TYPE 510: CLOSED CIRCUIT COOLING TOWER



Image from www.baltimoreaircoil.com

General Description

Type510 models a closed circuit cooling tower; a device used to cool a liquid stream by evaporating water from the outside of coils containing the working fluid. The working fluid is completely isolated from the air and water in this type of system. Closed circuit cooling towers are often referred to as indirect cooling towers or indirect evaporators.

Nomenclature

a	[-]	normalized power coefficients
Cp	[kJ/kg.K]	specific heat
$h(T)$	[kJ/hr.m^2.K]	heat transfer coefficient between the fluid and the air at the given temperature T
$\dot{m}$	[kg/hr]	mass flow rate (if its air it's the dry air mass flow rate)
P	[kJ/hr]	power
$\dot{Q}$	[kJ/hr]	heat transfer rate
T	[C]	temperature
y	[-]	exponent
γ	[-]	ratio of flow rate to design flow rate

Subscripts

air	refers to the air stream
design	refers to the design condition
fluid	refers to the fluid flowing through the coils (typically water)
in	refers to the condition at the inlet to the device
out	refers to the condition at the outlet from the device
sat	refers to the saturated air condition

Detailed Description

This model relies on algorithms presented in the technical paper "Building Energy and System Simulation Programs: Model Development, Coupling and Integration" by G.Zweifel, V.Dorer, M.Koschenz, and A.Weber. Users should consult this excellent resource for more detailed information on the process of modeling closed circuit cooling towers. Only a short technical discussion will be included in this document.

This model requires the user to provide conditions at the design point and then calculates the performance of the device over a wide range of off-design conditions. The design conditions are easy to find from a manufacturer's web site or technical brochures. While fundamentally simple, this model has repeatedly proven to match manufacturer's catalog data values over a wide range of operating conditions common to the HVAC and industrial fields.

The model relies on the basic premise that the saturated air temperature is the temperature at the air-water interface and is also the temperature of the outlet fluid (1). With this assumption the authors demonstrate that the saturated air enthalpy can be calculated from:

$$h_{sat}\left(T_{fluid,out}\right) = h_{air}\left(T_{air,in}\right) + \frac{\dot{Q}_{fluid}}{\dot{m}_{air}\left(1-\exp\left[-\lambda_{design}\left(\frac{\dot{m}_{air}}{\dot{m}_{air,design}}\right)^{y-1}\right]\right)} \qquad \text{(Eq. 510.1)}$$

Where y = 0.6 for most applications and:

$$\lambda_{design} = \ln\left[\frac{h_{sat}\left(T_{fluid,out,design}\right) - h_{air}\left(T_{air,in,design}\right)}{h_{sat}\left(T_{fluid,out,design}\right) - h_{air}\left(T_{air,out,design}\right)}\right] \qquad \text{(Eq. 510.2)}$$

The outlet fluid temperature at design conditions, the air and fluid flow rates at design conditions, and the inlet air conditions at design conditions are required by the model as parameters. From equation 510.2, this leaves only the outlet air enthalpy at design conditions ($h_{air}\left(T_{air,out,design}\right)$) as an unknown in order to solve for λ_{design}. However, the outlet air enthalpy may be found from an energy balance on the cooling tower and can be expressed as:

$$\dot{Q}_{fluid,design} = \dot{m}_{fluid} Cp_{fluid}\left(T_{fluid,in,design} - T_{fluid,out,design}\right) \qquad \text{(Eq. 510.3)}$$

$$h_{air}\left(T_{air,out,design}\right) = h_{air}\left(T_{air,in,design}\right) + \frac{\dot{Q}_{fluid,design}}{\dot{m}_{air}} \qquad \text{(Eq. 510.4)}$$

Using the energy balance on the fluid-side, equation 510.1 can now be rewritten as:

$$h_{sat}\left(T_{fluid,out}\right) = h_{air}\left(T_{air,in}\right) + \frac{\dot{m}_{fluid} Cp_{fluid}\left(T_{fluid,in} - T_{fluid,out}\right)}{\dot{m}_{air}\left(1-\exp\left[-\lambda_{design}\left(\gamma_{air}\right)^{-0.4}\right]\right)} \qquad \text{(Eq. 510.5)}$$

Where the fan control signal is defined as:

$$\gamma_{air} = \frac{\dot{m}_{air}}{\dot{m}_{air,design}} \quad \text{(Eq. 510.6)}$$

Given the inlet air temperature, humidity and flow rate (all inputs to the model), the fan control signal (an input), the inlet fluid temperature and flow rate (inputs), and the fluid properties (parameter), equation 510.5 can be iteratively solved in order to calculate the outlet fluid temperature.

The air flow rate is calculated by multiplying the design air flow rate (a parameter) by the input fan control signal:

$$\dot{m}_{air} = \dot{m}_{air,design}\ \gamma_{air} \quad \text{(Eq. 510.7)}$$

The power drawn by the fan when operating is given by equation 510.8 where the "a" coefficients are parameters provided by the user.

$$\dot{P}_{fan} = \dot{P}_{fan,rated}\left[a_0 + a_1(\gamma_{air}) + a_2(\gamma_{air})^2 + a_3(\gamma_{air})^3 + ..\right] \quad \text{(Eq. 510.8)}$$

References

1) "Building Energy and System Simulation Programs: Model Development, Coupling and Integration", G.Zweifel, V.Dorer, M.Koschenz, and A.Weber, EMPA

2) "Introduction to Heat Transfer", F.Incropera and D.DeWitt, John Wiley and Sons Inc, 1985