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Evaluation of CPMS installation and performance for energy savings

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Abstract. A large building or a factory with an open office area is commonly used for a centralized chiller plant system (CPS), including a chiller, chilled water pump, condensing pump, and cooling tower. A centralized control system called chiller plant management system (CPMS) has been installed to reduce complex operations and allow the system to operate according to the settings for appropriate working time. Even though there is an installation guide from developing countries, installing hardware and software in Thailand still lacks clear standards or guidelines. As a result, the communication speed between the control system and the device is inappropriate. It leads to restrictions on data transmission and difficulty assessing performance with appropriate data. As a guideline for future development, this research proposes development for evaluating hardware, software and CPMS performance (characteristic quantity (CQ) and heat balance). It is divided into hardware checks according to aggregate communication and sub-communication to obtain adequate data for the system performance evaluation. The guidelines have been developed by recommended equipment manufacturers widely used in Thailand. It is used in three large-scale commercial buildings. It was found that the communication device supports data transmission every 15 minutes, there is no communication signal interruption, and the software system is suitable for recording CPS data to support: (1) energy-saving assessment and (2) process of ecU9zzVtYvaluating the performance of the CPS system in terms of CQ analysis and heat balance theory. The finding process can be used to evaluate exiting CPMS performance before the improvement.

Keywords: Chiller plant manager system; Chiller plant system; Characteristic quantity; Heat balance

1. Introduction

Currently, a centralized control system is installed to manage the chilled water load more efficiently. The chiller plant management system (CPMS) is a scheduling automatic control system that can set the working time according to the time interval for the system to turn on and off according to the set-point selected by operators. The control system has standard functions, including: Function 1 - increase or decrease the number of chillers based on selecting full load amp (FLA) and outlet evaporator water temperature (Tevo); Function 2 – sequence status function used to activate pumps and cooling towers in sequence when chillers are staged-on or -off; it is used to protect a problem of program errors or machines to switch to the next device for continuing the system; Function 3 - the interlock function allows at least one chiller to operate, and when the FLA is lower than 50%, the control system will turn it off to prevent chiller damage or surge and; Function 4. - bypass function is to control the minimum flow rate of the system to turn on the chillers automatically and to control the water flow rate back to the system more appropriately. It is often designed for primary-secondary chiller plant systems since the primary water flow rate and secondary water flow rate are unequal; this function must be installed to optimize system performance [1]. Although there are standards and installation manuals for the CPMS systems from abroad, the CPMS systems in Thailand have different installation patterns [2, 3], as shown in Figure 1. It is found that the RS-485 cabling is used for communication, which has a delayed transmission communication speed when it converts to internet protocol. The main problems are: 1) Problems with the RS-485 communication subsystem, resulting in signal loss and multi-value storage because the sub-device does not support all real-time communication of the system; 2) Data collection and processing are performed at main controllers, increasing the processing load unnecessarily. A server must be added to separate the data collection from the control sequence processing; 3) The installation of the central controller supports both CPMS operation and control of an air-handling unit, which should separate the communication via hub switch and sub-DDC controller for easy verification and high efficiency; 4) Since the cabling system exceeds 100 meters, the signal should be modified by replacing the old communication system with fiber optics, supporting the plant expansion, and upgrading the system (hardware) in the next 7 years and; 5) System adaptation from RS-485 to full IP-control supports connection optimization control from EMIS (energy management information system) software with API (application programming interface) interface.

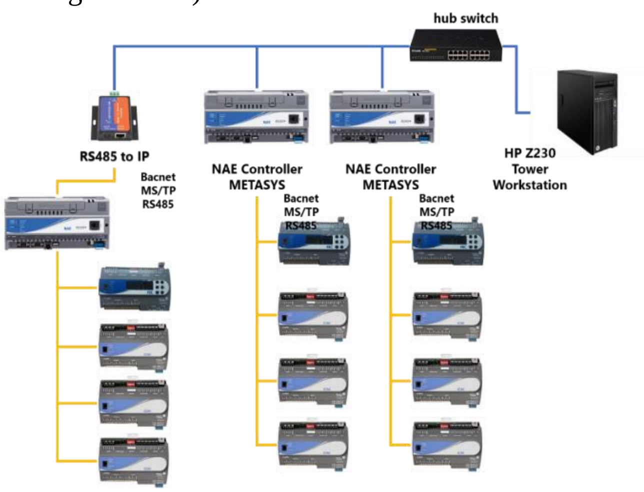


Figure 1. CPMS example in a standard factory

Due to complexity of the CPMS operations, a few researches developed CPMS evaluation frameworks during design [4], energy simulation [5], and operating security-based hardware evaluation [6]. From the above problem, it was found that there was a lack of an appropriate installation assessment model [3] to solve the problems. This project develops a guideline for evaluating the installation of CPMS hardware and software systems using international communication standards, which are divided into 6 Levels [7]; the evaluation of the CPMS composes of into two steps: (1) CPMS Hardware evaluation by assessing the device to meet the standards and (2) CPMS Software evaluation using the data quality to assure the system performance results. These two parts of the assessment form will be a guideline to help increase the performance of the CPMS system for energy saving.

2. CPMS Theory

The related theory in Section 2.1 describes the communication structure of CPMS, Section 2.2 describes the hardware behavior, and Section 2.3 describes the display characteristics and software requirements.

2.1. The communication structure of CPMS

Presently, the management of the building system is the application of a computerized control system and information technology for collecting information, monitoring, and controlling the operation of various devices to reduce energy consumption and operational cost saving, as shown in Figure 2.

For level 0 (Sensor/Field Devices), it is necessary to install a sensor system to monitor information or status through a local area network (LAN) or wirelessly. The data of level 0 can be transmitted via direct digital control (or IP-DDC) and network processing unit (level 1 and level 2). The central controller will send the information to the system control room (Level 3), which converts the signals sent from the sensors of various devices through the protocol into computer language, then displays it on the computer screen via software or Web-Browser (Level 4). Level 5 will be handled by building managers for effective building control and management.

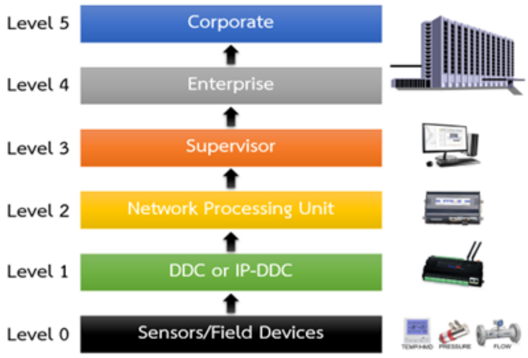


Figure 2. The building system communication structure [4]

2.2. Controller hardware

2.2.1. Direct Digital Control (DDC) (Level 1)

It is a device that processes data signals from measurements and sends signals to control devices (sensor/field devices). The device can access standard Web-Browser such as Google Chrome, Firefox, Opera, etc. From Figure 3, the device has high-speed communication via Ethernet LAN or fiber optic connection; the output signal is converted from analog signal to control the speed of the motor (variable speed drive, VSD) or actuator. There is a backup battery to supply to the internal clock system so that it can continue to work in the event of a power failure, and support for open protocol communication (BACnet, Modbus, etc.)

2.2.2. Network Processing Unit (NPU) (Level 2)

It is a device that communicates with IP-DDC as central processing to store values. In other words, it manages and controls the operation of network devices to display various values.

Typically, this device has an Ethernet LAN port to connect to the computer. It can also communicate with other systems by open protocol and can display data and communicate via the Internet (Web Browser User Interface). The output signal is analog, and the system is password protected.

2.3. Characteristic quantity

Characteristic quantity (CQ) law is developed based on ASHRAE RP 1275 project [8] and TRF project [3]; the method is used to analyze chiller performance using BACnet data (Table 1) in terms of relations between chiller load (FLA – full load amp) and water flow rate (or water temperature differences); FLA will be deviated from manufacturers' data whenever water flow-rate of chilled water and cooling pumps are not operated suitably. The equations used for the analysis are listed as depicted in Figure 3.

In Figure 3, CQ1 is determined by the chilled water temperature differences between inlet chilled water and outlet chilled water temperature; this value is between 0 – 10 F and proportional to the FLA between 0 – 100% for normal and constant flow chiller systems. For example, if chiller FLA is 60%, CQ1 equals 6 F compared to the manufacturing data.

Another parameter: CQ2, is determined by the cooling water temperature differences between inlet condenser water and outlet condenser water temperature; this value is between 0 – 10 F and proportional to the FLA between 0 – 100% for typical constant flow chiller systems. For example, if chiller FLA is 60%, CQ2 is approximated to 6 F with uncertainty ±3%.

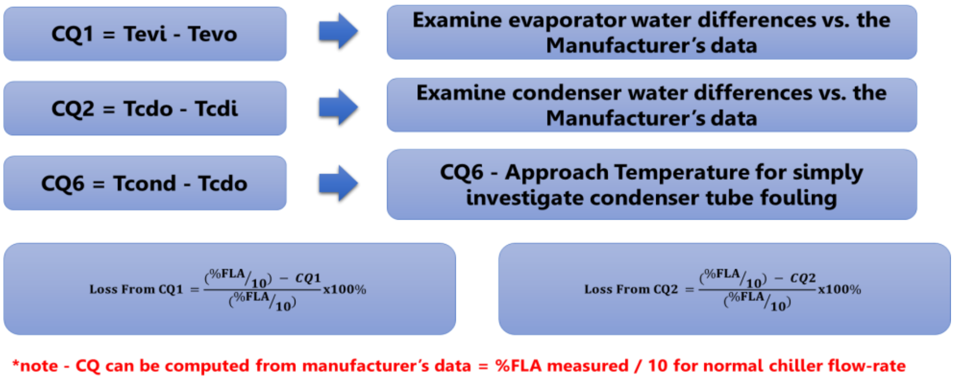


Figure 3. The building system communication structure

Additionally, CQ6 or condenser approach temperature is computed by the temperature differences between outlet condenser water and saturated condenser temperature; the expected value should be between 3.5 – 5 F at 80% FLA for diagnosing condensing fouling. If CQ6 is higher than 5 F, the condensing fouling is the main problem affecting the CQ2 value.

2.4. Heat balance

Heat Balance is an assessment of the percentage of the heat balance of total heat gain and heat dissipation within ±5% of the 80% operating time. It represents a suitably programmed sequence leading to the chiller power consumption within reasonable values. For example, the CPMS efficiency is less than 0.7 kW/ton, and the heat balance has no more than 5% for the 85% of total CPMS operations. The equation of the sample system (constant chiller flow-rate) as shown in Figure4. The heat balance can be computed via eq.1 [9]

$$\%\textbf{Heat Balance} = \left(\frac{(\dot{Q}_{evaporator} + W_{input}) - \dot{Q}_{condenser}}{\dot{Q}_{condenser}}\right) x\ 100\% \leq 5\% \qquad (1)$$

In eq. (1), the following variables are: $Q_{evaporator}$ is CPS system total cooling load; $Q_{condenser}$ is CPS cooling load; W_{input} is the total electricity cost of the chiller.

3. Method

The sequence of CPMS installation evaluation is as follows: 1) hardware installation assessment according to the building system communication structure in Figure 2 into the three parts: sensor/field devices; IP-DDC, and NPU (central network controller); 2) evaluation of the software by assessing three parts: graphical user interface (GUI), data interface, and data and; 3) heat balance and CQ analysis using data export from software.

Table 1. Data example for chiller interface and CQ analysis

No.	Parameters	CQ analysis
1	Outlet evaporator water temperature (Tevo, F)	CQ1 = Tevi – Tevo (2)
2	Inlet evaporator water temperature (Tevi, F)	
3	Outlet condenser water temperature (Tcdo, F)	CQ2 = Tcdo – Tcdi (3)
4	Inlet condenser water temperature (Tcdi, F)	
5	Full load amp (FLA, %)	CQ = %FLA/10 (4)
6	Saturated condenser temperature (Tcond)	CQ6 = Tcond – Tcdo (5)
7	Chiller set-point	-

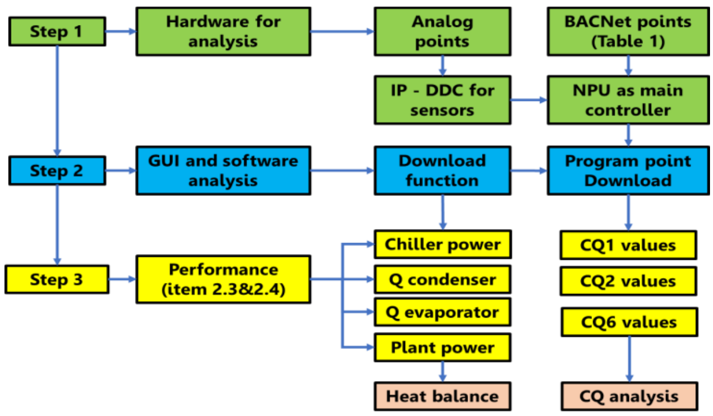


Figure 4. CPMS process evaluation

In Figure 4, hardware analysis (step 1) includes investigations of analog inputs for hardwired sensors inputted into IP-DDC control and BACnet points of the chiller controller interfaced into the NPU controller. Analog inputs and BACnet points can be depicted on the GUI for operator use. With suitable GUI design and data points, GUI can be used to trend parameter graphs before automatically downloading all available data of the NPU in step 2. Heat balance and CQ analysis are used to analyze the existing performance of the CPMS before designing the system improvement and assessing energy-saving possibilities.

4. Evaluation results

4.1. CPMS hardware evaluation

The step 1 is conducted In Figure 5; the communication structure conforms to the standard according to the manufacturing guide [10] and content analysis [3].

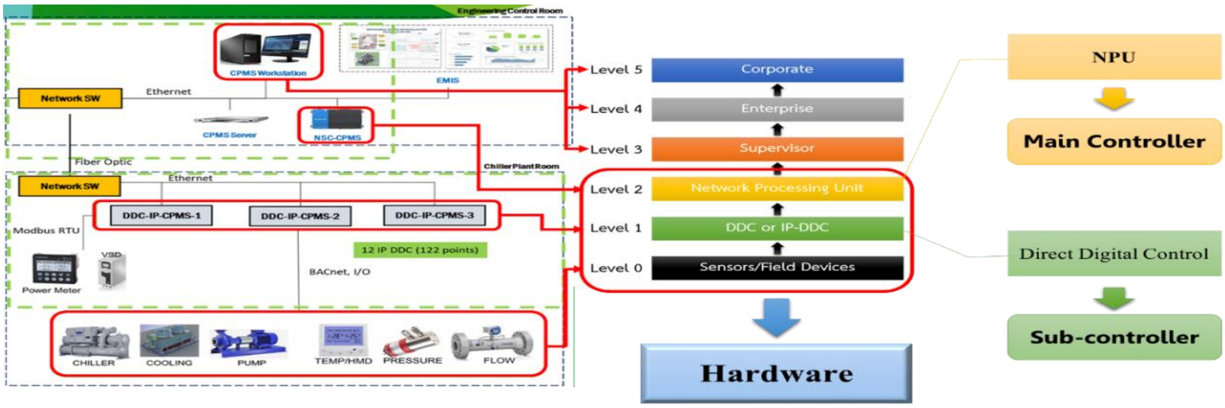
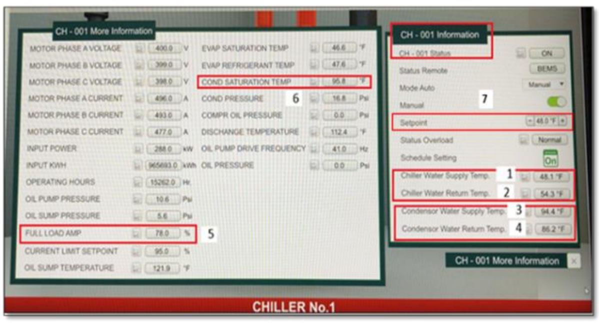


Figure 5. Hardware analysis

The existing CPMS communication is wired using an Ethernet LAN with the standard speed. Moreover, the hardware can collect all essential data; for example, the essential sensors can store the chiller's points, such as temperature, pressure, and water flow rate. The various data will be displayed in the data interface section. The subsystem equipment must comply with the standards. For instance, an NPU can be complied the device's standards by comparing the manufacturer's data with the standard, correctly. Also, each layer of the CPMS communication is designed based on the 5-level guide recommendations.

4.2. CPMS software evaluation

From the existing GUI system, it can notice that 1) the sensors are installed completely, and are displayed for heat balance and CQ analysis; therefore, it can check the download function for both hard-wired sensors and BACnet data points.

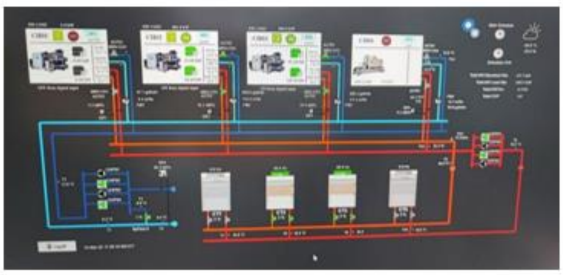


No.	Parameter
1 and 2	Outlet and Inlet Evaporator temperature
3 and 4	Outlet and Inlet Condenser temperature
5	Full Load Amp
6	Condenser Saturation Temperature
7	Setpoint

Figure 6. Data interface of the Table 1

2) the data interface (Figure 6) consists of the evaporator and condenser water inlet and outlet temperatures, condenser saturation temperature, %FLA and setpoint.

3) Using the data export function, the data can be extracted in Excel (.csv) format with selectable intervals of all variables. These data set will be further used to compute heat balance and CQ analysis.



ตัวแปร	Chiller No.2	Chiller No.3
kW Load	682.8 kW	684.6 kW
kW/Ton	0.7159	
kW absorbed	277.7 kW	
kW load site	1367.3 kW	

Figure 8. CPMS communication structure.

4.3. Performance evaluation

From Figure. 8, the CPMS plant can be computed the heat balance percentage and efficiency using eq. 1. From the data in Table 2, chiller efficiency is 0.60 kW/ton (magnetic bearing chiller) using the chiller power summation as W_{input} in Table 2. Also, this CPS plant can be concluded that the heat balance is 6.48% with average 0.80 kW/ton of the CPMS plant efficiency. The evaporator water flow-rate of CPS plant should be improved to reduce heat balance within 5%.

Table 2. Heat balance evaluation

Building 1	Equation	Results
$Q_{evaporator}$	Tons x 3.52	8088.26 kW
$Q_{condenser}$	Ton x 3.52	10110.3 kW
W_{input}	Chiller power summation	1367.4 kW
% Heat balance	Eq. (1)	-6.48%
Chiller efficiency	W_{input}/ $Q_{evaporator}$	0.60 kW/ton

For CQ analysis, the data interface in Figure 6 can compute CQ1 and CQ2 loss from the manufacturers' data using Eq. (2) – (5) in Table 1. The results can be summarized in Figure 9. This analysis can diagnose: (1) too less CQ1 (yellow areas), at least 20% leading to too high CHP water flow rate of around 20%; (2) too high CQ2 (green areas), at least 3.7% resulting in too low CDP water flow rate around 3.7%; and (3) too low CQ6 (the standard valve between 3.5 – 4.5 F) incurs in chiller No1 and No.2 due to refrigerant overcharge.

No.	Setpoint (F)	Tevo (F)	Tevi (F)	Tcdo (F)	Tcdi (F)	FLA (%)	CQ1 (F)	CQ2 (F)	Loss CQ1	CQ6	Loss CQ2
CH1	48	48.1	54.3	94.4	86.2	78	6.2	8.2	-20.5%	1.4	+5.1%
CH2	48	48.0	54.1	94.8	86.4	81	6.1	8.4	-24.7%	2.3	+3.7%
CH3	47	47.1	54.1	95.6	86.0	88	7.0	9.6	-20.5%	3.7	+9.1%

Figure 9. CQ analysis of the existing CPMS

Conclusion

From the standards and guidelines for installing CPMS hardware and software in Thailand, the speed of communication between the control system and the device is inappropriate. As a result, the data used for CPMS evaluation cannot be downloaded for quantifying the system performance. This project presents the audit and assessment process of hardware and software installation. The testing results with the CPMS system of the building example showed that the communication device supports data transmission every 15 minutes, and there is no communication signal interruption. The software system is suitable for recording CPS data to support energy savings that can be assessed with the heat balance equation and CQ analysis. The results show energy loss occurring in the existing system leading to energy saving potential whenever monitoring based commissioning or returning process are applied to retrofit the system performance.

References

[1] Woradechjumroen D, Mahasukhin P 2019 Standard development for monitoring-based commissioning of chiller HVAC systems in Thailand Full report – iTAP: Africvs Co.,Ltd

[2] Cheng C, Lee D 2018 Return on investment of building energy management system: a review *Int J Energy Res* **42** p4034

[3] Woradechjumroen D, Jansa P 2020 *Process and metrics development of BAS utilization efficiency for energy savings of a chiller system via EMIS tool – phase 1* Final Report - TRF and EGAT funding

[4] Osman K, Jankovich D 2020 A unified approach in system architecture development during energy efficient design of cooling plants J. Sustain. *Dev. Energy Water Environ. Syst.* **8(4)** p604
[5] Lyu Y, Pan Y, Yuan X, Zhu M, Huang Z, Kosonen R. 2021 A comprehensive evaluation method for air-conditioning system plants based on building performance simulation and experiment information *Buildings* **11** 522
[6] Wang J, Zhao T, Li W 2019 *Proc. Int. Conf. on Smart City and Intelligent Building (China)* vol 1 p271
[7] Capahart BL and Capehart LC 2005 *Web based energy information and control systems: case studied and applications* (Fairmont Press, Inc)
[8] Reddy T 2007 Development and evaluation of a simple model-based automated fault detection and diagnosis method suitable for process faults of large chillers *ASHRAE Transaction* **113 (2)** p27
[9] Building and Construction Authority 2016 *BCA green mark certification standard for existing buildings GM version 3.0*
[10] Kaewpiroj W 2012 *Automatic control: smart building case studies* Presented at ACAT Thailand