Case study of energy saving potential through combined use of chiller plant optimization and connected service

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Abstract

In this study, Johnson Controls’ Chiller Plant Optimization (CPO10™) and Connected Service (CS) are used in parallel to demonstrate how the smart solution could drive the Chiller Plant energy saving potential and illustrated with Sun Hung Kai Centre Chiller Plant Energy Efficiency Project as a Case Study.

The objective of Sun Hung Kai Centre Chiller Plant Energy Efficiency Project is to maximize the overall operation efficiency of the existing chiller plant, including 6 nos. of water-cooled centrifugal chillers of total tonnage 3,300RT, chilled water pumps and condensing water pump. Dated back to 2014, soon after conducting the energy audit to set up the energy use baseline, a smart solution implemented in parallel, of which is CPO10™, an intelligent solution automatically select the most efficient combination of chillers and pumps needed to match the building’s load, and CS, a cloud-based diagnostic service, supported by Johnson Controls.

Combining the power of these two smart solutions, energy saving by 10 percent achieved upon nearly one year operation. This translates [1] into a reduction of 300 tons CO₂ emissions. The saving attained was the result from the use of COP10™ and CS without any equipment upgrade or replacement.

Keywords

Chiller plant; optimization control; CPO10™; connected service; energy efficiency; energy saving.
1 Introduction

Energy saving is one of the Hong Kong government’s prior concerns and the mega trend. With the government’s endeavor efforts of setting up policies and measures to promote and advocate energy saving and green building, the total energy intensity was reduced by 34.9% from 2003 to 2013 [2]. The vast reduction was partially contributed by the enactment of Building Energy Efficiency Ordinance (BEEO) and voluntary disclosure of environmentally-related information of publicly listed companies under Hong Kong Exchanges and Clearing Limited in 2012.

The BEEO covered two parts, the Building Energy Code (BEC) focusing on the minimum energy efficiency requirements and the Energy Audit Code (EAC) focusing on energy audit requirements governing the building services installations. Both BEC and EAC were reviewed on regular basis and the revised version was issued in 2015 [3].

Apart from it, as per 2013 record, all commercial buildings consumed 119,965 TJ, which was the largest portion of energy end use in Hong Kong at that time. In view of the growing demand on the governance compliance and the cost saving needs, the building owners also looked for different measures and technologies to save energy and optimize building performance.

Sun Hung Kai Centre (SHKC), the headquarter of Sun Hung Kai Properties, is a mixed-use development comprising 53 storey of office and shopping arcade and it is one of the few buildings in Hong Kong achieving the “Excellent” certificate awarded by the Hong Kong Environment Technology Centre together with attaining the ISO 50001 energy management system certification. ISO 50001 provides requirement for energy management with the Plan, Do, Check, Act (PDCA) cycle which the cycle should be repeated annually.

Energy audit was done to investigate their energy use baseline during the Plan Stage of PDCA cycle in 2014. The report showed that the major energy use sections in 2013 were MVAC (64%), Lighting (17.8%) and Lift system (6.6%). In such, reducing the MVAC energy use would be on top of the list. As their service partner, Johnson Controls proposed a new energy saving solution adapting only system optimization and proactive maintenance approach without equipment upgrade or replacement.

This solution took a holistic approach of using a chiller plant optimization software CPO10™ together with CS as tracking tool to maximum the energy saving impacts. Both solutions were installed and commissioned in early 2015 and targeted to achieve 8% saving in water cooled chiller plant against 2014 energy use. In this document, the holistic approach means in combining both chiller plant optimization software (CPO10™) and advanced maintenance approach (CS). A successful case will be shown in the following sections.
2 Seven steps of chiller plant optimization

Considering a way to improve the efficiency for a building, the first step is to optimize the one which is commonly the major energy consuming section. David Klee and Gary Gigot published the white paper – Seven Steps to Maximizing Central Plant Efficiency [4] in 2011 and proposed a holistic approach that allows central plants to reach and sustain their high-performance, high-efficiency potential. The proposed approach put the steps into two groups that sync to the building lifecycle. In Figure 1, the 7 steps summarized into 2 groups, namely Operation Decision & Design Decision.

Design Decision refers to the decision made in the “Design & Build” stages of a building life cycle. In Figure 2, it is shown that the design decision affects 20% of the lifecycle expense including the purchase of equipment, installation and commissioning of system. The largest portion, 80% of the lifecycle expense, falls to the operational decision. Operational costs include the energy consumption, operation and maintenance cost of system.

![Figure 1 - Seven steps to maximizing central plant efficiency](image)

![Figure 2 - Simplified building lifecycle](image)
2.1 Operational decisions

Proposed optimization system in SHKC focuses on optimizing the operational decisions. Operational decisions affect actual potential recover from the design decisions. The best equipment requires the best operation practice to explore all of its energy saving potential. Unlike the design decisions, changing of operational decisions usually involve less investment and effort. Routine review of operational decisions help to maintain the plant at its maximum efficiency.

Optimization system takes advantage of building management system (BMS) to maximize efficiency. Optimization software used to be custom-built solution dedicated design for that particular plant. Until recently, some BMS manufacture standardized, documented, tested and proven the optimization software and simplify the setup and operation of optimization software. The pre-define intelligent logic that holistically operates the plant in the most efficient manner and control set points are automatically calculated based on real-time building load information, ambient environment and equipment characteristics. Detail of optimization system will be explained in Section 4.

Optimization system can maximize the efficiency of an equipment to its limit. Advanced maintenance plays a very important role in maintaining the equipment to its highest efficiency and performance. Conventional preventive maintenance focuses on maximize uptime and not proactive enough as the predictive maintenance. Some chiller manufacturers provide cloud platform for remote monitoring and diagnose the chiller performance by analyzing the data. Not only to identify issues before they become problem, but also identify issues which affect the equipment as well as whole plant performance. Details of maintenance enhancement service will be explained in Section 5.

Lastly, the most important part is measurement and verification of system performance. Verification of actual performance of optimization steps to ensure design and equipment running properly as expected. With continuous verification and review of performance, energy saving potential can be reached at its maximum value.

3 Case study and background

Sun Hung Kai (SHK) Centre had a major retrofit completed in 2008. This is a 36 years old building with commercial and retail, 6 numbers of 550 TR York® water cooled centrifugal chillers (3 out of 6 comes with variable speed driver) and 2 numbers of 180 TR York® water cooled screw chillers arrange parallel with dedicated primary chiller pump and condensing pump, with headed secondary chilled water pump and plate heat exchanger with indirect sea water heat rejection. Chiller plant schematic is shown in Figure 3. Total capacity of plant is 3,660 TR and it operates in 24/7 manner covering an area of 80,667m². The overall plant efficiency is 4.054 (0.867 kW/TR) and consumes 5,427,382 kWh. This translates into 4287 ton of CO₂.
A holistic smart solution comprised with Chiller Plant Optimization software (CPO10™) and advanced maintenance – Connected Service (CS) was applied in the SHK Centre case. The detailed concept will be explained in Section 4 and 5 respectively.

4 Direct saving by optimization system - CPO10™

Before the launch of standardized optimization software, nearly all chiller plant automation focusing on whatever equipment on-off control, rotation of equipment running hours to make even of wear and tear, meeting set points and fail change over. BMS program has different capacity control methods to switch on-off control of equipment in staging manner. A common control method is to provide staging control of chiller to match the building load demand in consideration of the capacity of chiller.

4.1 Importance of off design condition

Consultants or building owners often purchases equipment with capacity catering for the most demanding operation scenario or accommodating future growth whilst, the control logic design based on performance of the equipment that design condition. However, the design condition usually refers to the hottest day for the whole year and it is only take up 1% of the operation time, with reference to AHRI 550/590 [5]. For the remaining 99% of time, the system run in off-design condition.

In BEC 2015 [6] update, standard rated condition is stated and additional rating condition of 75% of full load and water-cooled condenser water temperature in 24°C (while ambient temperature of 27°C for air cooled condenser) is added. With reference to the climate record by Hong Kong Observatory [7], it is seen that the condenser...
temperature is very close to the mean of daily maximum temperature. With the 100% full load point cater to deal with the hottest summer, the additional 75% full load point can represent the most common operational point of chillers.

The chiller capacity and performance change from time to time with different percentage of loading and operational condition. In Figure 4, the part load performance of generic York® YK water-cooled centrifugal VSD chiller shows that the chiller capacity increases with reduction of the condensing water temperature.

![COP vs. Part Load Ratio](image)

**Figure 4 - Part load performance of generic York® YK water-cooled centrifugal VSD chiller**

4.2 Change of rotation method in chiller sequencing

Understanding the importance of off design condition of chiller, chiller lead-lag sequence should be taken into account to determine the chiller efficiency instead of just considering the balance of runtime and wear & tear of the equipment.

Optimization program focuses on the efficiency of a whole plant and selects lead chiller with the highest efficiency. Runtime of equipment and start-stop count of equipment will be taken into account by penalty factor of equipment efficiency. Hence, the equipment will be running at its highest efficiency mostly.

In SHKC case, those 6 sets of 550TR chiller comes with different drivers, 3 comes with constant speed driver and the other 3 comes with variable speed driver. Before implementation of CPO10™, the chiller lead-lag is mainly determined by balance of runtime and thus the efficiency of chiller is not maximized. The runtime and efficiency of chiller before and after implementation of CPO10™ are shown in figure 5 and 6.
The change of lead-lag sequence and operation runtime of equipment results in increasing chiller efficiency. Figure 7 and Figure 8 show the actual chiller part-load performance recorded for year 2015. The dots refer to the actual data extracted from BMS system, the solid line is the trend line of the actual data, and the dashed line is the chiller design part-load at condensing water temperature of 24 °C, the mean condensing water temperature for Hong Kong.
Figure 7 - Actual efficiency against designed part-load performance of VSD chiller for 2015

Figure 8 - Actual efficiency against designed part-load performance of CSD chiller for 2015
4.3 Take advantage of the environment

The change of efficiency highly relates to the ambient temperature and usually expresses as compressor lift of chiller. Compressor lift means the difference between refrigerant saturation pressure across suction (evaporator) and discharge (condenser) pressure of compressor in chiller. Figure 9 illustrates the effect of work done of compressor with change of lift.

![Figure 9 - Typical compressor ‘Lift’](image)

During optimization process in the SHK Centre project, chilled water temperature reset of 1°C is set after office hour and it bring 2.5% increase of COP. The chiller efficiency difference before and after temperature reset is shown in figure 10.

![Figure 10 - Chiller efficiency comparison before and after automatic temperature reset](image)
5 Indirect saving by advanced maintenance - CS

Apart from direct energy savings contributed by CPO10™, chiller sequencing and chilled temperature reset, indirect savings had been obtained by advanced maintenance, CS, which provides monitoring and diagnosis of equipment operation, energy performance and predictive diagnostic.

5.1 Equipment operation

The logging of operation can also reveal the execution of control system. In Figure 11, it is shown that the daily chilled water temperature reset formed a specific pattern on the graph. By using the standard format of graphical reporting, routine tracking and observation of extraordinary incidence can easily be read, hence it can help in maintaining the plant operates in its peak efficiency.

![Figure 11 - Snapshot of CS report by Johnson Controls (Temperature reset)](image)

5.2 Energy performance

As the optimization of chiller system closely related to the chiller part load performance, chiller performance report should show the actual efficiency and runtime of equipment in order to verify the chiller plant control system.

Figure 5 and 6 is the capture of the monthly chiller performance report by CS. The energy performance in monthly report help owners and operators verify the operation of optimization control.

5.3 Predictive diagnostic

The chiller plant efficiency drops if the chiller fails to run with highest efficiency. Maintenance service can change from passive to proactive with predictive diagnosis of operational data, any issues can be identified before they turn into problems.
Example of predictive diagnosis is the high approach temperature of evaporator shell (shown in Figure 12). As chilled water is a close loop system and the chance of dirt built in the evaporator in normal operation is unlikely to happen. The possible cause is the refrigerant charge is low or poor control of refrigerant level.

![Figure 12 - Snapshot of CS report by Johnson Controls (Evaporator approach)](image)

6 Result of implementation of CPO10™ and CS in the SHK Centre

The chiller plant control modification project of SHK Centre completed in Apr 2015 and measurement and verification for comparing the energy consumption of calendar year 2014 and 2015 was done. The scope of work includes replacing the current control system with new BMS along CPO10™ optimization program and adaptation of CS.

During the project implementation, there is no hardware of equipment change in design decisions as described Section 2.1. The whole project emphasizes on operational decisions and focusing on how to operate the plant only.

In order to normalize the effect of ambient environment, electrical consumption of 2015 is projected by cooling degree days (CDD) and electrical consumption of 2014. CDD is a measure of how much (in degree) and for how long period (in days) that outside air temperature is higher than the temperature balance of the building. As total cooling degree days in 2014 and 2015 are 2246 and 2385 respectively, the projected consumption of 2015 is 5,624,723 kWh. The electrical consumption is reduced by 565,188 kWh (equivalent to 10.41% saving) in against to 2015 projected consumption and this translates into 300 ton of CO2. The energy consumption is shown in Figure 13.

Combined with direct savings by CPO10™ and indirect savings by CS, the overall plant efficiency is improved by 10% from 4.054 (0.867 kW/TR) to 4.502 (0.781 kW/TR)
Building owners and operators search for ways to improve the energy efficiency to higher levels. HVAC is the most significant portion of energy use in the building. In particular, central chiller plant optimization plays a critical role on energy saving in operational decisions in Seven Steps of Maximizing Central Plant Efficiency.

Having employed a holistic smart approach including Chiller Plant Optimization software (CPO10™), take advantage of environment as temperature reset and advanced maintenance (CS) in the SHKC case study, the energy efficiency improved and as result, the energy consumption is reduced by 10% by combining direct and indirect savings factor. To sustain the central plant optimization, apart from applying the holistic approach, continuous measurement and verification for the building should be adopted.

8 References