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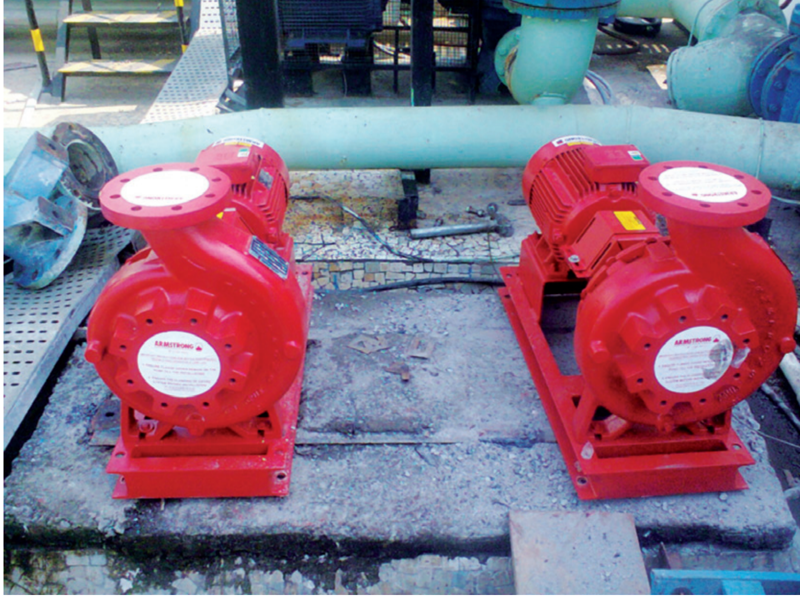

After energy audit at a site in Mumbai, 22 kW condenser water pumps (left) were replaced with 7.5 kW pumps (right)

Energy Audit of a Chiller System for Retrofit

By Sameer Rohankar
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Introduction

An HVAC system refers to a system that caters to (either individually or in an integrated manner) the heating, ventilation and air conditioning requirement of a building. HVAC system comprises of high side and low side equipment. The high side is often a chiller plant. Chilled water terminals inside the AHU rooms, AHUs and the air distribution system are collectively known as the low side.

The Energy Conservation Building Code (ECBC) of India defines the following climatic zones:

1. Hot and dry climate
2. Warm and humid climate
3. Moderate climate
4. Cloudy and sunny climate
5. Composite climate

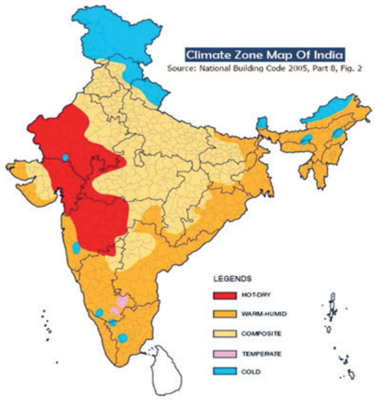

Figure 1: Climatic zone map of India

Figure 1 maps various climatic zones in India.

The annual energy consumption of an HVAC system varies as per the type of climatic zone. Hence the benchmark energy consumption index depends on the location of the HVAC installation.

Typical Energy Consumption Patterns

Figure 2 to *4* show the energy consumption patterns in typical building types. HVAC is the largest guzzler of energy in all types of buildings.

Within HVAC, the chiller consumes the largest amount of energy, as shown in *Figure 5*.

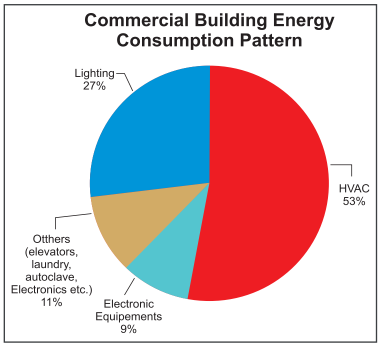

Figure 2: Typical energy consumption pattern in a commercial building

These contributions will vary depending on the type of average load on the chiller as well as the type of controls in the system.

Why is Energy Audit Necessary?

Since HVAC contributes 55-60% of the total energy consumption in a building, it is the major energy consuming system and needs attention to bring down the overall energy cost. As

About the Author

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the creation of baseline and understanding the science behind power consumption is complex and weather dependent, it is important to conduct an energy audit before going for an actual retrofit. Apart from Energy Audit, calibrated energy simulation reports using various energy simulation software can also be generated by energy experts to determine the accurate energy saving potential.

Estimates of energy saving will vary month wise due to ambient variations. A typical scenario for an air cooled chiller installation is shown in *Figure 6*. Blue bars indicate chiller power consumption, while violet bars indicate the power consumption of chilled water pumps. This scenario is applicable for the existing system as well as the proposed system. The variation depends on the weather.

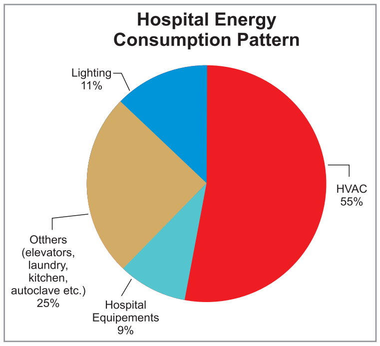

Figure 3: Typical energy consumption pattern in a hospital

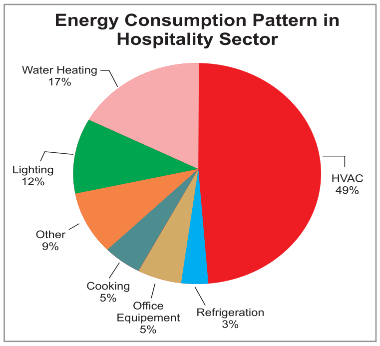

Figure 4: Typical energy consumption pattern in the hospitality sector

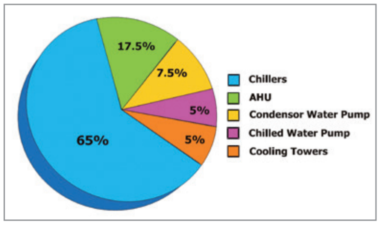

Figure 5: Typical energy contribution of components in an HVAC installation

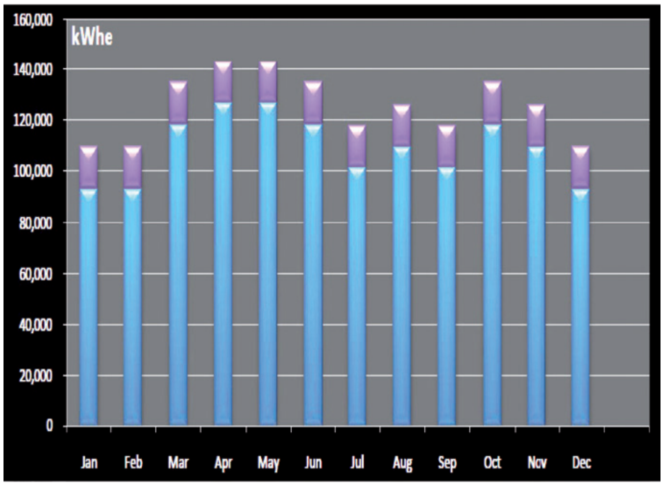

Figure 6: Typical month wise energy saving potential in an air cooled chiller installation

Component Wise Analysis of Costs

Table 1 lists the components of an HVAC system on the high and low sides.

Table 1: Components of HVAC system

High Side	
1	Cooling tower
2	CT fan
3	Condenser pump
4	Condenser piping and fittings
5	Chiller and its compressor
6	Chilled water pump
7	Chilled water distribution system
8	Chiller plant piping connections and fittings
9	Hot water generator in plant room
Low Side	
1	AHU/FCU/TFA/DX units
2	Blower
3	Supply and return ducts
4	Diffusers
5	Room distribution
6	Air dampers
7	Valve actuators
8	AHU connections and fittings
9	Electric heaters in AHU
10	Heat recovery wheels
11	Heating coils
12	Cooling coils
13	Spray ponds
14	De-humidifiers

Figure 7 shows the schematic view of a typical HVAC system.

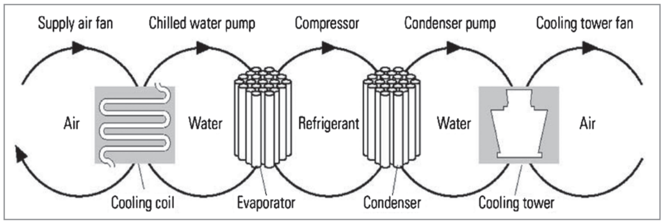

Figure 7: HVAC system schematic

Life Cycle Cost Evaluation of HVAC Components

While evaluating energy saving retrofit proposals, it is important to study the current energy consumption pattern of each component in the system. It is essential to carry out Life Cycle Costing (LCC) of each proposal. LCC can be viewed along with the initial capital cost to select the optimum proposal.

A few energy retrofit and extension projects undertaken by us have been analysed below for Capex and Opex evaluation, and LCC for 10 years has been reported along with the LCC/Capex index.

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Project 1: HVAC Project in a Textile Plant

Table 2: Capex and Opex in a textile plant

S. No.	Particulars	CAPEX, INR	% of Capex	kW	OPEX, INR	% of Opex	LCC/ Capex
1	SITC of chiller	36,04,126	37.9%	197	99,28,800	78%	27.55
2	SITC of pumps	9,27,972	9.8%	33.5	24,12,000	19%	25.99
3	SITC of cooling tower	9,49,468	10.0%	5.5	3,96,000	3%	4.17
4	SITC of piping and fittings	23,24,409	24.5%				
5	SITC of PHE system	1,142,209	12.0%				
6	SITC of electrical works	550,790	5.8%				
	Total	**94,98,974**	**100%**	**236**	**1,27,36,800**	**100%**	

SITC: Supply, Installation, Testing and Commission

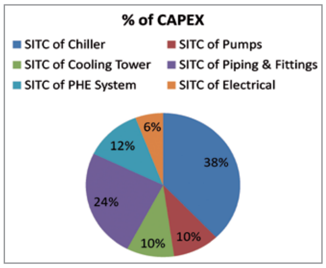

Figure 8: Distribution of Capex over system components in Project 1

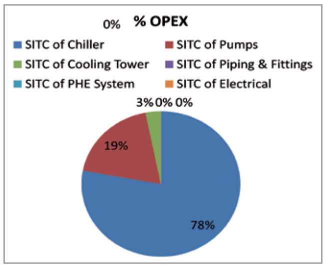

Figure 9: Distribution of Opex over system components in Project 1

Project 2: HVAC Project in Confectionery Industry

Table 3: Capex and Opex in a confectionery plant

S. No.	Particulars	CAPEX, INR	% of Capex	kW	OPEX, INR	% of Opex	LCC/ Capex
1	SITC of chiller	32,70,049	51.6%	156.24	78,74,496	58%	24.1
2	SITC of pumps	7,78,714	12.3%	74	53,28,000	39%	68.4
3	SITC of cooling tower	3,65,711	5.8%	5.5	3,96,000	3%	10.8
4	SITC of piping and electrical works	19,19,911	30.3%				
	Total	**63,34,385**	**100%**	**235.74**	**1,35,98,496**	**100%**	

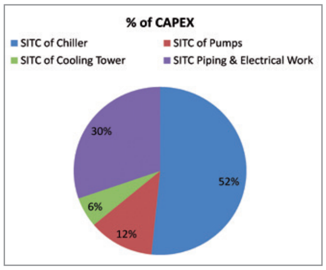

Figure 10: Distribution of Capex over system components in Project 2

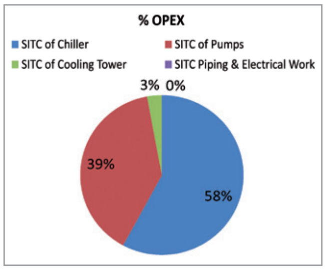

Figure 11: Distribution of Opex over system components in Project 2

Project 3: HVAC Project in a Synthetic Ropes Plant

Table 4: Capex and Opex in a synthetic ropes plant

S. No.	Particulars	CAPEX, INR	% of Capex	kW	OPEX, INR	% of Opex	LCC/ Capex
1	SITC of chiller	24,21,067	43.3%	75	37,80,000	65%	15.6
2	SITC of pumps	8,01,090	14.3%	24.3	17,49,600	30%	21.8
3	SITC of cooling tower	3,53,624	6.3%	3.7	2,66,400	5%	7.5
4	SITC of piping and fittings	14,50,944	26.0%				
5	SITC of electrical works	5,63,278	10.1%				
	Total	**55,90,003**	**100%**	**103**	**57,96,000**	**100%**	

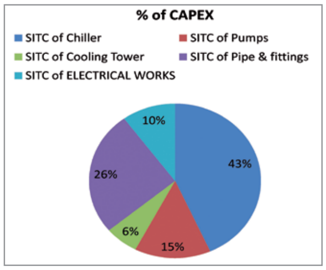

Figure 12: Distribution of Capex over system components in Project 3

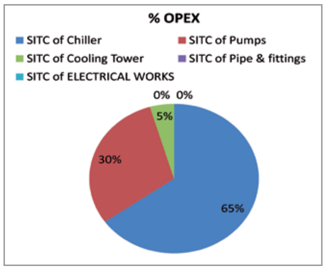

Figure 13: Distribution of Opex over system components in Project 3

Project 4: HVAC Project in Hotel cum Resort

Table 5: Capex and Opex in a hotel cum resort

S. No.	Particulars	CAPEX, INR	% of Capex	kW	OPEX, INR	% of Opex	LCC/ Capex
1	SITC of chiller	29,99,231	32.1%	166	83,66,400	86%	27.9
2	SITC of pumps	7,34,404	7.8%	20.5	10,33,200	11%	14.1
3	SITC of cooling tower	3,04,799	3.3%	5.5	2,77,200	3%	9.1
4	SITC of piping and fittings	44,78,200	47.9%				
5	SITC of electrical works	8,37,049	8.9%				
	Total	**93,53,683**	**100%**	**192**	**96,76,800**	**100%**	

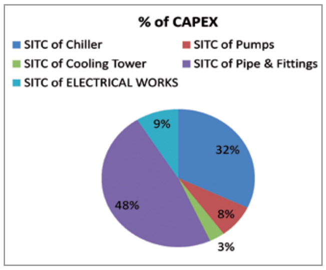

Figure 14: Distribution of Capex over system components in Project 4

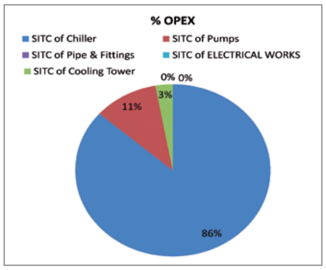

Figure 15: Distribution of Opex over system components in Project 4

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Observations

% Capex, % Opex and the ratio of LCC to Capex are the main indicators while focusing on energy optimization of HVAC project retrofits and component modifications.

Major Factors Affecting Energy Consumption

The major factors affecting energy consumption in an HVAC system are:

1. Building envelope design layout and materials of construction
2. Building leakages and infiltration
3. Building air exchange rates
4. Lighting loads
5. User room temperature and relative humidity
6. Efficiency of individual system components
7. Type of plant controls and hydronic system with reference to demand
8. Effective system design and use of advanced technology
9. Type of energy monitoring system

Approach in HVAC Energy Audits

Micro-level evaluation of energy consumption for each component of an HVAC system is important in HVAC energy audits. Understanding the importance of energy consumption of each component will help in prioritizing the project preferences for energy savings and help accurate energy saving calculations.

While conducting energy audits in an HVAC system, following are the grey areas to focus:

Demand Side Management

Chiller plant load is decided by the layout of the end user, internal loads, temperature and humidity requirement, occupancy patterns, etc.

Effective envelope design can help reduce the heat load and solar heat gain inside the space. Hence, low conductivity walls and low solar gain factor glass components can effect substantial reduction in heat load due to the envelope. The available technology for heat load reduction is:

1. Aerated ash concrete blocks instead of red bricks
2. Impregnated insulation inside the walls
3. Double glazed low-E glass for windows
4. Window frames with thermal barriers
5. Roofs with under-deck and over-deck insulations
6. Use of high albedo paint or highly reflective broken marble bricks above the roof
7. Effectively designed overhangs and wings for building shades
8. Building shading by adjacent trees
9. Use of attic space and courtyard to avoid direct heating of conditioned space
10. Higher room temperature set points

Heat load and reduced latent load due to low moisture condensate can result in lower capacity of chiller and allied systems.

Chiller Plant Sizing and Layout Design

As per heat load calculations, chiller plant sizing is done by HVAC consultants at peak demand, with due consideration for diversity factor of the loads. Chiller sizing, along with its component sizing, is accordingly done with some factor of safety.

While conducting energy audits in chiller plants, following are the general observations:

1. Chiller operates at part load for most of the time
2. Pumps run at constant flow
3. Temperature differentials across the cooler and condenser are very low
4. Pumps draw excess power
5. Balancing valves are over-throttled to balance water across the cooler and the condenser
6. Though full load design chiller efficiency is very good as per records, overall system specific power consumption (kW/TR) is quite high
7. Cooling tower delivers low efficiency
8. Cooling tower range and approach are different from design values
9. High cooler and condenser approach

Pumping System Efficiency

Chilled water and condenser water pumps are the main components of the pumping system of water cooled chillers. Normally, in commercial building, cooling towers are installed at the terrace while condenser and chilled water pumps are installed at the basement or ground level inside the chiller plant.

Chilled water pumping systems are of the following types:

1. Constant flow primary pumps,
2. Closed type constant flow primary – variable flow secondary (closed piping),
3. Open type constant flow primary – constant flow secondary pumping (hot well/cold well),
4. Variable primary flow, etc.

In constant flow primary pumps (*Figure 16*), a fixed amount of water flows across the cooler and it is circulated to the low side air handling units. As per heat loads on AHUs, water is either allowed to enter the AHU coil or partially diverted to the bypass line of the AHU. These systems always ensure constant flow across the cooler. However, a drawback of this system is that it consumes higher power, as pumps deliver a fixed flow irrespective of the varying load of AHUs.

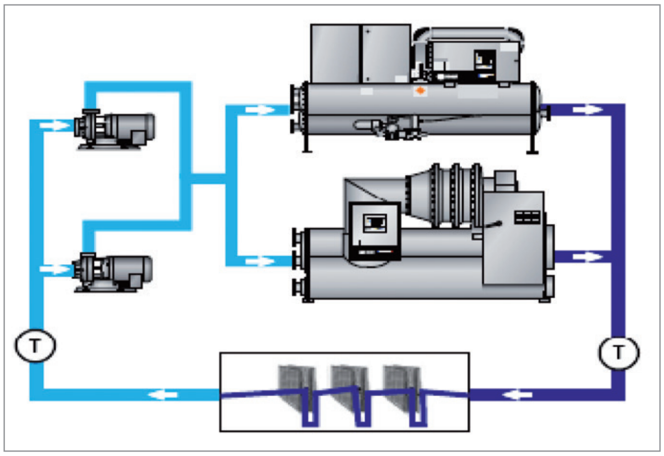

Figure 16: Constant flow primary pumps

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As an effective way to reduce the power consumption in constant flow primary pumps, primary-secondary pumping system has been introduced (*Figure 17*), where primary pumps maintain a constant flow, while secondary pumps deliver variable flow using variable frequency drives. AHUs are installed with two way valves rather than three way valves.

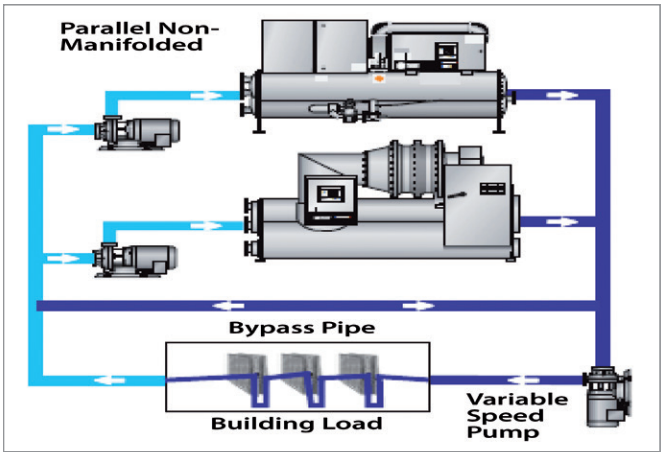

Figure 17: Primary-secondary pumping system

A variable primary flow system comprises of only primary variable pumps. In this case, flow across the cooler varies as per the chiller load in the primary circuit; a flow meter is introduced to ascertain the minimum required flow rate across the chiller unit. There is a de-coupler line which helps to modulate the flow of water as per the load (*Figure 18*). Variable flow systems help optimize the chilled water pump power consumption. However, this kind of system needs accurate design and control logic.

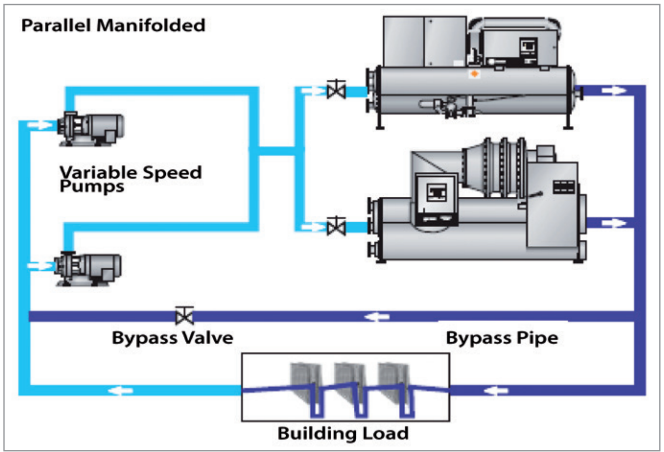

Figure 18: Variable primary flow system

In manufacturing industries, primary-secondary systems use hot well and cold well tanks (*Figure 19*). These are open type, and there is a loss of pressure in the hydraulic circuit.

Condenser water pumping systems are of following types:

1. Constant flow closed type cooling tower system
2. Constant flow open type cooling tower system

Closed type cooling towers are normally dry type with heat exchange condenser coils. There is no direct contact between the outside air and cooling water. This type of system is normally preferred in contaminated areas. It is also used for free cooling.

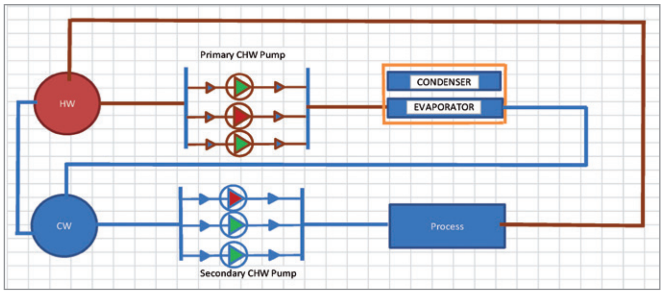

Figure 19: Primary-secondary system with hot well and cold well tanks

Open type wet cooling towers are widely used in HVAC systems. The condenser water pump sucks water from the cooling tower sump and supplies it to the condenser. Warm water is sent back to the cooling tower for heat rejection to the ambient.

Most condenser water pumping systems are designed with constant flow.

Cooling Tower Efficiency

The cooling tower rejects heat from the conditioned space along with the heat of compression to the ambient while cooling the circulating water. Its effectiveness depends on the ambient conditions, air flow rate carrying the heat of rejection, water flow rate per unit of circulating air flow, effective heat transfer area available around the fills and the operating range and approach of the cooling tower.

Normally a cooling tower is designed with 4-5 degree C range and around 3-4 deg C approach. Lesser the approach, better is the cooling. The cooling capacity of the cooling tower may hamper chiller performance and result in high discharge pressure and excess power consumption.

The performance of a cooling tower is dynamic, and drastically changes with water/air parameters as well as ambient conditions. Hence, while evaluating its performance, it is essential to record all the parameters and correlate them with the actual performance.

Chiller Plant Controls

In multiple as well as single chiller configurations, there is wide variation of cooling load and thus the required flow rate. Hence a control system needs to be in place that can control the number of pumps in operation as per chiller load and the number of chillers operating. The controllers can further be extended to control the flow rate as per the actual load on the chiller, which can help reduce the pumping power further while maintaining the design parameters.

However, to install a workable control system, a thorough understanding of machine performance and system dynamics is required. During the energy audit, various energy saving possibilities and controller architecture can be explored for maximum benefit.

Use of Innovative Products

While conducting energy audits, it is desirable to explore the possibility of using some innovative HVAC components and tools:

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1. Heat recovery wheel to pre-cool the fresh incoming air in Treated Fresh Air (TFA) unit
2. Air economizer in AHU to take the benefit of free cooling during favourable ambient conditions
3. Water economizer in AHU to take the benefit of free cooling during favourable ambient conditions
4. Geothermal or sea water as a source and sink for condenser water heat rejection
5. Alternate cooling technologies like air washer, adiabatic wet pads and waste heat source based vapour absorption chillers
6. Ice storage or phase change material (PCM) based thermal storage for demand side management of loads and chiller management
7. Automatic tube brushing system for condenser cleaning
8. Variable frequency drives for power and cooling load optimization
9. Metering system, sensors and control system for plant monitoring and optimization
10. Single window remote energy monitoring system for multiple sites
11. Heat pump and heat recovery chiller for hot water applications
12. Dry cooler for moderate temperature applications
13. Plate type heat exchanger
14. Automatic demand based ventilation system for CO_2 controls
15. Low flow designs to reduce HVAC component sizes
16. Energy simulation software to calculate energy savings

Case Studies on Energy Saving

Case 1: Low Side Equipment Modification and load Optimization at Pharmaceutical R&D Centre

Existing Scenario

The air conditioning requirement in the production department and laboratories of a pharmaceutical unit was catered to by a water cooled chiller. Most of the time the chiller was operating at part load, resulting in excess auxiliary power consumption.

Proposed Solution

As the total energy index (overall system kW/TR) was quite high, it was recommended to re-design the pumps and replace them with new pumps; to control the baseline energy consumption of cooling tower using variable frequency drives; and piping modification to reduce overall line pressure drops.

Post Implementation Results

This resulted in a reduction in daily power consumption of around 1000 units, equivalent to Rs.12,000 per day.

Annual energy savings achieved:	Rs. 35-40 lakh
Investment in project retrofit:	Rs. 30 lakh
Payback realised:	Less than 1 year

Project Risk

There is a possibility of failure if improper evaluation of the load profile is done and there is inadequate understanding of existing chiller characteristics.

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Energy Audit of a Chiller System for Retrofit

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Case 2: Replacement of Steam Based Hot Water Clarifier with Heat Pump for Hot Water Application in Luxury Hotel

Existing Scenario

At a 5 star hotel in Mumbai, steam was being generated using PNG.

Proposed Solutions

Instead of using a steam clarifier, use of heat pump for hot water generation and cooling as a bye-product was suggested for energy savings. A complete system including heat pump, minor piping, pumps and PHE along with controls was recommended.

Post Implementation Results

Annual energy savings achieved:	Rs. 25-30 lakh
Investment in project retrofit:	Rs. 55-60 lakh
Payback realised:	Around 2 years

Project Risk

There is a possibility of failure if heat pump sizing and system evaluation is not done properly

Conclusion

Detailed energy audit study of HVAC system is an appropriate tool for prioritizing the action plan for energy retrofit project implementation. Before embarking upon such projects, it is always beneficial to carry out a root cause analysis. Saving energy with an attractive payback period should be the objective. The energy auditor plays an important role here.