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Comparative Study Between Air-Cooled and Water-Cooled Condensers of the Air-Conditioning Systems

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ABSTRACT

The weather in Kuwait is very dry where the dry-bulb temperature exceeds the wet-bulb temperature more than 20°C in most of the summer months. Thus, the air-conditioning (A/C) system with the water-cooled (WC) condensers is expected to perform more efficiently than with the air-cooled (AC) condensers. This fact was behind the idea of a field study conducted in one of the major hospital in Kuwait during a summer season to investigate the performance of WC and AC systems in terms of peak power and energy consumptions. The cooling capacities for WC and AC systems were 373 and 278 tons-of- refrigeration, respectively. It was found that for the same cooling production, the peak power demand and the daily energy consumption of the WC system were 45 and 32% less than that of the AC system, respectively. The maximum reduction in the power demand coincided with the peak power demand period of the utilities i.e. between 14:00 and 17:00 hr, thereby offering a maximum advantage of peak power saving.

Key words: Air-conditioning, Air-cooled and water-cooled condensers, cooling tower

INTRODUCTION:

Air-conditioning (A/C) systems are classified as air-cooled (AC) or water-cooled (WC) depending upon the mode of rejecting energy from the condenser. In an AC system, the ambient air is passed over a finned heat exchanger in a once-through process, and dry-bulb temperature (DBT) is the main controlling parameter. WC systems reject heat to water in a shell-and-tube heat exchanger. The circulated water is rarely rejected as waste after a single pass through the condenser. Generally, in a closed loop, the thermal energy is transferred to the ambient air through the humidification process in a cooling tower (C/T). The controlling factor in this case is the wet-bulb temperature (WBT).

Kuwait has a long dry summer extending over seven months, from March to November. The design conditions and monthly average peak of DBT and WBT indicate the dry nature of Kuwaiti weather [1]. For most of the summer months the difference between the average DBT and WBT is over 20°C. Thus, WC systems are expected to perform more efficiently as the sink temperature is lower. In spite of the apparent advantage of the lower power and energy demand of the WC systems, most of the A/C systems in Kuwait are of the AC type [2]. Due to non-availability of natural and subsoil soft water, and scanty rainfall, most of the soft water requirement is met through seawater desalination, which is highly energy intensive [3]. The high cost of water is, therefore, an additional parameter affecting the choice between AC and WC systems.

This paper presents an analysis of field data on large-capacity AC and WC systems at a hospital building, tested during the peak summer season. The results show that the peak power demand and annual energy consumption of WC chiller are significantly less as compared to the AC chiller. These results are in line with the earlier findings of an analytical study and laboratory experimentation [4, 5].

EXPERIMENTAL SETUP:

The A/C system alternately providing chilled water via WC and AC systems to the office complex and the nurse's hostel was selected for conducting the experimentation. A schematic of the system is shown in Fig. 1. The cooling production subsystem consists of WC and AC chillers and the technical specifications for these chillers are given in Table 1. During the peak of the summer season, the system cooling demand was met using the WC system alone or by a combination of the AC system with an additional WC system (not shown in the plant schematic in Fig. 1.

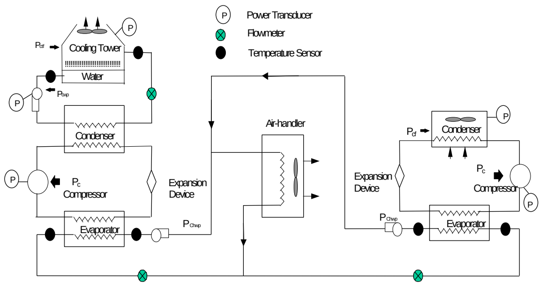

Figure 1. Schematic of the A/C system used for performance assessment.

Table 1. Technical Specifications of WC and AC Chillers

Parameters	WC	AC
Type of compressor	Centrifugal	Centrifugal
Ambient design conditions:		
DBT°C	NA	46
WBT°C	28	NA
Temperature of water leaving cooler (°C)	5.5	7.0
Temperature of water entering condenser (°C)	35	NA
Cooling capacity (RT)	373	278
Motor power (kW)	240	373
Chilled water temperature rise (°C)	5.5	5.5

Instruments were selected to measure the cooling production, consumption of electricity and water, and outdoor temperature and humidity. Locations for various measurement instruments are also shown in the Fig. 1. Laboratory-tested compatible thermocouples were installed in the thermo-wells at the inlet and outlet of the chilled water piping of the chillers. Additional thermocouples were used to measure the condenser water inlet and outlet temperatures for the WC chiller. Flow rates of the chilled water and the condenser water were measured using an ultrasonic portable flowmeter at the locations illustrated in Fig. 1. Instantaneous measurements of power drawn by motors of the compressors, pumps and fans were made using power transducers. Different measurements of the water temperatures, power, and ambient temperature and humidity were recorded at 15-minute interval and stored using a data logger. Water consumption by the C/T was measured manually using a domestic water meter installed in the makeup waterline of the C/T.

ASSESSMENT METHODOLOGY

Cooling production and cooling distribution subsystems constitute a total A/C system. In this study, the cooling distribution system is common for both types of A/C systems. Therefore, a comparative performance evaluation of the two types of systems has been made by comparing the power ratings (PRs) of the cooling production subsystem where PR is the rate of power demand (PD) per unit of cooling production, Q_c. The compressor and condenser fans are the main components that consume energy in a chilled water system with an AC condenser (Fig. 1). The power demand of the AC system, i.e., the PDAC, is the sum total of the compressor (P_c) and the condenser fan power (P_{cf}):

$$PDAC = P_c + P_{cf} \text{ kW} \qquad (1)$$

At a given time, it can be expressed as

$$PDAC = SCD * (PR_c + PR_{cf}) \text{ kW} \qquad (2)$$

where $PR_{c,}$ the PR of the compressor, is a characteristic of the make and model of the chiller and the ambient DBT. Also, in the case of a centrifugal, it is a strong function of the system cooling demand (SCD), which controls the loading of the compressor. The PR_{cf} in an AC system is regulated automatically to achieve the optimum PR for the cooling production subsystem of the AC system, i.e., the PRAC.

The compressor, condenser water pump, and C/T fans are the main power consumers of the cooling production subsystem in the WC system. The power demand of the WC systems, i.e., the PDWC, is the sum total of P_c, condenser water pump power (P_{cwp}), and C/T fan power (P_{ctf}):

$$PDWC = P_c + P_{cwp} + P_{ctf} \text{ kW} \qquad (3)$$

At a given time, it can be expressed as

$$PDWC = SCD * (PR_c) + P_{cwp} + P_{ctf} \text{ kW} \qquad (4)$$

where PR_c is a characteristic of the make and model of the chiller and the ambient WBT. Also, in the case of a centrifugal, it is a strong function of the compressor loading. Power for the auxiliaries comprised of P_{cwp}, and P_{ctf}, is generally constant, irrespective of the SCD in most of the installation. For WC systems operating in Kuwait, consumption of water (CW) in the C/T is important, as freshwater is not available in nature, therefore, the equivalent energy used for production of desalinated water (EECW) is an additional consumer of energy. In dual-purpose plants (electricity and water), commonly used in Kuwait and other Arabian Gulf countries, the EECW is about 22 kWh/m^3 [3]. CW is dependent upon the heat rejection in the condenser.

RESULTS AND DISCUSION

This field study is carried out to compare the performance of a large capacity AC and WC systems. Power rating, power consumption per unit cooling production, kw$_e$/ton, has been chosen as the criterion for performance. It is a function of compressor loading and system in addition to the source and sink temperatures. The experimental data collected during a summer season were carefully screened, and only consistent and reliable data were selected to estimate average hourly values for cooling production, compressor power, parasitic power for the auxiliaries, water consumption, and ambient DBT and WBT. Different data sets with the same cooling production and nearly similar chilled water temperatures were grouped and analyzed.

Chilled Water Systems with AC Condensers:

The compressor power rating for the AC system, PRAC$_c$, for different cooling demands are shown in Fig. 2. The correlations for different cooling productions are expressed are follows:

$PRAC_{c\,(110)} = 0.0282\ DBT + 0.6812\ kW/RT$ (5a)
$PRAC_{c\,(123)} = 0.0267\ DBT + 0.6380\ kW/RT$ (5b)
$PRAC_{c\,(129)} = 0.0250\ DBT + 0.6546\ kW/RT$ (5c)
$PRAC_{c\,(147)} = 0.0215\ DBT + 0.7134\ kW/RT$ (5d)

The compressor power consumption data for maximum loading was combined with the power requirements for the other components to estimate the PR for the system, PRAC$_s$. The correlation for the PRAC$_s$ can be defined as:

$PRAC_{s\,(147)} = 0.0215\ DBT + 0.9542\ kW/RT$ (6)

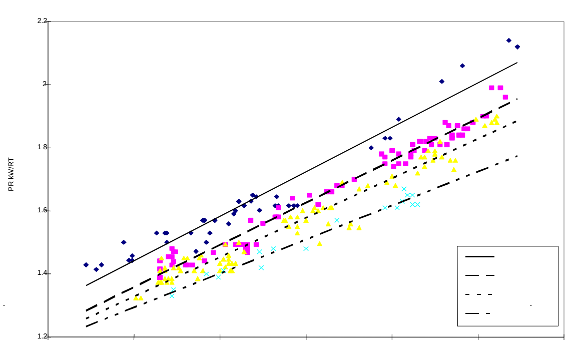

Figure 2. Compressor PR of an AC chiller at different cooling loads

Chilled Water Systems with WC Condensers

The compressor power rating of WC chiller, PRWC$_c$, at different cooling loads is shown in Fig. 3. The correlations are expressed as follows:

$PRWC_{c\,(231)} = 0.0017\ WBT + 0.7799\ kW/RT$ (7a)
$PRWC_{c\,(241)} = 0.0039\ WBT + 0.7025\ kW/RT$ (7b)
$PRWC_{c\,(252)} = 0.0037\ WBT + 0.7007\ kW/RT$ (7c)

The correlation for the compressor and system power rating at maximum loading for the WC system is given by:

$PRWC_{s\,(252)} = 0.0037\ WBT + 0.8007\ kW/RT$ (8)

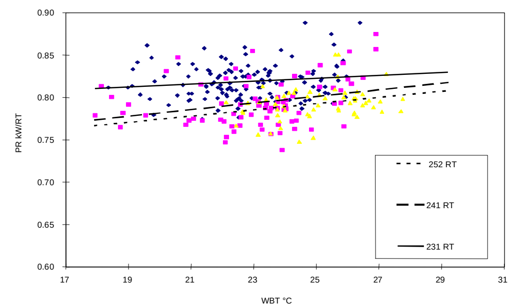

Figure 3. Compressor PR of a WC chiller at different cooling loads

Assessment of Peak Power and Daily Energy

Assessment of peak power and daily energy consumption by the WC and AC systems was made using the field performance data of one of the systems, while estimating that for the other system using the prevailing weather data and corresponding system PR. The hourly profiles of the DBT, WBT and SCD for September 11 are shown in Fig. 4. Hourly profiles of the EECW and measured PDWC are shown in Fig. 5. Using the Eq. 7, the corresponding DBT and the respective SCD, the hourly values of the PDAC were estimated and are also illustrated in Fig. 5.

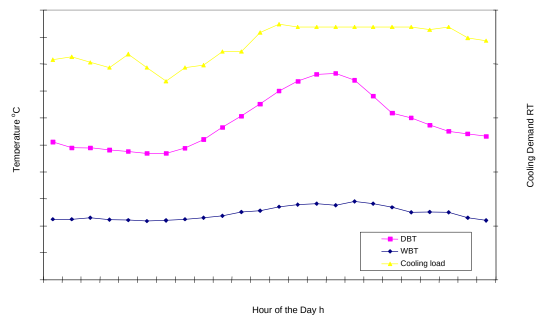

Figure 4. Hourly Profiles of ambient conditions and cooling demand (September 11, 1996)

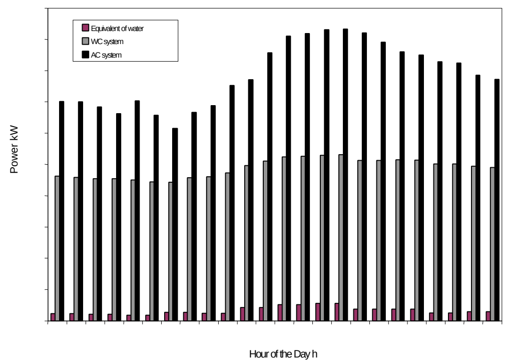

Figure 5. Hourly profile measured EECW and PWDC and estimated PDAC (September 11, 1996)

The results of peak power and daily energy consumption by the AC and WC systems for the test days of September 11 and 12 are summarized in Table 2. The WC system offers a peak power reduction of nearly 45%. The peak power demand coincides with the peak power demand period of the utilities, between 1400 and 1700 h. WC systems, thus, offer a stupendous opportunity for peak power attenuation in Kuwait, where 70% of the peak power demand is used by the A/C systems. Savings in the daily energy consumption of as large as 32%, even after accounting for EEWC, are equally important as they will help reduce the fuel consumption and environmental pollution significantly.

Table 2. Summary of Comparative Performance Assessment of AC and WC Systems

Performance Parameter	September 11, 1996			September 12, 1996		
	AC	WC	Savings (%)	AC	WC	Savings (%)
Peak power	437.5	236.7	45.9	451.7	249.2	44.8
Daily electricity kWh (no water)	9267.9	5468.8	41.0	9212.5	5485.1	40.5
Daily electricity kWh (with water)	9267.9	6285.4	32.2	9212.5	6262.8	32.0

The approach used for this study can be extended for estimating the annual benefits offered by the WC systems in Kuwait. For the two days of experimentation, the peak DBT was 48°C, and the corresponding WBT was 24°C. The savings in the peak power is likely to be more for many hours during the peak summer season when the DBT often exceeds 50°C with not much variation in the WBT. During moderate seasons, the savings in the daily energy consumption will fall with a reduction in difference between the DBT and WBT. Therefore, the yearly energy saving is likely to be less than 32%.

CONCLUSIONS

The main conclusions of this field study are as follows:

1. WC systems offer tremendous scope for minimizing the peak power demand as well as yearly energy consumption in hot and arid countries.
2. Alternate ways to produce soft water, such as reverse osmosis, needing less energy for desalination or direct use of seawater for condenser cooling will help or save more energy and should be considered seriously.

NOMENCLATURE

A/C = Air-conditioning
AC = Air-cooled
C/T = Cooling tower
CW = Water consumption (kg)
DBT = Dry-bulb temperature (°C)
EECW = Equivalent energy consumption of water (kWh/m^3)
P = Power demand of individual components (kW)
PDAC = Power demand of cooling production components
PDWC = Power demand of cooling production components of WC system (kW)
PR = Power rating (kW/RT)
PRAC = Power rating of AC system (kW/RT)
PRWC = Power rating of WC system (kW/RT)
Q_c = Cooling capacity (RT)
SCD = System cooling (RT)
WBT = Wet-bulb temperature (°C)
WC = Water-cooled

Subscripts

c = Compressor
cf = Condenser fans
chwp = Chilled water pumps
ctf = Cooling tower fans
cwp = condenser water pumps

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