WHITE PAPER

# CHILLER PLANT OPTIMIZATION - A PRACTITIONER'S PERSPECTIVE

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**Abstract**

Maintaining optimal energy efficiency in air conditioning systems is a constant challenge – one that all heating, ventilation and air conditioning (HVAC) engineers work tirelessly to overcome. However, for many years, the air conditioning industry has struggled to identify and resolve common problems that affect chiller operations and lead to poor performance, high energy consumption and greater operating cost. This paper explores the most common operational challenges in chillers identified by Infosys upon analyzing historical data from chiller plants on its own campuses. It also explains the solutions Infosys used to address these issues in a systematic manner.

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## 1.0 Introduction

Infosys has made significant investments in green initiatives across its campuses in India. For instance, all the campus buildings and chiller plants have been outfitted with the latest Internet-of-Things (IoT) technology. These sensors capture real-time operational data that can be monitored through a centralized command centre. Infosys also uses advanced technologies such as the Industrial IoT to continuously improve efficiency and manage energy, water, waste, security, and transportation within its campuses. As a direct result of these initiatives, we have reduced nearly 50% of our per capita energy consumption over a period of 9 years [1].

Air conditioning systems, particularly chillers, consume a large share of the total energy used in buildings. Over the past several years, Infosys has been collecting historical data and maintenance records from more than 130 chillers on its campuses. This data is being used to understand chiller performance, identify common operational problems and design relevant solutions. Chiller data is analyzed using Infosys' knowledge-based artificial intelligence (AI) platform NIA to develop diagnostics and prognostics models for chiller energy management systems.

## 2.0 Common operational issues

Chiller operations are complex. In this section, we identify and explain the top 6 challenges in chiller operations along with the solutions deployed by Infosys.

### 2.1 Low ΔT syndrome

A major challenge in several large capacity chiller plants with primary - secondary pumping system is the low temperature difference (ΔT) syndrome. This occurs when the appropriate chilled water temperature range, i.e., the difference in the temperature of chilled water entering and leaving the chiller system, is not achieved. Here, even though the building has a maximum heat load, the chiller operates at sub-par capacity in a partial load condition. Low ΔT syndrome arises due to the following reasons:

- Air handling units (AHUs) temperature set-points are below the designed value
- The variable frequency drives (VFDs) of AHUs operate in a fixed mode
- Peripheral system components not designed for the same temperature range
- Improper selection of coils and control valves
- Choked cooling coils
- Improper water balancing

Thus, to meet the maximum building load, the control valve responds by opening the valve to 100%, thereby allowing more chilled water to circulate. This reduces the chilled water flow rate in secondary water pumps. Further, it causes a 'negative' flow of return chilled water though the de-coupler line in order to meet the flow requirement, as shown in Figure 1.

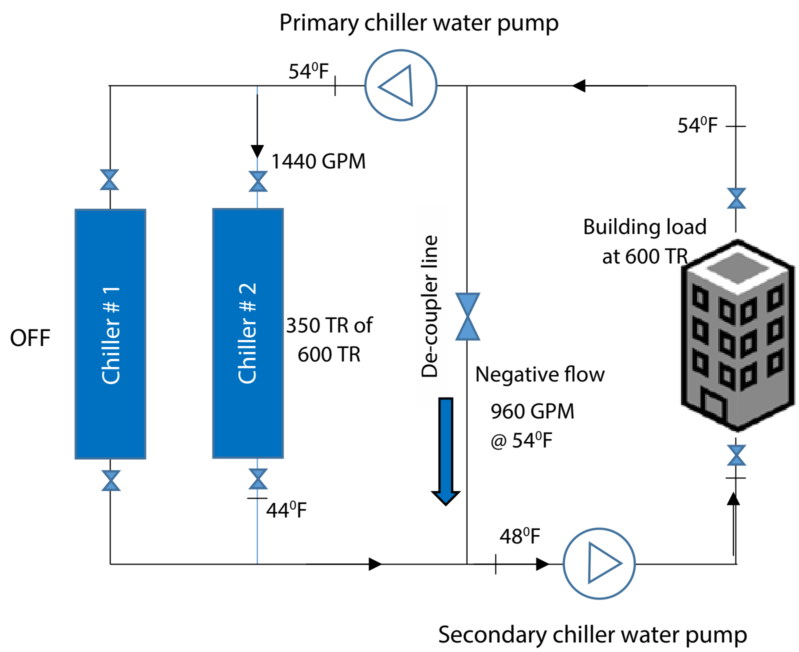



Fig 1: A chiller plant with low ΔT syndrome

In such a situation, the chiller plant operations are compromised leading to further complications:

- After mixing with the return water, the temperature of the chilled water supplied to the building increases
- Control valves remain completely open owing to high temperature of supply chilled water
- Energy consumption from secondary water pumping systems increases
- Chiller operations continue in the low ΔT syndrome condition

The following steps can address low ΔT syndrome:

- Adopting a variable primary pumping system – This eliminates the de-coupler line, enabling operators to immediately identify and rectify low ΔT syndrome (Refer Table 1)
- Reducing the temperature range – This allows the chiller to increase the flow rate with the same capacity. While it causes wastage of primary pumps, it offers energy savings from secondary pumps.

Conversion of variable primary chiller water flow (VPF) system in GEC-2, Infosys campus, Mysore [2]

| Facility description | Number |
|---|---|
| Capacity of installed chillers | 4 x 250 TR |
| Constant primary chiller water pumps | 5 |
| Variable secondary chiller water pumps | 4 |
| Condenser water pumps | 5 |
| Cooling towers | 5 |

Project benefits

| Equipment details | Before | After | % reduction |
|---|---|---|---|
| Number of chillers | 4 | 4 | - |
| Number of pumps | 14 | 8 | 43% |
| Number of valves | 74 | 25 | 66% |
| Load of chilled water pumps | 223 kW | 44 kW | 80% |
| Load of condenser water pumps | 75 kW | 44 kW | 41% |
| Chiller plant space | 3,200 sq.ft. | 2,450 sq.ft. | 23% |
| Annual energy consumption | 2.13 million kWh | 1.49 million kWh | 30% |

Table 1: Effect of variable primary chiller water flow system

## 2.2 Higher small temperature difference of chiller heat exchangers

The performance of chiller heat exchangers (including evaporators and condensers) depends on the small temperature difference, also known as the 'approach' [3]. The value of the approach is determined by the difference between the refrigerant saturation temperature and leaving water temperature, as illustrated in Figure 2. Typically, chiller heat exchangers are designed for an approach of 2.2°C. A higher approach value increases the load of the chiller and is caused by the following problems:

- Formation of fouling in internal tubes
- Inadequate water flow rate
- Improper flow of refrigerant inside the tubes
- Shortage of refrigerant gas

In most chillers, the approach values are displayed in the chiller control panel. It can also be estimated from the refrigerant pressure and leaving chilled water temperature for regular monitoring. Usually, the main reason for a high approach is due to fouling of condenser tubes as these are open loops and they depend on the quality of the condenser water.

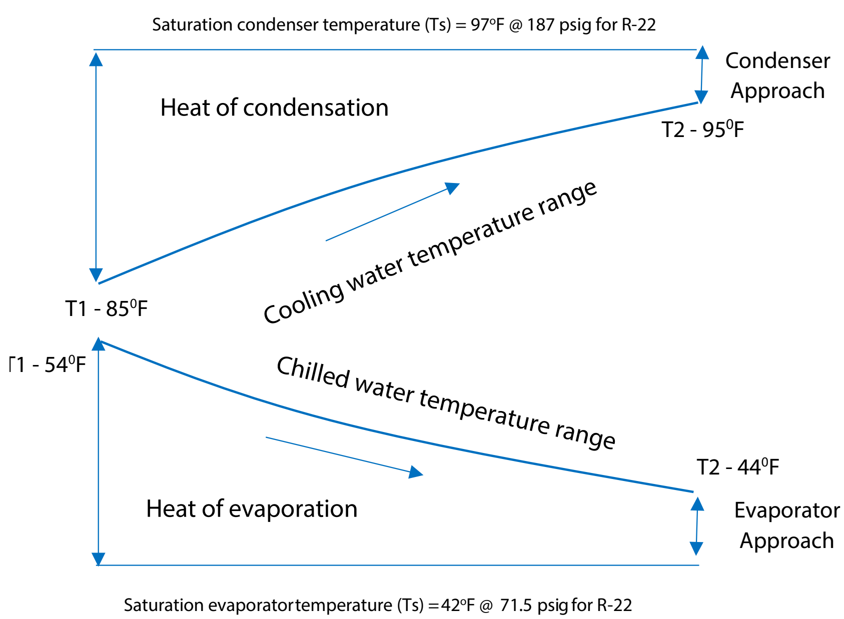



Fig 2: Performance of chiller heat exchangers (evaporator and condenser)

| Condenser approach (ºC) @ 7ºC LCHWT | kW/TR of chiller (IPLV) |
|---|---|
| 7.0 | 0.520 |
| 6.0 | 0.515 |
| 5.0 | 0.513 |
| 2.2 | 0.480 |

IPLV – Integrated part load value

LCHWT – Leaving chilled water temperature

kW/TR – Kilowatt per ton of refrigeration

Table 2: Performance of chiller heat exchangers (evaporator and condenser)

To minimize the high approach of condenser tubes, Infosys installed an automatic tube cleaning system for all the chillers. This system helped us get close to the desired chiller operating efficiency (ikW/TR). We also tested next-generation water treatment systems such as non-chemical, ozone and magnetic water treatment systems.

## 2.3 High temperature of condenser water entering the chiller

It is critical to supply condenser water at the right temperature for optimal chiller performance and energy consumption. However, in most chiller plants, the temperature of the condenser water entering the system is higher than normal owing to:

- Poor maintenance/selection of cooling towers
- Improper sizing of cooling towers

At the right temperature, the entering condenser water will lower the discharge pressure of the refrigerant and provide maximum condenser relief to the chiller. This helps chillers operate in a part-load condition. To lower the temperature of the entering condenser water, one should properly control the cooling tower fans and maintain the designed approach of cooling towers, i.e., maintain the appropriate temperature difference between entering condenser water and ambient wet bulb.

After identifying the importance of entry condenser water temperature, Infosys leveraged a logical control-based system to diligently operate and manage the cooling tower, thereby ensuring that the entering condenser temperature is as low as possible. This solution allows the chiller to operate at maximum efficiency.

(Refer Fig 3:)

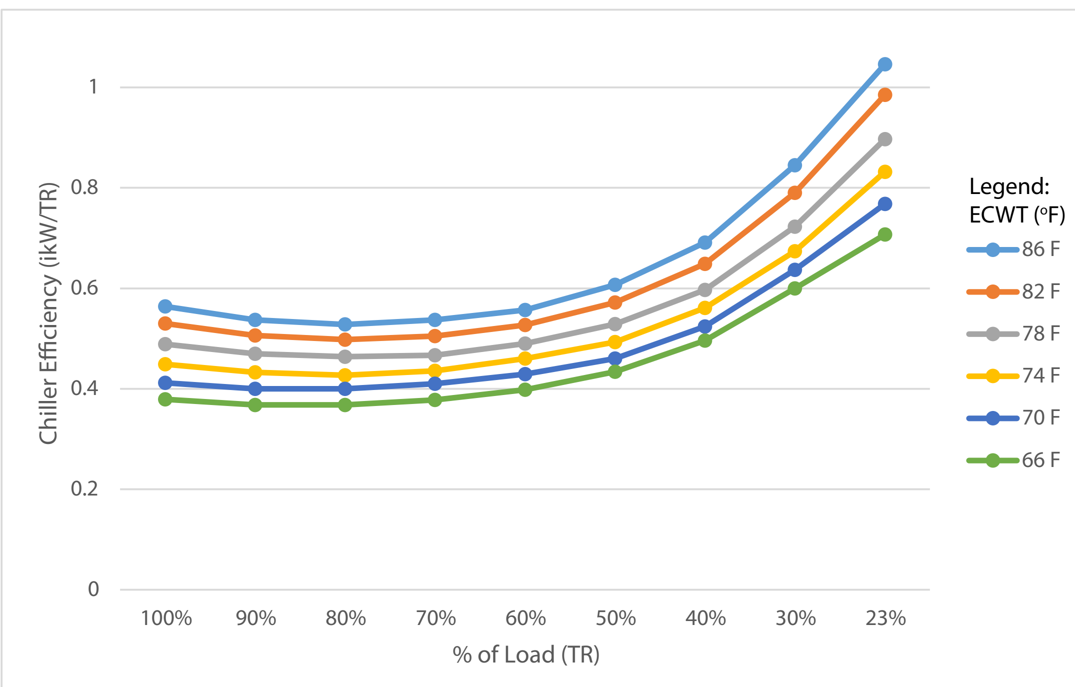
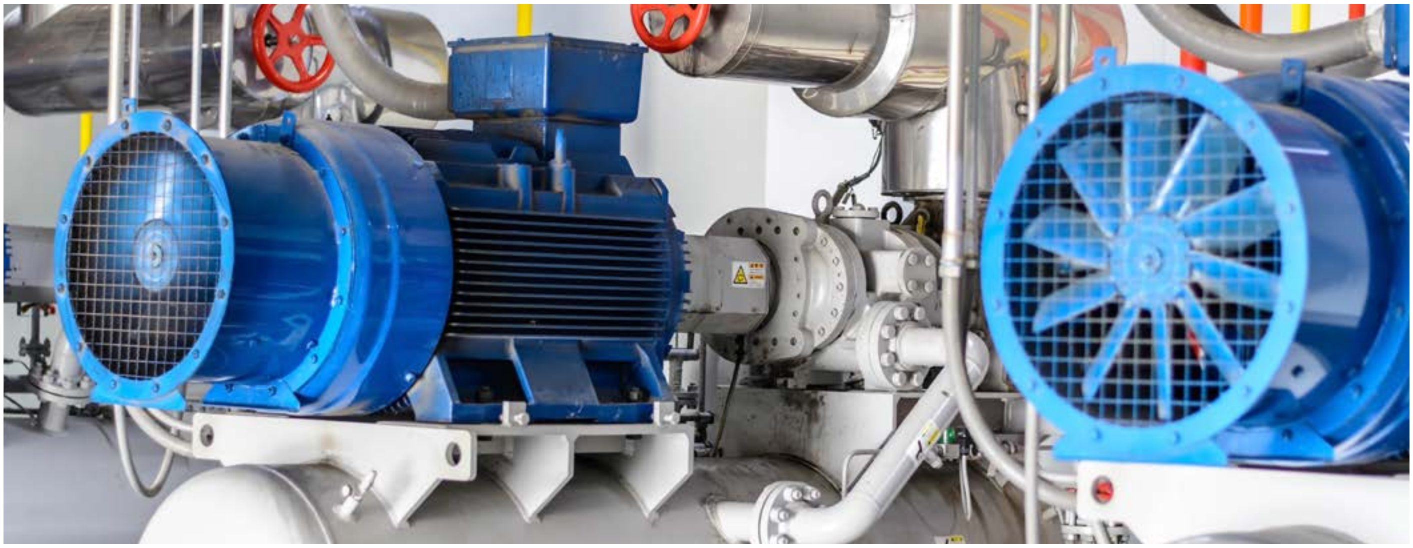



Fig 3: Example of Centrifugal Chiller Performance Curve
Note: ECWT - Entering Condenser Water Temperature



## 2.4 Incorrect size of chiller auxiliary water pumps

Often, when installing chiller auxiliary pumps such as chilled water pumps and condenser water pumps, the sizes are over-estimated to allow for 'safety factors'. However, this results in a mismatch between chiller design parameters. If the pumps deliver a higher flow rate than expected, then the flow gets throttled in the chiller and the balancing valve is forced to maintain the required flow. This increases the system operating pressure/ head and consumes higher power during operations.

Therefore, it is very important to calculate that the required flow rate and head based on the designed ΔT, then selecting the right capacity pump, which helps to operate at its best efficiency point (BEP). BEP is where the system curve crosses the pump curve as shown in Figure 4. Pumps can also be selected based on the flat and steep curve profiles. The steep curve is preferred for open systems such as cooling towers while a flat curve is recommended for systems with control valves.

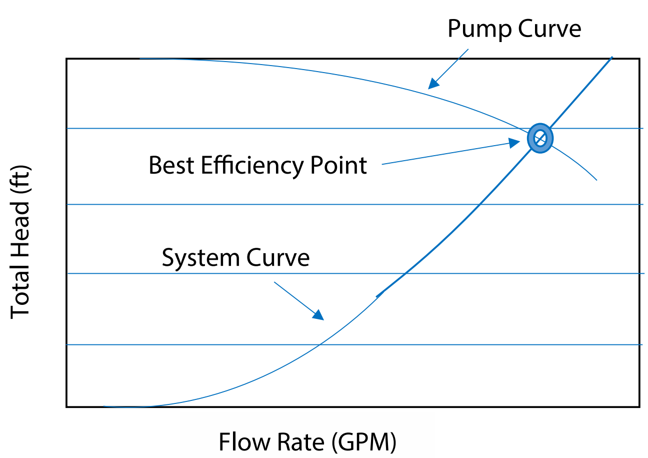



Fig 4: A typical performance curve for a centrifugal pump

## 2.5 Low quality of condenser water

While condenser water is not typically considered a parameter for operational efficiency, low-quality condenser water can create problems in the open cooling loop system, such as:

- Scale formation – Scale refers to precipitated solids or calcium carbonate crystals that obstruct heat transfer in the heat exchangers, thereby reducing the performance of the cooling system
- Metal corrosion – Corroding metal reduces the integrity, strength and thickness of the metal structure by creating holes in the material
- Biological fouling formation – This refers to the growth of organisms in protected environments such as internal tubes, which is difficult to remove. It reduces the heat transfer efficiency and results in microbiologically-induced corrosion, which can affect human health.

Infosys monitors and controls water quality using various control parameters such as conductivity, oxygen reduction potential, treatment chemical concentration levels, general water analysis, etc. Further, the auto bleed-off valve in the cooling tower ensures that water blow down to maintain the acceptable Total Dissolved Solids (TDS) in condenser.

## 2.6 Inaccurate sensors

Inaccurate sensors have a significant impact on energy conservation initiatives. For every 1°C decrease in chilled water temperature, there is a corresponding 1 % to 3% increase in chiller energy consumption [4]. Thus, inaccurate readings from temperature sensors, pressure sensors and water flow meters as well as inaccurate data due to manual error can severely affect chiller operations. The impact of inaccurate sensor values is illustrated in Table 3.

Well-defined and properly calibrated sensors and instruments can deliver high precision measurement, thereby eliminating excess energy usage. To ensure that we obtain accurate values of chiller operations, Infosys conducts regular instrument calibration as a part of chiller maintenance.

| Parameters | Unit | Design | Chiller panel | With calibrate dinstrument |
|---|---|---|---|---|
| **Leaving chilled water temperature** | °C | 6.67 | 6.50 | 6.68 |
| **Entering chilled water temperature** | °C | 10.56 | 10.20 | 10.42 |
| **Leaving condenser water temperature** | °C | 31.44 | 31.10 | 31.46 |
| **Entering condenser water temperature** | °C | 28.89 | 28.70 | 29.00 |
| **Chilled water flow rate** | GPM | 1812 | - | 1854 |
| **Condenser water flow rate** | GPM | 3180 | - | 3229 |
| **Pressure drop across evaporator** | ftWc | 5.00 | | 4.94 |
| **Pressure drop across condenser** | ftWc | 13.00 | | 13.49 |
| **Cooling capacity (tonnage)** | TR | 528 | 514 | 519 |
| **Compressor power input** | kW | 269 | 284 | 271 |
| **Chiller energy efficiency** | kW/TR | 0.51 | 0.55 | 0.52 |

Table 3: Validating actual vs. designed chiller operating parameters at 100% load

ftWc – Feet of water column
GPM – Gallon per min

## 3.0 Conclusion

Air conditioning systems account for nearly 40% of the total energy consumption of a typical commercial building. Thus, it is essential to ensure proper operations and maintenance of chiller systems to prevent high energy consumption, equipment deterioration and poor quality of circulated air. By using real-time operational and maintenance data collected from over 130 chillers on its campuses, Infosys has identified the leading causes of poor chiller performance. These include improper temperature differences in entering chilled water, leaving chilled water and condenser water as well as incorrect sizing of chiller pumps, inaccurate sensors and low quality of condenser water. Technologies such as the Industrial Internet-of-Things (IIoT) have helped Infosys create unique solutions for each of these challenges, thereby saving nearly 50% of per capita energy consumption. In future, operational data and analytics models can help Infosys explore and solve site-specific issues as well, thereby maximizing gains from their green energy initiatives.

## 4.0 Acknowledgements

I would like to acknowledge the technical support provided by the Green Initiatives team and Advanced Engineering Group. Special thanks to subject matter experts Dr. Ravi Kumar G.V.V., Dr. Ravi Prakash and Guruprakash Sastry for their useful inputs and valuable time spent in reviewing this paper.

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