Cooling Tower Operation in the Hot and Humid Climates of Arid Zones

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ABSTRACT

Air-conditioning (A/C) in Kuwait is a necessity for comfortable living as the summer is extremely hot. Dry weather for most of the summer months reflects the effectiveness of using water-cooled (WC) systems. Cooling towers (C/Ts) at a Ministry building in Kuwait were monitored and evaluated under actual operating conditions. Experimental results, weather data, and theoretical studies are used to demonstrate the effect of current operational practices on electrical power and water consumption. The performance of C/Ts has been evaluated under different operating conditions with different airflows through the C/T. It has been established that the use of a large flow of air, though helpful in providing cooler water temperatures, and thereby, improving the performance of the A/C system, increases the fan power and water consumption. The latter is of special concern to Kuwait and other countries in the region where the soft water is produced through seawater desalination.

Introduction

The peak electrical power and annual energy demands in Kuwait are both predominantly devoted to satisfying A/C requirements. A/C alone accounts for nearly 70% of the annual peak load demand and 45% of the annual energy consumption (Suri et al., 1989). Weather conditions largely influence the cooling demand of buildings and the electrical power requirements of their A/C systems. The latter depends on the choice of sink. Ambient air is a commonly used sink for most A/C systems. The common mode of rejecting energy from the condenser of the A/C system to the ambient air is through the use of air (dry sink) or water (wet sink). Accordingly, the A/C systems are classified as air-cooled (AC) and water-cooled (WC). In an AC system, the ambient air is passed over a finned heat exchanger in a once-through process, and its dry-bulb temperature (DBT) is the main controlling parameter. WC systems reject heat in a shell and tube heat exchanger to water which is rarely rejected as waste after a single pass through the condenser. Generally, in an open loop, the thermal energy is transferred to the ambient air through a humidification process in a C/T. The controlling factor in this case is another psychometric parameter of ambient air, i.e., the wet-bulb temperature (WBT).

Kuwait has long dry summers extending over seven months, from April through October. For most of the summer months, the average difference between the peak of DBT and WBT is about 16°C, while it's monthly average is around 10°C (Al Shaban et al., 1998). Thus, the WC systems are expected to perform more efficiently as the sink temperature is lower. The results of analytical and experimental studies strongly favor the use of WC systems for both residential and nonresidential buildings (Al-Marafie et al., 1986; Suri et al., 1989). The studies showed that the WC systems consumed 25% less electricity, and needed 40% less power at peak hours. In spite of the clear advantage of power and energy savings, most of the A/C systems in Kuwait, at present, are of the AC type (Al-Homoud et al., 1985). Some of the frequently stated reasons for the absence of large-scale usage of WC systems are the need for excessive maintenance, inability of WC A/C systems to meet the cooling demand of buildings during days of high humidity, and the use of desalinated water. The latter is of special concern to Kuwait and other countries in the region where the soft water is produced through seawater desalination, which is costly energy-intensive process (Maheshwari et al., 1995).

The C/T is a key piece of equipment in the WC system, as shown in Fig. 1. Thermal energy is transferred to the ambient air through a humidification process. The WBT is the controlling factor. This paper presents the in-situ performance results of C/Ts at a ministry building in Kuwait.

System Description

C/Ts for the A/C systems at the Ministry of Foreign Affairs (MOFA) were selected for monitoring of their in-situ performance. The chilled water plant consists of four WC centrifugal chillers, three chilled water pumps, three condenser water pumps, and three C/T fans with two-speed motors. Based on the design of the A/C system, the peak cooling load was less than the combined capacity of the three chillers, and so one of the chillers was a standby. The chillers rated tonnage is 530 refrigeration tons (RT).

The condenser cooling water system is comprised of three pumps, each with a motor of 75 kW; one of them is a standby. The C/T has three cells, and each cell has one fan. The three C/T fans can be operated at two speeds by a four-position switch (i,e., auto, stop, low, and high). The normal position of the switches is on auto. The number of fans in operation at any point in time is controlled automatically by the load on the C/T and the air WBT. The possible combinations of the C/T fans operations could be as given in Table 1. The motor power ratings for the low (L) and the high (H) speeds of the fan are 18.7 kW and 37.3 kW, respectively. The C/T fans are interlocked with the chillers, and are controlled by a temperature sensor located in the return condenser water pipe. A rise in the water temperature puts more and more fans into operation at higher speeds, thus providing an opportunity for a greater flow of air across the C/T for a given flow rate of water. The additional flow of air helps to bring the water temperature down close to the WBT.

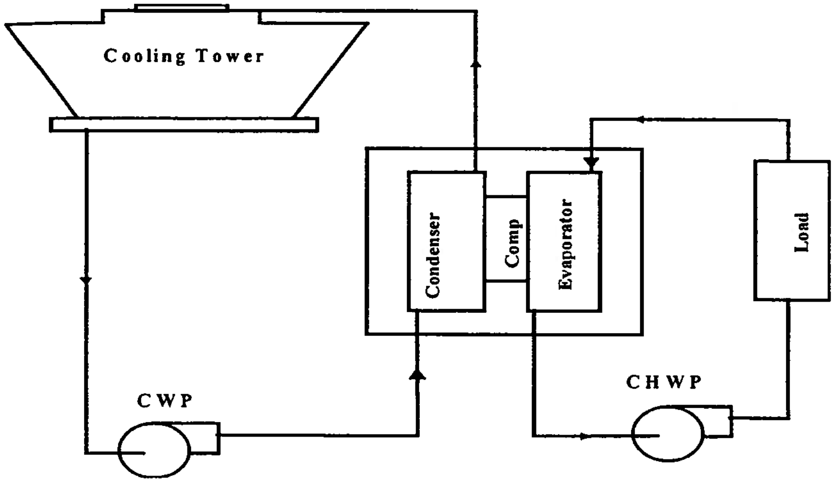

Fig. 1. Schematic diagram of the water circuitry in a typical A/C system.

Table 1: The Possible Combinations of C/T Fans' Speeds at the MOFA

No. of Combinations	No. of Fans in Operation	Combinations	Connected Power (KW)
1	1	1L	18 .7
2	2	2L	37 .4
3	3	3L	55 .1
4	3	1H,2L	74 .7
5	3	2H,1L	93 .5
6	3	3H	111.9

Data Collection and Analysis

Data was collected for many months during the summer season to assess the system's performance. A data logger was used, and the sensors were connected to measure the ambient DBT and relative humidity (RH), temperatures of the water at the condenser inlet (ECWT) and outlet (LCWT), temperatures of chilled water at the cooler inlet (ECHWT) and outlet (LCHWT), and the temperatures of water entering the C/T(EWT) and leaving the C/T (LCT). All the temperatures other than the DBT were measured using T-type thermocouples (Copper-Constantine), which were fabricated in the energy department's laboratory. These sensors, prior to their installation in the thermowells of the pipes, were tested using a high-quality temperature bath, Julabo from

Labortehnik, Germany, which has a temperature accuracy of ± 0.1°C. The power demand of the compressor (PC), condenser water pumps (CWPs), the chilled water pumps (CHWPs) and the C/T fans (CTFPs) were measured using data on voltage and amperes collected manually by the operator every hour. The condenser water flow rate and the chilled water flow rate were measured using an ultrasonic flow meter. These measurements were repeated periodically to ensure the accuracy of the measurements. Both the chilled water and the condenser water flow rates were kept constant throughout the experiment. The water consumption of the C/T was measured manually on an hourly basis using a water flow meter. These data were measured carefully to account for the actual water consumption in the C/T which is used for cooling production by avoiding the periods of intermittant blowdown of water, which is done on a regular basis to maintain the salinity of the water. The technical specifications of the instruments are given in Table 2.

Using the hourly ambient DBT and RH, the corresponding WBT was estimated with a software package. The C/T approach (CTAP), cooling production, Q_l, and heat rejection in the C/T, Q_h, were estimated as follows:

$$CTAP = LCT - WBT \quad (1)$$

$$Q_l = m_c\, c \; (ECHT - LCHT) \quad (2)$$

$$Q_h = m_h\, c \; (LWT - EWT) \quad (3)$$

where m_c and m_h are the water flow rates through the evaporator and condenser, respectively. Their respective values were 90.2 and 96.1 l/s, and these values were kept constant throughout the data collection process.

Table 2. Instrument Specifications

Performance Parameter	Instrument/sensor	Make	Accuracy
Ambient air dry bulb temperature (°C)	Pt 100	Testo	± 0.1(°C)
Ambient air relative humidity (%)	NTC	Testo	± 0.1% rF
Condenser water inlet temperature (°C)	T-type thermocouple	Local	Laboratory calibrated
Condenser water outlet temperature (°C)	T-type thermocouple	Local	Laboratory calibrated
Chilled water inlet temperature (°C)	T-type thermocouple	Local	Laboratory calibrated
Chilled water outlet temperature (°C)	T-type thermocouple	Local	Laboratory calibrated
Cooling tower inlet temperature (°C)	T-type thermocouple	Local	Laboratory calibrated
Condenser water flow rate (l/s)	Ultrasonic clamp on	Controltron	1-3%
Chilled water flow rate (l/s)	Ultrasonic clamp on	Controltron	1-3%
Cooling water make up (l/h)	Water meter	Commercial	

Results and Discussion

Data collected during the summer were analyzed to determine the functioning of the control scheme and the effect of approach on water and power consumpiton.

Functioning of the Control Scheme:

The LCWT for different combinations of C/T fan speeds were grouped together and plotted as shown in Fig. 2. Although the LCWT for a fixed fan speed has a temperature scatter of 1.5 to 2°C, the overall functioning of the control scheme is quite satisfactory showing a clear trend of more and more fans with higher speeds going into action to supply more air with increases in the LCWT.

For the last stage the scatter is really high, as any further increase in air flow was not possible, and the LCWT kept on rising with increases in the WBT

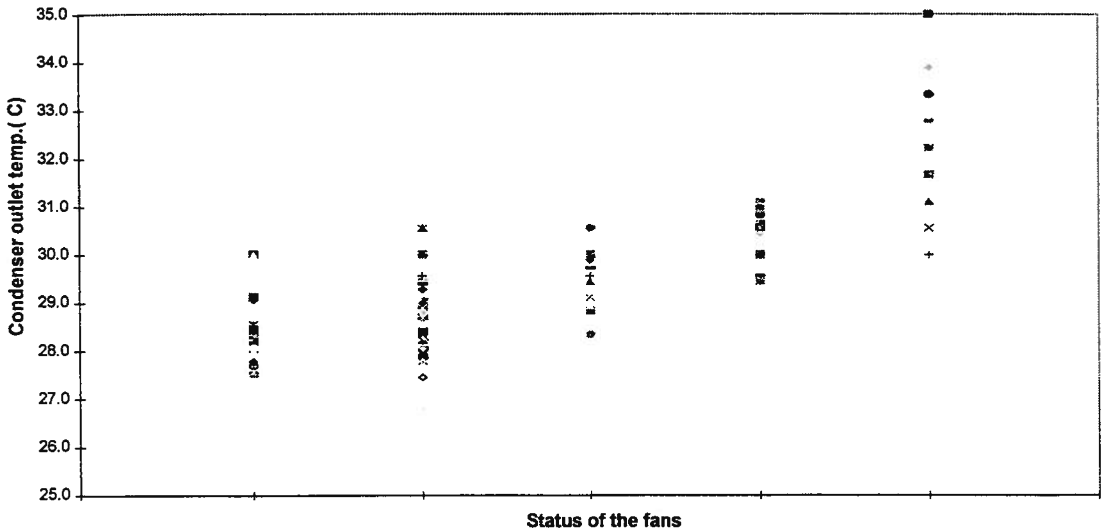

Fig. 2. Condenser outlet temperatures for variable speed CT fan motors.

Effect of Air Flow on CTAP

Different combinations of C/T fan speeds were grouped together, and the average CTAP for the same amount of heat rejection, 1100 kW, was estimated. The results are shown in Table 3. The table also presents the corresponding power of the C/Ts fans and water consumption.

The data presented in Table 3 has been used to highlight variation in the CTFP and C/T water consumption (CTWC) with the CTAP as shown in Fig. 3. Using the best fitting curve, linear co-relations have been developed as follows:

CTPF = - 13.974 * CTAP + 125.89 kW (4)

CTWC = -0.984 * CTAP + 8.4428 g/h/RT (5)

The power demand of the total A/C system (PT) can be expressed as follows:

PT = PC + CWP+ CHWP +CTFP + AHUP + CTWCP (6)

where AHUP is the power demand of the air-handling system, and CTWCP is the power equivalent the water consumed in the C/T.

Variation of the CTAP affects the ECWT, which in turn, increases the PC. As the actual performance rating of the chiller at the MOFA was not available, analysis was carried out using a Carrier model 30 KR-120-E-9, which estimated a 2.5% increase in the kilowatt-per-refrigeration-tons of compressor power for every degree centigrade rise in ECWT (Eitidal et al., 1995).

Using equations 4, 5 and 6, and not accounting for CWP, CHWP and AHUP as they are constant, the variation in the power requirements with CTAP has been estimated. Estimates have been made for a cooling capacity of 525 RT, a PC of 420 kW based on a kW/RT value of 0.8, and a CTAP of 3°C. The combined power demand for the actual energy equivalent to water production in Kuwait of 22 kWh/m3 (Maheshwari et al., 1995) and for places where water is freely available in nature (CTWCP = 0) are shown in Fig. 4. for the different CTAPs. It can be observed that for the places around the world where water is freely available; the combined power demand is nearly constant for a large range of CTAPs between 2 and 8 °C and the choice of CTAP is not critical. However, for the places using desalinated water , CTAP is critical. The higher the CTAP, the more energy saving can be achieved.

Table 3. Average CTAP for Different Combinations of C/T Fans' Speeds

Fan combination	Average CTAP °C	Fan power kW	Water consumption G/h/RT
2L	6.7	31.5	1.86
3L	5.6	46.5	2.42
1H2L	4.8	62.3	4.5
2H1l	3.3	78.2	4.93

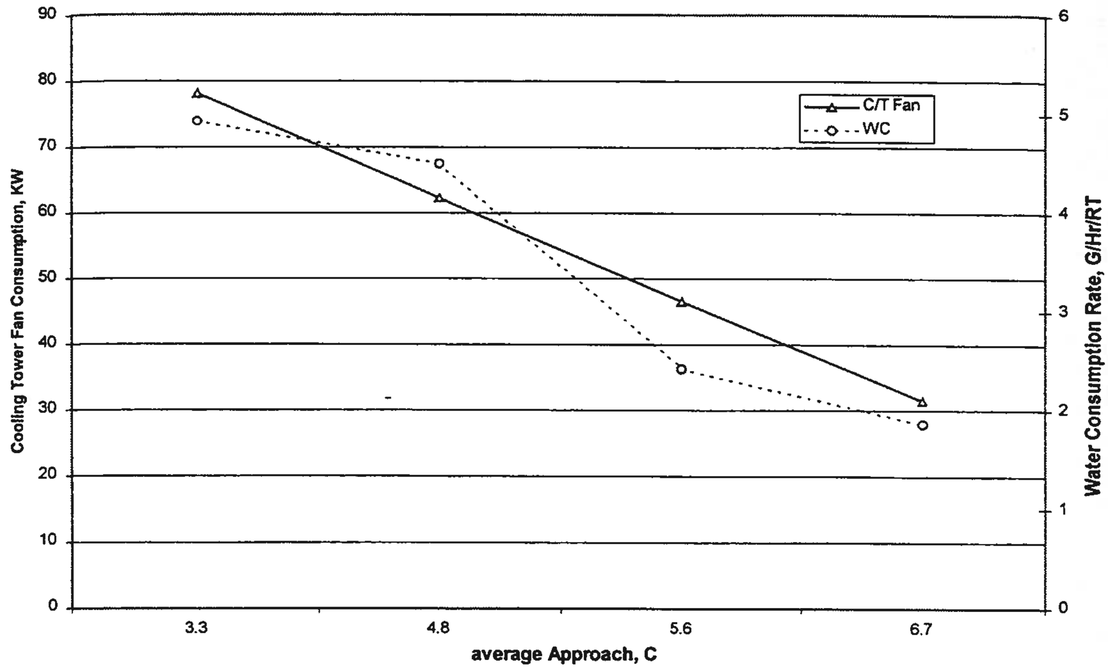

Fig. 3. The variation of C/T fan power and water consumption with respect to approach.

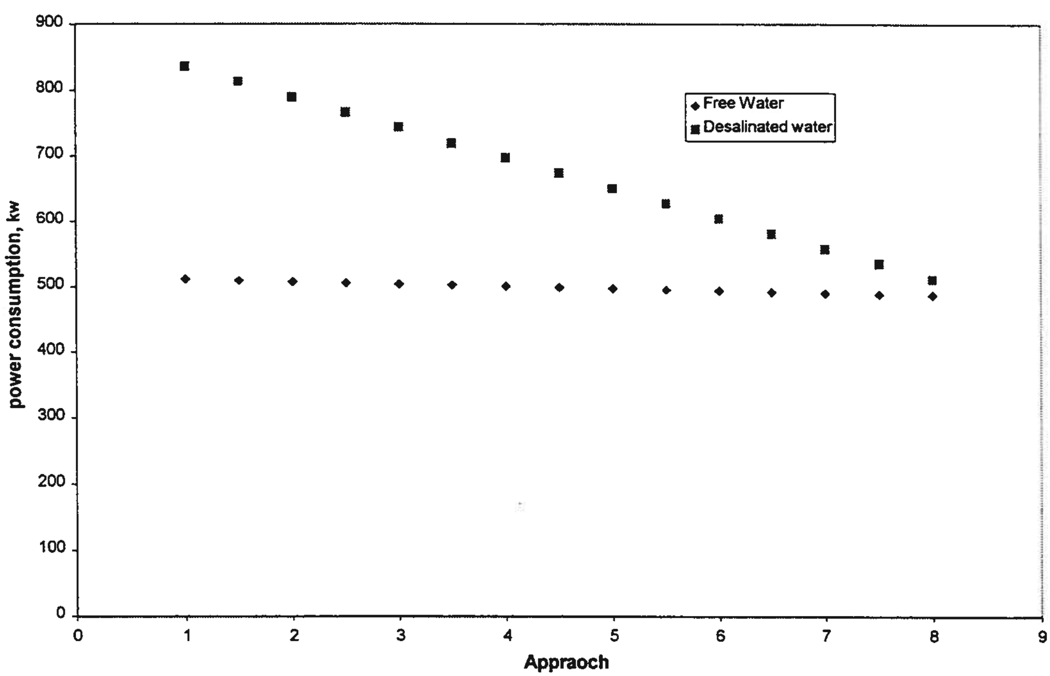

Fig. 4. Estimated variation in power consumption by approach.

Conclusions

The conclusions are the following:

1- The high flow of air through a C/T achives lower CTAP, though, it increases the power and water consumption.

2- Increase in C/T fan power is easily compensated by better performance of chiller resulting in a constant power demand by the system for different CTAP in the range of 2-8 °C.

3- In places with no availability of soft water, energy used for production of desalinated water is critical in decisions with regard to the operation of C/Ts, and a higher CTAP is advisable for better energy efficiency.

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