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Cooling Tower Performance and Determining Energy Saving Opportunities through Economizer Operation: A Review

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Abstract: *Cooling towers form an important part of chilled water systems and perform the function of rejecting the heat to the atmosphere. Chilled water systems are observed to constitute a major portion of energy consumption in air conditioning systems of commercial buildings and of process cooling in manufacturing plants. It is frequently observed that these systems are not operated optimally, and cooling towers being an integral part of this system present a significant area to study and determine possible energy saving measures. More specifically, operation of cooling towers in economizer mode in winter (in areas where winter temperatures drop to 40°F and below) and variable frequency drives (VFDs) on cooling tower fans are measures that can provide considerable savings. The chilled water system analysis tool (CWSAT) software is developed as a primary screening tool for energy evaluation for chilled water systems. This tool quantifies the energy usage of the various chilled water systems and typical measures that can be applied to these systems to conserve energy. The tool requires minimum number of inputs to analyze the component-wise energy consumption and incurred overall cost. In this thesis, a new model to predict cooling tower performance is created to give a more accurate picture of the various energy conservation measures that are available for cooling towers. The weaknesses of the current model are demonstrated and prediction capabilities of the new model analyzed and validated. Further the economic feasibility of having additional cooling tower capacity to allow for economizer cooling, in light of reduced tower capacity at lower temperatures is investigated.*

Keyword*: Energy, Efficiency, Cooling tower*

I. Introduction

A cooling tower is a device that is used to cool a water stream while simultaneously rejecting heat to the atmosphere. In systems involving heat transfer, a condenser is a device that is used to condense the fluid flowing through it from a gaseous state to a liquid state by cooling the fluid. This cooling to the fluid flowing through a condenser is generally provided by a cooling tower. Cooling towers may also be used to cool fluids used in a manufacturing process.

Cooling tower operation is based on evaporative cooling as well as exchange of sensible heat. During evaporative cooling in a cooling tower, a small quantity of the water that is being cooled is evaporated in a moving stream of air to cool the rest of the water. Also when warm water comes in contact with cooler air, there is sensible heat transfer whereby the water is cooled. The major quantity heat transfer to the air is through evaporative cooling while only about 25% of the heat transfer is through sensible heat.

Figure 1.1 taken from Mulyandasari [4] shows the schematic of a cooling tower.

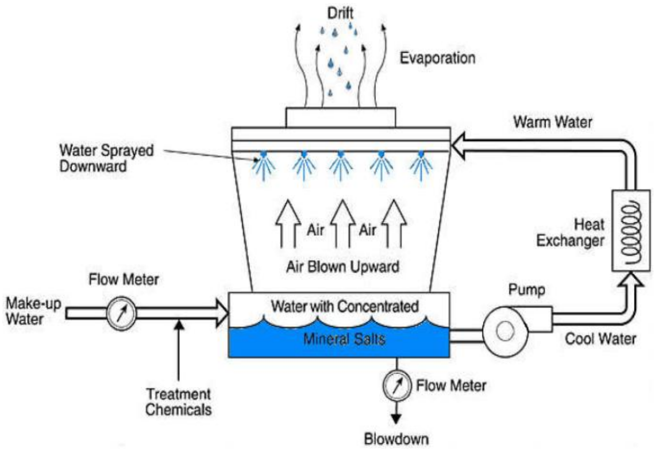

Figure 1.1 Schematic of a Typical Mechanical Draft Cooling tower

Some important terms relating to cooling towers as described by Stanford [5] are:
Approach- It is the difference between the temperature of water leaving the cooling tower and the wet bulb temperature. It is used as an indicator of how close to wet bulb temperature the water exiting the tower is.
Range- It is the difference between the temperature of water entering the tower and temperature of water leaving the tower.
Capacity- The total amount of heat a cooling tower can reject at a given flow rate, approach and wet bulb temperature. It is generally measured in tons.
Cell- It is the smallest tower subdivision that can operate independently. Each individual cell of a tower can have different water flow rate and air flow rate.
Fill- The heat transfer media or surface designed to maximize the air and water surface contact area.
Make up water- The additional water that needs to be added to offset water lost to evaporation, drift, blow down and other losses.
Dry bulb temperature – It is the temperature of air measured by a thermometer freely exposed to the air but shielded from moisture and radiation. In general
when temperature is referred to, it is dry bulb temperature.
Wet bulb temperature – It is the temperature of air measured by a thermometer whose bulb is moistened and exposed to air flow. It can also be said to be the adiabatic saturation temperature. The wet bulb temperature is always lesser than the dry bulb temperature other than the condition of 100% relative humidity when the two temperatures are equal.
Free Cooling or Waterside Economizer Operation – It is the operation of the cooling tower in conditions where just the cooling tower is able to provide the required temperature cold water for HVAC or process needs without needing mechanical cooling from the chiller. This saves energy because while the chiller may utilize about 0.7 kW/ton, the tower is now able to provide the same cooling at about 0.2 kW/ton.
Cooling Tower Classification
Cooling towers can be classified in many different ways as follows
Classification by build
Package type
Field Erected type
Classification based on heat transfer method
Wet cooling tower
Dry Cooling tower
Fluid Cooler
Classification based on type of Fill
Spray Fill
Splash Fill
Film Fill
Classification based on air draft
Atmospheric tower
Natural Draft Tower
Mechanical Draft Tower
Forced Draft
Induced Draft
Classification based on air flow pattern
Cross flow
Counter flow

II. Literature Review

In 1925, Merkel [6] was one of the first to propose a theory to quantify the complex heat transfer phenomena in a counter flow cooling tower. Merkel made several simplifying assumptions so that the relationships governing a counter flow cooling tower could be solved much more easily. Benton [2] and Kloppers and Kroger [7] list the assumptions of the Merkel theory as follows
The saturated air film is at the temperature of bulk water.
The saturated air film offers no resistance to heat transfer.
The vapor content of the air is proportional to the partial pressure of water vapor.
The force driving heat transfer is the differential enthalpy between saturated and bulk air.
The specific heat of the air water vapor mixture and heat of vaporization are constant.
The loss of water by evaporation is neglected. (This simplification has a greater influence at elevated ambient temperatures)
The air exiting the tower is saturated with water vapor and is characterized only by

its enthalpy. (This assumption regarding saturation has a negligible influence above ambient temp of 68°F but is of importance at lower temperatures)
The Lewis factor relating heat and mass transfer is equal to 1. (This assumption has a small influence but affects results at low temperatures.)
This model has been widely applied because of its simplicity.

The existing model by Benton [2] does not perform very well at low fan power and at low wet bulb temperatures. This means that estimates of energy use during free cooling operation and predicted fan energy savings through VSD are not very accurate. Figures 2.1 and 2.2 show the increased error in prediction of approach as the fan speeds are reduced. Figure 2.3 and Figure 2.4 show reduced tower performance prediction capability at low wet bulb temperature for a counter flow tower. As the wet bulb temperature reduces the magnitude of error is seen to increase. The lowering of prediction capability at lower wet bulb temperature can also be seen in the Figures 2.1 and 2.2 for fan speed variation. This makes a strong case for creation of a new model that can better predict cooling tower performance at these conditions.

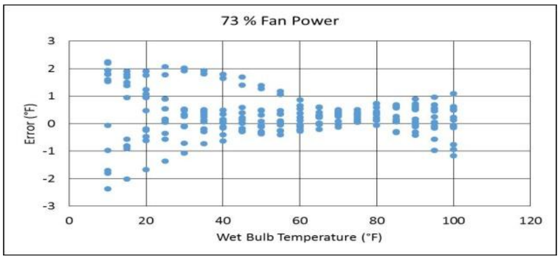

Figure 2.1: Error in Tower Performance Prediction with at 73% Fan Power

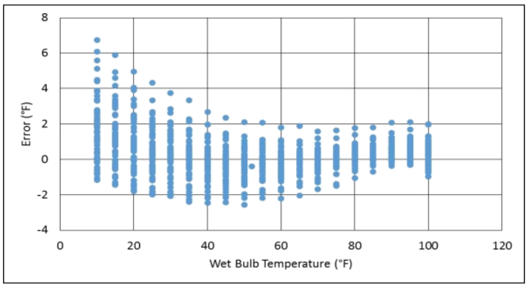

Figure 2.2: Error in Tower Performance Prediction with at 51% Fan Power

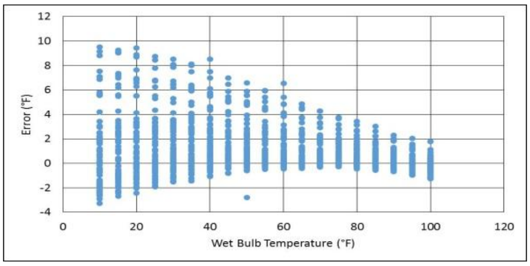

Figure 2.3: Variation in Tower Performance with wet bulb temperature for a Counter Flow Tower

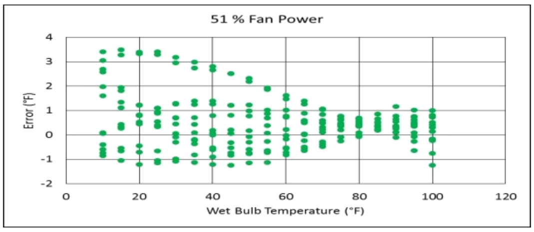

Figure 2.4: Variation in Tower Performance with wet bulb temperature for a Cross Flow Tower

Baker and Shryock [8] give a detailed explanation of the procedure of arriving at the final equations of the Merkel theory and also list some of the shortcomings of the Merkel theory and suggest some corrections. Benton [9] developed the FACTS model in 1983 and compared it to test data. In 1989 Jaber and Webb [11] developed equations to apply the ϵ–NTU method of heat exchanger design to design cooling towers. The Merkel method and ϵ–NTU method with modifications are the methods generally used to predict tower performance.

Kloppers and Kroeger [12] critically evaluate the Merkel theory by comparing it with the Poppe method. They conclude that the Poppe method is more accurate than the Merkel and ϵ–NTU methods and that the Merkel and ϵ–NTU methods give identical results since they are based on the same simplifying assumptions. With the advancement of computing power, computational Fluid Dynamics (CFD) models have been created to simulate performance of cooling towers [13]. Mehrabian et al [14] looked at the thermal performance of cooling towers under variable wet bulb temperature and report that as the wet bulb temperature increases, the approach, range and evaporation loss all increase considerably. Other information about low temperature tower performance is hard to come by.

III. Future Work

The improvements though marginal will find to those conditions where energy savings measures are possible leading to a better prediction of savings. CWSAT, the new model will use to predict tower fan energy use over a year and the results will compare. Further the economic benefit of adding an additional cooling tower will analyze and find that greater the load on the tower during times when the wet bulb temperature is lower than the required cold water temperature, an additional tower clearly adds economic benefit.

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