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A Case Analysis on Energy Savings and Efficiency Improvement of a Chiller Plant in a Luxury Hotel Building

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ABSTRACT

Energy is an efficient source in the present world and it is very significant. Huge building systems such as luxury hotels, commercial complex, malls and educational institutes require chiller plants for air-conditioning purpose in their premises. In this paper, a case analysis on energy savings and efficiency improvement of a chiller plant is done for a luxury hotel building located at Chennai, Tamil Nadu, India. The building consists of carrier make 2 Nos. 633 kW/180 TR and 1 No. 1185 kW/337 TR water cooled chillers. The chiller plant system at the site consumes up to 43% of the facility's annual energy cost. To increase the energy savings and efficiency of existing system and to achieve a lower number on the Specific Power Consumption (SPC), the existing chiller plant is retrofitted with 1 No. 879 kW/250 TR Premium efficiency chiller and an energy analysis is done by simulating the proposed chiller using Chiller Plant Automation (CPA) software and by understanding the energy usage of the chiller as per the site operating load and weather conditions. With the change in chiller, the system efficiency of the hotel increased by 40% and the energy consumption reduced to 38%.

1. INTRODUCTION

Huge buildings such as corporates, educational institutes, luxury hotels *etc.* are served by chiller or cooler plant for air conditioning purpose because of their heavy load demand. The chiller plant consumes huge amount of total electricity compare to other loads. The consumption of power by the chiller plant was affected by its Coefficient of Performance (CoP). In order to overcome this, a green scheduling algorithm was proposed in which the chiller plants are operated in safe with reduced peak power demand and total electricity cost [1]. Focusing on appropriate matching of chiller and supporting elements to minimize its working cost and to increase temperature stability and apparatus life. A PLC controller was employed to control the variable outputs and optimizes the performance of chiller compressors, chilled water pumps and Air Handling Units (AHUs). The Variable Speed Drive and necessary controller in the chiller plant reduces the Demand (KVA) peaks during the starting of chiller, chilled water pumps and also it minimizes the electricity tariff by 5% [2]. An energy efficiency model for chiller operation was proposed [3], in which chiller plant optimization algorithm was used to optimize the chiller parameters in which a Relative Root Mean Square Error method was implemented to evaluate the prediction accuracy and its result exhibits that this method is better than other models and it also improves the energy efficiency of chiller plants.

A chiller plant normally equipped with a chiller, cooling tower and pump subsystems. The chiller plant pumping is of three main configurations they are constant primary only systems, primary-variable secondary systems and variable primary pump systems. Since the cost of energy is quite high in a chiller plant, its operation is to be optimized in order to save the energy. The power consumption by the chiller plant is a nonlinear function of the temperatures [4]. Literature [5] focused on four methods of energy efficiency in a tourist building located in Mazatlan, State of Sinaloa, Mexico. Implementation of energy efficiency methods on lighting systems, pumps, chillers and buildings in the resort reduces the greenhouse gas emissions and improves the energy savings. Retrofitting of lighting systems and chiller, enhances the energy savings to a significant level. A cooling plant used for comfortable cooling service in airport, university, shopping complex *etc.* In earlier days, conventional cooling plant was in operation which is very complex. This complexity is a great challenge to energy efficient cooling process with higher cooling performance and lower energy consumption. To optimize the system and to minimize the energy consumption, an integrated root cause analysis technique was adopted to optimize the operation scheduling and save the power by 50% [6].

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A new cloud energy management system was introduced [7] to monitor and record the energy consumption of air conditioning apparatus in a commercial building and it also improves the energy efficiency to 65% of the system. There are many methods for improving the energy savings of a chiller plant, a joint optimization technique can be used to increase the component degradation thereby decreasing reliability. To achieve this, a dynamic chiller reliability model and a static hybrid model are developed [8]. A minimum path algorithm based on graphical method was proposed, in which this algorithm attains 25% of energy savings in the cost of operation compared to default chiller sequencing strategy [9].

The power consumed by the chiller is a highly non-linear function of the temperature. To obtain near optimal solutions and major energy savings, a decomposition and coordination approach with sequential programming was employed. This method is scalable and can be utilized for optimizing the chiller plant [10]. A Lagrangian approach was followed for solving the optimal chiller sequencing problem. This scheme takes lesser power compared to conventional scheme, which is appropriate for air conditioning system application [11]. An energy efficient free cooling system for data centers was proposed [12]. Here, an air economizer and water economizer are considered to be the primary cooling systems. The consumed energy in data center by traditional cooling system was compared with air economizer and water economizer for three different regions *i.e.* Chicago, Atlanta and Phoenix wherein the atmospheric air remains cool throughout the year. Therefore, it is witnessed that both economizers decrease the energy and cost.

A rule-based optimal control for the cooling water subsystem of chiller plants was discussed [13]. This paper proposes a simple optimal control rule for field operation based on the optimization results and explains how to solve the optimization problem of the cooling water subsystem. Literature [14] proposes the design of a chiller energy-saving optimization remote control system based on an improved particle swarm optimization (PSO) algorithm. It has a hardware detection and remote monitoring control system to detect various parameters of the chiller system. The use of remote monitoring and early warning devices enables the system to have the ability to monitor and control chiller systems in real time. Finally, data analysis was performed to achieve optimal energy-saving control.

A study was conducted at district cooling plant of UTP (Universiti Teknologi PETRONAS), which adapts RCA (Root Cause Analysis) diagnosis technique from steam absorption chiller to electric chiller, wherein two bottleneck models were developed for electric chiller's CoP (Coefficient of Performance) and CHW (chilled water supply) performance diagnosis [15]. Literature [16] explains the optimization techniques for industrial plant chiller control systems to enhance the energy savings. The control systems are improved for chilled water and condenser water temperature optimization and maximum heat recovery of split condensers as allied to cooling tower and heating load. The implementation of the optimization methods in distributed control instrumentation systems was also discussed. A non-linear discrete time system using a neuro-fuzzy system was identified and implemented [17] wherein the correlation of outdoor temperature, humidity and cooling load of the building are studied, and an algorithm was developed.

A unified method for multi-chiller management optimization was presented [18], which deals with the optimal chiller loading and optimal chiller sequencing problems. The primary goal was to decrease the power consumption and working costs. It depends on a cooling load estimation algorithm and the optimization was done using the multi-phase genetic algorithm, which provides an optimal solution for the complex multi-objective optimization problem.

The main objective of this paper is to perform a case analysis on energy savings and efficiency improvement of a chiller plant for a luxury hotel building located at Chennai, Tamil Nadu, India. The building consists of carrier make 2 Nos. 633 kW/180 TR and 1 No. 1185 kW/337 TR water cooled chillers. The chiller plant system at the site consumes up to 43% of the facility's annual energy cost. To enhance the energy savings and efficiency of the existing system and to achieve a lower number on the specific power consumption (SPC), the existing chiller plant is retrofitted with 1 No. 879 kW/250 TR Premium efficiency chiller. Also, an energy analysis is carried out by simulating the proposed chiller using Chiller Plant Automation (CPA) software and by understanding the energy usage of the chiller as per the site operating load and weather conditions.

2. CASE DESCRIPTION

A chiller plant system of a luxury hotel in Chennai, Tamil Nadu consists of Carrier make 2 Nos. 633 kW/180 TR and 1 No. 1185 kW/337 TR water cooled chillers. This chiller plant system consumes up to 43% of facility's annual energy cost. Table 1 shows the design specifications of existing chiller plant room and Figure 1 shows the monthly chiller energy consumption details from March 2017 to February 2018. Figure 2 depicts the chiller annual energy consumption from March 2017 to February 2018. The chiller annual energy consumption is around 10,76,247 kWh and Figure 2a shows the Air Conditioning, Heating and Refrigeration Institute (AHRI) benchmark.

A preliminary walkthrough at the site is conducted by evaluating the existing HVAC equipment, starting from the cooling tower to chillers. A detailed central plant audit is done to develop and design the customized energy solutions for the facility. Based on the audit carried out, it is found that existing chiller consuming 0.84 kW/TR (annual average energy consumption) and building cooling load is varying between 70 TR to 250 TR based on analysis chiller logbook. When comparing with the benchmark of AHRI, the present plant requires improvements in energy savings aspect. Figure 3 depicts the specific energy consumption of the existing chiller, in which chiller #3 is not in working condition and Figure 4 shows the existing plant room.

Table 1. Design of existing chiller plant room.

Particulars	Specifications
Existing Chiller	180 TR * 2 Nos screw chillers 337 TR * 1 No centri chiller
Make	Carrier
Type	180 TR – Fixed speed 337 TR – VSD chiller
Operating Pattern	24 /7 operation
Installation Year	2004
Chiller Design Efficiency	0.77 kW/TR
Chilled Water Circuit	Primary and variable secondary circuit

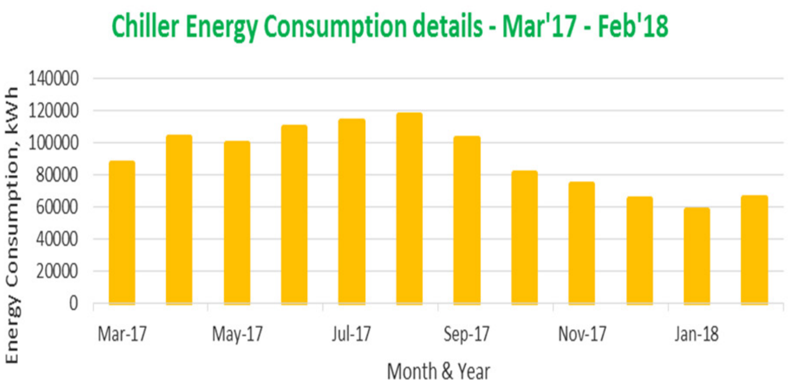

Fig. 1. Existing plant room energy consumption.

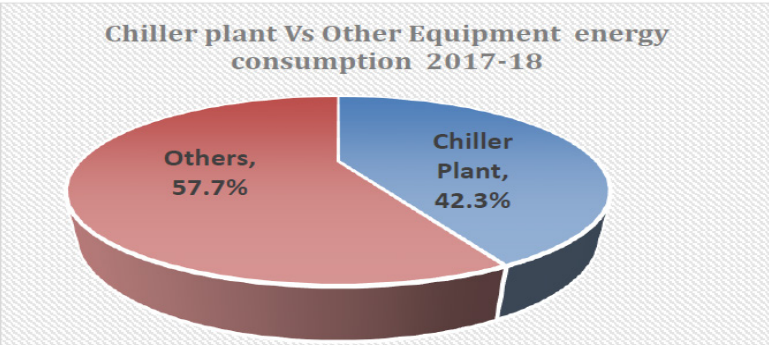

Fig. 2. Chiller annual energy consumption (Mar'17 - Feb'18).

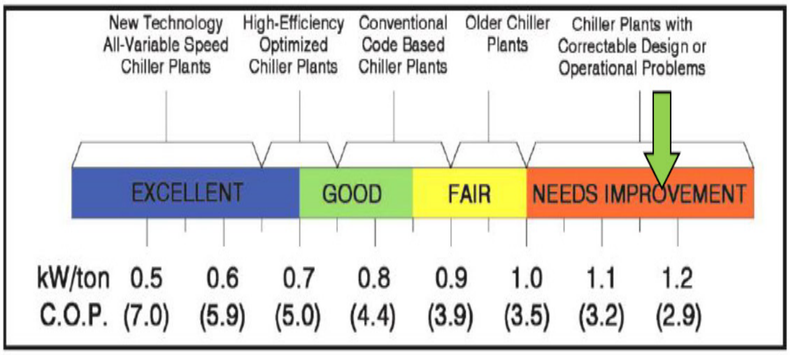

Fig. 2a. AHRI bench mark.

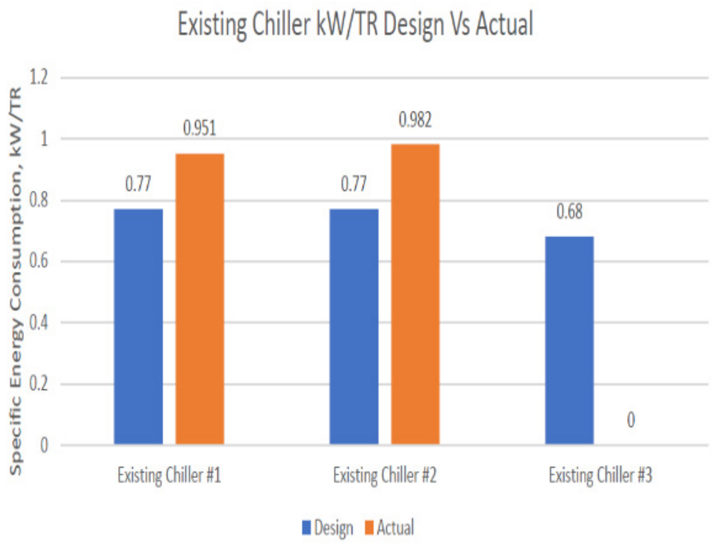

Fig. 3. Specific energy consumption of the existing chiller.

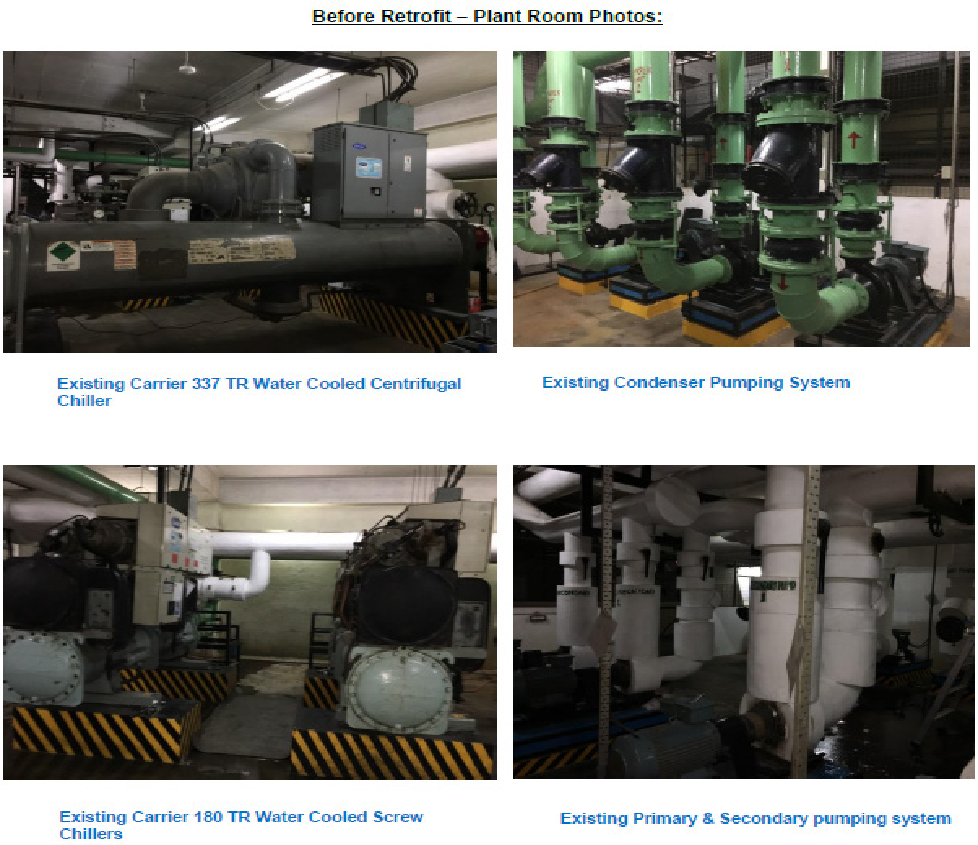

Fig. 4. Existing plant room.

3. PROPOSED PLANT ROOM ARCHITECTURE

Based on the energy auditing data and building cooling load analysis, retrofitting the existing chiller plant room system with 1 No. 879 kW/250 TR premium efficiency water cooled chiller with VSD is proposed. An audit on the chiller performance is conducted on 19th March 2018 and the audit details are provided in the Table 2. From the Table 2 it can be inferred that both the chillers are in operation with 100% loading condition and delivered capacity of 250-270 TR. Figure 5 depicts the annual building cooling load analysis. Based on this analysis from March 2017 to February 2018 and from the chiller logbook it is found that the maximum cooling load requirement of the building is 250 TR and delivered capacity of both chillers is around 270 TR. The total low side equipment's cooling load is 300 TR and considering the 80% diversity factor, it comes to 250 TR. Altogether, the designed new energy efficient chiller capacity is 250 TR to meet the entire building cooling load at full occupancy condition.

Table 2. Chiller performance audit data– March 2018.

Chiller Specifications	Unit	Chiller No#2	Chiller No#3
Rated chiller capacity	TR	180.00	180.00
Chiller set temperature	℃	7.00	7.00
Leaving chilled water temperature	℃	8.90	8.10
Entering condenser water temperature	℃	30.20	30.20
% load	%	100.00	100.00
Input power	kW	132.00	129.00
TR generated	TR	138.9	131.4
Specific power consumption	kW/TR	0.951	0.982
% deviation of capacity	TR	22.8%	27.0%
TOTAL tonnage delivered of both chillers	TR	270	

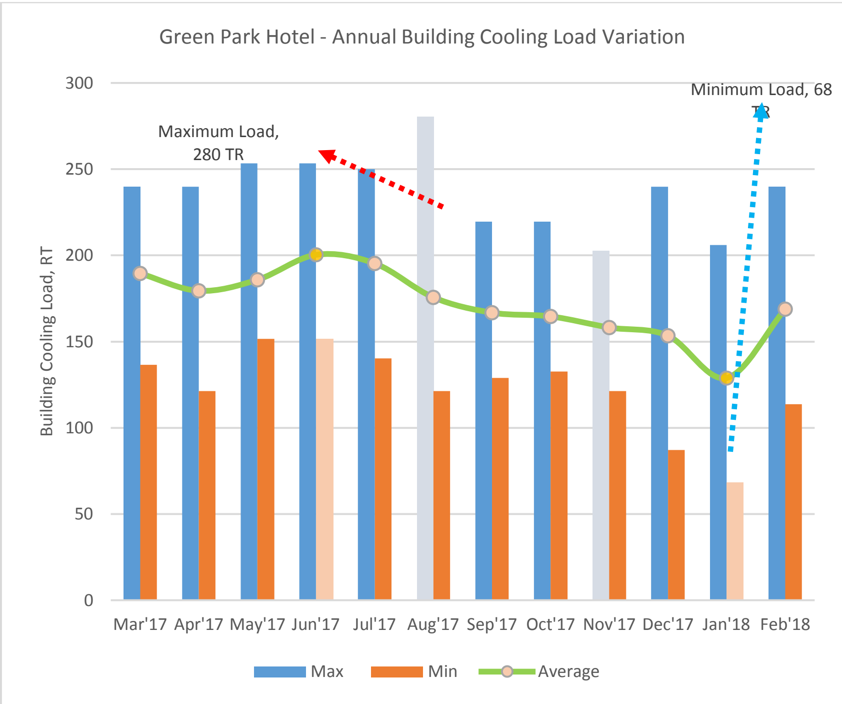

Fig. 5. Annual building cooling load analysis.

Further, an energy analysis is done in detail by simulating the proposed chiller as per the site operating load, prevailing weather conditions and understanding the energy usage of the chiller. In addition to the chiller replacement, a high efficiency system is also proposed. This system consists of a new primary and condenser water pumps, high efficiency cooling tower, automatic tube cleaning system (ATCS) and chiller plant automation (CPA) system for energy monitoring and verification. Table 3 shows the design specifications of retrofitted chiller plant room system.

Figure 6 shows the proposed plant room architecture. This plant room architecture consists of high frequency flow meters, energy meters and sensors. In order to measure and verify the savings, M and V protocol is developed and the installation of high frequency flow meters, energy meters and sensors are used to measure the chiller parameters.

Chiller Plant Automation is a software in which it receives multiple input data from the hardware of the chiller and its auxiliary system. It is configured with enabled auto mode, chiller stage calculation, chiller sequencer, auxiliary equipment control, staging up and staging down based on building cooling load, analysis of best efficiency point operation, adjusting the parameters *etc.* CPA helps the clients to calculate the cooling load of building, reduces the manpower cost, higher energy cost, cooling complaints, provides more efficient operation of meeting the building cooling load, monitoring and controlling of equipment efficiency through online from anywhere in the world. It is also used to measure and monitor real time energy reading in one minute interval (24*7). Figure 7 shows the CPA software installed at the site.

Table 3. Design specifications of retrofitted chiller plant room system.

Particulars	Specifications
Chiller make and model	York & YVWH
No. of proposed chiller	1 No
Capacity of each chiller	250 TR
Chiller annual average specific energy consumption	0.55 kW/TR
Proposed chiller annual energy consumption	7,06,640 kWh
Proposed chiller annual energy savings	3,63,672 kWh
Proposed chiller annual cost savings (Rs.10/kWh)	Rs. 36,36,720

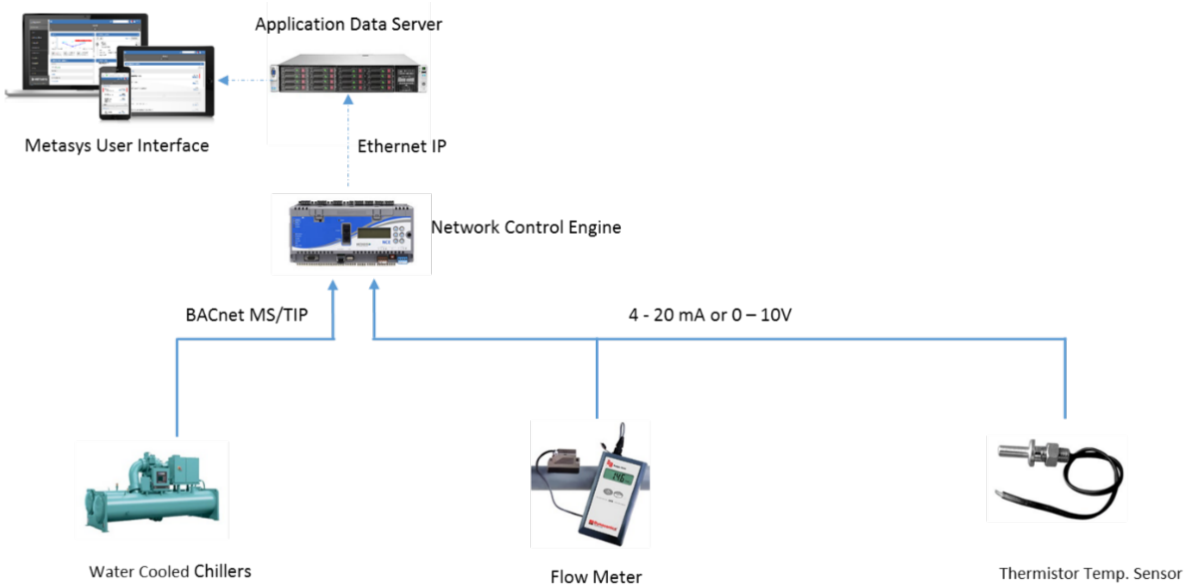

Fig. 6. Proposed plant room architecture.

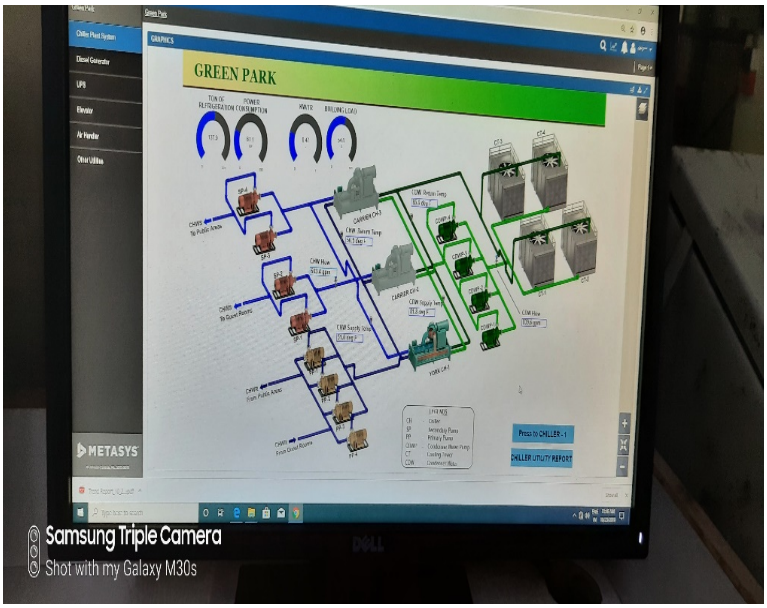

Fig. 7. CPA software installed at the site.

4. ENERGY SAVING MEASUREMENTS

A comparison between energy consumption of existing and proposed chiller plant room and energy savings is shown in Table 4. The energy savings for the month of March 2017 to February 2018 is only for the chiller. The energy savings of pumps and cooling tower are not considered. It is guaranteed that the retrofitted chiller plant yields an annual average efficiency of 0.55 kW/TR (on monthly basis savings guaranteed).

Table 4. Comparison between energy consumption of existing and proposed chiller plant room.

	Existing Chiller loading for the year 2017-18			Existing Chiller Plant Room Energy Consumption Details			Proposed Chiller Plant Room Energy Consumption Details			Saving per month
TR	Max	Min	Average	TRH	kWh	kW/TR	TRH	kWh	kW/TR	kWh
Mar’17	240	136	190	120059.7	87198	0.7263	120059.7	67065.6	0.5586	20,132.40
Apr’7	240	121	179	110024	103226	0.9382	110024	62896.05	0.5717	40,329.95
May’17	253	152	186	117736.7	99326	0.8436	117736.7	68481	0.5816	30,845.00
Jun’17	253	152	200	126901.5	109833	0.8655	126901.5	72669.45	0.5726	37,163.55
Jul’17	250	140	195	119739.8	113102	0.9446	119739.8	68687.85	0.5736	44,414.15
Aug’17	280	121	176	111276.7	117045	1.0518	111276.7	64835.58	0.5827	52,209.42
Sep’17	220	129	167	102259.3	102397	1.0013	102259.3	59707.07	0.5839	42,689.93
Oct’17	220	133	165	104286.1	81064	0.7773	104286.1	60168.24	0.5770	20,895.76
Nov’17	203	121	158	96986.89	74251	0.7656	96986.89	51240.16	0.5283	23,010.84
Dec’17	240	87	153	97205.87	64940	0.6681	97208.87	48263.42	0.4965	16,676.58
Jan’18	206	68	129	81691.77	58202	0.7125	81691.77	39827.54	0.4875	18,374.46
Feb’18	240	114	169	96631.62	65663	0.6795	96631.62	48733.15	0.5043	16,929.85
				1284800	1076247	0.84	1284800	712575.1	0.55	363,671.89

4. EXPERIMENTAL SETUP AND RESULTS

The chillers, pumps, cooling towers, ATCS and CPA were successfully commissioned during the month of September in the year 2019. The chillers energy consumption and other parameters were measured and monitored by CPA software from the month of October 2019 onwards. From the Table 4, it can be noticed that the annual average efficiency of existing 2 Nos 180 TR chillers are around 0.84 kW/TR and the new energy efficient variable speed chiller efficiency is 0.55 kW/TR at various loading and ambient temperature profile with 7℃ leaving the chilled water temperature throughout the year. Table 5 shows the energy savings for the month of October 2019. It is noticed that the new chiller average efficiency is 0.4843 kW/TR during month of October 2019 with leaving chilled water temperature of 10℃ and operating best part load efficiency. This new variable speed chiller acts very quickly and tunes the efficiency based on building cooling load, ambient temperature, chilled water set temperature with auto operation and always operates the chiller at best efficiency point. Figures 8, 9, 10 shows the comparison of committed vs achieved chiller energy savings, energy consumption and specific energy consumption for the month of October 2019.

Thus by retrofitting a new high efficiency chiller plant, the hotel is benefitted by 40% improvement in the system efficiency and 38% reduction in energy consumption. Figure 11 shows the retrofitted plant room.

Table 5. Energy savings for the month of October 2019.

Summary of Energy Saving for the Month of Oct’19				
A. Committed Energy Savings:				
Description	Unit	Existing System (Oct’17)	York Proposed System (Oct’17)	Actual - (Oct’19)
Total TRH generation	TRH	104,286	104,286	77,045
Total energy consumption	kWh	81,064	60,168	37,314
Specific energy consumption	kW/TR	0.7773	0.5770	0.4843
Energy savings	kWh		20,896	43,750
B. Simulated Energy Savings (Due to reduced TRH – lesser generation compared to Oct’17)				
Description	Unit	Existing System (Oct’17)	Committed - Proposed System (Oct’17)	Actual - (Oct’19)
Total TRH generation	TRH	77,045	77,045	77,045
Total energy consumption	kWh	59,889	44,451	37,314
Specific energy consumption	kW/TR	0.7773	0.5770	0.4843
Energy savings	kWh		15,437	22,575
Energy savings (Existing Vs Committed)			kWh	15,437
Achieved energy savings (Existing Vs Actual)			kWh	22,575
Additional energy savings achieved (Committed Vs. Actual)			kWh	7,137

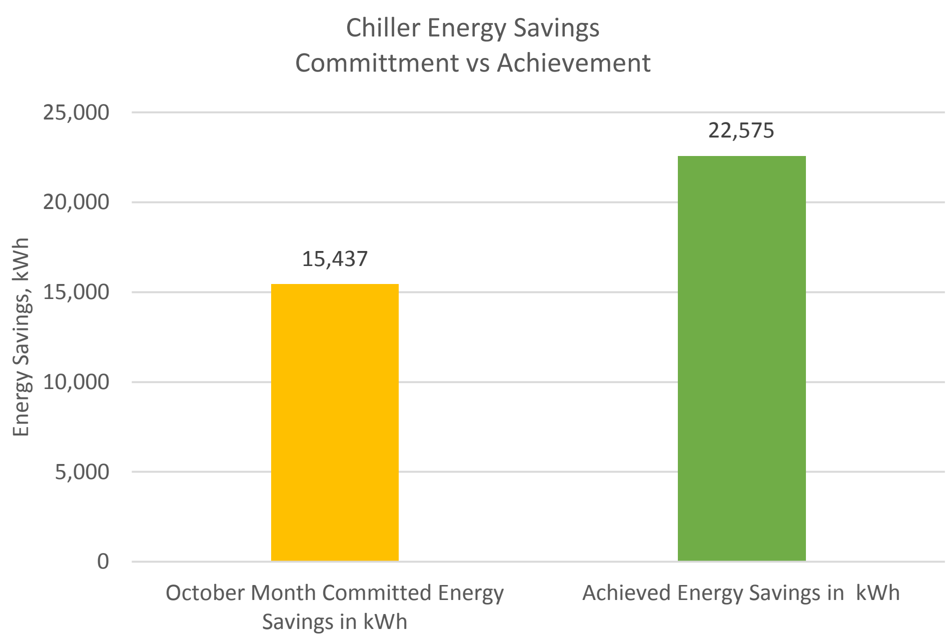

Fig. 8. Chiller energy savings for October 2019.

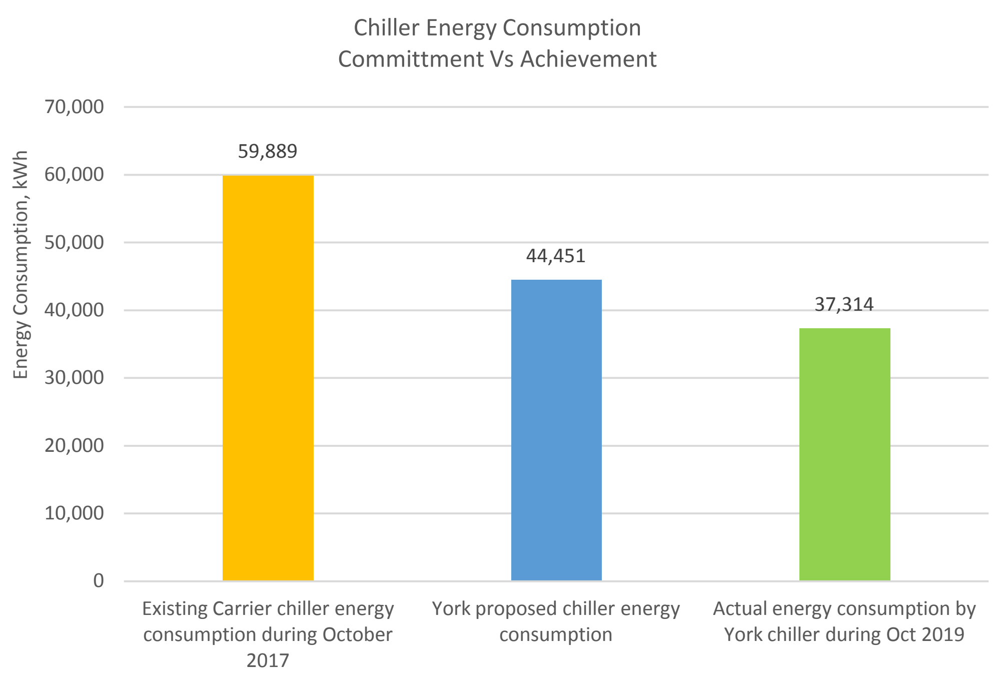

Fig. 9. Chiller energy consumption for October 2019.

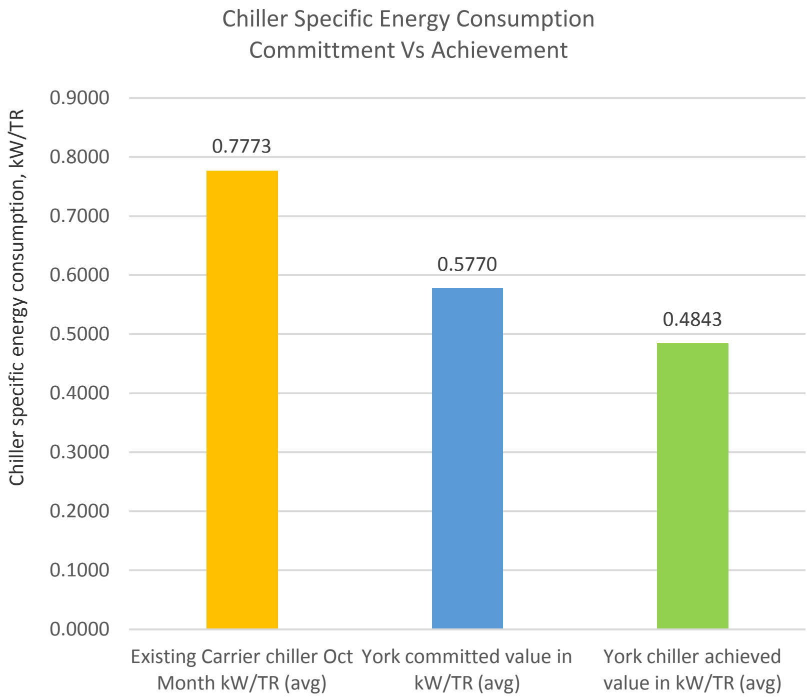

Fig. 10. Chiller specific energy consumption for Oct'2019.

Fig. 11. Retrofitted plant room.

6. CONCLUSION

Thus, in this paper, a case study on energy savings and efficiency improvement of a chiller plant is done. The existing chiller plant is retrofitted with 250 TR Premium efficiency water cooled chiller with VSD and an energy analysis is done to enhance the energy savings, efficiency of the existing system and also to achieve a lower number on the specific power consumption (SPC) in terms of ikW/TR, by simulating the proposed chiller using CPA software and by understanding the energy usage of the chiller as per the site operating load and weather conditions. With the incorporation of new system, the hotel is benefitted by 40% improvement in the system efficiency and 38% reduction in energy consumption.

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