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

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Abstract: ***Electrical energy conservation in industrial research facilities is challenging due to continuous operation, stringent environmental control requirements, and variable process loads. This study examines opportunities for electrical energy conservation at the SABIC Research and Technology Centre in Bangalore, identifying technically feasible and economically viable measures to reduce electricity consumption while supporting SABIC's sustainability goals. The facility has an average monthly electrical consumption of approximately 650,000 kWh, and the study aims to achieve a minimum 10% reduction in energy usage by 2026. A structured two-phase methodology was adopted. The first phase involved a detailed assessment of electrical energy, including load profiling, equipment-level measurements, and performance analysis of major energy-consuming systems, such as HVAC, laboratory ventilation, air compressors, chillers, cooling towers, and lighting. The second phase focused on optimization planning, during which identified inefficiencies were translated into prioritized energy conservation measures based on their energy-saving potential and economic feasibility. The analysis revealed that HVAC and laboratory ventilation systems account for the majority of electrical energy consumption. Retrofitting Air Handling Units with electronically commutated fans proved to be the most effective measure, providing annual energy savings exceeding 1.2 million kWh and a payback period of approximately 1.66 years. Additional improvements, including IoT-based laboratory monitoring, variable-speed drives for compressors, optimised transformer loading, and chiller sequencing, further enhanced efficiency. The novelty of this research lies in its integrated, data-driven optimisation framework that combines real-time operational analysis, economic evaluation, and climate-specific considerations. This study offers a replicable model for sustainable energy management in industrial R&D facilities without compromising operational performance.***

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

Nomenclature:
VSD: Variable Speed Drive
IGBC: Indian Green Building Council
EC: Electronically Commutated
VSDs: Variable Speed Drives
PDCA: Plan-Do-Check-Act
ROI: Return On Investment
ECMs: Energy Conservation Measures
VFDs: Variable-Frequency Drives
COP: Coefficient of Performance
EMS: Energy Management System
THD: Total Harmonic Distortion
Lab EMS: Laboratory Environmental Monitoring Systems
AI: Artificial Intelligence
AHUs: Air Handling Units

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I. INTRODUCTION

Electrical energy conservation has become a critical priority for industrial facilities worldwide, driven by rising energy costs, environmental regulations, and corporate sustainability goals. In this context, the SABIC Research and Technology Centre in Bangalore serves as 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 remains firmly committed to environmental stewardship. Its Bangalore facility, certified under ISO 14001:2015 and recognized as a Gold Category Green Building by the Indian Green Building Council (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 centre 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 optimisation, during which specific interventions are proposed and evaluated for technical feasibility, cost-effectiveness, and environmental impact [6].

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 include reducing transformer losses through load-pattern audits, improving chiller efficiency via AI-driven sequencing, and correcting power factor using hybrid filters and STATCOMs [6].

The methodology integrates A3 practical problem-solving techniques, emphasising 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 optimise energy use. By bridging gaps in the literature—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 [1,2].

In the sections that follow, we review the literature, 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 [1,2].

A. Objective

- To analyze the baseline electrical energy consumption of SABIC facilities and identify major energy-intensive systems.
- Evaluation of various potential energy conservation opportunities by Dec 2025 to meet the site energy consumption targets of 10% reduction against the year 2024.
- To evaluate subsystem-level efficiency improvement opportunities across HVAC, compressors, chillers, transformers, and cooling towers [6].
- To propose and assess Energy Conservation Measures (ECMs), including EC fan retrofits, VSD integration, IoT-based monitoring, and power factor improvement.
- To quantify potential energy savings, cost reduction, and return on investment (ROI) for each recommended ECM.
- To develop a digital, IoT-enabled Energy Management System for real-time monitoring, reporting, and decision-making.
- To formulate an energy conservation policy and KPI framework aligned with SABIC's sustainability goals and continuous improvement practices.

II. LITERATURE SURVEY

Electrical energy conservation has become a cornerstone of sustainable industrial operations. The reviewed literature spans diverse sectors, beverages, textiles, food processing, institutional buildings, and household, offering a rich foundation of strategies, outcomes, and challenges. This section synthesizes insights from 6 key studies as shown in the Table 1 and maps them to the context of SABIC's Bangalore facility.

Table I: Summary of the Article

S. No	Author(s)	Year	Sector	Key Findings
1	Paweł S. Zięba	2021	Polish Enterprises	Audits led to measurable savings; financial barriers hindered implementation.
2	Prachi Chauhan.	2021	General Review	Benefits: cost reduction, performance. Barriers: cost, awareness, and enforcement.
3	Zbigniew Bohdanowicz.	2021	Households	15–30% savings with efficient appliances; behavioural changes critical.
4	Yayan Saputra.	2022	Pipeline Industry	ISO 50001 reduced welding energy by 54.3%.
5	Dear Al Momani,	2023	Food Production	18% savings from boiler optimisation; 772.82 tons of CO_2 avoided.
6	Ahmed Al-Ardan.	2025	Institutional	LED retrofit cut lighting energy by 74%; high-EER AC units saved 28.4%.

Table 1 summarises earlier studies examined in the literature review, including authors, industries, and key conclusions pertinent to industrial energy audits. [1,2].

B. Analysis and Insights

i. Audit Methodologies

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

ii. 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 [6].

iii. Behavioural and Organizational Factors

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

iv. Standards and Certifications

ISO 50001 emerges as a robust framework for structured energy management. Its application in the welding and pipeline industries shows a measurable impact [4].

v. Environmental Impact

Several studies quantify CO_2 reductions, linking energy savings to sustainability goals. However, few explore lifecycle emissions or asset longevity improvements

Detailed Literature Gaps and Opportunities [1,2,3].

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Table II: Key Opportunities and Gaps in the Literature

S.No	Area	Literature Gap	Opportunity / Intervention	Expected Impact
1	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
2	Lab HVAC Control	Neglect of lab-specific temperature/RH monitoring	IoT-based demand ventilation and scheduling	5–10% HVAC savings; improved safety
3	Air Compressors	Focused only on leak detection; poor digital integration	VSD compressors, IoT leak detection	5–10% savings; reduced downtime
4	Cooling Towers	Poor linkage between water and energy optimization	EC fans, efficient pumps	10–20% savings; improved water-energy synergy
5	Transformer Losses	Sparse data on harmonics and fluctuating loads	Online monitoring (THD, load)	3–5% loss reduction; longer asset life
6	Chillers	Lack of Indian data on partial load and sequencing	AI-driven setpoint optimization, VFD retrofits	10–15% savings; COP improvement
7	Power Factor Correction	Static capacitor focus; no dynamic correction	IoT meters, STATCOMs, hybrid filters	PF >0.95; 5–10% cost reduction
8	Harmonics	Weak THD linkage to failures; few quantified studies	Harmonic audits, active filters	THD <5%; 10–15% asset life extension
9	Policy & KPIs	No literature on energy conservation KPIs	Develop site-specific KPIs and policy	Continuous improvement; accountability
10	IoT Energy Monitoring	Rare integration in audits	Real-time dashboards, alerts	Enhanced visibility; proactive management
11	Chiller Sequencing	Theoretical COP focus; no real-time control	AI-based sequencing	COP from 1.1 → 0.7 kW/TR
12	Diesel Generator Optimization	Limited case studies on DG efficiency	Load balancing, fuel monitoring	10–15% fuel savings
13	Rooftop Solar Integration	No hybrid grid-solar models discussed	Solar + grid optimization	Reduced grid dependency; cost savings
14	Lighting Systems	LED retrofit studies lack tropical data	Smart lighting controls	30–50% savings; improved comfort
15	HVAC Scheduling	Few studies on time-based HVAC control	Shift-based scheduling	5–10% savings; reduced idle load
16	Load Manager Use	Underutilised in Indian audits	Load profiling and peak shaving	Demand charge reduction
17	Asset Life Extension	Rarely quantified in audits	Predictive maintenance	Reduced downtime; longer equipment life

Table 2 links each research field to possible energy-saving implications by identifying specific gaps in the literature and opportunities for intervention [3].

Research in industrial energy conservation has demonstrated substantial potential to improve operational efficiency and reduce costs. As shown in Table 2, numerous studies indicate that effective energy audits can yield savings of 10%-30% of total electrical energy consumption. These savings are often realised through interventions in motors, HVAC systems, lighting, and process equipment [6].

Common strategies reported in the literature include high-efficiency motors, variable-frequency drives (VFDs), LED lighting, boiler optimisation, and structured energy management under 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 [1,2] [4].

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 optimisation through VFDs and temperature reset strategies has yielded reductions of 10–20%. The typical payback period for most industrial energy-efficiency projects ranges from 2 to 5 years.

Despite these advances, barriers such as high initial capital requirements, limited 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 the literature indicates that although many studies address individual systems or technologies, there is a lack of comprehensive frameworks that combine electrical, mechanical, and digital optimisation 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 Centre in Bangalore [1,2].

III. METHODOLOGIES

A. Overview of Research Design

This study adopts a comprehensive engineering research design to evaluate opportunities for electrical energy conservation 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

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

i. Baseline Energy Assessment
ii. Identification of Energy Conservation Measures (ECMs)
iii. Detailed Technical Evaluation
iv. Economic and ROI Analysis
v. Monitoring and Control Implementation

B. 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 standardised successful practices and identified new areas for improvement. This cyclical methodology ensures adaptability and fosters a culture of continuous energy optimization.

C. Baseline Data Collection and Energy Flow Mapping

Baseline data collection was conducted over 12 months using calibrated energy meters, operational logs, and supervisory control systems. As shown in Figures 3.1 & 3.2, the facility's electrical infrastructure comprises an 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. As shown in Table 3, the 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 visualise consumption patterns and identify high-impact areas for intervention [6].

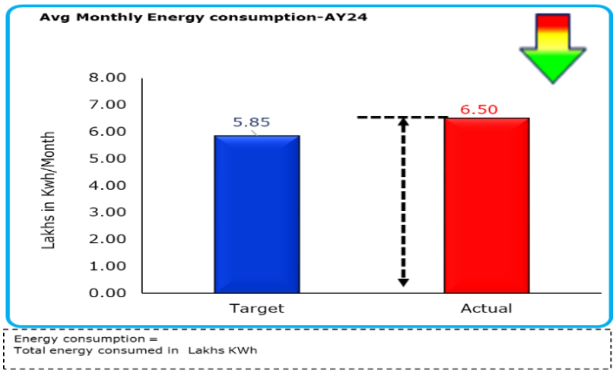
[Fig.3.1: Block Diagram for Power Distribution]

The 11 kV incoming supply, transformer configuration, and key electrical connections within the building are shown in Fig. 3.1, which depicts SABIC's total power distribution system.

Table III: Electrical Details

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

Table 3 provides key electrical characteristics of the facility, including power demand, transformer capacity, and energy consumption metrics used to establish a baseline assessment.



[Fig.3.2: Power Consumption Trend]

Fig. 3.2 illustrates the monthly power consumption trend, highlighting seasonal fluctuations and identifying high-load periods that are crucial for energy audit benchmarking.

D. 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:

i. *AHU EC Fan Upgradations:* Energy Efficiency Fan Upgradations.
ii. *Lab EMS System:* Temperature Monitoring and Control Through IoT.
iii. *Air Compressor VSD Evaluations:* Study of Air Compressor Load and VSD
iv. *Cooling Tower Fan Upgrade:* Energy Efficient Fan Upgradations.
v. *Chiller Efficiency Monitoring:* Analysis of Chiller Parameter
vi. *Power Factor Analysis:* Power Factor assessment
vii. *Energy Monitoring Through IoT:* Assessment of Energy Monitoring System implementations

E. Air Handling Unit (Ahu) EC Fan Upgradation

The AHU system, as shown in Fig. 3 .4, comprising 42 units, was identified as the single largest energy consumer. Existing driven motors are proposed for replacement 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

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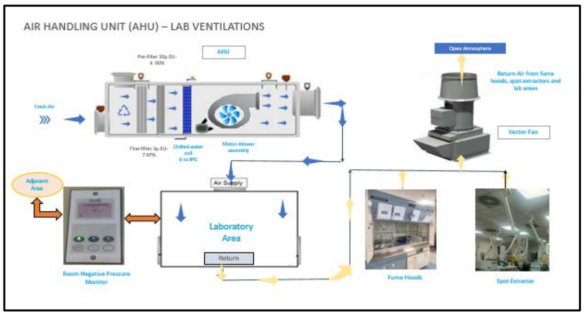
stability. ROI analysis showed payback periods of 0.9-1.6 years, making it a financially attractive option.

Existing centrifugal fans in AHUs, as shown in Figure 3.3, are proposed for replacement 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, as shown in Figure 3.5. Baseline annual AHU consumption was 3.24 million kWh, with projected post-retrofit savings of 0.9 million kWh annually, as shown in Figure 3.5 and Table 4.

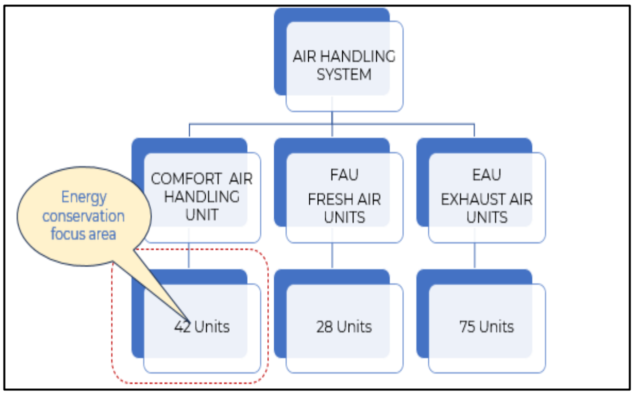
F. Ahu Schematic Diagram



[Fig.3.3: AHU Schematic Diagram]

Fig. 3.3 presents the schematic layout of the Air Handling Unit (AHU) system, illustrating airflow paths and the integration of components relevant to fan energy assessment.

G. Ahu System

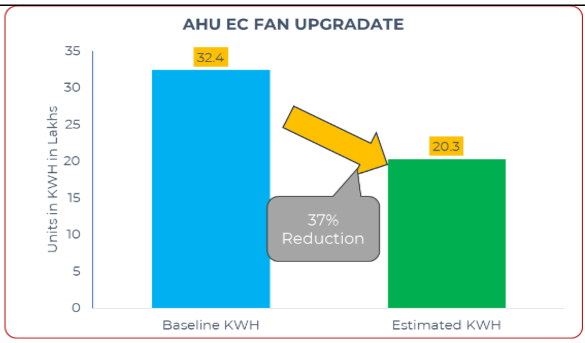


[Fig.3.4: AHU System]

Fig. 3.4 illustrates the physical configuration of the AHU system, showing its operational layout and spatial arrangement within the facility.

H. Estimated Savings

Table IV: AHU EC Fan Upgrade Savings, ROI and Benefits



[Fig.3.5: AHU EC Fan Upgrade Savings]

Fig. 3.5 shows the estimated annual energy savings following the AHU EC fan upgrade, quantifying reductions in kWh consumption and associated financial benefits.

- EC stands for Electronically Commutated, which basically means it is a fan with a brushless DC motor, hence there 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 are no transmission losses.
- It's a DC motor; hence, the power factor is unity.
- The EC fans are in-built VFD & direct-driven motors, which provide better efficiency

S. No	Name of the ECM's	Tentative Investment (INR)	Final Savings Commitment /Annum (INR)	Payback Period in Years (ROI)
1	Retrofit of a direct-driven AHU with an electronically commutated blower	160Lakhs	108 Lakhs	1.481.48

Table 4 Presents AHU EC fan retrofit savings, return on investment (ROI), and benefits, demonstrating significant annual energy reductions and a 1.48-year payback period.

i. 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 for automated tracking and AHU control via the MQTT protocol, as shown in Figures 3.7 and 3.8. The system achieved 5% energy savings while enhancing compliance and data accuracy.

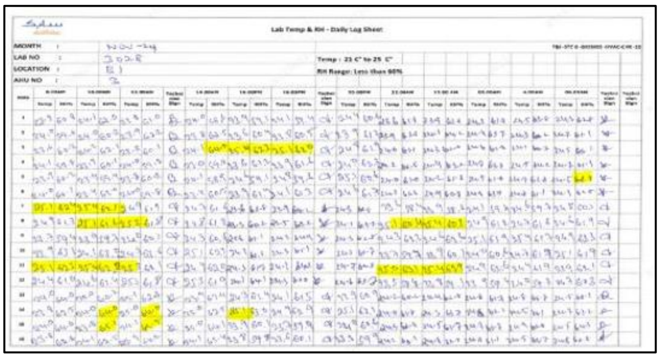
Laboratory HVAC systems operated on fixed schedules, leading to energy waste during low-level temperature and RH excursions. IoT sensors are proposed for real-time monitoring of temperature and relative humidity. Data was fed into a central dashboard, enabling demand-based ventilation and dynamic scheduling. The system achieved 5% energy savings as shown in Figure 3.10 and Table 5 while maintaining safety and compliance standards. The intervention also enhanced indoor air quality and reduced wear on HVAC components [6].

I. Current Practices

In STCB, overall, 48 laboratories are available, and room temperatures are monitored through manual mode as shown in Figure 3.6, and AHU is controlled through conventional controllers with a time-delayed response, which leads to more energy consumption as well as improved data recording, as shown in Figure 3.7

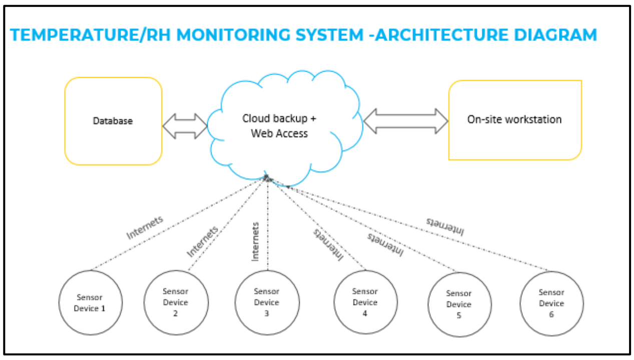
J. Lab Environmental Parameter Limit

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



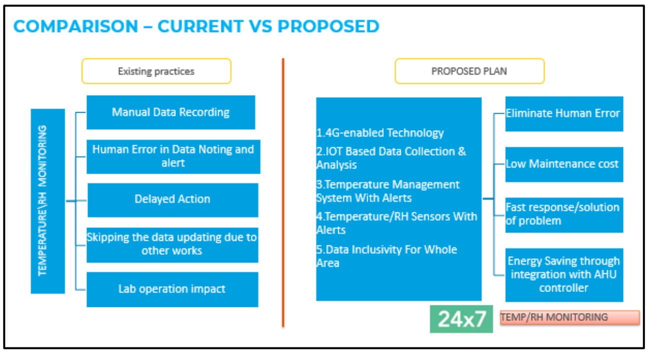
[Fig.3.6: Current Lab EMS Monitoring]

Fig.3.6 – Illustrates the existing manual monitoring setup for laboratory environmental conditions, indicating data collection limitations and inefficiencies.



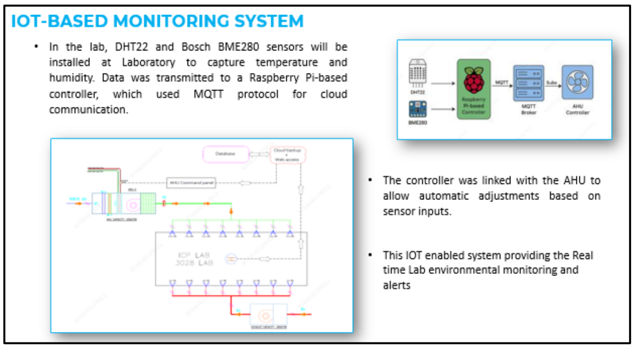
[Fig. 3.8: Temperature/RH monitoring System Architecture]

Fig. 3.8 Depicts the architecture of the temperature and relative humidity monitoring system, detailing sensor placement and communication pathways.



[Fig.3.7: Comparison -Current Vs Proposed]

Fig. 3.7 Compares current and proposed EMS configurations, highlighting the transition from manual to automated systems. Automated IoT-Based Monitoring for Enhanced Accuracy

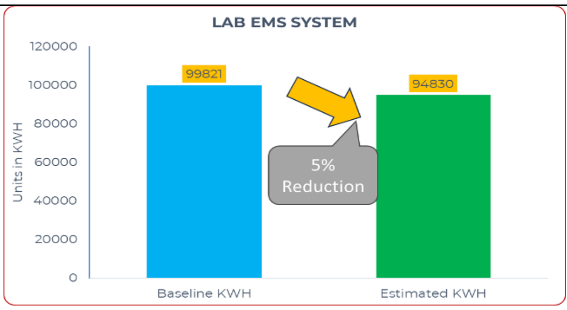


[Fig.3.9: IoT-Based Monitoring System]

Fig. 3.9 This represents an IoT-based laboratory monitoring framework that integrates sensors, controllers, and cloud data management systems.

K. Estimate Savings

Table V: Lab EMS System Savings, ROI and Benefits



[Fig.3.10: Lab EMS System Estimate Saving]

Fig. 3.10 Summarises the projected energy savings achieved through the implementation of the Lab EMS, quantifying performance improvements relative to the baseline.

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

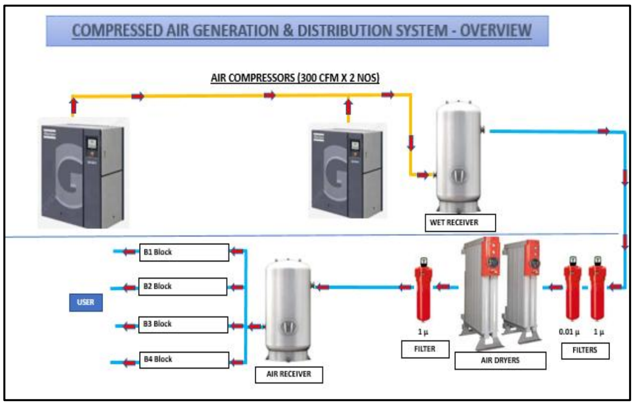
S. No	Name of the ECM's	Tentative Investment (INR)	Final Savings Commitment /annum (INR)	Payback Period in Years (ROI)
1	Lab EMS System (IoT-based Lab Temperature/RH Monitoring system and integrate with AHU Controllers)	15 Lakhs	5.39 Lakhs	2.78

Table 5 – Details Lab EMS investment, savings, and ROI, demonstrating a 2.78-year payback period through enhanced monitoring and HVAC optimisation [6].

L. Air Compressor VSD Evaluation

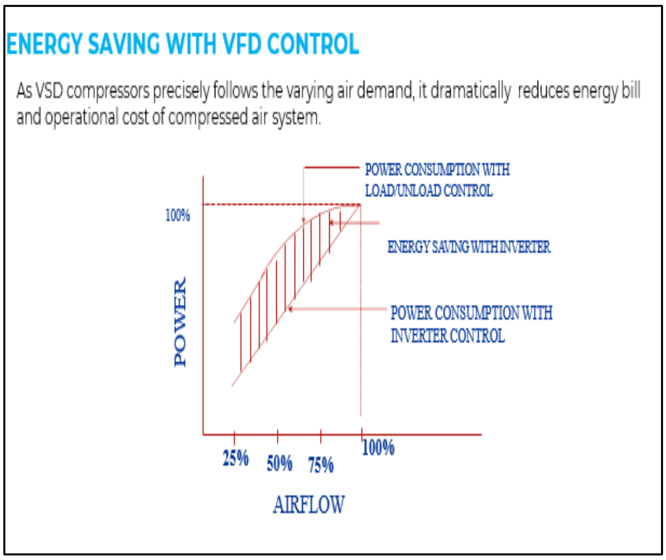
Two 300 CFM compressors, as shown in Figure 3.11, are proposed for retrofit with variable-speed drives to eliminate energy loss during unloading cycles, as shown in Figure 3.12. The modification resulted in a 20–30% reduction in energy consumption and minimised mechanical wear. Soft-start features reduced 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 at partial load. Variable Speed Drives (VSDs) are proposed for modulating motor speed in response to demand. The intervention yielded 5–10% energy savings and improved system reliability, as shown in Tables 6 & 7 and Fig.3.13. Pressure band optimisation further enhanced performance.



[Fig.3.11: Energy Saving with VFD Control]

Fig. 3.11 Illustrates the energy savings achieved through variable-frequency drive (VFD) control of air compressors, emphasising power modulation based on demand.



[Fig. 3.12: Traditional Compressors: Load/Unload Control]

Fig. 3.12 illustrates the operational differences between traditional load/unload compressor control and highlights inefficiencies during idle cycles.

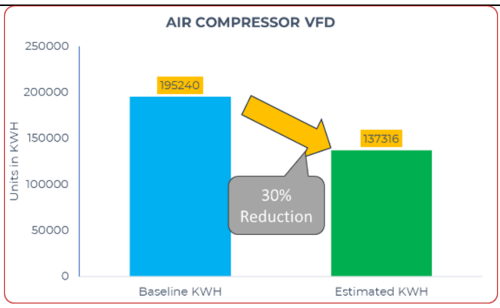
Table VI: Air Compressor VFD Saving and ROI

Payback 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 in CP VFD	**800000.00**	**Rs**
	Pay Back Period	**1.53**	**Year**

Table 6 presents field data and a payback analysis for implementing a variable-frequency drive (VFD) on an air compressor, quantifying significant annual energy and cost savings.

M. Estimated Savings

Table VII: Air Compressor VFD Savings, ROI and Benefits



[Fig.3.13: Air Compressor VFD Saving Estimate]

Fig. 3.13 presents the estimated annual power savings from compressors integrated with variable-frequency drives (VFDs), highlighting their potential for energy and cost 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 (INR)	Final Savings Commitment /annum (INR)	Payback Period in Years (ROI)
1	Air Compressor for VFD	8 Lakhs	5.27 Lakhs	1.73

Table 7: The financial evaluation of the compressor VFD installation shows a 1.73-year return on investment (ROI) and highlights operational benefits.

N. Cooling Tower Fan Retrofit

Cooling towers are proposed for retrofitting with EC fans and high-efficiency pump motors. 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.

[Fig.3.14: Cooling Tower Retrofit]

Fig. 3.14 This illustration depicts the upgraded cooling tower fan system, highlighting the integration of EC fans and optimised airflow performance.

Table VIII: Cooling Tower Fan Energy Saving Calculation

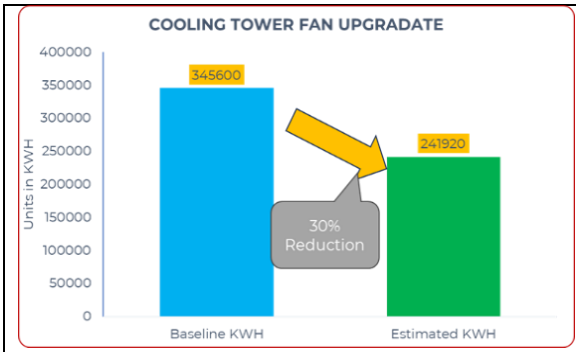
8 number of fans with a capacity of 7.5 KW =8 No's X7.5Kw = 60KW • Avg Cooling tower operation hours/day = 16Hrs • Avg Power consumption/month= 28,800 Units

Table 8: Calculates energy consumption and potential savings for cooling tower fan operation under baseline conditions.

Ageing 7.5 kW cooling tower fans, as shown in Table 8, are proposed to be replaced with EC technology fans, improving efficiency from 71.5% to 85.3%. As shown in Fig. 3.14, an annual chiller-related energy reduction of 3% was achieved, as shown in Fig. 3.15 and Table 9, along with improved reliability and noise reduction.

O. Estimated Savings:

Table IX: Cooling Tower Fans Savings, ROI and Benefits



[Fig.3.15 Cooling Tower Fan Upgrade Saving Estimate]

Fig. 3.15 Quantifies the energy savings of a cooling tower following an EC fan retrofit, confirming a reduction in electrical load and an improvement in thermal efficiency.

- EC stands for Electronically Commutated, which basically means it is a fan with a brushless DC motor, hence there 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 are no transmission losses.
- It's a DC motor; hence, the power factor is unity.
- The EC fans are in-built VFD & direct-driven motors, which provide better efficiency

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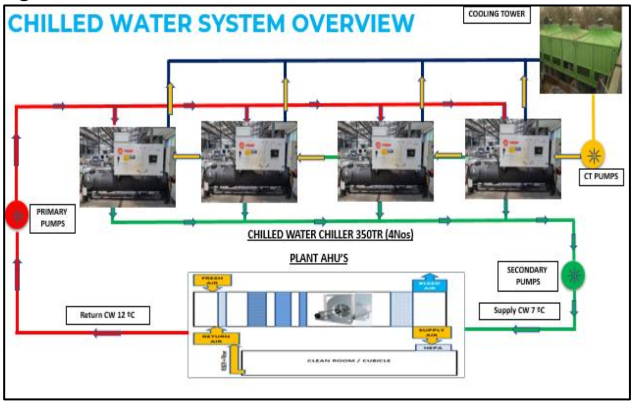
S. No	Name of the ECM's	Tentative Investment (INR)	Final Savings Commitment /annum (INR)	Payback Period in Years (ROI)
1	COOLING TOWER EC FAN UPGRADE	13.75 Lakhs	9.33 Lakhs	1.65

Table 9 consolidates the results of the cooling tower EC fan retrofit, reporting a 1.65-year ROI and improved efficiency.

P. Chiller Efficiency Monitoring and Optimisation

Chillers, as shown in Figure 3.16, were operating at suboptimal Coefficient of Performance (COP) due to fixed setpoints and manual sequencing. AI-driven algorithms were deployed to optimise 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, as shown in Fig. 3 .17, 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 the chiller's coefficient of performance (COP), resulting in annual energy savings of 122,640 kWh. Chiller efficiency monitoring and trends are shown in Tables 10 and 11 and in Fig. 3.17.



[Fig.3.16: Chilled Water System Overview]

Fig. 3.16 provides an overview of the chilled water system, highlighting the interconnections between chillers, pumps, and cooling loads.

Table X: Chiller Efficiency Monitoring Basis

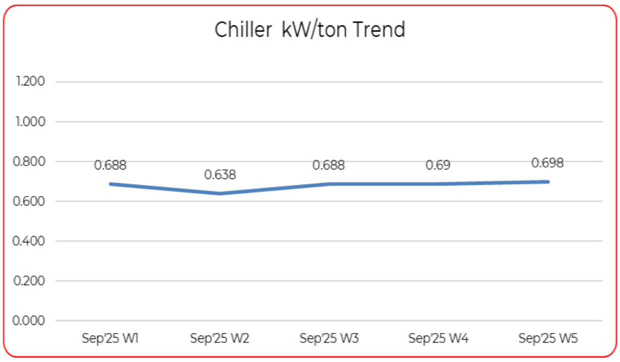
Chiller Efficiency Monitoring Basis	
Efficiency=	kW/TR
kW	Actual Power Consumed in kWh
TR	Actual Tons of Refrigeration Effect
TR=500 * GPM * ΔT	
500 is constant	
GPM is the water flow across the chiller evaporator	
ΔT is the temperature difference across the chiller evaporator	

Table 10 defines the basis for monitoring chiller efficiency by explaining the kW/TR calculation and evaluation parameters.

Table XI: Chiller Efficiency Monitoring Trend

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

Table 11 Displays chiller efficiency performance trends by comparing actual efficiency against target efficiency for performance validation.



[Fig.3.17: Chiller KW/ton Trend]

Fig. 3.17 presents the chiller kW/ton trend by comparing actual and target performance to evaluate operational efficiency.

Q. Observation

- Chiller Constant speed system needs to be converted to VFD to optimise the unloading hours.
- Set point optimisations, currently operating at 7 degrees, need to be increased to 8 degrees as well as meet the user load demand.
- Periodical cleaning of the condenser coil to reduce the load on the chiller

i. Power Factor Analysis

The 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 and 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.

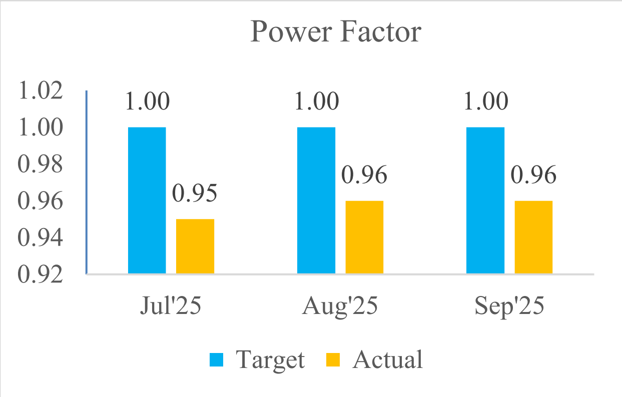
What causes the Power Factor (Why the real power is less than the apparent power):

- 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 a 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 a power factor.
- The motor or the load with a 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 larger sizes of current-carrying conductors (wires/cables) and other equipment.
- Higher costs.
- Current Power factor trend shown in Figure 3.18, and Power factor

improvement and payback details shown in Table 12



[Fig.3.18: Power Factor trend]

Fig. 3.18 This illustration shows the power factor trend at the facility, highlighting improvements in reactive power management before and after correction.

Table 12: Power Factor Correction and Payback Period Calculation

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

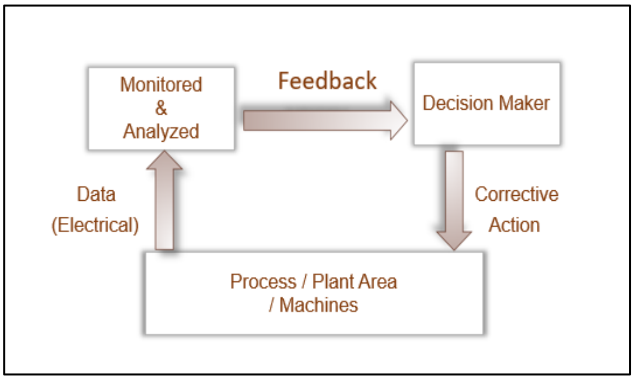
Table 12 provides a detailed calculation of power factor correction and payback, demonstrating a rapid recovery period of approximately 2.7 months.

ii. 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, as shown in Figures 3.19 & 3.20. The system facilitated data-driven decision-making and supported continuous improvement initiatives. Monthly reports and alerts are proposed 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.

R. How Ems Works



[Fig.3.19: EMS Works]

Fig. 3.19 Outlines the working principles of the IoT-based Energy Management System (EMS), summarizing its data-acquisition methods and control logic.

[Fig.3.20: EMS Dashboard Report]

Fig.3.20 Displays EMS report outputs, illustrating performance tracking, anomaly alerts, and KPI monitoring.

IV. RESULTS

A. Economic Evaluation

Each ECM was analyzed for savings potential, capital investment, and payback period. The consolidated result projected an overall energy-saving potential of 10–30%, with an average payback period of 1.71 years.

B. 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 to successful practices through policy and training.

C. 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 was employed. The primary analytical tools included Microsoft Excel for baseline calculations, Python (with pandas and matplotlib libraries) for data

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visualization, and IoT platforms such as Things Board and Blynk for real-time monitoring.

D. 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 in Table 13:

Table 13: Consolidated Energy Saving and ROI Calculation

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	Imme diate
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

Table 13 consolidates all ECM savings and ROI calculations, summarizing total energy savings of 2.13 million kWh and a weighted ROI of 1.29 years.

Total Annual Savings: 21,33,000 kWh **Total Cost Savings**: ₹19,184,000 **Total Investment**: ₹2446,75,000 **Weighted Average ROI**: 1.29 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.

V. DISCUSSIONS

The energy conservation initiative undertaken at SABIC Research and Technology Centre, Bangalore, demonstrates a multidimensional approach to industrial energy optimisation. 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 AHU's specific load and runtime characteristics, maximising 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 in response to 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.

Optimising air compressors with Variable Speed Drives (VSDs) and IoT-enabled leak detection further improved efficiency. Compressors are inherently energy-intensive, and their performance is susceptible 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, including EC fan retrofits and high-efficiency pump motors, demonstrated the importance of optimising the water-energy nexus. 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 the power distribution system. Online monitoring tools measured Total Harmonic Distortion (THD) and load imbalances, revealing opportunities to reduce losses by 3–5%. 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 stabilised cooling output during peak demand periods—the use of predictive algorithms enabled real-time adjustment of setpoints, enhancing system responsiveness.

Power factor correction is proposed to be achieved through the deployment of IoT meters, STATCOMs, and hybrid filters. These technologies maintained a 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 optimisation further reduced reliance on the grid and improved cost efficiency.

In summary, the discussion reveals that a holistic, data-driven, and digitally enabled approach to energy conservation can yield substantial technical,

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financial, and environmental benefits. The interventions are scalable, replicable, and aligned with global sustainability frameworks.

VI. CONCLUSION

This study presents a comprehensive evaluation of electrical energy conservation opportunities at the SABIC Research and Technology Centre, Bangalore. Using the A3–PDCA framework, the research systematically identified inefficiencies, implemented targeted interventions, and monitored outcomes across 10 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 [5, 6].

Optimising air compressors with VSDs and leak detection systems addressed both energy and reliability concerns. Cooling tower upgrades improved heat-rejection efficiency and enhanced chiller performance, while transformer-loss assessments and harmonic mitigation addressed power-quality issues often overlooked 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. Implementing a centralised 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 project's financial viability. 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 [1, 2].

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 [4].

A. 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 prioritising high ROI projects such as AHU and compressor retrofits, followed by IoT monitoring and transformer optimisation. 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.

VII. 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 standardise energy management practices and facilitate the sharing of global best practices. Moreover, assessing the reduction in carbon footprint from implemented measures would provide quantifiable sustainability metrics to guide long-term policy development.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.

- **Author's Contributions:** Each author has individually contributed to the article. K. Sivasankar, Conceptualisation, data collection, methodology, formal analysis, investigation, manuscript drafting, and overall correspondence. Dr. S. Muthukrishnan, Supervision, technical guidance, validation, result verification, and critical review of the manuscript.

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