cBalance Solutions Pvt. Ltd

Energy Audit Report

for

Sai Life Science Ltd

Unit IV Bidar, Karnataka

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1 Introduction

cBalance Solutions Pvt. Ltd. (India) was contracted by Sai Life Science Pvt. Ltd. to conduct a complete thermal and electrical energy audit, as the primary step of an objective to transform the industry into a 'green industry' through conservation of natural resources and reducing environmental impact of their operations.

The overarching objectives of the exercise were to:

- Determine the energy and related cost conservation potential for the Sai Life's building facilities (Unit – IV Bidar) based on technological interventions
- Determine the energy and related cost conservation potential based on architectural interventions (especially related to building envelope/Air Conditioned space insulation)
- Determine the electrical energy cost reduction potential based on operational process changes (related to reorganizing the scheduling of energy consuming activities)
- Establish the comparative financial feasibility of proposed alternatives on a life-cycle cost basis

Additionally, cBalance Solutions Pvt. Ltd. determined the GHG mitigation potential for the proposed alternatives to reduce the overall Carbon Footprint of Sai Life Sciences (Scope 1 and Scope 2 Emissions). This assessment culminates in a macro-level Marginal Abatement Cost Curve (MACC) Analysis.

MACC Curves: An enterprise-specific Marginal GHG Abatement Cost Curve (MACC) analysis is a key component of an institutionalized Sustainability Strategy. It is designed to discover the most cost-effective means of mitigating climate change impact through technological interventions or modifications in management practices. It is a vital decision-support input for planning capital expenditure on Energy Efficiency, Water Conservation, Waste Reduction & Management etc. projects in a manner that safeguards the financial sustainability of the Organization while achieving tangible environmental and socio-economic sustainability benefits for the planetary ecosystem. The idea is to harvest the low-hanging fruits first, accumulate the economic benefits from these no-regret options and then steps through more challenging interventions. In this way, it reduces financial risk and ensures longevity of the environmental program at large.

MACC Methodology: Costs and benefits are calculated based on real values of financial parameters such as inflation, interest rates, cost of electricity, energy etc. and resource conservation benefits of options reflect the enhancement in technological alternatives available over time.

2 Project Scope

The geographical scope of the project comprised execution of a detailed thermal and electrical energy audit of Sai Life Science Ltd. Unit IV Bidar (Karnataka, India) over 10-days, beginning 19th January 2015 through 28th January 2015.

The systems studied and assessed as part of the energy audit and conservation strategy devising process included the following:

- Boiler & Boiler Steam Distribution System
- Thermopack
- Compressors
- Nitrogen Plant
- Dowcal System
- Air Handling Units
- Chiller System
- HVAC Systems: Split ACs, Cassette ACs, DucTable ACs
- Lighting Systems: TFL Lights and CFL Bulbs

3 Methodology

The field measurement methodology adopted included the following processes and equipments:

- *Fluke Digital Power Analyzer:* for verifying total connected electrical load of Industrial building (kVA), the overall system Power Factor (PF), and other parameters including total current drawn (A) and Voltage (V), and measuring electrical parameters of compressors, chillers and HVAC equipment clusters - to establish baseline system performance.
- *MECO Clamp-On Meter:* for measuring electrical parameters of individual HVAC equipment - to establish baseline system performance.
- *Lutron Luxmeter:* for measuring lux levels on the working planes of the workspaces and human occupancy areas.
- *Lutron Anemometer:* for measuring flow rate (velocity) of condenser cooling air exiting the outdoor-units to determine the heat rejected by the individual HVAC equipment (equivalent to delivered cooling – tonnes of refrigeration or TR)
- *Psychrometer:* for measuring the dry bulb temperature (DBT) and wet bulb temperature (WBT) of the ambient and condenser-cooling air to establish the enthalpy change across the condensers of the outdoor units.
- *Measuring Tape:* to measure the diameter of outdoor unit fans to convert air velocity into mass flow rate.
- *Ultrasonic Flow Meter:* to measure the velocity of fluid with ultrasound to calculate volume flow.

4 Energy Audit Data Analysis

Following color coding is used has been used for the data interpretation in tables:

Color	Data Interpretation
	Rated or Derived Values
	On-field Measured Values
	Calculated Values based on Rated/Derived and On-field Measured Values

4.1 Baseline Performance Measurement

The plant consumes energy in the following forms

- ✓ Coal & Briquettes for Boiler
- ✓ Diesel for Thermo Packs
- ✓ Diesel for Captive Power Generation (DG Sets)
- ✓ Grid Electricity for Plant Process Reactors, Plant Utilities & Lighting

The following sections of the report present a overview of the patterns related to these forms of energy consumption.

The overall annual energy use distribution in terms of energy value (MegaJoules - MJ) and cost (INR) amongst the above mentioned fuels is presented in the Tables and charts below.

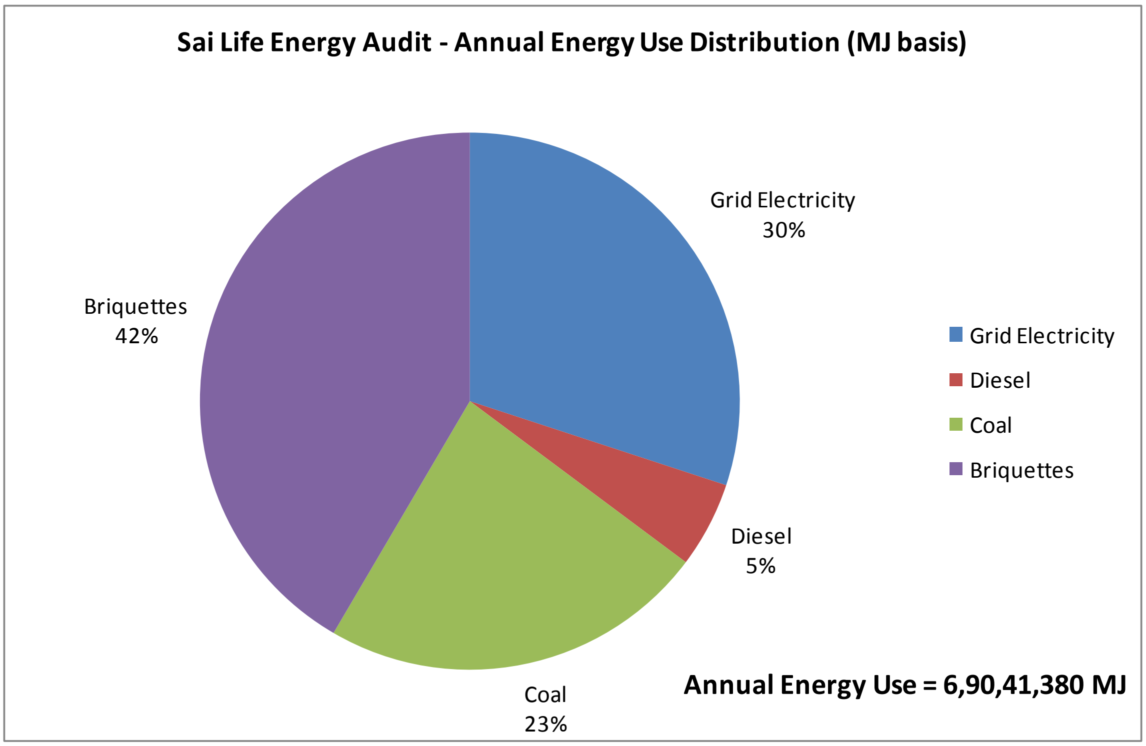
Table 1 Annual Energy Use Summary

Source	Annual Qty.	Units	Annual Energy Use (MJ)	Fuel Cost Basis	Units	Annual Cost (INR)
Grid Electricity	57,63,184	kWh	2,07,47,462	6.73	INR/kWh	3,88,01,477
Diesel	102,251	Litres	35,61,402	54	INR/litre	55,21,554
Coal	996.5	Tonnes	1,60,45,269	7.98	INR/kg	79,51,671
Briquettes	2048.4	Tonnes	2,86,87,246	5.38	INR/kg	1,10,21,309
Total			6,90,41,380			6,32,96,010

The cost basis for converting annual energy consumption to annual energy cost for each type of energy source is presented above alongside the fuel type. The overall energy use distribution assessment indicates that Briquettes form the most significant component of the end-use-energy on a net calorific value basis, contributing 42% of the annual energy use of 69,041 Giga Joules (GJ). Electricity use and Coal use are the next two major contributors, representing 30% and 25% of the annual energy used, respectively. The cost distribution across fuels does not however, follow the same pattern. It is notable that while electricity contributes only 30% to the 69,041 GJ of annual energy consumption, it exerts 61% of the annual energy cost of INR 6.32 Crore. Conversely, Briquettes represent only 17% of the annual energy cost while providing 42% of the annual energy on a calorific value basis. The overarching intelligence gathered from this macro analysis is that thermal energy use (Briquettes and Coal) exert a dominant influence on the total energy used by the Plant (67% of the total energy value) and therefore warrants a high priority in the energy audit and energy conservation roadmap development process.

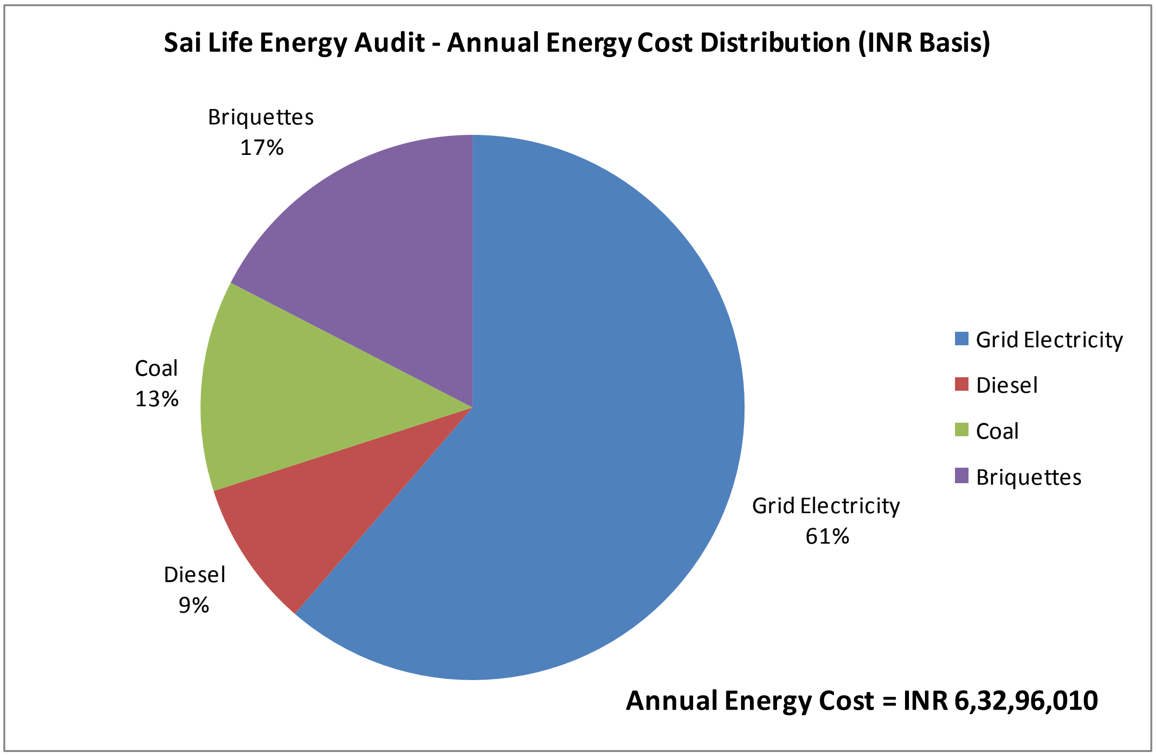
The most cost-effective fuel, in terms of cost per unit energy (joules basis) was seen to be coal which contributes only 13% to the annual energy cost while providing 23% of the annual energy used. This is not to be interpreted as an endorsement of the increased use of Coal as an effective means of energy conservation. It has detrimental locally polluting effects and is greenhouse gas emitting[1]. Its indirect impacts include, creating an economic demand for an inherently un-sustainable fossil fuel, and needs to be considered alongside its short-term financial benefits. These benefits can also be achieved through more sustainable means, such as renewable energy sourcing and integration of energy efficiency into the operational DNA of the organization.

Figure 1 Annual Energy Use Distribution (MJ basis)



[1] The average GHG Emission Factor for Indian Sub-Bituminous Coal Combustion is estimated to be 1.89 kgCO2e/kg

Figure 2 Annual Energy Cost Distribution (INR basis)



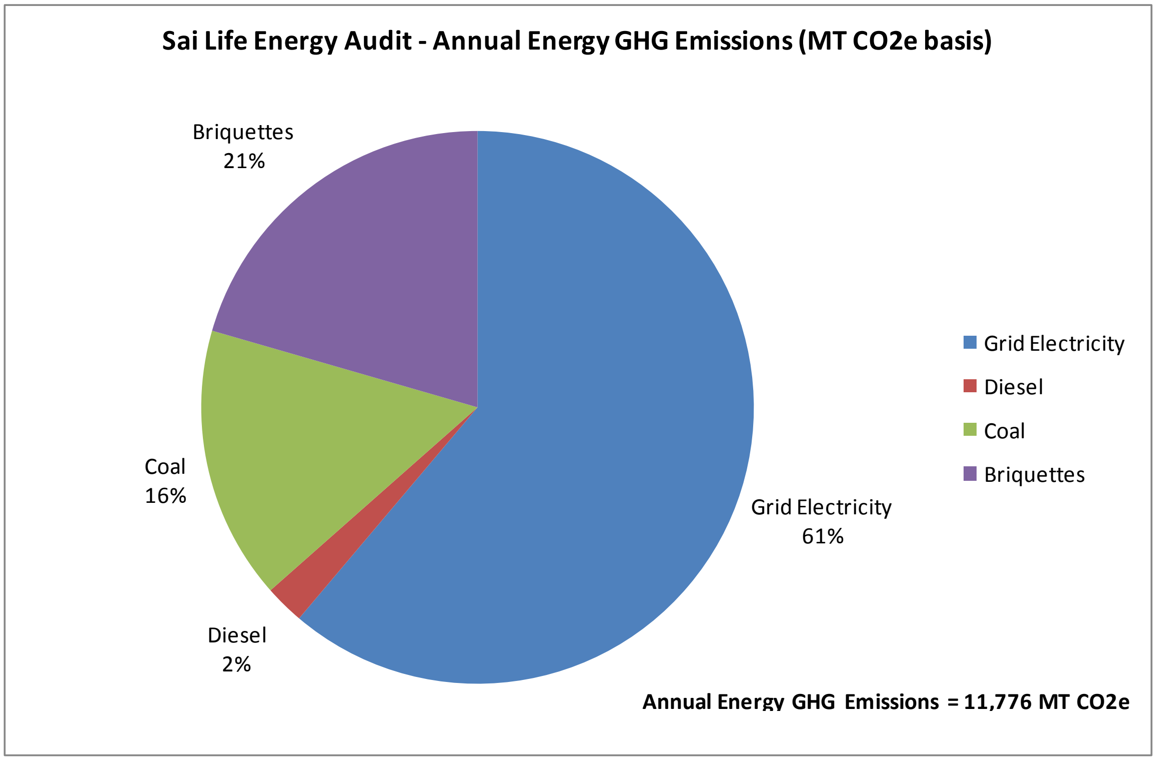
The relative and total impacts of fossil and electrical energy consumption on the Direct and Indirect (Scope 2) GHG Emissions of the plant are presented in the Tables and charts below.

Table 2 GHG Emission Factors and Inventory – Energy

Energy Source	GHG Emission Factor	Units	GHG Emissions (MT CO2e/year)
Grid Electricity	1.25	kg CO2e/kWh	7204.0
Diesel	2.66	kg CO2e/liter	272.0
Coal	1.89	kg CO2e/kg	1883.3
Briquettes	1.18	kg CO2e/kg	2417.1
Total			11,776

The analysis indicates that the annual energy related GHG emissions for the plant are 11,776 metric tonnes of CO2e. The relative contribution of the emission sources is presented below. The chart indicates that electricity related emissions are the most significant contributor to the plants energy related GHG emissions (61 %) followed by Briquettes (21 %) and Coal (16 %). Hence from a climate change mitigation perspective, mitigating electricity consumption would be a higher priority relative to thermal energy conservation.

Figure 3 Annual Energy Source GHG Emissions Distribution (MT CO2e basis)



4.1.1 Grid Electrical Energy Consumption

Grid Electricity is provided through a three-metered connection from Gulbarga Electricity Supply Company Ltd. Table 3 presents the details of the tariff structure of the Sai Life Kolar Unit. The details of Time–of–Day (TOD) tariff incentive / disincentive structure is presented in

Table 4.

Table 3 Tariff Structure

Consumer Name	**Sai Adventium Pharma Ltd, Kolar**
Commercial Tariff	HT – 2a (Time of Day)
Sanctioned / Contracted Demand	700 kVA
Contract Demand Charges	170 INR/ kVA
Excess Demand Charges above 700 kVA (Penalty)	340 INR/ kVA
New Tariff (May 2014 onwards) - kWh charges upto 100000 Units	5.7 INR/kWh
New Tariff (May 2014 onwards) - kWh charges above 100000 Units (Penalty)	6.0 INR/kWh
Old Tariff (till April 2014) - kWh Charges up to 100000 Units	5.35 INR/kWh
Old Tariff (till April 2014) - kWh Charges above 100000 Units (Penalty)	5.70 INR/kWh

Table 4 Time-of-Day (TOD) Structure

Details	TOD A (6:00 Hrs to 18 Hrs)	TOD A (18:00 Hrs to 22 Hrs)	TOD A (22 Hrs to 06 Hrs)
Incentive / Disincentive (INR/ kWh)	0.00	1	-1.25

Baseline electrical energy consumption was determined through a review of the electric bills paid by the facility over a 12 month period (November 2013 to October 2014). The electricity bills spanned 2 different Time-of-Day (TOD) Tariff regimes implemented by the utility provider.

Figure 4 shows the monthly electricity consumption in kWh. The maximum electricity consumption was 5,70,216 units recorded in August 2014. The minimum electricity consumption 4,15,360 units recorded in December 2013. The average monthly consumption of 4,80,265 kWh/month can be taken as present energy benchmark and the goal of the energy conservation process, the ultimate desired outcome of the Energy Audit process, is to identify possibilities for reducing this benchmark energy consumption to the greatest extent feasible. Figure 5 shows the monthly electricity charges paid to Gulbarga Electricity Supply Company Ltd. The maximum monthly electricity charge was INR 53,95,934 paid in July 2014, which included a one-time annual security deposit of INR 17,54,700. Excluding this security deposit, the maximum monthly electricity charge is seen to be INR 36,41,234. The minimum monthly electricity charge was INR 25,76,214 paid in December 2013. The average monthly electricity charge was calculated to be INR 32,18,351. The normalized average electricity charge for the manufacturing unit is calculated by dividing the total annual electricity cost (energy charges only – INR 3,32,57,839) with the total energy (in kWh) used. This was calculated to be INR 5.77/kWh and was used as the basis of all energy cost saving modeling activities conducted for the project. It is to be noted that the total annual electrical energy cost (including fixed charges, demand charges etc.) was INR 3,88,01,477 and the resultant gross electricity cost per kWh was therefore INR 6.73/kWh. This value however has only academic significance with respect to energy savings calculations as it does not truly specifically address the energy cost but rather the total cost of supply. The above analysis is summarized in Table 5 below. Other relevant details of the energy bills are presented in Appendix I.

Figure 4 Monthly Electricity Consumption

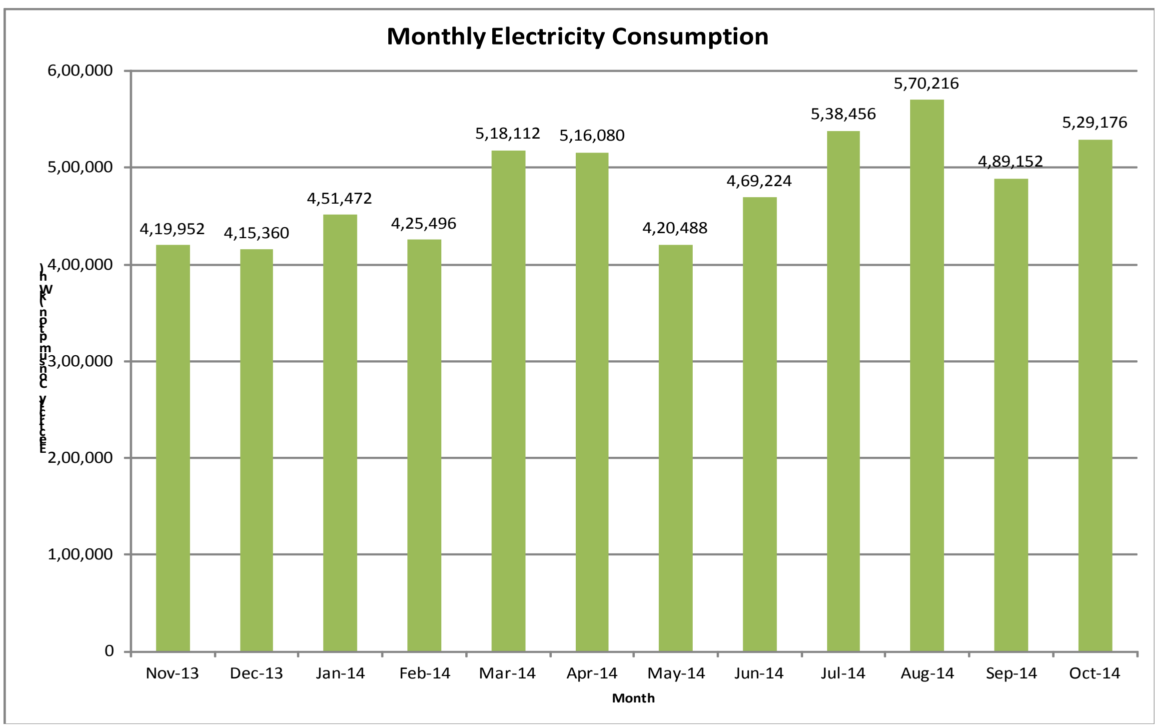
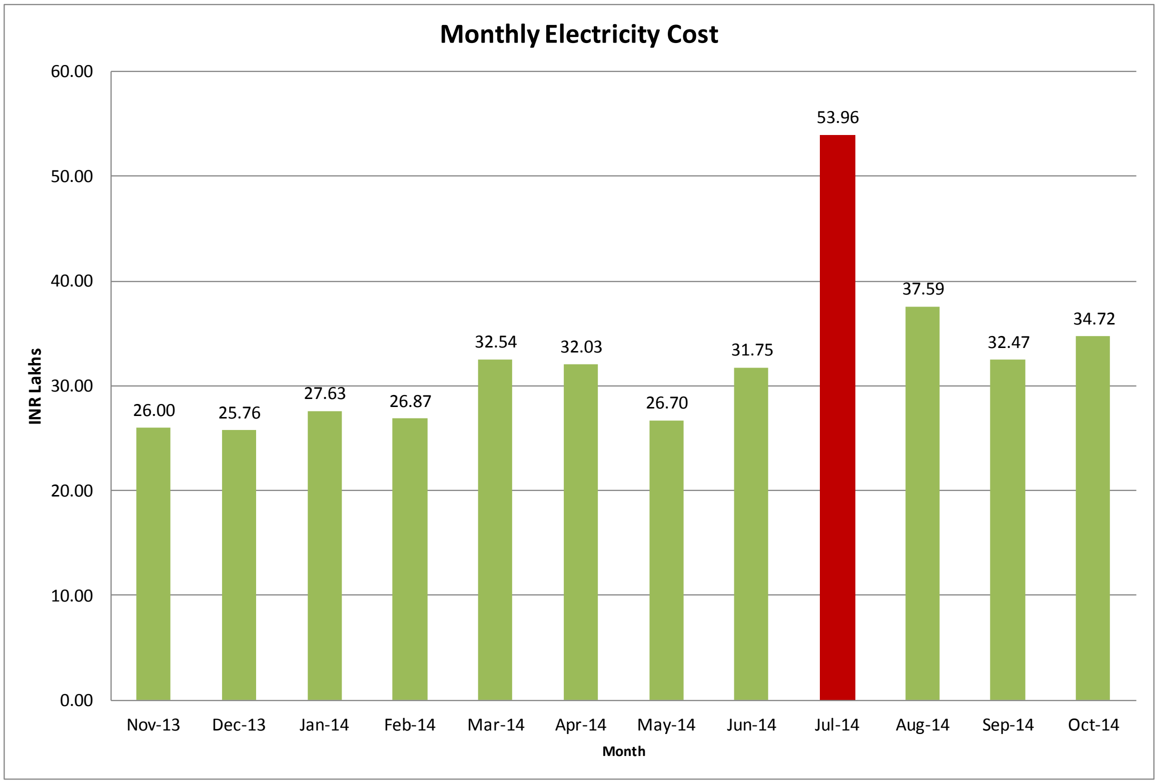


Figure 5 Monthly Electricity Cost

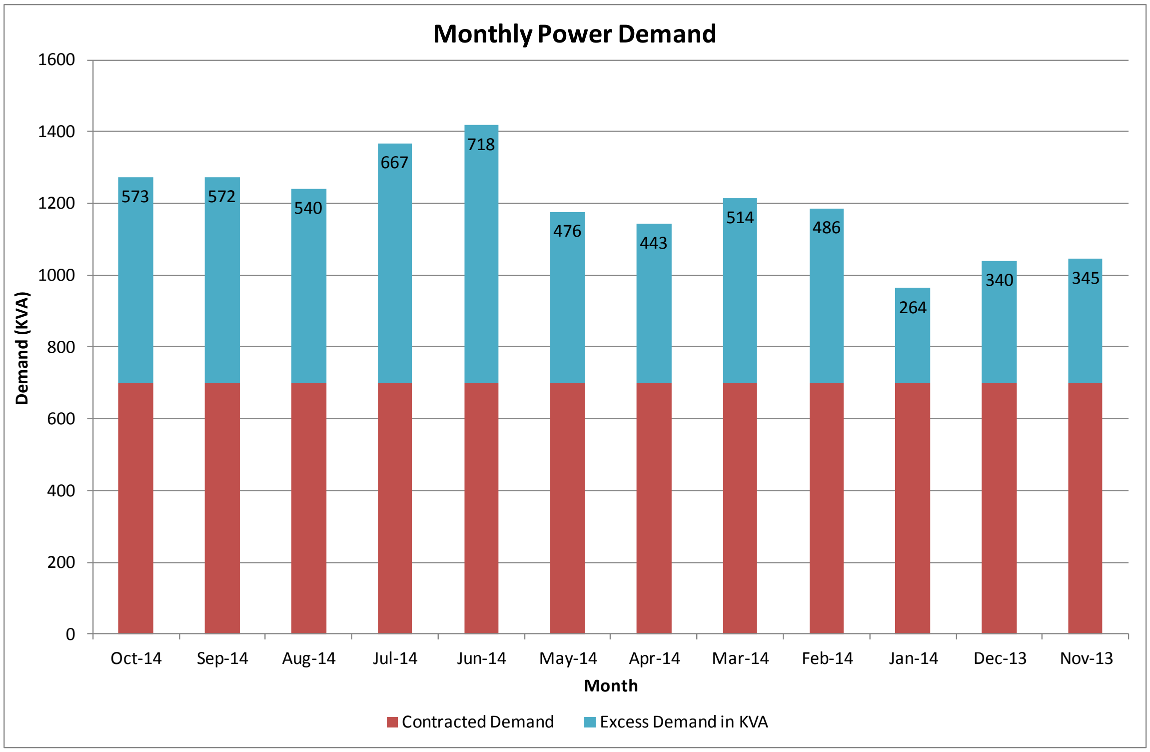


The figure below shows the demand recorded per month. The average recorded demand per month was 1,188 kVA. When compared with the contracted/sanctioned demand of 700 kVA, the excess average maximum demand per month was estimated to be 1180.30-700 kVA = 480.30 kVA. The monetary impact of this routine practice of exceeding contract demand leads to substantial average monthly penalty charge of 1,63,312 INR/Month stemming from a penalty charge of INR 170 per kVA of excess demand. Similarly, the maximum excess demand recorded was 718 kVA and the consequent penalty charged was INR 2, 44,120 INR in July 2014. The annual excess demand charge is a revealingly high amount of INR 20, 18,920 which represents 5.2% of the total energy cost.

Table 5 Annual and Monthly Energy Use Summary

	All Charges Included	Only Energy Charges	Units
Avg. Monthly Energy Consumption		4,80,265	kWh/month
Annual Energy Consumption		57,63,184	kWh/year
Avg. Monthly Demand		1,195	kVA
Avg. Monthly Excess Demand		495	kVA
Avg. Monthly Excess Demand Charges		1,68,243	INR/month
Annual Excess Demand Charge		20,18,920	INR/year
Annual Excess Demand Charge %		5.2%	%
Avg. Specific Energy Cost	6.73	5.77	INR/kWh
Avg. Monthly Energy Cost	32,33,456	27,71,487	INR/month
Annual Energy Cost	3,88,01,477	3,32,57,839	INR/year

Figure 6 Monthly Power Demand



4.1.2 Captive Power Generation (Diesel)

Captive Power Generation at the Sai Life Kolar Unit is accomplished by three (3) Diesel Generator (DG) sets . Two of these are of 500 kVA capacity, while the third is a 750 kVA DG set. DG sets are employed as backup power sources during power outages. Figure 7 presents the historical usage data (from Sept. 2014 to Jan. 2015) for the DG Sets and indicates that DG sets run for approximately 260 hours per month or 8.5 hours/day

Figure 8 and Figure 9 provide the diesel consumption and kWh generation by the DG Sets over a 5 months period. The total diesel consumption recorded over a 5 months period was 1,02,251 Liters which led to generation 3,95,188 kWh The average kWh generated per liter of diesel was thus 3.87 kWh/liter. The energy generation data yields an average daily generation of approximately 2,591 kWh by the 3 DG sets. Additional details related to DG set usage and diesel consumption etc. is provided in Appendix II.

Figure 7 DG Sets Running Hours

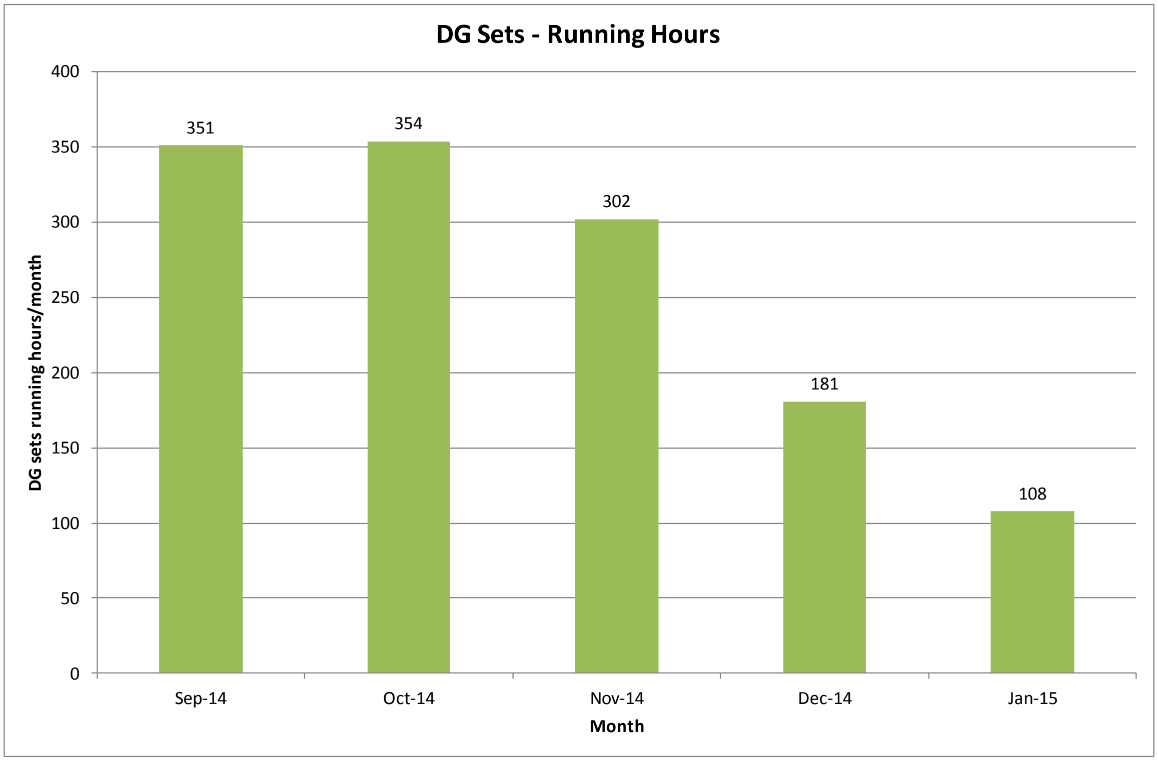


Figure 8 DG Sets Diesel Consumption

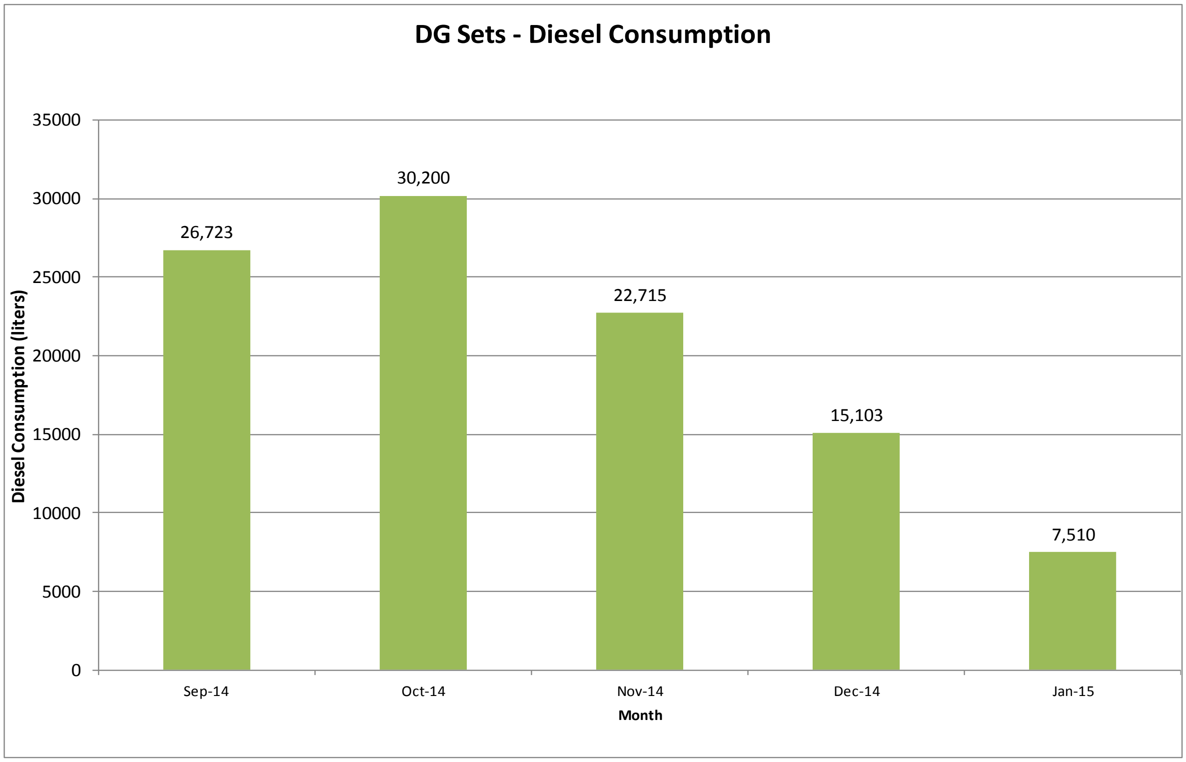
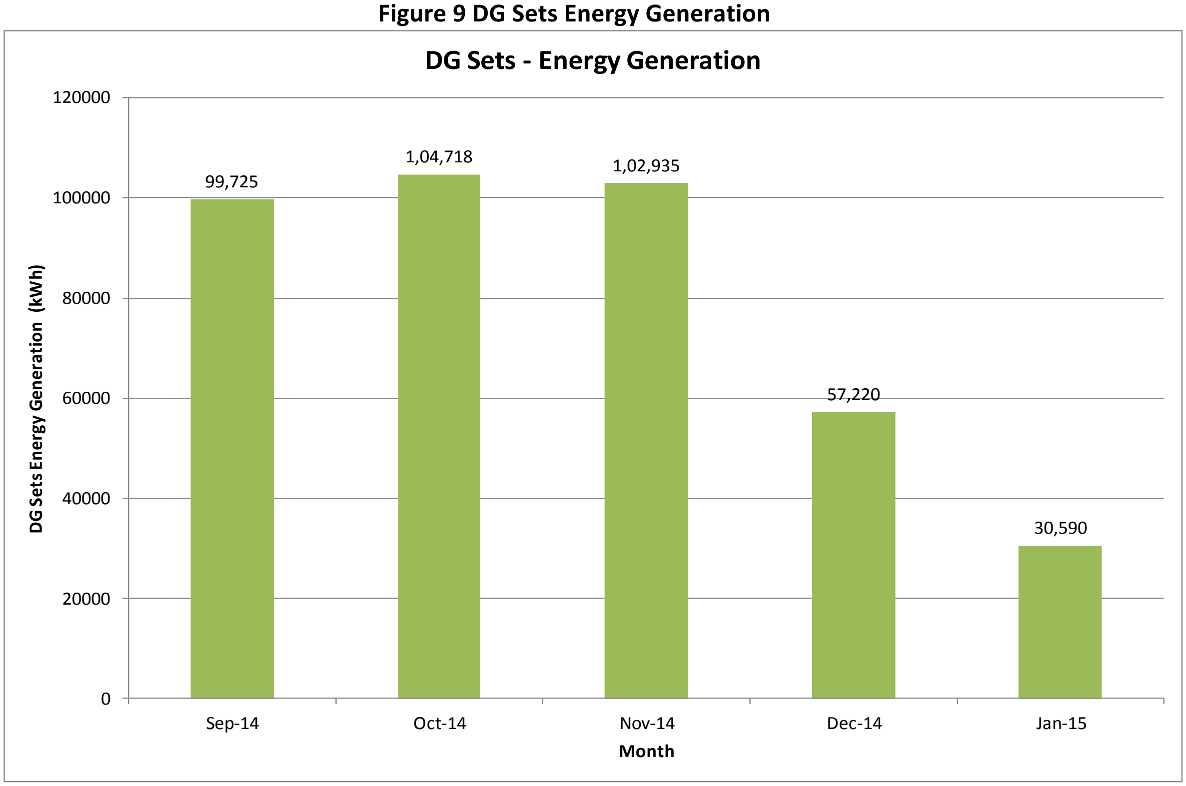


Figure 9 DG Sets Energy Generation



From the historical data of all three DG sets, it has been found that the measured kWh/litre of diesel is higher than the rated kWh/litre**.** Table 6 shows the DG set summary**.** The measured spec. fuel consumption of all DG sets is higher than the rated spec. fuel consumption.

Table 6 DG Set Summary

DG ID No	**DG 1 (500 kVA)**	**DG 2 (500 kVA)**	**DG 3 (750 kVA)**
Model	**Cummins**	**Cummins**	**Cummins**
Rated kWe@ 100%	400.00	400.00	600.00
Rated Sp. Fuel Consumption (ltrs/hr) @ 100% load	106.28	106.28	158.90
Rated Sp.Fuel Consumption (kWh/ltrs) @ 100% load	3.76	3.76	3.78
Rated kWe @ 75%	300.00	300.00	450.00
Rated Sp. Fuel Consumption (ltrs/hr) @ 75% load	81.59	81.59	121.60
Rated Sp. Fuel Consumption (kWh/ltrs) @ 75% load	3.68	3.68	3.70
Avg Sp.Fuel Consumption (ltr/hr)	64.99	68.68	99.03
Sp.Energy Generation (kWh)	260.84	267.73	379.54
Load (%)	65.21%	66.93%	63.26%
Measured Spec.Fuel Consumption (kWh/ltr)	4.06	3.94	3.83

4.1.3 Diesel for Thermo-Pack

Historical Data with regard to Diesel consumption for Thermo-Pack was not available from the Plant operation team. The Thermo-Pack system is only used sporadically for special product lines, and the Diesel consumption is not continuous. Due to these considerations, this component of energy consumption was considered immaterial for the energy audit, and omitted from further analysis.

4.1.4 Coal and Biomass Briquettes for Boilers

In this section, an overview of consumption of coal and biomass briquettes for boiler operation is presented. The daily fuel quantity consumed, annual fuel cost, and the resultant steam generation parameters are indicated in Table 7 below. The cost of steam generation was determined through fuel (coal and briquette) mass measurement and recording the corresponding steam generation. The trials conducted yield an average cost of INR 2.08/kg steam. In the absence of sophisticated and accurate weighing systems available on site, it is likely that the trial data may deviate from actual operational performance. However, fuel mixing is manual and is done based on the approximate judgment of operators who vary across shifts.

Table 7 Boiler Fuel Consumption & Steam Generation Summary

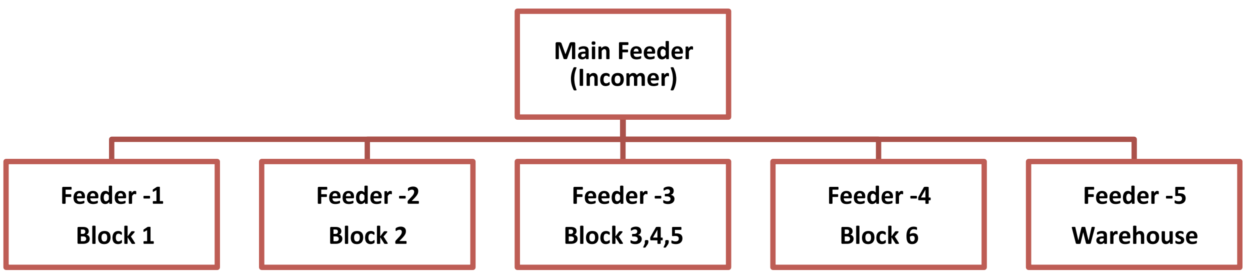
Fuel Data	**Annual Fuel Consumption [Tons]**	**Annual Fuel Cost [INR]**	**Annual Steam Generation [Tons]**	**Cost of Steam (INR/ kg)**
2730 kg Coal/day	996.45	79,51,671	9125.00	INR 2.08 per Kg Steam
5612 kg Briquettes/day	2048.38	1,10,21,309		

4.1.5 Plant Load Distribution and Area-Wise Energy Consumption Patterns

While understanding the cumulative energy consumption of the physical plant units was vital, it was of even greater significance to dissect this total energy consumption across energy consuming systems and sub-systems to identify the key energy consuming hotspots in order to be able to integrate them into an energy conservation plan for the plant. In addition to understanding the average energy consumption profile per month, the power analysis equipment was deployed for the purpose of gauging diurnal patterns of energy consumption i.e. the magnitude and periods of occurrence of maximum and minimum power demand.

Figure 10 shows the distribution of electricity from main feeder (i.e. entire Sai Life Unit) to the 5 sub-feeders supplying energy to the Block 1 , Block 2, Block 3 to 5 , Block 6 and Warehouse. In addition to this, the plant possesses a 6th sub-feeder catering exclusively to the Diesel Generators.

Figure 10 Distribution of Electricity from Main Feeder to Sub-Feeder



The time period of assessment for the main feeder (i.e. entire Sai Life Unit) to the 5 main sub feeders supplying energy to the Block 1, Block 2, Block 3 to 5, Block 6 and Warehouse is mentioned in Table 8.

Table 8 Feeder Assessment Time Period

Feeder ID	Time Duration
Main Incomer	24 hours
Sub Feeder -1 [Block 1]	24 Hours
Sub Feeder -2 [Block 2]	24 Hours
Sub Feeder -3 [Block 3,4,5]	23 Hours
Sub Feeder -4 [Block 6]	23 Hours
Sub Feeder -5 [Warehouse]	23 Hours

The energy and average power measurements result for all feeders is shown in Table 9 and allows the subsequent conclusions to be drawn with respect to the areas of the plant which draw a majority of the power consumed.

Table 9 Measured Power Consumption Summary

Block Ref.	kWh	Time (hrs)	Avg. KW (calc)	Power Factor (Calc)	kVA	kVAr	% Load (kW wise)	Cumulative Load %
Block 4 & 5	6691.0	23.0	290.95	0.98	296.89	41.26	33.1%	33.1%
Block 6	4499.5	23.8	188.81	0.76	248.44	-97.25	21.5%	54.6%
Block 1	3913.0	24.3	161.27	0.91	177.22	74.17	18.4%	73.0%
Warehouse	3504	23.2	151.3	0.87	173.85	112.70	17.2%	90.2%
Block 2	1303.0	24.3	53.66	0.86	62.40	31.03	6.1%	96.3%
Boiler Section			21.0	0.84	24.95	13.16	2.4%	98.7%
Block 3			11.38	0.94	12.11	11.27	1.3%	100.0%
Total (aggregate)			878.2		995.8	186.3	100%	
Service Entrance	19432.0	24.0	808.6	0.99	816.81	80.09		

The feeder-wise power measurement results indicate that the major electrical energy consuming areas are Block 4&5, Block 6, Block 1 and the Warehouse which together comprise 90% of the total power demand of the entire plant. It must be noted in the Table above that measured power consumption for Block 3 were arrived at through summing individual power measurement of equipment located within the zones as cumulative Block level energy measurement was not possible. It is also notable that the 24-hour measurement at the Service Entrance (which represents the total electrical consumption by the Plant) led to a measured average power consumption of 808.6 kW which was lower compared to the cumulative total (878.2 kW) obtained from the measurements/calculations performed for the individual Feeders. This is not a cause of concern or a source of discrepancy as it might to be at the apparent level; since individual Feeder-wise measurement and the measurement on the Main Incomer at the Service Entrance were conducted on different days, this variation is completely acceptable as it reflects the daily variations in the diverse Pharmaceutical manufacturing processes underway at the Plant on a given day.

In addition to measuring aggregate energy consumption, the power analyzers deployed for profiling feeder-wise energy consumption also recorded patterns of peak and minimum demands encountered across various Blocks comprising the Plan. This is presented in Table 10 below. It was noted that Block 1 and Block 3, 4 & 5 incomers demonstrate relatively large variations in demand whereas Block 2 and Block 6 demonstrate relatively smaller and rarer demand peaks. The demand peaks (wherever encountered) are over shorter intervals and thought to be due to Chiller ON / OFF operations rather than any other loads.

Table 10 Power Peaking Trends

Block Reference	**Demand [kVA]**		**Remark**
	Max.	Min.	

Block 1	506.8	92.5	Large peaks at small intervals
Block 2	117.0	0	Small peaks at long intervals
Block 3 & 4	117.0	0	Large peaks at small intervals
Block 6	143.9	0	Small peaks at long intervals
Main Incomer	1329.8	0	Superimposition of the above

The measured data serves as a general validation of the suspected high-energy consuming areas. Since energy conservation plan would have to be designed around improving performance of specific energy consuming equipment, a demand-type wise dissection and micro analysis is more important for the purposes of this Energy Audit and is presented below.

4.1.6 Power Factor

Average PF as per historical data is 0.91. The Utility Power Company charges penalty for PF violation only if the PF is below 0.90. PF improvement is however recommended from the point of view of demand reduction.

PF recorded during the field visit was 0.99 over 24 hour recording trend. This is a marked improvement over the power factor as recorded from past electricity bills which depict a poor power factor. These recorded values from past bills are summarized in the Table below.

Table 11 Power Factor Trends

Month	Recorded PF.
Oct-14	0.92
Sep-14	0.93
Aug-14	0.91
Jul-14	0.87
Jun-14	0.90
May-14	0.91
Apr-14	0.92
Mar-14	0.88
Feb-14	0.91
Jan-14	0.93
Dec-13	0.90
Nov-13	0.92
Annual Total	0.91

The Power and PF as per one day recording was presented in Table 9 earlier.

4.1.7 Load Type-Wise Consumption Patterns

The major sources of energy demand studied during the Energy Audit were the following:

- ✓ Lighting Load
- ✓ HVACR Load

- ✓ Compressors
- ✓ Cooling Towers
- ✓ Boilers

The following equipment sub-types (associated with the above mentioned systems) were studied as part of the Energy Audit:

- ✓ Lighting Fixtures
- ✓ Chillers
- ✓ Pumps
- ✓ Blowers
- ✓ Fans
- ✓ Compressors

Power consumption was measured using field audit equipment and represents primary field data. The results of the load study are tabulated below in descending order of magnitude of power consumption. The total load recorded across identifiable energy systems was approximately 458 kW. This was lower than the total Main Incomer load of 808 kW as presented earlier. This can be attributed to the fact that the periods of measurement for the individual equipment across Blocks, as well the demanded exerted by the processes, varied over time and differed from the periods of macro measurement for collective energy consumed from specific Feeders. The overarching conclusion of the analysis is that that the HVAC-Refrigeration Load is by the far the most critical component of plant-wide electrical energy consumption (accounting for approximately 59% of the load) followed narrowly by the Compressor and Cooling Tower Load. The three sources cumulatively contribute approximately 84% of the total energy demand of the Plant. Lighting, Boiler Electrical Usage (for Induced Draft and Forced Draft Fans), Vacuum Pumps and Scrubbers contribute approximately 16% of the energy demand.

Table 12 Load (System) Type-wise Consumption Pattern

Load Details	Power Consumption [KW]	% Load	Cumulative Load %
Others	350.3	43.3%	43.3%
HVACR	271.7	33.6%	76.9%
Compressor	59.6	7.4%	84.3%
Cooling Tower	53.1	6.6%	90.8%
Lighting	42.9	5.3%	96.1%
Boiler	21.0	2.6%	98.7%
Vacuum Pump	6.2	0.8%	99.5%
Scrubber	4.0	0.5%	100.0%
TOTAL LOAD	**808.6**	**100%**	

The Table 13 and

Figure **12** below present electrical energy consumption categorized by equipment sub-type (i.e. the specific equipment's comprising the various energy consuming systems). Dissecting the energy consumption by system sub-type reveals that the specific equipment type which consumes a majority of the energy across the Plant are the large Vapor-Compression Cycle based Chillers (i.e. compressor motors), consuming approximately 52% of the load followed by Pumps and Compressors across systems at the Plant which cumulatively consume another 30% of the total energy. It must be noted here that ancillary equipment associated with Chillers, Cooling Towers etc. (eg. Recirculation Pumps, Fans etc.) are classified as entities belonging to the primary equipment type. The outcome of this system sub-type analysis is presented below.

Figure 11 Power Consumption by Load (System) Type

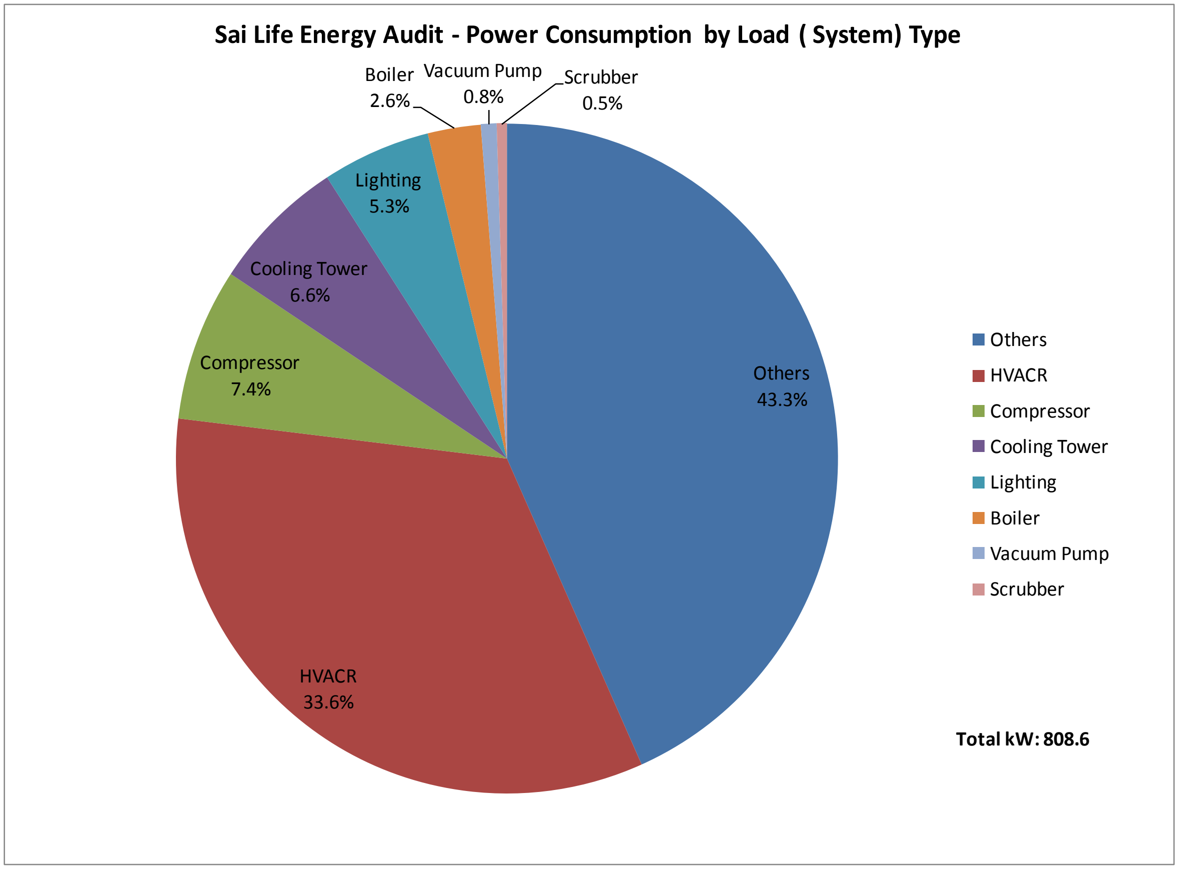
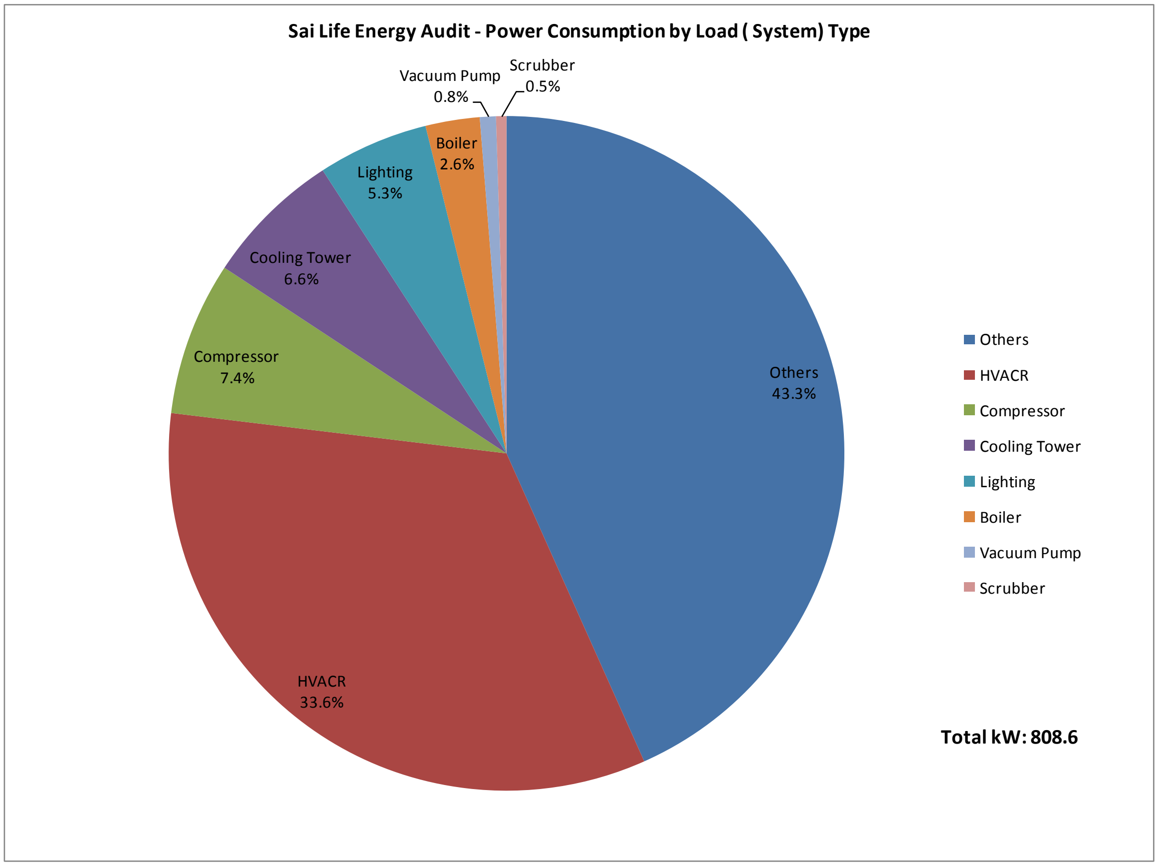


Table 13 Load (Sub-System) Type-wise Consumption Pattern

Load Details	Power Consumption [kW]	Absolute Load (%)	Cumulative Load %
Others	350.3	43.3%	43.3%
Chiller	237.3	29.3%	72.7%
Pump	81.8	10.1%	82.8%
Compressor	59.6	7.4%	90.1%
Lighting	42.9	5.3%	95.4%
Fan	34.9	4.3%	99.8%
Blower	2.0	0.2%	100.0%
TOTAL LOAD	**808.6**	**100%**	

Figure 12 Power Consumption by Load (Sub-System) Type



4.1.8 System-Wide Energy Performance Assessment & Energy Conservation Opportunities

4.1.8.1 Load Curve Management

The most overarching analysis conducted during the Energy Audit related to the potential for reducing energy cost for the Client without any additional expenditure on equipment or modifying operation processes. This is in recognition of the fact that rescheduling energy consuming activities which afford flexibility to occur during off-peak hours can lead to direct savings through alignment with the TOD tariff incentive time-Table. As presented earlier, the TOD tariff structure incentivizes energy consumption during the off-peak hours of 10 pm to 6 am. The analysis of possible energy cost conservation opportunities is presented below.

Table 14 TOD Losses / Gain Summary

TOD Details	TOD A (kWh) 6 - 18 Hrs	TOD B (kWh) 18 – 22 Hrs	TOD C (kWh) 22 – 6 Hrs
Incentive / Disincentive (INR/ kWh)	0	1	-1.25
Unit Consumption (kWh)	27,22,166	10,02,730	20,38,288
Loss / Gain during the Period (INR)	0	10,02,730 (Loss)	-25,47,860 (Gain)

The above analysis indicates that the Client currently suffers an increased energy cost of INR 10.02 Lakh approximately annually due to energy consumption during peak periods of 6 pm to 10 pm. Conversely, the Plant benefits in the range of approximately INR 25.5 Lakh by consuming close to 20 Lakh kWh out of the annual consumption of 57 Lakh kWh during the 'incentive period' of 10 pm to 6 am. While it might not be possible to shift many of the operations (especially HVAC and lighting operations) to off-peak hours, it would be beneficial to identify all non-essential activities that can be re-scheduled to take advantage of TOD tariff incentives. A simple indicative analysis indicates that transferring even 30% of the peak-period demand (from 6 pm to 10 pm) to the 10 pm to 6 am period would save INR 16, 97,655 annually[2].

4.1.8.2 Increase Contract Demand

The current contract demand of the Plant is 700 kVA/month while the maximum demand recorded is 1418 kVA in June 2014 and minimum demand recorded 964 kVA in Jan 2014. Average recorded demand per month is 1188.30 kVA. Table 15 presents a summary of the recorded Maximum Monthly Demand across a full annual cycle; other details pertaining to monthly energy consumption, power drawn etc. are presented in Appendix I.

Table 16 shows the penalty paid per month due to excess demand.

Table 15 Monthly Maximum & Excess Demand

Month	Tariff	Contract Demand [kVA]	Max. Demand Recorded [kVA]	80% of Contract Demand [kVA]	Billed Demand [kVA]	Recorded PF
Nov-13	HT-2a	700	1045	560	1045	0.92
Dec-13	HT-2a	700	1040	560	1040	0.90
Jan-14	HT-2a	700	964	560	964	0.93
Feb-14	HT-2a	700	1186	560	1186	0.91
Mar-14	HT-2a	700	1214	560	1214	0.88
Apr-14	HT-2a	700	1143	560	1143	0.92
May-14	HT-2a	700	1176	560	1176	0.91
Jun-14	HT-2a	700	1418	560	1418	0.90
Jul-14	HT-2a	700	1367	560	1367	0.87
Aug-14	HT-2a	700	1240	560	1240	0.91
Sep-14	HT-2a	700	1272	560	1272	0.93

[2] INR 16.97 Lakh/year was calculated by summation of the financial benefit of shifting of 30% of the TOD A energy consumption to the TOD C (benefiting at the rate of 1.25 INR/kWh) and similarly shifting 30% of the TOD B energy consumption (benefiting at the rate of 2.25 INR/kWh) to the TOD C tariff period.

Oct-14	HT-2a	700	1273	560	1273	0.92

Table 16 Penalty due to Excess Demand

Month	Max. Demand (kVA)	Excess Demand (kVA)	Excess Demand Charges
Oct-14	1273	573	1,94,820
Sep-14	1272	572	1,94,480
Aug-14	1240	540	1,83,600
Jul-14	1367	667	2,26,780
Jun-14	1418	718	2,44,120
May-14	1176	476	1,61,840
Apr-14	1143	443	1,50,620
Mar-14	1214	514	1,74,760
Feb-14	1186	486	1,65,240
Jan-14	964	264	89,760
Dec-13	1040	340	1,15,600
Nov-13	1045	345	1,17,300
Total			20,18,920

Above result shows that over a 12 month period 20,18,920 INR paid as a penalty due to excess demand. These charges can be eliminated by increasing contract demand from 700 kVA to 1250 kVA. By increasing contract demand to 1250 KVA, the Plant can save approximately INR 8.27 Lakh per year.

4.1.8.3 Power Factor Improvement

Table 17 shows the measured power factor at the sub-feeders. By installation of a 470 kVAr capacitor bank, the PF improves to 1, that reduces demand by 117 kVA/month, which saves upto 1.97 lakhs per year with a pay-back period of 1.3 years.

Table 17 Savings through PF Improvement by Installation of Capacitor

Block Ref.	Avg. KW (calculated)	Measured Power Factor	Measured (kVA)	Improved Power Factor	KVAr Required	Revised kVA	Diff. In (kVA)	Saving (INR/Year)	Capacitor (KVAr)	Capacitor Cost (INR)
Block 4 & 5	290.9	0.98	296.9	1.0	59.1	290.9	5.9	12,113	60	25,200
Block 6	188.8	0.76	248.4	1.0	161.5	188.8	59.6	1,21,635	170	71,400
Block 1	161.3	0.91	177.2	1.0	73.5	161.3	15.9	32,537	80	33,600
Warehouse	151.3	0.87	173.9	1.0	85.7	151.3	22.6	46,106	90	37,800
Block 2	53.7	0.86	62.4	1.0	31.8	53.7	8.7	17,822	40	16,800

Boiler Section	21.0	0.84	25.0	1.0	13.5	21.0	4.0	8,144	20	8,400
Block 3	11.4	0.94	12.1	1.0	4.1	11.4	0.7	1,482	10	4,200
							Total	2,39,839		1,97,400

Summary Energy Conservation Opportunities – Utilities

- **Load Curve Management**: By tansferring 30% of the peak-period demand (from 6 pm to 10 pm) to the 10 pm to 6 am period would save the Plant INR 16,97,655 annually.
- **Increase Contract Demand from 700 kVA to 1250 kVA:** By increasing contract demand to 1250 KVA, the Plant can save approximately INR 8.27 lakh annually.
- **Power Factor Improvement:** By installation of 470 kVAr capacitor bank, the PF can be improved to 1 which saves approximately INR 1.97 lakh per year with a payback period of 1.3 years.

4.2 Compressed Air System

4.2.1 Compressed Air System (Block 06) Assessment

There are two compressors with rating and specifications as mentioned below, located in Process Block No. 6 and No. 1. One of the two air compressors is in operation and the other is standby or taken in use only during high instantaneous demand. As the air compressor in Block 1 was on standby during the first site visit, this was not covered during the audit owing mainly to constraint of repeatedly stopping the compressed air used by plant process. Compressed Air System efficiency and performance was assessed through the Free Air Delivery and Leakage Test (Pump-Up Method) process as prescribed by the BEE Energy Audit Manual. The technical specifications, equipment nameplate (rating) details, as well as measured values of compressor performance are presented in Table 18 and Table 19 respectively. The Fluke Power Analyzer was used to record power and time taken loading and unload cycles to fill the compressor receiver with downstream air usage by all equipment across the plant stopped.

Table 18 Air Compressor Block 06 Rated Data

Location	Air Compressor ID	Make	Model	Max. Press. (Kg/cm²)	Rated Free Air Delivery (m³/min)	Power (KW)	Air Receiver Tank Capacity (Rated,m3)
Block 6	DACP05	Atlas Copco	GX11FF	7.25	1.61	11	1.0

Table 19 Air Compressor Block - 06 Measured Data

Initial Pressure P1 (Gauge, kg/cm2)	Final Pressure after Filling P2 (Gauge, kg/cm2)	Min. Pressure (Abs., kg/cm2)	Atm. Pressure P0 (kg/cm2)	Pump up time (min)	Power (KW)	Load Time (Min)	Unload Time (Min)	Compressor Working Hrs. (hrs/day)
1.03	7.25	5,75	1.03	5.2	12.9	1.63	0.33	24

Based on the rated and measured data, the Isothermal Efficiency of the system as well as Free Air Delivery and Leakage rate was calculated using the equations presented below and the results are shown in Table 20 and Table 22.

$$Isothermal\ Power\ (kW) = \frac{P_1 \times Q_f \times \ln r}{36.7}$$

Where,
P_1 = Absolute Intake Pressure (kg/cm^2),
Q_f = Free Air Delivered (m^3/hr), and
r = Pressure Ratio (P_1/P_2)

$$Free\ Air\ Delivery\ \left(Q_f, \frac{Nm^3}{min}\right) = \frac{P_2 - P_1}{P_0} \times \frac{V}{T}$$

Where,
P_2 = Final Pressure after Filling (absolute, kg/cm^2),
P_1 = Initial Pressure after Bleeding (absolute, kg/cm^2),
P_0 = Atmospheric Pressure (absolute, kg/cm^2),
V = Storage Volume of Receiver, After Cooler, and Piping (m^3), and
T = Time taken to reach Pressure P_2 (mins)

$$Leakage\ Qty.\left(\frac{Nm^3}{min}\right) = \frac{T}{T+t} \times Q$$

Where,
T = Time on-load (mins.),
t = Time un-load (mins.), and
Q = Free Air Delivered (m^3/min)

Table 20 Block 06 Air Compressor FAD Result

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Storage Volume (m³)	Atm. Pressure P0 (kg/cm2)	Pump up time (min)	Free Air Delivery (m³/min)	Free Air Delivery (m³/hr)
1.03	7.25	1	1.03	5.2	1.16	69.67

Table 21 Block 06 Air Compressor Isothermal Efficiency Result

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Pressure Ratio (P2/P1)	Power (KW)	Free Air Delivery (m³/hr)	Iso-thermal Power (KW)	Iso-thermal efficiency (%)
1.03	7.25	7.04	12.9	69.68	3.81	29.58%

Table 22 Block 06 Atlas Air Compressor Leakage Test Summary

Load Time (min)	Unload (min)	Free Air Delivery (m³/min)	Leakage (m³/min)	Leakage Qty. (m³/day)	Spec. Power for Comp. Air (kWh/m³)	Energy Loss due to Leakage (kWh/day)
1.63	0.33	1.16	0.966	1390.7	0.185	257.5

The above results indicate a staggeringly high leakage rate; 0.96 m3/min vs. a Free Air Delivery (FAD) of 1.16 m3/min which equates to a leakage percentage of approximately 83%. This high leakage rate has significant cost and environmental implications; the daily energy lost is calculated to be 258 kWh which translates to 1,489 INR/day or an annual loss of INR 5,43,361. It must also be noted that this leakage rate would be even higher if the test was performed in the manner ideally recommended by the Energy Audit Process. The prescribed method requires the complete opening of the downstream valve (on the line leaving the receiver towards the process equipment) while measuring the loading and unloading times. While conducting the test it was noted that even with the equipment shut off, the compressor was loaded at almost all times – i.e. the load time was much greater than the unload time; thereby adding a high uncertainty to the time measurement. This condition was precipitated due to the excessive system leakage which prevented the compressor from generating set pressure of 7.5 kg/ cm^2 with valve full open. Hence to alleviate this condition, and make accurate measurement of the unload time possible, the downstream valve was throttled to allow the test to yield reliable measurement. This is depicted in Figure 13 below. Un-throttling of the valve would perhaps lead to an even higher leakage rate emerging from the test.

Figure 13 Throttled Valve at Air Receiver Outlet

Another key performance parameter for Compressed Air Systems is the measured FAD versus the rated FAD. The measured FAD of 1.16 m3/min is 28% lesser than rated FAD of 1.61 m3/min. This lower than rated FAD results in a higher specific consumption than would be the case with optimally functioning equipment. It must however be noted that the lower than rated FAD could partially be attributed to the following unavoidable condition of partial throttling of the valve downstream from the Receiver Tank. The leakage test was a precursor to the investigative process of diagnosing the cause of the high leakage rate and identifying the primary leakage 'hotspots' contributing to the observed phenomenon of 83% leakage.

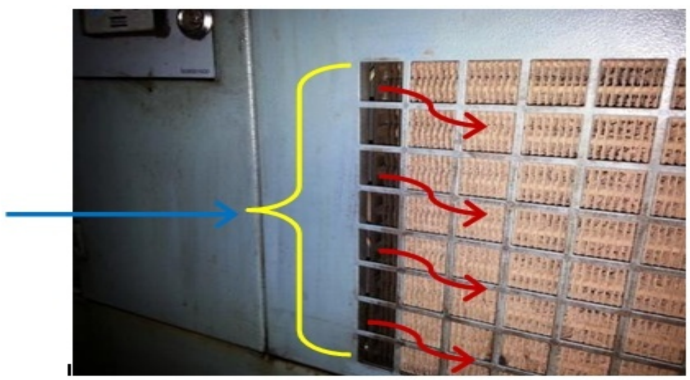
The figures below present the outcome of this investigative process. have been occurring downstream.

Figure 14 indicates a major source of leakage right at the Receiver Tank. The semicircular area was identified as the primary air leakage spot in addition to other equipment-side leakages that might have been occurring downstream.

Figure 14 Air Leakage Image from Receiver Tank

Another source of reduced system efficiency was the higher than expected inlet air temperatures which adversely impact compressor operation. It is generally accepted that a 4^0C rise in inlet temperature increases energy consumption by 1% to achieve the same an equivalent output[3]. Figure 15 indicates the source of this observed deficiency; the arrows indicate the path available for hot air to enter the compressor suction area thereby leading to a rise in the intake rise.

Figure 15 Compressor Suction Side Leakage



4.2.2 Air Compressor Block 01 Assessment (During Second Site Visit)

The air compressor (with rating and specifications as mentioned below) was located in Process Block 01. The Block 01 air compressor was on standby during the first site visit. This was not covered during the audit owing mainly due to the constraint of repeatedly stopping the compressed air used by the plant process. But during the second site visit, Block 06 air compressor was in maintenance. So the Block 01 air compressor was assessed during the second site visit. The Compressed Air System efficiency and performance was assessed through the Free Air Delivery and Leakage Test (Pump-Up Method) process as prescribed by the BEE Energy Audit Manual. The technical specifications, equipment nameplate (rating) details, as well as measured values of compressor performance are presented in Table 23 and

[3] Guidebook for National Certification Examination for Energy Managers and Energy Auditors, Bureau of Energy, Energy Efficiency in Electrical Utilities, Chapter 3.3 Compressed Air System, Table 3.3.

Table 24 respectively. The Fluke Power Analyzer was used to record power and the time taken for loading and unloading cycles.

Table 23 Air Compressor Rated Data

Location	Air Compressor ID	Make	Model	Max. Press. (Kg/cm²)	Rated CFM	Storage Volume (m³)	Power (KW)
Block 01 Air Compressor	DCAP01	Ingersoll Rand	7*5 ESV-1	9	100	0.5	22

Table 24 Air Compressor Measured Data

Initial Pressure P1 Abs (kg/cm2)	Final Pressure after Filling P2 Abs (kg/cm2)	Atm. Pressure P0 Abs (kg/cm2)	Pump up time (min)	Power (KW)	Load Time (Min)	Unload Time (Min)	Compressor Working Hours (hr/day)
1.03	9.00	1.03	1.47	17.63	0.25	0.75	24.00

Table 25 Air Compressor FAD Test Summary

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Storage Volume (m³)	Atm. Pressure P0 (kg/cm2)	Pump up time (min)	Free Air Delivery (m³/min)	Free Air Delivery (m³/hr)	Free Air Delivery (CFM)
1.03	9	0.5	1.03	1.47	2.64	158.27	93.16

Table 26 Air compressor Iso-thermal Efficiency Summary

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Pressure Ratio (P2/P1)	Power (KW)	Free Air Delivery (m³/hr)	Iso-thermal Power (KW)	Iso-thermal efficiency (%)
1.03	9	8.74	17.63	158.27	9.63	54.62%

Table 27 Block -01 Air compressor Leakage Test Summary

Load Time (min)	Unload (min)	Free Air Delivery (m³/min)	Leakage (m³/min)	Leakage Qty. (m³/day)	Spec. Power for Comp. Air (kWh/m³)	Energy Loss due to Leakage (kWh/day)
0.25	0.75	2.64	0.66	949.65	0.11	105.78

The above results indicate a staggeringly high leakage rate; 0.66 m3/min vs. a Free Air Delivery (FAD) of 2.64 m3/min which equates to a leakage percentage of approximately 25%. This high leakage rate has significant cost and environmental implications; the daily energy lost is calculated to be 105.78 kWh which translates to 610 INR/day or an annual loss of INR 2,22,807.

4.2.3 Nitrogen Compressor System (Block 06) Assessment

The Block 06 nitrogen air compressor system has been assessed twice because the solvent tank valve was open during the first site visit.

Trial 1 (During first site visit): Nitrogen compressors are used for reactions in the process blocks and purging the vessels in process blocks as well as solvent storage area. The existing compressors use Adsorbent Pressure Swing Technology that is known to be an efficient technology. Technical specifications, 'Nameplate' details (rated performance), and measured values of the Nitrogen Compressor are presented in Table 288 and Table 299 respectively. A Power Analyzer was used to record power and the loading and unloading time to fill the compressor receiver while air used by all equipment across the plant was stopped as outlined earlier in the report. To conduct this test in accordance with the prescribed method necessitated isolation of the system from all influxes which could distort the mass balance essential for estimating system performance. This would have required interruption of Nitrogen purging function in the solvent tank. The associated operational safety issues prevented this from occurring. The other alternative available to isolate the impact of this flux on measurements was to subtract the flowrate of the Nitrogen purging from the mass balance. However, this data too was not measurable by the company's operations team, the reasons for which are perfectly justifiable. In what was observed to be a broadly applicable feature across many critical pieces of equipment designed during earlier years, where energy efficient performance of equipment and its measurement wasn't a defining aspect of plant design, finding suitable locations of measure flow, pressure , temperature and other performance variables was sometimes impossible to find. This was the case with the Nitrogen purging equipment as well; the existing system was not designed in accordance with the specific needs of performance measurement during operation. This general critique of system design in not a indictment of the operation team. Instead, it is underscored here as an opportunity to integrate these progressive design principles into the blueprint for future plant designs to be undertaken by the company.

Table 28 Nitrogen Compressor Rated Data

Location	Air Compressor ID	Make	Model	Max. Press. (Kg/cm²)	Rated Free Air Delivery (m³/min)	Power (KW)	Air Receiver Tank Capacity (m3)
Block 6	Nitrogen Plant Comp.	Ingersoll Rand	ESV-1NL2	8.9	4.24	30	0.5

Table 29 Nitrogen Compressor - Measured Data

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Atm. Pressure P0 (kg/cm2)	Pump up time (min)	Power (KW)	Load Time (Min)	Unload Time (Min)	Compressor Working Hours (hrs/day)
1.03	4.8	1.03	5	26.5	3.05	0.5	24

Based on the rated and measured data, the Free Air Delivery and leakage rate was calculated and the results are shown in Table 30.

Table 30 Nitrogen Compressor FAD Test Result

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Storage Volume (m³)	Atm. Pressure P0 (kg/cm2)	Pump up time (min)	Free Air Delivery (m³/min)	Free Air Delivery (m³/hr)
1.03	4.8	0.5	1.03	5	0.475	28.52

Table 31 Nitrogen Compressor Isothermal Efficiency Result

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Pressure Ratio (P2/P1)	Power (KW)	Free Air Delivery (m³/hr)	Iso-thermal Power (KW)	Iso-thermal efficiency (%)
1.03	4.8	4.66	26.5	28.52	1.2319	4.65%

Table 32 Nitrogen Compressor Result Summary

Load Time (min)	Unload Time (min)	Free Air Delivery (m³/min)	Leakage (m³/min)	Leakage Qty. (m³/day)	Spec. Power for Comp. Air (KWh/m³)	Energy Lost due to Leakage/Day (KWh)
3.05	0.5	0.475	0.386	556.2	0.929	516.8

The above results indicate an excessively high leakage rate; 0.386 m3/min vs. a Free Air Delivery (FAD) of 0.475 m3/min which equates to a leakage percentage of approximately 81.5%. This high leakage rate has significant cost and environmental considerations; the daily energy lost is calculated to be 517 kWh which translates to 2,950 INR/day or an annual loss of INR 10,88,3013.

The assessment also indicated a perplexingly high discrepancy between the rated FAD and the measured FAD; measured FAD was seen to be 88.8 % less than the rated FAD in this case. It is possible that the pronounced discrepancy was an outcome of the discharge valve not being closed completely which would inordinately increase the time required to build up a given magnitude of pressure from an initial pressure at the start of a FAD test. This could lead to an exceedingly low FAD value being calculated. It is noteworthy that during the leakage test, Nitrogen purging persisted in the solvent storage area. This skewing influence leads to the interpretation that the leakage quantity calculated does not accurately represent the true leakage. Since even the average quantity of purging in the solvent storage area is not known and was certainly not measurable, perfect estimation of the true leakage quantity was implausible. Nonetheless, the general conclusion that can be drawn is that the leakage quantity is severe and needs immediate redressal.

Trial 2 (During the second site visit): Nitrogen air compressor FAD test and leakage test was carried out in three stages. In the 1st stage, pump up time of the air receiver tank was measured. In the 2nd stage the pump up time of the Nitrogen tank was measured and in the 3rd stage a leakage test was carried out. The detailed procedure of the trial is mentioned below.

Stage 1: In the first stage, the FAD test and leakage test was conducted up-to the compressor air receiver tank. During this test, the air compressor system was isolated up to the compressor air receiver tank. The rated and measured data of the air compressor has been mentioned below:

Table 33 Nitrogen Compressor Rated Details

Location	Make	Model	Max. Press. (Kg/cm²)	Rated CFM	Storage Volume of Air Compressor Tank (m³)	Power (KW)
Block 06 Nitrogen Air Compressor	Ingersoll Rand	8*7 ESVH BA	9	147	0.25	30

Table 34 Block 06 Nitrogen Compressor Measured Data (Air Receiver Tank)

Initial Pressure P1 Abs (kg/cm2)	Final Pressure after Filling P2 Abs (kg/cm2)	Atm. Pressure P0 Abs (kg/cm2)	Pump up time (min)	Power (KW)	Load Time (Min)	Unload Time (Min)	Compressor Working Hours (hr/day)
1.03	9.00	1.03	0.50	16.48	0.23	0.50	24.00

Based on the rated and measured data, the Free Air Delivery and leakage rate was calculated and the results are shown in Table 30 and Table 35

Table 35 Nitrogen Compressor FAD Test Summary (Air Receiver Tank)

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Storage Volume (m³)	Atm. Pressure P0 (kg/cm2)	Pump up time (min)	Free Air Delivery (m³/min)	Free Air Delivery (m³/hr)	Free Air Delivery (CFM)
1.03	9.0	0.25	1.03	0.5	3.87	232.14	136.63

Table 36 Nitrogen Compressor Iso- thermal Efficiency Summary (Air Receiver Tank)

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling P2 (kg/cm2)	Pressure Ratio (P2/P1)	Power (KW)	Free Air Delivery (m³/hr)	Iso-thermal Power (KW)	Iso-thermal efficiency (%)
1.03	9	8.74	16.48	232.14	14.12	85.69%

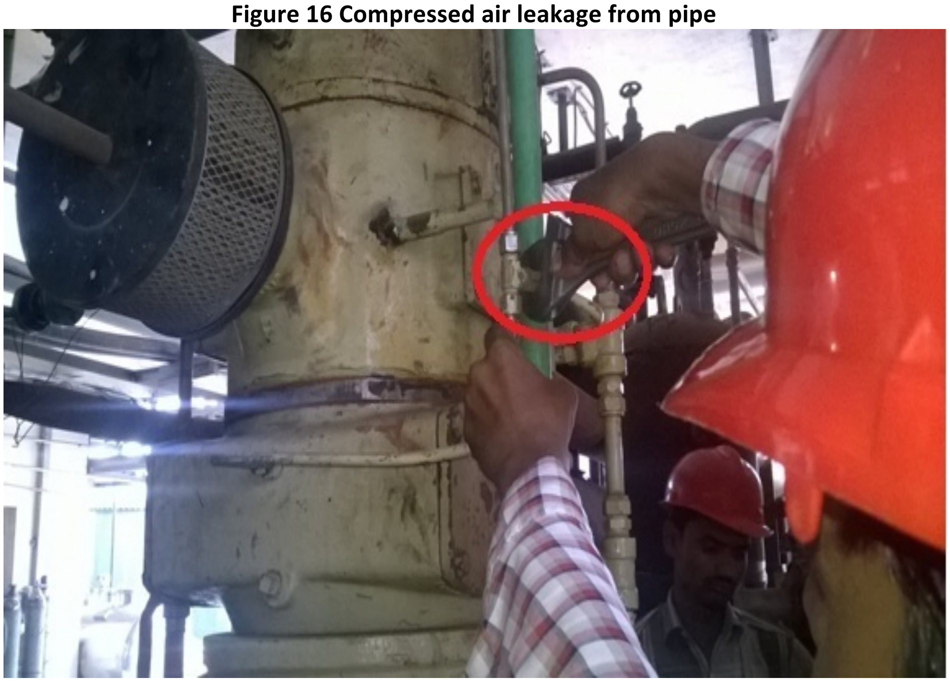
Table 37 Nitrogen Compressor Leakage test Summary (Air Receiver tank)

Load Time (min)	Unload Time (min)	Free Air Delivery (m³/min)	Leakage (m³/min)	Leakage Qty. (m³/day)	Spec. Power for Comp. Air (KWh/m³)	Energy Lost due to Leakage/Day (KWh)
0.23	0.5	3.87	1.22	1755.33	0.07	124.62

The above results indicate an excessively high leakage rate; 1.22 m3/min vs. a Free Air Delivery (FAD) of 3.87 m3/min which equates to a leakage percentage of approximately 31.5%. This high leakage rate has significant cost and environmental considerations; the daily energy lost is calculated to be 124.62 kWh which translates to 719 INR/day or an annual loss of INR 2,62,481. The leakage test was a precursor to the investigative process of diagnosing the cause of the high leakage rate and identifying the primary leakage 'hotspots' contributing to the observed phenomenon of 31.5% leakage.

The figures below present the outcome of this investigative process. Figure 16 indicates a major source of leakage right at the compressor. When air receiver tank pressure reaches compressor cut-off pressure, at that time the compressed air starts leaking from the small tee joint, until the receiver tank pressure goes down to the compressor cut-in pressure. This was identified as the primary air leakage spot in addition to other equipment-side leakages that might have been occurring downstream.

Figure 16 Compressed air leakage from pipe



Stage 2: In the second stage, the FAD test was conducted up to the nitrogen tank. The pump up time of nitrogen tank was measured. The outlet valve of the Nitrogen tank was closed during the pump up time measurement. The rated and measured data of the Nitrogen air compressor has been mentioned below:

Table 38 Nitrogen Air Compressor Rated Data

Location	Make	Model	Max. Press of Nitrogen tank. (Kg/cm² a)	Storage Volume of Nitrogen Tank (m³)	Power (KW)
Block 06 Nitrogen Air	Ingersoll	8*7 ESVH BA	6	5	30

Compressor	Rand				

Table 39 Block 06 Nitrogen Compressor Measured Data

Initial Pressure P1 Abs (kg/cm2)	Final Pressure after Filling P2 Abs (kg/cm2)	Atm. Pressure P0 Abs (kg/cm2)	Pump up time (min)	Power (KW)	Load Time (Min)	Unload Time (Min)	Compressor Working Hours (hr/day)
1.03	5.8	1.03	34.96	25.07	12	5.6	24.00

Table 40 Nitrogen Compressor FAD Summary

Initial Pressure P1 (kg/cm2)	Final Pressure after Filling Nitrogen Tank P2 (kg/cm2)	Storage Volume (m³)	Atm. Pressure P0 (kg/cm2)	Pump up time (min)	Free Air Delivery (m³/min)	Free Air Delivery (m³/hr)	Free Air Delivery (CFM)
1.03	5.80	5	1.03	34.96	0.86	51.61	30.38

Stage 3: In the third stage, a leakage test was conducted from the nitrogen tank to the end-users' point. While doing the leakage test the compressor was in the 'turn-off' condition. The pressure reduction time from the nitrogen tank was measured. The measured time has been mentioned below:

Table 41 Measured Unload time for Pressure Drop in Nitrogen Tank

Pressure Drop (kg/cm2 g)	Pressure Diff (kg/cm2)	Unload time (min)
4.8 – 4.5	0.3	5.6
4.5 – 4.2	0.3	5.3
4.2 – 4.0	0.2	2.7

Based on the above unloading time, the leakage test calculation has been done and presented in the table below:

Table 42 Block 06 Nitrogen Compressor Leakage test Summary

Load Time (min)	Unload Time (min)	Free Air Delivery (m³/min)	Leakage (m³/min)	Leakage Qty. (m³/day)	Spec. Power for Comp. Air (KWh/m³)	Energy Lost due to Leakage/Day (KWh)
12	5.6	0.86	0.59	844.54	0.49	410.10

The above results indicate an excessively high leakage rate; 0.59 m3/min vs. a Free Air Delivery (FAD) of 0.86 m3/min which equates to a leakage percentage of approximately 68%. This high leakage rate has significant cost and environmental considerations; the daily energy lost is calculated to be 410.1 kWh which translates to 2367 INR/day or an annual loss of INR 8,64,089.

4.2.4 Energy Conservation Opportunity in Compressor System

4.2.4.1 Lowering the Set Pressure

Based on the meticulous feedback solicited from field personnel operating the compressed air system, it was gleaned that none of the usage locations connected to the compressed air system across all Blocks need compressed air at a pressure greater than 4.5 kg/cm^2. The typical pressure drops for a 60 CFM compressor are presented in Table 4343. With an adequate size of compressed air piping according to recommended standards (approximately 65 mm to 70 mm bore), pressure drop in the header is expected to be approximately 0.3 kg/cm^2 and at the farthest point in distribution would be approximately 0.5 kg/cm^2. However, in the absence of a line layout of compressed air system, an educated guess related to the possible pipe bore diameter was required. A conservative approach was adopted (i.e. choosing a diameter that would lead to a pressure drop tending towards the higher side of the range; around 50 mm to 55 mm) and the estimated final pressure drop at farthest point was estimated to be between 1.5 to 1.8 Kg /cm^2 for an approximated farthest point within 500 meters. The pressure at the generation point i.e. compressor in the Block 06 case is 7.25 Kg/cm^2. Leading to a final pressure at the farthest point of (7.25 – 1.6) = 5.65 kg /cm^2. This indicates scope for lowering set pressure at compressor level. Another significant site observation was that the valve on the main header after the compressor was throttled. If the system set pressure is reduced by 1 kg/cm^2 to 6.25 Kg/cm^2 at the generation end, the expected farthest end pressure would be 6.25 – 1.6 = 4.65 Kg/cm^2. Similarly the Block 01 air compressor set pressure can also be reduced by 1 kg/cm2.

Table 43 Rated Pressure Drop for 60 CFM Compressor

Pipe Bore (mm)	Pressure drop (kg/cm2)/100 mtr.	Power Loss (KW)
40	1.08	5.7
50	0.40	2.0
65	0.13	0.72
80	0.024	0.10

The consequent annual energy and cost savings for Block 01 and Block 06 air compressor are presented in the Table 4444 below and indicate a potential for saving approximately 16,986 kWh/year and an associated cost reduction of approximately INR 97,416 per year through this relatively simple operational modification.

Table 44 Savings Summary by Reducing Delivery Pressure

Revised Delivery Pressure (kg/cm2)	Revised Press. Ratio	Revised Iso-thermal Power (kW)	Power Reduction (%)	Power Reduction (kW)	Energy Saving (kWh/year)	Energy Cost Saving (INR/year)
6.25	6.07	3.53	7.61%	0.98	8,594.7	48,989.76
8	7.4	9.1	5.43 %	0.96	8391.6	48425.9

The above recommendation should be implemented in conjunction with the following modifications:

- The leakage at the compressor is arrested and the valve is kept full open.
- Leakage within the compressor, which results in short cycling of air, is arrested. This precipitates a condition where part of the compressed air at higher temperature finds a local path back to the suction circuit, resulting in further deterioration in compressor performance as the recycled air is at a higher temperature, leading to a compromised performance owing to the detrimental impact of inlet air temperature on specific energy consumption as stressed earlier.

4.2.4.2 Dedicated Compressors for Process Blocks

All Process Blocks were observed to have compressed air needs that are transient and vary ostensibly as a function of the processes underway within the plant. Small capacity compressors for individual blocks (with delivery pressure of 4.5 to 5 Kg/cm^2) with the existing compressor persisting as a backup for emergency (should any individual block compressor fail) can result in noteworthy energy savings by virtue of the following:

- reduced pressure drop due to a lesser pipe length
- specific Process Blocks not in need of compressed air for certain periods can switch off; reducing power demand thereby
- smaller rating compressors with ON – OFF control can save power during unload by completely switching OFF

4.2.4.3 Justified Use of Compressed Air

Compressed air is a costly commodity as is evident from results of Leakage Test and FAD Test. The exhaustive site audit performed has yielded vital observations related to potential for more prudent use of this valuable resource. It has been observed compressed air is routinely employed for cleaning of AHUs filters and AHUs grills. An immediate low-hanging fruit opportunity available to the operational team for energy reduction is to explore the possibility of using other equivalent equipment in clean room areas for air washing and any other such areas so that such points may be cut off from compressed air line. These could be served by dedicated blowers instead which require much less energy to perform an identical function.

Summary Energy Conservation Opportunities – Compressed Air Systems

- **Lowering the Set Pressure of Air Compressor (Block 6):** Reducing delivery pressure by 1kg/cm² results in 8,595 kWh/year energy savings and an associated cost reduction of approximately INR 48,990 per year.
- **Lowering the Set Pressure of Air Compressor (Block 01):** Reducing delivery pressure by 1kg/cm² results in 8391.6kWh/year energy savings and an associated cost reduction of approximately INR 48,425.9 per year.
- **Maintenance of Air Compressor (Block 6): By proper main**tenance of air compressor, saving of 258 kW/day can be achieved, and associated cost reduction of 5,43,361 INR per year

- **Maintenance of Nitrogen Compressor (Block 6): By proper maintenance o**f the nitrogen compressor, savings of 517 kW/day can be achieved, and associated cost reduction of 10,88,301 INR per year.
- **Dedicated compressors for Process Blocks**: Small capacity compressors for individual blocks (with delivery pressure of 4.5 to 5 Kg/cm^2) with the existing compressor persisting as a backup for emergency (should any individual block compressor fail) can result in noteworthy energy savings.
- **Justify the use of Compressed Air:** Use blowers to clean the rooms and AHUs grills rather than compressed air.

4.3 Thermo-pack System

During the site visit, the Thermo-pack system was not operational as there was no operational need for it. The following data was collected post the site visit from client.

Table 45 Thermo-pack Details

Make	Model	Capacity (kCal/hr)	T F Flow Rate (m^3/hr)	HSD Consumption (kg/hr)	NG Consumption (Nm^3/hr)	LPG Consumption (Nm^3/hr)
Thermax Ltd	TPCM - 02/269	200000	14	23	28	9

Table 46 Burner Specifications

DTP 01 System	**DTP 02 System**
Annual working hours for Thermo-pack ---- ***2078Hrs (year 2014)***	Annual working hours for Thermo-pack ---- *350 Hours (2014)*
Burner Specifications **Make : Eco-flam** **Sr. No: 870818/04** **Fuel oil: Gas oil, max. Viscosity at 20°C; 20 MM²/S (2.9°E)** **Max.: 18PLDHT(L+S)L=350mm** **KW Min.: 107 Max. : 213** **Kg/hr/Min: 9 Max. : 18** **1.5°E, 20°C, IP – 40** **220 VAC, 50HZ**	Burner Specifications Make : Riello Model : G 24 I/AD, Type: 08062 D Fuel oil : Gas oil, max. viscosity at 20°C ; 20 MM²/S (2.9°E) Thermal power : 142 / 272 kW/ 122.000/ 234.00 kcal/h Output : 12/ 23 kg/h Electrical supply : Single phase 220V + 10% - 15% ~ 50Hz Motor : 1.85 A / 220 V Capacitor : 8µF / 450V Ignition transformer : Primary 30VA 220-240V 50/60 Hz – sec. 18Ma / 2 x10KV Absorbed electrical power : 0.4kW Weight : 24 kg, Electrical protection : IP 40

The existing Thermic Fluid Heating system was seen to perform satisfactorily at a 81% burner efficiency which was arrived at by accounting for the standard calorific values of the fossil fuels used and their reported hourly usage rates versus rated output capacity of 200,000 kcal/hr. Since the energy efficiency of the existing equipment is relatively acceptable, the only plausible alternative for energy cost reduction was considered to be a system using a alternative burner system (the ECOFLAM 20.1 system) using a cheaper fuel, Fuel Oil, as compared to the existing Diesel Fuel, Natural Gas and LPG Fuel based system.

Table 47 Saving Calculation by Using ECOFLAM20.1

Diesel Calorific Value (kCal/kg)	Furnace Oil Calorific Value (kCal/kg)	Burner Eff. (%)	ECO Flam Fuel Oil Burner 20.1 Eff. (%)	HSD Cons. (kg/hr)	Operating Cost of DTP-01 (INR/year)	Operating Cost of Furnace Fuel (INR/Year)	Annual Savings (INR/year)
10800	10500	81%	75%	25.4	35,16,700	24,71,111	10,45,589

It is to be noted however, that during extreme winters the Furnace Oil storage system would need heating due to the increased viscosity during these periods. Heating of Furnace Oil can be accomplished using available steam for a temporary period who's additional cost would not be substantial and hence not considered.

Furthermore, Flue Gas that is currently vented from the boiler chimney presents added opportunity for energy savings through installation of a heat recovery system. The anticipated energy savings from such a system installed to compliment the Thermo-Pack will most likely compensate for the steam energy required for heating Furnace Oil during winter periods.

Summary Energy Conservation Opportunities - Thermopack

ECOFLAM 20.1 – Replacing the existing burner system to ECOFLAM20.1 can result in savings of INR 10,45,589 annually. The capital cost of equipment is INR 42,750 which leads to very attractive payback period of 0.04 years

4.4 Lighting System

4.4.1 Lighting System Performance Assessment

The lighting load across the facility is estimated to be 83.3 kW, which represents approximately 7.7 % of the average monthly electrical load of the Plant. Lighting is an essential service required by occupants of indoor and outdoor spaces and is designed to perform and functional and aesthetic role as per specific requirements that are addressed during the lighting system design phase. The intensity levels (lux, lumens per m2) required by occupants vary with application and area of usage. There are recommendations provided by the BEE to evaluate the efficacy of the lighting installed in spaces as a function of use cases. The measured lux values across the Plant are presented in Appendix VI. The measured lux values were compared with the recommended lux values[4] and the resulting comparison for areas with higher than required lux levels is presented in Table 48 below for major indoor areas of the facility. The Table also indicates the potential energy and cost conservation opportunities available through reduction of fixtures in these areas to curb excessive illuminance without hampering the functions to be performed by occupants of these spaces.

[4] EN 12464-1, EUROPEAN STANDARD, Light and lighting - Lighting of work places - Part 1: Indoor workplaces and Guidebook for National Certification Examination for Energy Managers and Energy Auditors, Bureau of Energy , Energy Efficiency in Electrical Utilities, Chapter 3.8 Lighting System, Table 8.2.

Table 48 Lighting System – Excess Illuminance Assessment and Energy Conservation Summary

Scenario	Area Name	Fitting Type	Fixture Nos.	Total Watts (W)	Req. Lux Level	Measured Lux	Energy Saving (kWh/yr)	Cost Saving (INR/yr)
Outdoor Lightings	B1 Wall Mount	HPMV	1	250	20	35	391	2,257
Outdoor Lightings	B1 Terrace	HPMV	1	250	20	27	237	1,365
Outdoor Lightings**	Between B1 & Utility	CFL	12	432	20	48	920	5,308
Outdoor Lightings**	B6 Front Gate Tray	HPMV	2	500	20	40	913	5,266
Outdoor Lightings	B2 Back Side	CFL	4	144	20	24	88	506
Outdoor Lightings	Between B1 & B5	HPMV	1	250	20	36	406	2,340
Outdoor Lightings**	Near Fire pump Area	HPMV	7	1750	20	40	3,194	18,430
Outdoor Lightings	Between B6 & Garden Area	HPMV	1	250	20	28	261	1,505
Outdoor Lightings**	Nitrogen Area	HPMV	4	1000	20	40	1,825	10,532
Outdoor Lightings	Scrap Yard Wall	HPMV	2	500	20	21	87	502
Outdoor Lightings	Between Boiler & ETP	HPMV	4	1000	20	21	174	1,003
Indoor Lighting - Block 01**	Block -1 Main Entrance Ground Flr Passage	CFL	10	260	20	56	1,098	6,337
Indoor Lighting - Block 04	Block-4 Small Room near Elect. Room Ground Flr	PL Lamp	4	144	200	305	326	1,880
Indoor Lighting - Block 04**	Block-4 Entrance Ground Flr	PL Lamp	8	288	100	477.5	1,496	8,632
Indoor Lighting - Block 04**	Block-4 Centrituge Room 2	PL Lamp	8	288	200	404	955	5,514
Indoor Lighting - Block 04	Block-4 1st Floor Passage	PL Lamp	4	144	100	180	420	2,426
Indoor Lighting - Block 05	Prod. Block- 5 1st Flr Preparative HPLC Room	PL Lamp	6	216	200	205.5	38	219
Indoor Lighting - Block 05	Prod. Block- 5 1st Flr Passage Near Column Purification Room	PL Lamp	12	432	200	233.5	407	2,350
Indoor Lighting - Block 06	2nd Flr Control Room	PL Lamp	8	224	200	225	164	944
Indoor Lighting – QC	Quality Control Gr.Floor	PL Lamp	4	144	200	288	289	1,668
Indoor Lighting - Near Boil House	MEE Room	T5 Tube	1	28	200	220	17	97
Indoor Lighting - Near Boil House	Reverse Osmosis Plant	CFL	6	156	200	550	652	3,764
Indoor Lighting – Cafeteria**	Cafeteria 1st Flr	T5 Tube	20	560	150	307.5	1,884	10,875
Indoor Lighting - Ware House**	Ware House – 2 Storage Place	CFL	54	1404	150	338	5,131	29,608
						Total	21,371	1,23,325

Note: Color Code

(red)	Shows the immediate savings of 5000 INR & above annually by reducing Lux level

Lighting technology advancement since the advent of CFL, LED bulbs provide opportunities for significant energy savings through equipment replacement. A listing of high energy efficiency lighting devices and their respective efficiency attributes (lumens/watt) is provided in Table 49 Lamp Efficiency Metrics below.

Table 49 Lamp Efficiency Metrics

Type	Lumen / Watts
PL	60
FTL	25
Bulb	15
CFL	60
Halogen Spot Light	25
LED	75
T5	25
Metal Halide	75
Halogen FL	80
HPMV	50

Extensive field measurements with Lux Meters were carried out throughout the indoor and outdoor spaces of the facility and these measurements and primary analysis is tabulated in Appendix VI. A summary of the lighting fixture types that comprise the lighting load, the respective load, and their consequent energy consumption is presented in the Table 50 below.

Table 50 Fixture-Wise Lighting Load and Energy Consumption Summary

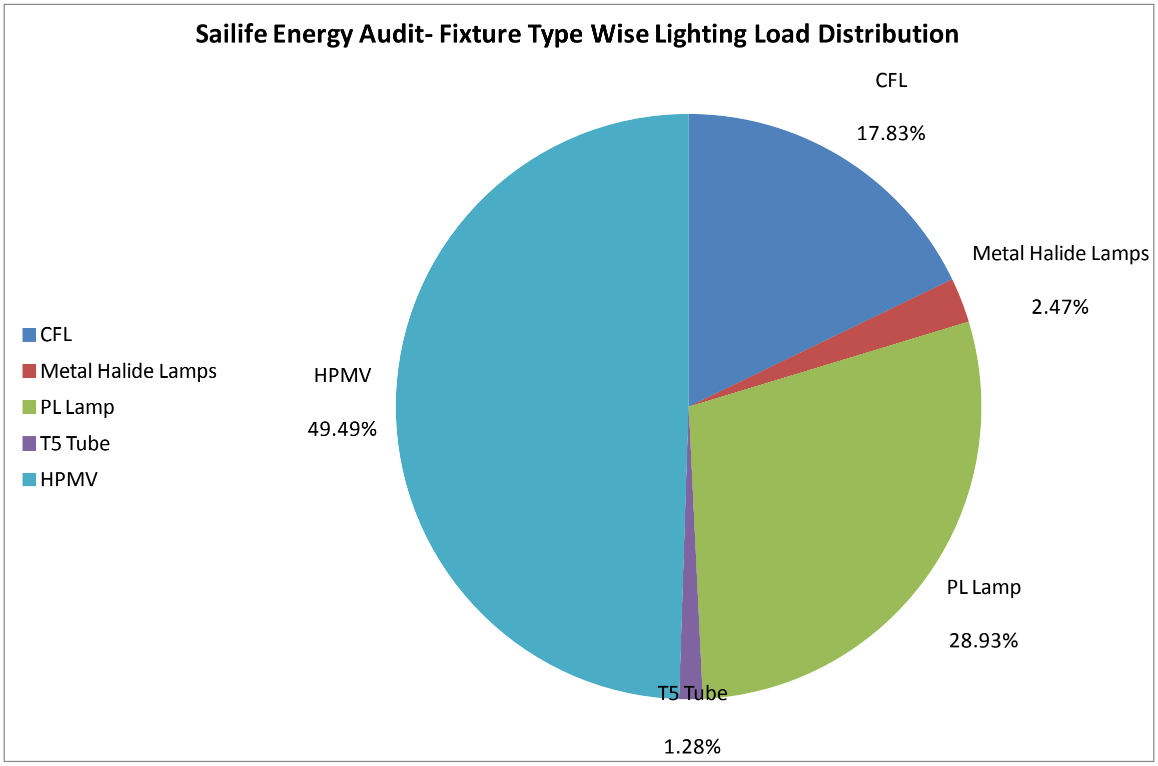
Fixture Type	Application	Qty.	Load (kW)	Energy Consumption (kWh/yr)	Energy Cost (INR/yr)
CFL	Indoor	601	16.1	1,05,455	6,08,554
PL Lamp	Indoor	659	23.4	1,54,027	8,88,850
T5 Tube	Indoor	37	1.0	6,807	39,279
HPMV	Indoor	102	24.9	1,63,265	9,42,157
CFL	Outdoor	17	0.7	2,376	13,712
Metal Halide Lamps	Outdoor	8	2.0	7,300	42,126
HPMV	Outdoor	61	15.3	55,663	3,21,214
Total		1,485	83.3	4,94,892	28,55,892

The assessment indicates that the facility has 1,485 lighting fixtures leading to a annual energy consumption of approximately 4.95 Lakh kWh of electricity and leading to a energy cost of INR 28.6 lakh per year. In terms of annual energy consumption and annual energy cost, this represents approximately 8.6 % of the total kWh/year consumed and energy bill paid by the Plant.

The majority of the load comprises energy intensive High Pressure Mercury Vapor Lamps, followed by the CFL and older PL (Phillips Lighting) Lamps used across the facility.

This distribution of lighting load by fixture type is provided in Figure 17 below.

Figure 17 Lighting Load Fixture Type-wise Distribution



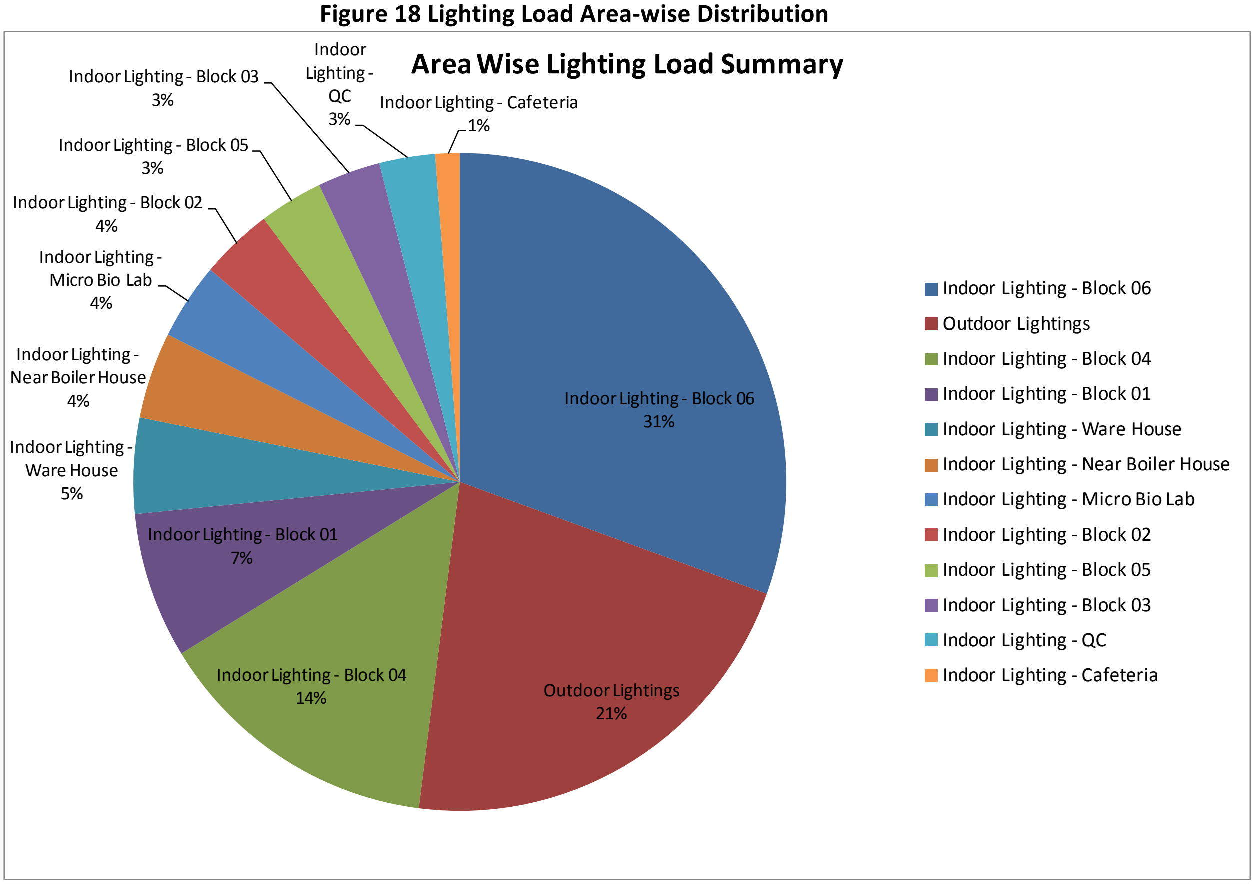
The assessment also allowed for lighting load to be determined per physical area of the facility. This distribution by area is presented below. The analysis indicates that a majority of the lighting load (75% of total load) is generated by the following areas of which the Indoor Lighting in Block 6 comprises a majority of the load (30.5 % of the total facility's load):

- Indoor Lighting - Block 06
- Outdoor Lighting
- Indoor Lighting - Block 04
- Indoor Lighting - Block 01

Table 51 Area-Wise Lighting Load and Energy Consumption Summary

Area Name	Qty.	Load (kW)	Load %	Energy Consumption (kWh/yr)	Energy Cost (INR/yr)
Indoor Lighting - Block 06	212	25.41	30.5%	1,66,970	9,63,540
Outdoor Lightings	86	17.90	21.5%	65,339	3,77,052
Indoor Lighting - Block 04	345	11.88	14.3%	78,071	4,50,529
Indoor Lighting - Block 01	214	5.97	7.2%	39,210	2,26,269
Indoor Lighting - Ware House	124	3.91	4.7%	25,676	1,48,167
Indoor Lighting - Near Boiler House	47	3.53	4.2%	23,192	1,33,836
Indoor Lighting - Micro Bio Lab	88	3.14	3.8%	20,617	1,18,973
Indoor Lighting - Block 02	126	2.99	3.6%	19,671	1,13,514
Indoor Lighting - Block 05	53	2.63	3.2%	17,305	99,865
Indoor Lighting - Block 03	90	2.60	3.1%	17,082	98,576
Indoor Lighting – QC	64	2.30	2.8%	15,137	87,353
Indoor Lighting – Cafeteria	36	1.01	1.2%	6,623	38,217
Total	1,485	83	100%	4,94,891.82	28,55,892.22

Figure 18 Lighting Load Area-wise Distribution



A vital parameter for assessing the effectiveness of Lighting Systems is the Installed Load Efficacy Ratios [ILER]; a ratio of the the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior to a recommended target level. It is a dimensionless quantity comprised of a ratio of two quantities (lux per watt per square meter, lux/W/m²). It is defined by the following mathematical relationships which necessitate the calculation of another dimensionless quantity, the Room Index which quantifies the relative shape of a given room and incorporates the impact of the mounting height of lighting fixtures.

$$ILER = \frac{Actual\ lux/W/m2}{Target\ lux/W/m2}$$

$$Room\ Index\ (RI) = \frac{L \times W}{H_m \times (L + W)}$$

Where,
L = length of the room interior (m),
W = width of the room interior (m), and
H_m = mounting height of the fixture (m)

In the ILER calculation procedure presented above, the 'Target' lux/W/m2 is determined according to the following Table as a function of the Room Index.

Table 52 Target lux/W/m2 as a function of Room Index

Room Index	Commercial Lighting (Offices, Retail Stores etc) Std or good colour rending (Ra: 40-85)	Industrial Lighting (Manufacturing areas, workshops) Std or good colour rending (Ra: 40-85)	Industrial Lighting where Std or good colour rending is not essential (Ra: 20-40)	Avg. Target Lux/w/m²
1.00	33	33	52	42.5
1.25	36	36	55	45.5
1.5	39	39	58	48.5
2	42	42	61	51.5
2.5	44	44	64	54
3	46	46	65	55.5
4	48	48	66	57
5	49	49	67	58

ILER values were calculated for major indoor areas of the facility and are presented in the Table below along with recommended values for ILER[5]. The Table also indicates a priority list of areas that need immediate attention to achieve immediate energy and cost reduction.

[5] Guidebook for National Certification Examination for Energy Managers and Energy Auditors, Bureau of Energy , Energy Performance Assessment For Equipment & Utility Systems, Chapter 4.14, Buildings and Commercial Establishments, Table 14.6

Table 53 ILER Assessment

Area Name	ILER	Assessment
Block -1 Main Entrance Ground Flr Passage	0.02	
Block -1Colum Chromatography Area Gr. Flr	0.07	
Block -1 Passage Ground Flr	0.09	
Block -1 Drying Area 1 G. Flr	0.07	
Block -1 Passage Ground Flr	0.21	
Block -1 Carbon Slurry	0.05	
Block -1 Wash Area	0.06	
Block -1 Blending &Packing Area	0.17	
Block -1 High Distillation Area	0.09	
Block -1 Centrifuge Area	0.21	
Block -1 Day Store Room	0.03	
Block -1 Dusting Area	0.02	
Block -1 Passage	0.40	
Block-2 DSSR Ground Flr	0.11	
Block-2 Carbon Room Gr. Flr	0.04	
Block-2 Washing Area Gr Flr	0.10	
Block-2 Draying Area Gr. Flr	0.11	
Block-2 Wet Process Area Ground Flr	0.06	
Block-2 Drying Area Gr. Flr	0.05	
Block-2 Passage 1st Flr	0.12	
Block-2 Office Room 1st Flr	0.14	
Block-2 DSSR 1st Flr	0.17	
Block-4 VTD Room Gr. Flr	0.02	
Block-4 Wash Room Gr. Flr	0.09	
Block-4 DNFD Area Gr. Flr	0.01	
Block-4 RVD Room	0.13	
Block-4 VTD Room	0.39	
Block-4 1st Floor Process Area DGLR -10	0.32	
Block-4 1st Floor Clean Room 1	0.40	
Block-4 1st Floor Crystallizer Room	0.08	
Block-4 1st Floor ANFD Room	0.16	
Block-4 1st Floor Passage	0.24	
Block-4 1st Floor Dray Store Room -Near Process Aear	0.32	
Block 6, 1st Floor Elect. Room	0.19	
Block 6, 2nd Floor	0.02	
Block-4 Small Room near Electrical Room Ground Flr	0.82	
Block-4 Centrifuge Room 2	0.66	

Table 54 ILER Color Code

ILER	Assessment	Color Code
0.75 or over	Satisfactory	
0.51 - 0.74	Review Suggested	
0.5 or less	Urgent Action Required	

4.4.2 Lighting Recommendations and Energy Conservation Opportunities

ILER Improvement

ILER Ratios of 0.75 an above are desired and considered satisfactory while values within the range of 0.51 to 0.74 represent areas wherein improvement of lighting efficiency through the following measures can be considered:

- higher lumens/watt fixtures through more efficient technology
- improved maintenance and cleaning of luminaries and room walls to reduce impact of dust and dirt accumulation leading to illuminations loss including
- wall repainting
- reducing lux levels (by eliminating a fraction of the installed fixtures) if higher than required or recommended illuminance levels are prevalent.

ILER values lower than 0.5 should serve as an alarm for immediate action to improve lighting efficiency according to the measures above.

As presented in the Tables above, the ILER values are generally much lower than 0.5 in most areas and require immediate attention. The potential energy and associated cost savings from improving ILER values can be estimated by comparing the energy requirement in the current situation relative to the energy requirement for a perfect scenario with ILER equal to 1.0. The savings estimate for the Plant is presented in the Table below and indicates a total energy savings potential of approximately INR 4.31 Lakh through improvement in ILER values across the Plant.

Table 55 Energy and Cost Savings from ILER Improvement

Sr. No.	Area	Energy Wastage (kWh/year)	Energy Cost Wastage (INR/year)
1	Block -1 Main Entrance Ground Flr Passage	1,669	9,633
2	Block -1Colum Chromatography Area Gr. Flr	3,968	22,896
3	Block -1 Passage Ground Flr	928	5,354
4	Block -1 Drying Area 1 G. Flr	639	3,685
5	Block -1 Passage Ground Flr	540	3,114
6	Block -1 Carbon Slurry	324	1,870
7	Block -1 Wash Area	323	1,861
8	Block -1 Blending &Packing Area	854	4,930
9	Block -1 High Distillation Area	928	5,354
10	Block -1 Secondary Change Room	342	1,972

Sr. No.	Area	Energy Wastage (kWh/year)	Energy Cost Wastage (INR/year)
11	Block -1 Centrifuge Area	186	1,076
12	Block -1 Day Store Room	333	1,920
13	Block -1 Dusting Area	667	3,847
14	Block -1 Passage	613	3,540
15	Block-2 DSSR Ground Flr	4,285	24,726
16	Block-2 Carbon Room Gr. Flr	289	1,668
17	Block-2 Washing Area Gr Flr	272	1,568
18	Block-2 Draying Area Gr. Flr	305	1,762
19	Block-2 Wet Process Area Ground Flr	643	3,713
20	Block-2 Drying Area Gr. Flr	326	1,881
21	Block-2 Drying Area Gr. Flr	302	1,744
22	Block-2 Power Process Area Ground Flr	302	1,744
23	Block-2 DSSR 14 Ground Flr	302	1,744
24	Block-2 DSSR 15 1st Flrs	604	3,488
25	Block-2 DGLR07 1st Flr	302	1,744
26	Block-2 DGLR08 1st Flr	302	1,744
27	Block-2 DSSR11 1st Flr	302	1,744
28	Block-2 DSSR12 1st Flr	302	1,744
29	Block-2 DSSR13 1st Flr	302	1,744
30	Block-2 Passage 1st Flr	1,197	6,905
31	Block-2 Office Room 1st Flr	585	3,375
32	Block-2 DSSR 1st Flr	125	721
33	Block-4 Small Room near Electrical Room Ground Flr	167	965
34	Block-4 VTD Room Gr. Flr	593	3,424
35	Block-4 Wash Room Gr. Flr	138	794
36	Block-4 DNFD Area Gr. Flr	8,889	51,298
37	Block-4 RVD Room	1,643	9,480
38	Block-4 VTD Room	577	3,330
39	Block-4 Centrituge Room 2	643	3,711
40	Block-4 1st Floor Process Area DGLR -10	2,911	16,801
41	Block-4 1st Floor Process Area DGLR -10	1,360	7,848
42	Block-4 1st Floor Clean Room 1	283	1,631
43	Block-4 1st Floor Crystallizer Room	1,744	10,066
44	Block-4 1st Floor ANFD Room	1,187	6,851
45	Block-4 1st Floor Passage	723	4,175
46	Block-4 1st Floor Dray Store Room[Near Process Aear]	320	1,847
47	Block 6-1st Floor Elect. Room	1,336	7,711
48	Block 6-2nd Floor	28,872	1,66,612
Total			4,31,353

Deployment of Lighting Transformer

Outdoor light sources are ‘discharge type’ light sources wherein optimum power consumption requires applied line to line voltage to be in the range of 380 to 390 Volts.

Contrastingly however, the system line to line voltage is observed to be in the range of 405 to 420 Volts during day time and in the range 430 to 450 Volts during night (when outdoor lighting is 'ON'). Since power consumption of 'discharge type' devices is proportional to the applied voltage, the higher voltages escalate the power consumed by the fixtures. This situation prevalent across the Plant can be rectified through the means of a Lighting Transformer that regulates the voltage applied to a fixture to within the optimal range of 380 to 390 Volts after it is turned 'ON'. It is estimated that this could yield a power consumption reduction of 10% to 12%. The results of the energy conservation analysis are presented below and indicate that the Plant could reduce energy consumption by 8,712 kWh/year and energy costs by 50,724 INR/year. The analysis also revealed that the anticipated capital investment required for a 50 kVA Lighting Transformer would be INR 1.15 Lakh therefore yielding a simple payback period of approximately 2.3 years.

Table 56 Savings by Implementation of Outdoor Lighting 50 kVA Transformer

Type of Outdoor Lighting Source	Outdoor Lighting Power Cons. (kW)	Cost of 50 kVA Transformer (INR)	Reduction in Power Cons. (%)	Estimated Power Cons. (kW)	Power Savings (kW)	Energy Savings (kWh/yr)	Energy Savings (INR/yr)	Payback (Years)
Discharge Type	17.90	1,15,000	13%	15.51	2.39	8,712	50,274	2.3

Deployment of LDR / Twilight Timer

A Light Dependent Resistance (LDR) or Twilight timer could be applied at the Plant to achieve automated switching 'ON' and 'OFF' of outdoor lights as a function of ambient light conditions (i.e. in accordance with sunrise and sunset). This intervention provides the obvious benefit of inadvertent operation of lights during daylight hours which can be witnessed in manually operated outdoor lighting systems.

Reduce Excess Illuminance

As indicated in the illuminance assessment earlier, some of the Indoor areas of the Plant are provided with excess lighting that greatly supersedes standard lux requirements. The most prominent of these areas are the Cafeteria, Warehouse, Block 4 Ground Floor Entrance, Nitrogen Area etc. The analysis conducted to ascertain potential energy conservation benefits of eliminating excess lighting fixtures led to the conclusion that aligning lux levels across the Plant with standard lux levels could yield energy savings of 21,371 kWh/year and an annual cost saving of approximately INR 1.23 Lakh/year without any capital investment.

Replacement with LED Lights

LED lighting technology affords numerous benefits over conventional lighting systems such as CFL, TFL, HPMV, Metal Halide etc. lighting technologies. The primary advantages are listed below.

Advantages of LED Lights

- LED lights are Reliability (no spontaneous failure)
- Emits less heat

- Use less power relative to most conventional lighting systems
- Are more energy efficient relative to conventional lighting systems and consume 50% to 60% lower power than most lighting systems to achieve the same light output
- Quick ON / OFF response
- Free of hazardous materials
- Long lifetimes in the range 40,000 hours to 50,000 (approximately 40 times longer than that of a Incandescent Bulb) which translates to longer service intervals between street light replacement
- Flexibility in colors

Limitations of LED Lights

LED Lights can lead to more glare compared to conventional lighting systems and the 'Light Cone' does not spread expansively as is the case with 'Discharge Type' lights. This limitation can be overcome by reducing the mounting height for light fittings in most of areas. For the Plant under consideration, this does not pose major challenge as the inner road width is sufficient and large vehicles do not traverse under most normal conditions.

Table 57 below provides a summary of annual energy cost saving possibilities by usage of High Efficacy LED Lamps to replace the extensively used (10 to 18 hours per day) HPMV, Metal Halide, PL and CFL Lamps. The model developed for the project accounted for the nuance that Indoor Lights can be replaced by conventionally available LED Bulbs while Outdoor Lights (HPMVs etc.) will require replacement with the more expensive LED Flood Light Lamps which also provide a marginally higher lumens per watt. The analysis indicates that a total of approximately INR 7.82 Lakhs could be saved through switching out the HPMV and Metal Halide Lamps with High Performance LED Lamps in Indoor and Outdoor Lighting Scenarios as indicated below. The estimated incremental capital cost (i.e. the cost difference between replacing the existing fittings with new units of the same technology versus the cost of the alternative proposed) for the project would be INR 30.9 Lakhs, yielding a payback period of 4.3 years and an annual energy conservation and GHG Mitigation potential of 1.19 Lakh kWh/year and 149.3 MT CO_2e/year, respectively.

Other options for Lighting Energy Conservation

<u>Use of Motion / PIR Sensors</u>

Energy consumption from building interiors and exteriors that do not require continual lighting and cooling due to infrequent occupancy (eg. stairwell and compound lighting in buildings and fan/light operation in toilets and elevators in commercial and residential premises) can be significantly diminished by use of Passive Infrared Sensors- PIR Sensors to controls HVAC and lighting fixtures. Incorporating PIR Sensor-control in tubelights, used 12 hours per day (approximate usage in stairwell lighting applications), can mitigate energy consumption by approximately 160 kWh per fixture. This alternative is even more viable when multiple fittings can be sensed and controlled by a single PIR sensor.

Use of Cord / Pull Switches

Chord switches can be wired up to individual fittings easily and are a low capital cost alternative.

Table 57 Lighting Environmental and Cost Savings Estimate from Equipment Replacement (Outdoor & Indoor)

	BAU[6]	BAU	BAU	Interv.	Interv.	Savings			
Details	**Rated Capacity (lumens)**	**hrs./yr**	**Eff. (lum/kW)**	**Eff. (lum/kW)**	**Incremental Capital Cost (INR)**	**Cost Savings – Energy & Penalty (INR/yr)**	**Payback Period (yrs)**	**Energy Conservation (kWh/yr)**	**GHG Mitig. (MT CO2e/yr)**
HPMV to LED – Indoor	12,42,500	6570	50,000.0	78,000.0	26,95,956	5,41,693	5.0	84,772.0	105.96
HPMV to LED - Outdoor	7,62,500	3650	50,000.0	85,566.7	3,05,372	2,17,064	1.4	31,268.1	39.09
Metal Halide to LED - Outdoor	92,308	3650	46,153.8	85,566.7	91,157	23,342	3.9	3,362.4	4.2
TOTAL					30,92,485	7,82,099.00	4.30 (Avg.)	1,19,402.50	149.25

[6] BAU = Business-as-Usual

Summary Energy Conservation Opportunities – Lighting System

- **Luminance Assessment:** Reducing the number of fixtures can result in savings of INR 1,23,325 annually.
- **ILER Improvement:** By improving ILER to 0.75 or more can result in savings of INR 4,31,353 yearly.
- **Installation of 50 kVA Transformer:** By installing a 50 kVA Transformer for outdoor lightings an energy saving of 8,712 kWh/year. An associated cost reduction of approximately INR 50,274 per annum. The capital cost of the requisite equipment is INR 1,15,000 with a payback period of 2.3 years.
- **Replace HPMV to LED Light (Indoor):** Replacement of all indoor HPMV lights with LED lights results in an energy saving of 84,772 kWh/year and an associated cost reduction of approximately INR 5,41,693 annually. Capital cost of equipment INR 26,95,956 with a payback period of 5 years.
- **Replace HPMV to LED Light (Outdoor):** Replacement of all outdoor HPMV lights with LED lights results in an energy saving of 31,268.1 kWh/year and an associated cost reduction of approximately INR 2,17,064 annually. Capital cost of equipment INR 3,05,372 and payback period of 1.4 years.
- **Replace Metal Halide to LED Light (Outdoor):** Replacement of all outdoor Metal Halide lights to LED lights results in energy saving of 3,362.4 kWh/year and associated cost reduction of approximately INR 23,342 annually. Capital cost of equipment INR 91,157 and payback period of 3.9 years.

4.5 HVAC-Refrigeration System

The Heating Ventilation, Air Conditioning and Refrigeration System at the Plant consists of the following sub-systems which work as a integrated whole to achieve the end-uses for various process cooling, space cooling, and comfort cooling needs.

1) Chillers (to produce- chilled water in three general temperature ranges: -20^{O}C, -5 ^{O}C, and 20 ^{O}C) connected to AHUs to generate cooled, dehumidifed air for space cooling needs, and directly used for process cooling loads.

2) Direct Expansion (DX) Refrigeration Systems connected to AHUs to generate cooled, dehumidifed air for space cooling needs.

3) Fresh Air Handling Units (AHUs to satisfy fresh air ventilation needs for occupant comfort, health and safety needs)

4) Cooling Towers (connected to Water-Cooled Chiller Condenser Coils required operating the primary refrigerant cycle)

5) Spilt-Unit Room ACs

An overview of the HVAC system at the Plant, encompassing the above sub-systems, is presented below.

Table 58 HVAC System and Sub-System Rated and Measured Performance Overview

System Type	Rated Capacity	Units	Meas. Capacity	Units	Rated Power (kW)	Measured Power (kW)	Energy Cons. (kWh/year)
Chillers	455	TR	165.3	TR	235	265.6	11,63,372
DX System	10.5[7]	TR	10.5	TR	9.2	6.7	35,299
Split Unit ACs	122	TR	122[8]	TR	122.03	122.03	2,97,910
Sub-Total	*587.5*	*TR*	*297.8*	*TR*	*366.2*	*394.4*	*14,96,581.1*
% of Total Plant Load					*33.7%*	*36.3%*	*26.0%*
Cooling Towers	870	TR	249.4	TR	124.96[9]	96	6,30,457.2
Sub-Total	870.0	TR	249.4	TR	124.96	96	6,30,457.2
% of Total Plant Load					*13.1%*	*8.5%*	*10.5%*
Fresh Air AHUs	1,31,175	m3/hr	1,48,434	m3/hr	64.5	42.3	2,22,550
Chiller Con. AHUs	89,079	m3/hr	1,04,810	m3/hr	49.5	42.5	2,23,451
Sub-Total	*2,20,253.6*	*m3/hr*	*2,53,244.0*	*m3/hr*	*114.0*	*84.9*	*4,46,001.0*
% of Total Plant Load					*10.5%*	*7.8%*	*7.7%*
Overall Total					604.2	575.2	25,73,039.3
% of Total Plant Load					*55.7%*	*53%*	*44.6*

The above overview indicates that the rated and measured power of the combined HVAC Systems at the Plant account for nearly 56% and 53%, respectively, of the total average

[7] Rated TR data was not available
[8] Measured TR taken to be same as rated TR since individual measurement of TR for all split unit ACs was not feasible.

monthly load on the electrical system. The total installed chiller capacity is 587.5 TR and it represents one of the most critical components of the energy management and conservation plan that emerges as the outcome of this Energy Audit. The energy consumption of the HVAC system accounts for approximately 37 % of the annual energy consumed and the associated cost at the Plant level. Of the sub-systems assessed as part of the Energy Audit, the Chillers and Split ACs form a bulk of the energy consumed followed by Cooling Towers, AHUs and the DX systems.

Each of the above systems was independently studied to determine performance levels achieved by them and then related to the corresponding systems to estimate overall system efficiencies. The goal was ascertain the operational performance as measured relative to best-available-technologies to thereby facilitate an analysis of the energy, cost and GHG mitigation potential of equipment overhaul or replacement.

4.5.1 Chillers, DX Systems and AHU Performance Assessment

Chilled Water and DX Systems transfer the heat energy from a process vessel or building environment to the atmosphere. Energy in the form of electricity is used to power mechanical equipment designed to transfer heat from a colder, low energy level to a warmer, high energy level.

Both, Chilled Water and DX Systems use a Vapor Compression (or Vapor Absorption Cycle) Cycle as the core process, but differ in notably in their use of the chilled refrigerant. Chilled water chillers use a refrigeration cycle to cool water to 42 to 45^{O}F for pumping to chilled water-cooling coils over which air is then blown over to provide cool air to the conditioned space. DX systems are similar to the extent that they too use a refrigeration cycle, but distribute refrigerant directly to DX cooling coils over which air is blown.

The following Chilled Water and DX systems (with connected AHUs for space cooling or directly for process cooling without connected AHUs) were encountered at the Plant. The installed loads across the HVAC system types is also presented alongside.

Table 59 Summary of Chilled Water and DX System Capacities and Load Types

Block No	System Details	System Type	Loads
Block 1	+ 5°C Chiller 78 TR x 1 no	Chilled Water	AHUs + Process Loads
Block 1		DX System	AHUs
Block 3	+ 5°C Chiller, 22 TR x 2 nos	Chilled Water	Clean Room
Block 3	-20°C Chiller, 28 TR x 1 no	Chilled Water	AHUs + Process Loads
Block 4	+ 5°C Chiller, 315 TR x 1 no	Chilled Water	AHUs + Process Loads
Block 5	None		None
Block 6	-20°C Chiller, 72 TR x 1 no	Dowcal	Process Loads
Block 6	- 40°C Chiller, 10 TR x 1 no	Dowcal	Process Loads

In the context of comfort cooling, technical literature related to HVAC system design indicates that a temperature band of 22 ^{o}C – 25 ^{o}C with a relative humidity of 55% is the most appropriate combination for human comfort. Furthermore, research by the Indian Green

Building Council (IGBC) specifies that an indoor temperature of 24^{0}C is ideal for thermal comfort for Indians. The goal of Energy Audit-connected Chilled Water systems was to optimize the Air Conditioning system to deliver the comfort in the most economical manner by examining and enhancing technical performance parameters of the existing equipment, recommending economically feasible overhauls, and operation and maintenance protocols being followed.

4.5.1.1 Chiller Performance Assessment

The below Table 60 provides an estimate of the operational performance of the Chillers (AHU connected and otherwise) audited at the Plant during 1st and 2nd site visit. The assessment conducted indicates that the total rated Chiller capacity at the Plant is 455 TR. While it would have been ideal to measure operational performance of this entire capacity, it was only possible to measure complete performance metrics for the 315 TR systems owing to difficulty in measuring flow rate in the Brine fluid lines for the other Chillers during 1st site visit. It was noted that the 40 TR (-20°C) Chiller is located near 315 TR (+5°C) Chiller in the same Block and are served by a common condenser. The condenser line sizing is inadequate for 315 TR but is oversized for 40 TR. As a result, when 40 TR (-20°C) is running, the valve on the condenser water line is throttled by 20% and this leads to avoidable energy loss.

During the 2nd site visit complete performance metrics for DCRC 05 (Block 06 – 72 TR) and DCRC 02 (Block 01 – 40 TR) was measured. While owing to difficulty in measuring flow rate in Brine fluid lines for DCRC 05 and DCRC 02, Cool Pack software (Cool Pack is a collection of simulation models for refrigeration systems. The models each have a specific purpose of cycle analysis, dimensioning of main components, energy analysis and optimization. It consists of Refrigeration Utilities, EESCool Tools and a transient element called Dynamic) was used to analyze the operational TR of the DCRC 05 and DCRC 02 based on the following input data respectively. Table 60 and Table 61 show the input data for DCRC 05 and DCRC 02.

Table 60 Block 06 (DCRC 05) - 72 TR Chiller Data

Sr.no	Description	Input value	Units
1	Compressor type	Screw Type	
2	Refrigerant Used	R -22	
3	Rated TR	72	TR
4	Rated Power	132	KW
5	Refrigerant suction Pressure	0.8	kg/cm2g
6	Refrigerant discharge Pressure	13.5	kg/cm2g
7	Refrigerant temp at outlet of compressor by digital indicator	74	DegC
8	Measured Power	106.3	KW
9	Power factor	0.8	
10	Current	151.2	Amp
11	Condenser Outlet Temp	74.9	DegC

12	Chilled water in Temp	-15.9	DegC
13	Chilled water out Temp	-17.1	DegC

Table 61 Block -01 40 TR Chiller Data

Sr.no	**Description**	**Measured value**	**UoM**
1	Compressor type	Screw Type	
2	Refrigerant Used	R717	
3	Rated TR	40	TR
4	Rated Power	48	KW
5	Refrigerant suction Pressure	1.8	kg/cm2g
6	Refrigerant suction Temperature	NA	Deg C
7	Refrigerant discharge Pressure	12.5	kg/cm2g
8	Refrigerant discharge Temperature	NA	DegC
9	Refrigerant temp at outlaet of compressor by digital indicator	54	DegC
10	Measured Power	49	KW
11	Power factor	0.89	
12	Current	78.95	Amp
13	Condenser inlet Temp	29.5	DegC
14	Condenser Outlet Temp	30.8	DegC
15	Chilled water in Temp	3.5	DegC
16	Chilled water out Temp	-0.6	DegC

Figure 19 and Figure 20shows the output of 72 TR and 40 TR chiller systems respectively.

The operational TR of the 72 TR chiller system is 195.0 kW which is 55.45 TR. The operational kW/TR of the system is 1.91. And EER of the system is 1.83.

The operational TR of the 40 TR chiller system is 140 kW which is 39.80 TR. The operational kW/TR of the system is 1.23. And EER of the system is 2.85.

Figure 19 p,h Diagram of 72 TR Chiller System

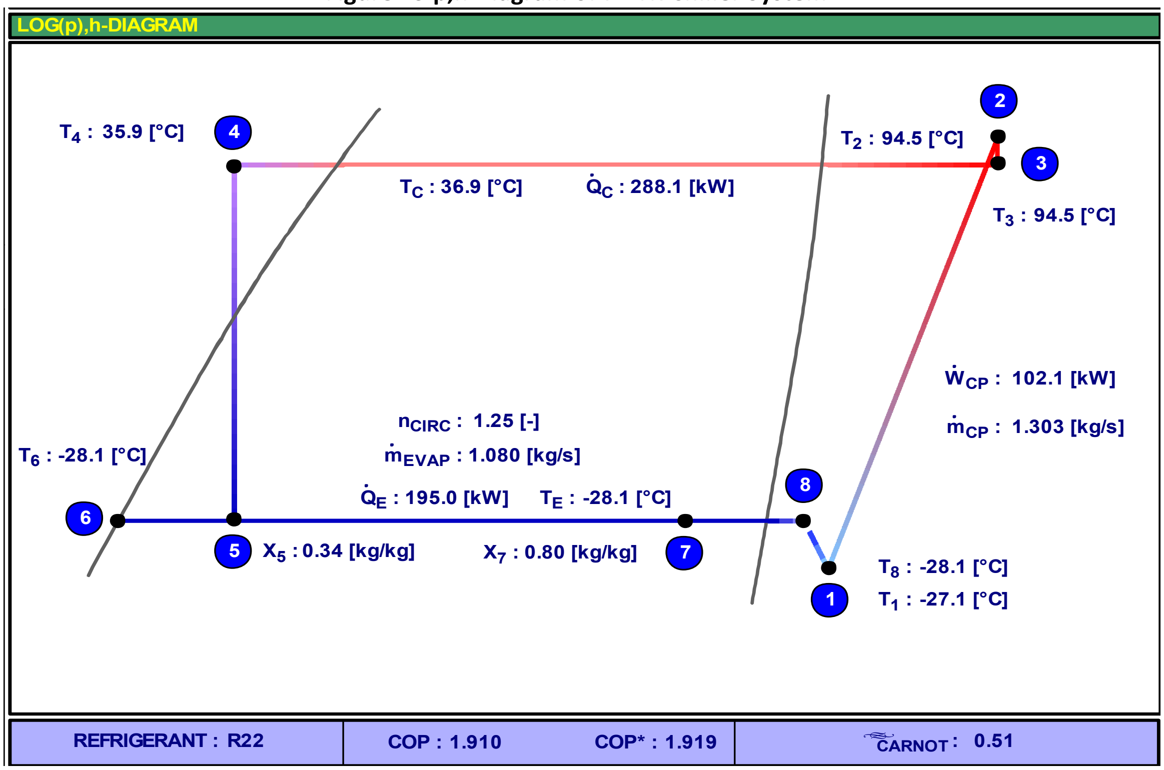
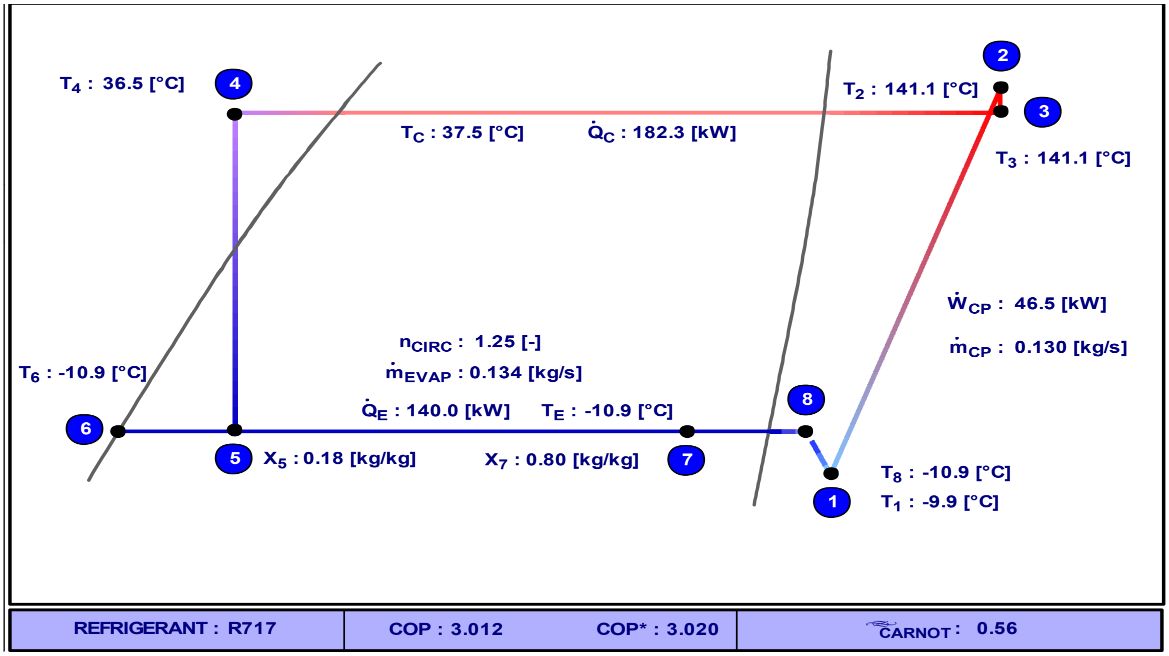


Figure 20 p,h Diagram of 40 TR Chiller System



The audited chiller consumes an estimated 265.6 kW of power and leads to an annual energy consumption of approximately 11,63,372 kWh/year. A summary of the chiller performance assessment is mentioned in the table below.

Table 62 HVAC System - Chiller Performance Assessment

ɔcation	Chiller ID	Type	Working Fluid	Fluid Temp (0C)	Rated Capacity (TR)	Evap. Inlet Temp. (0 C)	Evap. Outlet Temp. (0 C)	Chilled Water Flow Rate (m3/hr)[10]	Active Power (kW)	Measured TR	kW/TR	EER	Energy Cons. (kWh/year)
lock 06	DCRC05	Compact Screw	Brine	-20	72	Not Measured	Not Measured	Not Measured	106.3	55.45[11]	1.91	1.84	4,64,28
lock 04	DWCC05	Single Screw	Water	5	315	6.7	5.1	132	72.36	70.05	1.03	3.40	3,16,93
lock 04	DCRC03	Compact Screw	Brine	-20	28	-7.8	-10.5	Not Measured	38.25	NA	NA	NA	1,67,53
lock 01	DCRC02	Not Known	Brine	-20	40[12]	-0.7	-5.1	Not Measured	49	39.80	1.23	2.86	2,14,62
otal					455				265.6				11,63,37

[10] Brine side flow measurement could not be done as the sensors of the flow meter were not suitable for flow measurement on low temperature line

[11] 72 TR System performance assessment was measured during the second site-visit.

[12] 40 TR System performance assessment was measured during the second site-visit.

4.5.1.2 DX System Performance Assessment

The Table 63 below provides an estimate of the operational performance of the DX Systems audited at the Plant. The rated TR of the system was not known while the measured refrigeration capacity was 10.5TR. The system consumes an estimated 6.7 kW of power, lower than the rated power of 9.2 kW for the system, and leads to a annual energy consumption of approximately 35,299 kWh/year. The measured Energy Efficiency Ratio (EER) for the 2 systems Chillers ranged from 0.4 to 20.3.

Table 63 HVAC System – DX System Performance Assessment

Location	AHU ID	Rated Air Flow (m^3/hr)	Motor Rated (KW)	Measured Power Cons. (kW)	Measured Air Flow Rate (m^3/hr)	TR (Meas.)	kW/TR	EER	Energy Cons. (kWh/yr)
Block 01	DAHU 24	6,796	5.5	1.7	8,136	9.85	0.17	20.3	8,968
Block 01	DAHU 25	3,058	3.7	5.0	3,100	0.63	7.98	0.4	26,331
Total		9,854	9.2	6.7	11,236	10.5			35,299

The above data indicates a measured AHU flow rate higher than the rated flow rate, yet measured power consumption lower than the rated motor power. This along with the inordinately high (20.3) and low (0.4) EERs for the 2 units calculated indicate critical issues with either the data measured at the site or a unique operational situation wherein:

- the DAHU 24 unit's compressor was in OFF mode while the AHU fans were running (thereby leading to a low total power consumption for fan and compressor) and a resultant unexpectedly high EER, and
- the supplied air stream for DAHU 25 is mixing with the ambient air through short-cycling across the AHU thereby reducing the measured TR and leading to a unacceptably low EER

In the context of the overall power consumption of the HVAC system , however, the DX system does not occupy a prominent position; it consumes only 6.7 kW out of the total 404 kW measured power consumption of the HVAC system. The data discrepancy is therefore not a major concern and can be addressed if required during subsequent measurements that can be arranged by the Consultant through coordination with the Plant Operational team using equipment available on site.

4.5.1.3 AHUs Performance Assessment

Chiller /Hot Water Line Connected AHUs

The Table below provides an estimate of the operational performance of the Chillers connected AHUs audited at the Plant. The assessment conducted indicates that the total rated Chiller-connected AHU capacity at the Plant is 80,079 m^3/hr and the corresponding rated power consumption is 49.5 kW. The measurements indicated that the system consumes an estimated

42.5 kW of power and leads to a annual energy consumption of approximately 2,23,451 kWh/year to deliver a higher-than-rated flowrate of 104,810 m^3/hr[13].

The key efficiency parameters for AHUs are Static Fan Efficiency, % Loading, and the cfm/TR delivered.

- Static Fan Efficiency could not be measured at the Plant in almost all instances due to the absence of pre-existent ports in the ducting to measure suction and discharge pressure in conjunction with the fact that drilling apertures into the ducting sheets was highly unfeasible.
- The % loading of the system was considered largely adequate as evident from the measured power consumption being relatively close to the rated power consumption at a system level.
- The cfm/TR delivered was excessively high. Approximate values for this are expected to be in the range of 500 cfm/TR delivered. The results make it abundantly clear that the witnessed cfm/TR is much higher than this benchmark in all instances. This is indicative of the fact that AHUs are not effective and the much lower than expected total refrigeration delivered (~ 17 TR) for all the AHUs combined is alarming. In many instance it was noted that the cooling effect delivered is near zero as witnessed in the case of DAHU 09, DAHU 13 and DAHU 14. There are two possible explanations for this low TR and high cfm/TR
    - Low ambient temperature (winter time temperatures) reduced the cooling load significantly while the fans were still running
    - A marginal difference in the enthalpy calculated for the ambient air and the supplied was witnessed in many instances which led to low delivered TRs. The figure below is a schematic representation of a typical Chiller-connected AHU system indicating the inlet and outlet air streams. The startlingly low delivered cooling is a sign of short circuiting between the exhaust and inlet air streams or a case wherein ventilation air enters and leaves a space or duct before it has a chance to mix well enough with room air to deliver cooling to the indoor space.

[13] This could be due to inaccuracy of Anemometer readings. For precise flow measurements Flow Hoods are usually employed. However, Flow Hood setups are cumbersome and not designed for portability and mounting in most site conditions. The most common practice is therefore to use Anemometers.

Figure 21 Schematic Diagram of Chiller-connected AHU System

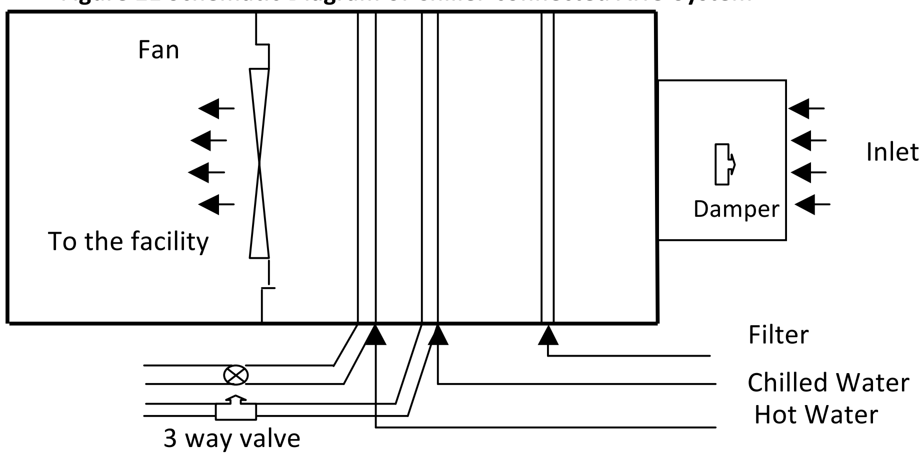


Table 64 HVAC System – Chiller-connected AHUs Performance Assessment

Sr. No	Location	AHU ID	Rated Air Flow (m^3/hr)	Motor Rated (kW)	Meas. Power (kW)	Del. TR	Meas. cfm/TR	Meas. Air Flow (m^3/hr)	Energy Cons. (kWh/yr)
1	Block 01	DAHU01	5,097	3.7	2.9	0.71	4,342	5,253	15,273
2	Block 01	DAHU02	5,097	3.7	2.5	1.33	1,566	3,537	13,242
3	Block 01	DAHU03	6,796	3.7	4.3	1.73	2,270	6,679	22,675
4	Block 02	DAHU09	20,388	9.4	6.4	0.07	2,67,017	32,003	33,390
5	Block 03	DAHU11	10,194	NA	4.5	2.10	4,741	16,948	23,607
6	Block 04	DAHU14	10,175	5.5	3.8	0.25	26,922	11,291	19,751
7	Block 04	DAHU13	3,323	1.5	1.4	0.02	26,922	770	7,219
8	Block 04	DAHU 16	6,050	5.5	3.5	2.07	1,002	3,529	18,386
9	Block 04	DAHU 17	8,250	5.5	4.7	0.95	5,443	8,758	24,747
10	Block 04	DAHU 19	6,062	5.5	4.3	3.36	1,057	6,033	22,720
11	Block 04	DAHU 20	7,646	5.5	4.3	4.22	1,394	10,008	22,441
	Total		89,079	49.5	42.5	16.8		1,04,810	2,23,451

Fresh-Air Ventilation AHUs

The Table below provides an estimate of the operational performance of the Fresh-Air Ventilation AHUs audited at the Plant. The assessment conducted indicates that the total rated AHU capacity at the Plant is 131,175 m^3/hr and the corresponding rated power consumption is 64.5 kW. The measurements indicated that the system consumes an estimated 42.3 kW of power and leads to a annual energy consumption of approximately 2,22,550 kWh/year to deliver a higher-than-rated flow rate of 148,434 m^3/hr. The key efficiency parameters for Fresh-Air AHUs are Static Fan Efficiency and % Loading.

- Static Fan Efficiency could not be measured at the Plant in almost all instances due to the absence of pre-existent ports in the ducting to measure suction and discharge pressure in conjunction with the fact that drilling apertures into the ducting sheets was highly unfeasible.

- The % loading of the system was determined from a comparison of the measured power consumption relative to rated power consumption at a system level. It was seen to be notably low at about 65 % on average. While DAHUs 4, 5, 6 in Block 1 operate at a motor (fan) loading of approximately 80 %, all other AHUs operate at a loading in the range of 51% to 60%. These operational observations allude to the opportunity for energy savings through modulating fan speeds that could be turned down using VFDs.

Table 65 HVAC System – Fresh-Air Ventilation AHUs Performance Assessment

Sr. No	Location	AHU ID	Rated Air Flow (m^3/hr)	Motor Rated (kW)	Meas. Power Cons. (kW)	Meas. Air Flow (m^3/hr)	Energy Cons. (kWh/yr)
1	Block 01	DAHU 04	10,849	5.5	4.5	14,649	23,464
2	Block 01	DAHU 05	10,849	5.5	4.5	11,580	23,901
3	Block 01	DAHU 06	10,849	5.5	4.5	13,817	23,470
4	Block 02	DAHU 07	20,028	7.5	3.9	10,944	20,311
5	Block 02	DAHU 08	20,028	9.5	5.1	34,307	26,881
6	Block 02	DAHU 10	1,669	1.5	0.8	4,120	4,365
7	Block 03	DAHU 12	13,691	5.5	4.6	9,972	24,175
8	Block 04	DAHU 15	4,296	1.5	0.9	NA	4,892
9	Block 04	DAHU 18	8,876	7.5	4.5	12,492	23,688
10	Block 06	DAHU 21	30,042	15	9.0	36,554	47,404
11	Block 06	DAHU 22	NA[14]	NA	NA	NA	NA
12	Block 06	DAHU 23	NA[15]	NA	NA	NA	NA
Total			1,31,175	64.5	42.3	1,48,434	2,22,550

4.5.2 Chillers, DX Systems and AHU Energy Conservation Opportunities

4.5.2.1 Existing Chiller Replacement with Efficient Chiller

The performance assessment presented earlier indicated that the EER of the 72 TR, 315 TR and 40 TR, chiller system was 1.84, 3.40 and 2.86 respectively, which is lower than the carrier efficient chiller systems in the market. Mentioned EER of Carrier chiller systems in Table 66 is based on AHRI Standard 550/590 at standard rating condition (See Appendix VII).

By replacing the existing chiller systems with more efficient Carrier chiller systems, approximately 4,95,931 kWh/year energy can be saved which leads to annual savings of 28,61,889 INR. The savings are based on the measured Tonnage of each chiller system. The annual savings analysis by existing chiller replacement with efficient chiller system is given in the table below.

[14] Dedicated to FBD Process - was not in operating condition
[15] Critical Production Batch was going on so field measurement was not done

Table 66 Energy Conservation by Replacing Existing Chiller System by Energy Savings Chiller System

Details	Rated Cap. (TR)	Meas (TR)	Meas. kW/TR	Meas. EER	Rated kW/TR of Efficient Chiller	Revised EER of Efficient Chiller	Energy Savings (kWh/yr)	Annual Savings (INR/yr)
72 TR Voltas Chiller Replacement with Carrier Chiller	72	55.45	1.91	1.84	0.712	4.96*	2,91,355.83	16,81,388.87
315TR Daikin Chiller replacement with Carrier Chiller	315	70.05	1.03	3.40	0.636	5.53*	1,21,804.09	7,02,899.81
40 TR Chiller Replacement With Carrier Chiller	40	39.8	1.23	2.86	0.756	4.65*	82,771.07	4,77,650.37
							4,95,931	28,61,889

(Note - * Value indicates EER at full load condition based on AHRI Standard 550/590 at standard rating condition)

4.5.2.2 VFDs for Chiller Connected AHUs

It is evident that effective and optimized operation of the plant requires the quantity of chilled water by-pass and hot water injection flow rate to rapidly respond to varying process and space cooling loads encountered daily in order to maintain the desired temperature and humidity conditions. Achieving this dynamic real-time response will necessitate AHU fan speed control along with hot and cold water flowrate regulation. Application of VFDs to achieve this Fan speed modulation will result in the valuable co-benefit of energy savings and hence VFDs in automation circuit are recommended for consideration.

The performance assessment presented earlier indicated that the cooling effect delivered was near zero in the case of DAHU 09, DAHU 13 and DAHU 14. The Plant should consider regulating the speed of the Fan motors associated with these units which are currently not providing effective cooling as the energy used in operating the motors at full-speed represent wasted energy. The Table below presents the projected energy and cost savings estimates for speed reduction up to 80% for these Fan motors. The analysis indicates that this intervention can yield annual energy and cost savings of approximately 34,693 kWh/year and INR 2.00 Lakh/year, respectively. With an equipment cost of INR 89,750, the payback period is an acceptable **0.5 years**.

Table 67 HVAC System – Chiller-Connected AHUs VFD Application Energy and Cost Savings Assessment

AHU ID	Meas. Power (hp)	Scenario: Turned Down Fan Speed (RPM)	Scenario: Turned Down Fan Power (kW)	VFD Efficiency %[16]	VFD Power Saving - (kW)	VFD Energy Saving - (kWh/year)	VFD Cost Saving - (INR/year)
DAHU 09	8.52	1160.00	3.25	0.96	2.96	19,477.48	1,12,399.49

[16] Method of estimating VFD Efficiency presented in Appendix III.

DAHU 14	5.04	1160.00	1.92	0.95	1.73	11,383.02	65,688.47
DAHU 13	1.84	2320.00	0.70	0.89	0.58	3,832.55	22,116.64
			Total		5.28	34,693.05	2,00,204.60

4.5.2.3 VFDs for Fresh-Air Ventilation AHUs

The overall performance overview of Fresh-Air Ventilation AHUs implied the possibility of mitigating the energy inefficiency associated with part load operation (at ~ 65 % loading) of many of the AHUs serving Block 2, 4, and 6. Similar to the Chiller-connected AHUs, application of VFDs on these AHUs can yield energy savings commensurate with the turned-down speeds to achieve the same flowrate without the use of dampers and valves to throttle air flow. It must be recognized that reduced Fan speeds can also be achieved through changing the pulley ratio of the Fan-Motor system. However, this option involves a undesirable limitation in that pulley ratio modification can only achieve speed reduction in discrete steps albeit at a much lower cost.

The Table below presents the projected energy and cost savings estimates for speed reduction up to 80% for all Ventilation AHU Fan motors. The analysis indicates that this intervention can yield annual energy and cost savings of approximately 21,390 kWh/year and INR 1.82 Lakh/year, respectively with at a acceptable payback period of 3.9 years.

Table 68 HVAC System – Fresh-Air Ventilation Connected AHUs VFD Application Energy and Cost Savings Assessment

AHU ID	Meas. Power (hp)	Scenario: Turned Down Fan Speed (RPM)	Scenario: Turned Down Fan Power (kW)	VFD Efficiency %[17]	VFD Power Saving - (kW)	VFD Energy Saving - (kWh/year)	VFD Cost Saving - (INR/year)
DAHU 04	5.99	1152.00	2.3	95%	2.1	13,522.9	78,037.3
DAHU 05	6.10	1152.00	2.3	95%	2.1	13,774.3	79,488.1
DAHU 06	5.99	1152.00	2.3	95%	2.1	13,526.0	78,055.2
DAHU 07	5.18	1152.00	2.0	96%	1.8	11,848.4	68,373.8
DAHU 08	6.86	1160.00	2.6	96%	2.4	15,680.3	90,487.1
DAHU 10	1.11	1152.00	0.4	89%	0.4	2,317.4	13,373.4
DAHU 12	6.17	1152.00	2.4	95%	2.1	13,932.3	80,399.4
DAHU 15	1.25	1160.00	0.5	89%	0.4	2,597.0	14,986.4
DAHU 18	6.04	2320.00	2.3	96%	2.1	13,817.7	79,738.6
DAHU 21	12.09	1168.00	4.6	96%	4.2	27,652.6	1,59,575.7
DAHU 22							
DAHU 23							
Total					19.6	1,28,669	7,42,515

[17] Method of estimating VFD Efficiency presented in Appendix III.

4.5.2.4 Consolidation of DX System Capacity

Considering that the performance assessment of the DX system was inconclusive due to absence of rated performance data as well as the confounding measurements resulting from the audit process, the assessment presented below is likely to alter significantly should the system be re-assessed to yield data and results contrary to those available currently.

It is surmised that DAHU 25 is running at lesser effectiveness compared to DAHU 24; a conclusion that stems from the strikingly low delivered TR. If these two AHUs supply adjacent areas, the DX system could be consolidated in such a manner that the AHU No. 24 serves the areas served by itself as well as its corresponding unit (AHU No. 25). It is anticipated that this modified operational configuration could significantly curb the part load operation possibly prevailing currently and consequently allow for energy conservation relative to the current mechanism in place at the Plant. It is recommended that this analysis be re-visited subsequent to re-measurement of the DX system performance.

4.5.2.5 Thermal Energy Storage System for partial Chiller replacement

Thermal Energy Storage (TES) based HVAC systems, relative to conventional compressor based systems, can reduce peak electrical load imposed during the afternoon peak cooling load periods on the local electric grid. This technology essentially relies upon standard chillers operating at off-peak hours to produce ice or chilled water and stored in an insulated tank. This stored coolness is then used for space conditioning during hot afternoon hours, using only circulating pumps and fan energy in the process and circulated though the buildings AHUs. Thermal storage systems can be retrofitted into existing water-based central air conditioning systems and is a very useful advantage since it reduces barriers for rapid adoption on a wide scale.

A thermal energy storage system yields the following three primary benefits:

Load Shifting

- the fact that TES uses energy during off-peak periods permits taking advantage of Time-of-Day tariffs provided by electrical utilities that monetarily incentivize use of energy during those periods.
- TES operation (to compliment or completely take over) peak cooling demand enables reduced peak demand charges.

Reduced Capital and Maintenance Costs

- TES systems that are used for 'peak shaving' and 'load leveling' are characterized by smaller chillers (than in a Business-as-Usual scenario such as for direct cooling) operating at full load all night as opposed to a larger chiller operating at full or part load during the day. This has a cascading beneficial impact as it allows for smaller auxiliaries such as cooling-tower fans, condenser water pumps, or condenser fans.

- The smaller equipment sizes or reduced quantity of equipment's lead to reduced maintenance needs.

Energy Efficiency

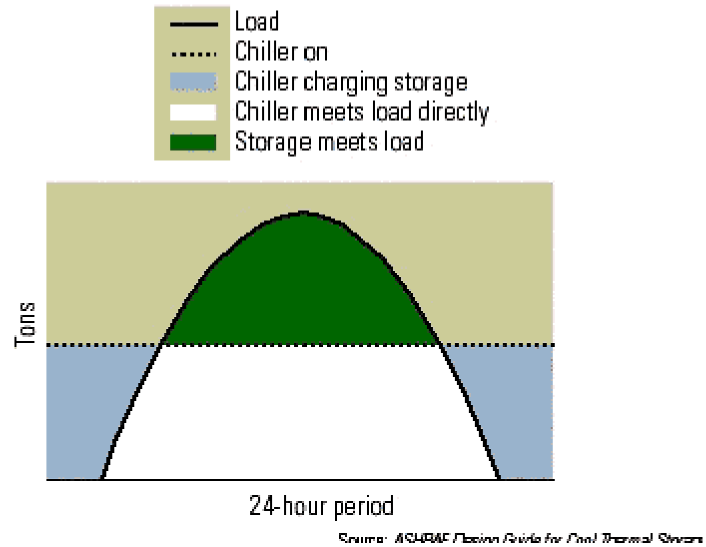
- Conventional systems usually operate at partial operating conditions which are detrimental to efforts towards energy efficient performance of compressors, pumps, fans etc. which are usually designed to operate most efficiently as a defined operating point known as the Best-Efficiency-Point (BEP). For instance, For electric motors, efficiency varies with load, with the best efficiency being at about 75% of load. Deviating from this operating condition, as would be the case with part load operating conditions, results in higher specific energy consumption for performing a given function. In contrast, the chiller and other ancillary equipment used in a TES system operates at full-load conditions for shorter periods of time during the charging cycle at night and the resulting equipment's operating efficiency is maintained close to the optimal value at most times. Thus, TES system chillers either run at their full efficiency or not at all. This therefore affords the desirable scenario wherein chiller operation is not dependent on the varying cooling load profile of the building or for process cooling loads.
- A key source of energy efficiency inherent in TES systems is the night time operation of chiller condensers when outdoor dry and wet bulb air temperatures are cooler and the resulting heat rejection is improved. The net effect is usually a net decrease in kWh consumption for achieving the desired refrigeration effect.

Control strategies for TES systems are generally classified into a few key categories: partial storage, demand limiting, and full storage.

Partial storage (load leveling and peak shaving)

These systems function by generating only a portion of the daily during the previous off peak period and storing it for peak period use during which the load is satisfied by a confluence of the installed compressor-based system and stored energy (the ice or chilled water in the thermal storage tanks). This operation mechanism is depicted pictorially in the figure below. It is the strategy of choice when the peak-cooling load is much higher than the average load.

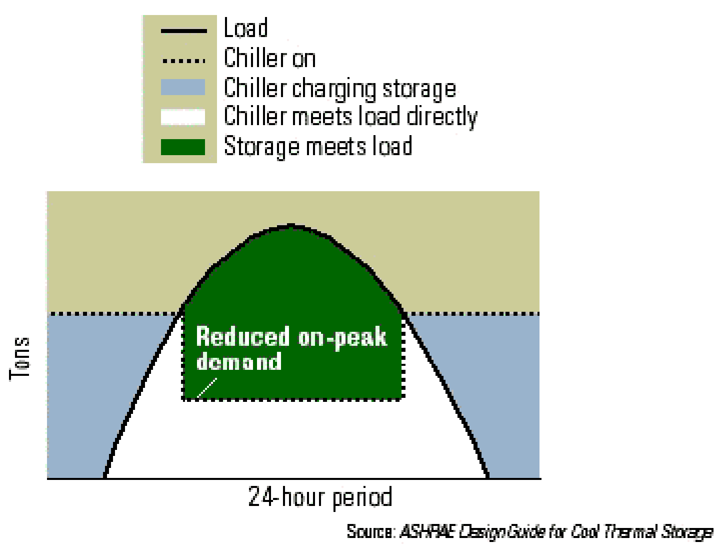
Figure 22 Load-Leveling and Peak Shaving TES System Operation



Demand Limiting

In a demand-limiting system the advantages of avoiding electric drive based compressors is driven further by ensuring that the chiller operates at reduced capacity during on-peak hours (not just avoiding peaking but actually reducing its load) and the peak is handled through the stored cooling energy. This strategy is presented in the figure below.

Figure 23 Demand-Limiting and Peak Shaving TES System Operation

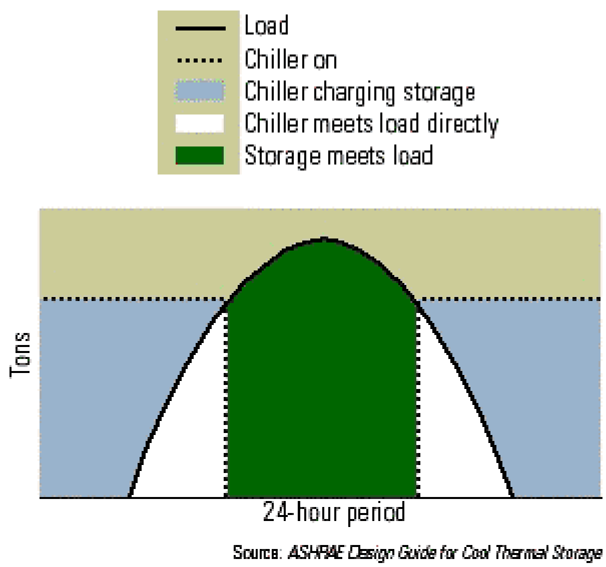


Full Storage (load shifting)

Full storage refers to discharging stored capacity without any concurrent chiller operation during the peak cooling load. The system operates at full capacity during all non-peak hours to generate adequate chilled water or ice for satisfying the cooling load on the hottest anticipated days. This strategy is most advantageous where on-peak demand charges are high or the on-peak period is short. However, the system does require larger chillers and ice storage equipment as the system will have to provide the entire cooling capacity itself without the assistance of the primary compressor system which is the case with the partial storage, load-leveling strategy.

This operation mechanism is depicted pictorially in the figure below.

Figure 24 Load Shifting TES System Operation



The primary components of a TES system are a storage medium, a tank, a packaged chiller or built-up refrigeration system, and interconnecting piping, pumps, and controls. TES systems are broadly classified by storage medium and storage technology. Three types of storage media are generally witnessed in industrial applications: chilled water, ice, and eutectic salts.

The size and configuration of the HVAC system components is determined by the storage media used which establishes storage tank sizes. The corresponding storage technologies are chilled water tanks, ice systems, and phase-change materials. Overall, ice systems offer advantage of the densest storage capacity (stemming from the high latent heat of fusion of water) but a commensurately more complex charge and discharge equipment. Water systems offer the lowest storage density due to absence of any phase change steps wherein significant energy can be stored in the modified physical state, but have relatively simple discharge systems. Eutectic salts represent a mean of these above two extremes in terms of storage density and system complexity.

A well documented disadvantage of the ‘ice storage’ based TES systems is the potential for increased energy consumption to provide the same cooling service. This stems from the phenomenon of increased energy requirement for a compressor to produce ice as opposed to chilled water and the additional energy needed to pump fluids in and out of storage. The impact of this is that the refrigeration capacity of compressors is rendered de-rated by 25 to 30%. This noTable disadvantage can however be overcome to not only nullify its impact but even yield net energy savings due to the full load chiller operation at night versus part-load operation during the day. Furthermore, the chiller size can be reduced that required for direct cooling, thereby allowing reduced auxiliary equipment sizing such as cooling tower or condensing system.

The net impact of TES systems versus conventional systems can be summarized through the following operational benefits:

- In the case of Ice Storage based TES systems, Chiller size can be reduced by 40 to 60%[18]
- Proportionate reduction in refrigerant use and leakage (thereby reducing fugitive GHG emissions from refrigerant leakage)
- Can reduce annual energy consumption on a ton-hour basis for air conditioning by up to 12% to 25%[19]
- Reduction of 30 to 40% in fan electrical demand and energy consumption for cold air distribution due to lower temperature air (and hence lower volumetric flow rate requirements) that can be generated through the system to serve the same cooling loads[20]
- Cooling towers size reduction 50%
- Reduced electricity charges: demand charge (kW) and energy penalty cost (INR/kWh) avoided due to reduced energy consumption during peak tariff periods.

For the existing Plant, the 315 TR Chiller in Block 4 is presently not utilized to full capacity and is a ideal candidate for augmenting with a TES that that operates during the day time (i.e. load shifting). The existing electric-drive Chiller system would be used during the periods of favorable TOD electricity tariff (10 PM on wards till 6: AM) while stored Chilled water provides the necessary cooling during peak day time periods. It is, however, emphasized that accurate sizing, life-cycle energy conservation, and cost reduction analysis can only be conducted once all relevant current and historical Chiller operational data is made available. These specific data requirements are explicitly listed in Appendix V.

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[18] Source: PDHonline Course M145, HVAC: Cool Thermal Storage

[19] Source: Bahnfleth, W.P., and W.S. Joyce. 1994. Energy use in a district cooling system with stratified chilled-water storage. ASHRAE Transactions 100(1):1767-1778., PDHonline Course M145, HVAC: Cool Thermal Storage pp. 27 – “ice storage reduces the nominal capacity of the chiller and cooling tower from 400 tons to 200 tons”

[20] Source: 2012 ASHRAE Handbook—HVAC Systems and Equipment, CHAPTER 51 THERMAL STORAGE

4.5.3 Comfort Cooling Air Conditioning (Split Unit ACs)

4.5.3.1 Split Unit AC Performance Assessment

The Table below provides an estimate of the operational performance of the Split Unit ACs audited at the Plant. The Plant possesses 59 Split Unit ACs comprising mainly 1.5 TR and 2 TR ACs with a few larger Package/DucTable Split ACs with a 8.5 TR rated capacity. The assessment conducted indicates that the total rated Split ACs capacity at the Plant is 122 TR and the corresponding rated power consumption is 122 kW. The measurements indicated that the system consumes an estimated 2,97,910 kWh/year. The key efficiency parameter for Split Unit ACs is the Energy Efficiency Ratio (EER) Efficiency. The analysis indicated that the average energy efficiency of the 1.5 TR Bluestar ACs(16 Nos.) is relatively low at 1.95 while the energy efficiency of the other ACs is generally higher than 3.5. This indicates a clear opportunity for energy savings from the replacement of some of the 1.5 TR ACs. To clarify this potential, the % 'inefficient' and 'efficient' AC capacity across small and large ACs was calculated. 'Efficient' ACs were defined as those with a field-measured EER that would qualify for at least a BEE 3-Star Rating (EER of 2.9 to 3.1). Those with lower field-measured EERs were classified as 'Inefficient'. The conclusion of this assessment is provided in the Tables and charts below. The charts clearly indicate that the percentage of efficient equipment is approximately 76% while inefficient capacity is only 24 %.

Table 69 HVAC System – Split Unit AC Performance Assessment

Brand	Rated Capacity (TR)	Qty.	Total Capacity (TR)	kW/TR)	EER	Total Rated Power (kW)	Star Rating	Status	Energy Cons. (kWh/yr)
Carrier	1	1	1	NA	NA	NA	NA	NA	NA
Voltas	1	1	1	NA	NA	NA	NA	NA	NA
Blue Star	1.5	16	24	1.80	1.95	43.2	No Star	Inefficient	1,00,915
Carrier	1.5	2	3	1.27	2.76	3.82	2 Star	Inefficient	8,924
Voltas	1.5	8	12	0.83	4.25	9.92	5 Star	Efficient	23,173
OLG	1.5	1	1.5	1.30	2.71	1.95	2 Star	Inefficient	4,555
Blue Star	2	19	38	0.77	4.57	29.26	5 Star	Efficient	68,351
Carrier	2	3	6	0.61	5.81	3.63	5 Star	Efficient	8,480
Voltas	2	5	10	0.83	4.26	8.25	5 Star	Efficient	19,272
Blue Star	8.5	2	17	0.92	3.83	15.6	5 Star	Efficient	45,552
Carrier	8.5	1	8.5	0.75	4.67	6.4	5 Star	Efficient	18,688
Total		59	122			122.03			2,97,910

Figure 25 Split AC Star-Rating-wise Capacity Distribution

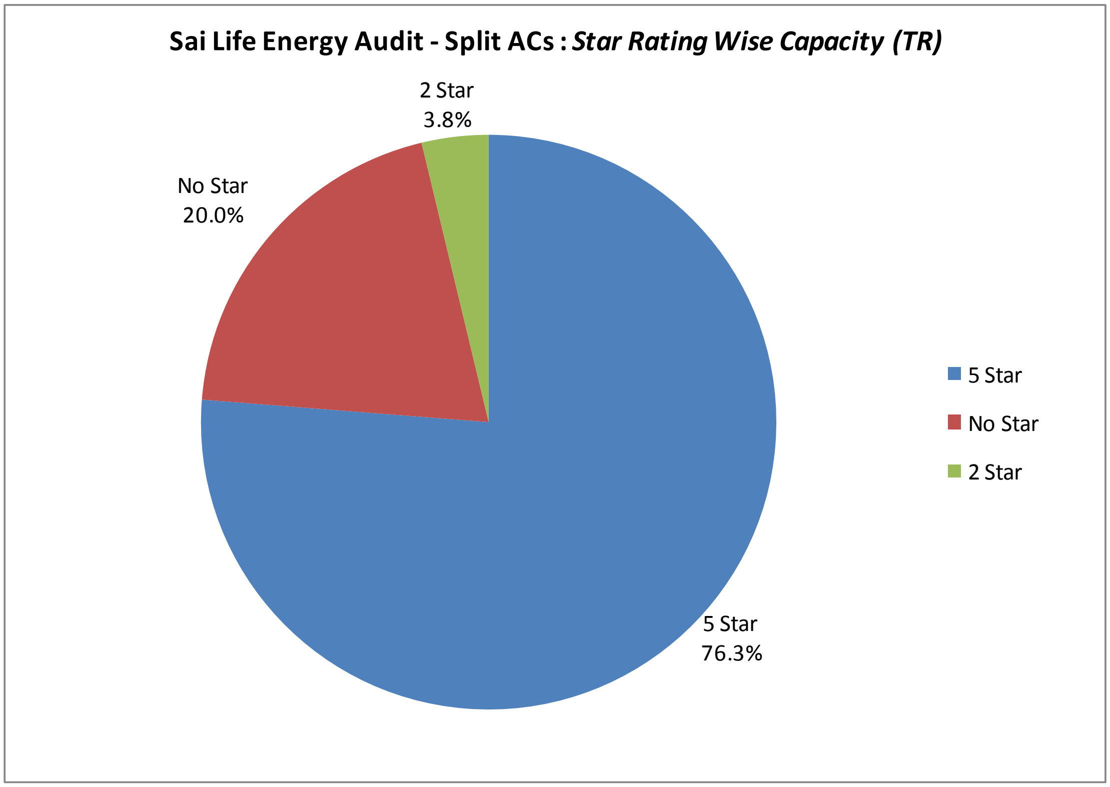
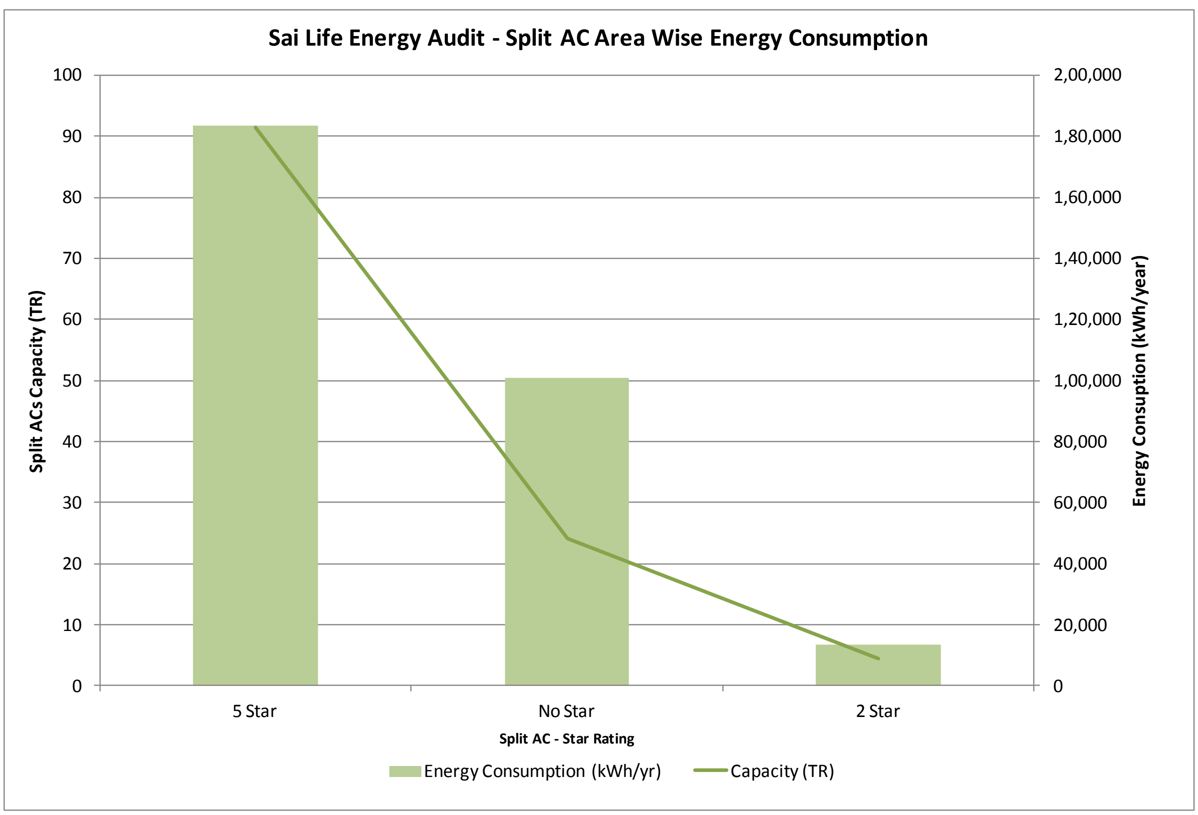


Figure 26 Split AC Star-Rating-wise Energy Use Distribution



4.5.3.2 Split Unit AC Energy Conservation Opportunities

Replacement with High Efficiency '6 Star' ACs

All 1.5 TR and 2 TR Split ACs that are functioning at a EER (Energy Efficiency Ratio) of less than 3 Star and/or are more than 5 years old are recommended for immediate replacement by Godrej EON Natural Refrigerant (R290) ACs if the distance between indoor and outdoor units is less than 20 ft. else be replaced by R-32 Refrigerant-based 5 Star-rated ACs.

Natural Refrigerant ACs present significantly competitive life-cycle energy, cost and carbon footprint characteristics for commercial consumers in India relative to the business-as-usual Window or Split-ACs (of 2 to 3 BEE Star Rating) using conventional HCFC or HFC refrigerants (f-gases).

Commonly encountered HCFCs (R22, R124, R141b, R142b) have GWPs ranging from 470 to 1,800. The refrigerant industry seeks to replace R22 and other HCFCs with HFCs which have very low Ozone Depletion Potential (ODP) but still have very high GWPs ranging from 650 to 1,300. Globally, there is a consensus amongst the scientific and HVAC engineering community that Natural Refrigerants such as Hydrocarbons (R290 or Propane) are the best alternatives. This class of refrigerants have zero ODP and a negligible GWP of 3.3, they are cheaper and more energy efficient than their conventional f-gas counterparts. The estimated yearly conservation benefits for 3000 hours use per year per AC compared to a 3-Star 1.5 Ton AC are:

- Energy conservation: 740 to 1715 kWh/year
- Cost savings: 5,400 to 18,700 INR/year (@ INR 9/kWh)
- Carbon footprint reduction: 1,2 to 2,2 tonnes CO2e/year
- The payback period for the incremental cost of these ACs versus BAU options is less than 2 years in most cases

The project energy and cost savings estimates for replacement of 19 Split Unit ACs with low EERs with Godrej Eon ACs is presented below. The analysis indicates that this intervention can yield annual energy and cost savings of approximately 21,390 kWh/year and INR 1.82 Lakh/year, respectively with at a acceptable payback period of 3.9 years.

Table 70 HVAC System – Split Unit AC Replacement with '6 Star' AC – Energy and Cost Saving Estimates

	BAU			Intervention		Savings		
Details	**Rated Cap. (TR)**	**Nos. of Units**	**Eff. (EER)**	**Eff. (EER)**	**Capital Cost (INR.)**	**Cost Savings - (INR/yr)**	**Payback Period (yrs.)[21]**	**Energy Conserv. (kWh/yr)**
Split Units (1.5 TR) - 2 Star to 6 Star	1.5	3.0	2.8	3.7	1,11,690.6	22,748.7	4.9	2,669.2
Split Units (1.5 TR) -1 Star to 6 Star	1.5	16.0	2.6	3.7	5,95,683.5	1,59,556.0	3.7	18,721.2
Total					7,07,374.1	1,82,304.7	3.9	21,390.4

[21] Payback period calculated based on total cost to arrive at a conservative estimate. Incremental-cost based payback would be significantly lower.

Replacement with Ducted Evaporative Air Cooling

From the Table above it can be noted that except for 1 x 8.5 TR AC for the Microbiology Lab, 1 x 8.5 TR AC for Block 5 and 1 x 2 TR AC for the UPS rooms, all Split Unit ACs are deployed for comfort cooling.

An evaporative cooler produces effective cooling by combining a natural process - water evaporation - with a simple, reliable air-moving system. Fresh outside air is pulled through moist pads where it is cooled by evaporation and circulated through a house or building by a large blower. As this happens, the temperature of the outside air can be lowered by as much as 30 degrees. This technology can provide significant savings relative to conventional electric compressor-based AC systems in areas with low humidity (which is applicable to the geographical region where the Plant is situated). Furthermore, this system will drastically improve air quality for and occupational health of office staff since these systems do not recirculate air unlike Air Conditioning systems. Incidences of building-sickness with these systems will be largely eliminated and will improve overall workforce productivity.

The projected energy and cost savings estimates for replacement of all comfort cooling Split Unit ACs with Ducted Evaporative Air Cooling Systems is presented below. The analysis indicates that this intervention can yield annual energy and cost savings of approximately 1,65,527 kWh/year and INR 9.55 Lakh/year, respectively with at a attractive payback period of 1.6 years.

Table 71 HVAC System – Split Unit AC Replacement with Evaporative Cooling – Energy and Cost Saving Estimates

BAU				Intervention			Savings		
Rated Cap. (TR)	Nos.	Eff. (EER)	Energy (kWh/yr)	EER	Energy (kWh/yr)	Capital Cost (INR)	kWh/yr	INR/yr	Payback (yrs.)
8.5	1.00	4.67	12,334	20.13	2,862	1,03,607	9,472	54,662	1.90
1.5	16	1.95	83,255	17.88	9,096	3,08,589	74,159	4,27,950	0.72
1.5	2	2.76	7,362	17.88	1,137	38,574	6,225	35,922	1.07
1.5	8	4.25	19,118	17.88	4,548	1,54,294	14,570	84,078	1.84
1.5	1	2.71	3,758	17.88	569	19,287	3,190	18,406	1.05
2	19	4.57	56,390	18.51	13,914	4,80,884	42,475	2,45,115	1.96
2	2	5.81	4,664	18.51	1,465	50,619	3,199	18,461	2.74
2	5	4.26	15,899	18.51	3,662	1,26,549	12,238	70,621	1.79
Total	54		2,02,780		37,253	12,82,404	1,65,527	9,55,215	1.62

4.5.3.3 Evaporative Air Pre-Cooling for Condensers

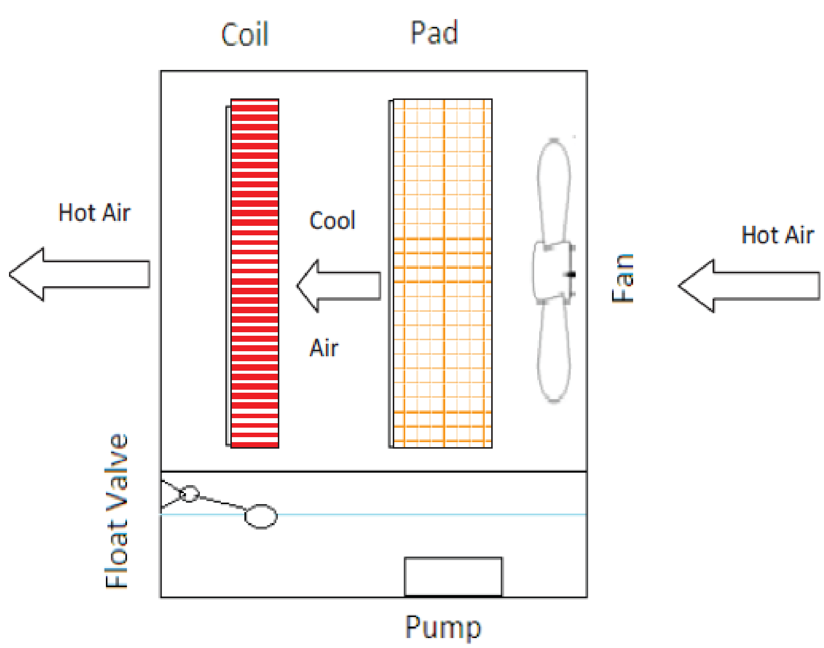
It is a commonly held belief amongst HVAC engineers that water-cooled systems are preferable to air-cooled condenser systems. The widespread reluctance amongst professionals is based on the misinformed belief that systems with air cooled condensers have a lower EER (Energy Efficiency Ratio – Btu/watt) relative to water cooled systems for the same ambient conditions. It is also asserted that the adverse impacts are magnified in hot and dry summer months when cooling loads generally peak in conjunction with higher ambient air temperatures. While it is true that water-cooled condensers are more efficient than air cooled systems during these extreme hot weather conditions, when put into perspectives these conditions are relevant only for a few hours a day in a few months in a year. During other periods, an air-cooled system is drastically more energy efficient. For instance, during monsoons the high ambient wet bulb temperature is high and the low dry bulb temperature render cooling towers less effective for achieving cooling with a given power consumption. Furthermore, during winters and evenings, nights and early mornings both the ambient temperature and the cooling loads are low wherein air-cooled systems are adequate and perform the cooling function without the use of cooling towers, pumps, piping and shell and tube condensers[22].

The conventional methods for improving the EER of air cooled systems are:

- Increasing the air quantity which results in higher fan energy and larger condenser coil face area.
- Spraying water directly on the coils which improves efficiency but adversely affects condenser fins over prolonged periods.

It is recommended that the Plant consider Evaporative Pre- Cooling for the air cooled condensers used in the Plants DX and Split Unit-based HAVC sub-systems. The pre-cooling process involves placing an evaporative cooling pad, tank and pump between the condensing unit's fan and its coil and presented in the schematic diagram below. The hot dry air is adiabatically cooled to near its saturation temperature before it passes over the condenser coil thereby improve the EER of the HVAC system.

Figure 27 Schematic Diagram of Evaporative Pre-Cooler



[22] Source: Cooling India March 2014, Evaporative Pre-Cooling for Air Cooled Condensers

The Table below presents the projected energy and cost savings estimates for application of Evaporative Pre-Cooling for all Air Cooled Condensers installed currently at the Plant which is expected to improve system EER by 60 %. The analysis indicates that this intervention can yield annual energy and cost savings of approximately 88,191 kWh/year and INR 5.09 Lakh/year, respectively with at an acceptable payback period of 4.88 years.

Table 72 HVAC System – Split Unit AC Replacement with Evaporative Cooling – Energy and Cost Saving Estimates

BAU					Intervention				Savings		
Rated Cap. (TR)	**Nos.**	**Eff. (EER)**	**Power (kW)**	**Energy Cons. (kWh/yr)**	**% increase in EER**	**Revised EER**	**Energy Cons. (kWh/yr)**	**Capital Cost (INR)**	**Savings (kWh/yr)**	**Savings (INR/yr)**	**Payback (yrs)**
8.5	2.00	3.83	15.6	30,064	0.6	6.1	18,790	72,000	11,274	65,060.02	1.11
8.5	1.00	4.67	6.4	12,334	0.6	7.5	7,709	36,000	4,625	26,691.29	1.35
1.5	16	1.95	43.2	83,255	0.6	3.1	52,034	5,76,000	31,221	1,80,166.21	3.20
1.5	2	2.76	3.8	7,362	0.6	4.4	4,601	72,000	2,761	15,931.36	4.52
1.5	8	4.25	9.9	19,118	0.6	6.8	11,949	2,88,000	7,169	41,371.50	6.96
1.5	1	2.71	2.0	3,758	0.6	4.3	2,349	36,000	1,409	8,132.50	4.43
2	19	4.57	29.3	56,390	0.6	7.3	35,244	6,84,000	21,146	1,22,029.24	5.61
2	3	5.81	3.6	6,996	0.6	9.3	4,372	1,08,000	2,623	15,138.97	7.13
2	5	4.26	8.3	15,899	0.6	6.8	9,937	1,80,000	5,962	34,406.74	5.23
Total			122.0	235176.2			1,46,985	20,52,000	88,191	5,08,928	4.88

4.5.4 Cooling Towers

4.5.4.1 Cooling Tower Performance Assessment

The Table below provides an estimate of the operational performance of the Cooling Towers audited at the Plant. The Plant possesses 9 Cooling Towers with a rated combined capacity of 870 TR and a corresponding rated power consumption of pumps of 87.7 kW. The total rated power consumption should also include power consumption for Cooling Tower Fans. However, this data was not available to the Plant operators and management and hence constitutes an incomplete scenario. The measurements indicated that the system consumes an estimated total power (Pumps and Fans) or 91.8 kW and 6,03,257 kWh/year electrical energy while delivering a much lower than rated cooling magnitude of 207.7 TR.

The key efficiency parameter for Cooling Towers is the 'Effectiveness ' parameter defined by the following mathematical relationships:

$$Range = Inlet_{Hot\ Water\ Temp\ 0C} - Outlet_{Cold\ Water\ Temp\ 0C}$$

$$Approach = Outlet_{Cold\ Water\ Temp\ 0C} - Ambeint_{Wet\ Bulb\ Temp\ 0C}$$

$$Cooling\ Tower\ Effectiveness\ (\%) = \frac{Range}{Range + Approach}$$

The assessment presented below indicates Cooling Tower effectiveness at the Plant ranges from 3 % to 66 % (except for one instance where it is greater than 100 %). Cooling Tower Effectiveness is a key performance indicator and therefore an indicator of energy efficiency as well. It was seen that the ETP plant's DCTR 06, Block 4's DCTR 10, SRS plant's Cooling Tower and Block 4's DCTR 09 function with poor effectiveness in the range of 3 % to 30 % and these cooling towers show scope for energy savings.

It is evident that the % Effectiveness must necessarily be less than 100 % since the 'Approach' temperature difference cannot be less than 'zero' (i.e. the exiting outlet water temperature cannot be lower than the ambient wet-bulb temperature). It was learned that the anomalous 'Effectiveness' value for DCTR 07 associated with Block 4 is an outcome of a unusual operational situation wherein water at low temperature is added to the water basin where it continues to circulate thereby lowering the temperature of basin water below the WBT.

Table 73 Cooling Tower Performance Assessment

Sr. No	Location	Cooling Tower ID	Rated Capacity (TR)	Motor (kW)	Total Power Consumption (kW)	Measured Effectiveness (%)	Actual Capacity (TR)	kW/TR	EER	Annual Energy Consumption (kWh/year)
1	Block 06 Terrace	DCTR 12	0	5.5	24.02	47.06%	0.00	NA	0.0	1,57,811
2	Block 04	DCTR 10	up to 50 deg C	0	27.15	33.44%	41.43	0.66	5.4	1,78,376
3	Block 06	DCTR 11	500	22.5	4.16	46.07%	0.00	NA	0.0	27,331
4	Block 01	DCTR 05	100	7.5	2.29	60.32%	33.49			15,045
5	Block 01	DCTR 03	100	7.5	6.57	45.95%	49.23	0.05	26.4	43,165
6	ETP Plant	DCTR 06	100	9.3	13.53	33.31%	69.95	0.19	18.2	88,892
7	SRS Plant		0	11	11.87	37.49%	28.31	0.42	8.4	77,986
8		DCTR 09	35	7.5	2.24	7.99%	13.71	0.16	13.7	14,717
9	Block 04	DCTR 07	35	2.2	4.13	24.99%	13.26	0.31	13.3	27,134
										6,30,457

4.5.4.2 Cooling Tower Energy Conservation Opportunities

Improved Effectiveness and Reduced Fan Power Consumption

The rated effectiveness of the Cooling Towers was estimated to be 55 % based on manufacturer data related to design inlet and outlet water conditions (temperatures and flowratres). However, inadequate design data (related to rated L/G flowrate ratio, fan diameter) as well as hazards involved in measuring fan diameter and flow rates atop Cooling Tower Fans prevents estimation of the potential energy savings through increase in effectiveness or through an increase in the L/G ratio.

The mechanisms through which this would materialize are:

- Achieving a lower water exit temperature with the same fan flowrate which therefore allows for reduced water flowrate in the chiller condensers and associated pumps thereby leading to energy savings
- An increased L/G ratio allows for reduced fan flow rate to treat the same water flowrate, through improved maintenance or replacement of Fills which can improve heat-transfer rates or conductance etc.

Cooling Tower Load Consolidation

The unavailability of the design data or possibility of measuring the L/G ratio for the cooling towers prevents estimation of the potential savings from Load Consolidation of towers operating at partial load.

Improved Maintenance

It is possible that the reduced effectiveness of the above mentioned Cooling Towers is due to the following phenomena which should be verified through intricate observation and subsequently addressed:

- Clogging of spray nozzles: this could not be verified while the Cooling Towers were operational and needs to be assessed during a shutdown
- Uneven water and air flow: this phenomenon was witnessed above many Towers
- Clogging of fills in the Towers is perhaps recurrent and requires meticulous cleaning
- Fan blade angle should be increased to increase air flow

The specific maintenance checks and subsequent to be performed for each of the towers is presented below. Immediate implementation of this strategy is recommended to yield immediate energy conservation and cost saving benefits.

Appendix VII presents photographic evidence of uneven distribution of water over Cooling Towers fills and poor water quality (indicating clogged fills) for some of the Units where photography was feasible.

Table 74 Cooling Tower Maintenance Recommendations

Cooling Tower ID	Maintenance Recommendation
DCTR 10	Clogging of fills
IEC 1083 / DCTR 11	Fan blade angle to be increased to increase air flow and fills cleaning required
DCTR 06	Increase fan blade angle and clean fills.
SRS Plant	Fills to be cleaned/ replaced
DCTR 09	Fills to be cleaned/ replaced

Replace SS Fans with FRP Fans

It was noted that the Block 6 Cooling Tower (DCTR 12) Fan is made of Stainless Steel (SS). Replacement of the fan with an FRP fan can yield energy saving in the range 20% to 30%. This recommendation can be followed uniformly across the Plant wherever SS Fans are encountered for Cooling Tower applications. The projected energy and cost savings estimates for replacement of SS Fans with FRP Fans across the Cooling Towers is presented below. The analysis indicates that this intervention can yield annual energy and cost savings of approximately 29,598 kWh/year and INR 1.71 Lakh/year, respectively. The equipment cost is expected to be INR 60,000 which leads with at an attractive payback period of 0.4 years.

Table 75 Cooling Tower Fan Replacement – Energy and Cost Saving Estimates

Rated Fan Motor Power (hp)	Measured Fan Power (hp)	Increase in Efficiency	Revised Fan Power (kW)	Fan Power Saving - (kWh)	Fan Energy Saving - (kWh/year)	Fan Cost Saving - (INR/year)
49.62	24.15	0.25	13.52	4.51	29,597.85	1,70,801.51

Energy Saving with Reflect Water Pumps

The Table below presents the projected energy and cost savings estimates for speed reduction up to 80% for all Reflect Water Pumps. The analysis indicates that this intervention can yield annual energy and cost savings of approximately 1.68 Lakh kWh/year and INR 9.71 Lakh/year, respectively. Considering a equipment cost of INR 3.15 Lakh for all the VFDs for this system, the payback period is a very acceptable 0.52 years.

Table 76 Cooling Tower Pump VFD Application – Energy and Cost Saving Estimates

Rated Motor Power (hp)	Actual Rated Power (hp)	Scenario: Turned Down Fan Speed (RPM)	Scenario: Turned Down Fan Power (kW)	VFD Efficiency %	VFD Power Saving - (kWh)	VFD Energy Saving - (kWh/year)	VFD Cost Saving - (INR/year)
7.38	8.05	1,176.00	3.07	95.0%	2.77	18,174.69	1,04,881.45
29.50	27.52	2,360.00	10.51	97.0%	9.69	63,655.58	3,67,339.82
4.69	2.08	2,296.00	0.79	89.0%	0.66	4,325.13	24,959.18
10.06	3.07	2,320.00	1.17	96.0%	1.07	7,021.14	40,517.18
10.06	5.74	2,320.00	2.19	96.0%	2.00	13,122.48	75,726.43
12.47	11.69	2,360.00	4.46	96.0%	4.07	26,735.52	1,54,283.75
14.75	12.90	2,336.00	4.93	96.0%	4.49	29,494.92	1,70,207.53
10.06	0.00	2,360.00	0.00	96.0%	0.00	0.00	0.00
2.95	2.75	2,304.00	1.05	89.0%	0.87	5,720.33	33,010.53
						1,68,249.79	9,70,925.86

Summary Energy Conservation Opportunities – HVAC System

- **Existing Chiller Replacement by Efficient Chiller System:** By replacing current chiller system to more efficient chiller system yields annual energy savings and cost savings of approximately 4,95,931 kWh/year and INR 28,61,889 per year.
- **VFDs for Chiller Connected AHUs :** By Implementation of VFDs for Chiller connected AHUs (DAHU 09,13,14) yields annual energy and cost savings of approximately 34,693 kWh/year and INR 2,00,000 per year, respectively. With an equipment cost of INR 89,750, the payback period is an acceptable 0.5 years.
- **VFDs for Fresh-Air Ventilation AHUs:** By Implementation of VFDs for Chiller connected AHUs yields annual energy and cost savings of approximately 1,28,669 kWh/year and INR 7,42,515 per year, respectively.
- **Thermal Energy Storage System for partial Chiller replacement:** Thermal energy storage system reduces capital and maintenance cost and also highly efficient.
- **1 Star and 2 Star Split ACs System Replacement with 6 Star ACs:** Replacement of 1 star and 2 star Splits Units (1.5 TR) with 6 Star Split Units can results in energy savings of 21,390.4 kWh/year and associated cost reduction of approximately INR 1,82,304.7 per year. With an equipment capital cost of INR 7,07,374 and payback period of 3.9 years.

- **Split ACs System Replacement with Evaporative Air Coolers:** Replacement of split ACs system with evaporative air cooler can results in energy saving of 1,65,527 kWh/year and associated cost saving INR 9,55,215 per year. With an equipment capital cost of INR 12,82,404 and payback period of 1.62 years.
- **Evaporative Air Pre-Cooling for Condensers:** Implementation of pre air coolers can yield annual energy and cost savings of approximately 88,191 kWh/year and INR 5,08,928 year, respectively with at an With an equipment capital cost of INR 20,52,000 and payback period of 4.88 years
- **Cooling Tower Fan Replacement:** Replace SS 304 Fan with FRP Fan can yield annual energy and cost savings of approximately 29,597.85 kWh/year and INR 1,70,801.51 per year respectively With an equipment capital cost of INR 60,000 and payback period of only 0.4 years.
- **VFDs Cooling Tower Condenser Water Pumps:** By Implementation of VFDs on condenser water pumps yields annual energy and cost savings of approximately 1,68,250 kWh/year and INR 9,70,925 per year, respectively. With an equipment cost of INR 3,15,037 the payback period is an acceptable 0.52years.

4.6 Boilers and Steam System

4.6.1 Boiler & Steam System Performance Assessment

Numerous manufacturing processes at the Plant require steam at locations within the manufacturing blocks and the Effluent Treatment Plant (ETP). Steam is generated using a Boiler fired with a blend of solid fuels, coal and bio mass briquettes, fed manually to the boiler.

4.6.1.1 Thermal Efficiency and Loading Assessment

A set of experimental trials was conducted, described as under, to assess efficiency under controlled conditions using the 'Direct Method' of efficiency assessment as outlined by the BEE Energy Audit Manual.

- ✓ Batches of fuel (Briquette + Coal) were prepared for firing the Boiler over a given time period
- ✓ Feed Water supply to Feed Water Tank was stopped
- ✓ Condensate supply line to Boiler was blocked
- ✓ Feed Water tank dimensions was noted
- ✓ Feed Water temperature was recorded
- ✓ Outer dimensions were measured
- ✓ Water level drop, subsequent to consumption of fuel stock, was measured
- ✓ Total fuel consumed during the trial was measured

The performance parameters measured during the trials are presented below.

The relevant equations used to determine Boiler efficiency were:

$$\text{Heat Input (kcal)} = \text{GCV of Fuel (kcal/kg)} \times \text{Fuel Mass (kg)}$$

$$\text{Heat Output (kcal)} = \text{Mass of Steam (kg)} \times (Enthalpy\ of\ Steam - Enthalpy\ of\ Feed\ Water)$$

$$\text{Efficiency (\%)} = \frac{\text{Steam Flow Rate (kg/hr)} \times (Enthalpy\ of\ Steam - Enthalpy\ of\ Feed\ Water)}{Fuel\ Firing\ Rate\ (\frac{kg}{hr}) \times \text{GCV of Fuel (kcal/kg)}}$$

Table 77 Boiler Efficiency Trials Performance Parameters

Parameter	Trial No. 1	Trial No. 2
Make	Thermax Ltd	Thermax Ltd
Model	CPD-50/10.54/23	CPD-50/10.54/23
Boiler Type	Mixed Fuel	Mixed Fuel
Capacity (TPH)	5	5
Fuel Used -01	Coal	None
Fuel Used -02	Briquette	Briquette
Fuel -01 Avg Consumption (kg/hr)	336.0	0.0
Fuel -02 Avg Consumption (kg/hr)	243.0	648.0
Quantity of Steam Generated (TPH)	1.91	1.82
Steam Pressure (kg/cm²)	8.5	8.5
Steam Temperature (°C)	175.0	175.0
Enthalpy of Generated Steam (kCal/kg)	661.6	661.6
Feed Water Temperature (°C)	32.0	32.0
Enthalpy of Feed Water (kCal/kg)	32.0	32.0
Enthalpy of Consumed Fuel (kCal) – INPUT ENERGY	22,23,502.5	23,48,028.0
Enthalpy of Steam Generated (kCal) – OUTPUT ENERGY	12,03,070.1	11,45,781.0
Boiler Loading (%)	42.8 %	40.8%
Boiler Efficiency (%)	54.1 %	48.8%

It is to be noted that while the rated capacity of the Boiler was 5 TPH, (at 100^0C Feed Water Temperature), the effective rated capacity (for purposes of determining the operational loading rate as a %) was expected to be lower since the return Feed Water temperature was measured to be approximately 38^0C. This 'de-rated' capacity was calculated to be approximately 4.5 TPH and the % loading was calculated based on this value.

The results of the 1st trial yield a 54.1 % Boiler efficiency and a 42.8 % loading[23]. This contrasts significantly with the Boiler efficiency calculated from values provided in the Boiler operation log sheets. This data is presented below and yields a Boiler efficiency of 34.6 %; notably lower than the measured values.

Table 78 Boiler Log Sheet Data

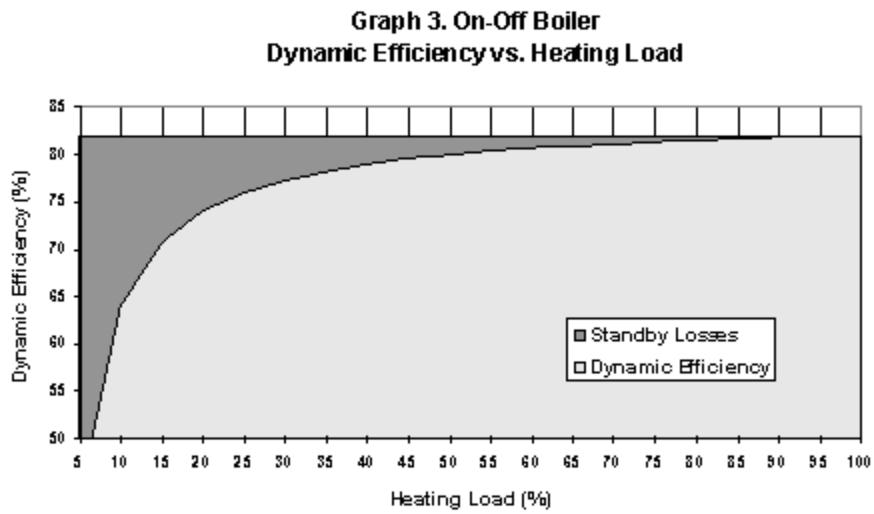
Parameter	Value
Daily (24 hr.) Steam Generation (kg)	25,000
Daily (24 hr.) Coal Consumption (kg)	8,000
Daily (24 hr.) Briquette Consumption (kg)	3,000

[23] Note: results of Trial 2 were not considered representative due to uncertainty related to time taken to consume the Briquette fuel completely during the test.

It is undeniably clear that Boiler operational data collection, especially fuel feed monitoring and record keeping, processes need to be reviewed and adhered to.

The most vital outcome of the Boiler Efficiency trials was that the measured efficiency was seen to be much lower than anticipated relative to the average industry benchmarks. Figure 28 below indicates the expected Boiler Efficiency as a function of Heat Load %[24]. As expected, the plot indicates an increasing Dynamic Efficiency of the Boiler for higher Heat Load conditions. For the Heat Load conditions simulated during the trials (~ 43%), the benchmark efficiency curve below indicates a minimum expected Dynamic Efficiency of approximately 75%. This is approximately 20% higher than the measured efficiency of 54%.

Figure 28 Benchmark Boiler Dynamic Efficiency % vs. Heat Load % Curve



4.6.1.2 Energy and Efficiency Loss Assessment

The 'Indirect method' of assessment was used to ascertain relative contributions of various sources of efficiency loss to the overall efficiency loss witnessed during the trials described earlier. The 'Indirect Method' requires laboratory analysis of fuel to determine chemical composition of the fuel, and analysis of flue gas using a Flue Gas Analyzer. While fuel analysis was conducted, and the results obtained are presented as under, a Flue Gas Analyzer was not employed for this Project. This prevented accurate assessment of the some of the parameters required for undertaking a exhaustive 'Indirect Method' analysis. The parameters that could not be ascertained accurately were as follows:

- % O_2 in Flue Gas
- % CO_2 in Flue Gas
- % Excess Air Supplied
- Actual Mass of Supplied Air

[24] Source: http://www.raypak.com/support/tech_corner/modulation

In the absence of these measurements, the Excess Air supply was assumed rather than calculated to arrive at Actual Air supply.

Table 79 Coal Fuel Analysis Results

Sr. No	Characteristics	Values
1	Total Moisture	3.37%
2	Ash	38.51%
3	Volatile Matter	22.68%
4	Fixed Carbon	35.44%
5	Carbon	42.67%
6	Hydrogen	2.75%
7	Nitrogen	0.85%
8	Sulphur	0.39%
9	Oxygen	11.46%
10	NCV in Kcal/kg	3846
11	GCV in kCal/kg	3997

Table 80 Biomass Briquette Fuel Analysis Results

Sr. No	Characteristics	Sample -1 (Black Briquette)	Sample- 2 (White Briquette)
1	Total Moisture	8.66%	8.29%
2	Ash	10.64%	9.71%
3	Volatile Matter	71.55%	71.27%
4	Fixed Carbon	9.15%	10.73%
5	Carbon	39.39%	39.45%
6	Hydrogen	5.48%	5.03%
7	Nitrogen	0.55%	0.45%
8	Sulphur	0.10%	0.10%
9	Oxygen	35.18%	36.97%
10	NCV in Kcal/kg	3348	3342
11	GCV in kCal/kg	3638	3609

The results of the losses calculated through the 'Indirect Method' are presented below. These loss assessments were compared to expected range of losses calculated from Boilers using typical Indian Coal[25] and Bio-Coal Briquettes[26]. This therefore required establishment of fuel properties for 'typical' fuels and are presented below.

[25] Source:

[26] Source: Minimum values obtained from Bepex International LLC USA and maximum values obtained from Krishna Bio Industry

Table 81 Typical Indian Coal Fuel Properties

Sr. No	Characteristics	Min. Value	Max. Value
1	Total Moisture	10.00%	20.00%
2	Ash	25.00%	50.00%
3	Volatile Matter	16.00%	30.00%
4	Fixed Carbon	24.00%	40.00%
5	Carbon	30.00%	55.00%
6	Hydrogen	2.00%	4.00%
7	Nitrogen	0.70%	1.15%
8	Sulphur	0.30%	0.80%
9	Oxygen	4.00%	8.00%
10	Excess Air	15.00%	60.00%
11	GCV in kCal/kg	2800	5000
12	Abrasive Index	40	60
13	Ash Softening Temp.	1300 Deg C	

Table 82 Typical Bio-Coal Fuel Properties

Sr. No	Characteristics	Min. Value	Max. Value
1	Total Moisture	2.78%	8.00%
2	Ash	7.50%	19.70%
3	Volatile Matter	63.43%	60.30%
4	Fixed Carbon	26.37%	20.00%
5	Carbon	52.04%	36.10%
6	Hydrogen	4.53%	4.80%
7	Nitrogen	0.47%	0.29%
8	Sulphur	0.05%	0.02%
9	Oxygen	32.69%	35.90%
10	Excess Air	25.00%	35.00%
11	GCV in kCal/kg	3800	4000
12	Abrasive Index	40	60
13	Ash Softening Temp.	1300 Deg C	

Theoretical losses estimated from fuels defined by the above properties are presented below. The hybridized values for a mixed-fuel operation are also presented based on a Coal to Biomass Briquette weight ratio of 58 % and 42 %, respectively.

Table 83 Estimated Boiler Heat Losses from Typical Indian Coal & Biomass Briquette

Description of Losses	Coal		Briquette		Mixed Fuel	
	Min. Loss (%)	Max. Loss (%)	Min. Loss (%)	Max. Loss (%)	Min. Loss (%)	Max. Loss (%)
Heat Loss Due to Evaporation of Water Formed due to Hydrogen	4.33%	4.85%	7.22%	7.27%	5.54%	5.86%
Heat Loss Due to Moisture Presents in Fuel	2.40%	2.69%	0.49%	1.35%	1.60%	2.13%
Radiation and Convection Loss in Packaged Boiler	1.50%	2.50%	1.50%	2.50%	0.10%	1.00%

Heat Loss Due to Moisture Presents in Air	0.10%	1.00%	0.10%	1.00%	8.30%	9.13%
Heat Loss Due to Dry Flue Gas	7.55%	10.93%	9.33%	6.64%	1.50%	2.50%

It is to be noted that three (3) other sources of heat losses from Boilers could not be estimated. Namely, heat losses due to partial combustion (conversion of C to CO), heat loss due to un-burnts in Fly Ash, and heat loss due to un-burnts in Bottom Ash could not be determined. This is attributed to the absence of Flue Gas composition analysis to determine CO % and CO_2 % in the Flue Gas stream and absence of Fly Ash and Bottom Ash GCV in the Fuel Analysis Report provided by the Plant.

Field measurements of operational parameters relevant for the 'Indirect Method' are presented in below.

Table 84 Boiler Operation Parameters for 'Indirect Method'

Parameter	Value
% of Excess Air in Coal	50.0%
% of Excess Air in Briquette	35.0%
Ambient DBT (K)	305.15
Ambient WBT (K)	291.15
Humidity Ratio	0.00813
Max. Surface Temperature (K)	355.15
Min. Surface Temperature (K)	350.15
Min. Flue Gas Temp. (°C)	209
Max. Flue Gas Temp. (°C)	237
Avg Wind Velocity (m/s)	1.7
Specific Heat of Flue Gas (kCal/kg)	0.24

The resultant losses calculated for each type of energy loss from the above operational data is presented below.

Table 85 Boiler Heat Losses from 'Indirect Method'

Sr. No	Details of Losses	Loss (%)	Status
1	Heat Loss due to evaporation due to H2 in fuel (%)	6.33%	Not Acceptable
2	Loss due to moisture presents in Fuel (%)	1.00%	Acceptable
3	Loss due to moisture in Air (%)	0.15%	Acceptable
4	Loss due to dry flue gas (%)	8.98%	Acceptable
5	Loss due to Radiation and Convection (%)	5.45%	Not Acceptable

It is evident from the above energy loss assessment that the heat losses due to evaporation of H_2 in the fuel and from radiation and convection from the Boiler surface are notably above 'acceptable' levels relative to values assessed for typical Indian Coal and Biomass Briquettes. Of these two types of losses, the type of loss that can be directly addressed is perhaps the losses due to Radiation and Convection (~ 5.5 %) which is much greater than an acceptable loss of approximately 2 % as mentioned earlier.

Finally, it must be underscored that heat losses due to incomplete combustion of fuel and that lost from bottom ash could also have played a vital role in the reduced efficiency observed through the 'Direct Method'. However, these could not be assessed as part of this Energy Audit and if the Plant seeks to harness greater energy conservation opportunities through optimization of Boiler performance, it could consider accurately determining the heat loss due to incomplete combustion and also optimize excess air supplied to the Boiler in consonance with the findings.

4.6.2 Boiler & Steam System Recommendation and Energy Conservation Opportunities

4.6.2.1 Thermal Efficiency Enhancement

The energy cost implications of efficiency de-gradation of 20% for a daily steam generation rate of 25 TPD (as indicated by Boiler log sheets) are computed and presented in Table **86** below. This can also be interpreted as potential energy savings potential for Boiler energy efficiency up-gradation through equipment refurbishment, maintenance or overhaul.

The potential cost savings through Boiler efficiency enhancement from ~ 54 % to ~ 75 % (i.e. ~ 28 % energy reduction) are approximately INR 53.05 Lakh/year for an energy intensity reduction of 12,383 GJ/year.

Table 86 Boiler Efficiency Enhancement Savings Estimate

Parameter	Trial No. 1	Trial No. 2
Boiler Efficiency (%)	54.1%	48.8%
Revised Boiler Efficiency	75.0%	75.0%
Fuel Cost - 01 (INR/kg)	7.98	7.98
Fuel Cost - 02 (INR/kg)	5.38	5.38
Avg. Steam Generation (kg/day)	25,000.0	25,000.0
Annual Fuel Energy Savings (%)	27.9%	34.9%
Total Heat Input - for Avg. Daily Steam Generation (kCal/year)	10,61,71,95,349	11,77,23,93,132
Revised Heat Input (kCal/year) - for Avg. Daily Steam Generation	7,65,95,25,000	7,65,95,25,000
Total Fuel Cost - for Avg. Daily Steam Generation (INR/year)	1,90,46,188	1,74,80,712
Revised Total Fuel Cost - (INR/year) - for Avg. Daily Steam Generation	1,37,40,423	1,13,73,554
Annual Fuel Cost Savings (INR/year)	53,05,765	61,07,158
Annual Fuel Energy Savings (GJ/year)	12,383	17,220

4.6.2.2 Modified Boiler-Firing Mechanism for Fuel Cost Reduction

The Boiler at the plant is operated in mixed-fuel mode and the Coal to Biomass Briquette weight ratio is 58.0 % and 42.0 %, respectively. On a kCal basis, this distribution is 60.4 % and 39.6 % across Coal and Biomass Briquettes, respectively. The relative cost per kCal of energy produced by the two fuels used is presented below and indicates that Biomass Briquettes are notably cheaper per unit of heat output; Biomass Briquettes are 25.6% cheaper per kCal. Additionally, the cost per kg of steam generated was assessed for three scenarios; coal based, Biomass Briquette based, and Mixed Fuel based (based on the currently practiced fuel splits on a energy basis).

Table 87 Relative Fuel Use and Cost

Sr. No	Fuel Type	Fuel Split (mass %)	Fuel Split (energy %)	Cost (INR/kg)	GCV (kCal/kg)	Cost (INR/kCal)
1	Coal	58.0	60.4	7.98	3997.0	0.00199
2	Biomass Briquettes	42.0	39.6	5.38	3623.5	0.00148

Table 88 Relative Steam Generation Cost

Sr. No	Fuel Type	Current Fuel Use (kCal fuel/kg steam)	Current Steam Cost Split (INR/kg steam)	Fuel Split (energy %)	Relative Steam Cost (INR/kg steam)
1	Coal	702.8	1.40	60.4%	2.32
2	Biomass Briquettes	460.8	0.68	39.6%	1.73
3	Mixed Fuel	1163.5	2.09	100.0%	2.09

The results of the above fuel and steam generation cost analysis indicate that steam generation cost in the currently practiced mixed fuel mode is approximately 2.09 INR/kg steam and the relative steam costs of the two fuels are INR 2.32/kg steam (if using only Coal) and INR 1.73/kg steam (if using only Biomass Briquettes). For a daily steam generation requirement of 25 TPD, switching to 100 % Biomass Briquette fuel can yield an annual energy cost reduction of INR 32.81 Lakh/year. It must be noted that this is not an energy conservation intervention and strictly a energy cost reduction alternative proposed for the Plant. The modification of the fuel feed system would require revamping as the fuel feed rate (in terms of mass per hour) would increase if only Biomass Briquette is used as fuel. Hence, the cost of this fuel feed overhaul would need to be determined and weighed against the annual cost savings potential to determine its feasibility.

4.6.2.3 Condensate Recovery

The Energy Audit site visit revealed that the condensate recovery from the Steam Distribution System was startlingly low; approximately only 1,000 litres out of the 25,000 TPD is recovered as condensate (from Block 6). This amounts to a exceptionally low 4 % recovery rate while the rest of the condensate is drained. It is also evident that the reason for this low recovery is not a Operational indifference towards energy conservation but rather stems from the challenge posed by condensate that is contaminated with chemicals and hence not readily usable by the Boiler without integration of a separation process step in the relevant condensate return lines. Given this context, the Operational team is not to be criticized for the current practice of achieving 4 % condensate recovery and energies must instead by directed to overcome the challenge of treating contaminated condensate at a low cost. Past experience and documented case studies in the field of Energy Auditing reveal that approximately 60 % to 70 % condensate recovery is routinely achieved in Indian industry. A conservative estimate of 40 % condensate recovery was considered here to project the potential for energy and cost savings through condensate recovery (post installation of a separation process to purify the returning condensate). The results of the condensate recovery analysis are presented below and indicate that achieving 40 % condensate recovery can yield a annual energy savings of approximately 330 GJ/year and a cost savings of INR 1.41 Lakh/year.

Table 89 Condensate Recovery Energy and Cost Savings Estimate

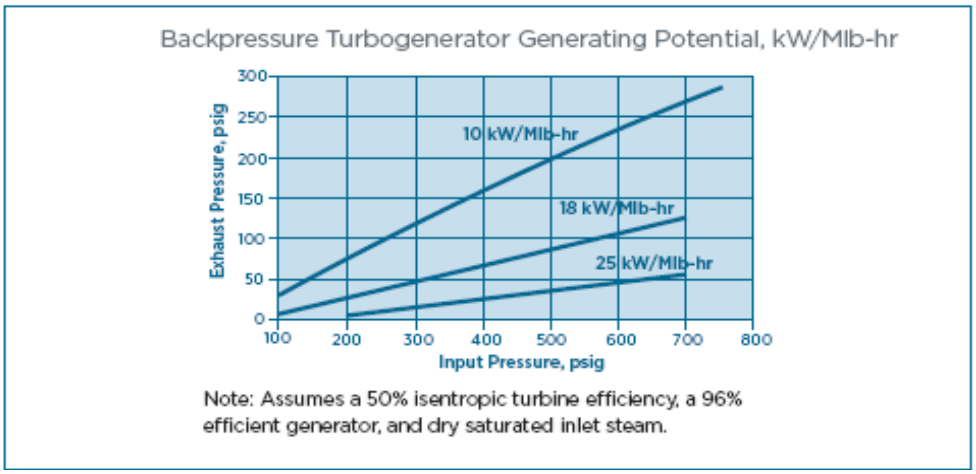
Parameter	Value
Scenario: Condensate Recovery (%)	40%
Current: Condensate Recovery (liters/day)	1000
Condensate Feed Water Temp. (°C)	45.0
Current: Feed Water Enthalpy (kCal/kg)	32.0
Enthalpy of Condensate Feed Water (kCal/kg)	45.01
Current: Condensate Recovery (%)	4.00%
Scenario: Condensate Recovery (liters/day)	10,000.0
Daily Feedwater Enthalpy Savings - Additional (kCal/day)	1,16,820.0
Fuel Saving by Condensate Recovery (kCal/day)	2,15,905.6
Fuel Saving by Condensate Recovery (GJ/year)	329.94
Fuel Cost Saving by Condensate Recovery (INR/year)	1,41,369.3

4.6.2.4 Electricity Generation through Backpressure Turbo Generator

Steam is generated at 9 bar at the Boiler outlet but the steam utilization pressure for different sections of the plant is lower. Currently, Pressure Reducing Valves (PRVs) are used to achieve this pressure drop. Instead, if a Back Pressure Turbo generator is used, it can convert high pressure steam into electrical energy while dropping the pressure as indicated in the

Figure 29 below[27].

Figure 29 Potential Energy Generation from Backpressure Turbogenerators



Applying an inlet pressure of 9 kg/cm2 (129 psi) and an exhaust pressure of 3.5 Kg/cm2 (50 psi), the power generation capacity was estimated to by 10 kW per Mlb per hour (i.e. per 1000 lbs/hr). The daily steam generation requirement is known to be 25,000 kg/day or an annual requirement of 20,117 Mlb per year. The resultant energy generation potential was assessed as presented below and leads to the conclusion that installation of a 10 kW/Mlb-hr Backpressure Turbogenerator can yield an annual energy generation of approximately 1.2 Lakh kWh/year and a consequent cost savings of approximately INR 6.97 Lakh/year. The power generated could be supplied to continuous but non essential loads in the plant. The capital cost of 10 KW back pressure turbine is estimated at INR 12,35,000.00 including installation commissioning, with life span of 12 to 15 years. This therefore yields a payback period of approximately 1.77 years.

Table 90 Backpressure Turbogenerator Energy Generation and Cost Savings Estimate

Parameter	Value
Rated Power Generation (kW)/Mlb-hr	10
Current: 60 % of Steam Generation Rate (TPH)	1.147

[27] Source: http://www.energy.gov/sites/prod/files/2014/05/f16/steam20_turbogenerators.pdf

Power Generation (kW)	25.2
Annual Steam Generation (Mlb)	12,070.3
Annual Energy Generation (kWh/year)	1,20,702.9
Annual Cost Savings (Rs)	6,96,545.4

4.6.2.5 VFD application for Boiler ID and FD Fans

It is evident from the above analysis that the Boiler is operated at part load (approximately 40% loading). A direct adverse impact of this continual part-load operation is that the dampers of the Forced Draft (FD) and Induced Draft (ID) Fans are closed and valve on Boiler Feed Water Pump on the discharge line is throttled to create artificial headloss thereby wasting energy.

VFD application to the FD and ID fan motors could eliminate the need for creating this artificial headloss to control air flowrate by modulating the motor speed instead and thereby reduce input motor power required. The equation governing the relationship between motor speed and power input required, the Affinity Law, is presented below which indicates that power consumption increases by the cubic power for a linear increment in speed. Therefore a relatively small impact on speed reduction can greatly reduce power requirement for a motor.

$$\frac{kW1}{kW2} = \frac{N1^3}{N2^3}$$

The Boiler's FD Fan was characterized by the following rated and operated parameters:

- Damper Position: 70% closed
- Fan Motor Rating: 3.7 KW
- Fan Speed: 1440 RPM
- Actual Power Consumption: 2.55 KW @ 0.78 PF

The corresponding parameters for the ID Fan were:

- Damper Position: 70% closed
- Fan Motor Rating: 13.89 KW
- Fan Speed: 1475 RPM
- Actual Power Consumption: 4.52 KW @ 0.90 PF

The task of estimating the reduced flowrate of the FD and ID Fan with 70 % closed position of inlet dampers required establishment of a predictive mathematical relationship between degree of damper opening or % damper opening as a function of % flowrate. Technical literature[28] was reviewed to estimate this mathematical relationship and the outcome of this research is depicted through the following charts for four distinct damper types: Parallel Blade Outlet Dampers, Opposed Blade Outlet Dampers, and Opposed Blade Outlet Dampers and a virtual 'Composite Damper' that was modeled as a hybrid of the aforementioned Dampers. In the absence of information about the specific damper type, the Composite model was selected

[28] Source: http://www.nyb.com/Catalog/Letters/EL-11.pdf - Figure 9

as being representative of the flow rate response to partial damper opening and closing positions.

Figure 30 Fan Flowrate % vs. Damper Opening % - Parallel Blade Outlet Damper

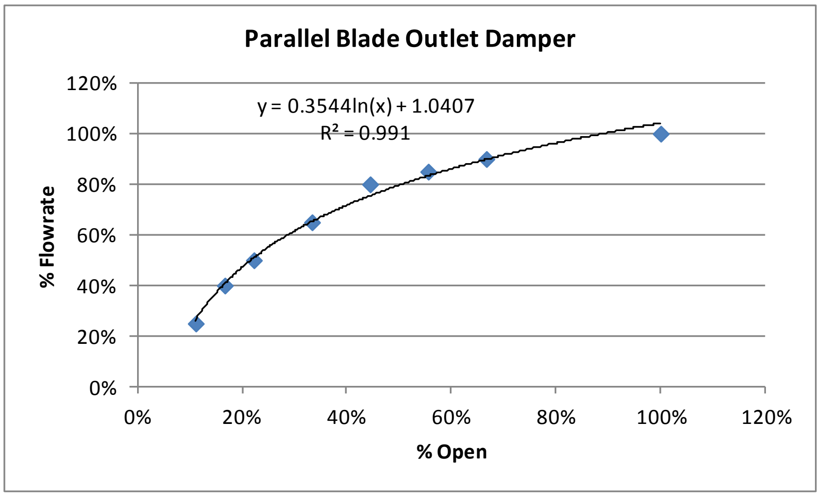


Figure 31 Fan Flowrate % vs. Damper Opening % - Inlet Damper

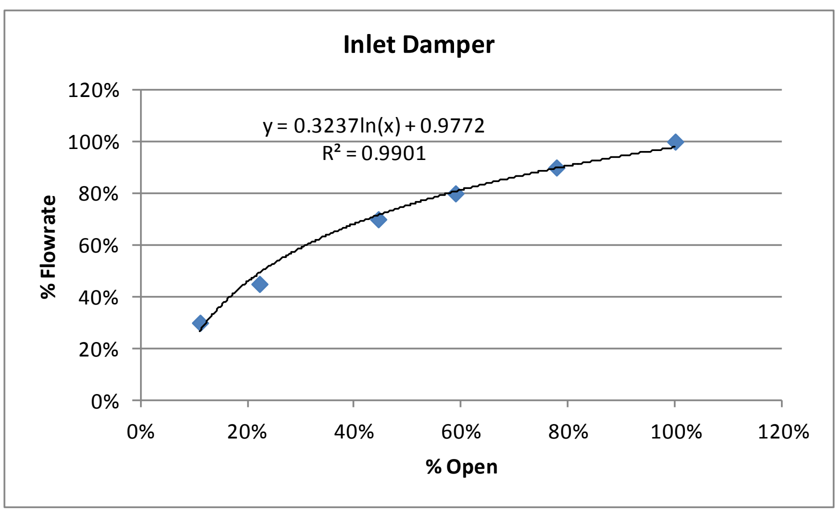


Figure 32 Fan Flowrate % vs. Damper Opening % - Opposed Blade Outlet Damper

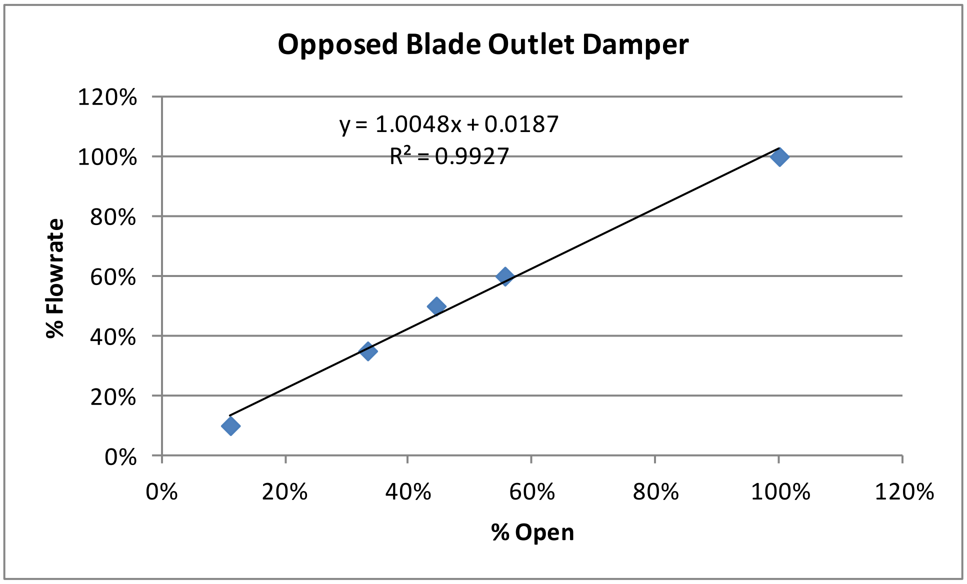
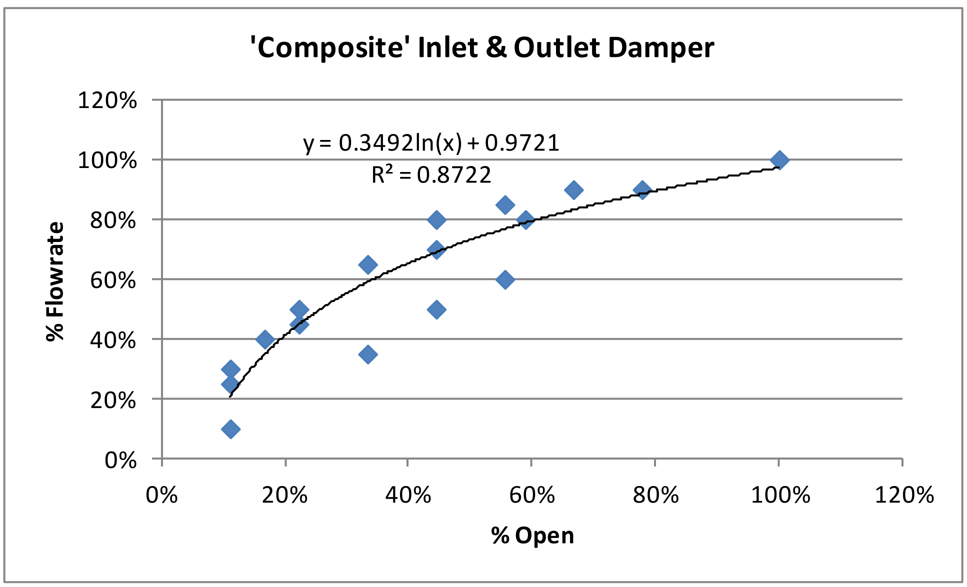


Figure 33 Fan Flowrate % vs. Damper Opening % - 'Composite' Inlet & Outlet Damper



The predictive relationship for the 'Composite'Damper type was used to estimate the % Flowrate achieved by the FD and ID Fan when operating with the damper in a 30 % open position. The following equation was used to estimate this.

$$y = 0.349 \ln x + \ 0.9721$$

Where,
x = Damper Opening %
y = Flowrate %

For a 30 % open condition, it was seen that flowrate would be approximately 55.2 % of full Fan flowrate. The equation governing the relationship between motor speed and flowrate developed, the Affinity Law, is presented below which indicates that speed is directly proportional to flowrate

$$\frac{Q1}{Q2} = \frac{N1}{N2}$$

Thus the speed required to achieve 55 % of rated flowrate would be 55 % of the rated speed and the resultant power savings would be computed by the earlier mentioned cubic relationship. The results of applying the Affinity Law and the calculated energy and cost savings for the FD and ID Fan are presented below.

Table 91 VFD Energy and Cost Savings Estimate – Boiler FD and ID Fans

Parameter	Value
FD Blower Motor Power - Actual (kW)	2.55
FD Damper Opened (%)	30%
Running Hours of FD Blower (hrs/day)	8
FD Blower Motor Speed (RPM)	1440
ID Blower Motor Power (kW)	13.89
ID Damper Opened (%)	30%
Running Hours of ID Blower (hrs/day)	8
ID Blower Motor Speed (RPM)	1475
FD Fan Flowrate %	55.2%
ID Fan Flowrate %	55.2%
Scenario: Turned Down FD Fan Speed (RPM)	794.4
Scenario: Turned Down ID Fan Speed (RPM)	813.7
Scenario: Turned Down FD Fan Power (kW)	0.43
Scenario: Turned Down ID Fan Power (kW)	2.33
VFD Efficiency % - FD	84%
VFD Efficiency % - ID	95%
VFD Power Saving - FD (kW)	2.04
VFD Power Saving - ID (kW)	11.44
VFD Energy Saving - FD (kWh/year)	5,957.71
VFD Energy Saving - ID (kWh/year)	33,390.67
Total Energy Savings (kWh/year)	39,348.38
VFD Cost Saving - FD (INR/year)	34,380.38
VFD Cost Saving - ID (INR/year)	1,92,688.88
Total Savings	2,27,069.27

The above analysis is based on a VFD drive efficiency of 84% for the 3.7 kW FD Fan VFD drive and 95 % efficiency for the 18.8 kW ID Fan VFD drive. These efficiencies are based on technical literature reviewed [29]and relevant efficiency Tables are presented in Appendix III.

The analysis indicates that application of VFDs for the Boiler FD and ID Fans can yield energy savings of up to 39,348 kWh per year and a consequent cost savings of approximately INR 2.27 Lakh/year.

4.6.2.6 Feed Water Tank Insulation

It was observed that the Feed Water Tank is not insulated which is possibly causing sufficient heat loss to be of concern. It can be easily understood that feeding water at a higher temperature to a Boiler would proportionally reduce fuel consumption to achieve a given steam generation rate. Raising and maintaining a high Feed Water temperature is usually an operational priority and this is conventionally achieved through mixing of condensate at higher temperature with the lower temperature feed water. In order to maximize the benefit available through elevating Feed Water temperature, it is essential that heat loss by radiation from the surface of the Feed Water Tank be curbed through application of insulation techniques. It is interesting to note that as condensate recovery is minimal at present, absence of insulation on the Feed Water Tank is of no major consequence. However, once condensate recovery rate is enhanced as part of the energy conservation roadmap implementation process, insulation for Feed Water Tank is deemed vital.

4.6.2.7 Boiler Feed Water Solar Thermal Water Heating System

Solar Thermal Water Heating Systems heat water by the use of solar energy. These generally comprise of solar thermal collectors, a fluid system to absorb the heat from the collectors, a toughened glass shield, an insulated storage tank, a cold water supply tank, and insulated piping. The two most prevalent types of Solar Thermal Water Heating Systems are described below[30].

Flat Plate Collector

Flat plate collectors have been the mainstay of solar heating for decades. They operate by using flow tubes to circulate water or antifreeze over a dark, insulated absorber plate enclosed in a glazed box. In flat plate collectors, heat is lost through the top surface of the collector. This heat loss increases as the water temperature in the collector gets hotter during the day. So while the collector is highly efficient at the beginning of the day (e.g. 70% efficiency), the efficiency decreases as the water circulating through the collector gets hotter. Direct systems circulate the actual water to be heated through the collector. Indirect systems circulate antifreeze or glycol through the collector and transfer the heat to the water with a heat

[29] Source: U.S. Department of Energy's Industrial Technologies Program – Motor Tip Sheet No. 12: Use AdjusTable Speed Drive Part- Load Efficiency When Determining Energy Saving (2005 draft version)
[30] Source: http://www.home-energy-metering.com/, http://www.solarassociation.org.nz/system/files/Chapter1_SWH%20Overview.pdf

exchanger. Indirect systems can operate year round in climates with freezing temperatures. Passive solar collectors rely solely on the power of the sun to provide convective circulation. Active collectors use pumps and controls to manage and regulate the flow of system fluids. Kilowatt-hours used to power an active system need to be accounted for when determining net system output unless powered by a photo voltiac array.

Evacuated Tube Collector

Evacuated tubes take the flat plate concept and extend it to a higher level of efficiency. They produce higher temperatures and can be used in both residential and commercial applications. Evacuated tube collectors are formed from an array of evacuated tubes joined to a manifold, through which the heat transfer fluid flows. Tubes may have a heat pipe or have a means of taking the heat transfer fluid in a loop through the tube. In evacuated tube systems, heat loss is greatly reduced. This is because the space between the absorber and the glass outer tube is evacuated. There is little air to move and transfer heat by conduction and convection, so heat loss cannot easily take place. Each evacuated tube is a collector in itself with either a flat fin absorber attached to an inner tube or an inner cylindrical absorber surface.

Since evacuated tubes are round they can capture more of the Suns energy throughout the day than flat panels. Flat panels face the sun directly at noon, but are at some other angle of incidence during the rest of the day. Round evacuated tubes expose the same amount absorption area to the sun from early morning to late afternoon.

The water temperature within a Solar Thermal system has been known to be raised up to 900C for Boiler Feed Water Applications. The Table below presents commonly encountered outlet water temperatures for Industrial applications of Solar Thermal Systems[31].

Table 92 Industrial Process Heat Systems in the United States Using Flat-Plate Collectors

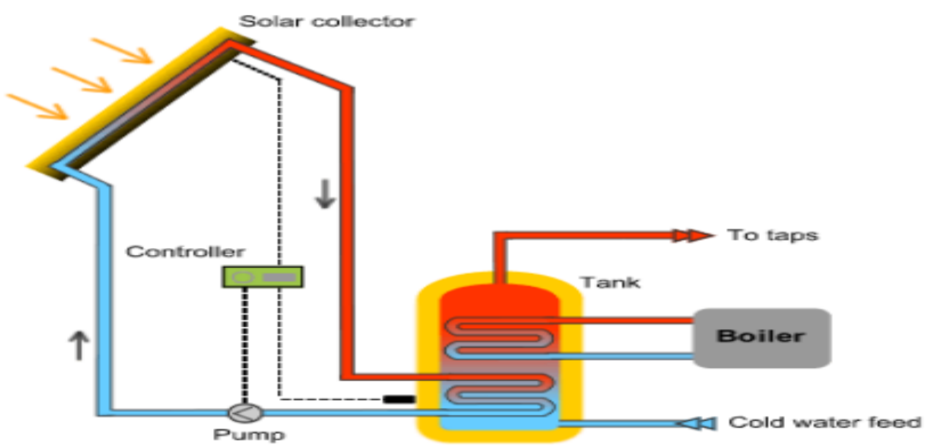
Company	Location	Process Application	Temp. (^{0}C)	Area (m2)
Hot- Water Systems				
Anhauser-Busch, Inc.	Jacksonville, FL	Beer pasteurization	60	427
Aratex Services, Inc.	Fresno, CA	Heat process water	50 -70	624
Berkeley Meat Co.	S. Lake Tahoe, CA	Sanitation	82	232
Campbell Soup Co.	Sacramento, CA	Preheat can wash water	91	372
Coca-Cola Bottling Co.	Jackson, TN	Bottle washing	NA	881
Easco Photo	Richmond, VA	Film processing	46	NA
General Extrusion, Inc.	Youngstown, OH	Solution heating	71-82	409
Iris Images	Mill Valley, CA	Film processing	24-38	59
Jhirmack Enterprises, Inc.	Redding, CA	Preheat boiler water	71-93	622
Mary Kay Cosmetics	Dallas, TX	Sanitizing	60	305
Riegel Textile Corp.	LaFrance, SC	Heat dye-beck water	88	621
Spicer Clutch (Dana)	Auburn, IN	Parts washing	54	87
Hot-Air Systems				
Gilroy Foods, Inc.	Gilroy, CA	Preheat drier air / boiler feedwater	90	553

[31] Source: http://www.powerfromthesun.net/Book/chapter06/chapter06.html

Gold Kist, Inc.	Decatur, AL	Preheat drier air [b]	82	1217
LaCour Kiln Services	Canton, MS	Lumber drying	82	234
Lamanuzzi & Pantaleo	Fresno, CA	Raisin drying	62	1951

A typical schematic diagram of solar water heating system is shown in Figure 34 below. The solar water heating system can be used for bathing, washing, boiler feed water preheating and other similar purposes. The cost of solar water heating system is in the range from Rs.140/- to Rs.220/- per litre. The investment made can be recovered in 4 to 6 years time. The life of the system is around 10-15 years, if maintained properly. The operation and maintenance cost is negligible.

Figure 34 Schematic Diagram for Solar Thermal Feedwater Heating System



The assessment conducted to adequately size the Solar Thermal Flat Plate Collector System and estimate the associated energy and cost savings is presented below.

Table 93 Solar Thermal Energy and Cost Savings Estimate – Boiler Feed Water System

Parameter	Value
Solar Insolation (kWh/m2/day)	5.65
Density (kg/m3)	995.1
Specific Heat of Water (kJ/kg0C)	4.18
Volume (liters/day)	25,123
Cold Water Temp. (oC)	32.0
Hot Water Temp. (oC)	85.0
Efficiency (%)	55.2%
Collector Area Required (m2)	493
Heating Energy Required (kJ/day)	55,35,850
Equipment Cost (INR)	60,57,948.4
Input Energy Savings (GJ/year)	3,734.4
Energy Cost Reduction (INR/year)	16,00,073.5

The results indicate that for a 25,000 kg/day Solar Thermal Water Heating System that raises the Boiler Feed Water temperature from an existing value of 32^0C to 85^0C prior to entering the boiler, the collector surface area required is approximately 493 m2 (based on Solar Insolation of 5.65 kWh/m2/day for Hyderabad and a 55 % FPC efficiency). The capital cost associated with such a system is expected to be approximately *INR 60.6 Lakh and will lead to a input (fuel) energy savings of 3,734 GJ/year and reduce fuel costs by INR 16.00 Lakh/year. The simple payback period for this intervention is therefore approximately 3.8 years.

4.6.2.8 Steam Leakage Reduction

Steam leakage across the Plant was investigated through visual observation and complimented with the use of a **Thermal Imaging Camera.** Various locations were identified where active steam was found leaking and the following four (5) spots were identified as steam leakage hotspots upon which the steal leakage reduction strategy must be focused. The associated Thermal Images are presented in Appendix IV and indicate temperatures ranging from 124^0C to 155^0C

- Block 6 – 1st Floor (Left)
- Main Pipe going to Block 4
- DCRC 04 Steam header going to Block 4
- Near STP Drain
- Block – 3 Terraces

The exact leakage affected area could not be measured. However, the cumulative area of leakage was estimate to be equivalent to a 4.5 to 5 mm dia. aperture and the following equation (Napier's equation) was used to estimate the cumulative steam leakage rate across the Plant.

$$W = 24.24 \times P_{abs} \times D^2$$

Where,
W = Leakages in lb/hr
P_{abs} = Absolute drop in pressure across orifice in lb/inch^2
D = Dia. of leaking orifice in inches

Table 94 Steam Leakage Reduction Energy and Cost Savings Estimate

Parameter	Value
Leakage Dia (inches)	0.1870
Pressure Drop (psi)	103.1
Leakage Rate (lb/hr)	87.42
Leakage Rate (tonnes/year)	347.3
Leakage Rate (%)	3.92%
Steam Generation Cost (INR/kg steam)	2.09
Annual Input (Fuel) Energy Loss (GJ/year)	1,692
Annual Leakage Cost (INR/year)	7,24,994

The above analysis indicated that at a steam pressure of 7 to 7.5 kg/cm^2, the estimated steam leakage rate would be 39.2 kg steam/hr or 343 tonnes of steam per annum. The consequent fuel energy loss and impact on added fuel cost was estimated to be 1,692 GJ/year and INR 7.25 Lakh/year, respectively.

It recommended that a regular surveillance and maintenance program for identifying leaks on pipelines, flanges and joints and their prompt mitigation is undertaken to harness this low-hanging-fruit energy saving opportunity.

4.6.2.9 Flue Gas Waste Heat Recovery

The Boiler Flue Gas exit temperature measured ranged from 209^{0}C to 237^{0}C. This elevated temperature of a largely continuous fluid stream was seen as a potential energy conservation opportunity through waste heat recovery for heating Boiler Feed Water (i.e. an Economizer) or as a Recuperator for heating pre-combustion air.

The analysis related to Waste Heat Recovery related energy and cost savings is presented below. The analysis was based on the following key operational assumptions:

- Boiler operates to produce 25 tonnes steam per day
- Boiler efficiency is 54 %
- Boiler uses Coal and Biomass Briquettes fuels in a mass ratio of 52 % : 48 %
- 50 % excess air is supplied for Coal combustion
- 35 % excess air is supplied for Biomass Briquette combustion
- 40 % waste heat recovery is achieved through a heat-exchanger installed as the heat recovery device
- Waste heat recovered (in energy units) is valued based on the estimated cost of generating the heat through a Boiler of the same efficiency (i.e. 54 %)
- Flue Gas temperature is 223^{0}C and the ambient air temperature is 32^{0}C

The theoretical air quantity was calculated using the following equation based on the % Carbon, Hydrogen, Sulphur, and Oxygen content of the fuel as determined from the Fuel Analysis (F.A) test.

$$Stoichiometric\ Air = (11.6 \times C\%) + \left(34.8 \times \left(H_2\,\% - \frac{O_2\,\%}{8}\right)\right) + (4.35 \times S\%)$$

The results of the analysis are presented below.

Table 95 Boiler Flue Gas Waste Heat Recovery Energy and Cost Savings Estimate

Parameter	Value
Avg. Flue Gas Temp. (°C)	223.00
F.A of Coal - Carbon as C	42.67%
F.A of Coal -Hydrogen as H	2.75%
F.A of Coal - Sulphur as S	0.39%
F.A of Coal - Oxygen as O	11.46%
Theoretical Air Required (kg of Air/kg of Coal)	5.425
F.A of Briquette -Carbon as C	39.39%
F.A of Briquette -Hydrogen as H	5.48%
F.A of Briquette - Sulphur as S	0.10%
F.A of Briquette -Oxygen as O	35.18%
Theoretical Air Required (kg of Air/kg of Briquette)	4.9503
Actual Mass of Air Supplied (kg/kg of Fuel)	7.527
Daily Fuel Consumption (kg/day)	7,574.57
Daily Flue Gas Generation (kg flue gas/day)	57,015.10
Energy Flow Rate of Flue Gas (kCal/day)	26,13,572.11
WHR from Flue Gas (kCal/day)	10,45,428.84
Fuel Input Energy Savings (kCal/day)	19,32,151.54
Fuel Input Energy Savings (GJ/year)	2,952.68
Fuel Cost Savings (INR/year)	12,65,121.74

The results indicate that installing a Waste Heat Recovery system for harnessing energy from the flue gas stream can yield approximately 2,953 GJ/year energy savings and reduce energy costs for the Plant by approximately INR 12.65 Lakh/year.

4.6.2.10 Boiler Surface Radiation and Convection Loss Reduction

It was observed that the Boiler surface is not insulated which is possibly causing sufficient heat loss to be of concern. It can be easily understood that insulating the Boiler surface would proportionally reduce fuel consumption to achieve a given steam generation rate. The theoretical radiative and convective heat loss from the Boiler surface was calculated using the following equation based on the Boiler surface temperature, the ambient dry-bulb temperature and the prevailing wind velocity.

$$R\left(\frac{W}{m^2}\right) = 0.548\times\left(\left(\frac{T_s}{55.55}\right)^4 - \left(\frac{T_a}{55.55}\right)^4\right) + 1.957\times(T_s - T_a)^{1.25}\times\sqrt{\frac{(196.85\times V_m) + 68.9}{68.9}}$$

Where,
V_m = Wind Velocity (m/s)
T_s = Surface Temperature (K)
T_a = Ambient Temperature (K)

The analysis related to Waste Heat Recovery related energy and cost savings is presented below. The analysis was based on the following key operational assumptions:

- Boiler operates to produce 25 tonnes steam per day
- Boiler efficiency is 54 %
- Boiler uses Coal and Biomass Briquettes fuels in a mass ratio of 52 % : 48 %
- The Boiler surface temperature is 79.5^{0}C and the ambient air temperature is 32^{0}C
- Wind Velocity is 1.7 m/s
- Surface area of the Boiler was 143 m^2

The results of the analysis are presented below. The analysis was based on improving insulation of the Boiler surface to mitigate the % energy loss to 2 %32.

Table 96 Boiler Radiative and Convective Energy and Cost Savings Estimate

Parameter	Value
Avg Surface Temperature (K)	352.65
Ambient DBT (K)	305.15
Avg Wind Velocity (m/s)	1.70
Heating Surface Area (m²)	143.66
Heat Loss due to Radiation & Convection (kCal/hr)	1,21,282
Heat Loss due to Radiation & Convection (kCal/day)	15,86,635
Fuel Input Energy Savings (GJ/year)	2,425
Fuel Cost Savings (INR/year)	10,38,887

The results indicate that radiative and convective energy from the Boiler surface results in approximately 2,425 GJ/year energy loss and increases energy costs for the Plant by approximately INR 10.39 Lakh/year. Addressing this heat loss through the application of insulation strategies is extremely prudent and recommended for immediate implementation.

4.6.3 Boiler & Steam System Energy Conservation Summary

The exhaustive analysis presented for a wide spectrum of energy conservation opportunities related to the Plant Boiler and Steam Distribution System is summarized here and major conclusions are underscored to develop a priority list of interventions. Payback periods, the associated GHG mitigation potential, as well as Marginal Abatement Cost Curve values for these and all other relevant interventions across all systems are presented later in the report

Table 97 Boiler and Steam System Energy and Cost Savings Summary

[32] Source: Energy Performance Assessment for Equipment and Utility Systems, Guidebook for National Certification Examination for Energy Managers and Energy Auditors, Bureau of Energy Efficiency, pp. 12

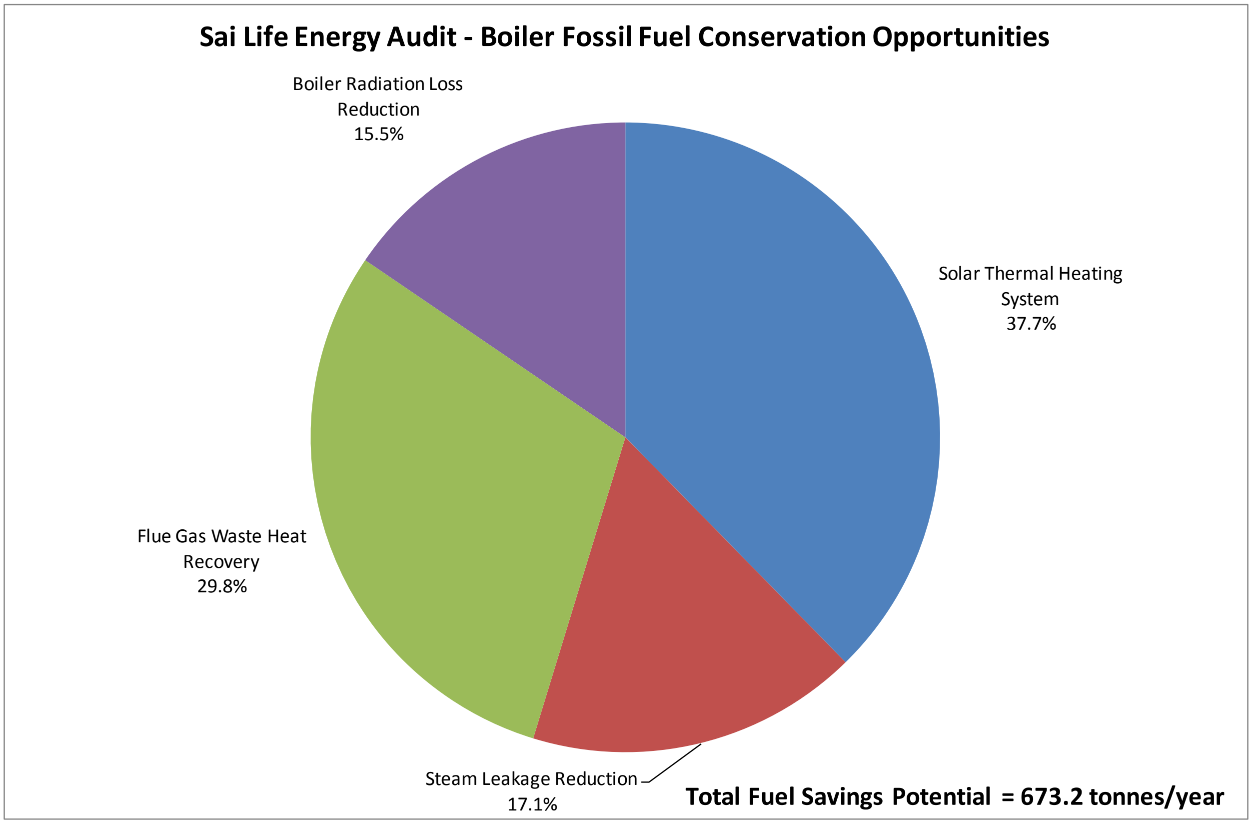
Parameter	Value
Summary of Energy Savings (GJ/year, kWh/year)	
Improved Condensate Recovery (GJ/year)	329.94
Backpressure Turbogenerator Energy Recovery (kWh/year)	1,20,702.9
VFD for FD & ID Fan (kWh/year)	39,272.12
Solar Thermal Heating System (GJ/year)	3,734.43
Steam Leakage Reduction (GJ/year)	1,692.07
Flue Gas Waste Heat Recovery (GJ/year)	2,952.68
Boiler Radiation Loss Reduction (GJ/year)	1,535.63
Total Energy Savings (GJ/year)	10,244.74
Total Energy Savings (kWh/year)	2,40,443.69
Total Fuel Savings (%, fossil fuel energy value)	23.0%
Total Fuel Savings (%, electricity)	4.2%
Summary of Fuel Savings (kg fuel/year)	
Improved Condensate Recovery	20,520.96
Solar Thermal Heating System	2,32,264.38
Steam Leakage Reduction	1,05,239.09
Flue Gas Waste Heat Recovery	1,83,643.26
Boiler Radiation Loss Reduction	95,508.98
Total Fuel Savings (tonnes fuel/year)	637.18
Total Fuel Savings (%, fuel mass basis)	23.0%
Summary of Cost Savings (INR/year)	
Alternate Fuel Firing	32,80,818.10
Improved Condensate Recovery	1,41,369.28
Backpressure Turbogenerator Energy Recovery	11,60,908.94
VFD for FD & ID Fan	2,26,629.21
Solar Thermal Heating System	16,00,073.55
Steam Leakage Reduction	7,24,994.00
Flue Gas Waste Heat Recovery	12,65,121.74
Boiler Radiation Loss Reduction	6,57,963.06
Total Cost Savings (INR/year)	90,57,877.88
Total Cost Savings (% of Annual Energy Cost)	12.9%

The relative contribution of various fossil fuel saving alternatives is presented in the chart below. It is evident that the primary fuel saving opportunity available to the Plant is the installation of a Solar Thermal System for Boiler Feed Water pre-heating, which is expected to reduce annual fossil fuel consumption by 37.7 %. The next most significant opportunity available is installation of a Waste Heat Recovery system to harness the energy available in the hot Flue Gas stream which can reduce fossil fuel consumption by approximately 30 %.

In terms of cost saving opportunities (which may or may not reduce energy consumption eg. alternative fuel firing etc.), the most significant cost saving opportunity is presented by

Overall, the proposed conservation measures can reduce annual Plant fuel consumption by 23.0 %, reduce annual Plant electricity consumption by 4.2 % and yield energy cost savings of INR 90.58 Lakh/year i.e. 12.9% of the current annual energy bill (including fossil fuel and electricity consumption).

Figure 35 Boiler Fossil Fuel Conservation Opportunities - % contribution (mass basis)



4.7 Other Loads

4.7.1 UPS System

There are small standalone UPS systems used block wise for feeding power to computers and other sensitive loads in the plant. Rated UPS capacities and measured input power recorded across the Plant are presented in the Table below.

Table 98 Block Wise UPS Details

Block Ref.	UPS Rating (kVA)	Input kW
Block 1	6	0.70
	15	6.13
	11	0.20
	10	6.70
Block 2	20	7.00
	11	1.80
	11	3.05
	20	---
	10	4.80
Block 3	7	1.80
Block 6	5	2.20
	5	1.20
	20	--
	5	0.70
Total	156.0	35.08

It was noted that the input power (35.08 kW) is significantly lower than the rated power of 156 kVA. UPS systems within this load range are usually devoid of PF correction and the PF is poor; generally in the range 0.70 to 0.75. Thus input kVA would be therefore be 46.77 kVA. The online UPS systems have conversion losses of about 15% to 20% of the rated input kW. Cumulative conversion losses for the installed UPS system were calculated to be 17.55 kW

Since UPS systems are high impedance devices i.e. weak sources of power, their utilization for powering loads at long distances should be avoided. It is therefore prudent to adopt a strategy of de-centralizing the current UPS system to a decentralized network with a dedicated UPS for each block, appropriately sized for the functions of each Block. The right-sizing will result in lower total installed capacity and hence lower losses and yield noteworthy energy conservation benefits. The suggested UPS system configuration is presented in the Table below.

Table 99 Recommended Decentralized UPS System

Block ID	Existing Load (kVA)	Recommended UPS System
Block 1	13.73 kVA	20 kVA
Block 2 + Block 3	(16.65 + 1.8) = 18.45 kVA	25 kVA
Block 6	4.1 kVA	10 kVA
Total		55 kVA

The revised conversion losses at 15 % of the installed capacity are thus expected to be in the range of 3.75 kW which yields a power saving of 13.8 kW relative to the previous system. The consequent energy and cost savings are presented in the table below.

Table 100 Recommended Decentralized UPS System

Block ID	Existing Load (kVA)	Recommended UPS System

Block 1	13.73 kVA	20 kVA
Block 2 + Block 3	(16.65 + 1.8) = 18.45 kVA	25 kVA
Block 6	4.1 kVA	10 kVA
Total		55 kVA

Table 101 Energy and Cost Savings from UPS System

Parameter	Value	Units
Power Saving	13.8	kW
Hours/Year	8,760	hrs.
Energy Cost	5.77	INR/kWh
Annual Energy Savings	1,20,888	kWh/year
Annual Cost Savings	6,97,613	INR/year
Capital Cost	6,20,000	INR
Payback Period	0.89	years

It must be underscored that the existing 10 kVA and 20 kVA system can be integrated into the revised system while a new 25 kVA UPS would have to be procured. It is also recommended that the existing batteries can be used judiciously in consultation with the UPS Vendor / Manufacturer.

4.7.2 Scrubbers

The GLRs (Glass Lined Reactors) and SSRs (Stainless Steel Reactors) in Process Blocks employ Scrubber Systems. The existing system configuration for one of the Blocks (No.4) is presented in the Table below. Blocks 1 and Block 6 possess similar Scrubbers as well through rated power data for them was not available.

Table 102 Plant Block 04 Scrubber System

Block ID	Blower Power (kW)	Pump Power (kW)	Total Power (kW)
Block 4: Scrubber 1	1.18	0.63	1.81
Block 4: Scrubber 2	0.78	1.42	2.20
Total			4.01

It was observed that the scrubbers have to be manually operated and switched off when not required. This manual operation gives rise to the possibility of human error or neglect leading to Scrubbers operating even when not required. Automation of Scrubber 'Start-Stop' will eliminate instances of idle running of the Scrubber Motor would get eliminated and thereby lead to direct energy and cost saving benefits. The Plant can consider the following configuration:

- Every GLR and SSR in a given block would be equipped with status sensing (ON – OFF).
- Individual GLR and SSR status signals would be in series.

- A time delay would be built in such that at the end of use of any reactor along the GLR and SSR line, after an adjustable time delay, triggers a switching OFF after a pre-defined time that can be adjusted with a timer.

4.7.3 Vacuum Ejection System

This system's usage characteristics and potential for energy savings through automation are similar to those presented for the Scrubbers discussed above. The existing system configuration for the Plant is presented in the table below.

Table 103 Plant Vacuum Ejection System

Block ID	Vacuum Pump Power (HP)
Block 1	57.5
Block 2	13 x 5
Block 4	3 x 5
Block 6	7 x 10
Total	207.5

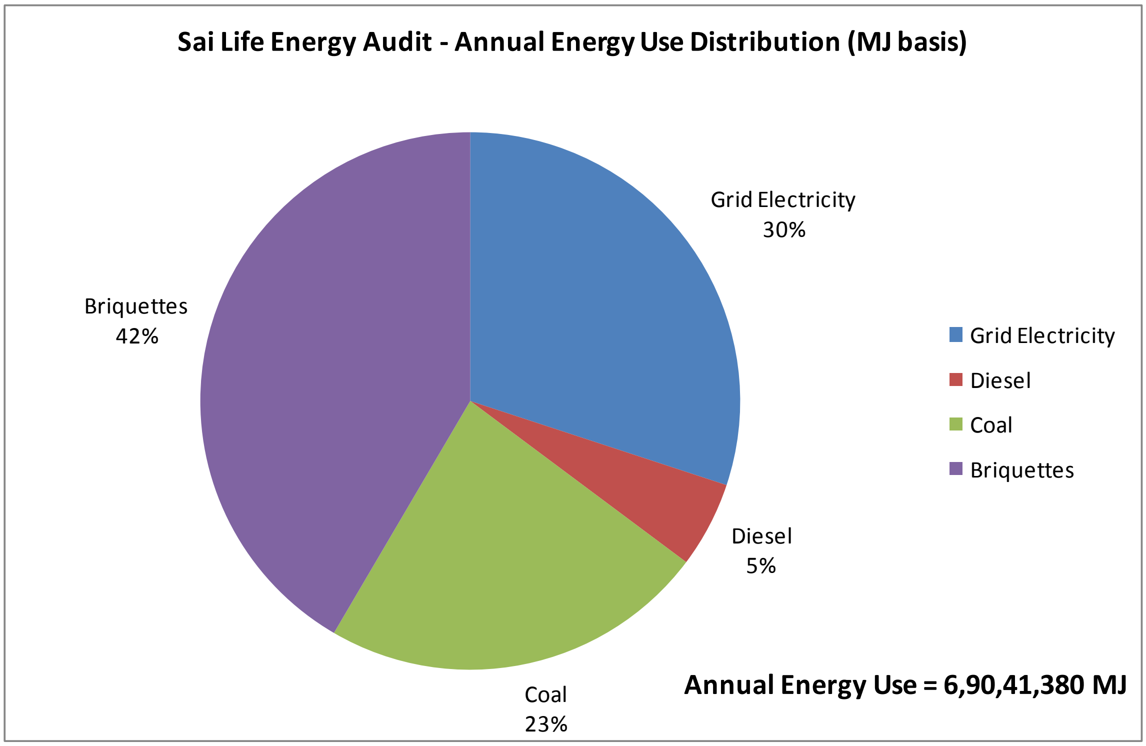
Summary Energy Conservation Opportunities – Other Loads

- **UPS System:** Installing a separate 25, 20, 10 kVA UPS system can yield energy savings of 1,20,888 kWh/year and associated cost saving of INR 6,97,613 per year. Capital cost of the system is INR 6,20,000 with a payback period of 0.89 years
- **Automation for Scrubbers & Vacuum Pumps:** Installation of Automation devices for Scrubbers and Vacuum Pumps will eliminate idle running of motors which leads to direct savings in cost as well as energy.

Conclusion

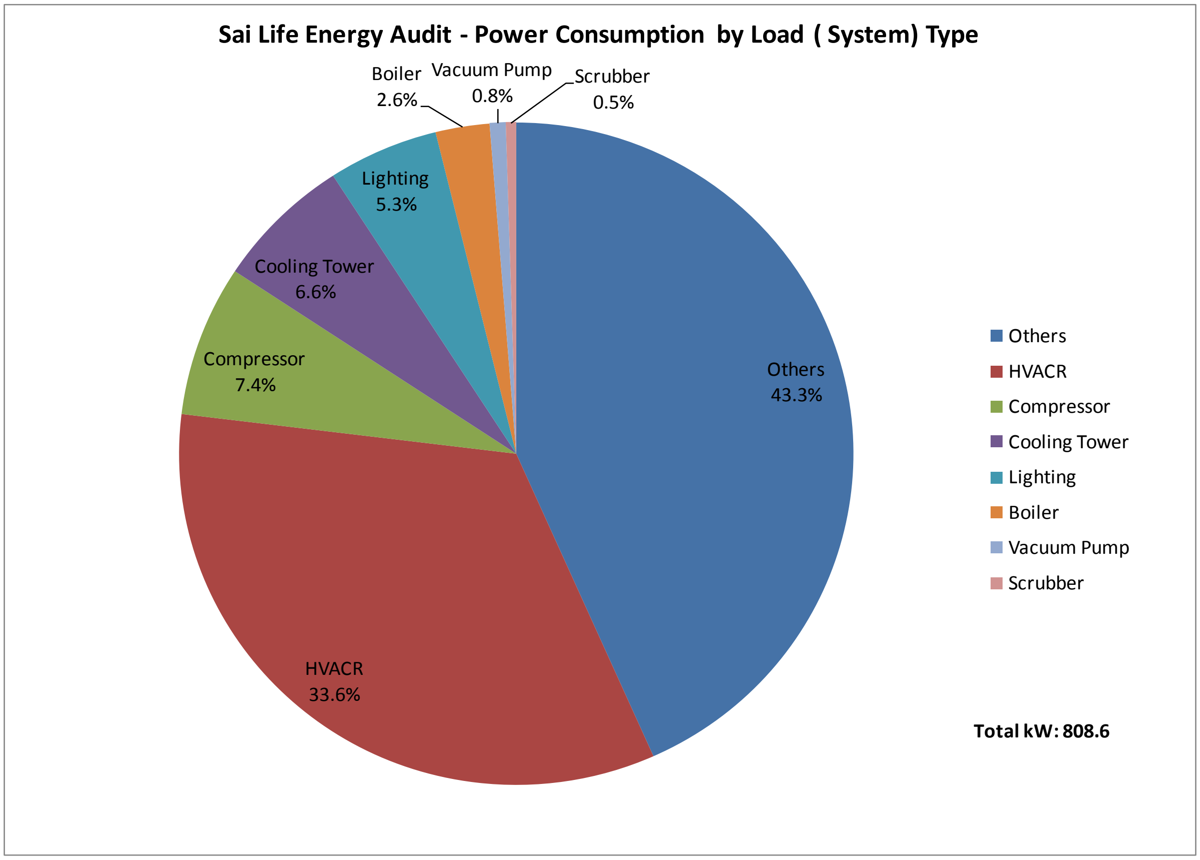
The total current annual electrical energy consumption of the Bidar Plant of Sai Life Sciences Pvt. Ltd. is approximately 57.6 Lakh kWh/year (4.80 Lakh kWh/month). In addition to electricity, the Plant consumes 3045 metric tonnes of Coal and Biomass Briquettes for thermal energy and 102,251 liters of diesel annually for power generation. The average energy cost being paid by the facility is INR 54.26 Lakh per month and INR 6.32 Crore per year. The fuel cost distribution indicates that Grid Electricity contributes 61 % to the total annual energy bill followed by Biomass Briquettes which comprise 17 % of the total annual energy cost.

Figure 36 Annual Energy Cost Distribution (INR basis)



The system-wise electrical energy consumption results is presented below.

Figure 37 Power Consumption by Load (System) Type



The system-wise electrical energy breakdown clearly underscores the importance of the HVAC-Refrigeration system which is the most critical component of energy consumption (accounting for approximately 33.6% of the load) followed narrowly by the Compressor and Cooling Tower Load. The three sources cumulatively contribute approximately 84% of the total energy demand of the Plant. The overall benefits of proceeding with implementation of the various interventions proposed in the earlier section are substantial; ***the Bidar Plant has the invaluable opportunity to reduce its energy cost by 22.6 %.*** The consolidated environmental, cost and energy conservation impacts of all proposed alternatives is presented in Table 104 below.

- Reduce **Greenhouse Gas Emissions by 2,907 metric tonnes of CO2 per year** (equivalent to planting approximately 11,628 trees every year)
- Conserve **15.3 lakh units of electricity every year** (enough to power 1,279 average Indian homes per year)
- Reduce its **operational cost by INR 1.42 Crore every year**
- The capital cost for implementing all the proposed projects is approximately **INR 1.42 Crore**
- The payback period for these investments is a **very feasible 1.24 years***.

Table 104 Overall Conservation Summary from Energy Efficiency & Renewable Energy

Parameter	Value	Units
Capital Cost	1,42,19,789*	INR
Energy Conservation - Electrical	15,34,656	kWh/year
Energy Conservation - Thermal	10,245	GJ/year
Demand Reduction	257	kVA
GHG Mitigation	2,907	MT CO2e/year
Cost Savings	1,42,94,183	INR/year
Payback Period	1.24*	years
% Energy Conservation - Electrical	26.6%	
% Energy Conservation - Thermal	14.8%	
Total Energy Conservation (Cost)	22.6%	
CONTEXT		
Trees	11,628	trees/year
Homes	1,279	homes/year
Cars	3,230	cars/year

(Note: * In the total capital cost and payback period analysis, the replacement cost of existing chiller system with more efficient chiller system is not included. Inclusion of the same would result into higher capital cost and longer payback period)

It must be noted that the actual savings may vary in the range ± 20% depending upon site conditions and other unforeseen variables.

The recommended priority list for implementation of all energy related interventions proposed follows the order of the relative Marginal Abatement Cost Curve specifically developed for the facility as the culminating outcome of the Energy Audit.

The MACC Curves for the facility are presented below in Figure 38.

Figure 38 Marginal Abatement Cost Curve

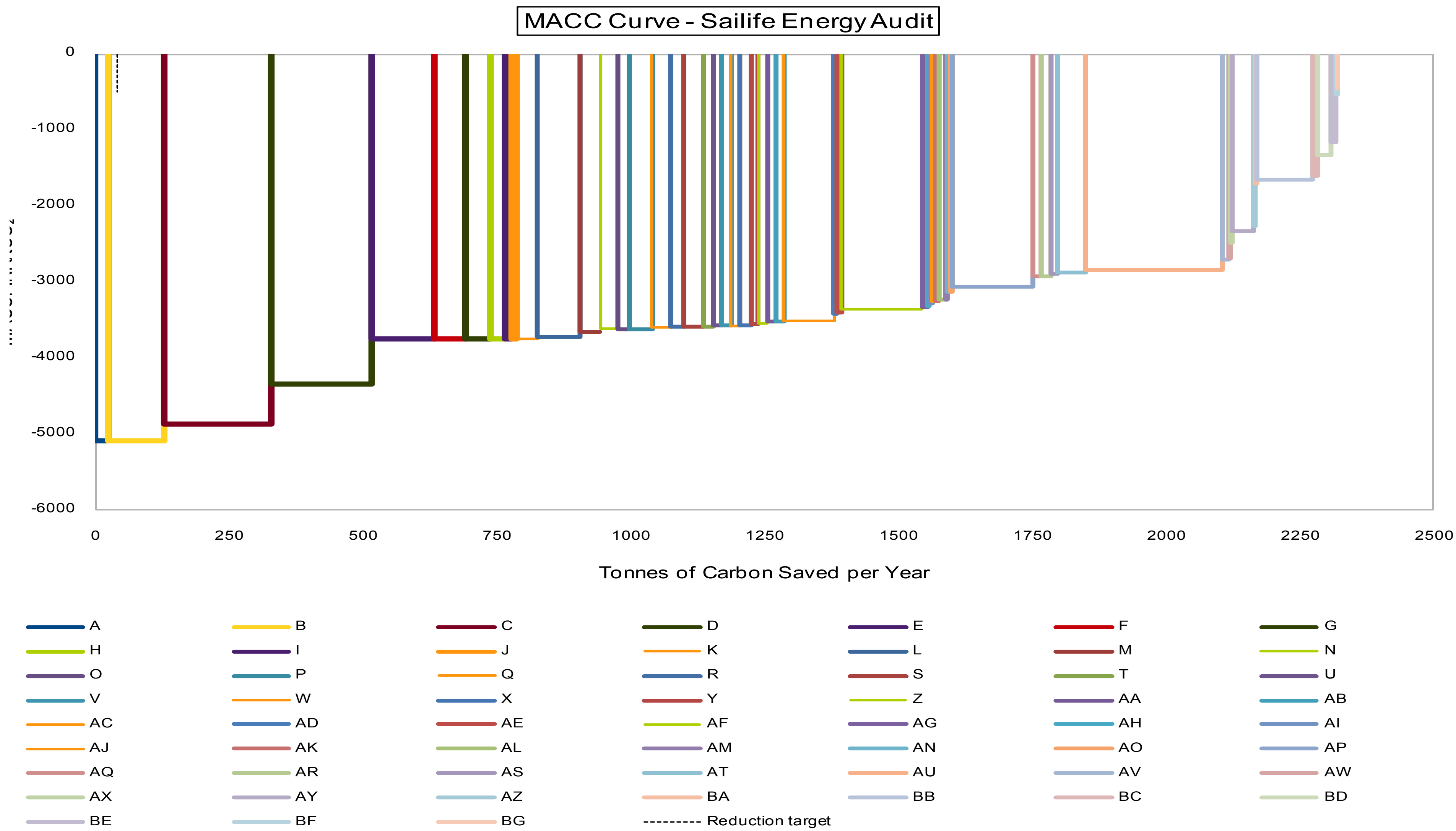


Table 105 Energy Efficiency Roadmap Projects & Marginal Abatement Costs Summary

Pr. ID	System	Project Description	Capital Cost (INR)	Annual Savings (INR)	Payback Period (yrs)	MAC (Carbon Not Discounted)
A	Boiler System	Reduce Steam Leakage Loss	0	7,24,994	0.00	-5084.88
B	Boiler System	Improve Condensate Recovery to 40%	0	1,41,369	0.00	-5084.88
C	Boiler System	Boiler Radiation Loss Reduction	2,31,951	6,57,963	0.35	-4863.87
D	Boiler System	Flue Gas Waste Heat Recovery	15,00,000	12,65,122	1.19	-4341.57
E	Compressed Air System	Harnessing the leakage in Nitrogen Distribution Line	0	8,63,802	0.00	-3744.47
F	Compressed Air System	Proper Maintenance of Air Compressor Block 06	0	5,42,321	0.00	-3744.47
G	Compressed Air System	Proper Maintenance of Nitrogen Air Compressor up to the Air Receiver Tank	0	2,62,490	0.00	-3744.47
H	Compressed Air System	Proper Maintenance of Air Compressor Block 01	0	2,22,807	0.00	-3744.47
I	Lighting System	Remove the Excess Fixtures	0	1,23,325	0.00	-3744.47
J	Compressed Air System	Reduce Delivery Press. By 1kg/cm² Block 06	0	49,598	0.00	-3744.47
K	Compressed Air System	Reduce Delivery Press. By 1kg/cm² Block 01 Air Compressor	0	48,426	0.00	-3744.47
L	Lighting System	HPMV to LED – Outdoor	3,05,372	2,17,064	1.41	-3723.17
M	HVAC System	Installation of VFD for Cooling Tower DCTR 10	75,105	3,67,340	0.20	-3650.08
N	HVAC System	Installation of VFD for SRS Cooling Tower	46,490	1,70,208	0.27	-3618.37
O	HVAC System	Installation of VFD for Cooling Tower DCTR 06	42,588	1,54,284	0.28	-3617.04
P	HVAC System	Installation of VFD for Cooling Tower DCTR 12	29,257	1,04,881	0.28	-3615.69
Q	Boiler System	Installation of VFD for Induced Draft Fan	60,000	1,92,249	0.31	-3600.39
R	HVAC System	Installation of VFD for Ventilation DAHU 21	51,723	1,59,576	0.32	-3594.83
S	HVAC System	Installation of VFD for Chiller Connected DAHU 09	38,716	1,12,399	0.34	-3585.45
T	HVAC System	Replace SS 304 Fan to FRP Fan DCTR 12	60,000	1,70,802	0.35	-3582.30
U	HVAC System	Installation of VFD for Ventilation DAHU 12	29,257	80,399	0.36	-3576.48
V	HVAC System	Installation of VFD for Ventilation DAHU 05	29,257	79,488	0.37	-3574.55

W	HVAC System	Installation of VFD for Ventilation DAHU 06	29,257	78,055	0.37	-3571.43
X	HVAC System	Installation of VFD for Ventilation DAHU 04	29,257	78,037	0.37	-3571.39
Y	HVAC System	Installation of VFD for Ventilation DAHU 08	38,716	90,487	0.43	-3546.94
Z	HVAC System	Installation of VFD for Chiller Connected DAHU 14	29,257	65,688	0.45	-3538.85
AA	HVAC System	Installation of VFD for Ventilation DAHU 18	37,385	79,739	0.47	-3528.02
AB	HVAC System	Installation of VFD for Cooling Tower DCTR 03	37,385	75,726	0.49	-3516.55
AC	HVAC System	Installation of VFD for Ventilation DAHU 07	33,986	68,374	0.50	-3514.99
AD	HVAC System	1.5 TR Split AC Replacement by Evaporative Cooler	3,08,589	4,27,950	0.72	-3411.57
AE	Boiler System	Installation of VFD for Forced Draft Fan	25,000	34,380	0.73	-3408.77
AF	HVAC System	Installation of VFD for Cooling Tower DCTR 07	27,500	33,011	0.83	-3359.88
AG	UPS System	UPS System Modification -Installation of 25, 20 ,10 kVA UPS System	6,20,000	6,97,613	0.89	-3334.17
AH	HVAC System	Installation of VFD for Cooling Tower DCTR 05	37,385	40,517	0.92	-3318.50
AI	HVAC System	Installation of VFD for Chiller Connected DAHU 13	21,777	22,117	0.98	-3289.90
AJ	HVAC System	1.5 TR Split ACs Replacement by Evaporative Cooler	19,287	18,406	1.05	-3260.71
AK	HVAC System	1.5 TR Split ACs Replacement by Evaporative Cooler	38,574	35,922	1.07	-3248.73
AL	HVAC System	Installation of VFD for Cooling Tower IEC 1083	27,500	24,959	1.10	-3235.81
AM	HVAC System	Evaporative Pre - Cooler for 8.5 TR Split AC Condenser	72,000	65,060	1.11	-3233.57
AN	HVAC System	Installation of VFD for Ventilation DAHU 15	19,797	14,986	1.32	-3134.61
AO	HVAC System	Evaporative Pre - Cooler for 8.5 TR Split AC Condenser	36,000	26,691	1.35	-3121.80
AP	HVAC System	Installation of VFD for Ventilation DAHU 10	19,797	13,373	1.48	-3061.05
AQ	Boiler System	Back Pressure Turbine for generating Electricity	12,35,000	6,96,545	1.77	-2925.93
AR	HVAC System	2 TR Split ACs Replacement by Evaporative Cooler	1,26,549	70,621	1.79	-2917.20
AS	HVAC System	1.5 TR Split ACs Replacement by Evaporative Cooler	1,54,294	84,078	1.84	-2897.26
AT	HVAC System	8.5 TR Split ACs Replacement by Evaporative Cooler	1,03,607	54,662	1.90	-2869.42
AU	HVAC System	2 TR Split ACs Replacement by Evaporative Cooler	4,80,884	2,45,115	1.96	-2838.75

AV	Boiler System	Installation of Solar thermal Water Heating System	60,57,948	16,00,074	3.79	-2711.33
AW	Lighting System	Installation 50 kVA Transformer for Outdoor Lightings	1,15,000	50,274	2.29	-2688.43
AX	HVAC System	2 TR Split ACs Replacement by Evaporative Cooler	50,619	18,461	2.74	-2478.65
AY	Lighting System	Metal Halide to LED – Outdoor	91,157	23,342	3.91	-2335.65
AZ	HVAC System	Evaporative Pre - Cooler for 1.5 TR Split AC Condenser	5,76,000	1,80,166	3.20	-2268.52
BA	HVAC System	Evaporative Pre - Cooler for 1.5 TR Split AC Condenser	36,000	8,133	4.43	-1700.85
BB	HVAC System	Evaporative Pre - Cooler for 1.5 TR Split AC Condenser	72,000	15,931	4.52	-1658.05
BC	Lighting System	HPMV to LED – Indoor	26,95,956	5,41,693	4.98	-1602.10
BD	HVAC System	Evaporative Pre - Cooler for 2 TR Split AC Condenser	1,80,000	34,407	5.23	-1329.28
BE	HVAC System	Evaporative Pre - Cooler for 2 TR Split AC Condenser	6,84,000	1,22,029	5.61	-1156.77
BF	HVAC System	Evaporative Pre - Cooler for 1.5 TR Split AC Condenser	2,88,000	41,371	6.96	-530.72
BG	HVAC System	Evaporative Pre - Cooler for 2 TR Split AC Condenser	1,08,000	15,139	7.13	-451.04

For effective implementation of project it is opined that a PMC (Project Management Consultant) may be appointed by the management. The PMC can prepare blueprints, draft specifications and BOQs, execute floating of enquiries, and conduct techno-commercial negotiations with approved vendors. The PMC will also oversee project implementation and may be entrusted with energy saving certification.

Currently, the facility routinely consumes a higher peak demand relative to its contracted demand and as a consequence pays a significant sum (approximately INR 20.2 Lakh per year) as excess demand penalty charges every year. A significant demand reduction is expected through implementation of the recommended energy saving projects. However, if these projects are not implemented in their entirety and if increased loads are expected in the near future, the management may apply for and get revised demand (up to 250 kVA) sanctioned with the help of a PMC to avoid penalty charges due to excess demand.