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# Energy Audit of a Central HVAC Chiller Plant with focus on kW/TR Optimization

Jayesh Anavkar[1], Huzaif Gadkari[2], Naved Hunerkar[3], Afnan Shirgaonkar[4], Shaad Sakharkar[5]

*Jayesh Anavkar, Mechanical Engineering & Finolex Academy of Management and Technology, Ratnagiri, India*
*Huzaif Gadkari, Mechanical Engineering & Finolex Academy of Management and Technology, Ratnagiri, India*
*Naved Hunerkar, Mechanical Engineering & Finolex Academy of Management and Technology, Ratnagiri, India*
*Afnan Shirgaonkar, Mechanical Engineering & Finolex Academy of Management and Technology, Ratnagiri, India*
*Shaad Sakharkar, Mechanical Engineering & Finolex Academy of Management and Technology, Ratnagiri, India*

**Abstract:**

Energy efficiency in HVAC systems is a major concern due to increasing energy demand and operational costs. Chiller plants are among the largest energy consumers in commercial and industrial facilities. This study presents a detailed energy audit of a chiller plant to evaluate its performance and identify opportunities for energy savings. Key parameters such as chilled water temperature, condenser water temperature, flow rates, and power consumption were measured and analysed.

The performance of the system was assessed using indicators such as Coefficient of Performance (COP) and kW/TR. The audit revealed inefficiencies due to improper load management, heat exchanger fouling, and suboptimal operating conditions. Based on the analysis, several energy conservation measures (ECMs) were proposed, including optimization of cooling tower operation, implementation of variable frequency drives (VFDs), and improved maintenance practices.

The implementation of these measures resulted in a significant improvement in system efficiency and enhanced operational performance. The study demonstrates that systematic energy auditing and optimization can lead to substantial cost savings and sustainable operation of chiller plants.

Keywords: Energy Audit, Energy Efficiency, Coefficient of Performance (COP), kW/TR, Performance Analysis

## 1. Introduction: -

In the modern industrial and commercial landscape, Heating, Ventilation, and Air Conditioning (HVAC) systems represent the single largest consumer of electrical energy, often accounting for 40% to 60% of a facility's total utility expenditure. At the heart of these systems is the Chiller Plant, a complex assembly of compressors, heat exchangers, and pumping networks designed to provide essential cooling.

If not managed or monitored properly, the chiller plant becomes the primary driver of escalating operating costs. Over time, factors such as mechanical wear, refrigerant degradation, and heat exchanger fouling lead to "Efficiency Creep," where the system consumes significantly more power to meet the same cooling demand. For large-scale operations, even a marginal drop in efficiency can result in millions of rupees in wasted expenditure. This project examines an existing chiller plant through the lens of mechanical engineering principles, utilizing Weather Bin Data and Excel-based modelling to establish a baseline for performance and identify the potential for high-efficiency upgrades.

Beyond these foundational aspects, the performance of a chiller plant is also heavily influenced by dynamic operating conditions such as ambient temperature variations, cooling load fluctuations, and part-load efficiency characteristics of equipment. In real-world scenarios, chillers rarely operate at full load; instead, they function predominantly under partial load conditions where inefficiencies are more pronounced. This makes it essential to evaluate system performance across a range of operating points rather than relying solely on rated conditions.

## 2. Importance Of Energy Audit

In any industrial setup, a chiller plant is often the most power-intensive component, making a systematic energy audit essential not only for maintenance but also as a strategic tool to ensure optimal performance. The audit begins by establishing a clear performance baseline, replacing assumptions with measurable data on energy consumption and cooling output. This enables engineers to accurately assess how far the system has deviated from its original design efficiency over time. Additionally, energy audits play a crucial role in identifying hidden inefficiencies such as fouled heat exchangers, refrigerant degradation, and sensor inaccuracies—issues that silently increase energy consumption without delivering useful cooling.

Another key importance of an energy audit lies in enabling data-driven decision making. Since engineering improvements and upgrades often require substantial capital investment, an audit provides concrete, empirical evidence to support these decisions. It helps determine whether the system requires minor optimization, component-level retrofits, or a complete replacement, thereby aligning technical needs with financial feasibility. Furthermore, audits contribute to improved operational reliability by detecting conditions such as short-cycling, excessive pressure drops, or improper system balancing, which can lead to premature wear and reduced equipment lifespan.

Beyond economic and operational advantages, energy audits also support environmental responsibility. By identifying and eliminating unnecessary energy consumption, they directly contribute to reducing the carbon footprint of the facility. In the context of modern engineering practices and regulatory frameworks such as Energy Conservation Building Codes (ECBC), conducting regular energy audits becomes a foundational step toward achieving sustainable, energy-efficient, and environmentally compliant industrial operations.

## 3. Methodology

### 3.1 Component Details:

The chiller plant analysed in this study consists of a water-cooled vapor compression system with primary components involved in heat transfer and fluid circulation. The chiller unit includes the evaporator and condenser, where chilled water and condenser water temperatures were measured during the audit. The evaporator section is responsible for cooling the chilled water, with inlet and outlet temperatures recorded to determine the cooling effect and ΔT.

The condenser section rejects heat to the condenser water circuit, where inlet and outlet temperatures were monitored to evaluate heat rejection performance and condenser efficiency. The system also includes a chilled water pump, which circulates water through the evaporator and load side, and a condenser water pump, which transfers heat from the condenser to the cooling tower.

A cooling tower is used to dissipate heat from the condenser water to the atmosphere. Key parameters such as water temperatures, flow rates, and power consumption of the chiller were recorded from this integrated system and used for performance evaluation during the energy audit.

### 3.2 Problem Identification:

Chiller plants are major energy consumers in industrial and commercial systems, and their efficient operation is essential for reducing energy costs. However, due to improper operation, maintenance issues, and varying load conditions, these systems often perform below their designed efficiency. In the present case, analysis of the recorded data indicates irregular temperature differences, fluctuating cooling performance, and higher power consumption, suggesting possible inefficiencies such as low ΔT and poor heat transfer.

Therefore, a systematic energy audit is required to evaluate the actual performance of the chiller plant, identify energy losses, and suggest measures to improve overall efficiency and reduce power consumption.

### 3.3 Calculations utilizing Excel Tools

All performance calculations of the chiller plant were carried out using Microsoft Excel based on measured field data. The formulas used for evaluating the system are presented below, followed by sample calculations.

#### 3.3.1 Chiller Performance Calculations

The following relations were used to determine the performance of the chiller:

1.Evaporator temperature difference; $\Delta T_e = T_i - T_o$
2.Evaporator approach = $T_o - T_s$
3.Condenser temperature difference: $\Delta Tc = T_o - T_i$
4.Condenser Approach = $T_s - T_o$
5.Compressor input power: kW = $\sqrt{3} \times V \times I \times PF$
6.Cooling capacity: TR = $(\dot{m} \times C_p \times \Delta T) / 3.517$
7.Specific energy consumption: kW/TR = Power / TR

Table 3.1 Chiller calculations

| Description | Unit | |
|---|---|---|
| | | Set 1 |
| Time | | 12.30 PM |
| Ambient Temperature | DB / WB (Deg C) | |
| Evaporator | | |
| Entering chilled water temperature | °C | 12.7 |
| Leaving chilled water temperature | °C | 8 |
| Temperature difference across evaporator | °C | 4.7 |
| Evaporator saturation temperature | °C | 4.1 |
| Evaporator approach | °C | 3.9 |
| Evaporator water flow | m³/hr | 408 |
| Condenser | | |
| Entering water temperature | °C | 24.9 |
| Leaving water temperature | °C | 29.4 |
| Temperature difference across condenser | °C | 4.5 |
| Condenser saturation temperature | °C | 30.4 |
| Condenser approach | °C | 1.0 |
| Condenser water flow | m³/hr | 599 |
| Compressor | | |
| Compressor load | % | 94 |
| Pre-Rotation vanes position | % | 30.0 |
| Voltage | V | 403.0 |
| Current | A | 504.0 |
| Power factor | | 0.946 |
| Input power | kW | 332.4 |
| Capacity of chiller | TR | 635 |
| Specific energy performance | kW/TR | 0.523 |

Sample Calculation (Set 1) Using the measured data:
1.Evaporator temperature difference: $\Delta T_e = 12.7 - 8 = 4.7$°C
2.Evaporator approach = 8 − 4.1 = 3.9°C
3.Condenser temperature difference: $\Delta Tc = 29.4 - 24.9 = 4.5$°C
4.Condenser approach = 30.4 − 29.4 = 1.0°C
5.Compressor power = $\sqrt{3} \times 403 \times 504 \times 0.946 \approx 332.4$ kW
6.Cooling capacity = $408 \times 4.186 \times 4.5 \approx 635$ TR
7.Specific energy performance = 332.4 / 635 = 0.523 kW/TR

#### 3.3.2 Pump Calculations

The performance of pumps was evaluated using:
1.Head $H = (P\_d - P\_s) / (\rho \times g)$
2.Hydraulic power $P_h = \rho \times g \times Q \times H$
3.Input power $P = \sqrt{3} \times V \times I \times PF$
4.Efficiency $\eta = P_h / P$

Table 3.2 Pump Calculations

| Measured | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pump | Voltage | Current | Power | PF | Suction Pr | Discharge Pr | Measured Flow |
| No | V | A | kW | | kg/cm² | kg/cm² | m³/hr |
| 1 | 413 | 32 | 19.3 | 0.84 | 4.7 | 5.8 | 402.0 |
| 2 | 413 | 35.6 | 20.9 | 0.82 | 4.8 | 6.1 | 398.0 |

| Rated | | | Actual Head | Hydraulic P w x Q x H | Efficiency |
|---|---|---|---|---|---|
| Design Head | Rated flow | Rated Power | | | |
| m | m³/hr | kW | | | |
| 15 | 408 | 22 | 11 | 12 | 62% |
| 18 | 390 | 22 | 13 | 14 | 67% |

Sample Calculation
1. Head= $(5.8 - 4.7) / (1000 \times 9.81) \approx 11$ m
2. Hydraulic power= $1000 \times 9.81 \times 402 \times 11 \approx 12$ kW
3. Input power= $\sqrt{3} \times 413 \times 32 \times 0.84 \approx 19.3$ kW
4. Efficiency= $12 / 19.3 \approx 62\%$

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### 3.3.3 Cooling Tower Calculations

The cooling tower performance was evaluated using:

1.Range = T_in − T_out

2.Approach = T_out − T_wb

3.Effectiveness = Range / (Range + Approach)

Table 3.3 Cooling Tower Calculations

| Time | Cooling tower inlet temperature | Cooling tower outlet temperature | Ambient temperature DB / WB | | Range, DegC | Approach, DegC | Condenser Water Flow Rate, m3/hr | Heat Rejection, TR | Effectiveness, % | Chiller -3 load % |
|---|---|---|---|---|---|---|---|---|---|---|
| 4.45 PM | 31.6 | 27.4 | 29.4 | 19.0 | 4.3 | 8.4 | 598.6 | 841 | 34% | 75 |
| 5.05 PM | 31.1 | 26.6 | 29.0 | 19.8 | 4.5 | 6.8 | | 891 | 40% | 73 |

Sample Calculation

1.Range= 31.6 − 27.4 = 4.3°C

2.Approach= 27.4 − 19 = 8.4°C

3.Effectiveness= 4.3 / (4.3 + 8.4) ≈ 34%

SPC (Specific Power Consumption)

The overall plant performance was evaluated using:

SPC = Total Energy Consumption / Total TRH

For the existing system:

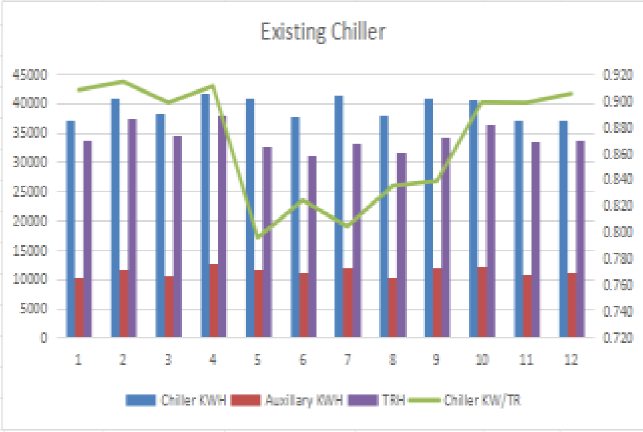
SPC = 2,149,481 / 2,388,736 ≈ 0.90 kW/TR

### 3.3.4 Return on Investment

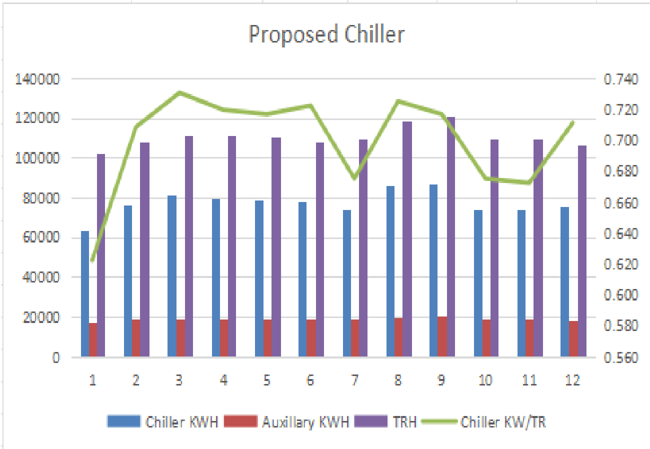
Due to confidentiality constraints imposed by the mall management, detailed financial and operational data used for the return on investment (ROI) analysis cannot be disclosed in this report. However, the final evaluated results are presented for assessment purposes.

The ROI was estimated based on a comparative analysis between the existing and proposed chiller plant systems. The evaluation considered key performance parameters such as annual energy consumption, specific power consumption (kW/TR), and overall system efficiency. The reduction in energy usage achieved by the proposed system was used to estimate the annual cost savings. Based on the analysis, the proposed system yields a return on investment of approximately 3.4 years, indicating that the initial investment can be recovered within a relatively short period. This payback period demonstrates that the implementation of a high-efficiency chiller system is both economically viable and energy-efficient. In addition to financial benefits, the proposed system also offers improved operational performance and reduced energy consumption, making it a sustainable solution for the facility.

A comparative graphical analysis between the existing and proposed systems further highlights the improvement in performance and reduction in energy consumption, supporting the obtained ROI.




**GRAPH 3.1 Existing Chiller Data**




**Graph 3.2 Proposed Chiller Data**

The graphs clearly indicate that the proposed chiller system operates at a higher cooling load (TRH) compared to the existing system. From the data, it can be observed that the proposed system consistently delivers higher TRH values across most operating periods, indicating its ability to handle increased cooling demand. Despite operating at higher loads, the proposed system demonstrates lower specific energy consumption (kW/TR). The existing system shows kW/TR values reaching close to 0.90, whereas the proposed system maintains values in the range of approximately 0.65–0.72, indicating a significant improvement in efficiency.

In the existing system, the variation in kW/TR is relatively high, with noticeable fluctuations across different months. In contrast, the proposed system exhibits a more stable kW/TR trend, reflecting improved operational control and optimized performance. Additionally, the monthly energy consumption pattern shows that while the proposed system consumes energy to meet higher loads, the increase in energy consumption is not proportional to the increase in cooling output. This confirms that the system is producing more cooling effect per unit of energy input. The auxiliary energy consumption also shows improved utilization in the proposed system, contributing to better overall plant efficiency. This improvement can be attributed to enhanced system design, better flow balancing, and optimized component performance.

Overall, the graphical comparison demonstrates that the proposed chiller plant is capable of handling higher loads with improved efficiency, reduced specific energy consumption, and more stable operation. These improvements strongly support the feasibility of the proposed system and validate the energy savings and return on investment obtained from the analysis.

## Results:

1.Earlier system –
Energy consumption = 100 %
Specific Power Consumption = 100 %
2.Improved system –
Energy consumption = 68.8 %
Specific Power Consumption = 68.8 %
Energy consumption is reduced by 31.2 % with performance improvement of 31.2 %.

## Conclusions:

The energy audit of the chiller plant indicates that the existing system operates at a higher specific power consumption compared to standard benchmark values, reflecting lower efficiency. The observed kW/TR values are relatively high and exhibit fluctuations under varying operating conditions, indicating inconsistent performance

The proposed chiller system demonstrates a significant improvement in performance by operating at lower kW/TR values while handling higher cooling loads. A notable improvement is observed in the overall plant performance, where the specific power consumption reduces from approximately **0.90 kW/TR** in the existing system to about **0.619 kW/TR** in the proposed system, indicating a substantial enhancement in energy efficiency. The proposed system also exhibits a more stable operational trend, reflecting better control and optimized energy utilization under varying load conditions. Based on the analysis, the proposed system achieves a **return on investment (ROI)** of approximately **3.4 years**, indicating that the upgrade is not only technically advantageous but also practically feasible within a reasonable time frame.

Overall, the study highlights that the implementation of an improved chiller system can enhance energy efficiency, ensure stable operation, and provide a reliable and sustainable solution for commercial HVAC applications.

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