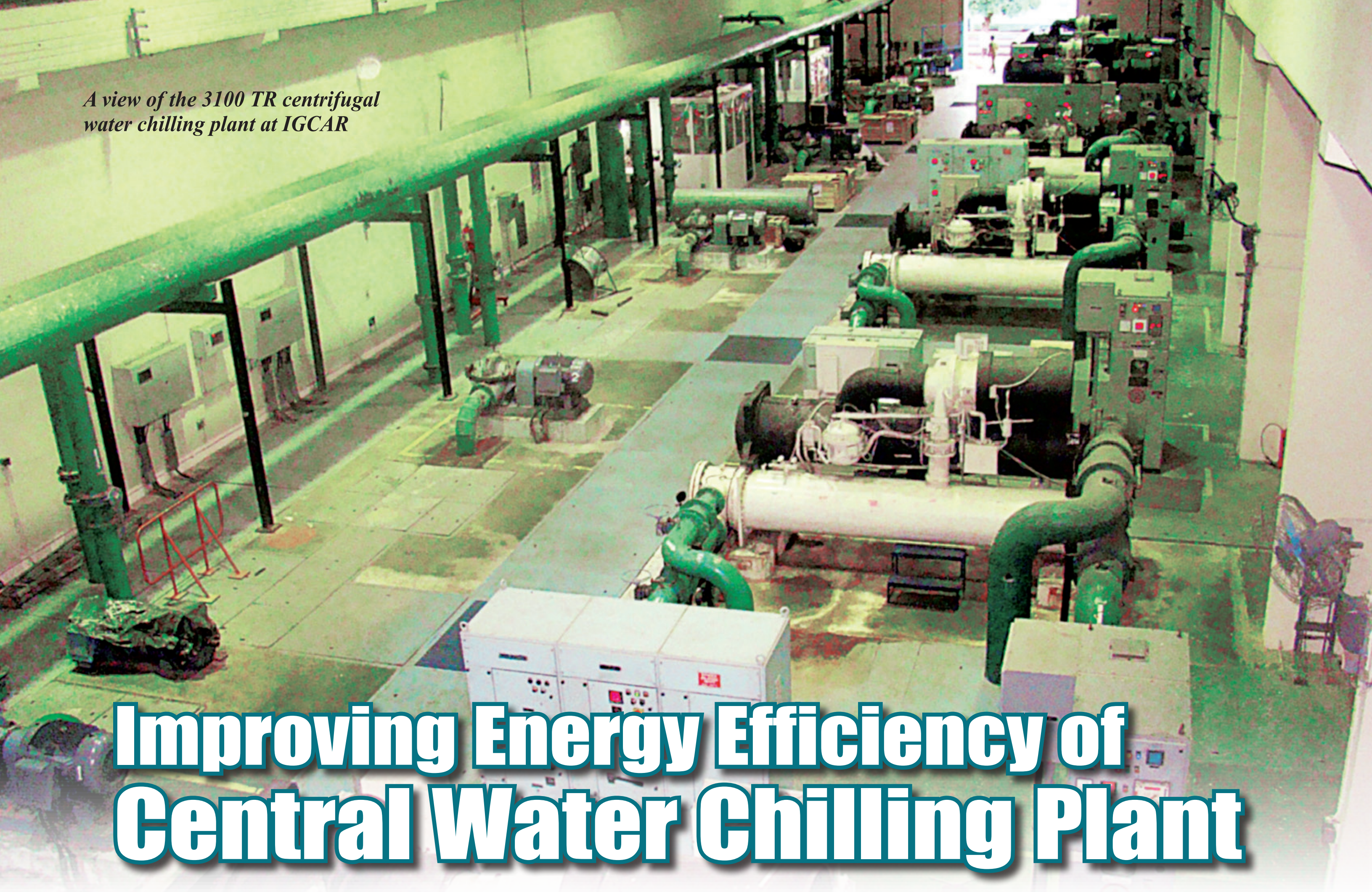

A view of the 3100 TR centrifugal water chilling plant at IGCAR

Improving Energy Efficiency of Central Water Chilling Plant

By C. Chandran and K. K. Rajan
Indira Gandhi Centre for Atomic Research
Department of Atomic Energy, Kalpakkam

Abstract

This article highlights various energy conservation measures implemented at central water chilling plant, IGCAR, Kalpakkam. It stresses that chillers are part of a system and maximizing chiller efficiency alone cannot ensure that the system will operate efficiently. It is also important to choose, operate and maintain the motors, pumps, cooling towers, air handling units, etc. efficiently to reduce overall energy consumption and ensure efficient operation of the chilling plant.

Introduction

Central Water Chilling Plant (CWCP) is the nodal point of air conditioning system of Indira Gandhi Centre for Atomic Research (IGCAR), and was established in 1978 for providing uninterrupted, reliable air conditioning and ventilation services to Fast Breeder Test Reactor (FBTR) and radioactive laboratories at IGCAR. The installed capacity of the plant is 3100 TR and peak load demand of the centre is 2100 TR. In addition to CWCP, several independent AC plants and packaged unit systems of 2400 TR capacity have been installed to meet the air conditioning requirement of various laboratories. Energy consumption towards operation of AC equipment is about 50% of total power consumption of the centre.

There are 6 x 500/550 TR capacity state-of the art, energy efficient and environment friendly centrifugal chillers and auxiliaries like chilled water pumps, condenser water pumps, cooling towers and air handling units (AHUs) available to meet the requirement. The special features of the centrifugal chillers are:

- Improved tube design of condenser and evaporator,
- Design of heat exchangers with higher fouling factor allowance,
- Refrigerant cooled energy efficient motors,
- Microprocessor based automatic load control system.

Chillers are part of the system; maximizing chiller efficiency alone cannot ensure that the system will operate efficiently. It

---

About the Author

C. Chandran has a master's degree in mechanical engineering from IIT Madras. He has over 20 years of experience in AC projects, O & M of central chilling plants and material handling equipment. He presently heads the AC & Ventilation Systems division. He is the immediate past president of ISHRAE Kalpakkam Sub-chapter.

K. K. Rajan is an Outstanding Scientist and Director of Engineering Services Group. He graduated in electrical engineering from Calicut University. He has been engaged in the field of fast reactor engineering. He is a member of Indian Nuclear Society and a fellow of Institution of Engineers (India).

continued on page 60

continued from page 58

is also important to select, operate and maintain the motors, pumps, cooling towers, AHUs, etc. efficiently to reduce overall energy consumption and ensure efficient operation of the plant. Significant energy saving can be achieved by operating the plant at higher temperature during the winter season and part load conditions. Implementation of effective maintenance programmes like cooling water quality management, refurbishment and up-keep of cooling towers, energy efficient motors, condition monitoring of rotating equipment, etc. plays a significant role in improving the overall plant efficiency.

The following energy conservation measures have been successfully implemented at CWCP, IGCAR:

- Monitoring and recording of daily power consumption.
- Automation of cooling tower fan operation.
- Replacement of pump motors with energy efficient motors.
- Replacement of old and damaged underground chilled water pipelines with new pre-insulated chilled water pipelines, thus reducing leakage rate.
- Installation of side stream filtration units in cooling water system to control turbidity and to reduce condenser tube fouling.
- Implementation of auto blow down system to control Total Dissolved Solids (TDS) within three cycles of concentration in the cooling water.
- Periodic upkeep of cooling towers.
- Automation of user end AHUs for scheduled operation and control with Building Management System.

Selection of Chillers

Centrifugal/screw/reciprocating type chillers, package chillers (air or water cooled), unitary air conditioners (window/split AC), etc. are used for air conditioning. Specific power consumption, life cycle cost, water quality and availability are the key factors for selection of AC systems.

The specific power consumption in kW/TR is referred as energy efficiency of the chiller. Lower kW/TR indicates higher efficiency. Inefficient chillers can waste significant amount of electricity, and modest improvement in efficiency can yield substantial energy savings. Hence, selection of chillers based on specific power consumption is very essential. Selection of chillers with reference to load requirement and specific power consumption is shown in *Table 1*.

Table 1: Specific power consumption values of chillers

Type of chiller	Load range (TR)	Specific power consumption (kW/TR)
Centrifugal chillers	90 -1000	0.5 - 0.65 (0.9-1.1 overall)
Screw chillers	70 - 750	0.65 - 0.9 (water cooled) 1.1 - 1.5 (air cooled)
Reciprocating chillers	Up to 150	0.7 - 1.0 (water cooled) 1.0 - 1.3 (air cooled)
Package units	5 - 15	1.1-1.5 (air cooled)
Split/ Window AC	0.8 - 3	1.2 - 1.4

Based on experience and data available, comparison of specific power consumption for water cooled and air cooled chillers is given in *Table 2*. Water cooled chillers are energy efficient compared to air cooled systems. If water availability and quality is not a concern, water cooled system is preferable.

Table 2: Specific power consumption data

Description	Water cooled chiller		Air cooled chiller	
	kW/TR	%	kW/TR	%
Chiller	0.65	62.5	1.2	82.2
Condenser water pumps	0.094	9.0	--	--
Cooling tower fans	0.037	3.6	--	--
Chilled water pumps	0.078	7.5	0.078	5.4
AHUs	0.181	17.4	0.181	12.4
Total	**1.04**	**100**	**1.459**	**100**

Life Cycle Cost Analysis

Life cycle cost analysis can be used as tool for evaluation and selection of the best energy efficient system suitable for air conditioning application. Life cycle cost of chiller, taking into consideration capital cost, O&M cost, inflation, interest and depreciation, can be computed using the following equation.

$$PV = \frac{FV}{(1+i)^n}$$

where PV: Present value at time = 0; it is the current worth of future sum of money payments,

FV: Future value at time = n; it is the sum of O&M cost and running cost with appropriate inflation,

i: interest rate,

and n: number of years.

A typical life cycle cost comparison of central water cooled AC (CAC) plant with air cooled package AC (PAC) at IGCAR for 2000 TR capacity, for a life span of 15 years is shown in *Figure 1*. Even though the initial cost for Central AC plant is higher than PAC, after about 8 years, the CAC plant is more economical.

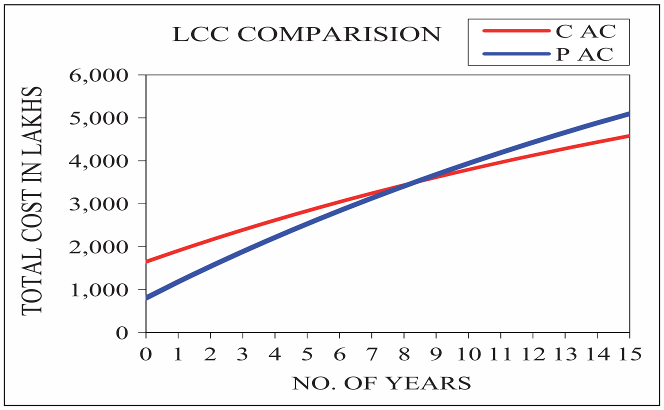

Figure 1: Life cycle cost comparison of central and package AC

Replacement of Pumps and Motors

As part of energy conservation activities, 12 numbers old 45/55 kW motors of chilled water and condenser water pumps were replaced with energy efficient motors, resulting in saving of 2 kW for each motor.

continued on page 62

continued from page 60

Replacement of Chilled Water Piping

The 27 years old conventional insulated underground chilled water piping was damaged due to corrosion. These pipelines were replaced with factory made pre-insulated chilled water pipelines *(Figure 2)*. The pre-insulated pipe consists of carrier pipe, Polyurethane Foam (PUF) insulation and High Density Polyethylene (HDPE) as a protective jacket. Replacement of old and damaged underground chilled water pipe lines with new pre-insulated chilled water pipelines reduced leakage rate from 6 m^3/h to 2.5 m^3/h. The benefits of pre-insulated pipes are improved thermal insulation, quick and easy installation and energy saving.

Figure 2: Damaged old pipes replaced with pre-insulated pipes

Automation of Cooling Tower Operation

There are 16 cooling towers in all for heat rejection to the ambient. The required number of cooling towers are operated manually based on cooling water temperature entering the condenser. Cooling Tower Manager (CTM) was installed to automate the operation of the required number of cooling tower fans based on the approach to wet bulb temperature.

CTM has the following features:

- Temperature and relative humidity sensor to measure wet bulb temperature.
- Step controller to regulate the number of fans.
- Immersion temperature sensor to measure cooling tower sump/outlet temperature.
- Water flow switch.

The schematic of CT automation system is shown in *Figure 3*.

CTM computes the actual approach (based on the difference between sump and wet bulb temperature) and compares it with the set value (set at 3 to 4°C approach), and automatically regulates (switches on or off) the required number of fans to maintain the cooling tower sump temperature. On an average, 6% power was saved due to automation of fan operation.

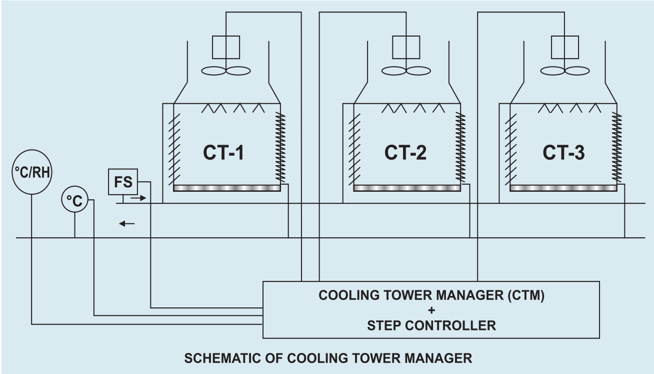

Figure 3: CT automation

Automation of Plant Operation

Automation of AC equipment operation through microprocessor based intelligent Building Management System (BMS) using campus LAN backbone was implemented. It involves automation of centrifugal chillers, chilled water pumps, condenser water pumps, cooling tower fans, booster pumps and AHUs present in 16 buildings.

The entire system consists of a network of Direct Digital Controllers (DDCs) connected to the central BMS located at CWCP through LAN. The equipment connected to the system could be monitored and operated from a remote location by a web browser. The schematic drawing of BMS is shown in *Figure 4*.

The automation of chilling plant involves control and monitoring of chiller process parameters, AHUs, cooling towers, etc.

- Precise scheduling of AHU's ON/OFF operation to avoid running beyond office hours and holidays.
- Controlling of chilled water flow by two-way modulating valves based on return air temperature to regulate the booster pump speed through Variable Frequency Drive (VFD) to meet the chilled water requirement.

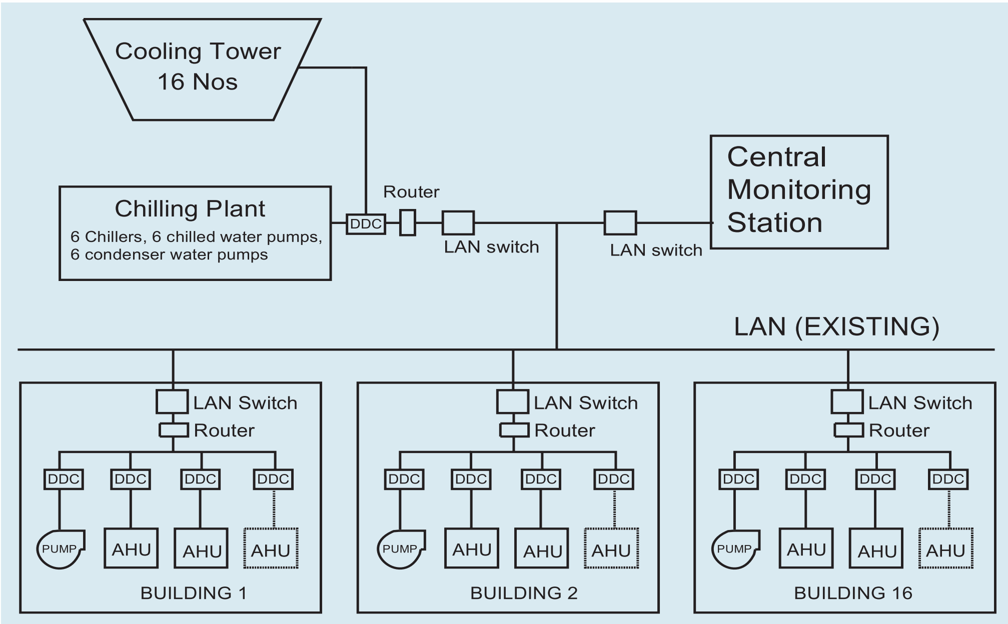

Figure 4: Schematic of BMS

continued on page 64

continued from page 62

- Controlling AHU speed by VFD to meet variable air flow demands.
- Monitoring of ON/OFF status, energy consumption and process parameters.

The centralized monitoring and control of AC equipment distributed in various buildings in IGCAR saves energy to the order of 5 to 6% and eases the operation of CWCP with minimum manpower.

Water Quality Management

The quality of circulating water through an evaporating cooling system has a significant effect on overall system efficiency and the useful life of system components. The concentration of dissolved solids in condenser cooling water system increases due to evaporation and results in scaling of condenser tubes. Also, air-borne impurities such as dust, mud, sand, suspended matter, etc. enter the cooling water system through cooling towers and deposits on condenser heat exchanger surfaces (Figure 5), resulting in reduction in heat transfer. Palar river water is used for make-up purpose. As the water quality is good (pH: 8.5, TDS 200 ppm and hardness 96 ppm), water treatment was not envisaged initially. The quality of makeup and circulating water is shown in *Table 3*. However, after commissioning state-of-the-art new generation machines in 2001, it was observed that the new machines were very sensitive to water quality.

Due to scale formation in the condenser tubes, the condenser approach was gradually increasing resulting in high condenser pressure and surging of the machines. Since the tubes are very thin and internally grooved, no chemical cleaning was recommended by the Original Equipment Manufacturer (OEM). As there was no alternative, we were forced to carry out chemical cleaning periodically to descale the condenser tubes. It was observed that the fouling rate was very high, forcing us to descale frequently and operate the chiller at lower capacity within a short period of tube cleaning. On inspection of condenser tubes, the presence of hard scale due to precipitation of calcium and magnesium carbonates and fouling due to mud, slime, suspended matter, etc. was noticed. Subsequent water sample analysis of the circulating cooling water revealed that the Total Dissolved Solids (TDS) was about 1200 ppm. The high TDS of circulating water resulted in frequent scaling of the condenser tubes.

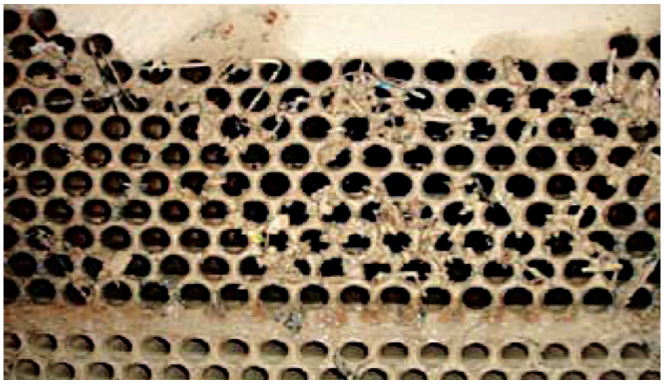

Figure 5: Fouling in condenser tubes

Table 3: Water quality

Parameter	Make- up water	Condenser circulating water	
		Actual	Acceptable limit
TDS (ppm)	223	1200	< 500
Turbidity (NTU)	25	15-25	< 5
TSS (ppm)	50	5-50	< 5
Hardness (ppm)	96	300	< 250

It may be noted that the TDS value had gradually increased to 1200 ppm in spite of periodic blow-down, as there was no provision to monitor the TDS of the cooling water system.

The following measures were implemented to improve cooling water quality, to minimize the scaling/fouling of the condenser tubes and to improve the performance of the chillers:

- Auto blow-down system to maintain the Cycle of Concentration (COC) within three as per engineering practice.
- Installation of side stream filtration system to minimize the fouling of the tubes due to turbidity and suspended solids. Also, liquid chlorination system was introduced to control algae growth and minimize bio-fouling.
- Refurbishment of cooling towers.

Auto Bleed-off System

An automatic bleed-off system consisting of online pH and conductivity meters along with a solenoid operated valve was installed later, to control and maintain the TDS within three COC in condenser cooling water system to minimize the scaling in the condenser tubes. The auto bleed-off system, shown in *Figure 6*, comprises of pH and TDS sensors, pH and TDS controller and a solenoid operated ball valve. The TDS analyzer compares the actual value with the set value and regulates the blow-down valve. The cooling tower sump make up this with float valves.

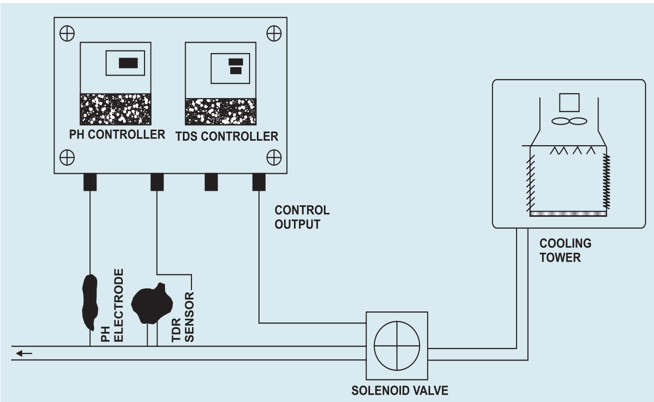

Figure 6: Auto bleed off system

Side Stream Filters

Ingress of dirt, dust, sand and other debris into the cooling water system through the cooling tower and make-up water results in accumulation of suspended solids and increase in turbidity. The biological growth and accumulation of sediments results in poor performance of cooling towers and chillers and high energy consumption. A side stream filtration, as shown in

continued on page 66

continued from page 64

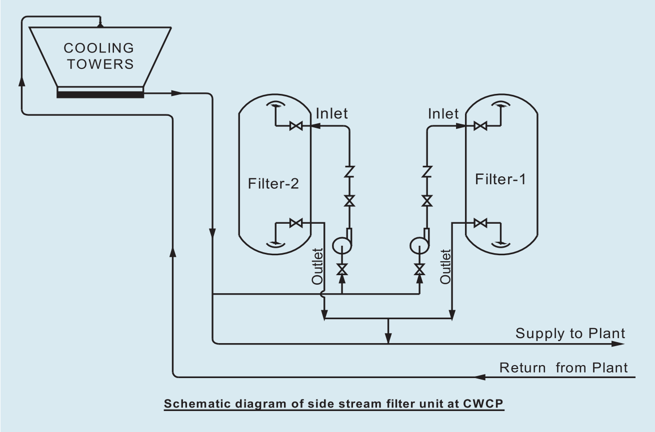

Figure 7: Side stream filters

Figure 7, is introduced in the condenser cooling water system. The side stream filtration unit is a multi-grade sand filter. It is filled with filtering media (fine sand) on top supported by layers of different size and grades of pebbles. Suspended solids collected in the filter are periodically removed from the filter by back wash with fresh water.

The filtered water was tested, which revealed that the level of total suspended solids was less than 5 ppm and turbidity was less than 5 NTU.

Introduction of side stream filtration resulted in reduction in frequency of tube cleaning, lower maintenance cost, effective heat transfer and improved performance of the chillers.

Revamping of Cooling Towers

It was observed that during summer all the 16 cells are put in service to remove the heat load of just three chillers and to maintain the condenser water inlet temperature within the permissible limit of 32°C. The performance of cooling towers was evaluated and it was noticed that their effectiveness was below 33%. Poor performance of the cooling towers resulted in high condenser water inlet temperature, which eventually caused surging in the chillers and high energy consumption. Also, the wooden fills and structures were aged, resulting in frequent maintenance. Hence, cooling towers were upgraded and revamped as indicated below:

- The tower capacity was upgraded from 187.5 TR to 240 TR per cell.
- The wooden splash bars were replaced with PVC perforated C-bars in order to minimize maintenance and enhance life of the cooling towers.
- Wooden structural supports and grids were replaced keeping the concrete basin and interconnecting piping intact.
- The asbestos louvers and end casing were replaced by Fiber Reinforced Plastic (FRP) parts.

Performance after Revamping

After revamping, the effective average performance of cooling towers has improved to 54% from 33%. It is found that 10-12 cells are sufficient to run 3-4 chillers and the current taken by each fan is 13 A (8 kW) against 16 A (9.8 kW), resulting in substantial savings in energy as shown in *Table 4*.

Table 4: Energy savings after revamping

	No. of CTs	Average power consumption/fan (kW)	Total power consumption (kW)	Saving (kW)
Before	16	9.8	156	–
After	12	8	96	60

Conclusion

As a result of all these measures, there is considerable reduction in total machine hours to meet the average heat load of 1500 TR. The annual energy consumption pattern towards operation of CWCP for the period from 2008 to 2013 is shown in *Figure 8.*

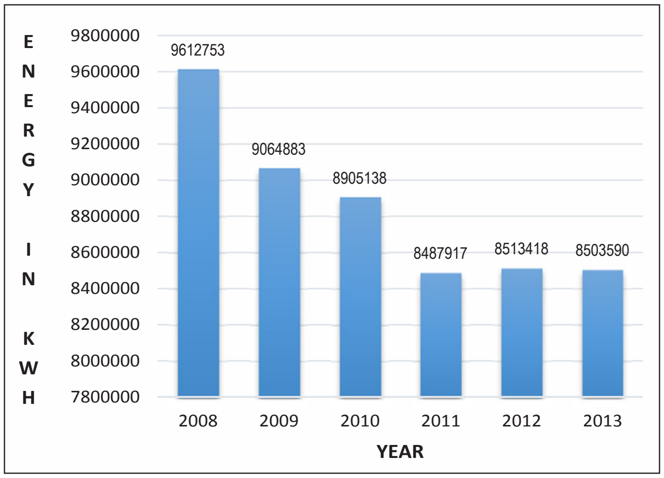

Figure 8: Annual energy consumption - CWCP

To meet an average load of 1500 TR, about 11.7% of energy saving has been successfully achieved by implementing various energy conservation measures. Based on the experience of Operation & Maintenance of Cooling Towers, it is essential to monitor pH and TDS values of re-circulating water periodically. Water treatment is inevitable irrespective of the quality of make-up water, because of gradual accumulation of salt content leading to considerable scale formation in the condenser tubes. Monitoring of TDS and carrying out blow-down of condenser cooling water to maintain about 3 cycles of concentration, assessment of cooling tower integrity and side stream filtration system are very essential to operate the plant efficiently.

Abbreviations

AC - Air Conditioning
CWCP - Central Water Chilling Plant
BMS - Building Management System
AHU - Air Handling Unit
TR - Ton Refrigeration
VFD - Variable Frequency Drive
DDC - Direct Digital Controller
LAN - Local Area Network
HDPE - High Density Polyethylene
TDS - Total Dissolved Solids
TSS - Total Suspended Solids

This paper was presented at the National Conference on Refrigeration and Air Conditioning (NCRAC) held at IIT Madras during 12-14 December 2013.