac{T_{primary,in} - T_{primary,out}}{T_{primary,in} - WB_{primary,in}} \quad \text{(Eq. 757.3)}$$

Since the data file that provides device effectiveness is to be read by the TRNSYS Data Reading routine, the file syntax must conform to the standard format. That is to say that the first line of the data file must contain at least one value of inlet dry bulb temperature of the primary air stream, specified in degrees C. The second line must contain at least one value of inlet wet bulb temperature of the secondary air stream, also specified in degrees C. The subsequent lines much each contain a single value of effectiveness that corresponds to a single pair of primary air stream inlet dry bulb temperature and secondary air stream inlet wet bulb temperature. An example data file has been provided with this component in the "\trnsys16\TESS Models\SampleCatalogData\ directory and has been reproduced for reference at the end of this document. As with all calls to the TRNSYS Data routine, Data is able to interpolate in multiple dimensions within the range of independent variable values present in the file. In the case of Type757's call to the Data routine, the independent variables are primary stream inlet dry bulb temperature and secondary stream inlet wet bulb temperature. The TRNSYS Data routine is not able to extrapolate beyond the data range present in the file. If a value above or below the range is given Data will return the values that correspond to the maximum or the minimum of the range and will print a warning to the TRNSYS list file and simulation log files. With the returned effectiveness value, Type757 next calculates the expected exiting primary stream dry bulb temperature. The full state of the exiting primary air stream is next determined through a call to the Psychrometrics routine. If Psychrometrics is sent saturation conditions, it again resets the exiting primary stream humidity ratio, in which case the condensate flow rate is calculated using equation 757.2. In order to calculate the total energy transfer from the primary air stream, the enthalpy of the condensate must be known. This value is determined through a call to the TRNSYS Steam routine. The condensate is assumed to drain from the primary air stream as a saturated liquid at the same temperature as the exiting air. The total energy transfer (Q_{up} in Figure 2) is given by 757.4.

$$\dot{Q}_{up} = \dot{m}_{primary}\left(h_{primary,in} - h_{primary,out}\right) \quad \text{(Eq. 757.4)}$$

On the secondary air stream side of the device, the air cannot exit at a dry bulb temperature lower than the inlet wet bulb temperature; otherwise it is over saturated. Consequently, a limiting case is next checked by Type757. The secondary air stream outlet dry bulb temperature is set to the secondary air stream inlet wet bulb and an average secondary air stream dry bulb temperature is calculated. This average temperature is used in a call to the TRNSYS Air Properties routine, which returns the corresponding air specific heat. The Psychrometrics routine is next called with secondary stream outlet pressure, and equal dry and wet bulb temperatures, both set to the entering wet bulb temperature. The secondary air stream is assumed to undergo a constant wet bulb process. Thus the entering and exiting wet bulb temperatures are equal. Psychrometrics returns the exiting air humidity ratio.

The latent heat of vaporization is next calculated by calling the TRNSYS Steam Properties routine twice, once with the average secondary stream dry bulb temperature and a vapor quality of zero then again with the average secondary stream dry bulb temperature and a vapor quality of one. The returned values give the enthalpy of the saturated liquid and of the saturated vapor in the secondary air stream. The energy that was expended evaporating water from the wetted surface in the secondary air stream duct is given by equation 757.5

$$\dot{Q}_{evap} = \dot{m}_{\sec}\left(h_{vapor} - h_{liquid}\right)\left(\omega_{\sec,out} - \omega_{\sec,in}\right) \quad \text{(Eq. 757.5)}$$

The term ($h_{vapor} - h_{liquid}$) is referred to as the latent heat of vaporization. The maximum amount of energy that can be transferred from the primary to the secondary air stream is then

$$\dot{Q}_{\max} = \dot{m}_{\sec}\left(h_{vapor} - h_{liquid}\right)\left(\omega_{\sec,out} - \omega_{\sec,in}\right) + \dot{m}_{\sec} Cp_{\sec}\left(T_{\sec,in} - T_{\sec,out}\right) \qquad \text{(Eq. 757.6)}$$

If necessary, the total energy transfer calculated in equation 757.4 is limited to the value calculated in equation 757.6 because the secondary air stream cannot absorb all of the energy that is being rejected by the primary stream. Under normal circumstances, the primary air stream energy removal would not be larger than the maximum amount of energy that can be absorbed in the secondary air stream. Only if the data file contains unrealistic effectiveness values might limiting cases come into play.

To this point in the model it has been assumed that the dry bulb temperature of air exiting the secondary stream is equal to the wet bulb temperature of air entering that stream. In other words it has been assumed that air exits the secondary side saturated. This, however, may not balance energy with the amount of energy that was removed from the primary air stream based upon effectiveness data. If energy does not balance between Q_{up} and Q_{max}, Type757 initiates an iterative search to find a value of the exiting secondary air dry bulb temperature that balances energy with the calculated Q_{up}. The energy balance error is obtained by combining equations 757.6 and 757.4 to obtain 757.7

$$\begin{aligned} ERR = {} & \dot{m}_{\sec} Cp_{\sec}\left(T_{\sec,out} - T_{\sec,in}\right) - \dot{m}_{\sec}\left(h_{vapor} - h_{liquid}\right)\left(\omega_{\sec,out} - \omega_{\sec,in}\right) \\ & + \dot{m}_{primary}\left(h_{primary,in} - h_{primary,out}\right) \end{aligned} \qquad \text{(Eq. 757.7)}$$

The following table contains example data from the file required by Type757.

Sample Indirect.dat

```
20.0  25.0  30.0  35.0  40.0 !Inlet dry bulb temperatures of the primary air stream (degrees C)
10.0  15.0  20.0  25.0       !Inlet wet bulb temperatures of the secondary air stream (degrees C)
0.30                     !  Effectiveness of the device at 10 WB, 20 DB
0.15                     !  Effectiveness of the device at 10 WB, 25 DB
0.00                     !  Effectiveness of the device at 10 WB, 30 DB
0.00                     !  Effectiveness of the device at 10 WB, 35 DB
0.40                     !  Effectiveness of the device at 10 WB, 40 DB
0.35                     !  Effectiveness of the device at 15 WB, 20 DB
0.30                     !  Effectiveness of the device at 15 WB, 25 DB
0.00                     !  Effectiveness of the device at 15 WB, 30 DB
0.50                     !  Effectiveness of the device at 15 WB, 35 DB
0.45                     !  Effectiveness of the device at 15 WB, 40 DB
0.40                     !  Effectiveness of the device at 20 WB, 20 DB
0.35                     !  Effectiveness of the device at 20 WB, 25 DB
0.60                     !  Effectiveness of the device at 20 WB, 30 DB
0.55                     !  Effectiveness of the device at 20 WB, 35 DB
0.50                     !  Effectiveness of the device at 20 WB, 40 DB
0.45                     !  Effectiveness of the device at 25 WB, 20 DB
0.70                     !  Effectiveness of the device at 25 WB, 25 DB
0.65                     !  Effectiveness of the device at 25 WB, 30 DB
0.60                     !  Effectiveness of the device at 25 WB, 35 DB
0.55                     !  Effectiveness of the device at 25 WB, 40 DB
```