Cooling Towers

This is an abstract (100% copy) of the report "MICROSCALE ASSESSMENT OF THE ANTHROPOGENIC HEAT MITIGATION STRATEGIES" by Ayu Sukma Adelia, Jordan Ivanchev, Luis G. Resende Santos, David Kayanan, Jimeno A. Fonseca, Ido Nevat.
Available in here: https://www.research-collection.ethz.ch/handle/20.500.11850/453429

Cooling towers work by feeding cool water to the heat load (e.g. an AC system's condenser). The warmed water then exchanges the heat with a continuous stream of ambient air by evaporative cooling. We model this process as a controlled volume, thermodynamic system as shown in fig. 7, which is governed by the 1st Law of Thermodynamics (energy balance) as

$$\dot{m}_{w1}h_{w1} - \dot{m}_{w2}h_{w2} = \dot{m}_{a4}h_{a4} - \dot{m}_{a3}h_{a3} \tag{2}$$

next, by mass balance as

$$\dot{m}_{a3} = \dot{m}_{a4} = \dot{m}_{a} \tag{3}$$

$$\dot{m}_{w1} - \dot{m}_{w2} = \dot{m}_{a}(w_4 - w_3) \tag{4}$$

and by the water sensible heat gain as

$$\dot{Q} = \dot{m}_{w1}c_w(HWT - CWT) \tag{5}$$

where the subscripts w and a refer to liquid water and humid air, respectively. $\dot{m}$ are mass flows, h are enthalpies, and w are humidity ratios. The heat load is given by $\dot{Q}$. HWT and

CWT are the hot and cold water temperature, respectively. c_w is the specific heat capacity of water.

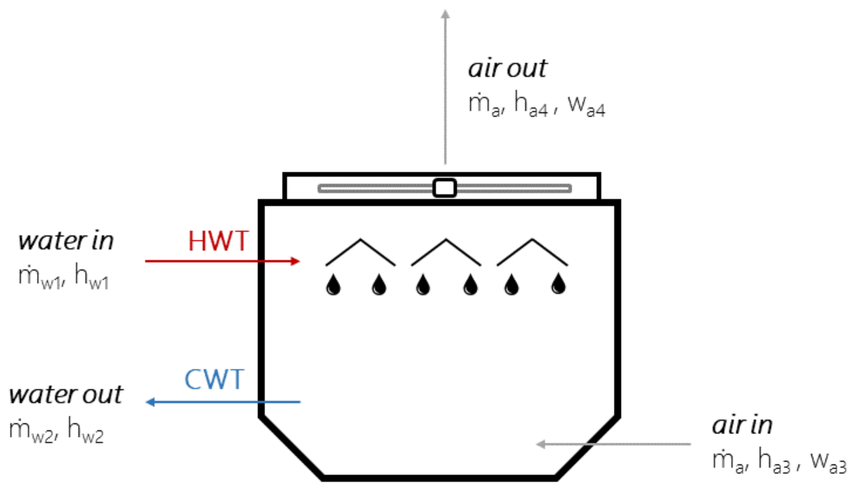

Figure 7: Thermodynamic system model of a cooling tower

Given an hourly AC heat load $[kW]$, which is assumed to include the cooling tower pump work, and the ambient air conditions (in particular, the wet bulb temperature, WBT in $[°C]$), the model then calculates the exhaust air state and the air mass flow. The output is the hourly exhaust dry bulb temperature (DBT in $[°C]$), humidity ratio $[kg_{vapor}/kg_{dry\ air}]$ and the exhaust speed $[m/s]$.

Cooling towers from 100 kW to 50 MW were designed, and each required building/DCS had an array of cooling tower units designed to meet their maximum heat load. The following operating points define the design of the tower: rated capacity $[kW]$; a maximum WBT of $29.7°C$ obtained from the prevailing weather conditions used in the ANSYS simulation (See section 3.3.3.2); CWT of $32.8°C$, based on a realistic approach of about $3\,C°$ [13]; HWT of $38°C$; and a fan exhaust area based on [14]. We also define a pump control of the tower that limits the water flow from $20\% - 120\%$ of nominal, and a fan control that regulates the air flow such that the exhaust DBT is maintained at the HWT, and at a relative humidity of 95%, if permitted by the ambient conditions and the load [15]. These exhaust conditions are based on the approximate thermal equilibrium with the hot water from the process. At runtime, the model applies these design constraints and control characteristics and solves the heat transfer process eqs. (2-5). Thereafter, the exhaust speed is calculated from the volumetric air flow given by

$$\dot{m}_a v_{a4} = A\dot{x} \tag{6}$$

where v is the specific volume, A is the exhaust area, and $\dot{x}$ is the exhaust speed.

More specific details on the cooling tower design can be found in the Annex (Figs. 44-46). A sample output is shown in fig. 8.

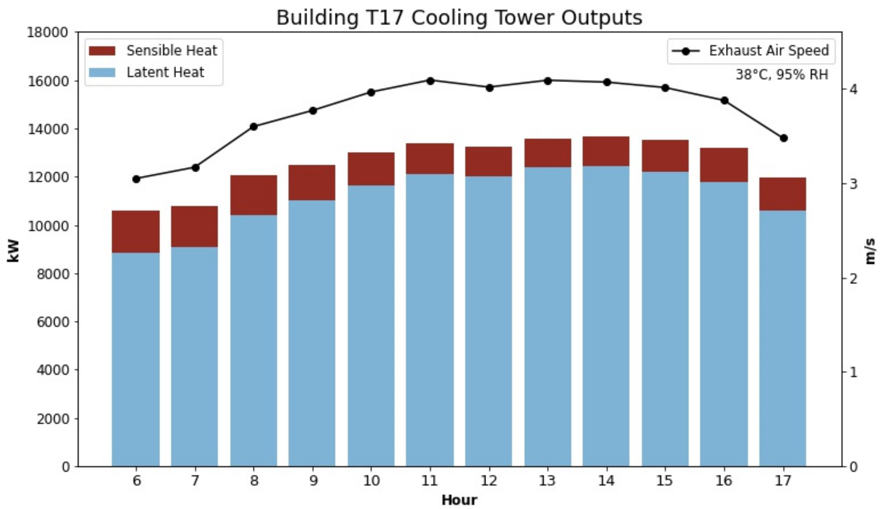

Figure 8: Sample cooling tower performance

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6 Annex

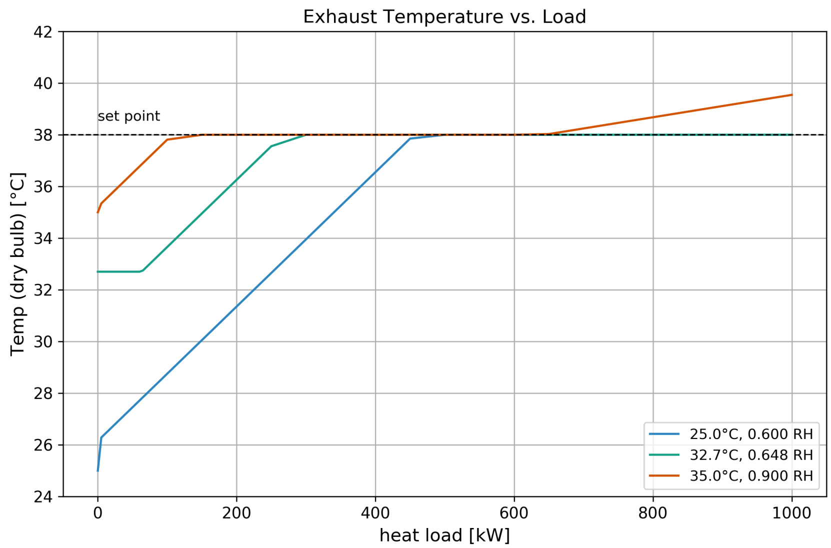

Figure 44: Exhaust dry bulb temperature vs. load at different ambient air conditions, 1000 kW model

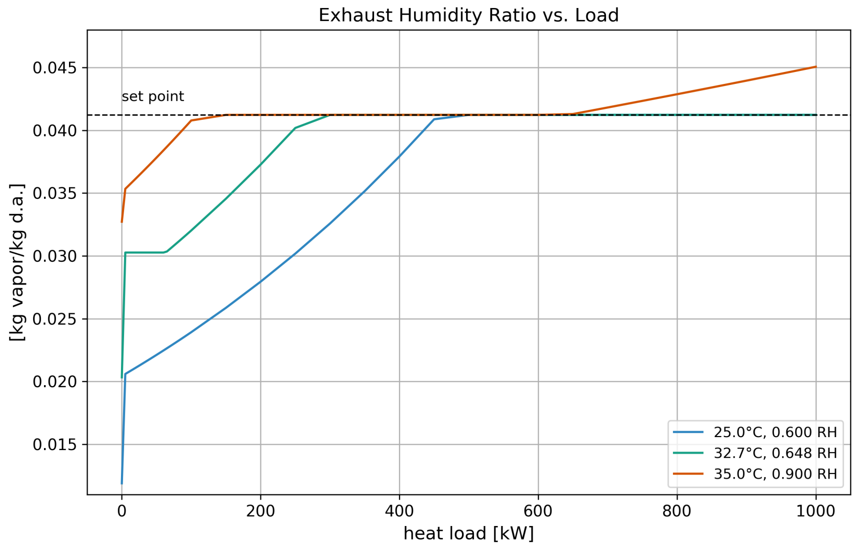

Figure 45: Exhaust humidity ratio vs. load at different ambient air conditions, 1000 kW model

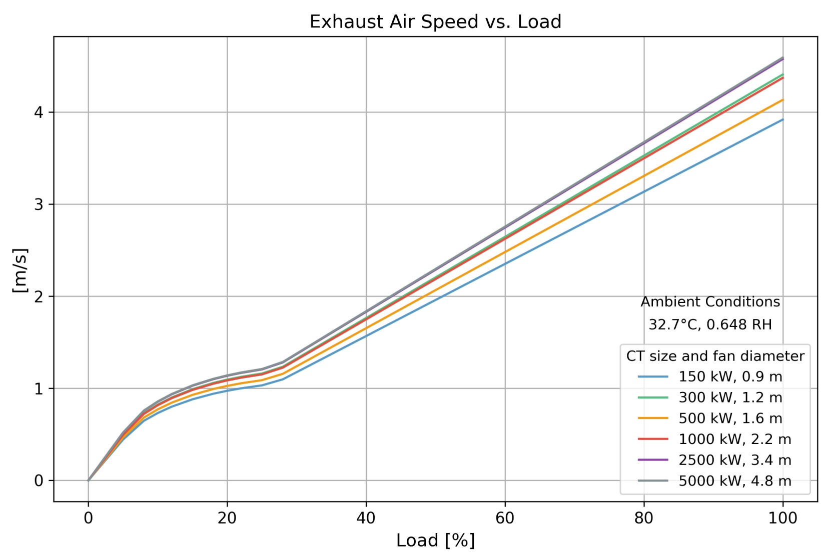

Figure 46: Exhaust air speed of largest unit per fan diameter, mean ambient air conditions