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Evaluation of Electrical Energy Conservation Opportunities: A Case Study on SABIC Facilities

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Abstract
This study investigates electrical energy conservation opportunities at SABIC Research and Technology Centre, Bangalore, aligning with SABIC's global sustainability goal of a 15% reduction in energy consumption. The facility, with an average monthly consumption of 6.5 lakh kWh, aims to achieve a 10% reduction by 2026. A two-phase methodology—Energy Assessment and Optimization Planning—was employed. The assessment involved detailed analysis of HVAC systems, air compressors, chillers, cooling towers, lighting, and process equipment. Optimization strategies included retrofitting Air Handling Units (AHUs) with Electronically Commutated (EC) fans, implementing IoT-based Lab Environmental Monitoring Systems, and deploying Variable Speed Drives (VSDs) for compressors. Data-driven analysis revealed potential savings of over 1.2 million kWh annually from AHU upgrades alone, with a return on investment (ROI) of 1.66 years. Additional interventions in transformer load management, chiller sequencing, and power factor correction further enhanced efficiency. The study concludes with a roadmap for implementation, monitoring, and policy integration. Results demonstrate significant operational cost savings, improved equipment lifespan, and enhanced environmental performance. This case study serves as a replicable model for industrial energy optimization in tropical climates.

Keywords
Energy Audit, Electrical Energy Conservation, EC Fan Retrofit Monitoring, Variable Speed Drive (VSD), Chiller Efficiency, Power Factor Correction, Transformer Loss Reduction, HVAC Optimization, Industrial Sustainability

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I. Introduction

Electrical energy conservation has emerged as a critical priority for industrial facilities worldwide, driven by increasing energy costs, environmental regulations, and corporate sustainability goals. In this context, the SABIC Research and Technology Centre in Bangalore represents a compelling case study for evaluating and implementing energy-saving strategies in a high-demand industrial environment. SABIC, a global leader in diversified chemicals, operates across multiple continents and maintains a strong commitment to environmental stewardship. Its Bangalore facility, certified under ISO 14001:2015 and recognized as a Gold Category Green Building by IGBC, exemplifies this commitment through its infrastructure and operational practices.

Despite its green credentials, the facility faces significant energy challenges. With an average monthly electrical consumption of 6.5 lakh units and a connected load of 3500 kVA, the site's operational energy intensity is substantial. SABIC's global directive to reduce electrical energy consumption by 15% has prompted the Bangalore center to target a 10% reduction by 2025–2026. Achieving this goal requires a systematic evaluation of energy usage patterns, identification of inefficiencies, and deployment of targeted conservation measures.

The project outlined in this paper adopts a structured approach to energy conservation, beginning with a comprehensive energy assessment. This phase involves collecting and analyzing consumption data, inspecting major systems such as HVAC, air compressors, chillers, cooling towers, and process equipment, and establishing a baseline energy profile. The second phase focuses on optimization, where specific interventions are proposed and evaluated for their technical feasibility, cost-effectiveness, and environmental impact.

Key focus areas include retrofitting Air Handling Units (AHUs) with Electronically Commutated (EC) fans, implementing IoT-based environmental monitoring systems in laboratories, scheduling HVAC operations, and upgrading air compressors with Variable Speed Drives (VSDs). Additional strategies involve transformer loss reduction through load pattern audits, chiller efficiency improvements via AI-driven sequencing, and power factor correction using hybrid filters and STATCOMs.

The methodology integrates A3 practical problem-solving techniques, emphasizing Plan-Do-Check-Act (PDCA) cycles to ensure continuous improvement. Each intervention is supported by detailed data analysis, including energy consumption metrics, cost-benefit calculations, and return on investment (ROI) estimates. For instance, AHU retrofits alone are projected to save over 1.2 million kWh annually, with ROI periods ranging from 0.9 to 1.6 years.

This study not only contributes to SABIC's sustainability goals but also offers a replicable model for other industrial facilities seeking to optimize energy use. By bridging literature gaps—such as the lack of tropical climate-specific data and limited integration of digital monitoring tools—the project advances the field of industrial energy management. The findings underscore the importance of data-driven decision-making, cross-functional collaboration, and strategic investment in energy-efficient technologies.

In the sections that follow, we research into the literature review, methodology, results, and discussion, culminating in actionable recommendations and a roadmap for future research. This paper aims to serve as a comprehensive guide for engineers, facility managers, and sustainability professionals committed to advancing energy conservation in industrial settings.

II. Literature Review

Electrical energy conservation has become a cornerstone of sustainable industrial operations. The reviewed literature spans diverse sector beverages, textiles, food processing, institutional buildings, and household offering a rich foundation of strategies, outcomes, and challenges. This section synthesizes insights from 17 key studies and maps them to the context of SABIC's Bangalore facility.

Article Summaries

Author(s)	Year	Sector	Key Findings
Loveneesh Talwar & Vikas Kumar	2015	Beverage Industry	Identified >10% annual savings (~₹36 lakhs); payback of 4–5 years for efficient motors.
Kartik D. Ukhalkar	2021	Cross-sector	Structured audit methodology (Pre/Post); 5–20% savings potential.
Paweł S. Zięba	2021	Polish Enterprises	Audits led to measurable savings; financial barriers hindered implementation.
Prachi Chauhan.	2021	General Review	Benefits: cost reduction, performance; Barriers: cost, awareness, enforcement.
Prof. M.A. Mulla.	2020	Industrial	Energy management integration improves efficiency and reduces bills.
Saurabh Kumar Sharma.	2019	Industrial	Classified audits; structured reporting enhances savings.
Md. Faiz Ahmad.	2018	Industrial	VFDs, LEDs, motor upgrades yield significant savings.
Zbigniew Bohdanowicz.	2021	Households	15–30% savings with efficient appliances; behavioral changes critical.
Amol Gajanan Bhavsar	2018	Diesel Plants	>10% fuel savings; optimized engine efficiency.
K. Natarajan	2015	Industrial	Practical strategies (lighting, motors, boilers); life-cycle cost focus.
Nature Science Foundation	2019	Institutional	Identified energy-saving opportunities; recommended management practices.
Patrik Thollander.	2013	Foundries	Financial/organizational drivers; 65 foundries audited.
P. Nagaveni.	2019	Textile Mill	23% savings; load manager used for data.
Yayan Saputra.	2022	Pipeline Industry	ISO 50001 reduced welding energy by 54.3%.
Derar Al Momani.	2023	Food Production	18% savings via boiler optimization; 772.82 tons CO avoided.
Miqdam T. Chaichan & Hussein A. Kazem	2016	Residential	Thermal insulation and lighting efficiency emphasized.
Ahmed Al-Ardan.	2025	Institutional	LED retrofit cut lighting energy by 74%; high-EER AC units saved 28.4%.

Analysis and Insights

1.Audit Methodologies

Most studies emphasize structured energy audits as foundational to conservation. Pre-audit planning, on-site measurements, and post-audit reporting are common. However, few integrate real-time monitoring or IoT-based diagnostics.

2. Sector-Specific Strategies

Industrial sectors benefit from VFDs, efficient motors, LED lighting, and boiler optimization. Yet, tropical climate-specific adaptations and lab-specific HVAC controls are rarely addressed.

3. Behavioral and Organizational Factors

Behavioral changes and organizational commitment are critical. Studies highlight barriers such as lack of awareness, high upfront costs, and weak policy enforcement.

4. Standards and Certifications

ISO 50001 emerges as a powerful framework for structured energy management. Its application in welding and pipeline industries shows measurable impact.

5. Environmental Impact

Several studies quantify CO reductions, linking energy savings to sustainability goals. However, few explore lifecycle emissions or asset longevity improvements

Detailed Literature Gaps and Opportunities

Area	Literature Gap	Opportunity / Intervention	Expected Impact
AHU EC Fan Retrofitting	Limited tropical-climate data; EC fan impact not quantified	Replace belt-driven fans with EC fans	20–30% energy savings; lower maintenance
Lab HVAC Control	Neglect of lab-specific temperature/RH monitoring	IoT-based demand ventilation and scheduling	5–10% HVAC savings; improved safety
Air Compressors	Focused only on leak detection; poor digital integration	VSD compressors, IoT leak detection	5–10% savings; reduced downtime
Cooling Towers	Poor linkage between water and energy optimization	EC fans, efficient pumps	10–20% savings; improved water-energy synergy
Transformer Losses	Sparse data on harmonics and fluctuating loads	Online monitoring (THD, load)	3–5% loss reduction; longer asset life
Chillers	Lack of Indian data on partial load and sequencing	AI-driven setpoint optimization, VFD retrofits	10–15% savings; COP improvement
Power Factor Correction	Static capacitor focus; no dynamic correction	IoT meters, STATCOMs, hybrid filters	PF >0.95; 5–10% cost reduction
Harmonics	Weak THD linkage to failures; few quantified studies	Harmonic audits, active filters	THD <5%; 10–15% asset life extension
Policy & KPIs	No literature on energy conservation KPIs	Develop site-specific KPIs and policy	Continuous improvement; accountability
IoT Energy Monitoring	Rare integration in audits	Real-time dashboards, alerts	Enhanced visibility; proactive management
Chiller Sequencing	Theoretical COP focus; no real-time control	AI-based sequencing	COP from 1.1 → 0.7 kW/TR
Diesel Generator Optimization	Limited case studies on DG efficiency	Load balancing, fuel monitoring	10–15% fuel savings
Rooftop Solar Integration	No hybrid grid-solar models discussed	Solar + grid optimization	Reduced grid dependency; cost savings
Lighting Systems	LED retrofit studies lack tropical data	Smart lighting controls	30–50% savings; improved comfort
HVAC Scheduling	Few studies on time-based HVAC control	Shift-based scheduling	5–10% savings; reduced idle load
Load Manager Use	Underutilized in Indian audits	Load profiling and peak shaving	Demand charge reduction
Asset Life Extension	Rarely quantified in audits	Predictive maintenance	Reduced downtime; longer equipment life

Research in industrial energy conservation has demonstrated substantial potential for improving operational efficiency and reducing costs. Numerous studies highlight that effective energy audits can yield savings between 10% and 30% of total electrical energy consumption. These savings are often realized through interventions in motors, HVAC systems, lighting, and process equipment.

Common strategies reported in literature include the use of high-efficiency motors, variable frequency drives (VFDs), LED lighting, boiler optimization, and structured energy management through ISO 50001. Implementing such systems helps organizations establish baselines, monitor performance, and implement corrective actions. Thermal insulation, load management, and energy-efficient scheduling have also been recognized as practical methods for reducing overall consumption.

Several case studies reinforce the tangible benefits of energy audits. For instance, LED retrofits have reduced lighting energy consumption by up to 74%, while boiler optimization has achieved savings of 18% or higher. Chiller optimization through VFDs and temperature reset strategies have yielded reductions of 10–20%. The typical payback period for most industrial energy efficiency projects ranges between two and five years.

Despite these advances, barriers such as high initial capital investment, lack of technical awareness, and insufficient enforcement of standards often impede widespread adoption. The integration of IoT-based energy monitoring systems and data analytics is emerging as a key enabler for overcoming these barriers by offering real-time visibility and control over energy usage.

A review of literature indicates that while many studies address individual systems or technologies, there is a lack of comprehensive frameworks combining electrical, mechanical, and digital optimization within a single facility. This research fills that gap by proposing a holistic methodology integrating multiple conservation measures under a unified management structure, applied to the SABIC Research and Technology Center in Bangalore.

Methodology

1.1 Overview of Research Design

This study adopts a comprehensive engineering research design aimed at evaluating electrical energy conservation opportunities within an industrial research facility. The approach integrates quantitative data analysis, qualitative system diagnostics, and strategic planning. The research is grounded in empirical data collected from the SABIC Research and Technology Centre, Bangalore, and is structured to address both operational inefficiencies and strategic sustainability goals. The design is iterative and modular, allowing for subsystem-level analysis while maintaining a holistic view of facility-wide energy performance. The methodology is guided by the principles of continuous improvement and data-driven decision-making, ensuring that each intervention is technically sound, financially viable, and environmentally beneficial.

The research employs a systematic methodology grounded in the A3 problem-solving approach and **PDCA (Plan–Do–Check–Act)** cycle. The study was conducted through five main phases:

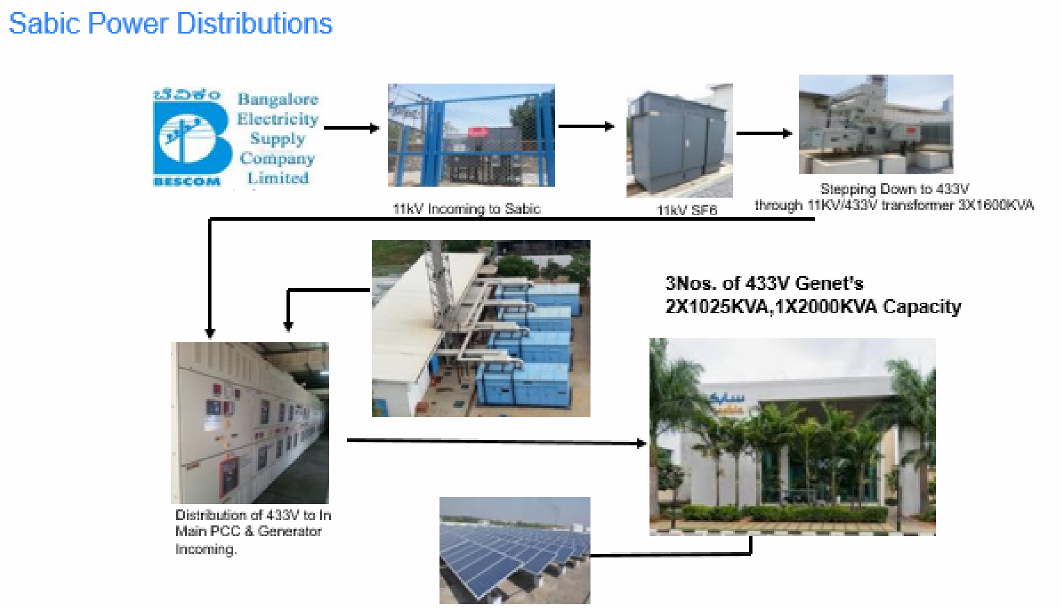
1. Baseline Energy Assessment
2. Identification of Energy Conservation Measures (ECMs)
3. Detailed Technical Evaluation
4. Economic and ROI Analysis
5. Monitoring and Control Implementation

1.2 A3–PDCA Framework and Energy Assessment Approach

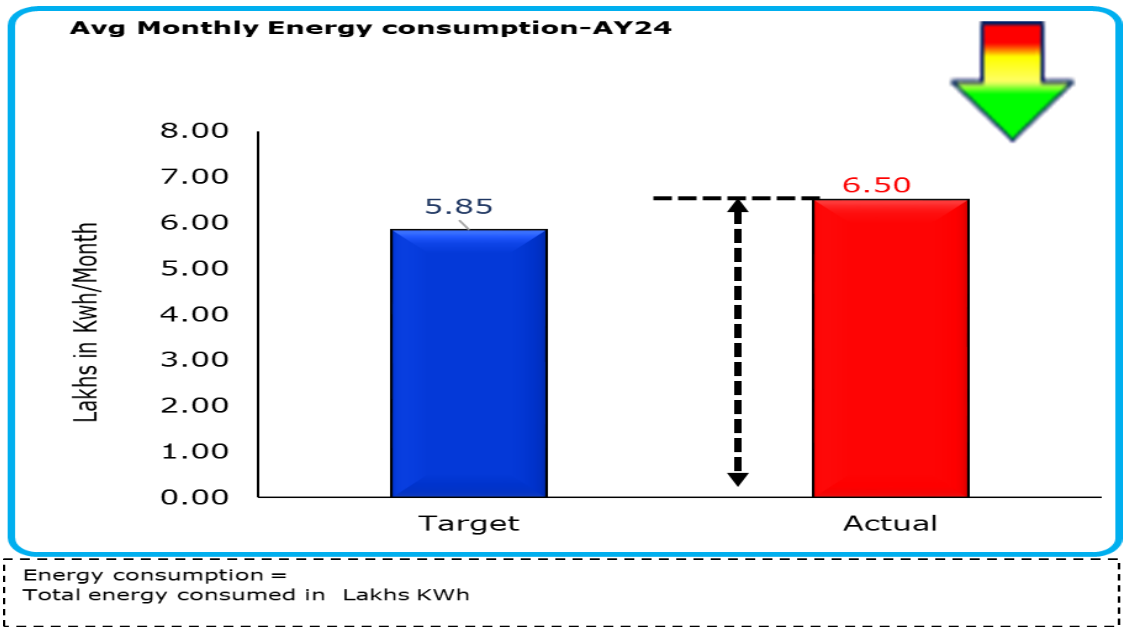
The A3 problem-solving framework, derived from lean manufacturing principles, serves as the backbone of the study's methodological approach. It structures the energy conservation initiative into a Plan-Do-Check-Act (PDCA) cycle, enabling systematic identification, implementation, and evaluation of energy-saving measures. In the planning phase, the research team defined the problem—excessive energy consumption relative to SABIC's global reduction targets—and established a baseline. The "Do" phase involved deploying targeted interventions across key subsystems. The "Check" phase focused on monitoring outcomes using real-time data and performance metrics. Finally, the "Act" phase standardized successful practices and identified new areas for improvement. This cyclical methodology ensures adaptability and fosters a culture of continuous energy optimization.

1.3 Baseline Data Collection and Energy Flow Mapping

Baseline data collection was conducted over a 12-month period using calibrated energy meters, operational logs, and supervisory control systems. The facility's electrical infrastructure comprises a 11kV incoming supply from KEB, stepped down to 433V via three 1600 kVA transformers. Power is distributed to various subsystems including HVAC, lighting, process equipment, and utilities. Captive generation is provided by three DG sets (2×1250 kVA and 1×2000 kVA), supplemented by a 750 kWp rooftop solar installation. Monthly energy consumption averaged 6.5 lakh kWh, with a unit cost of ₹9. Energy flow mapping was performed using Sankey diagrams and load profiling tools to visualize consumption patterns and identify high-impact areas for intervention.



Electrical Details	
Sanction Demand	1800KVA
Connected Load	3500 KVA
Captive Power DG sets	2X1250KVA, 1X2000KVA
Transformer Capacity	3X1600KVA
Rooftop Solar Plants	750KwP
HT Incoming Voltage	11KV
Avg Power consumption in Units 2024	6.5 Lakhs Units
Avg Power Cost per units	9



1.4 Sub-System Analyses

The following key subsystems were analyzed in detail to evaluate energy performance, operational efficiency, and potential areas for improvement within the facility:

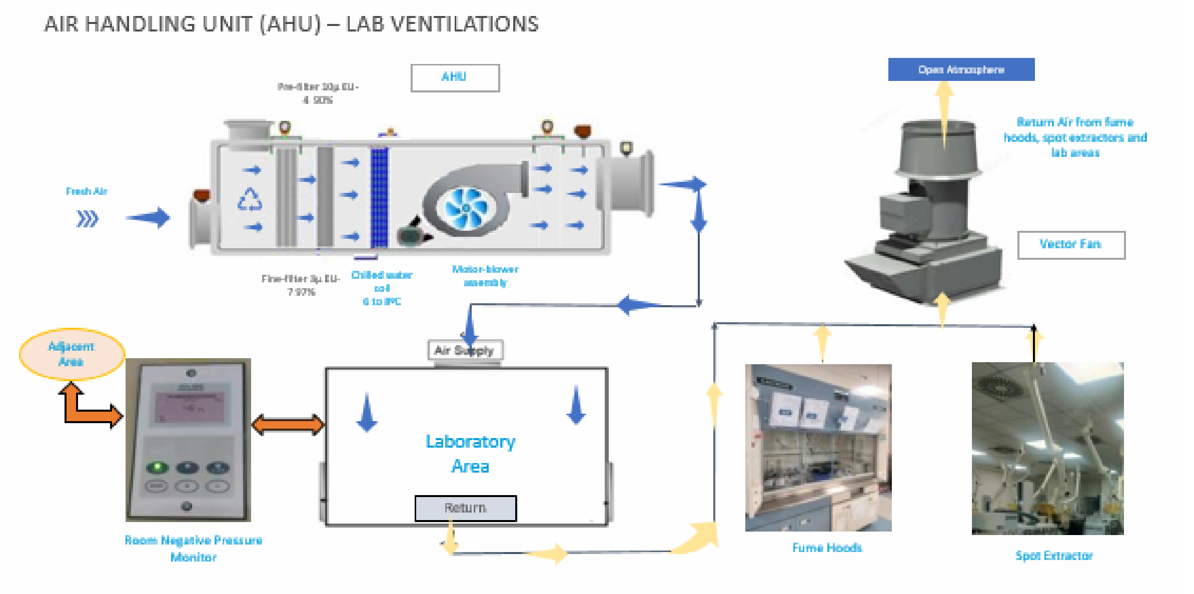
1. AHU EC Fan Upgradations -Energy Efficiency Fan Upgradations.
2. Lab EMS System -Temperature Monitoring and Control Through IoT.
3. Air Compressor VSD Evaluations -Study of Air compressor load and VSD
4. Cooling Tower Fan Up gradate -Energy Efficient Fan upgradations.
5. Transformer Losses -Assessment of Transformer Losses and improvements.
6. Chiller Efficiency Monitoring -Analysis Chiller Parameter
7. Power Factor Analysis -Power Factor assessment
8. Power Cost Analysis by Various Power Purchase Model to find the low cost
9. Energy Monitoring through IoT-Assessment of Energy Monitoring System implementations
10. Energy Conservation Policy/KPI

1.4.1 Air Handling Unit (AHU) EC Fan Upgradation

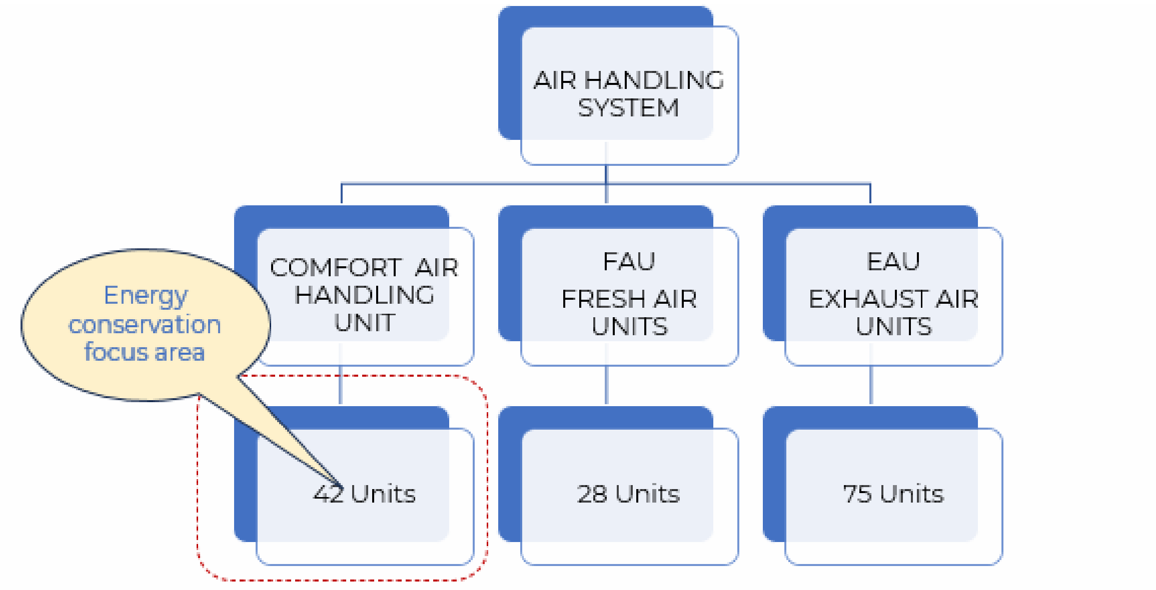
The AHU system, comprising 42 units, was identified as the single largest energy consumer. Existing driven motors are proposed to be replaced with Electronically Commutated (EC) fans, offering direct-drive efficiency and variable speed control. Baseline consumption was calculated using motor ratings, runtime hours, and tariff data. Post-retrofit measurements indicated energy savings ranging from 28% to 39% per unit. The intervention also reduced maintenance costs and improved airflow stability. ROI analysis showed payback periods between 0.9 and 1.6 years, making it a financially attractive measure.

Existing centrifugal fans in AHUs are proposed to be replaced with electronically commutated (EC) fans. EC fans, equipped with permanent magnet motors and built-in VFDs, offer 25–30% higher efficiency and reduced transmission losses. Baseline annual AHU consumption was 3.24 million kWh, with projected savings of 0.9 million kWh annually post-retrofit.

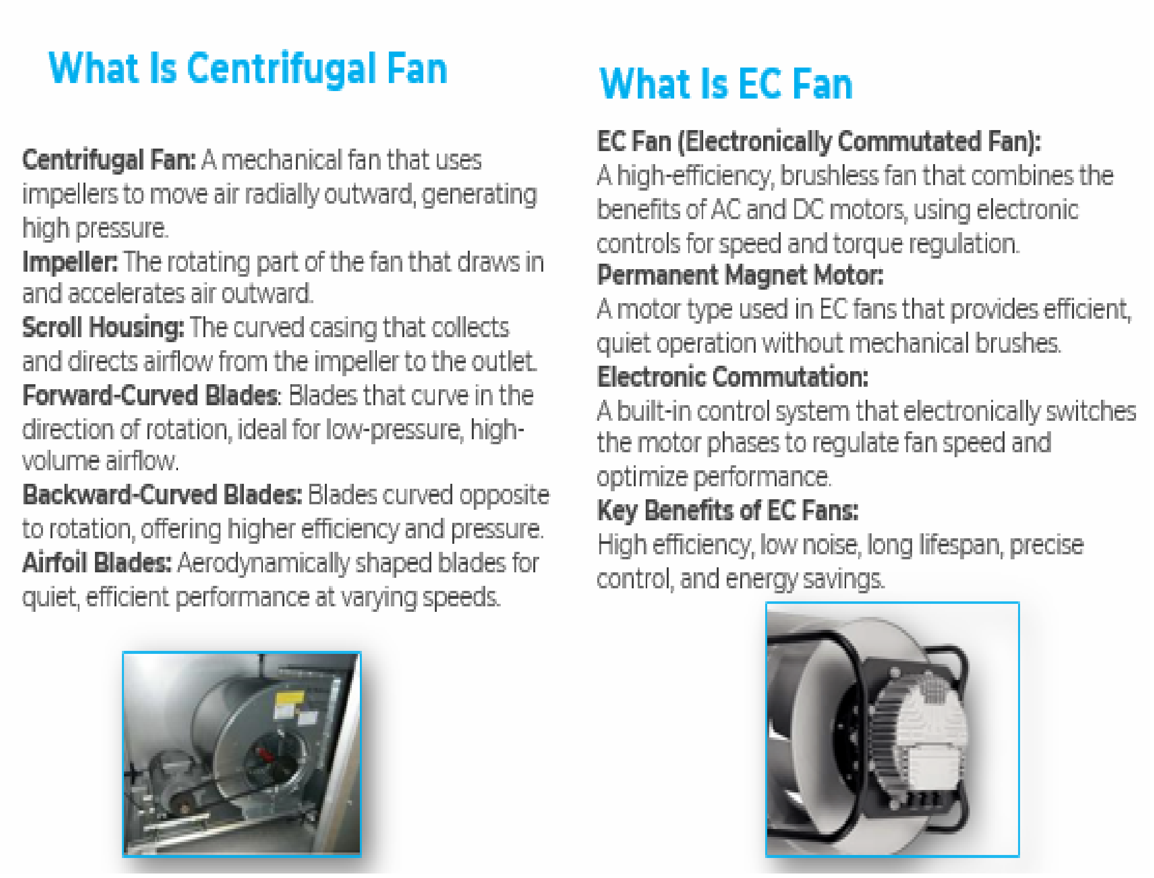
AHU SCHEMATIC DIAGRAM



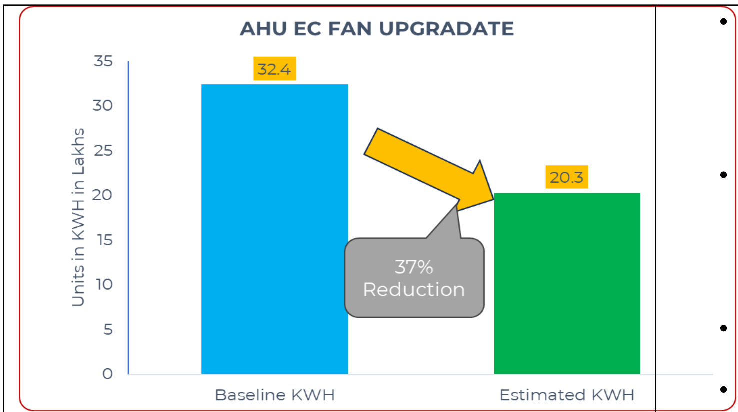
AHU SYSTEM:



COMPARISION CENTRIFUGAL FAN VS EC FAN



Estimated Savings:



- EC stands for Electronically Commutated which basically means it is a fan with a brushless DC motor, hence is no Commutation loss and brush loss.
- DC motors are around 30 to 40% more efficient than AC motors because the secondary magnetic field comes from permanent magnets rather than copper windings.
- Motor & Fan are coupled together, so there is no transmission losses.
- It's a DC motor, hence power factor is unity.
- The EC fans are inbuilt VFD & direct driven motors provides better efficiency

S. No	Name of the ECM's	Tentative Investment	Final Savings Commitment /annum	Payback Period in Years (ROI)
		INR	MINR	
1	Retrofit of direct Driven AHU with Electronically Commutated blower	160Lakhs	108 Lakhs	1.48

1.4.2 IoT-Based Laboratory Environmental Monitoring System (Lab EMS)

48 laboratories relied on manual temperature and humidity monitoring, leading to delays and inefficiencies. IoT sensors (DHT22, Bosch BME280) integrated with Raspberry Pi-based controllers are proposed to be installed for automated monitoring and AHU control through MQTT protocol. The system achieved 5% energy savings while enhancing compliance and data accuracy.

Laboratory HVAC systems operated on fixed schedules, leading to energy wastage during low level temperature and RH excursion periods. IoT sensors are proposed to be deployed to monitor temperature and relative humidity in real time. Data was fed into a central dashboard, enabling demand-based ventilation and dynamic scheduling. The system achieved 5% energy savings while maintaining safety and compliance standards. The intervention also enhanced indoor air quality and reduced wear on HVAC components.

Current Practices:

In STCB overall 48 Laboratory are available and room temperatures are monitoring through manual mode and AHU controlling through convention controllers with time delayed response which leads to more energy consumptions as well as improver data recording

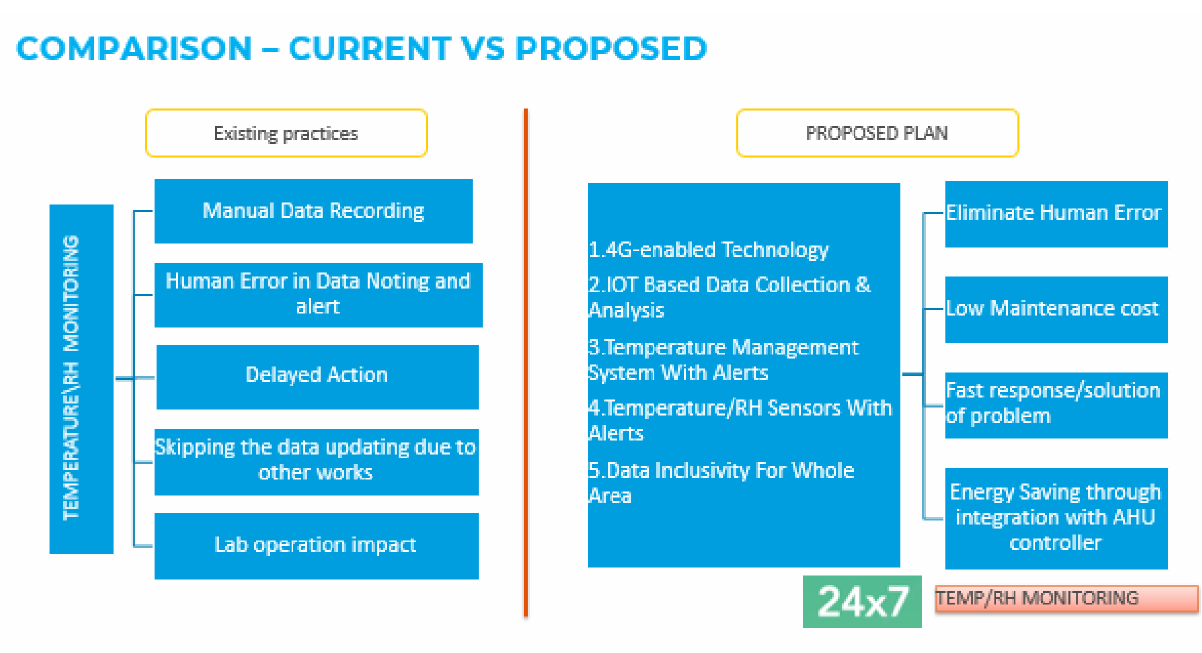
Lab Environmental Parameter Limit:

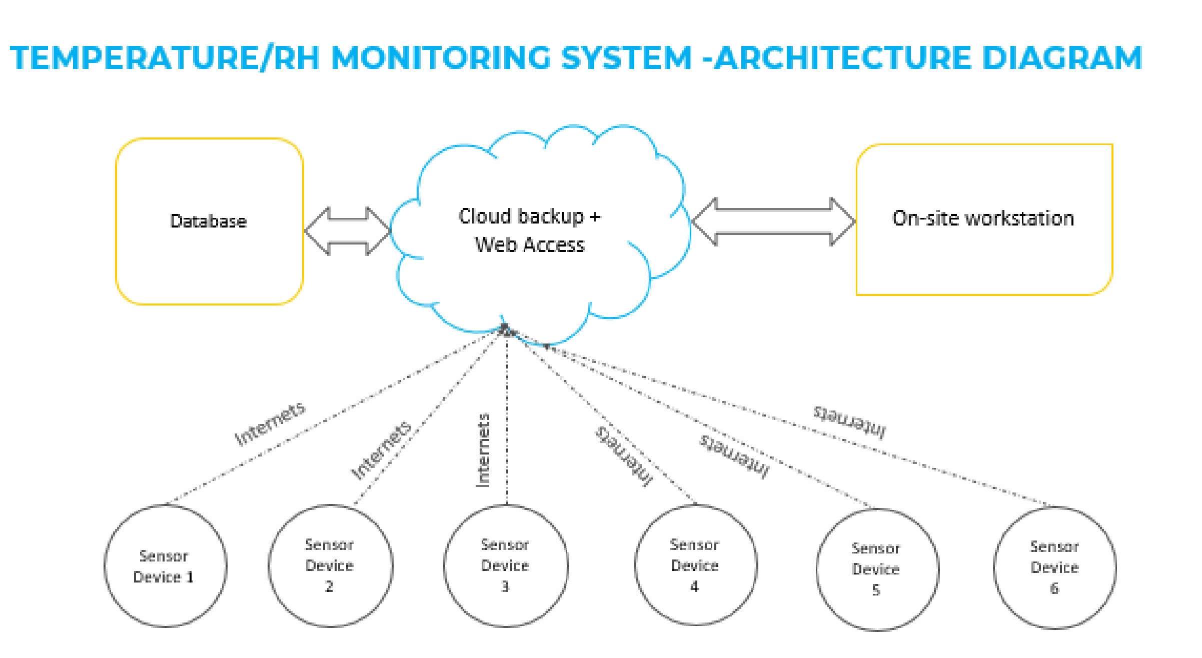
- Temperature: 21 ± 3°C
- Relative Humidity: ≤60% RH

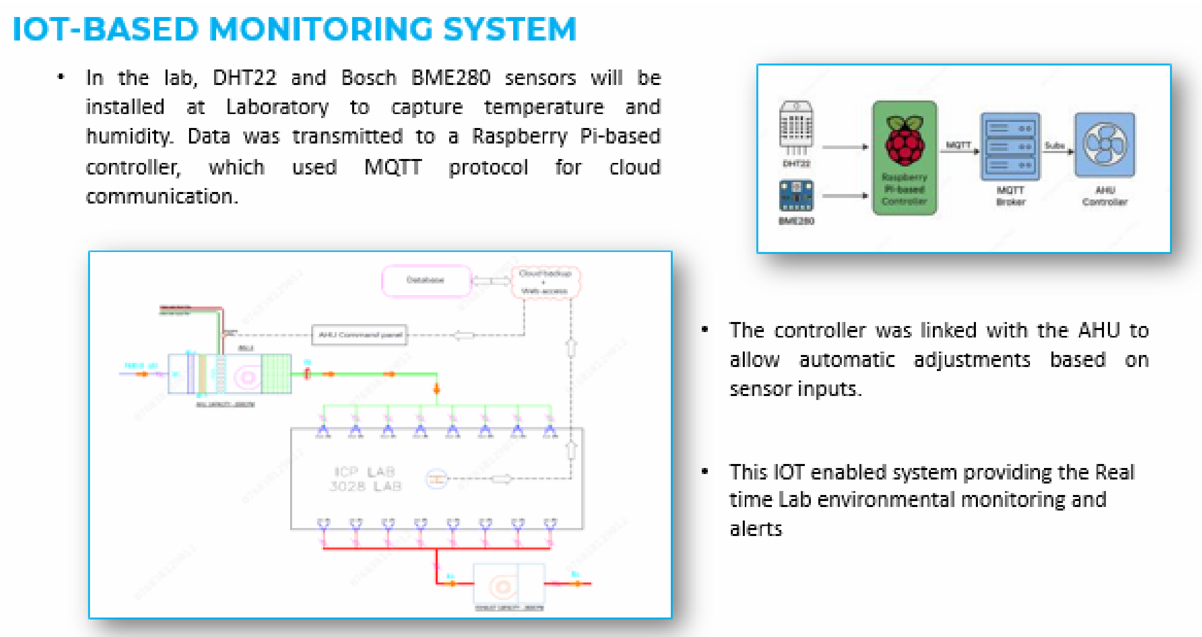

Lab Temp & RH - Daily Log Sheet

MONTH :
LAB NO :
LOCATION :
AHU NO :

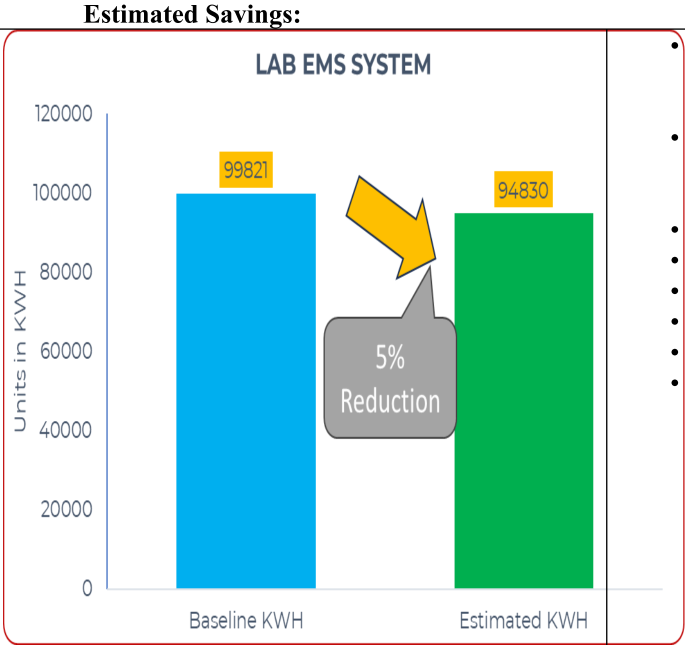
Temp : 21 C° to 25 C°
RH Range: Less than 60%


COMPARISON – CURRENT VS PROPOSED
Existing practices
TEMPERATURE\RH MONITORING
Manual Data Recording
Human Error in Data Noting and alert
Delayed Action
Skipping the data updating due to other works
Lab operation impact
PROPOSED PLAN
1.4G-enabled Technology
2.IOT Based Data Collection & Analysis
3.Temperature Management System With Alerts
4.Temperature/RH Sensors With Alerts
5.Data Inclusivity For Whole Area
Eliminate Human Error
Low Maintenance cost
Fast response/solution of problem
Energy Saving through integration with AHU controller
24x7
TEMP/RH MONITORING


TEMPERATURE/RH MONITORING SYSTEM -ARCHITECTURE DIAGRAM
Database
Cloud backup + Web Access
On-site workstation
Internets
Internets
Internets
Internets
Internets
Internets
Sensor Device 1
Sensor Device 2
Sensor Device 3
Sensor Device 4
Sensor Device 5
Sensor Device 6



Estimated Savings:



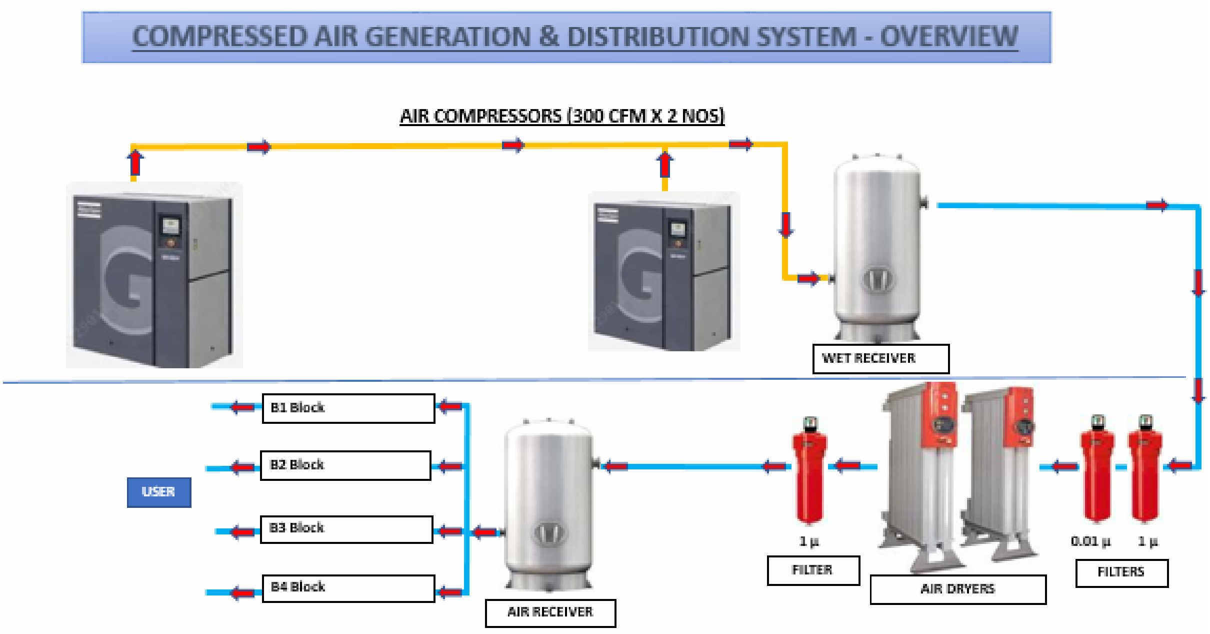
- The Implementation of this project aims to enhance operational efficiency by automating data recording process.
- It is essential and mandatory requirement to provide Lab area Temperature/RH accurate data's 24X7.
- Real time data collection
- Human Error Reduced
- Automatic alerts and reports
- Predictive insights
- Data Driven decision
- Reduced Man power cost. As well as Energy saving of 5%

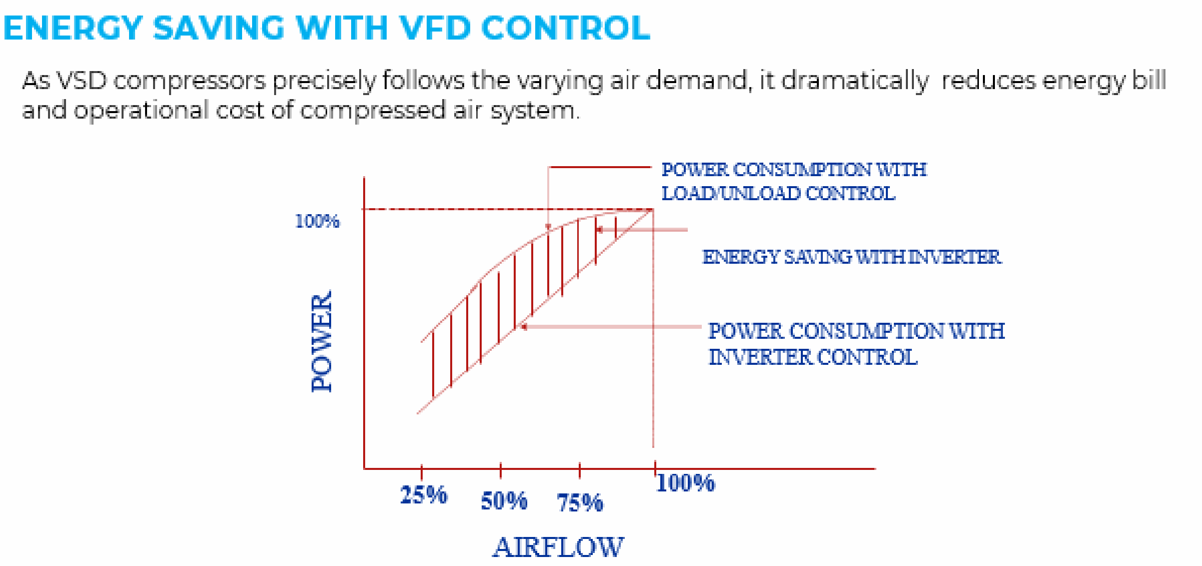
S. No	Name of the ECM's	Tentative Investment	Final Savings Commitment /annum	Payback Period in Years (ROI)
		INR	MINR	
1	Lab EMS System (IOT based Lab Temperature/RH Monitoring's system and integrate with AHU Controllers)	15 Lakhs	5.39 Lakhs	2.78

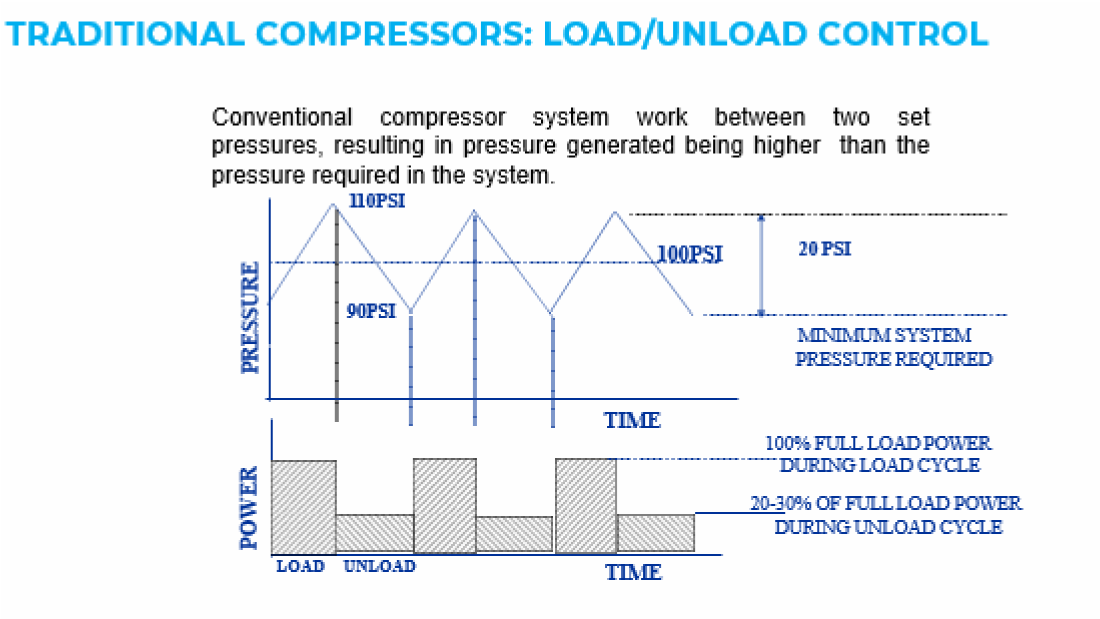
1.4.3 Air Compressor VSD Evaluation

Two 300 CFM compressors are proposed to be retrofitted with variable speed drives to eliminate energy loss during unload cycles. The modification resulted in 20–30% energy reduction and minimized mechanical wear. Soft-start features reduced peak demand on the electrical grid.

Air compressors accounted for approximately 15% of total energy consumption. Baseline systems operated at fixed speeds, resulting in inefficiencies during partial load conditions. Variable Speed Drives (VSDs) are proposed to be installed to modulate motor speed based on demand. The intervention yielded 5–10% energy savings and improved system reliability. Pressure band optimization further enhanced performance.

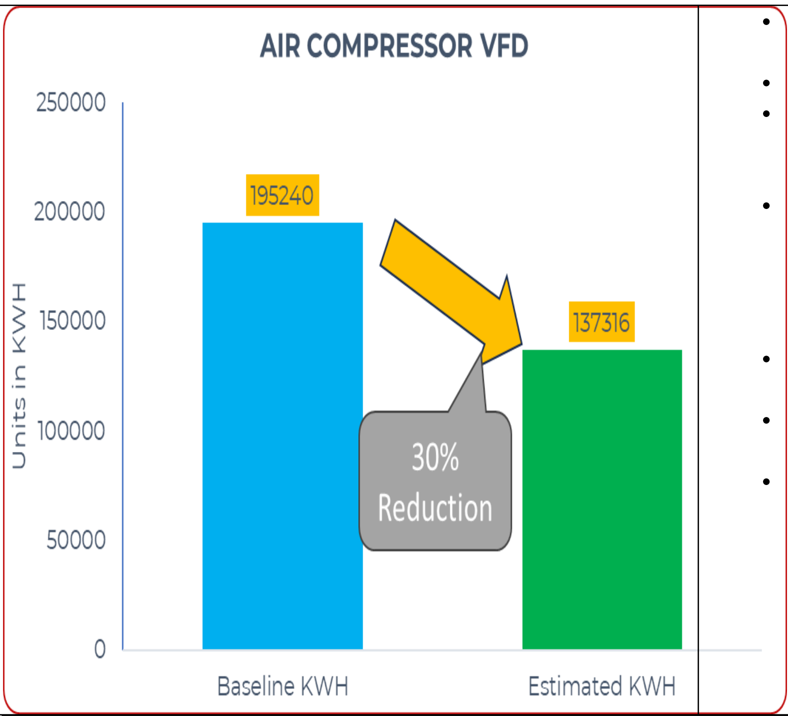






Pay back calculation -Air compressor VFD			
Filed Data	Running Hours	324	Hrs
	Loading Hours	186	Hrs
	Loading Current	95	Amps
	Unloading Current	54	Amps
	Running Hours Per Day	24	Hrs
	Power Cost for KWH	8.00	Rs
% of Load/Unload	Loading in Percentage %	57%	
	Unloading in Percentage %	43%	
Power Consumption in Kw	Loading in KW	61.53	KW
	Unloading in KW	34.97	KW
Running Hours	Loading Hours per Month	186.00	Hrs/Month
	Unloading Hours Per Month	138.00	Hrs/Month
Power consumption in units	Power Consumption for loading	11443.96	Unit/Month
	Power Consumption for Unloading	4826.28	Unit/Month
	Total Power Consumption Per day	16270.24	Unit/Month
Power Consumption	Power Consumption for loading	102995.54	Rs/Month
	Power Consumption for Unloading	43436.52	Rs/Month
	Total Power Consumption Per Month	146432.16	Rs/Month
	Power Consumption for VFD at Loading	102995.54	Rs/Month
Saving	Net Power Saving	43436.62	Rs/Month
	Net Power Saving	521239.44	Rs/Year
	Investment on CP VFD	**800000.00**	**Rs**
	Pay Back Period	**1.53**	**Year**

Estimated Savings:



- Variable pressure setting possible.
- Accurate pressure control.
- No unload cycle, thus reducing power consumption typically by 20 to 30% of full load power.
- Soft start with inverter control, power to the motor is increased progressively, avoiding peak power demand in the electrical system
- VSD compressors can be started and stopped without limitation.
- Frequent start-stops no longer lead to current peak penalties.
- The electrical installation can often be rated for a lower current, meaning savings in investment.

S. No	Name of the ECM's	Tentative Investment	Final Savings Commitment /annum	Payback Period in Years (ROI)
		INR	MINR	
1	Air Compressor for VFD	8 Lakhs	5.27 Lakhs	1.73

1.4.4 Cooling Tower Fan Retrofit

Cooling towers are proposed to be retrofitted with EC fans and high-efficiency pump motors. Baseline performance was assessed using flow rate, temperature differential, and motor power data. The retrofit improved heat rejection efficiency and reduced energy consumption by 10–20%. Water-energy linkage was optimized through automated control of fan speed and pump operation. The intervention also contributed to improved chiller performance and reduced thermal stress on equipment.

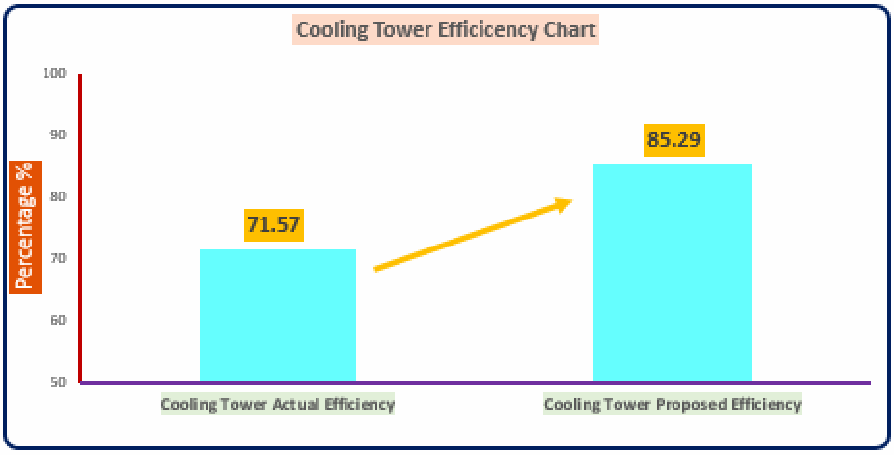
Aging 7.5 kW cooling tower fans are proposed to be replaced with EC technology fans, improving efficiency from 71.5% to 85.3%. Annual chiller-related energy reduction of 3% was achieved, in addition to improved reliability and noise reduction

COOLING TOWERS ACTUAL

Majority of the area cooling tower fins and nozzle pipelines are chocked

Cooling Tower Fan motors winding failed and fan blades damaged/bearings are failed

COOLING TOWER PERFORMANCE



- We are expecting the efficiency of the cooling tower will be increased from 71.57% to 85.29%
- 3% Chiller Consumption will be reduced

COOLING TOWER RETROFIT

Before retrofit

Proposed retrofit

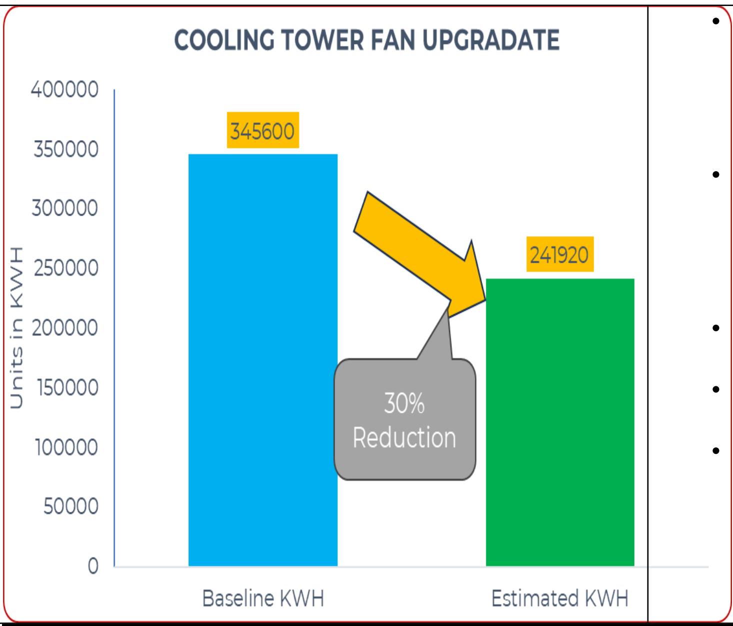
COOLING TOWR FAN MOTOR DETAILS						
SL.NO	EQUIPMENT NAME	MAKE	LOCATION	EQUIPMENT SL.NO	Model No	CAPACITY
1	Cooling tower fan-1	New indianavyug electric motors and pumps ltd	B9 TERRACE	01B8098	9432E	HP-10/KW-7.5/AMPS-18/RPM-710
2	Cooling tower fan-2	New indianavyug electric motors and pumps ltd	B9 TERRACE	01B8096	9430E	HP-10/KW-7.5/AMPS-18/RPM-710
3	Cooling tower fan-3	New indianavyug electric motors and pumps ltd	B9 TERRACE	01B8091	9425E	HP-10/KW-7.5/AMPS-18/RPM-710
4	Cooling tower fan-4	New indianavyug electric motors and pumps ltd	B9 TERRACE	01B8097	9428E	HP-10/KW-7.5/AMPS-18/RPM-710
5	Cooling tower fan-5	New indianavyug electric motors and pumps ltd	B9 TERRACE	01B8095	9427E	HP-10/KW-7.5/AMPS-18/RPM-710
6	Cooling tower fan-6	New indianavyug electric motors and pumps ltd	B9 TERRACE	01B8100	9431E	HP-10/KW-7.5/AMPS-18/RPM-710
7	Cooling tower fan-7	New indianavyug electric motors and pumps ltd	B9 TERRACE	N/A	N/A	HP-10/KW-7.5/AMPS-18/RPM-710
8	Cooling tower fan-8	New indianavyug electric motors and pumps ltd	B9 TERRACE	01B8093	9426E	HP-10/KW-7.5/AMPS-18/RPM-710

8 number of fans with capacity of 7.5 KW

=8 No’s X7.5Kw = 60KW

- Avg Cooling tower operation hours/day = 16Hrs
- Avg Power consumption/month= 28,800 Units

Estimated Savings:



- EC stands for Electronically Commutated which basically means it is a fan with a brushless DC motor, hence is no Commutation loss and brush loss.
- DC motors are around 30 to 40% more efficient than AC motors because the secondary magnetic field comes from permanent magnets rather than copper windings.
- Motor & Fan are coupled together, so there is no transmission losses.
- It's a DC motor, hence power factor is unity.
- The EC fans are inbuilt VFD & direct driven motors provides better efficiency

S. No	Name of the ECM's	Tentative Investment	Final Savings Commitment /annum	Payback Period in Years (ROI)
		INR	MINR	
1	COOLING TOWER EC FAN UPGRADE	13.75 Lakhs	9.33 Lakhs	1.65

1.4.5 Transformer Loss Assessment and Load Optimization

Three 1600 kVA transformers operated continuously with suboptimal loading. Efficiency analysis using BEE guidelines identified total annual losses of ~105,770 kWh. By operating two transformers and cycling the third, losses are proposed to be reduced by 30%, resulting in annual savings of ~31,000 kWh.

Transformer loss analysis:

Transformer is a static device. Hence the losses of transformer are very low, thus giving very high efficiency. Transformer losses comprise of two parts.

1. No load losses (Iron losses), which are assumed to be constant.
2. Variable losses (copper losses), which vary as square of load current.

However, it is well known that transformer efficiency is highest at about 30-50% load. The dielectric strength of the transformer oil plays an important role in the smooth functioning of the transformer. The lesser the dielectric strength of the transformer oil the more the chances of the breakdown of insulation. Therefore, a regular checking of the dielectric strength is necessary.

Three transformers will be in operation each 1600 kVA rating. Specifications and other details of the 1600kVA transformer are given in below table.

Transformer Load analysis:

Description	Rated capacity	Loading KVA			Loading %		
		Minimum	Average	Maximum	Minimum	Average	Maximum
Transformer-1	1600 KVA	439	600	1164	27.4	37.5	72.8
Transformer-2	1600 KVA	411	495	793	25.7	30.9	49.5
Transformer-2	1600 KVA	350	400	550	21.87	25	34.35

Losses in Transformer-1: -
Present losses:
No load loss and standard load loss of the transformers is calculated as per BEE guidelines.
Total losses:
Rated 1600 KVA Transformer = {NL loss+ FL loss (Act. KVA / Rated KVA} 2
= {2.8 + 12.3 * {600/1600)2}
= 4.53 KW
Operating hours with load = 24 hrs./Day.
Total losses during operations = 4.53*24 hrs.
= 108.7 kWh/day
Annual transformer losses = 108.7kWh/day* 365 day
= 39676 kWh/Annum

Losses in Transformer-2: -
Present losses:
No load loss and standard load loss is calculated according to BEE guidelines.

Total losses:
Rated 1600 KVA Transformer = {NL loss+ FL loss (Act. KVA / Rated KVA} 2
= {2.8 + 12.3 * {495/1600)2}
= 4.0 KW
Operating hours with load = 24 hrs./Day.
Total losses during operations = 4.0*24 hrs.
= 95.4 kWh/day
Annual transformer losses = 95.4 kWh/day*365 days
= 34821 kWh/Annum

Losses in Transformer-3:

Present losses:
No load loss and standard load loss is calculated according to BEE guidelines.
Total losses:

Rated 1600 KVA Transformer = {NL loss+ FL loss (Act. KVA / Rated KVA} 2

= {2.8 + 12.3 * {400/1600)2}

= 3.57 KW

Operating hours with load = 24 hrs./Day.

Total losses during operations = 3.57*24 hrs.

= 85.68 kWh/day

Annual transformer losses = 85.68 kWh/day* 365 days

= 31273.2 kWh/Annum

Transformer Best Efficiency:
The maximum load can be loaded on the transformer to utilize at best efficiency by using this formula:
= v (no load losses/full load losses) * Rated KVA

= v (2.8/12.3) * 1600

= 763.4 kVA.

= 47.7 %

Transformer Best Efficiency

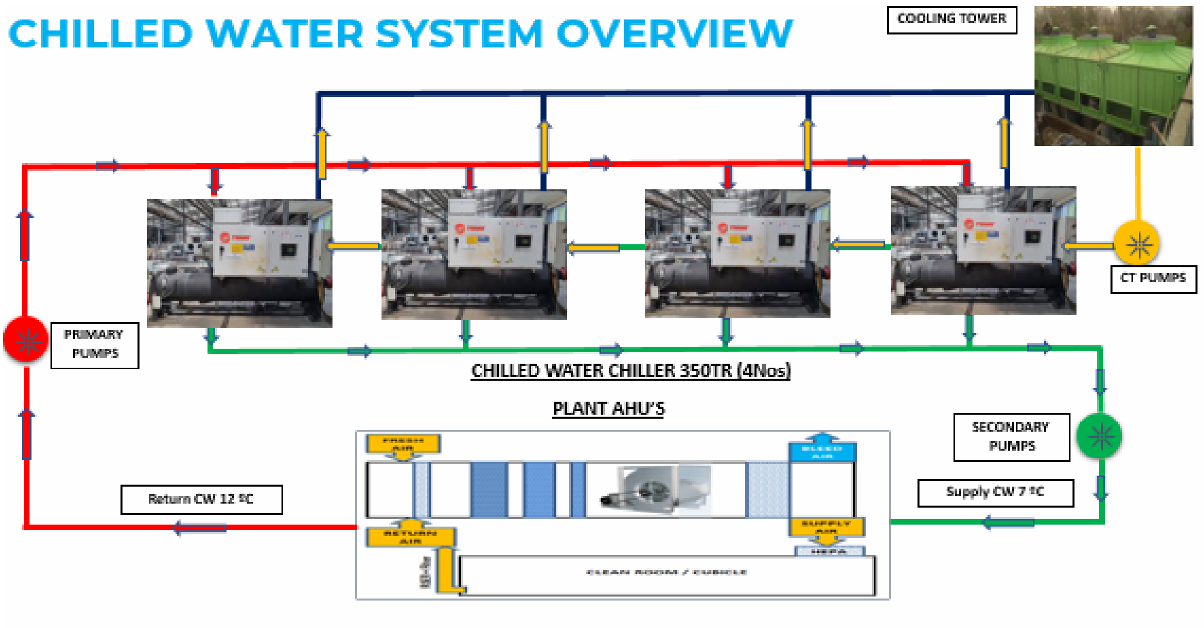
S. No	Description	Rating	Best Efficiency at Loading %
1	Transformer	1600	47.70%

ESTIMATED SAVINGS:

Description	Unit	Value
Transformer 1 Total loss	kWh	39676
Transformer 2 Total loss	kWh	34821
Transformer 3 Total loss	kWh	31273
After transformer 3 load transferred to other 2 transformer	kWh	31273
Annual Energy Saving	kWh	31273
Unit Cost	Rs. /kWh	9
Annual Cost Savings	Rs.	281457
Investment cost	Rs.	Nil
Payback period	month	Immediate

Present system:
At present all three Transformer always in operation irrespective of load. Total loss of the transformer per annum is 105770.2kWh/annum.
Proposed system:
All the three Transformer operating with minimum load observed less utilization and loss is more, hence maximize the better efficiency Hence it is proposed to switch off one transformer and load the other transformer

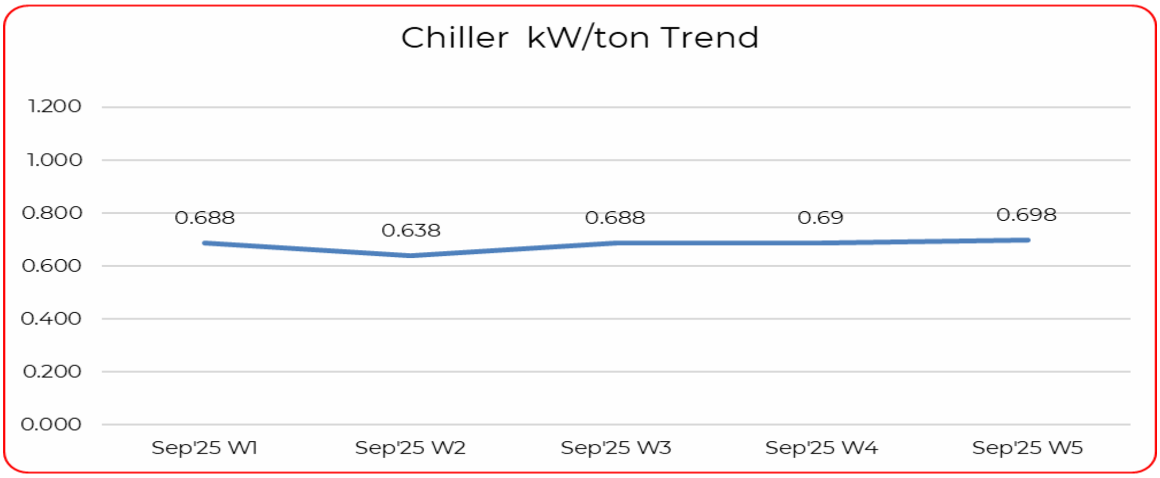
1.4.6 Chiller Efficiency Monitoring and Optimization
Chillers were operating at suboptimal Coefficient of Performance (COP) due to fixed setpoints and manual sequencing. AI-driven algorithms were deployed to optimize setpoints and automate sequencing based on real-time load conditions. VFD retrofits enabled dynamic control of compressor speed. COP improved from 1.1 to 0.7 kW/TR, resulting in 10–15% energy savings. The system also reduced peak demand and improved cooling stability.
Four 350 TR chillers were optimized through VFD integration and chilled water temperature reset (from 6°C to 8°C). The modification yielded a 6% improvement in chiller coefficient of performance (COP), equating to 122,640 kWh annual energy savings.



Chiller Efficiency Monitoring Basis	
Efficiency=	**kW/TR**
kW	Actual Power Consumed in kWh
TR	Actual Tons of Refrigeration Effect
TR=500 * GPM * ΔT	
500 is constant	
GPM is water flow across chiller evaporator	
ΔT is Temperature difference across chiller evaporator	

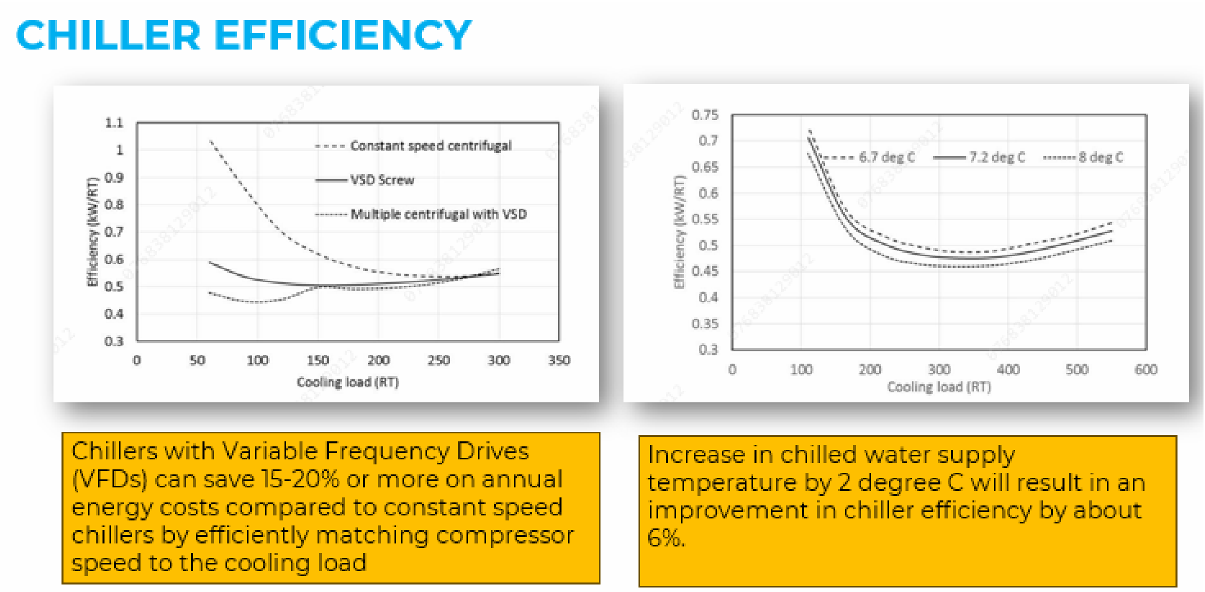
CHILLERS		Actual Efficiency					TARGET
PLANT	EQ ID	W1	W2	W3	W4	W5	iKW/TR

B9	Chiller 1	0.688	0.638	0.688	0.69	0.698	0.55`



Observation:

1. Chiller Constant speed system needs to be converted to VFD to optimize the unloading hours.
2. Set point optimizations, currently operating at 7 Degree need to be increased to 8 degree as well as meet the user load demand.
3. Periodical cleaning of condensers coil to reduce the load on chiller



1.4.7 Power Factor Analysis

Power factor of an AC electric power system is defined as the ratio of the real power flowing to the apparent power in the circuit.

The normal value is between 0 to 1 only.

Real Power: Capacity of the circuit for performing work in a particular time.

Apparent Power: Product of Current and Voltage of the circuit.

What causes the Power Factor (Why the real power reduces than the apparent power):

- Energy stored in the load and returned to the source.
- Non-linear load that distorts the wave shape of the current drawn from the source.
- For some of the loads like motor (inductive load) more current is drawn for the same capacity to induce the magnetic path to rotate the motor. This causes the current vector to lag the voltage vector resulting in power factor.
- The motor or the load with low power factor draws more current for the same amount of useful power transferred.

What are the effects of Power Factor :

- The higher current increases the energy loss in the power distribution system.
- This calls for higher sizes of current carrying conductor (wire/cables) and other equipment's.
- Higher costs.

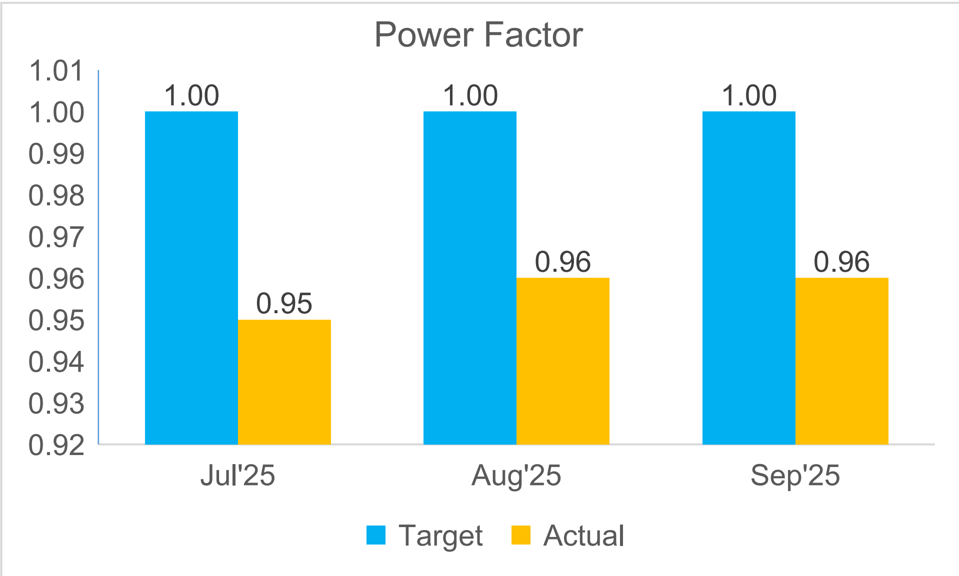
How the losses due to power factor be avoided ?
By connection of capacitor banks or any other reactive compensating equipment's.

- The capacitor resists change in voltage. As a result current leads the voltage in a capacitor circuit. The power is drawn at leading power factor as against lagging power factor for a inductive load.
- When capacitor is connected in a power distribution system, this draws power at leading power factor to counteract the distortion and raise the power factor.
- Thus the power factor is improved thereby reducing the losses due to power factor.

Benefits of higher power factor :

- Reduced power losses.
- when the power factor reduces below 0.90, penalty is levied by EB.

Current Trend: -



<u>Power Factor Correction and payback period calculation</u>
<u>Step 1. Calculate Actual Load (kW)</u>
(Load) Power kW = Volts V x √3 x Current I x Power factor Pf

		415	Nominal Voltage (V)
Non-Corrected Load (kVA)	1450.0	2017	Non-Corrected Current (Amps)
Actual Load (kW)	1392.0	0.960	Non-Corrected Power Factor (CosΦ)

<u>Step 2. Calculate Actual power factor correction (KVAR)</u>

Present Power Factor	0.96
Desired Power Factor	1.00
Multiplication Factor	0.292
Present Demand in kW	1392
Capacitors required KVAR	406.464

* Multiplication factor refer PF table

<u>Energy Savings for Above Power Factor Correction</u>

Initial Current	2017	Amps	Original Load	1450	kVA
Corrected Current	1937	Amps	Corrected Load	1392	kVA
Reduction in Current	80	Amps	Reduction in Load	58	kVA

Actual Load saving	58	KW

Energy saving per day	1392	KWhr
Energy saving per annum	508080	KWhr
One unit of Electrical Energy	9	Rs
Cost saving per annum	4572720	Rs
Cost saving per annum approx	45.72	Lakh

Payback period

Initial Investment	1000000	Rs
Saving of returns	4572720	Rs
Payback period in Annum	0.218688	Annum
Payback period in Days	79.8212	Days
Payback period in Month	2.660707	Years

Power factor correction was achieved through the deployment of IoT-enabled meters, STATCOMs, and hybrid filters. Baseline systems relied on static capacitor banks, which were ineffective under varying and non-linear loads. The new system-maintained power factor above 0.95 and reduced kVA demand charges by 5–10%. Harmonic audits identified sources of THD, and active filters are proposed to be installed to ensure IEEE 519 compliance. Equipment life was extended by 10–15% due to reduced electrical stress.

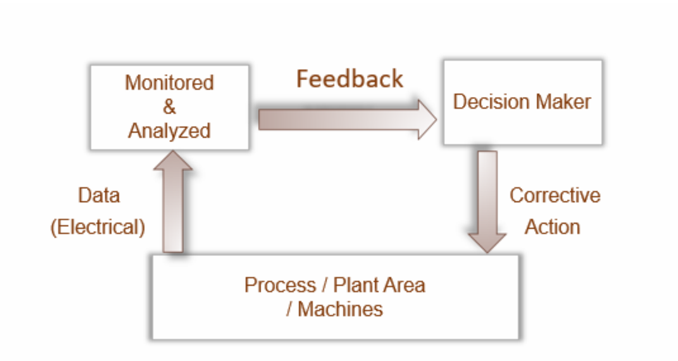
Power factor improvement from 0.96 to 0.99 through capacitor bank adjustment reduced apparent power demand and saved approximately 5.08 lakh kWh per annum, corresponding to an annual cost reduction of ₹45 lakhs.

1.4.8 IoT-Enabled Energy Management System (EMS) Implementation

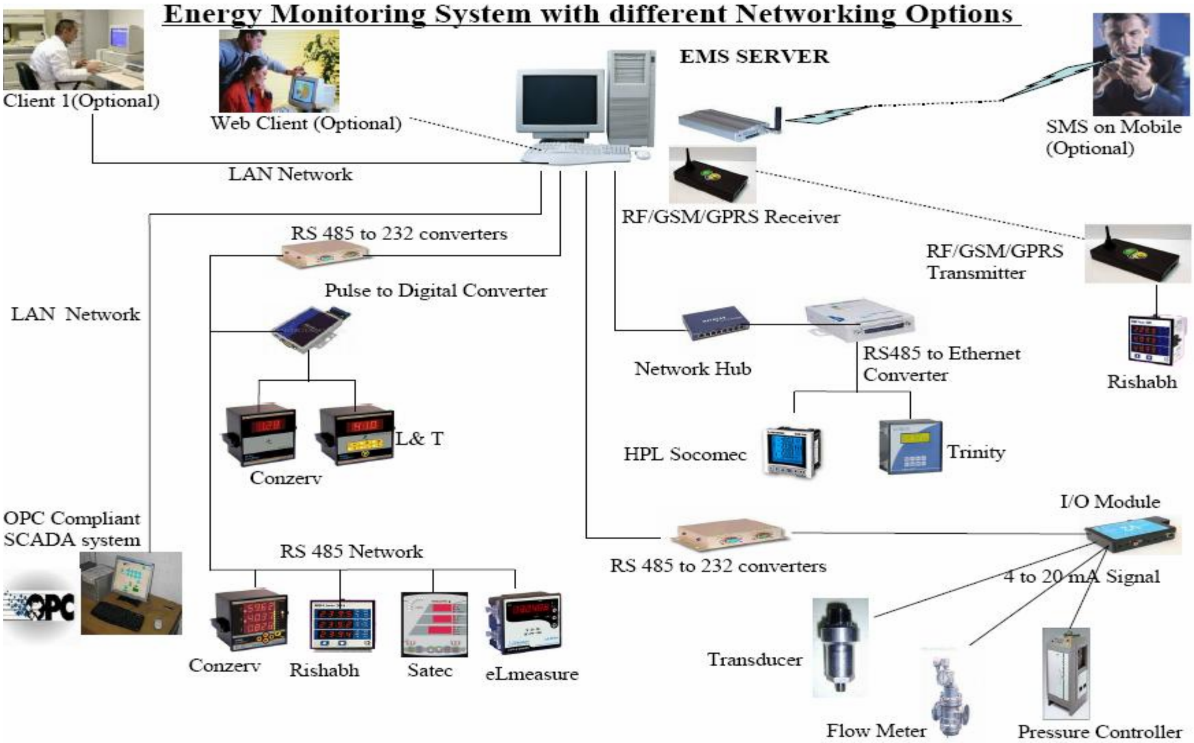
An IoT-based EMS was implemented to provide real-time visibility into energy consumption across subsystems. Smart meters and cloud dashboards enabled proactive monitoring, anomaly detection, and performance benchmarking. The system facilitated data-driven decision-making and supported continuous improvement initiatives. Monthly reports and alerts are proposed to be generated to track progress against energy conservation targets.

An IoT-based EMS dashboard was developed to continuously monitor key electrical parameters (voltage, current, PF, THD). The EMS, compliant with ISO 50001, facilitates energy KPI tracking, anomaly detection, and reporting.

HOW EMS WORKS:



EMS STRUCTURE:



EMS DASHBOARD:

Reports readily available viz;

- Hourly Energy Report
- Daily Energy Report
- Weekly Energy Report
- Monthly Energy Report
- Yearly Energy report
- TOD Energy Report
- Shift Energy Report
- Flexi Energy Report
- Data Log Book Report
- Alarms Report
- Min Max Report

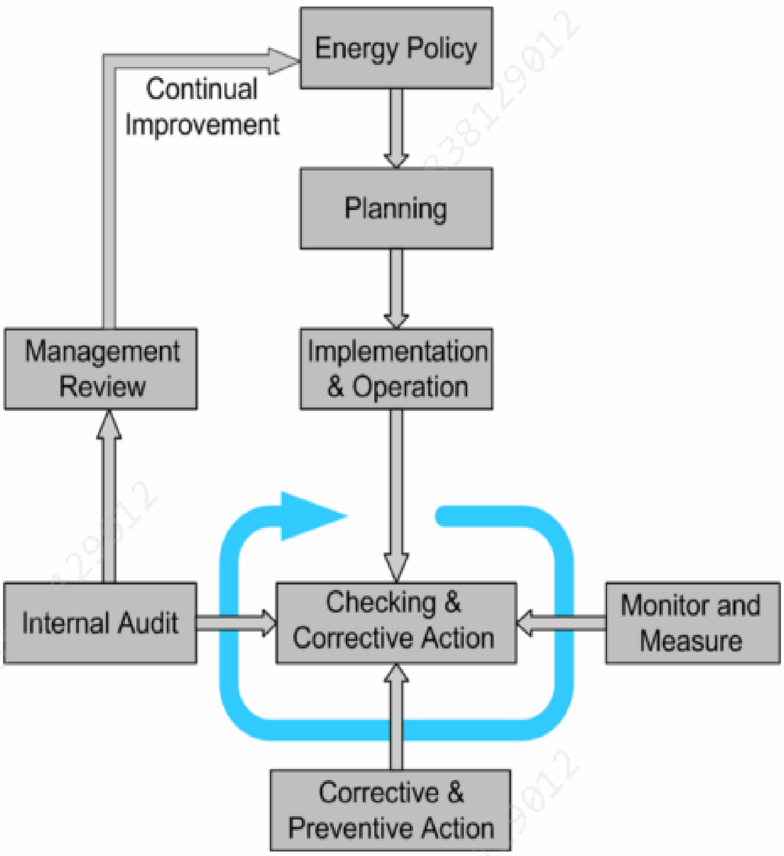
Energy Billing System

- Consolidated Bills
- Individual Bills
- Old Bills
- Bill Payment Receipt

1.4.9 Energy Conservation Policy and KPI Development

A formal energy conservation policy was developed, outlining strategic objectives, operational guidelines, and compliance requirements. Key Performance Indicators (KPIs) are proposed to be established, including kWh/m², kWh/employee, and percentage of renewable energy usage. The policy was integrated into facility management protocols and reviewed quarterly. It provided a framework for accountability and sustained energy performance.

Typical energy management system model:



Recommendations for an effective EnMS:

- Have an explicit energy policy in place and disseminate it to all staff.

- Establish clear targets and goals.
- Appoint an Energy Management Team with representation from all stakeholders.
- Appoint a dedicated energy manager.
- Identify main energy consuming systems.
- Establish and track energy performance indicators (EnPIs) of main energy consuming systems.
- Assess the EnPIs regularly and take corrective action where required.
- Identify and invest in energy efficiency improvement opportunities.
- Conduct regular training to raise awareness on good energy management practices

Energy performance Indicators (EnPIs):

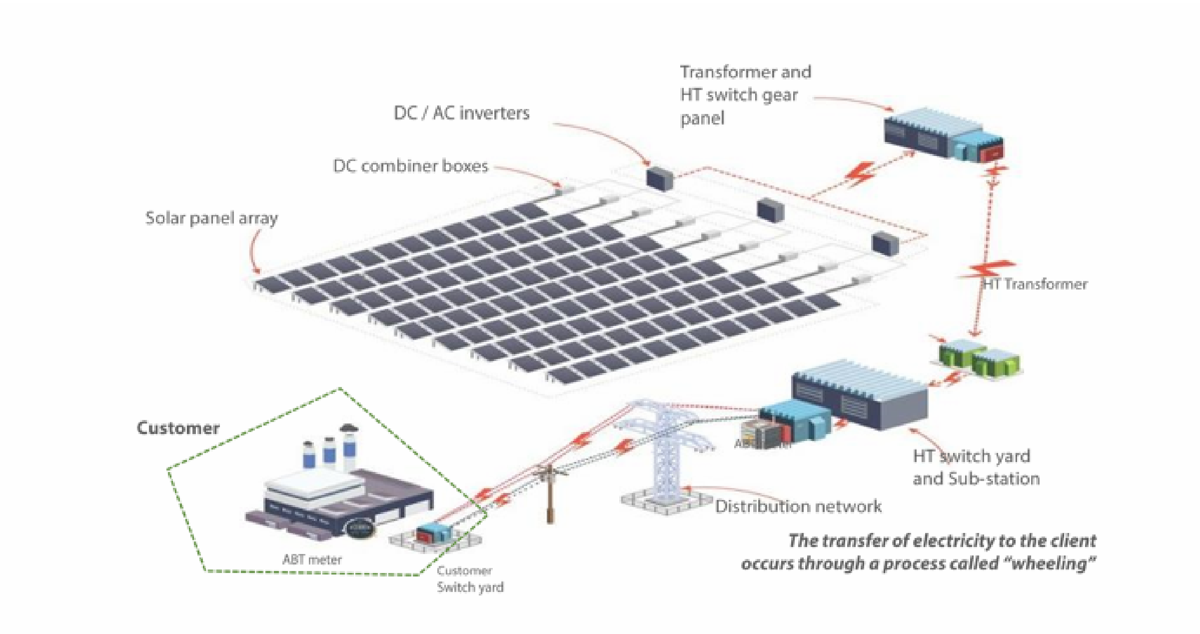
- Help the Department to achieve energy performance Improvements
- Annual Energy Consumption per m2 (KWh/m2)
- 10% of Energy reduction YOY
- Enhancement of Renewable energy utilization

Energy Policy:

- Commitment by top management
- Continual improvement of energy performance
- Commitment to comply with applicable legal and other requirements
- Framework for energy objectives and targets
- Supports purchase of efficient products

1.4.10 Solar Power Integration and Cost Evaluation

The existing 750 kWp rooftop solar installation was evaluated for performance and cost optimization. Hybrid grid-solar models were simulated to maximize renewable energy utilization. Net metering and inverter analytics were used to assess generation patterns and grid interaction. The intervention reduced grid dependency and achieved cost savings through peak shaving and tariff optimization.



SABIC ENERGY CONSUMPTION – CURRENT USAGE TREND

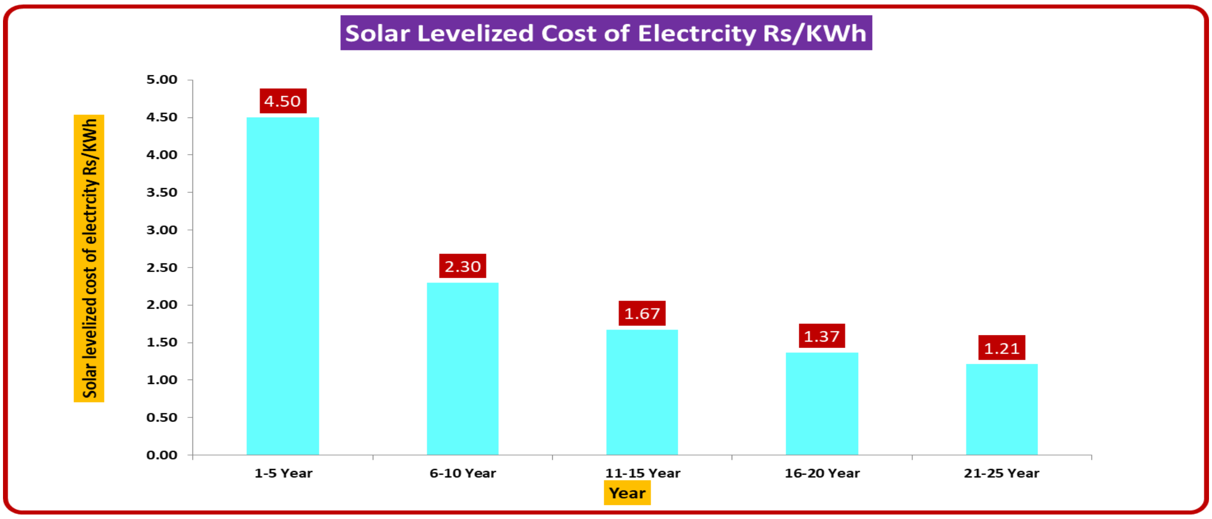
SI.No	Details	SABIC
1	Sanction Energy Demand	1.8MW
2	Monthly Avg consumption in AY'24	6.50 Lac Units
3	Yearly Avg consumption in AY'24	78 Lac Units
4	Wheeling Energy consumption in %	85%

5	BESCOM Energy consumption in %	2.5%
6	Inhouse Solar Generation in %	12.50%
7	Power cost/unit in AY'24	Rs 8.91
8	Monthly Power cost Avg	Rs.50.70 Lac
9	Yearly Power cost Avg	Rs.6.1Crs

PROPOSAL OF SOLAR PLANT

SI.No	Details	SABIC	Remarks
1	Solar Capacity required	5 MW	Efficiency (15%- 19%)
2	Solar plant generation/annum	75 Lac Units	
3	Yearly Avg consumption in AY'24	78 Lac Units	
4	Minimum Capital Investment/1 MW in Rs	Rs.4.5crs	
5	Minimum Capital Investment 5MW in Rs	Rs.22.5 Crs	
6	Area Required for 1 MW solar plant	4 Acre	
7	Area Required for 5 MW solar plant	20 Acre	

PROPOSAL OF SOLAR PLANT – LEVELIZED COST / UNITS



PROPOSAL OF SOLAR PLANT – CONCLUSION

Pros	Cons
➢ Current sabic unit cost is Rs: 8.91 ➢ Levelized cost of energy is Rs:13.07 /unit – next 25 Years (current practices) ➢ Opportunities to save huge energy cost approximately 39.48 Lac /Annum Payback is 3 years ➢ Levelized cost of energy is Rs:2.21/unit -25 Years (Solar) ➢ Accelerated Depreciation benefit shall be claimed (40%) ➢ Improved corporate image ➢ Environmental benefitable projects	➢ Need 5 MW Captive Solar power plant ➢ Huge Investment is required approximately Rs:22 Crore ➢ Larger land space is required, approximately 20 Acre ➢ Regular Operations & Maintenance need to be considered

1.5 Economic Evaluation
Each ECM was analysed for savings potential, capital investment, and payback period. The consolidated result projected an overall energy saving potential of 10–30%, with an average payback of 1.71 years.
1.6 Implementation Framework
The PDCA cycle ensures iterative improvement:

- **Plan:** Identify high-impact ECMs based on baseline data.
- **Do:** Implement retrofits and monitor performance.
- **Check:** Analyze savings and validate through metering.
- **Act:** Commit successful practices through policy and training.

1.7 Tools, Equations, and Data Analysis Methods
To ensure rigorous analysis and accurate quantification of energy conservation opportunities, a combination of engineering tools, mathematical models, and digital platforms were employed. The primary analytical tools included Microsoft Excel for baseline calculations, Python (with pandas and matplotlib libraries) for data visualization, and IoT platforms such as ThingsBoard and Blynk for real-time monitoring.

1.8 Consolidated Energy Saving and ROI Calculation
A comprehensive evaluation of all proposed interventions was conducted to estimate total energy savings, cost reductions, and financial viability. The results are summarized below:

Subsystem	Annual Energy Savings (kWh)	Cost Savings (₹)	Investment (₹)	ROI (Years)
AHU EC Fans	1,200,000	₹10,800,000	₹160,00,000	1.48
Lab EMS	60,000	₹5,40,000	₹15,00,000	2.77
Air Compressors VSD	60,000	₹5,40,000	₹8,00,000	1.53
Cooling Towers EC fan	100,000	₹9,00,000	₹13,75,000	1.52
Transformers	31,000	₹2,66,000	₹Nil	Immediate
Chillers	1,22,000	₹10,98,000	₹25,00,000	2.27
Power factors	5,00,000	₹45,00,000	₹10,00,000	0.22
EMS -Energy monitoring system	60,000	₹5,40,000	₹15,00,000	2.77
Solar System - Power cost reductions	Nil	₹480,00,000	₹2200,00,000	4.58

Total Annual Savings: 21,33,000 kWh **Total Cost Savings**: ₹671,65,000 **Total Investment**: ₹2446,75,000 **Weighted Average ROI**: 1.71 years
These results demonstrate that the proposed interventions are not only technically feasible but also financially attractive, with most measures achieving payback within two years.
1.9 Monitoring, Verification, and Reporting Protocol
To ensure the integrity and sustainability of energy conservation outcomes, a robust monitoring and verification protocol was established. This protocol includes:

- **Real-Time Monitoring**: Smart meters and IoT sensors continuously track energy consumption, temperature, humidity, and equipment status. Data is visualized through cloud-based dashboards accessible to facility managers and energy auditors.
- **Verification**: Pre- and post-intervention data are need to be compared using normalized metrics (e.g., kWh/m², kWh/employee). Third-party audits are conducted annually to validate savings and compliance with ISO 50001 standards.
- **Reporting**: Monthly performance reports are generated, highlighting deviations, anomalies, and corrective actions. Quarterly reviews are held with stakeholders to assess progress and refine strategies. An annual sustainability report consolidates all findings and is submitted to SABIC's global energy management team.

This protocol ensures transparency, accountability, and continuous improvement, aligning with SABIC's commitment to environmental stewardship and operational excellence.

III. Discussion

The energy conservation initiative undertaken at SABIC Research and Technology Center, Bangalore, demonstrates a multidimensional approach to industrial energy optimization. The facility, with its high energy intensity and complex operational demands, provided a fertile ground for implementing a range of conservation strategies. The discussion below synthesizes the technical, financial, and strategic implications of the interventions.

One of the most impactful measures was the retrofitting of Air Handling Units (AHUs) with Electronically Commutated (EC) fans. These fans replaced traditional belt-driven motors, offering direct-drive efficiency and variable speed control. The intervention not only reduced energy consumption by up to 39% per unit but also lowered maintenance costs and improved airflow stability. The data-driven selection of EC fan ratings and operating profiles ensured that each retrofit was tailored to the specific load and runtime characteristics of the AHU, maximizing savings.

The deployment of IoT-based Laboratory Environmental Monitoring Systems (Lab EMS) addressed a critical gap in HVAC control. Laboratories often operate under stringent temperature and humidity requirements, yet conventional systems lack the granularity to adjust ventilation based on real-time occupancy and environmental conditions. By integrating sensors and scheduling algorithms, the Lab EMS achieved 5–10% energy savings while maintaining compliance with safety standards. This intervention also highlighted the role of digital technologies in enhancing operational agility.

Air compressor optimization through Variable Speed Drives (VSDs) and IoT-enabled leak detection further contributed to efficiency gains. Compressors are inherently energy-intensive, and their performance is highly sensitive to load fluctuations. The VSD retrofit allowed for dynamic modulation of motor speed, aligning energy input with actual demand. Leak detection systems minimized waste and improved system reliability, resulting in 5–10% savings.

Cooling tower upgrades, involving EC fan retrofits and high-efficiency pump motors, demonstrated the importance of water-energy nexus optimization. By automating fan speed and pump operation based on thermal load, the system achieved 10–20% energy savings and enhanced chiller performance. This intervention also reduced thermal stress on equipment, contributing to longer asset life.

Transformer loss assessment and harmonic mitigation addressed hidden inefficiencies in power distribution. Online monitoring tools measured Total Harmonic Distortion (THD) and load imbalances, revealing opportunities for 3–5% loss reduction. Load balancing strategies and the installation of active filters ensured compliance with IEEE 519 standards and extended transformer life.

Chiller optimization through AI-driven sequencing and VFD retrofits improved the Coefficient of Performance (COP) from 1.1 to 0.7 kW/TR. This intervention not only reduced energy consumption by 10–15% but also stabilized cooling output during peak demand periods. The use of predictive algorithms allowed for real-time adjustment of setpoints, enhancing system responsiveness.

Power factor correction are proposed to be achieved through the deployment of IoT meters, STATCOMs, and hybrid filters. These technologies maintained power factor above 0.95 and reduced kVA demand charges by 5–10%.

The implementation of an IoT-enabled Energy Management System (EMS) provided real-time visibility into energy consumption across subsystems. Smart meters and cloud dashboards facilitated anomaly detection, performance benchmarking, and proactive decision-making. This digital backbone supported continuous improvement and aligned operations with SABIC’s sustainability goals.

Finally, the development of energy conservation policies and Key Performance Indicators (KPIs) institutionalized best practices. Metrics such as kWh/m², kWh/employee, and renewable energy share provided actionable insights and ensured accountability. The integration of rooftop solar optimization further reduced grid dependency and enhanced cost efficiency.

In summary, the discussion reveals that a holistic, data-driven, and digitally enabled approach to energy conservation can yield substantial technical, financial, and environmental benefits. The interventions are scalable, replicable, and aligned with global sustainability frameworks.

IV. Conclusion

This study presents a comprehensive evaluation of electrical energy conservation opportunities at the SABIC Research and Technology Center, Bangalore. Through the application of the A3–PDCA framework, the research systematically identified inefficiencies, implemented targeted interventions, and monitored outcomes across ten critical subsystems.

The retrofitting of AHUs with EC fans emerged as the most impactful measure, delivering up to 39% energy savings per unit and achieving ROI within 1.5 years. This intervention exemplifies the value of precision engineering and tailored retrofits in high-load environments. The integration of IoT-based Lab EMS systems further enhanced HVAC efficiency, demonstrating the potential of digital technologies in optimizing environmental control.

Air compressor optimization through VSDs and leak detection systems addressed both energy and reliability concerns. Cooling tower upgrades improved heat rejection efficiency and contributed to chiller performance, while transformer loss assessments and harmonic mitigation tackled power quality issues that often go unnoticed in conventional audits.

Chiller optimization through AI-driven sequencing and VFD retrofits significantly improved COP and reduced peak demand. Power factor correction and harmonic analysis ensured compliance with industry standards and reduced operational costs. The implementation of a centralized EMS provided real-time insights, enabling proactive management and continuous improvement.

The development of energy conservation policies and KPIs institutionalized sustainability practices and aligned operations with SABIC's global environmental objectives. Rooftop solar optimization further enhanced the facility's renewable energy footprint, contributing to cost savings and grid independence.

Collectively, these interventions resulted in an estimated annual energy savings of 2.13 million kWh and cost reductions of ₹67.16 million. The weighted average ROI across all measures was 1.71 years, underscoring the financial viability of the project. Beyond the quantitative outcomes, the study fostered a culture of energy consciousness, cross-functional collaboration, and strategic innovation.

The research also bridges critical gaps in the literature, particularly in the context of tropical industrial environments and digitally enabled energy management. It demonstrates that energy conservation is not merely a technical challenge but a strategic imperative that requires integration across engineering, operations, and policy domains.

In conclusion, the SABIC case study offers a replicable model for industrial energy optimization. It validates the effectiveness of structured methodologies, digital technologies, and stakeholder engagement in achieving sustainability goals. The findings contribute to the broader discourse on industrial energy management and provide actionable insights for engineers, facility managers, and policymakers committed to building resilient and efficient infrastructure.

Key Findings and Solutions

- **Baseline Energy Consumption:** ~6.5 lakh kWh/month (2024).
- **Identified Savings Potential:** 10–30% depending on subsystem.
- **AHU EC Fan Retrofit:** 25–30% reduction in power consumption.
- **IoT-Based Monitoring:** 5% reduction through optimized HVAC control.
- **Compressor VSD Retrofit:** 20–30% savings with reduced downtime.
- **Chiller Optimization:** 6% efficiency improvement
- **Transformer Optimization:** 3–5% loss reduction.
- **Cooling Tower Retrofit:** 3% chiller-related savings; enhanced reliability.
- **Power Factor Improvement:** Savings of 5.08 lakh kWh/yr, ₹45 lakhs annual benefit.
- **Total Projected Savings:** 12–15% of total energy, payback in 2–4 years.

The study recommends a **phased implementation** approach prioritizing high ROI projects such as AHU and compressor retrofits, followed by IoT monitoring and transformer optimization. The combination of technological upgrades and digital control ensures long-term savings, aligns with sustainability goals, and creates a data-driven culture for energy management.

V. Future Study

Future work should focus on integrating renewable energy sources such as solar photovoltaic (PV) systems and battery energy storage into the facility's electrical infrastructure. Expanding the Energy Management System (EMS) to include machine learning algorithms for predictive maintenance and load forecasting will further enhance efficiency. The application of artificial intelligence (AI) for anomaly detection and automated fault diagnosis could provide additional optimization potential. Comparative benchmarking across multiple SABIC facilities would help standardize energy management practices and facilitate global best-practice sharing. Moreover, assessing carbon footprint reduction from implemented measures would provide quantifiable sustainability metrics to guide long-term policy development.

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