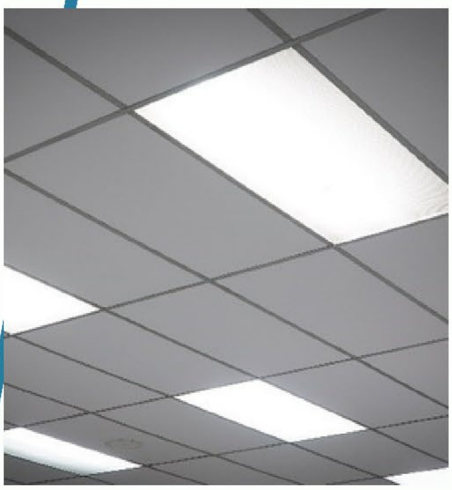
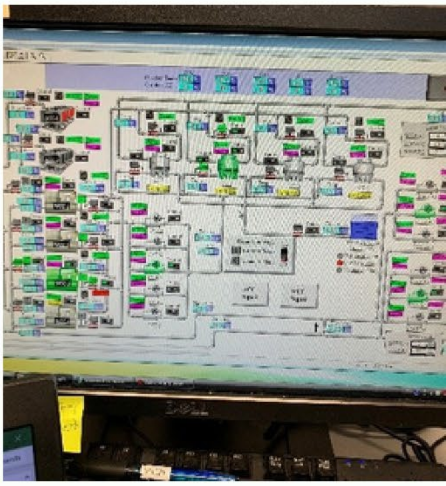
EMSD

TECHNICAL GUIDELINES ON RETRO-COMMISSIONING

2023







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Disclaimer

The Electrical and Mechanical Services Department of the Government of the Hong Kong Special Administrative Region, China ("the EMSD") publishes this Technical Guideline on Retro-commissioning (TG-RCx) to serve as a basic and clear procedural guidance on RCx and to facilitate building owners, RCx service providers or relevant parties to carry out RCx.

This TG-RCx serves as good reference at the time of publication, and shall be reviewed and updated with trade practitioners on need basis. Users of relevant trade stakeholders such as building owners, RCx services providers, and relevant parties are free to consider and adopt the subject practices when satisfying their own operational needs and reference. Users should not only rely on the information given in this TG-RCx and could consult independent and relevant professional personnel whenever there are doubts about the application of the relevant guidelines stated on TG-RCx on individual circumstances.

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Acknowledgement

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- American Society of Heating, Refrigerating and Air-Conditioning Engineers (Hong Kong Chapter)
- Building Services Operation and Maintenance Executives Society
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- Hong Kong Green Building Council
- Hong Kong Institution of Engineers (Building Services Division)
- The Association of Consulting Engineers of Hong Kong
- The Hong Kong Association of Energy Engineers
- The Hong Kong Federation of Electrical and Mechanical Contractors Limited

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1. Introduction

1.1 Background

Pursuant to the Hong Kong's Climate Action Plan 2050 published in October 2021 by the HKSAR Government, it is stated that "Retro-commissioning" is one of the key energy management tools to promote energy saving for existing buildings in order to strive for carbon neutrality before 2050.

Retro-commissioning (RCx) is a cost effective and systematic process consisting of periodical checking of an existing building's performance to identify operational improvements that can save energy and in-turn lower energy bills and improve the indoor environment.

1.2 Benefits of Retro-commissioning

There are many benefits to carrying out RCx, which include:

- provision of building energy cost savings with no or low investment, resulting in short payback periods;
- reduction in Operation and Maintenance (O&M) costs;
- reduction in the likelihood of energy consuming equipment/ systems failing, extending the lifespan of the equipment;
- ensuring that energy consuming equipment/systems operate at their most efficient levels;
- providing a healthy and comfortable indoor environment for the occupants;
- increase in the asset value of the building, and
- enhancement of the knowledge and skills within the building management team for development of O&M capabilities.

1.3 Overview and Objectives of Retro-commissioning

"Retro-commissioning" covers the scope of "existing building commissioning", "re-commissioning" and "continuous commissioning". There are four stages in RCx: Stage 1 - Planning, Stage 2 - Investigation, Stage 3 - Implementation and Stage 4 - Ongoing commissioning. RCx starts with the collection of operational data of energy consuming equipment/systems, followed by on-site measurement testing and data analysis to then come up with proposed Energy Saving Opportunities (ESOs). Through the implementation of the ESOs, the operational performance of building systems can be improved, which in turn enhances the building's energy efficiency and occupant comfort levels.

1.4 Overview and Objectives of Energy Audit

An energy audit involves a systematic review of energy consuming equipment/systems in a building to identify their Energy Management Opportunities (EMO). This in turn provides useful information for the building owner to choose and implement the energy saving measures for environmental consideration and economic benefits.

An energy audit begins with the collection of relevant information that may affect the energy consumption of the building, followed with the reviewing of the collected information, the analysis of the conditions and performance of the existing equipment, systems and installations along with energy bills. Energy audits can achieve energy efficiency and conservation through the implementation of EMOs identified in the energy audit.

1.5 Difference between Retro-commissioning and Energy Audit

RCx is more focused on checking whether the energy consuming equipment/ systems can be operated properly as per design or user requirements, and to identify areas of improvement (e.g. shifting of system control settings, inaccurate sensors, improper operational schedules and improper air & water balancing, etc.). RCx also incorporates the identification and implementation of ESOs, as well as providing an ongoing commissioning plan for the building owner/operators to maintain the building's performance to high levels of energy efficiency.

1.6 Aim of the Technical Guidelines

This Technical Guideline on Retro-commissioning (TG-RCx) is designed to serve as a basic and clear procedural guidance on RCx. To facilitate carrying out RCx for building owners, relevant checklists, data collection forms and report templates are provided within these guidelines and appendices. Examples of ESOs commonly identified during the RCx process have also been described in this TG-RCx where appropriate.

To ensure the benefits of RCx are maintained beyond completion of the RCx process, this TG-RCx also addresses the importance of ongoing commissioning, and proposes strategies for this building owner's reference.

2. Interpretations

‘**air-conditioning**’ means the process of cooling, heating, dehumidification, humidification, air distribution or air purification.

‘**air handling unit (AHU)**’ means equipment that includes a fan or blower, cooling and/or heating coils, and provisions for air filtering and condensate drain etc.

‘**central control & monitoring system (CCMS)**’ means a centralised system that connects various sensors and control equipment installed in the building. It allows the building operation and maintenance personnel to monitor the building operation condition and to control various systems remotely.

‘**chilled/heated water plant**’ means a system of chillers/heat pumps, with associated chilled/heated water pumps and if applicable associated condenser water pumps, cooling towers and/or radiators.

‘**chiller**’ means an air conditioning equipment that includes evaporator, compressor, condenser, and regulator controls, which serves to supply chilled water.

‘**coefficient of performance (COP) - cooling**’ means the ratio of the rate of heat removal to the rate of energy input, in consistent units, for an air-conditioning equipment.

‘**coefficient of performance (COP), heat pump - heating**’ means the ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a heat pump type air conditioning equipment.

‘**constant air volume (CAV) air distribution system**’ means a system that controls the dry-bulb temperature within a space by varying the temperature of supply air that is maintained at constant volume flow to the space.

‘**electrical installation**’ means fixed equipment, distribution network or accessories for electricity distribution or utilization in the building.

‘**energy saving opportunity (ESO)**’ means the saving opportunities identified during the investigation stage of RCx.

‘**equipment**’ means any item which serves the purpose of conversion, distribution, measurement or utilization of electrical energy. This includes luminaires, air conditioning equipment, motors, motor drives, machines, transformers, apparatus, meters, protective devices, wiring materials, accessories and appliances.

‘**escalator**’ should have the same meaning assigned by section 2 of the lifts and Escalators Ordinance (Cap. 618).

‘**harmonics**’ means the frequency component of the periodic oscillations of an electromagnetic wave that is an integral multiple of the fundamental frequency. This frequency is 50 Hz for the power distribution system in Hong Kong.

‘**implementation stage**’ means the stage in the RCx process where selected energy saving opportunities (ESOs) are carried out. A verification process is also carried out in this stage to determine if the ESO contributed to any energy savings. After completion of the implementation and verification, a final RCx report should be carried out which summarizes the outcomes of the implementation stage.

‘**investigation stage**’ means the stage in the RCx process that involves in-depth system analysis to determine potential gaps in energy efficiency. A detailed list of recommended energy saving opportunities (ESOs) should be generated in this stage, including estimated energy savings and payback period. The selected methodology for energy saving verification should also be presented clearly. A list of selected energy saving opportunities (ESOs) should be confirmed at the end of this stage and agreed with the building owner(s)/ facility manager, which will then be implemented in the ‘implementation stage’.

‘**lift**’ should have the same meaning assigned by section 2 of the Lifts and Escalators Ordinance (Cap. 618).

‘**lighting installation**’ means a fixed electrical lighting system in the building

‘**luminaire**’ means a lighting device which distributes light from a single lamp or a group of lamps; a luminaire should include control gears if applicable, and all necessary components for fixing and mechanical protection of lamps.

‘**meter**’ means a measuring instrument which measures, registers or indicates the value of voltage, current, power factor, electrical consumption or demand, water flow, energy input/output etc.

‘**on-going commissioning stage**’ means the stage in the RCx process that aims to ensure building systems remain optimized continuously, achieved by data being continuously gathered and compared.

`**operational data**’ means measured time-series data collected from the systems / equipment installed in the building. These are normally collected from portable data loggers or central control management system.

‘**operational documentation**’ means a plain-text report where the actual status of different equipment and/or systems is documented.

‘**planning stage**’ means the stage in the RCx process that includes the collection of building documentation such as schematic drawings, layout plans, electricity bills, etc. To ensure sufficient understanding of a building’s systems operation, an initial site walk-through should be carried out. After this walk-through, and review the trend log data, a RCx plan should be written which covers the system analysis to carried out and the site measurement plan to enable the ‘investigation stage’.

‘**retro-commissioning**’ means a knowledge based systematic process to periodically check an existing building’s performance, with the aim of identifying operational improvements that can save energy (thus lowering energy costs) and improve the indoor environment.

‘**variable air volume (VAV) air distribution system**’ means a system that controls the dry-bulb temperature within a space by varying the volume of supply air to the space automatically as a function of the air-conditioning load.

‘**variable speed drive (VSD)**’ of a motor means a motor drive that controls the motor speed across a continuous range.

3. Pre-RCx Preparation

3.1 Assess in-house capability

In preparation for carrying out RCx, the building owner can first assess their O&M team to see if they possess sufficient resources and the know-how required for running RCx tasks, which will be explained in detail in the later sections. O&M staffs are normally the most suitable individuals to perform RCx tasks, as they are familiar with the building system installations, operation patterns and understand the building occupants' need.

As RCx may involve on-site measurement for data collection during the process, O&M staff can check if they have sufficient measuring equipment to facilitate the tasks. In form 2.1, a list of measurement equipment is provided and can be used for further reference.

3.2 Training to enhance in-house capability

Further training can be considered to enhance the capability of the in-house O&M team. The following EMSD website provides additional information on training relevant to RCx.

https://www.rcxrc.emsd.gov.hk

Any additional costs on training for in house O&M team and purchase of measuring equipment should be taken into consideration.

3.3 Engage third party service provider

If the O&M team is not suitable to carry out RCx, the building owner may consider engaging an external RCX service provider to facilitate the procedure with the help of the O&M team. More detail is discussed in section 4.1.2 of this guideline.

4. How to Conduct Retro-commissioning for a Building

4.1 Overview

There are four (4) stages in RCx. In each stage, the major activities are shown as the following:

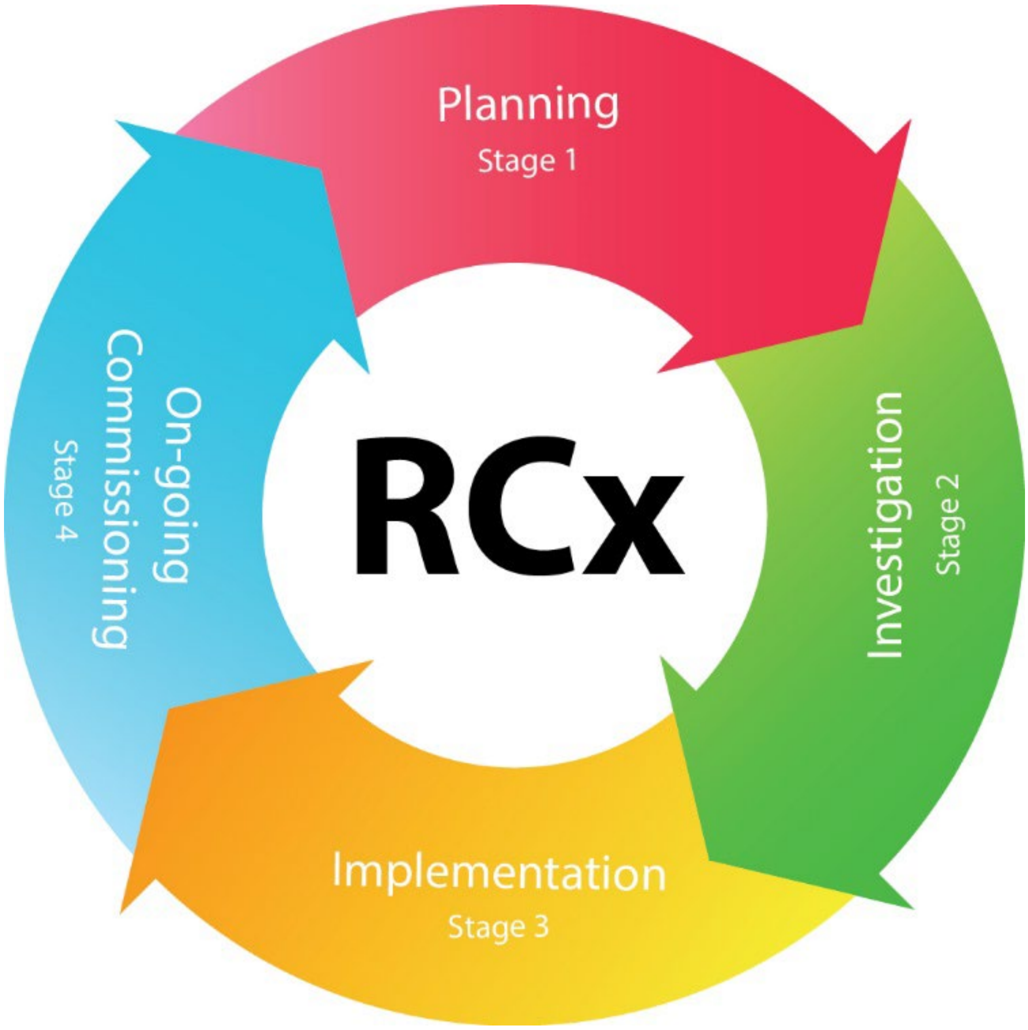


Fig. 4.1 RCx Procedures

The objective of the Planning Stage is to adequately prepare for the RCx process by defining a RCx plan which covers the system analysis to be carried out, and a site measurement plan. If system information is insufficient from the O&M manual, it can be collected from a site walk through and spot measurement.

The Investigation Stage then identifies any existing operational problems which are leading to inefficient energy use or unsatisfactory indoor environment, and determines any other Energy Saving Opportunities (ESOs) which could improve the performance of the building. Once operational issues are identified and ESOs proposed, the RCx Team should prepare an *Investigation Report* which includes a cost/benefit analysis on the proposed ESOs, implementation details, measurement and verification methods, and any anticipated disturbance to normal services operation to discuss within the relevant stakeholders. Selected ESOs should then be agreed with the building owner ahead of the Implementation Stage.

During the implementation stage, the RCx team should follow the agreed implementation and measurement & verification (M&V) plan to ensure appropriate actions are carried out. Carrying out of the M&V is also important and should be recorded. Regular RCx meetings should be held to monitor the implementation progress.

In the On-going Commissioning Stage, an Ongoing Commissioning Plan should be developed by the RCx Team to ensure the benefits from the RCx process are maintained. Provision of training by the RCx team to the O&M staff to implement the ongoing commissioning plan is an essential step in this stage. The key tasks of each stage are listed in the table below, which can be cross-referenced with the various content sections.

Retro-commissioning Activities	Cross-referred Clause
Stage 1. Planning stage	
Develop commissioning objectives	4.2.7
Hire a Retro-commissioning service provider	4.1.2
Review the documentation	4.2.1
Obtain the historical utility data	4.2.2 ,4.2.4, 4.2.5
Develop Retro-commissioning plan	4.2.7
Stage 2. Investigation stage	
Understand how and why the building systems are currently operated and maintained	4.3.1& 4.3.2
Identify the issues and potential improvements	4.3.3
Select the most cost-effective improvements measurements for implementation.	4.3.5
Stage 3. Implementation stage	
Carry out the facility improvement measurements from the findings list	4.4.1
Verify the predicted results and system performance	4.4.2
Develop a RCx Final Report	4.4.3
Develop an Ongoing Commissioning Plan	4.4.4
Stage 4. On-going commissioning	

Table 4.1. RCx tasks in various stage

4.1.1 Roles and Responsibilities of RCx Team

If the Building Owner(s) believe that their O&M staff are capable of carrying out RCx they can consider that option. Often O&M staff are the most suitable parties to conduct RCx of a building as they are familiar with the equipment/services/systems & operational pattern of the building. Otherwise, the Building Owner(s) may consider engaging a RCx service provider to carry out the RCx.

Before commencement of the RCx process, a RCx team should be formed consisting of the following parties:

(1) Building Owner(s) (or Building Owner's representative or Occupier);
(2) Building Manager;
(3) O&M staff;
(4) Contractors; and
(5) RCx service provider (optional).

In the absence of a RCx service provider, the O&M staff will have the role of the RCx service provider.

If a RCx service provider is engaged to conduct the RCx, the RCx service provider, along with the members of the RCx team, will carry out the RCx process, and report findings and energy saving opportunities (ESOs) to the building owner(s). The RCx service provider should seek the building owner(s)'s agreement on any proposed energy saving opportunities (ESOs) before carrying out those selected ESOs in the Implementation Stage. The RCx service provider can also engage a contractor to carry out the actual ESO implementation works and/or the ongoing commissioning activities. The RCx team can carry out M&V with reference to relevant international standard like IPMVP. For more detail, refer to section 4.3.4.

The following table provides a high-level description of the responsibility of each RCx team member for each of stage of the process. If a third party RCx service provider is not involved, the responsibilities should be carried out by competent O&M staffs or contractors.

Stage	RCx Task	Building Owner/ Building Owner's representative/ Occupier	Building Manager	O&M Staff	Contractors	RCx Service Provider (Internal/ External)
Planning	Define success criteria	✓				
	Define Owners Facilities Requirements (OFR)		✓			

Stage	**RCx Task**	**Building Owner/ Building Owner's representative/ Occupier**	**Building Manager**	**O&M Staff**	**Contractors**	**RCx Service Provider (Internal/ External)**
Planning	Organize project kick-off meeting		✓			✓
	Participate in project kick-off meeting	✓	✓	✓	✓	✓
	Review Systems Manual		✓			✓
	Compare Current Facilities Requirements (CFR) to the operation requirement in the O&M manual		✓			✓
	Gather facility's data			✓	✓	✓
	Establish a benchmark					✓
	Determine the state of the facility			✓	✓	✓
Investigation	Work with service provider to establish ESOs		✓			✓

Stage	RCx Task	Building Owner/ Building Owner's representative/ Occupier	Building Manager	O&M Staff	Contractors	RCx Service Provider (Internal/ External)
Investigation	Agree on proposed ESOs to be implemented		✓		✓	
	Conduct Interviews		✓	✓	✓	✓
	Conduct walkthroughs			✓	✓	✓
	Provide latest O&M Manuals		✓			
	Update O&M Manuals		✓	✓	✓	
	Diagnostics, testing air balance and functional testing				✓	
	Create M&V plan		✓			✓
	Agree M&V plan				✓	
	Check data trending, alarm summaries, maintenance records			✓	✓	✓
	Visual inspections			✓	✓	✓

Stage	RCx Task	Building Owner/ Building Owner's representative/ Occupier	Building Manager	O&M Staff	Contractors	RCx Service Provider (Internal/ External)
Investigation	Identify no/low cost actions and capital renewal items					✓
	Plan assessment for each ESO					✓
	Establish ESOs based on cost benefit analysis					✓
Implementation	Receive training including contingency plans and Q&A sessions		✓	✓		
	Implement ESO(s)			✓	✓	
	Functional testing of all systems and equipment			✓	✓	
	Provide training				✓	✓
	Install M&V equipment				✓	

Stage	RCx Task	Building Owner/ Building Owner's representative/ Occupier	Building Manager	O&M Staff	Contractors	RCx Service Provider (Internal/ External)
Implementation	Determine energy baseline				✓	✓
	Verification of changes in performance				✓	✓
	Take photos, screen captures and videos			✓	✓	✓
	Verify that ESO action is having the desired intent			✓	✓	✓
Ongoing commissioning	Validate success criteria	✓				
	Update Owners facility's Requirement (OFR)		✓			✓
	Keep O&M Manual up to date		✓	✓	✓	
	Respond to guaranty claims, if required				✓	
	Determine energy consumption				✓	✓

Stage	RCx Task	Building Owner/ Building Owner's representative/ Occupier	Building Manager	O&M Staff	Contractors	RCx Service Provider (Internal/ External)
Ongoing commissioning	and energy savings					
	M&V Reports					✓
	Implement follow-up plan for issues discovered during implementation process			✓	✓	
	Develop on-going commissioning plan		✓			✓
	Update documents, as built prints and specifications, control drawings and sequences		✓		✓	✓
	Develop Operation and Maintenance manuals		✓		✓	✓

Table 4.1.1 Roles and Responsibilities of RCx Team
(This table is FOR REFERENCE ONLY)

4.1.2 Selection of Suitable RCx Service Provider

The selection of the RCx service provider should be based on the provider possessing relevant certifications, technical knowledge, experience, availability and communication skills.

Previous experience in similar projects on retro commissioning is recommended. Commissioning employees will preferably have design and hands-on facilities experience, and be familiar with energy performance metrics, trouble-shooting and controls experience.

If the building owner chooses to engage a third-party service provider, they can refer to the RCx service provider list in the EMSD RCx resource centre website (https://www.rcxrc.emsd.gov.hk).

Annex A under the Retro-Commissioning Technical Guideline Supplementary Information provides a summary list of information for third party RCx service provider engagement procurement. This includes information that should be provided by the building owner to help facilitate the RCx exercise, as well as the scope of work that should be provided by the RCx service provider.

4.1.3 Timing and Resources Considerations in RCx

If the building owner requires an in-depth and complete analysis of the existing operational conditions of the building systems, a data collection / record period of 12 consecutive months for utility bills and operational data (e.g. cooling load, energy meters etc.) should be required. Alternatively, data collection / record period for covering a representative cycle of operation for particular building services installation can be considered (e.g. lighting operation pattern in a week, etc.). This can help to identify the full range of potential ESOs, which is the ultimate objective of the RCx process.

In cases where resources are limited and the scope of the RCx is reduced, monitoring of the most energy intensive season, when the most significant underlying operational problems are likely to be presented, is recommended.

4.2 Stage 1 – Planning

The flowchart below details the steps and expected deliverables in Planning Stage.

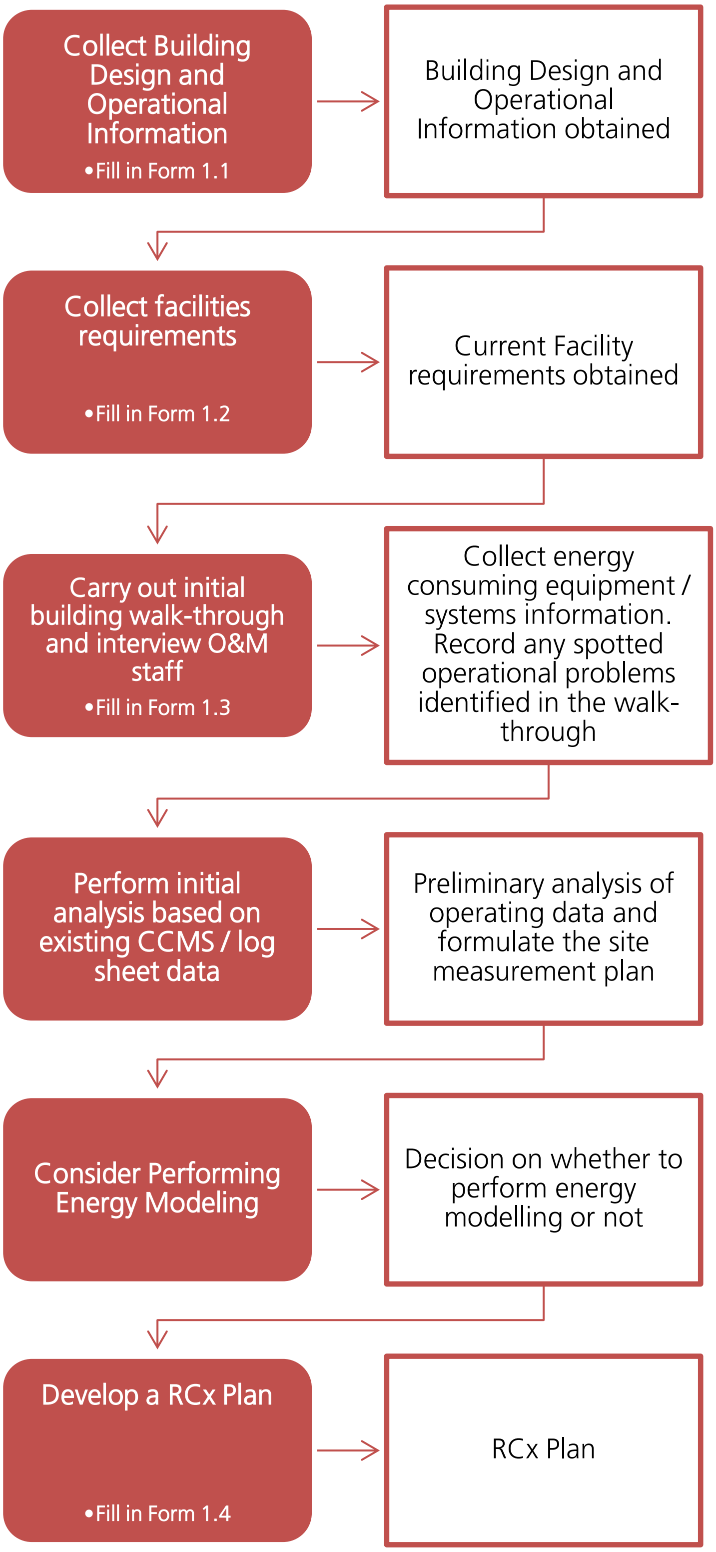


Fig. 4.2 Flow Chart for Planning Stage

4.2.1 Collect Building Documentation

The first step for the RCx Team is to obtain as much building design and operational information as possible in order to familiarise the current building operation. The most critical document required for any project ahead of undertaking the RCx process is the O&M Manual. An O&M Manual is a composite document used by the owner/operator, which contains information about building operations and maintenance. If the building has been previously commissioned, these documents should be updated to reflect current operating conditions of the building.

The O&M Manual can include the following sections as suggested by ASHRAE Guideline 0-2019 – The Commissioning Process:

(a) System Description.
(b) Basis of Design document and design criteria.
(c) Construction Record Documents, specification, and approved submittals.
(d) Operational documentation & maintenance manuals.
(e) Air conditioning system schedule.
(f) Operational record-keeping procedures, including sample forms, logs, or other means, and rationale of each.
(g) Training materials.
(h) Commissioning Process report.
(i) CCMS/Building Points list.

If an O&M Manual does not exist, the RCx Team can carry out a detail site walk through and spot on-site measurement to collect the necessary information / data in order to have a better understanding of the existing installation.

Operational documentation in an O&M Manual will vary depending on the availability, or not, of a Central Control & Monitoring System (CCMS). The following sub-sections describe the critical information required for both these scenarios.

Apart from the O&M Manual, the RCx Team will need to collect HVAC, Electrical, Lighting, Plumbing, Lift and Escalator system schematic diagrams and relevant services layout plans in order to familiarise themselves with plant operation and for further planning of their site investigation work. If available, the RCx Team should collect the CCMS data / log sheet data, for analysis in later stages.

The RCx Team should also collect the electricity bills and any metering data available for the last three years - if available - to enable analysis of the energy consumption breakdown and to understand how the building has performed in the past. This information is useful for the RCx Team to determine which types of installation may have the greater potential for energy/cost saving.

Form 1.1 Building Design and Operational Information Checklist;

4.2.1.1 Operational documentation: No CCMS installed

It is recognised that some buildings may not have a CCMS installed. In this scenario, it is important to check the existing operational status of HVAC systems and other types of energy-relevant equipment in the building. A comprehensive check on data points related to chiller plant performance is recommended, for air-side system control, equipment and lighting control, it is suggested to carry out sample check due to the large coverage scale.

If documentation regarding the actual operational status of the building, such as the HVAC control sequence, is not available then it may be considered to be part of the planning investigation tasks. This documentation can be reported using plain-language with photographs, test records and reports. Operational checks status might be carried out (but not limited to) for chilled water plants as main priority. Air distribution systems, terminal units, domestic hot water, lighting and small power can be sample checked at critical points due to the large coverage scale.

Once created, operational documentation provides a means of verifying the operation of the systems. This can then be re-used by the Facility Management team to perform re-commissioning and ensure that systems are operating efficiently, and savings are maintained post-RCx. Furthermore, operational documentation plays a key role in the on-going commissioning tasks.

4.2.1.2 Operational documentation: CCMS installed

For a building which has a CCMS installed, key HVAC parameters which are responsible for the day to day control/monitoring of energy consuming equipment should be monitored at a granularity that allows the user to analyse systems performance and other key parameters such as comfort, air flow, lighting levels, etc. For technical considerations for CCMS data, refer to section 4.2.4. for further details.

For reference, an example of a recommended data-set required for a Chilled water central plant system is presented in the following table.

System	Chilled water central plant.
CCMS points	Chilled water flow rate. Chilled water supply and return temperatures. Power analyser for chillers. Power analyser for chilled water pumps and associated VSD operating status (if available) Power analyser for condenser water pumps. (for water cooled chiller plant only) Power analyser for cooling tower fans. (for water cooled chiller plant only) Cooling tower fan operating status Chilled water system by-pass valve operating status
Logging interval	15-minutes is recommended by ASHRAE Guideline 14:2023 and 30 minutes to 1 hour can be considered as acceptable or otherwise stated by the client if measurement boundary taken place
Duration	12 months can be considered as acceptable or otherwise stated by the client if measurement boundary taken place.

The above CCMS data points can be used for KPI calculation like chiller plant COP

4.2.2 Collect Current Facilities Requirements

A Current Facilities Requirements (CFR) Form template has been provided to facilitate collection of relevant information from the building manager. In this form, occupant comfort is investigated, and air-conditioning and lighting installation are covered.

The RCx Team can compare the operation requirements listed in the O&M manual with the CFR. These requirements are then used to assess whether the existing systems are performing correctly. If the existing systems are not meeting the requirements, it may be a result of unidentified operational problems which require further site investigation.

Form 1.2 Current Facilities Requirements Form

4.2.3 Carry out Initial Building Walk-through and interview with O&M staff

Once the information of the energy consuming equipment and systems is collected, the RCx Team (particularly the O&M staff) will perform an initial building walk-through to observe the operation conditions and to confirm that the provided and collected information matches the actual installations. Through interview with the O&M staff, any existing issues identified, and/or operational gaps should be recorded. Some examples of these are:

- systems that simultaneously and excessively heat and cool;
- facilities / equipment not operating as scheduled;
- equipment operated or lighting switched-on unnecessarily, particularly air handling units that operate for extended periods when the building is unoccupied;
- improper building pressurisation of either positive or negative e.g. doors that are difficult to open or close;
- equipment or piping that is unreasonably hot or cold; unusual noises at valves or other mechanical equipment; and
- spaces that are over-illuminated.

Form 1.3 Building Walk-Through Checklist;

4.2.4 Data Management and Central Control & Monitoring System (CCMS) requirement

In order to gain a better understanding of the building's operation, adequate collection of operational information and data for further analysis can provide the RCx team with unique insights and help identify areas of the building on which to focus resources. Operational data collection from sensors can be achieved through a number of means including existing or new CCMS installations and portable or fixed Internet of Things (IoT) data loggers.

The data generated by a network of data points including sensors and equipment can be monitored using a CCMS installation or other data logging equipment. Before setting up a CCMS, it is important to create a list of data points to be recorded and ensure the CCMS has the capability to store the data point data. Below is a list of some common building system data points that are recommended for monitoring and logging.

Recommended data points:

Data Point	Location	Unit
Chiller plant		
Chilled water supply temperature	Chiller plant room	°C
Chilled water return temperature	Chiller plant room	°C
Chilled water flow rate	Chiller plant room	l/s
Individual chiller power	Plant room	kW
Individual chilled water pump power	Plant room	kW
Individual condenser water pump power (water cooled chiller plant only)	Plant room	kW
Individual cooling tower fan power (for water cooled chiller plant only)	Plant room	kW
Hot water plant		
Hot water supply temperature	Plant room	°C
Hot water return temperature	Plant room	°C
Hot water flow rate	Plant room	l/s
Boiler / heat source equipment energy or fuel	Plant room	kWh

Table 4.2.4(a) List of recommended CCMS data points for logging

Data points for advanced control analysis:

Data Point	Location	Unit
Chilled water by-pass flow rate	Chiller plant room	l/s
Chilled water by-pass valve status	Chiller plant room	%
Chilled water differential pressure	Chiller plant room	kPa
Chilled water pump operation frequency	Chiller plant room	Hz
Chiller valve position	Chiller plant room	ON/OFF
Individual chiller chilled water supply temperature	Chiller plant room	°C
Individual chiller chilled water supply temperature setpoint	Chiller plant room	°C
Individual chiller chilled water return temperature	Chiller plant room	°C
Individual chiller chilled water flow rate	Chiller plant room	l/s
Condenser water leaving temperature (for water cooled chiller plant only)	Chiller plant room	°C
Condenser water entering temperature (for water cooled chiller plant only)	Chiller plant room	°C
Condenser water differential pressure (for water cooled chiller plant only)	Chilled plant room	kPa

Data Point	Location	Unit
Cooling tower fan operation frequency/ status (for water cooled chiller plant only)	Cooling tower motor	Hz or High/Low
Cooling tower valve position	Cooling tower	% or ON/OFF
PAU/AHU supply air temperature	AHU supply duct	°C
PAU/AHU return air temperature	AHU return duct	°C
PAU/AHU fan operation frequency	AHU fan motor	Hz
PAU/AHU return air carbon dioxide (CO_2) concentration	AHU return duct	ppm
PAU/AHU static pressure	AHU supply duct	Pa
PAU/AHU damper position	AHU fresh air and return air mixing	%
PAU/AHU cooling coil valve position	AHU cooling coil	% or ON/OFF
PAU/AHU chilled water flow rate	AHU cooling coil	L/s
Room air temperature	Room	°C
Room relative humidity	Room	%
Total lighting power	NA	kW
Total plug socket power	NA	kW
Total lift & escalator power	NA	kW
Outdoor dry-bulb temperature	NA	°C
Outdoor wet-bulb temperature	NA	°C
Outdoor humidity	NA	%

Table 4.2.4(b) Additional CCMS data points for logging

The setup and installation of data monitoring can lead to high capital costs if not properly planned and implemented, especially where additional hardware is required. It is recommended that a list of points to be monitored is created and prioritised based on their benefit to the project taking into account the owner/clients requirements before setting up the system. Identifying essential data points first and, if financial budget allows it, additional data points which would add value to the building performance analysis can be considered. Where there is an existing CCMS additional data points logging will require configuration on the CCMS and additional controllers and bandwidth may be required. The building owner can consult the CCMS service providers for further information regarding system configuration and options for data collection.

Logging interval and period

The time interval of data logging can impact the quality of information gathered from a building system. In general, sub hourly data logging intervals are preferable for most point types with intervals of 15 minutes (recommended by ASHRAE Guideline 14:2023 – Measurement of Energy Demand and Water Savings), data interval of 30 to 60 minutes are also acceptable in some cases. When setting up data logging through the CCMS, the system and controllers memory limitations should be taken into account especially where higher data resolution (i.e. 1 min) is implemented which can result in higher installation and operation costs. See “Data Storage” section for more information.

The duration of storing the recorded data can vary depending on the type of data and its analysis applications. Typically for systems driven by weather-dependent operation, it’s recommended the data be stored and available for a minimum 12-month or cover a full seasonal change so the operational trends in different seasons can be fully examined.

For systems using temporary data logger installations (i.e. portable data loggers), shorter data storage durations may be acceptable where data collected over a period of 1 – 2 weeks for each season can be considered to analyse the performance in the “design” weather conditions.

Some systems that can provide useful input to analysis but do not vary greatly or do not have a direct relationship with weather, such as lighting, small power etc. can be measured over a shorter period if installation of permanent data loggers is not feasible. Logging this data for periods as short as 1 week can provide sufficient understanding of the operation pattern through a working week and can be extrapolated for analysis over longer periods.

Data format and tagging

Data from different CCMS providers can be in different formats or different file types.

A CCMS data archive must have the ability to output data in a simple file structure such as CSV or TXT file to allow for analysis in the analysis tool of choice. The data output should at a minimum provide data point references, recorded values and the associated timestamps. CSV and TXT files are compatible with spreadsheet tools and many other data analysis tools exist where users can interrogate this data.

Typically found data format template is shown in Annex C under the Retro-Commissioning Technical Guideline Supplementary Information for further reference.

Data storage

Data loggers such as CCMS controllers have finite memory for storing recorded data logs. The duration of data storage can depend on the on-board memory available and the interval at which data is recorded, and it is common for these logs to reach the memory capacity and for recorded data to be overwritten after as little as 1 to 10 days. To overcome this, data logs on a controller should be archived to a central data storage at regular intervals to avoid loss of data. The frequency of archiving data should be less than the duration of the data logging storage available on the controller. Data should be archived either on the CCMS in a file system, in a database capable of storing the large dataset or other third-party data storage solutions. Some data analysis tools can store data in addition to their analysis capabilities.

IoT Sensors

IoT sensors can be used to carry out on-site measurement on indoor parameters such as room temperature, humidity, lux level, etc. for remote monitoring and analysis through the cloud-based data transmission. The IoT sensors can transmit data to the cloud and the data can be accessed remotely in visual presentation in order to obtain the building operational data for analysis.

4.2.5 Conduct Initial Analysis based on Existing Central Control & Monitoring System (CCMS) / Log Sheet Data

In this step, the RCx Team should conduct initial analysis based on CCMS/log sheet data to check if the data collected is accurate and reasonable. The following items can be included in the preliminary analysis:

1. Chiller plant
2. Heat rejection system
3. Water-side system
4. Air-side system
5. Electrical system
6. Lighting system
7. Lift & Escalator
8. Plumbing and Flushing system

By doing this, the RCx Team can assess the current operational conditions of the existing building systems, formulate new site measurement plans, and identify areas of faulty operation which require further investigation.

The following examples detail common cases of faulty operation which the RCx team should check for. These examples refer to faults which often negatively affect the energy performance and/or durability of HVAC systems in warm climates.

Water side – Rapid Step changes – AHU cooling coil valve control.

Situation

Cooling coils in air handling units (AHU) have a modulating valve to regulate the flow of chilled water in order to meet set-point requirements.

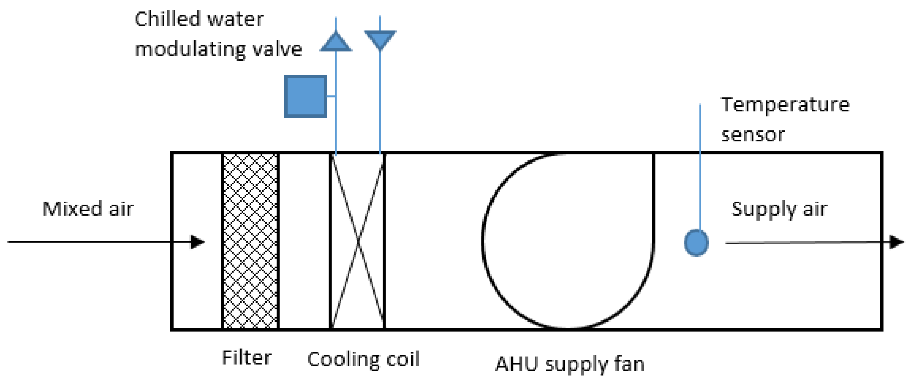


Fig. 4.2.5(a) Chilled water valve data point location schematic

Fault Identified

In this example (see Fig. 4.2.5(b)), the cooling coil valve consistently modulates between 0% and 40% (green line), and hence struggles to keep a stable supply temperature (blue line).

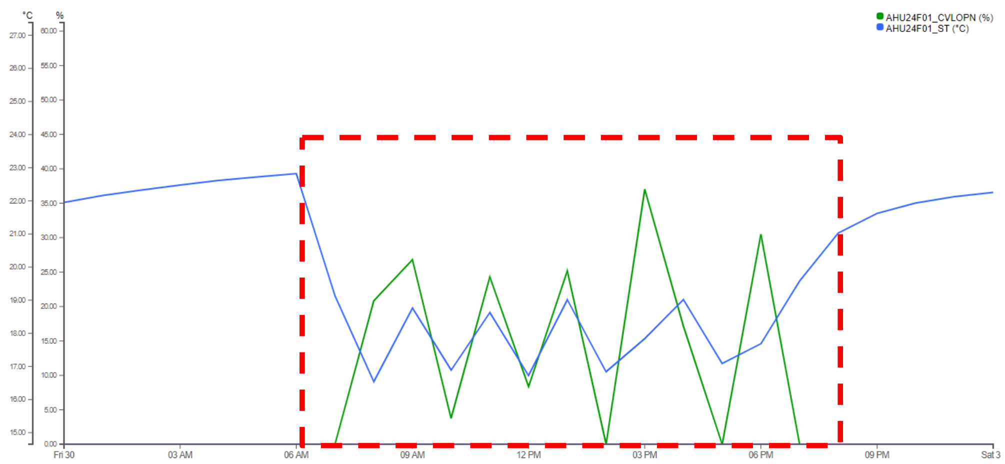


Fig. 4.2.5(b) Rapid step changes data example

Recommended Actions

This may be due to the inappropriateness of control set-point and dead-band settings in the current system and should be investigated further.

Water side – Rated brake power comparison – Chilled Water pumps rated break power comparison.

Situation

Equipment manufacturers provide rated power of pumps and other components; however it is important to verify the actual power of the installed component.

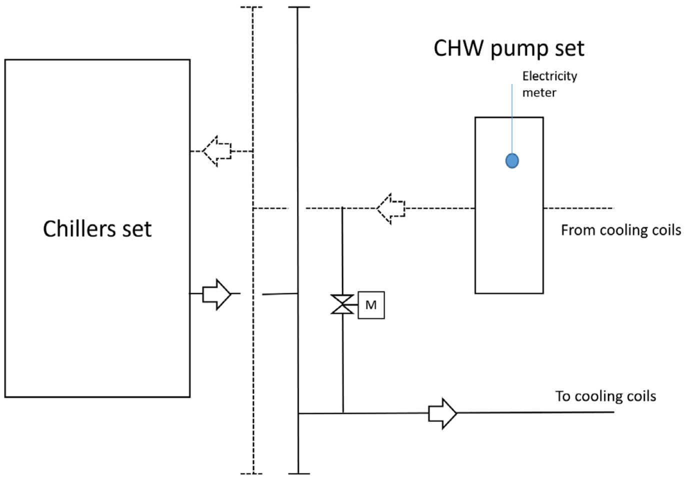


Fig. 4.2.5(c) Chilled water pump electricity meter data point location schematic

Fault identified

In this example, according to the O&M manual, the chilled water pump rated pump brake power is 11.9kW. However, from the energy meter recording shows a power consumption at the range from 26.5kW to 40kW (see below).

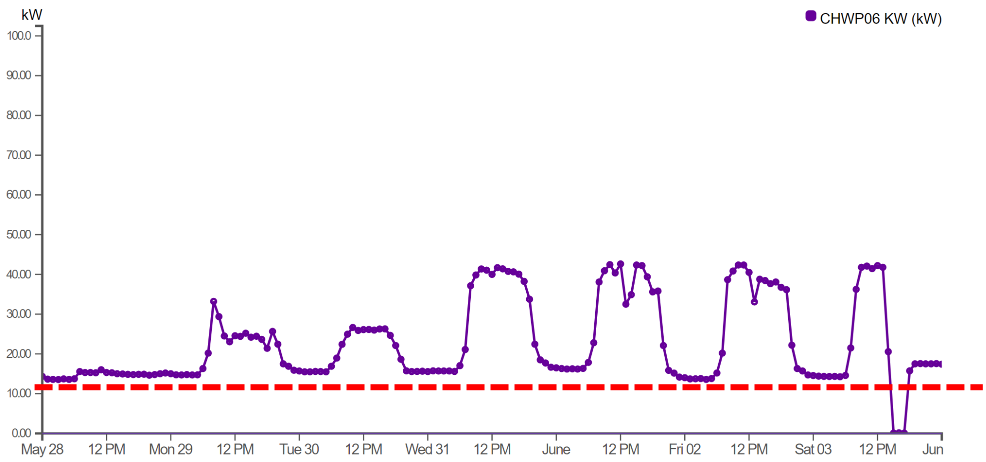


Fig. 4.2.5(d) Measured electricity consumption and rated brake power comparison example

Recommended action

The location of the recorded data point should be checked. The nameplate of motor and pump should be checked, if available. Also, the energy meters and differential pressure of the pump should be checked to ensure they are calibrated.

Air side – Operating hours – AHUs operating out of hours

Situation

On the HVAC air-side, logged data can be used to detect issues mainly related to operating hours that are out of schedule. Operation outside of operating hours leads to excess of energy provided for air conditioning zones when not required.

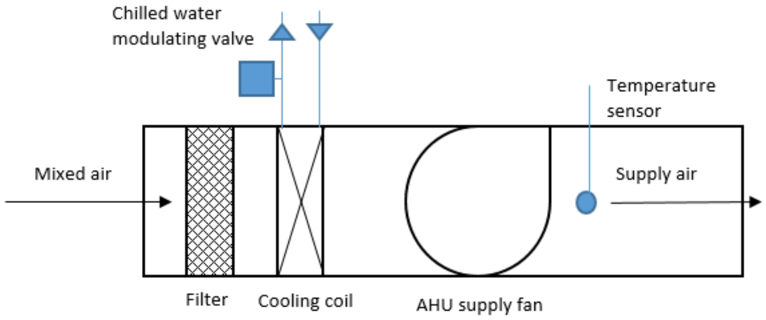


Fig. 4.2.5(e) Air handling unit schematic

Fault identified

In Fig. 4.2.5(f), it shows that the air handling units are operating out of the scheduled hours (6:00a.m. to 7:00p.m.). There is air flow rate (~1,000l/s) detected out of the scheduled operating hours.

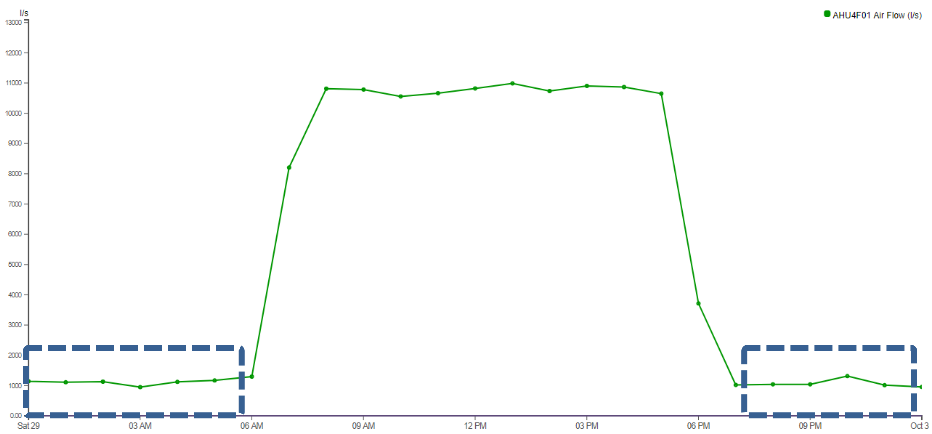


Fig. 4.2.5(f) AHU out of hours operation data example

Recommended action

Check the operational hours setting to ensure the out of hour operation is intentional. The control mode should be checked to ensure it is not overridden manually.

Air side – Operating hours – PAU Operating out of hours.

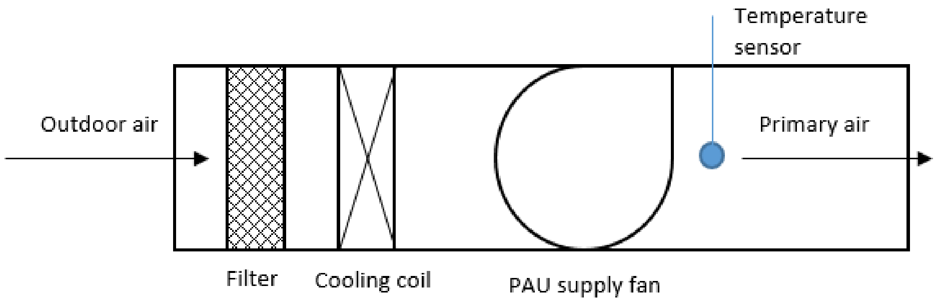


Fig. 4.2.5(g) Primary air handling unit data point location schematic

Situation:

PAU operation should be operated from 8:30a.m. to 6:30p.m.

Fault identified

In Fig. 4.2.5(h), it shows that there is a drop in the air temperature between 6a.m. to 9a.m.. This is a period when the PAU should not be operating according to the programmed schedule, resulting in wasted energy consumption.

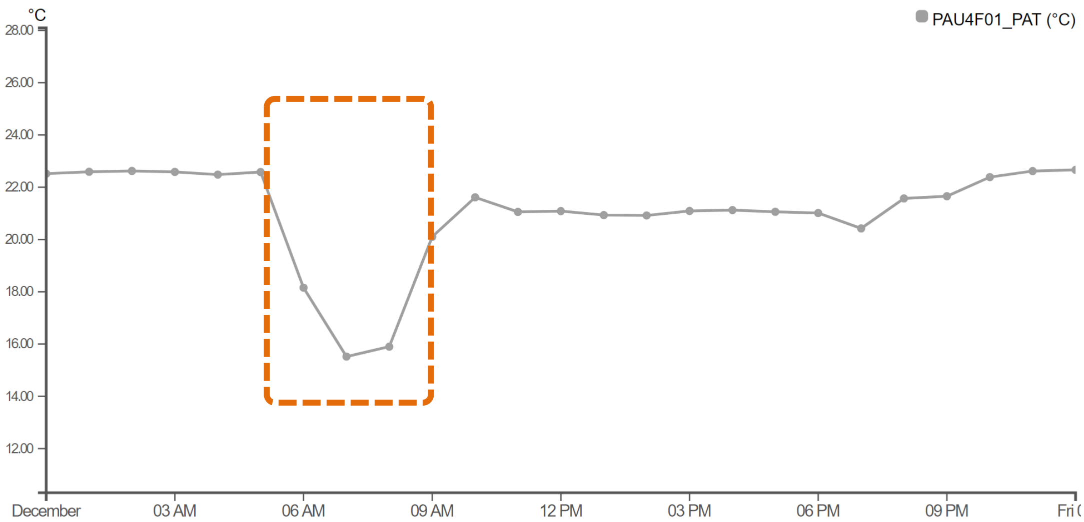


Fig. 4.2.5(h) PAU out of hours operation data example

Recommended action

The programmed schedule should be checked. The cooling coil valve should be checked to ensure proper operation.

Lighting – Night-time lighting energy consumption

Situation

Lights should be off during non-occupied hours.

Fault identified

Graph shows significant night-time lighting energy consumption.

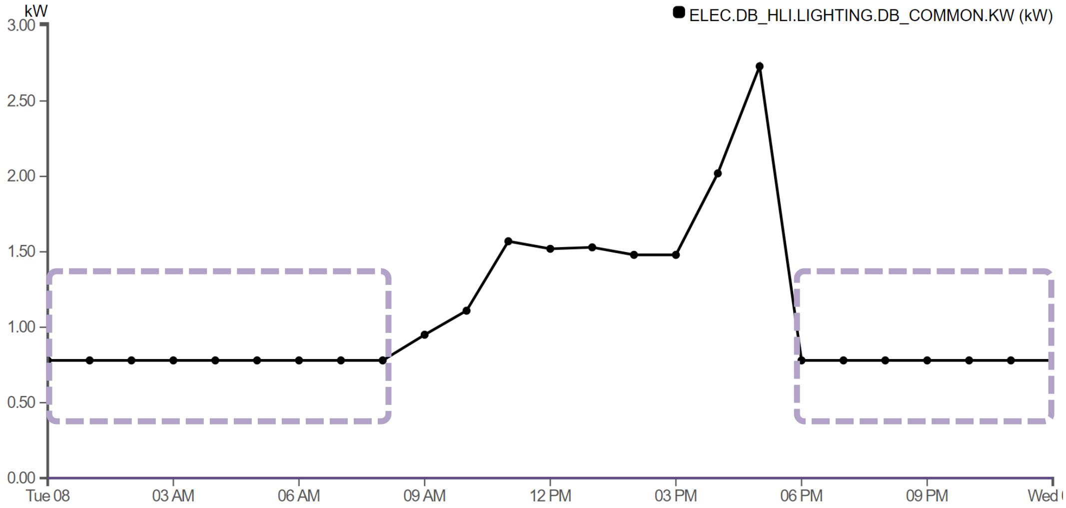


Fig. 4.2.5(i) Lighting out of hours operation data example

Recommended action

To check if leaving lights on are intentional. Check programmed schedule if automatic control is available.

Building small equipment – Significant Baseloads observed

Situation

Night time equipment load should be minimal for required continuously operating equipment only.

Fault identified

Non-continuous equipment load observed during night time (Note: some baseloads can be required to operate continuously e.g. refrigerators).

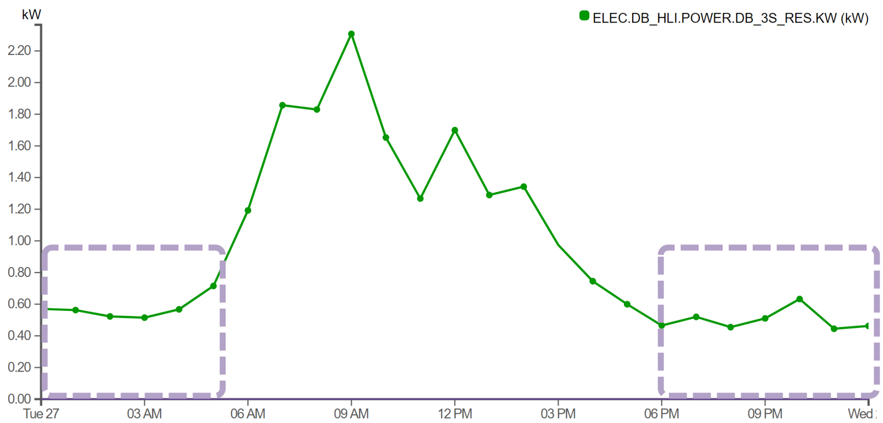


Fig. 4.2.5(j) Small equipment out of hours operation data example

Recommended action

Any non-continuous operation equipment should be identified and switched off.

4.2.6 Consider Performing Energy modelling (Optional)

In this step, the building owner should consider the benefits of developing an energy model of the building if sufficient building information is available for input. In certain circumstances, where energy and operational data is limited to a certain period, simulation models can be used to "generate" the missing building performance data.

Energy modelling can be used to (1) accurately evaluate a detailed breakdown of energy use in the building; and (2) better evaluate the realistic energy cost savings for ESOs, to help in selecting the optimal opportunities for implementation.

For further details on energy modelling and its benefits, please refer to Section 4.6 – Application of Energy modelling in RCx (Optional).

4.2.7 Develop a RCx Plan

To summarize all the findings in planning stage and plan the subsequent activities in RCx for optimizing the existing building, RCx Team will develop a RCx plan which includes the following items:

Summary of the Findings in Planning Stage

- RCx plan
- Preliminary analysis on CCMS data/ log sheet data
- Preliminary analysis (Energy Modeling) - Optional

Actions in the Following Stages

- Site Measurement Plan
- Data that needs to be collected
- Data that needs to be verified

A sample of RCx Plan is provided in this guideline for further reference.

Form 1.4 A sample of RCx Plan

4.3 Stage 2 – Investigation

The procedures and expected deliverables at investigation stage are shown in Fig. 4.3 below:

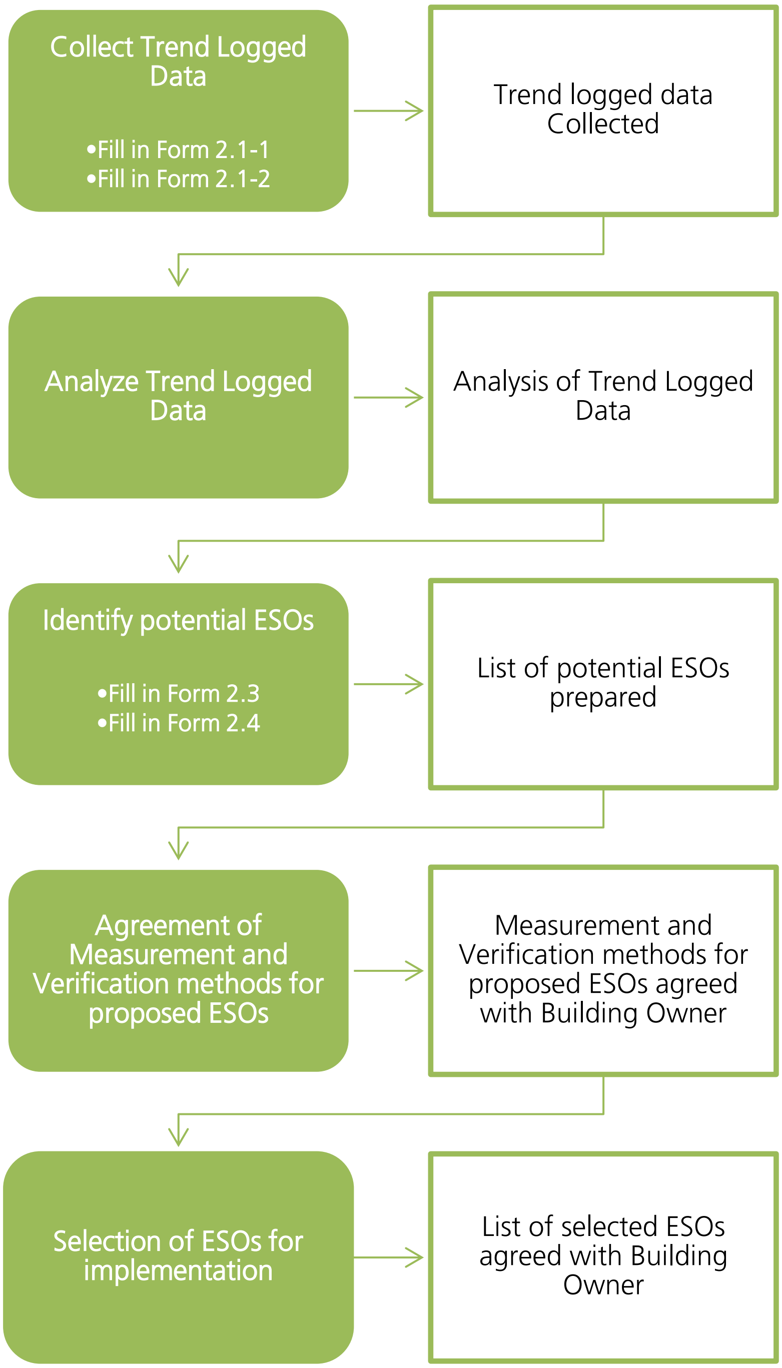


Fig. 4.3 Flow Chart for Investigation Stage

4.3.1 Collection of Trend Logged Data

During the process of collecting time-series operational data, at intervals typically ranging from fifteen minutes to one hour. The RCx Team can collect the trend logged data directly from the Central Control & Monitoring System (CCMS), provided that a) there is a CCMS installed in the building, and b) the trend logged data is adequate and accurate enough for analysis.

For buildings without CCMS, or where the CCMS has limitations in storing or presenting the data, it is recommended that the RCx Team use portable IoT data-loggers to collect operational time-series data instead.

How Trend Logged Data is collected by CCMS / Cloud-based system

- There are typically significant amounts of data that can be collected directly from CCMS/ Cloud-based system.
- Locate each point and provide a meaningful description regarding what is being measured/controlled. Consider the use of tags.
- Make sure sensors are working properly and calibrate them if necessary.
- Depending on the type of data and analysis methodology CCMS collection intervals vary, but common intervals are in minutes (i.e. 15 mins, 30 mins...) to hourly
- Data collection should at least cover a full operational cycle (a day, a week, a month, a year...) depending on the operation of building and the seasonal variability. For instance, lighting schedules in an office building will likely have a weekly operational cycle and they are unlikely to vary across the year. T he performance of a cooling tower, on the other hand, will vary across the year. A period of one year is recommended to allow for annual analysis across all seasons
- IoT sensors should measure, monitor and transmit the data to the cloud-based system for data logging through wireless network.
- IoT sensors should be able to measure at least with one hour interval for thermal comfort parameter including temperature, humidity and lux level.
- Battery operated IoT sensors can be used. Battery capacity should be sufficient to sustain at least 1 year without charging or replacement of battery.
- IoT sensors should have protective enclosure for fixing and equipped with associated data transfer measures for cloud-based data transmission.

How Trend Logged Data is collected by Portable Data Loggers

- The recommended measurement period when using portable data loggers is at least one week to allow for meaningful analysis
- The data should be collected throughout the year to ensure the completeness of data. It is suggested that the most appropriate season where the signitficant underlying operational problems would likely occur, can be recorded for the convenience of data analysis.
- If this data is intended to be used for M&V, carry out a quality assurance test to ensure that data is being logged correctly as established in the M&V plan.

Form 2.1 provides a list of Instrumentation for Data Collection by Data Logger;

Problems typically faced when using CCMS data as a basis for analysis can be divided into a) data quantity issues, and b) data quality issues.

Data quantity issues refer to the lack, partial or total, of readings. Partial losses of data are also referred as gaps. Quality issues can be caused by technical problems such a low battery or lack of storage capacity. On the other hand, data quality refers to errors in the reported values.

While data quantity problems are typically addressed on a case-by-case basis, data quality issues are not as easily identified. Both types of problems should be addressed before undertaking building performance analysis based on the data available.

The following includes some of the recommended for checking the data quality:

1. Data source verification
   The installed sensors should be checked regularly to ensure they are operated in good condition. It is a good practice to conduct sensor re-calibration and keep record of the valid calibration certificate of the sensors to ensure the sensors' readings are accurate.

2. Cross-checking of data
   Data collected from one sensor can be used to compare with data of other sensors to ensure the sensor's function properly, for example, the energy meter of a chiller can be used to compare to the flow meter and temperature sensor of that chiller.

Data should also be compared with previous reading to check if any reading is out-of-range-values

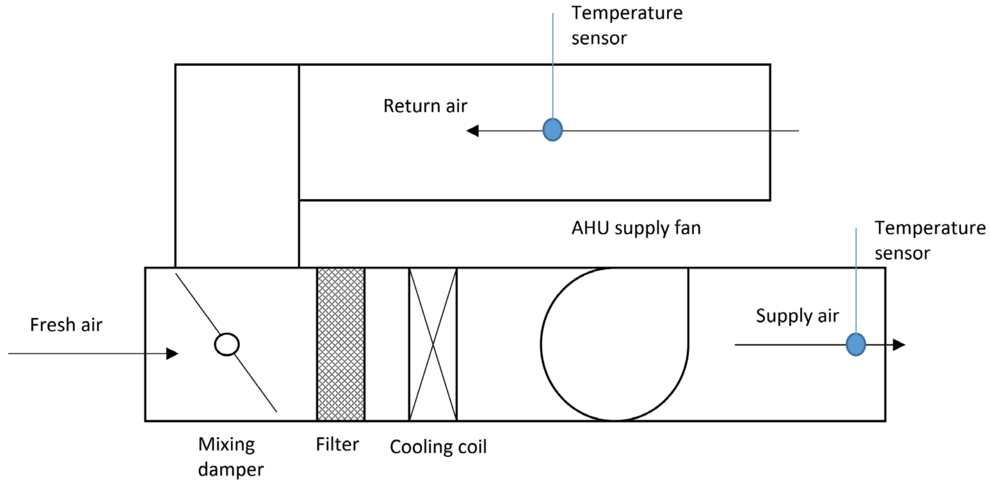
3. Data correction
   Some data collected cannot be compared directly, for example, the energy usage of a chiller this year cannot be directly compared with last year. It is because the energy usage of the chiller is affected by the weather. Hence, normalisation / routine adjustment should be conducted for the cooling consumption comparison.

Above are simple practices to ensure the data quality and accuracy. Training or guidance for meter readers should be provided to ensure the method of data record is consistent.

In this section, a list of common examples of data quality problems are presented.

Out-of-range values - Value is outside reasonable thresholds (above or below)

<u>Situation</u>
In this example the AHU supply temperature range is typically between 10°C and 15°C, and the return temperature range is between 17°C and 23°C.



<u>Fig. 4.3.1(a) Air handling unit supply and return air temperature data point locations schematic</u>

Data Quality Issue Identified

In Fig 4.3.1(b), it can be seen that there are frequent records of extremely low temperature from the return temperature sensor.

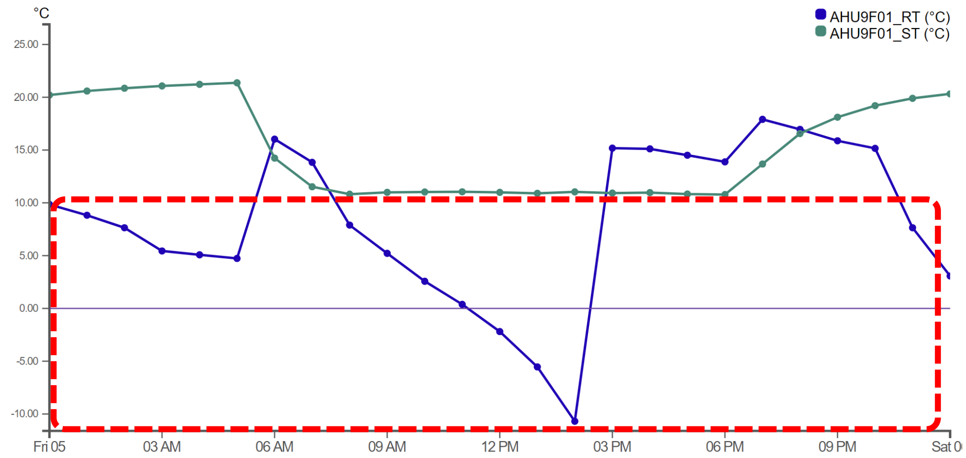


Fig 4.3.1(b) Temperature out of range data example

Recommended Action

It is recommended to check the sensor for malfunction.

Sensor calibration/positioning – large sensed differences between similar sensors

Situation

In the drawing below, temperature sensors installed on the ceiling (marked as "T" within a circle) are distributed across a multi-purpose classroom.

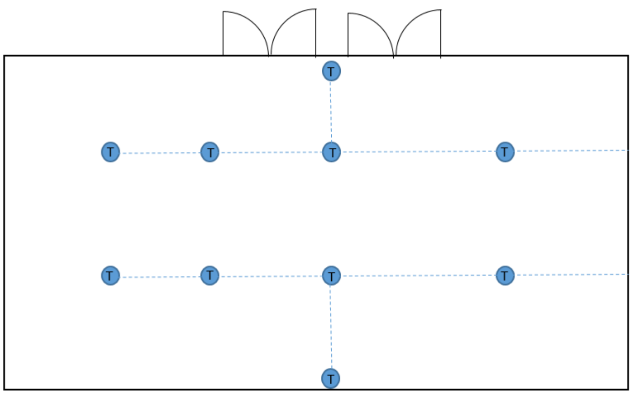


Fig. 4.3.1(c) Room temperature sensors data point location schematics

Data quality issue identified

Fig. 4.3.1(d) shows room temperature values for a Multipurpose Classroom. A temperature difference of up to 7°C exists between sensors.

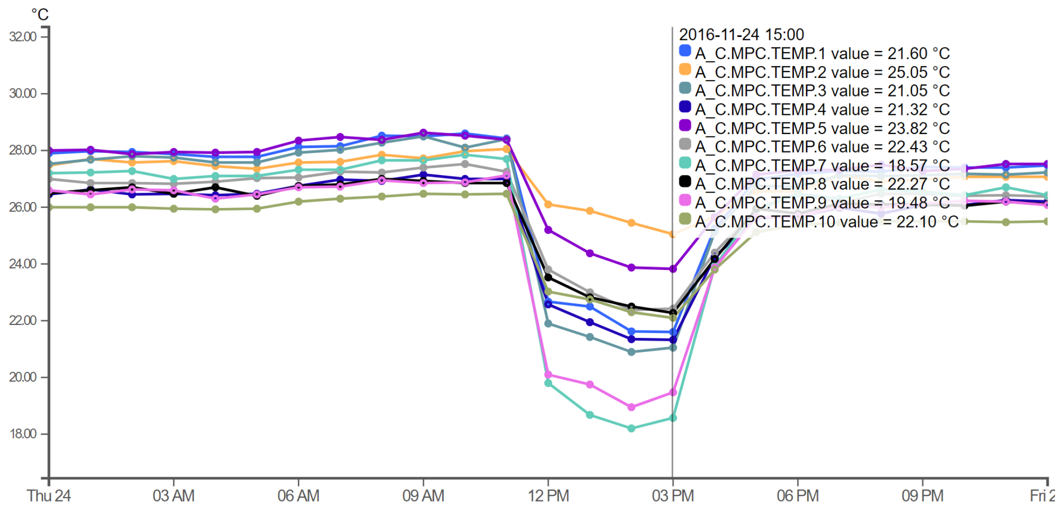


Fig. 4.3.1(d) Sensors reading inconsistent data example

Recommended action

Sensors need to be recalibrated and/ or re-arrange sensors positions to avoid being too close to air supply diffusers leading to inaccurate readings on room temperature.

4.3.2 Analyse Trend Logged Data

Once the data quantity and quality issues have been resolved, the RCx Team can use the trend logged data to better analyse the operational trends of energy consuming equipment/ systems and identify areas for operational improvement.

As an initial analysis step, the RCx Team should plot trends of the operational data to visualise:

(1) the hourly, daily, weekly, or monthly trends, for various key parameters such as the indoor air temperature in a room, chilled water supply and return temperature, chilled water flow rate etc.

(2) compare parameters to assess how one parameter varies when another changes, such as how the total operating chiller capacity varies with the instantaneous cooling load.

These charts will help the RCx Team discover faulty or poor operation, which may be causing inefficient energy use or poor indoor environment. Examples of this include the room air temperature is found to be always higher or lower than the set point, or the operating chillers' COP at night load becomes unacceptably low.

On the HVAC side, comparison between different sensors or energy meters is an effective strategy to detect and diagnose operational faults due to the strong interaction between components and systems in a building.

These comparisons are usually carried out by personnel familiar with the actual operation of the system or experienced building services consultants. Hence, this guideline will not go in detail to these types of analysis, but one example is provided for illustrative purposes.

Valve position - AHU valve opened when operation is off.

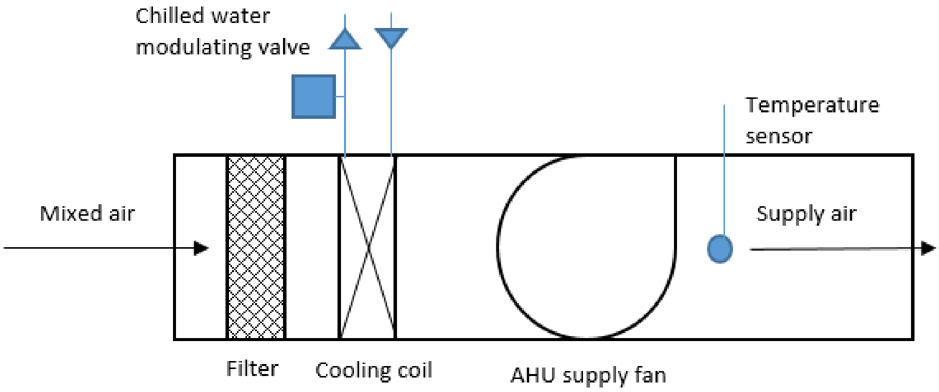


Fig. 4.3.2(a) Air handling unit chilled water valve data point location schematic

Situation

AHU cooling coil valve should be controlled in ON/OFF or modulate the opening position depending on the AHU operation.

Fault detection

In Fig. 4.3.2(b), the AHU cooling coil flow rate (blue) is still running despite the fans (brown line) has stopped operating.

Recommended action

The valve position should be checked regularly. The operation hour setting should be checked.

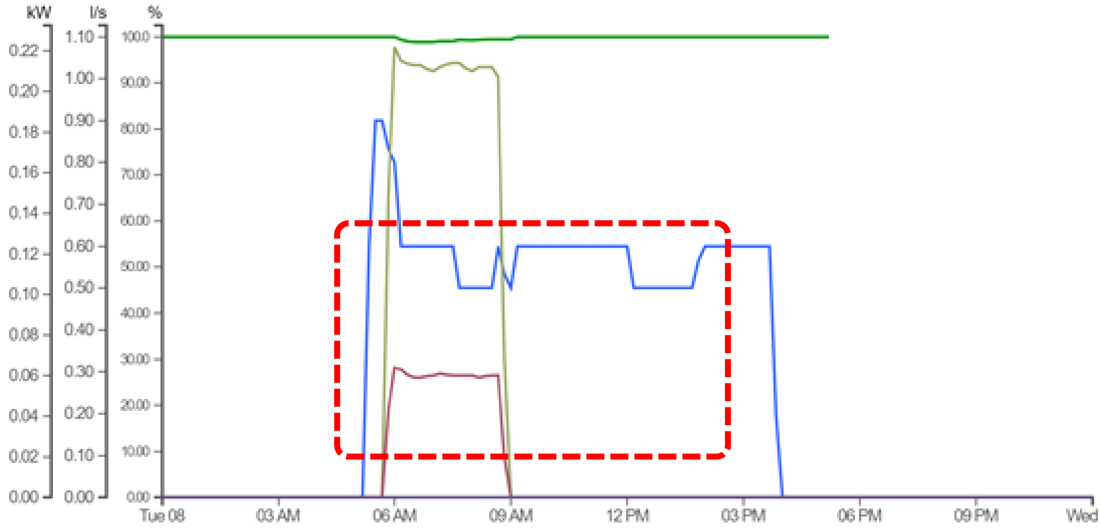


Fig. 4.3.2(b) Valve position inconsistent data example

4.3.3 Identify Potential Energy Saving Opportunities (ESOs)

When all the underlying operational problems are found with the help of equipment and system investigation test results, the ESOs can then be identified. The RCx Team will develop a list of ESOs with details on estimated energy saving, payback periods, implementation periods, any anticipated interruption to normal services and the measurement and verification (M&V) methods to be used to validate energy savings. The steps for the M&V energy saving calculation should be clearly described to the building owner. Where a proposed ESO requires repair items, a list of potential appropriate repair items should be clearly shown to building owner for consideration.

Form 2.3 provides a List of Proposed Energy Saving Opportunities (ESOs)

4.3.4 Agreement of Measurement and Verification Method for Energy Saving Opportunities (ESOs)

Measurement and Verification (M&V) is a term given to the process to verify and report energy saving delivered by Energy Saving Opportunities (ESO). M&V is an essential step for different parties in an energy saving project. In general, M&V provides a basis for determining the reduction of energy consumption.

In building owners' dimension, M&V allows the building owners to determine the effectiveness of the Energy Saving Opportunities (ESO) after implementation in a reliable and transparent, impartial and reproducible manner.

In facility managers' dimension, M&V provides performance feedback, which can facilitate operations and maintenance troubleshooting.

In engineers' dimension, M&V becomes the major validation vehicle for energy efficient design strategies at the component and at the whole building level.

To ensure this occurs, each proposed ESO should have a detailed energy saving determination, its calculation method, cost of implementation, and preliminary M&V plan reported to the building owner. The calculation methods employed should be clearly agreed with the building owner so the RCx Team can perform the same calculation to determine the actual energy savings under the agreed measurement and verification (M&V) options during the Implementation Stage.

Calculation of savings varies on each project depending on the nature of each ESO. In general:

Energy savings = Baseline Period Energy – Reporting Period Energy +/- Adjustment

There are two types of adjustments named Routine adjustment and Non-routine adjustment. They are used to adjust the savings to be reported based on the same conditions for fair comparison.

The former type is for any energy governing factors that are expected to change routinely during the reporting period, for example, weather. The latter type is for those factors that are not usually expected to change such as number of occupants, or the operation of the equipment.

It is important that the uncertainty and M&V boundary should be well defined for M&V process. All the equipment, systems or facilities within the boundary must be measured or estimated. And the other essential point to pay attention is that the existing/baseline data is essential for the calculation as shown in the equation.

The overview of M&V tasks and procedures are shown in below:

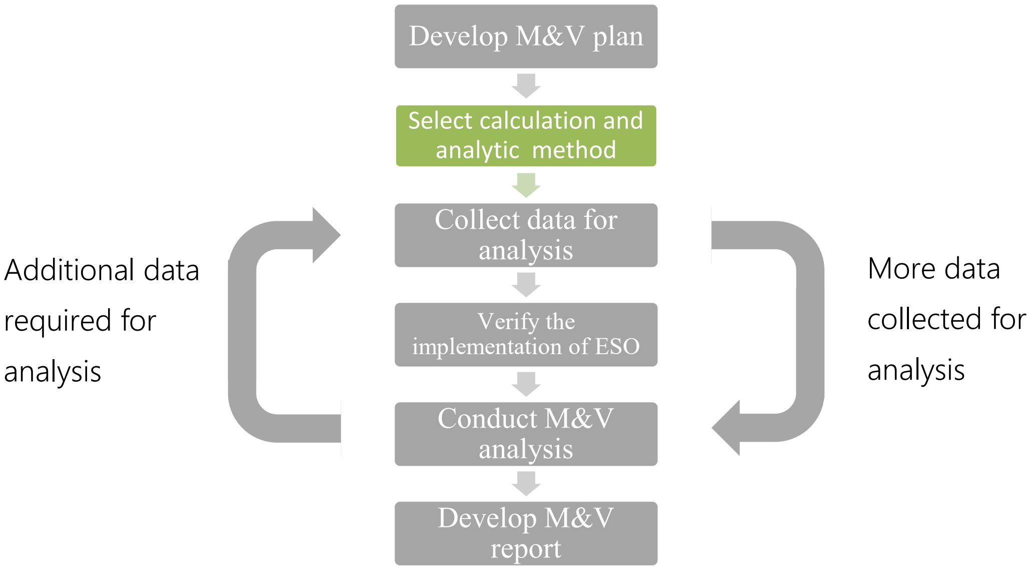


Fig. 4.3.4 (a) Flow Chart for Measurement and Verification

According to EVO 10000-1:2022 – International Performance Measurement and Verification Protocol – Core Concepts, four M&V options exist; a high-level description of each of them is presented below. Alternative approaches can be found in ISO 17741:2016 – General technical rules for measurement, calculation and verification of energy savings of projects and ASHRAE Guideline 14:2023 - Measurement of Energy Demand and Water Savings.

Option A – ESO isolation: key parameter measurement

This option estimates the savings of the ESO by measuring the most critical key parameter and just approximating the other parameters within the measured boundary. This approach introduces uncertainty to the estimation of savings, however it is a cost effective option for M&V when estimated parameters are more or less known.

For example, considering an ESO to install a timer for lighting control, the electricity demand before and after the timer installation will be the key parameter. In this case, the current operating hours of lighting should be obtained from measuring devices or sensors and the new proposed operating hours of lighting shall be agreed by all relevant stakeholders. Hence, the electricity saving can be estimated when compared to the baseline of operating hours. The actual electricity saving measurements before and after the installation of the ESO can be done on-site during M&V process.

Option B – ESO isolation: All parameters measured

This option estimates savings of the ESO by measuring all energy-related parameters within the relevant measurement boundary. This method relies on sub-metered data to estimate savings by comparing energy use before and after the implementation.

For example, considering an ESO to install a variable speed drive (VSD) at chilled water pump motor to control and adjust the pump flow rate, this ESO is related to the chiller plant performance and therefore multiple parameters related to the chiller plant will be measured including chiller power, chilled water pump power, chilled water supply and return temperature, etc. A power meter is installed on the motor to measure electric power in intervals. In the baseline period, this meter is in place for a week or weeks for verify constant loading. The meter is in place throughout the reporting period to track variations in power use.

Option C – Whole facility

Whole-facility metering uses utility bill data for estimating savings of the whole-facility using an adjusted baseline relative to weather in terms of cooling degree days (CDD) and other facility adjustments. This option is ideal when more than one ESO is implemented and estimating savings individually is not required. However, it should only be used when expected savings for the whole-facility are higher than 10%. If the performance of the facility is weather-dependent, a baseline period of at least 12 months is recommended (it should not be less than 9 months including the peak cooling season). This recommendation is suggested by the EVO 10000-1:2022 – International Performance Measurement and Verification Protocol – Core Concepts

If a CCMS is in place it can be used to determine facility adjustments that could have an energy impact, such as operating hours and cooling set-points. If a CCMS is not in place, close communication with the O&M staff is required to obtain this information from building logs.

Option D – Calibrated simulation

In the case of the calibrated simulation option, an energy model is used to provide an estimation of savings directly. This option is useful when multiple ESOs are implemented and it is required to estimate savings separately. Also, option D is useful when baseline data is limited or inexistent, for instance, metering was installed alongside with the ESO.

In all cases, model uncertainty should be estimated to determine if the model is within acceptable calibration ranges to accurately determine savings (consider ASHRAE Guideline 14:2023).

For this option, data obtained for CCMS or no-CCMS situations are the same as described for option C.

Additional benefits of this approach include the possibility of simulating ESOs before they are actually implemented, allowing a more informed selection, as well as providing benchmarking during the ongoing commissioning stage. However, option D is considered an advanced option due to the need of building energy modelling expertise and deep knowledge about the building its characteristics, which have an impact on the M&V cost.

Table 4.3.4(a) highlights the main characteristics of each of the M&V options available for estimation of savings, however detailed information about these can be found in the EVO International Performance for Measurement and Verification Protocol (IPMVP), EVO 10000-1:2022:

Approach	M&V option	Measurements required	Applications
ESO isolation	Option A	A key parameter during baseline and reporting period.	Lighting ESOs where operating hours can be calculated from operational schedules.
	Option B	All significant variables during baseline and reporting period	Air-conditioning ESOs where saving will be varied according to weather conditions.
Whole-facility metering	Option C	Utility bill data during baseline and reporting period. Weather data and other building adjustments.	Multiple ESOs to be implemented or the expected impact of an ESO is higher than 10%.
Calibrated simulation	Option D	General building information. Significant variables during baseline or reporting period.	No baseline data is available. ESO affect many systems.

Approach	M&V option	Measurements required	Applications
		Weather data and other building adjustments.	Many systems of the facility are affected by the ESO(s).

Table 4.3.4(a) M&V options summarised table

There is another option suggested in the U.S. Department of Energy National Renewable Energy Laboratory report called "Deemed Approach". This approach can be considered when the measure / ESO is relatively common and its estimated savings are small and at equipment level. The evaluator can then deem savings rather than simulate them. A spreadsheet tool is used to calculate savings, adhering to functionality requirements presented in the report. For further details, refer to National Renewable Energy Laboratory Chapter 16: Retro-commissioning Evaluation Protocol Report.

In general the cost of M&V depends on the number of variables to be metered, number of meters required, meter maintenance costs, length of baseline and reporting period, analysis required, reporting frequency and uncertainty limits. For the case on option D, the cost of creating and calibrating a building energy model should be considered. Additional M&V costs might be included on a case-by-case basis. EVO 10100-1:2019 – Uncertainty Assessment for IPMVP can be used to assess uncertainty in metering, sampling and modelling.

The M&V budget should consider the amount of savings expected, the payback period and acceptable amount of uncertainty. In general, it is commonly accepted that the budget of the total M&V should not be higher than 10% of the expected/achieved savings during the reporting period. For further reference, please refer to EVO 10000-1:2022 Concepts and Options for Determining Energy and Water Savings Volume 1 for IPMVP.

In Table 4.3.4(b), a non-exhaustive list of ESO scenarios are presented including the suggested option(s). EVO 10000-1:2022, Annex A presents a flowchart helpful to determine which M&V option is more adequate based on costs and expected savings. Additionally, Annex B lists a more comprehensive series of scenarios and their suggested options.

Scenario	Suggested option				
	A	B	C	D	Deemed Approach
• Expected savings are less than 10% of the total facility. • ESO(s) can be isolated within a reasonable measurement boundary. • Most of the parameters can be estimated, only a single key parameter is considered for measurement.	✓				
• Expected savings are less than 10% of the total facility. • ESO(s) can be isolated within a reasonable measurement boundary. • All significant parameters should be metered through sensors and energy meters due to high variability.		✓			
• It is required to assess impact of ESO(s) in the whole facility and it is expected to be higher than 10% facility energy use. • Utility data before and after ESO(s) implementation is available. • Assessing the impact of ESO(s) individually is not required.			✓		
• It is required to assess impact of ESO(s) in the whole facility. • Utility data after ESO(s) implementation is available but data before implementation is incomplete or fully absent. • Assessing the impact of ESO(s) individually is required.				✓	
• The measure / ESO is relatively common and its estimated savings are small and at equipment level.					✓

Table 4.3.4(b) Suggested M&V options for different scenarios

Finally, each ESO recommendation should be accompanied with a preliminary M&V plan containing the following sections (as defined in ISO 50015-2014):

1. Documentation of energy uses within the M&V boundaries for the selected option
2. Identify a proper baseline period
3. Identify required information to create a data-gathering plan
4. Identify required data for the baseline period
5. Identify existing energy data
6. Identify required M&V equipment

4.3.5 Selection of Energy Saving Opportunities for Implementation

The RCx Team should, based on the cost-benefit analysis on the potential improvement and saving opportunities, discuss the recommended items to be implemented with the building owner.

As a rule of thumb, it is important to firstly identify the no-cost action items, followed by low-cost action items, and finally identify capital renewal items especially focused on heavy energy consumers.

Agreement on the M&V methodologies and calculation approaches should be made with building owner before the implementation stage and the preliminary M&V plan should be updated to a final version as defined in ISO 50015-2014. It will ensure that the six fundamental steps in the M&V process are achievable, these steps are:

1. Establishment of an M&V plan, it includes selecting M&V option as defined in EVO 10000-1:2022
2. Gathering of data
3. Verify ESO implementation
4. Carry out M&V analysis
5. Create M&V reports
6. Repeat the process if necessary

4.4 Stage 3 – Implementation

A workflow of the steps and expected deliverables in the Implementation Stage is illustrated below:

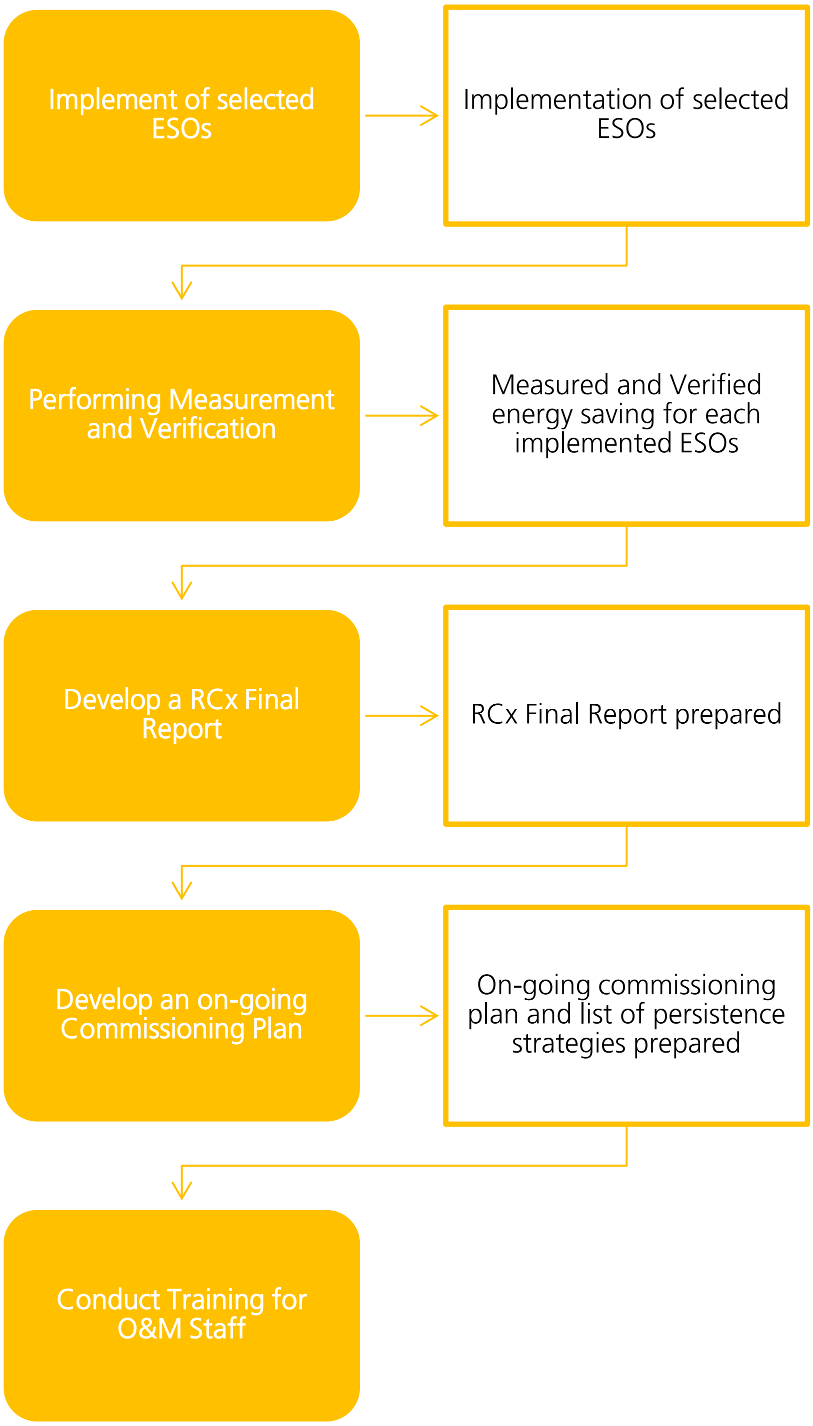


Fig. 4.4 Flow Chart for the Implementation Stage

4.4.1 Implement Selected Energy Saving Opportunities

Selected Energy Saving Opportunities can be implemented by internal O&M staff, or the Building Owner may engage contractors to perform selected Energy Saving Opportunities and associated implementation work if required. In the Implementation Plan, a clear description for each ESOs should be presented. The RCx Team can choose the most suitable approach to execute the ESOs, and then organise and define the work needed in the RCx implementation plan.

The building owner may choose to carry out a staged implementation plan to accommodate budget constraints or to minimise the interruption of system operation. The RCx Team should liaise with the building owner and O&M staff to mutually agree the RCx Implementation Plan.

4.4.2 Performing Measurement and Verification

After the selected ESOs are implemented, the RCx Team should collect the post-implementation data and then verify the energy savings. The post-implementation data is compared to the original baseline data to check whether the anticipated energy savings are attained or not; this process must be in accordance with the M&V plan defined in 4.3.4 Agreement of Measurement and Verification Method of Energy Savings Opportunities, where the content of the M&V report is defined.

The M&V report typically includes (as defined in ISO 50015-2014):

1. List of implemented ESOs
2. ESOs that were planned but not implemented
3. Changes in implemented ESOs as per original plans
4. Documentation of facility adjustments
5. Energy performance or energy improvement results

The post-implementation data can also be used to update the energy savings estimates as needed. Finally, this data can be used to establish the new baseline for the performance of that building system. Throughout the life of the equipment or systems, the new baseline can be used to establish criteria or parameters for tracking whether improvements are performing properly.

For some seasonally-dependent ESOs (e.g. air-conditioning and heating ESOs), it may not be possible to carry out the full M&V calculations within the Implementation Stage, as this stage may be completed before the appropriate season/weather conditions for measurement has taken place. In these cases, the M&V process may be continued during the ongoing commissioning stage and all the M&V methods and processes should be kept consistent to the ones created at the implementation stage.

The figure below shows M&V steps in the context of the RCx stages:

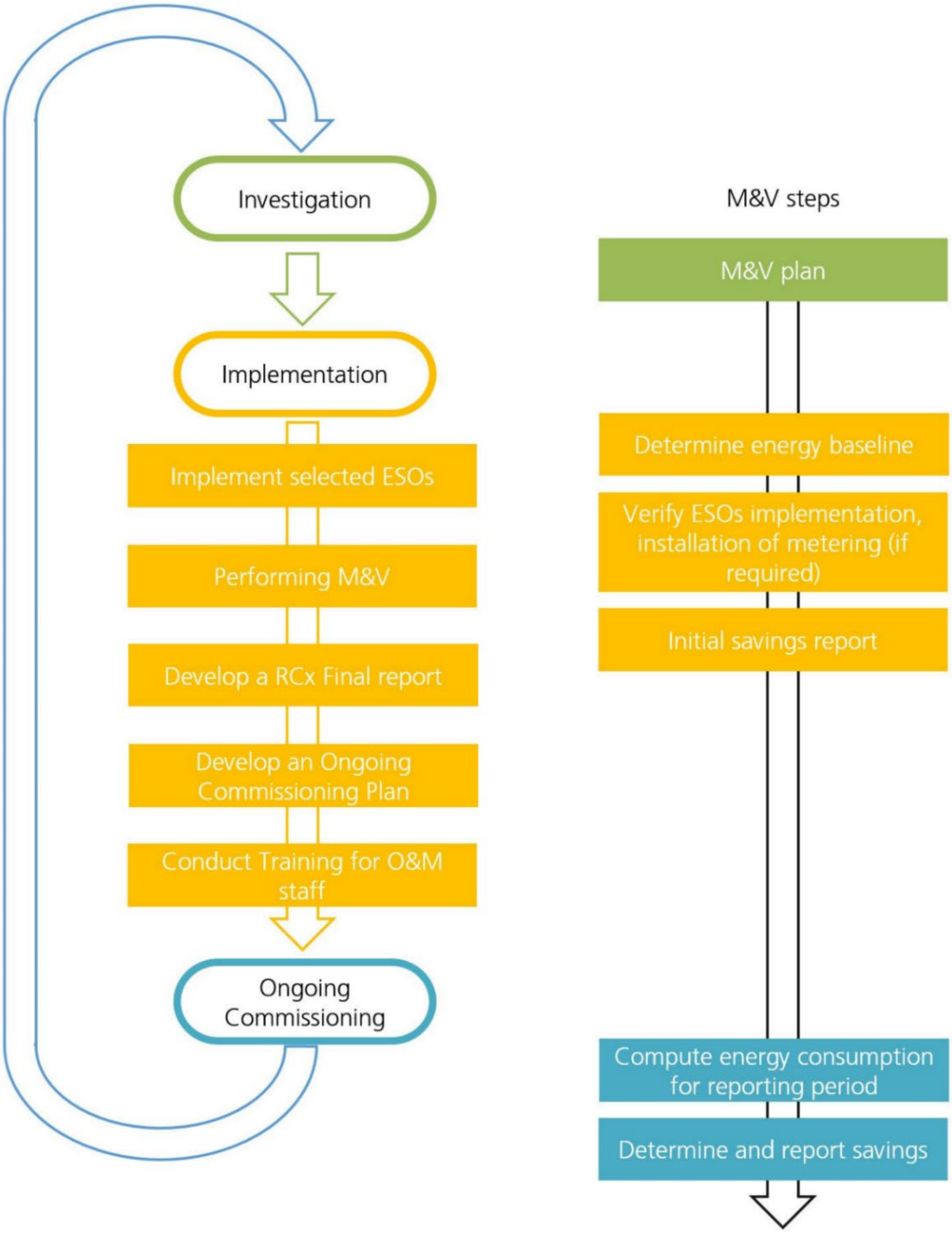


Fig 4.4.2 RCx stages with M&V steps

4.4.3 Develop a RCx Final Report

The RCx Final Report is a comprehensive record of the project, which can become a part of the on-site resources for O&M staff. The specific contents of the Final Report should include but not limited to the following:

- Executive Summary
- Current facility requirement
- The findings log with descriptions of the implemented measures
- Updated savings estimates and actual improvement costs
- The CCMS trending plan and data logger diagnostic/monitoring plan
- All completed equipment and system investigation tests and results
- Recommended frequency for re-commissioning
- Complete documentation of revised or new control sequences (or where this can be found)
- Recommendations for maintaining the new improvements
- Training Summary including training materials
- A list of capital improvements recommended for further investigation

4.4.4 Develop an Ongoing Commissioning Plan

In order to ensure the benefits of the Retro-commissioning project continue beyond the life of the project itself, the RCx team should assist the owner in determining the best strategies for keeping the new improvements efficiently over time. Below are the examples of viable strategies:

- Developing policies and procedures for updating building documentation
- Providing ongoing training for building staff
- Ensuring efficient operating performance
- Tracking energy and system performance
- Periodically recommissioning the building, paying close attention that the original RCx improvements are still producing benefits
- Instituting a plan of on-going commissioning
- Continuous collection of operational data for input to a simulation model (if available) for continuous energy use analysis and prediction.

4.4.5 Conduct Training for O&M Staff

Building operators, managers and O&M staff should have sufficient knowledge and skills to ensure the benefits of Retro-commissioning are maintained over the long-term. The RCx Team should develop and conduct additional training for O&M staff before and at the end of the project with a view to providing an opportunity to address how staff can maintain the Retro-commissioning improvements. Below are some recommended training practices:

- A training session that involves a classroom workshop with some hands-on demonstrations on the building equipment, this session should be recorded
- Include a follow-up session after certain period; this period is intended to give enough time for trainees to consider relevant follow-up questions which should be addressed in this session
- Provide explanations to staff to better help them understand the performance of the building through the analysis of the KPI during the on-going commissioning stage
- Carry out Q&A sessions from O&M staff
- Recorded training sessions for future reference and as a resource for training new O&M staff

4.5 Stage 4 – Ongoing Commissioning

The procedures and expected deliverables in the Ongoing Commissioning stage are shown as the following:

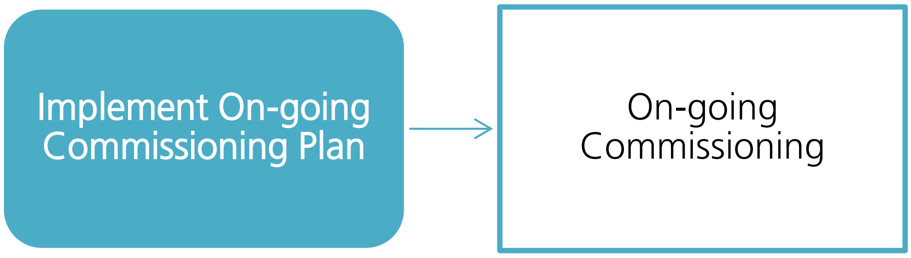


Fig. 4.5(a) Flow Chart for Ongoing Commissioning Stage

In this stage, ongoing commissioning is focused on ensuring that the building systems continue to run in the most efficient manner. This process should occur throughout the life a building in a continuous (scheduled or unscheduled) manner. To achieve this, data logging is required for the building systems, the collected data can be used to compare a building's current performance against recommendations stated in previous RCx to ensure the implemented improvements continue.

If it is decided that ongoing commissioning is to occur in a scheduled manner, it's proposed that this should be carried out every 3 to 5 years. However, an ongoing commissioning strategy through monitoring-based commissioning (MBCx) is a more recommended approach, which is also one of the credit requirement under the LEED rating system. MBCx is intended to provide continuous feedback to the building operators, who should be skilful and knowledgeable to establish a predictive baseline, benchmarking, track changes in performance (energy, occupant and staff performance) and to enhance communication. Additionally, MBCx can be used as a preventive measure of the building systems, focused exclusively on occupant complaints and other emergency corrective actions.

The recommended workflow for MBCx consist of sensor calibration, data collection, preparation of data for analysis, analysis of data, KPIs calculations/estimations, and reporting operational issues (if any). In the case of operational issues being reported, corrective actions should be carried out and the resolution can be documented and updating the O&M Manual. The MBCx is then used for tracking the building performance.

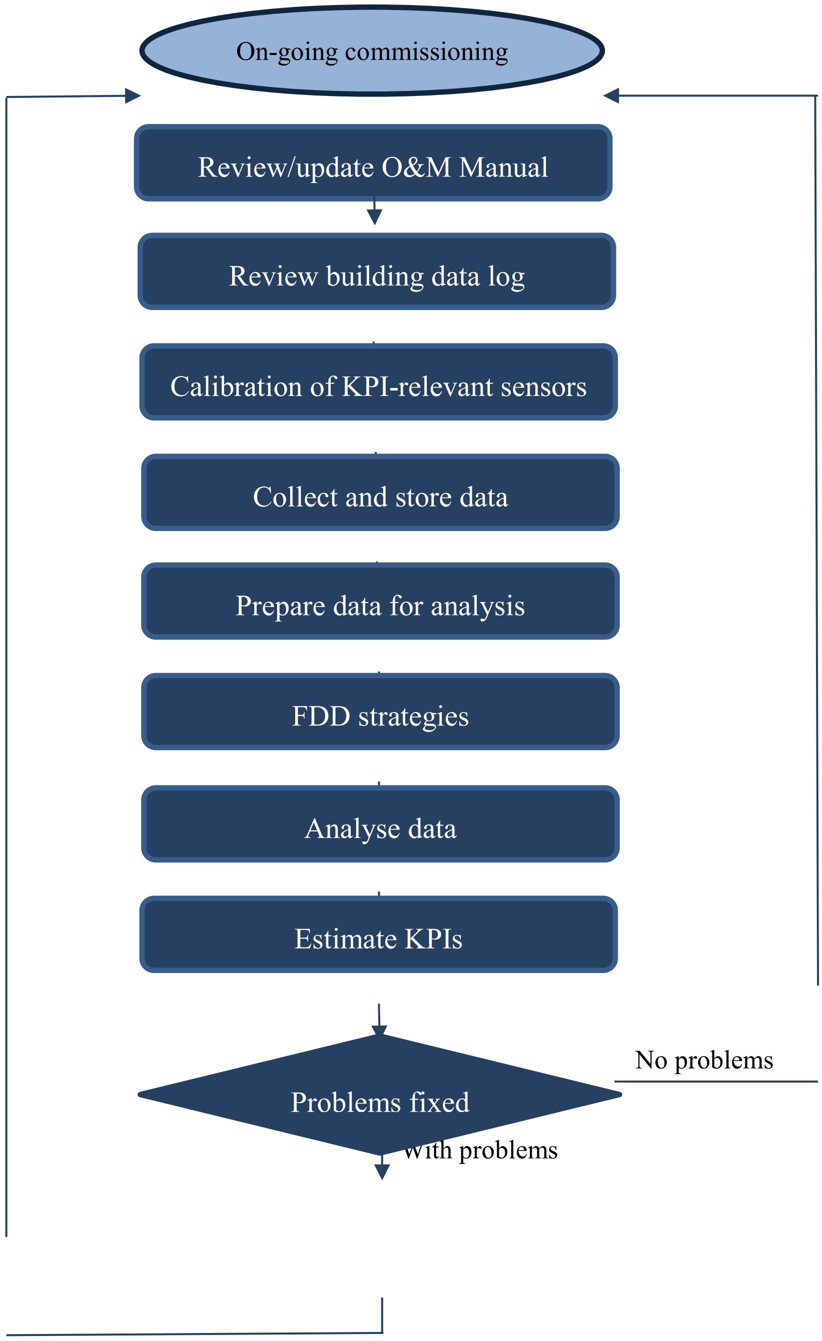


Fig 4.5(b) On-going commissioning process

Samples of Key Performance Indicators (KPIs):

1. Equipment / Plant Efficiency
2. Degrading Chilled Water Plant temperature range (delta-T) and temperature approach
3. Whole Building Electricity Consumption
4. System Electricity Consumption

Equipment / Plant Efficiency

As air conditioning system is one of the major energy consumers within a building, it is important to ensure it is running efficiently throughout the year. After the implementation of the related ESOs, regular monitoring of its performance efficiency can be used as an indicator if the system is working in an optimal manner.

If sufficient information is available, chiller plant efficiency can be calculated as COP. The table below provides the efficiency calculation for chiller plant as suggested by the Code of Practice for Building Energy Audit.

Equipment	Metric
Chiller plant efficiency (COP)	$\frac{cooling\ \ capacity\ \ kW}{\sum Chillers,\ Fans,\ CW\ Pump\ kW}$
Waterside transfer efficiency (W/L/s)	Pump kW *1000 / Pump L/s
Airside transfer efficiency (W/L/s)	Fan kW*1000 / Fan L/s

Table 4.5(a) Example for chiller plant efficiency calculation

Degrading Chilled Water Plant temperature range (delta-T) and temperature approach

In a typical chilled water system with primary and secondary loops, the primary loop is usually constant flow and the secondary loop will be variable flow to respond to cooling demands of the air conditioning terminals. A bypass pipeline decouples the two chilled water loops.

In reality, especially during part load operation, the chilled water system might fail to operate as efficiently as anticipated due to the problems such as deficit flow, improper operation of downstream airside equipment, improper setting of differential pressure / malfunction of differential pressure sensors. When the required flow rate of the secondary loop exceeds that of the primary loop, the chilled water will flow inversely through the bypass pipeline and will mix with the supply chilled water, resulting in an increased supply temperature to the terminal units. This in turn reduces the temperature difference as compared to the design value. As a result, the secondary flow is not properly controlled to match the actual demand or actual load.

The delta T between the supply and return chilled water can be monitored and compared with the design value when at high or peak load condition, if inadequate flow control, the delta T is well below the design value, and further investigation should be carried out to identify the problems.

Degradation of the system temperature range may be due to dirty coils, control valve degradation, mismatch of flow control and setpoint configuration.

The schematic drawings below illustrate the location of the node points that should be monitored to identify the system low delta T issues.

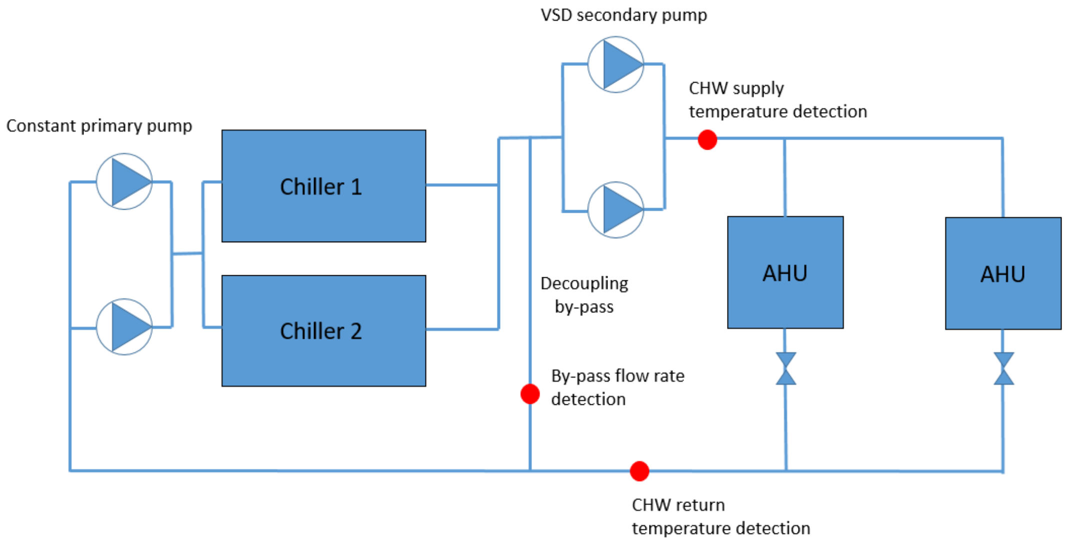


Fig 4.5(c) Constant primary variable secondary chilled water loop data monitoring points for degrading system delta T analysis

The low system delta T problem may also occur even with just a primary loop, although it is more likely to happen with constant flow configuration. The return chilled water will flow through the by-pass when the cooling load demand reduces. This results in lower chilled water return temperature hence further reducing the part load ratio of chillers.

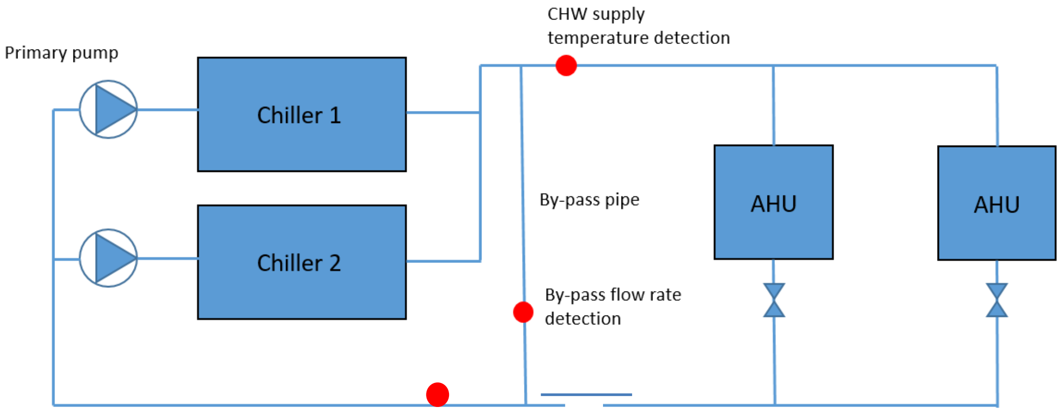


Fig 4.5(d) Primary only chilled water loop data monitoring points for degrading system delta T analysis

The following data points can be monitored to evaluate if the degrading system delta T occurs.

- Chilled water supply and return temperature difference
- Design temperature difference setpoint
- Primary and secondary loop flow rate
- Bypass pipeline flow rate

Whole Building Electricity Consumption

Electricity usage bills and sub-metering data are important indicators of how the retro-commissioned building is performing as compared to previous years. However, due to potential changes in weather and operational hours between years, it is not possible to make a direct comparison between the same times of the year to calculate this KPI. To make a valid comparison between current electricity bills and the previous years' bills, a regression analysis should be carried out to compute the adjusted baseline. The adjusted baseline represents how much the bills would have been under the same operating conditions of the baseline. Cooling-degree-days and operational hours are the most common inputs for the regression. However, other well-documented independent variables can be considered. Normal spreadsheet tools are suitable for doing regression analysis.

An example of a baseline adjustment is shown below. Electricity bills for the first and the second year after a retro-commissioning action are presented. A cooling degree-day (CDD) normalization is carried out as it was noticed that the second year after RCx was considerable warmer than the first year, hence the extra cooling energy should be included in the baseline for comparison. Besides external weather, there are other factors that might affect the KPIs, these include change of room usage, change of building requirements and change of occupancy pattern, etc. In the example below, it is noticed that there is a 20% increase in the utility bills between the 2nd and the 1st year, however after adjusting the baseline to the 2nd year weather – which is warmer- the estimated increase is about 7%.

1 year after RCx (Baseline)			2 years after RCx		
Period	CDD	Electricity (Bills) Initial baseline	CDD	Electricity (Bills)	Adjusted baseline
Jan	17	3,965	18	4,322	3,668
Feb	26	3,224	26	4,224	3,899
Mar	90	4,588	100	6,160	5,821
Apr	160	7,578	254	10,476	9,809
May	327	10,876	385	13,885	13,194
Jun	357	10,893	427	14,583	14,284
Jul	442	12,983	541	17,930	17,210
Aug	454	15,845	511	17,550	16,436
Sep	357	14,505	406	14,934	13,739
Oct	256	11,406	322	12,538	11,559
Nov	138	7,691	162	8,078	7,428
Dec	40	4,169	36	4,784	4,157

Table 4.5(b) Electricity bills regression adjustment example

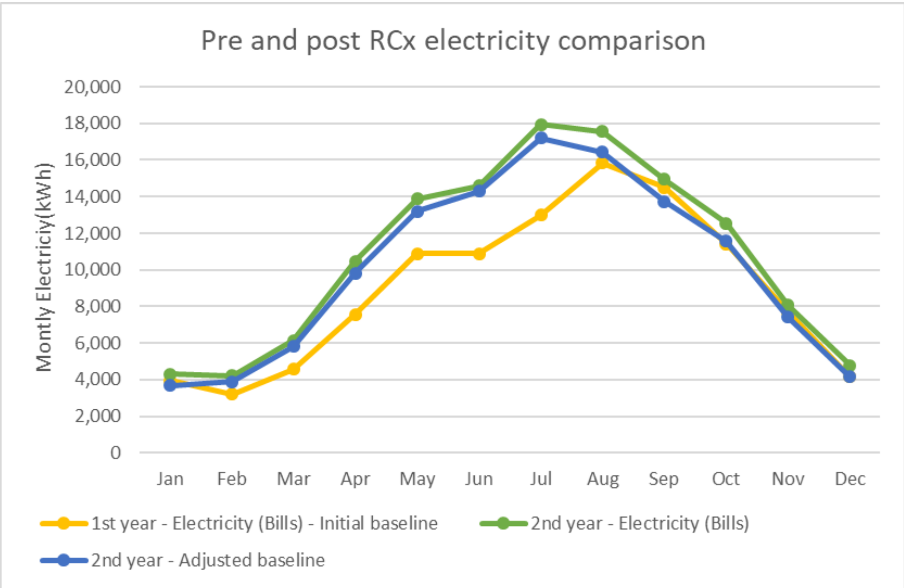


Fig. 4.5(c) Electricity bill comparison after regression adjustment

System Electricity Consumption (With ESO Implementation)

Besides looking at the whole building electricity, the user can consider monitoring individual system electricity consumption as per the implemented and verified ESOs through the M&V process. As for whole building electricity consumption, a regression analysis should be considered to account for factors that might affect the consumption performance.

Finally, if one of the cases below is presented:

- Large differences between the adjusted baseline and collected data exist;
- Electricity consumptions are higher with respect to the building energy model;
- There is a significant efficiency drop with respect to the baseline.

Following actions can be considered, such as:

- Review ongoing staff training;
- Review control, sequencing and operations;
- Retro-commissioning process may be carried out again.

4.6 Applications of Energy Modelling in RCx (Optional)

Identifying the biggest opportunities for energy saving opportunities and improvements in existing buildings can be achieved by reviewing which energy consuming equipment or systems utilize the most energy. Where there is sub-metering installed that measures the different types of energy consuming equipment/ systems in the building, this can be used to easily determine the actual breakdown of annual building energy consumption between each set of equipment and systems.

However, many of the existing buildings in Hong Kong do not have such sub-metering provisions. In such cases, computerized energy simulation tools can be used to create building energy models which can provide detail on all thermodynamic aspects of the building's performance, including equipment and systems energy consumption. These models can be created based on the existing system information, operational schedules and electricity bills.

Building simulation modelling can also be of benefit to RCx situations where detailed measured data is available, as the operational data can be used for a number of energy modelling strategies that will further enhance the RCx process. Examples of this include:

(1) Utilising operational data to improve the energy model's prediction, to closer match the actual building's performance (calibration), which will allow the RCx Team to more accurately assess the potential energy or cost saving reductions that can be achieved when analysing various energy saving proposals through scenario-based model simulation.

(2) Provision of an energy model that, once updated with recent operational data and building adjustments, will provide a benchmark for performance comparison during continuous commissioning.

(3) Performing measurement and verification (M&V) which accurately measures the savings that can been generated as a result of implementing an energy saving proposal in the building.

(4) Provision of the energy model as a high value asset to the client, which can be used for various purposes including adoption for future projects focusing on re-design or ESO evaluation, or to RCx to ensure savings persist beyond the initial M&V period carried out in the implementation stage.

In general, the applications for energy modelling in RCx include:

(1) An approach to evaluate the breakdown of energy use for the existing building accurately where measured data isn't available;

(2) Identification of reasons for the gap between the simulated results (design performance of the building) and the energy bill (actual performance of the building);

(3) Better estimation of the amount of energy and cost savings that can be achieved for identified energy saving opportunities; and

(4) Measurement and Verification using a calibrated energy model.

4.6.1 Benefits and considerations

As introduced in the previous section, energy modelling can have a number of benefits for long term Retro-commissioning. This section discusses these benefits in further detail:

(1) Building model simulations can be used to provide a detailed breakdown of a building's energy consumption where there is limited measured operational data available. As sub-metering may not be available to measure all energy consuming equipment/systems in a building, energy models can reasonably predict the energy use

for different building systems and the energy consumption breakdown, based on the available information along with electricity bills. In addition to this, annual energy consumption of different building systems can also be predicted in cases where there are only limited periods of measured operational data available (which may occur in the case of portable data-logging for example). Examples of this are shown in Fig. 4.6.1(a) and Fig. 4.6.1(b) below.

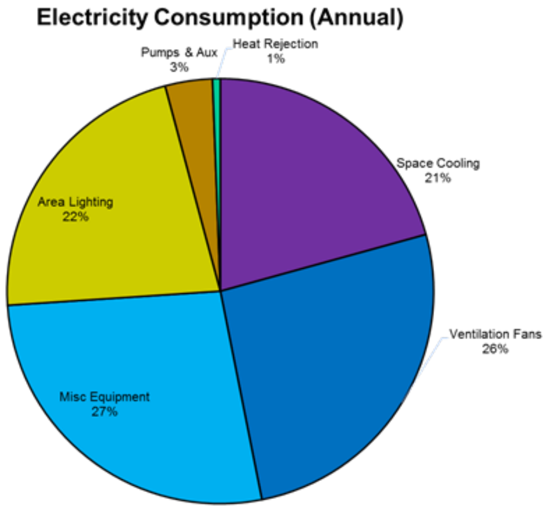


Fig. 4.6.1(a) Sample pie-chart of the energy consumption for various Building Services systems

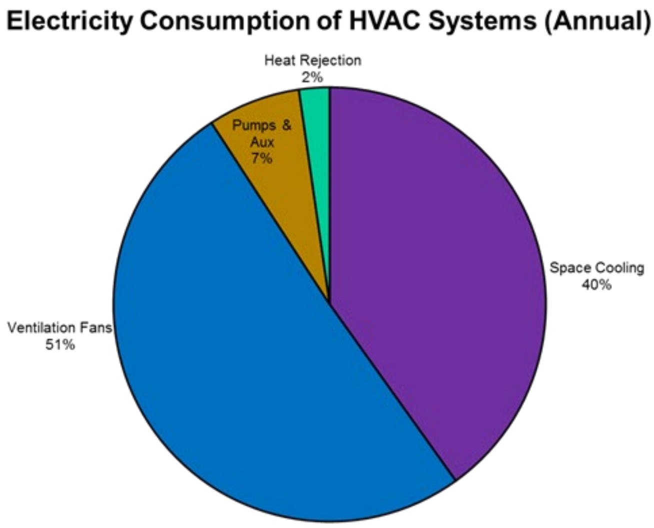


Fig. 4.6.1(b) Sample pie-chart of the energy consumption for various HVAC systems

(2) Building model simulations can predict a building's energy usage even when no information is available for one of the existing building systems. Professional assumptions can be made for the inputs to the energy model and, based on the previous electricity bills and all available information for other building systems, the energy consumption of those building systems can still be estimated, allowing for identification of opportunities for improving the efficiency of the building systems where no operational data is available.

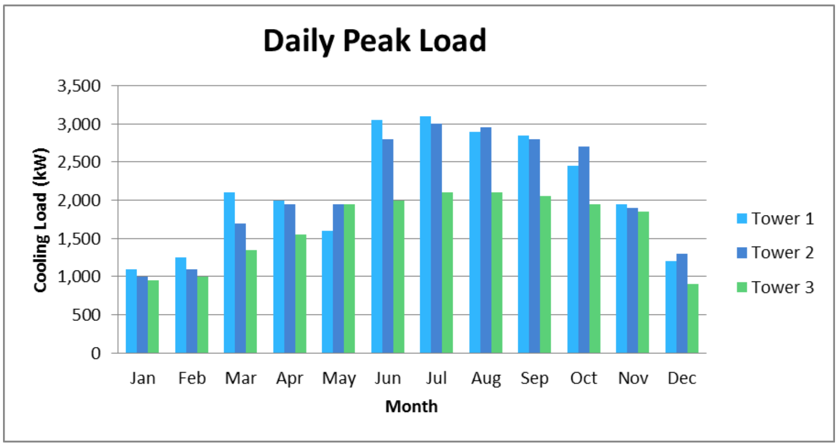


Fig. 4.6.1(c) Sample diagram of Daily Peak Cooling Load

(3) Building energy models can be utilised to better estimate the potential payback of implementing various ESOs. Energy models, which may already be created for the reasons detailed in benefit (1) and (2), provide a baseline model for the building's current operation. This model can subsequently be updated to simulate different operational or ESO scenarios, which is then compared against the baseline model to better estimate the amount of energy and/or cost savings that could be achieved by implementing potential ESOs identified in the investigation stages. This allows for improved estimation of the payback periods of each opportunity identified, hence assisting the building owner in selecting the most cost effective ESOs for implementation. An example of this is illustrated in Fig. 4.6.1(d).

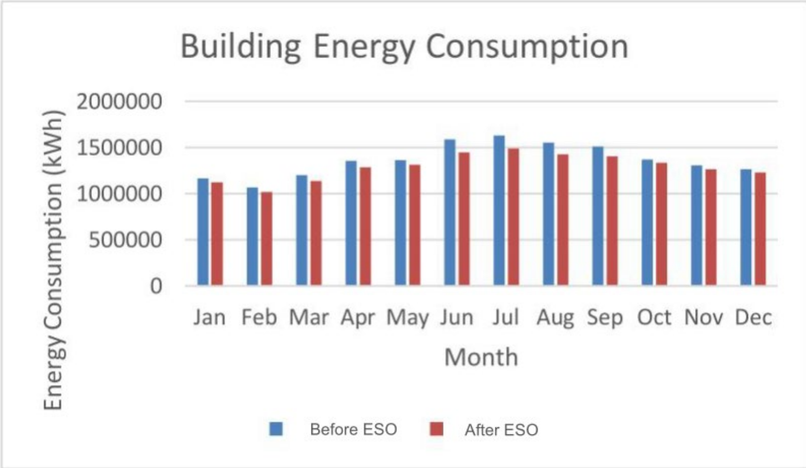


Fig. 4.6.1(d) Comparison of monthly building energy consumption before and predicted consumption after implementation of Energy Saving Opportunities (ESOs)

(4) Baseline models can also be used to identify faulty equipment, or improper operation of a building's systems. When the energy consumption of the baseline model is compared to the electricity bills, and the latter is evidently higher, it may indicate that some of the building systems are not operating correctly, or that some equipment (such as sensors) may be malfunctioning. Further analysis can be used to determine potential remedies to be implemented to adjust the system back to its optimal efficient operating conditions.

Although energy modelling provides an effective platform for monitoring and managing energy efficiency in buildings, there are two aspects to be considered before undertaking development of a building energy model:

(1) **Availability of the information for simulation** - Although an energy model can be prepared even where no operational time-series data can be obtained for some building systems (by combining historical electricity bills with professional assumptions), the overall accuracy of the energy model will be affected based on any assumption made. This may lead to an inaccurate estimation of energy saving for the proposed ESOs, and it is therefore advised to collect the following information ahead of creating a model:

a. Building information (e.g. architectural layout, elevations, floor area, shape, floor to floor height, number of stories, orientation, type of usage);

b. Thermal properties of façade (e.g. U-value of walls and fenestration, shading coefficient of fenestration);

c. HVAC configuration and operation (e.g. MEP layout, pump and fan flow rate, temperature set point, system type, operation schedule, equipment control strategies);

d. Equipment efficiency (e.g. chiller COP, pump efficiency, fan and motor efficiency, boiler efficiency);

e. Lighting and equipment power density, occupancy density and miscellaneous load (i.e. lift & escalator, cold water pump, exterior lighting, domestic hot water); and

f. Feasibility of adoption of energy saving opportunities i.e. renewable energy, heat recovery, demand control ventilation, daylight, motion sensor.

(2) **Additional effort for model creation -** Although there are numerous benefits to creating a building energy model, it may lead to additional manual effort and associated costs to create the model. However, considering the medium to longer-term energy and cost savings in identifying and rectifying inefficient operation of the building, as well as the value of having a way to accurately evaluate energy saving and payback periods for different ESOs ahead of implementation, energy modelling is recommended as a worthwhile undertaking to consider as part of the RCx process.

4.6.2 Building Energy Modelling Tools

There are a range of building energy modelling software programs available in the market, which provides customers the choice to select the appropriate software based on the scale of the building, and the systems involved.

A range of available building energy modelling software programs are listed in Table 4.6.2(a) and Table 4.6.2(b).

(Note: this is not a definitive list, and other programs can be considered where appropriate. Any simulation programs used for energy modelling purposes should meet the requirements listed in the Code of Practice for Energy Efficiency of Building Services Installation Appendix A section 2).

Free Building Energy Modelling Tools

Program:	Information source:
eQuest	www.doe2.com/eQuest
Energy Plus	energyplus.net/
ESP-r	https://www.strath.ac.uk/research/energysystemsresearchunit/applications/esp-r/
BEEP	www.bse.polyu.edu.hk/research/BEP/BEEP/BEEP.htm

Table 4.6.2(a) List of free building energy modelling tools

Commercial Building Energy Modelling Tools

Program:	Information source:
Trace 3D Plus	https://www.trane.com/commercial/north-america/us/en/products-systems/design-and-analysis-tools/trane-design-tools/trace-3d-plus.html
IES <VE>	www.iesve.com
Design Builder	www.designbuilder.co.uk
TAS	www.edsl.net/tas-engineering/
HAP	www.carrier.com/commercial/en/us/software/hvac-system-design/hourly-analysis-program/
TRNSYS	www.trnsys.com/
Ener-Win	pages.suddenlink.net/enerwin/

Table 4.6.2(b) List of commercial building energy modelling tools

For further reference on how to carry out energy modelling please refer to the Code of Practice for Energy Efficiency of Building Services Installation Appendix A.

5. Equipment Provisions and Considerations for New Buildings and Major Retrofitting Works in Existing Buildings

It was found that some existing buildings were insufficiently equipped for measuring and monitoring energy performance which imposes difficulty in performing retro-commissioning. In response to this concern, this section presents recommendations of equipment provisions in new buildings or major retrofitting works in existing buildings to facilitate future retro-commissioning. In addition, this section also highlights other considerations such as provision of adequate access for conducting retro-commissioning, and provision of isolation valves for sensors or meters, etc.

Guidance notes in this section are not intended to be definitive or exhaustive. Metering devices should be provided for monitoring the performance of:

- Chiller plant and individual chillers, including power, energy consumption, COP, etc.
- Cooling towers (for example, energy consumption of fans)
- Heat pump/unitary air-conditioner of 350 kW or above (cooling/heating capacity, including power, energy consumption, COP, etc.)
- Major air handling equipment (centralized air handling units) such as power, energy consumption, etc.
- Hydraulic pumps and the water-side of the HVAC system
- Small power and lighting installation
- Each lift, escalator or passenger conveyor
- Other major equipment/ systems, etc.

Metering devices should be selected according to Annex D of the Supplementary Information document. Other than the devices mentioned above, provisions of the following items should also be considered for future retro-commissioning and maintenance requirements.

- Test points
  - The test points are designed on pipework, which allow easy tapping points for sample testing during retro-commissioning without interrupting the operation. The location of test points should be close to the measurement device and easily accessible for future sampling.

- Isolation valves
  - Isolation valves are essential for sensor removal for maintenance or calibration while maintaining normal operation of the system.

- Differential water pressure across pumps, evaporator/condenser of chiller and cooling coil of AHU/PAU at index circuit
  - Digital or mechanical differential pressure gauges with built in high, low and by-pass valve to measure the differential pressure across pumps for understanding the pressure head required and differential pressure across evaporator/condenser of chiller for understanding the pressure drop across chiller and cooling coil of AHU/PAU at index circuit

- Differential air static pressure across fan of AHU/PAU
  - Provision of total static pressure measuring points for the AHU/PAU (parts from AHU vendors and installed by contractor)

- Temperature sensor for waterside and airside systems
  - Digital water temperature sensors for chilled water mains / risers, cooling coil of AHU/PAU and condensing water mains / risers for monitoring the chilled / condensing water temperature differential across the heat exchange devices of waterside equipment. Digital air temperature sensor of air-path before and after the cooling coil of AHU/PAU for monitoring the air temperature differential across the heat exchange devices of airside equipment

- Appropriate installation location for data visualization
  - The display of data should be visualized by eye of human being at floor level

- Appropriate installation requirement
  - All the sensors and meters should be installed as per the requirement advised by the manufacturer / supplier

- Adequate maintenance space
  - Sufficient access space should be allocated for building operators or the RCx team for future retro-commissioning implementation. The design for adequate maintenance space could be referred to Design & Maintenance Guide 08 (Space Requirements for Plant Access, Operation and Maintenance), BSRIA Guide BG55/2018 (Safety in Building Services Design) or any other international guidelines.

Apart from the above mentioned, the selection and provision of equipment in a new building shall take consideration on the energy efficiency as defined in the Buildings Energy Efficiency Ordinance or other equivalent Ordinances and review on the adoption of new technology / products in the market. The following lists out few examples for consideration:

- Lighting installation
    - Automatic lighting control should be considered to provide in a space by means of programmable controls or occupancy sensors to reduce unnecessary use of lighting during unoccupied hours.

- Plumbing and flushing installation
    - All sanitary fittings (e.g. water taps, water closets, urinal equipment, etc.) should meet the water efficiency rating of the Voluntary Water Efficiency Labelling Scheme (WELS) of the Water Supplies Department (WSD) so as to reduce the water usage and reduce the power consumption of water pumps.

- Air-side equipment installation
    - AHU filtering system may be considered to adopt a new technology air filters with high filtration efficiency but low pressure drop as available in the market. Requirement on the maintenance or replacement works shall be rationally reviewed.

Appendix A

Sample Technical Approach for Identification of Energy Saving Opportunities (ESOs)

Appendix A - Sample Technical Approach for Identification of Energy Saving Opportunities (ESOs)

Examples presented in this section are not meant to be definitive or exhaustive. Throughout the RCx process, some possible energy saving opportunities (ESOs) and/or building operational improvements can be identified. The RCx Team will carefully discover the underlying operational problem in their own analysis of the trend logged data.

Energy saving opportunities (ESOs) may involve different building services systems/installations but not limited to:

1. Air-conditioning (Central Chiller Plant);
2. Air-conditioning (Heat Rejection System);
3. Air-conditioning (Air-Side System);
4. Air-conditioning (Water-side System);
5. Electrical System;
6. Lighting System; and
7. Others

Below are different Technical Approaches for Identification of Energy Saving Opportunities (ESOs).

Acknowledge Hong Kong Green Building Council for providing certain examples on RCx.

Example 1 - Air-conditioning (Chilled water plant)

Energy Saving Opportunity:
Chiller Sequencing Optimisation – More chillers to operate at partial load

Background Information:

The building is served by 4 sets of VSD air-cooled chillers (3 duty & 1 standby) with 4 sets of chilled water pumps (3 duty & 1 standby). The chilled water configuration in Fig. A.1(a) is a differential pressure bypass system with variable speed drives for adjusting the speed of chilled water pumps.

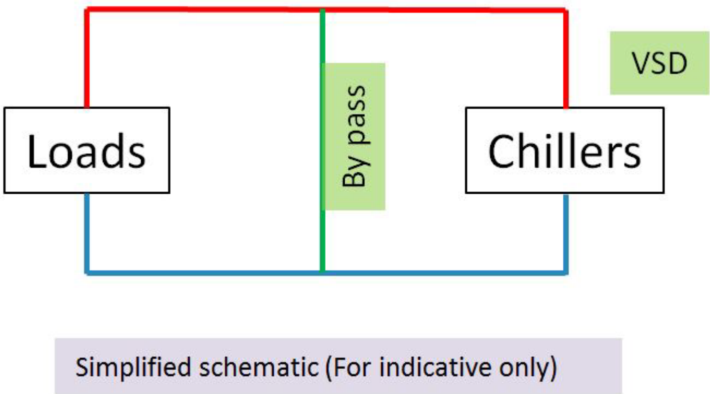


Fig. A.1(a) Chilled water loop simplified schematic

Facility / Equipment:

Chillers

Site Measurement, Observation and Findings:

Fig. A.1(b) shows a graph with the y axis showing the % of full load ampere FLA, of the individual chillers in operation and the x axis showing the % of the cooling load of the whole plant. The yellow dotted line is a hypothetical line indicating a direct proportional relationship between the % FLA of individual chillers with the % loading of the various chiller combination. This line is used as a rough reference indicating on how different chiller combinations perform at various loads.

The operating data between the overall loading range 25% to 70% has been entered into the graph.

The following was observed:

1. Two chiller combinations (2 chillers and 3 chillers) have been used between an overall loading of 30%-50% loading.

2. When the two-chiller combinations were operating at near full load, the % FLA remained at 1 (100%) instead of a corresponding drop in % FLA following the dotted reference line.

3. The FLA at a lower % part load was lower than the reference line. This indicated the chillers were operated at a higher efficiency during part load condition. The performance curve by the manufacturer in Fig. A.1(c), confirmed this finding

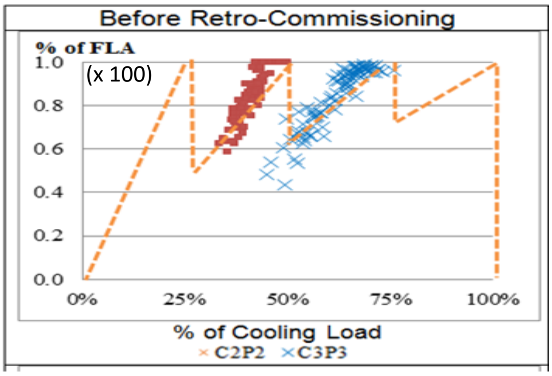
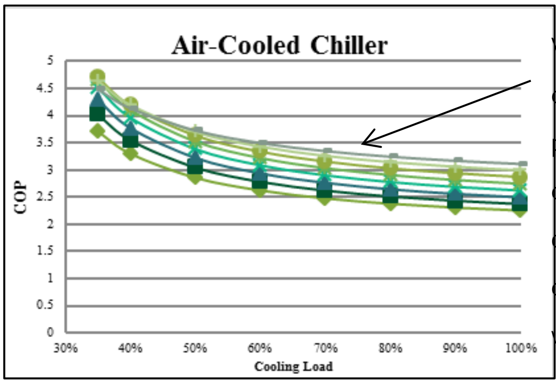


Fig. A.1(b) FLA% vs cooling load % (before RCx)



VSD Air-cool chiller's performance curves under different condensate water temp.

Fig. A.1(c) COP vs cooling load %

Recommendation:

It is recommended to operate a 3-chiller combination to cater for percentage of load reduced to 40% and a 2-chiller combination to cater to the load being reduced to 30%. Fig. A.1(d) shows the performance after adopting the above strategy.

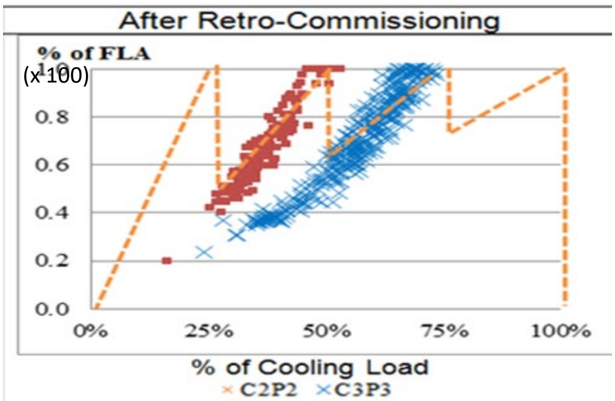


Fig. A.1(d) FLA % vs cooling load % (after RCx)

Energy Saving Estimation:

As shown in Fig. A.1(e), the implementation of chiller sequencing improvement, the efficiency (COP) of the two combinations has been improved by 8.2% on average. It is estimated that the annual energy saving would be around 4.8%.

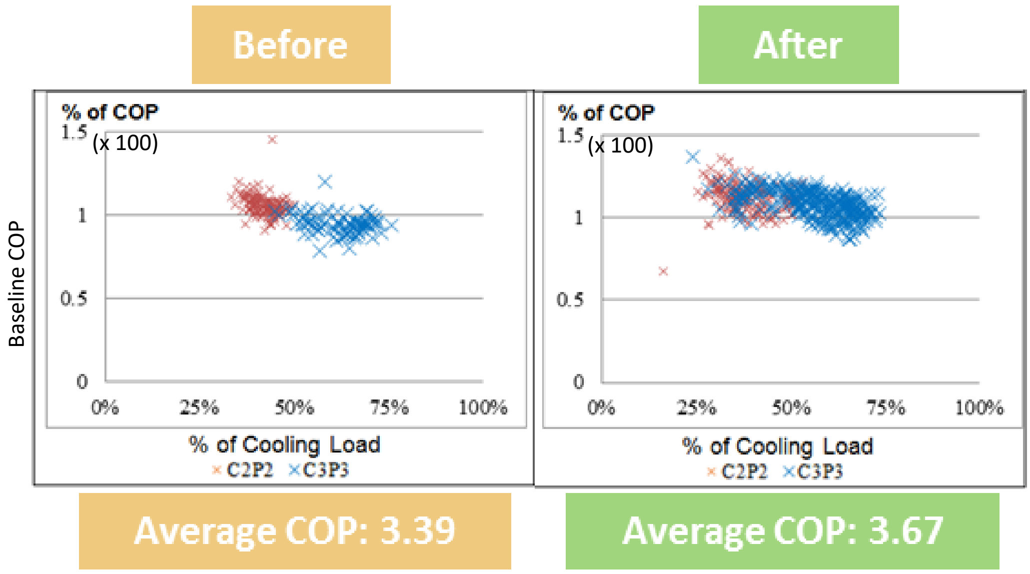


Fig. A.1(e) COP comparison before and after RCx

Remarks:

100% of COP = Baseline COP (before RCx) = 3.39

108.2% of COP = Improved COP (after RCx) = 3.67

Example 2 - Air-conditioning (Chilled water plant)

Energy Saving Opportunity:
Adding a standby mode to prevent activation of low-cut function in the oil-free chiller at light load operation

Background Information:

The building is served by 2 sets of air-cooled chillers (1 duty & 1 standby). One of the chillers is an oil-free centrifugal chiller (the duty chiller - new) with 2 compressors and the other one is an air-cooled screw chiller (the standby chiller - old) with 4 compressors. The minimum load capacity of the compressor is about 20-30%. In Fig. A.2(a), the chilled water configuration is a differential pressure bypass system with same number of constant speed chilled water pumps as the chillers.

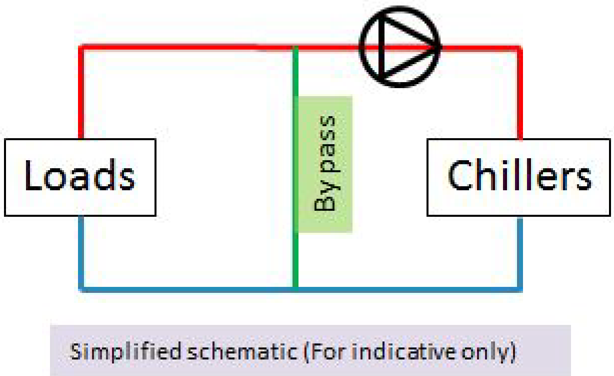


Fig. A.2(a) Chilled water loop simplified schematic

Facility / Equipment:

Chillers

Site Measurement, Observation and Findings:

1. During peak seasons, the oil-free chiller was only running at about 50-60% of its rated capacity.

2. Because it is a constant pump speed differential pressure bypass system, the chilled water temperature difference is only about 3°C or below resulting from the large among of chilled water needed to be bypassed back to the chiller.

3. When the ambient temperature drops below 20°C, the cooling load will fall to <15% and trigger the "low-cut" protection of the chiller. To prevent tripping the oil free chiller, the practice is to operate the air-cooled screw chiller during those light load conditions which decreases the efficiency of the plant. Fig. A.2(c) shows the comparison between the efficiency of the oil free chiller and the screw chiller

Before Retro-commissioning

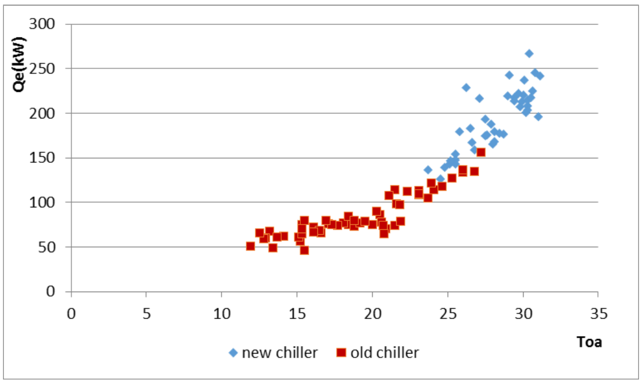


Fig. A.2(b) Cooling load vs outdoor ambient temperature (before RCx)

Qe(kw) – Cooling Load

Toa – Outdoor ambient temperature

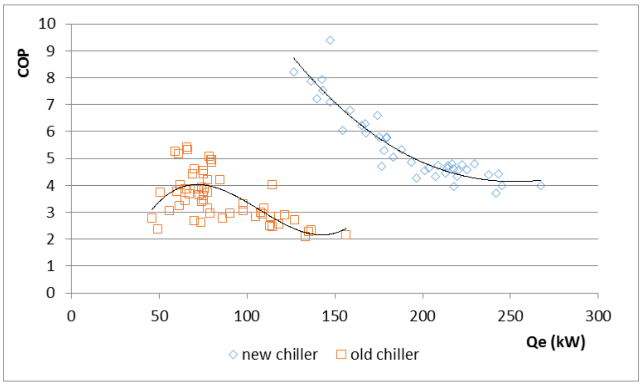


Fig. A.2(c) Chiller COP vs cooling load (before RCx)

Recommendations:

Two suggestions were proposed:

1. Maintain the chilled water temperature difference across the chiller by no less than 5°C. This can be achieved by converting the system to primary variable flow (this will be implemented at a later stage).

2. Work with the chiller manufacturer to modify the low temperature cut control so that the chiller will be switched to standby mode (with the compressor stopped) instead of tripping the chiller when the chiller water is lower than the cut-off temperature. The compressor will automatically cut-in when the chilled water temperature has raised to the normal operating temperature range of the chiller.

3. This has eliminated the need to use the screw chiller and hence increased the overall efficiency of the chiller plant.

Energy Saving Estimation:

After the implementation of the above recommendations, the oil free chiller can be operated when the ambient temperature is below 20°C. Fig. A.2(d) & Fig. A.2(e) compare the performance before and after the implementation.

After Retro-commissioning

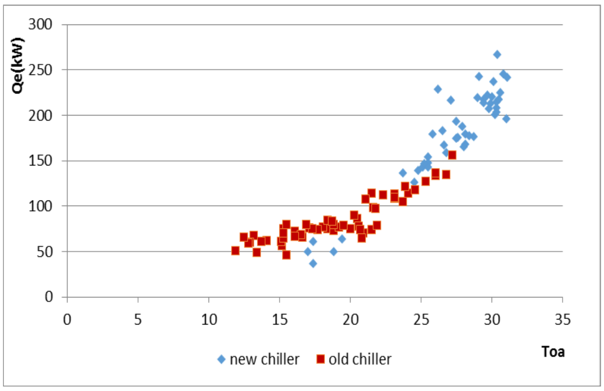


Fig. A.2(d) Cooling load vs outdoor ambient temperature (before and after RCx)

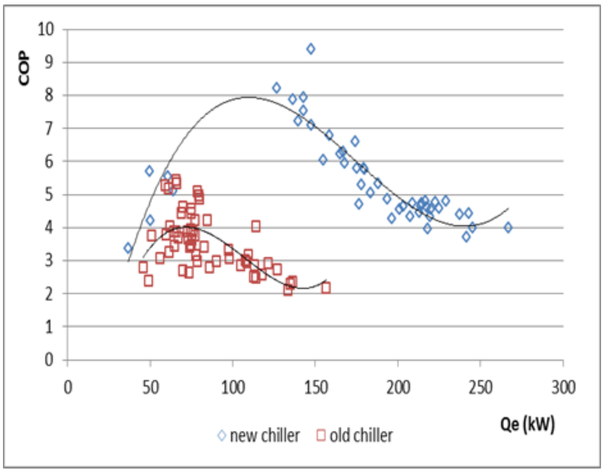


Fig. A.2(e) Chiller COP vs cooling load (before and after RCx)

Example 3- Air-conditioning (Central Chiller Plant)

Energy Saving Opportunity:
Adjust the chiller's load factor by CHWST setpoint reset in order to improve chiller efficiency.

Background Information:

In Fig. A.3(a), there are 2 sets of water-cooled chillers [1 no. 350kW Constant Speed Drive (CSD) screw type chiller and 1 no. 350kW Variable Speed Drive (VSD) screw type chiller] served for the whole building. Based on different cooling loads, the CSD chiller and the VSD chiller will be operated together.

Facility / Equipment:

Chiller No.1 (350kW CSD screw type chiller) and Chiller No.2 (350kW VSD screw type chiller)

Site Measurement, Observation and Findings:

- Trend logging of chilled water flow rate;
- Trend logging of chilled water temperature differential; and
- Trend logging of power input for operating chiller plant equipment.

By the above collected data, existing chiller load distribution was found to be as follows:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Outdoor Air Temp (°C)	16	15.5	17.5	23.6	26.7	29.4	29.8	28.4	27.9	26.8	22.3	19.6
Building Cooling Load (kW)	211	222	229	422	457	510	528	535	524	457	394	239

Table A.3(a) Weather data in 2016 (obtained from HKO) and one building cooling load in 2016

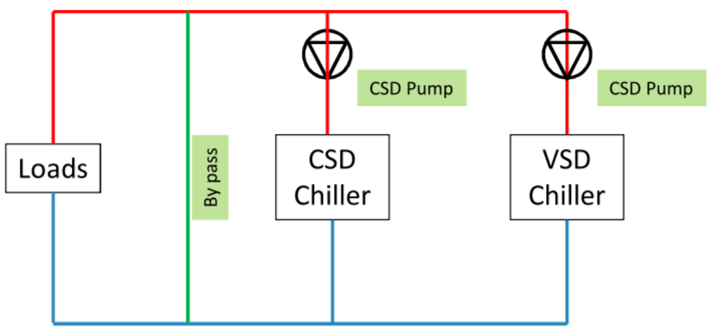


Fig. A.3(a) Simple block diagram for a plant system

	Chiller 1	**Chiller 2**
Type of Chiller	CSD	VSD
Existing CHWST Setpoint	7°C	7°C
Existing Distribution of Chiller Average Load Factor	60%	60%

Table A.3(b) Existing chiller load distribution

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chiller 1 (CSD) COP	NA	NA	NA	4.04	3.97	3.56	3.56	3.56	3.56	3.97	3.85	NA
Chiller 2 (VSD) COP	5.36	5.36	4.8	4.19	4.38	3.81	3.68	3.68	3.68	4.38	4.64	6.22

Table A.3(c) Monthly COP figure before CHWST setpoint reset

Based on the properties of CSD and VSD chiller, it is observed that CSD chiller has a higher COP near full load condition while VSD chiller has higher COP near its part load condition. Thus, chiller load distribution should be properly adjusted so that the CSD chiller can bear more loading while the VSD chiller bears less loading. As a result, the overall COP of chiller plant would be improved.

A COP graph of the chiller should be obtained from the chiller supplier as this is an essential tool for reviewing chiller load factors.

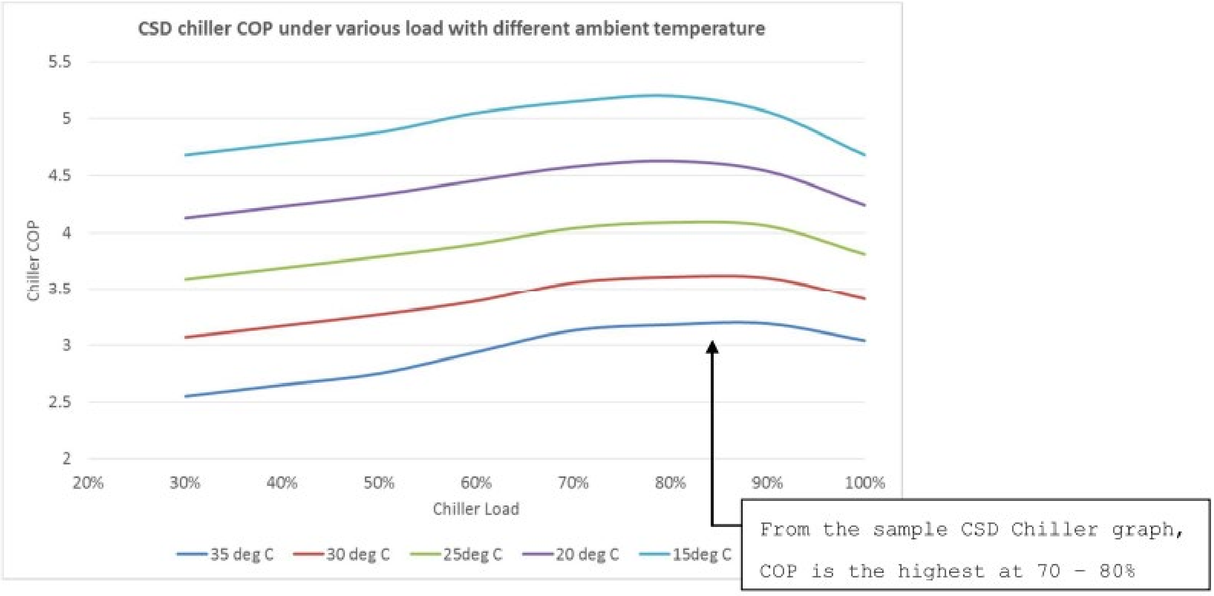


Fig. A.3(b) Sample COP graph of 350kW CSD Air Cooled Screw Type Chiller

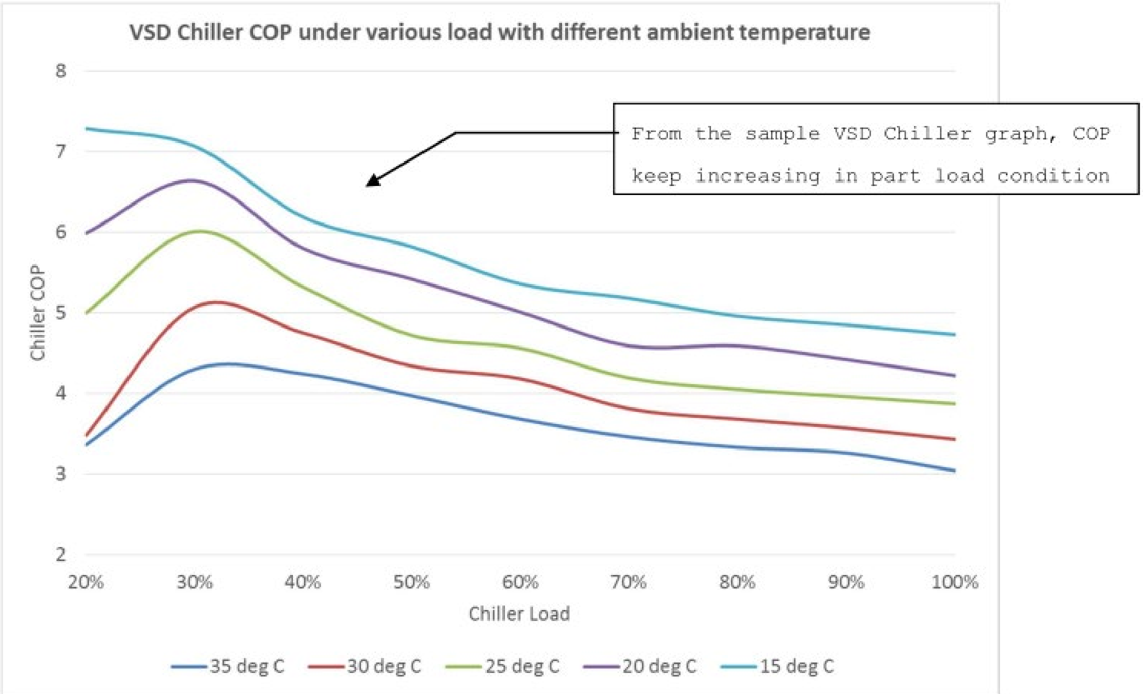


Fig. A.3(c) Sample COP graph of 350kW VSD Air Cooled Screw Type Chiller

Recommendation:

In order to capture the higher COP range, it is recommended to reschedule the load so that the CSD chiller can bear more loading while the VSD chiller can bear less loading so as to improve their overall COP. We can observe from Fig A.3(b) and Fig A.3(c) that Chiller 1 (CSD) and Chiller 2 (VSD) can operate at higher COP respectively with the proposed chiller load distribution according to Table A.3(d).

	Chiller 1	**Chiller 2**

Type of Chiller	CSD	VSD
Proposed CHWST Setpoint	6.5°C	7.5°C
Proposed Distribution of Chiller Average Load Factor	70%	50%

Table A.3(d) Proposed chiller load distribution

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chiller 1 (CSD) COP	NA	NA	NA	4.07	4.07	3.61	3.61	3.61	3.61	4.07	3.97	NA
Chiller 2 (VSD) COP	5.36	5.36	4.8	4.56	4.64	4	4	4	4	4.64	4.72	6.22

Table A.3(e) Monthly COP Figure After CHWST Setpoint Reset

Energy Saving Estimation:

- Chiller No.1 and Chiller No.2 operating for the period from April to November
- Chilled water supply temperature reset as the above Table A.3(d)
- Operating in office hours
- Mon-Fri: 08:00a.m. to 06:00p.m.
- Estimated Annual electricity consumption of the two chillers before RCx: 353,370kWh
- Estimated Annual electricity consumption of the two chillers after RCx: 343,450kWh

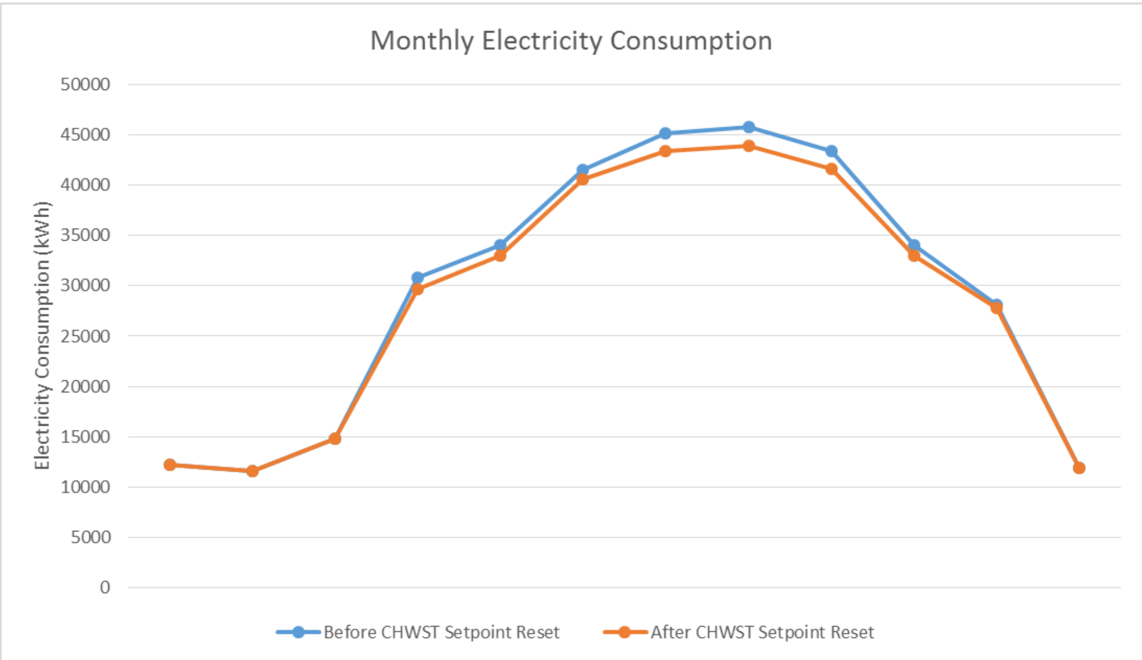


Fig. A.3(d) Monthly Electricity Consumption Before and After CHWST Setpoint Reset

Annual electricity consumption saving= 9,920kWh (~3% of annual chiller electricity consumption)

There is still room for further adjustment in the implementation stage which may increase the energy savings of this strategy.

Example 4- Air-conditioning (Central Chiller Plant)

Energy Saving Opportunity:
Evaluating existing chiller plant performance with retrofitting consideration

Background Information:

In June, when the ambient temperature was around 30°C, all 4 chillers were in operation since some of the chiller compressors were out of order and under maintenance. In Fig. A.4(b), the chillers were always operating at 85% of full load ampere (FLA), which approached their maximum limit, with all workable chiller compressors were in operation. Under such operating condition, the chilled water supply temperature was unable to meet the set-point of 8.5°C.

On the other hand, the differential pressure bypass valve was always kept partially opened even the isolating valves on the bypass pipe were manually closed. Hence, a portion of chilled water supplied from the chillers needs to flow back to the chillers again via the bypass pipe. As a result, the differential temperature of chilled water was about 3.5°C or below as shown in Fig. A.4(c), which represents the cooling output being about 60% or less when there is constant flow through the chillers.

Since the constant flow chilled water pumps were connected directly to individual chillers without a common header, this configuration reduced the flexibility in controlling the flow through the chillers (e.g. 3 pumps 4 chillers were not available) during operation, especially when some of the compressors of chillers were under maintenance.

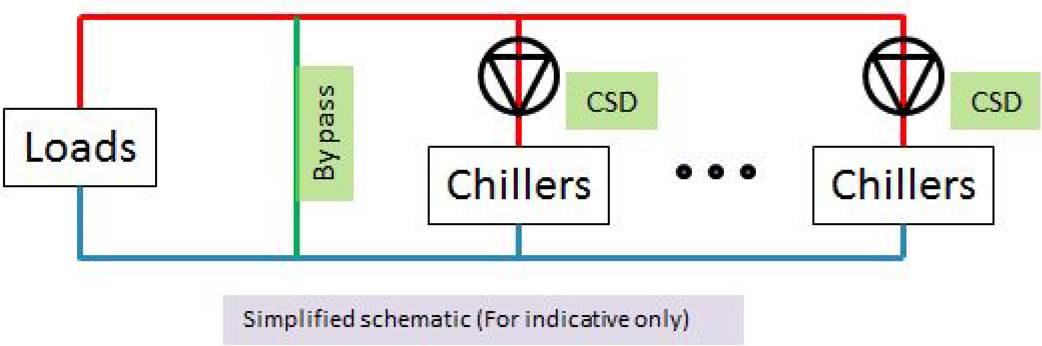


Fig. A.4(a) Simple block diagram for a plant system

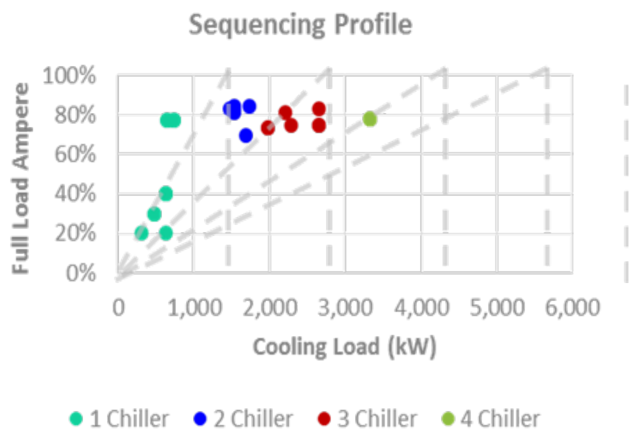


Fig. A.4(b) Chillers ampere ratio vs cooling load (kW)

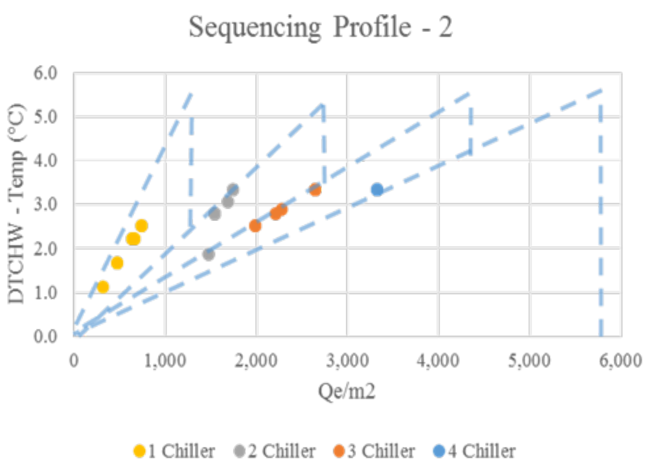


Fig. A.4(c) Chillers chilled water temperature difference vs cooling load

Facility / Equipment:

The building is served by 4 sets of air-cooled reciprocating chiller (3 duties & 1 standby) with 4 sets of chilled water pumps (3 duties & 1 standby). Each chiller is equipped with 4 compressors. The chilled water system configuration is a differential pressure bypass system and each chilled water pump is directly connected to individual chillers (i.e. constant flow through chillers).

Site Measurement, Observation and Findings:

1. The chillers have been in operation for more than 20 years and a number of chillers were under servicing during the site inspection

2. Chilled water supply temperature cannot meet the 8.5°C set point.

3. Fig. A.4(b) indicates that more chillers than required are needed to cater for the loading.

4. Fig. A.4(c) indicates a very low chilled water temperature difference (< 3°C) across the chillers and the chilled water has been bypassed through the differential pressure bypass valve.

5. Operators have set an 85% FLA limit to the chillers to prevent it from breaking down.

The above has indicated that the chillers are already too old and have been significantly deteriorated.

Recommendations:

The following suggestions were recommended:

1. To replace the chillers. A study to evaluate the various replacement options is shown at the following session.
2. To convert the chilled water system to a variable flow system. This requires connection of the chilled water pumps with a common header and installation of variable speed drives on all chilled water pumps.

Once the client agreed to perform major ESO implementation work, a scenario analysis was carried out as shown in Table A.4 based on the original case (i.e. all 4 chillers are undertaken replacement). Results indicated that if all chillers are replaced, the estimated payback period would be 9-10 years. For Option 1 & Option 2, the payback period would be shortened to 8 years and 6 years respectively if only some of the chillers were replaced. However, with Option 2 (only replacing 2 chillers), there will only be 10% less energy saved annually in comparison with the original case. For Option 3, i.e. replacing with only 2 chillers of higher cooling capacity, it can achieve a higher energy saving with a shorter payback period. In conclusion, it is crucial to consider the building's actual operation profile as well as efficiency of the HVAC system in different scenario analysis to determine an ESO implementation plan.

	Original	Option 1	Option 2	Option 3
Chiller	4 x 400 TR Air-cooled (VSD)	3 x 400 TR Air-cooled (VSD)	2 x 400 TR Air-cooled (VSD)	2 x 450 TR Air-cooled (VSD)
Estimated Payback	9-10 years	8 years	6 years	5.5-6 years
Annual Saving (kWh)	1,365,000	1,365,000	1,210,000	1,490,000

Table A.4 Chillers replacement options with payback calculation

Example 5 - Air-conditioning (Central Chiller Plant)

Energy Saving Opportunity:
To upgrade chiller plant control system in order to improve energy efficiency operation

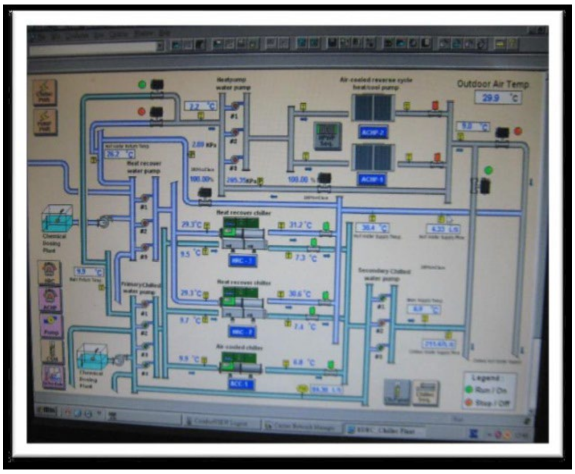
Background Information:

In a building, the central chiller plant is comprising of a single 1,000 kW air-cooled screw type chiller and two 1,000 kW heat recovery screw type chillers for day-mode or high-demand operation time. The chiller plant for day-mode operation is a secondary loop design with operating primary and secondary chilled water pumps that deliver the chilled water in the system (i.e. four 9.0kW primary pumps and three 34.0kW secondary chilled water pumps).

In night mode operation, 2 sets of air-cooled packaged screw heat pumps (300 kW) are operated with three 9.0 kW primary chilled water pumps in a differential bypass design.

Facility / Equipment:

Central chiller plant



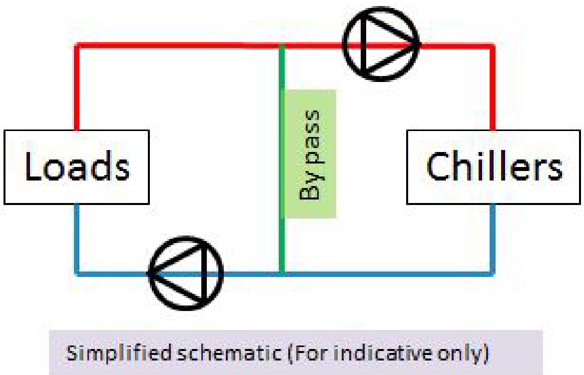


Fig. A.5 Simple block diagram of a plant system

Site Measurement, Observation and Findings:

Flow meters could not provide accurate and reliable readings and the control logic of the existing chiller plant could not be revealed or identified in the documents. Also, there is no saved record on the logging of operating data for analysis of past performance on the chiller plant.

Inconsistencies are found between the on-site measurement of the chilled water flow and the readings from the control and monitoring system of the existing chiller plant. As such, the plant is not monitoring the actual demand and providing appropriate control functions based on the realistic situations.

Recommendation:

It is recommended to repair/replace the water flow sensors together with the automatic control system of the chiller plant so as to identify the actual load profile and develop a proper control sequencing program to meet the cooling demand with adjusted chiller performance.

Energy Saving Estimation:

- Chilled water temperature reset (1.5°C) for day mode operation (December to April)
- Reduction of operation for extra secondary chilled water pump (3 hrs saving per day on weekday from June to November)
- Adjusted operation of night mode chiller for equipment cooling (December to April)
- Prevent extra pump operation of night mode chiller (May to November)

Annual electricity consumption saving = 10,000 kWh (a) + 7,300 kWh (b) + 68,000 kWh (c) + 8,000 kWh (d) = <u>93,300kWh</u>

Remarks:

(a) Chilled water temperature reset for day mode operation
(b) Reduction of operation for extra secondary chilled water pumps
(c) Refine the operation of night mode chiller for equipment cooling
(d) Reduction of extra night mode chilled water pumps

Example 6 - Air-conditioning (Heat Rejection System)

Energy Saving Opportunity:
Optimisation of Cooling Tower to reduce the condensing water entering temperature of chillers

Background Information:

The building is served by 4 sets of centrifugal chillers (2 duty & 2 standby) with associated fresh water cooling towers and condensing water pumps connected in a one-to-one basis. The cooling towers, condensing water pumps and chillers are connected in series to common headers. Variable speed drives are installed for speed control of cooling tower fans.

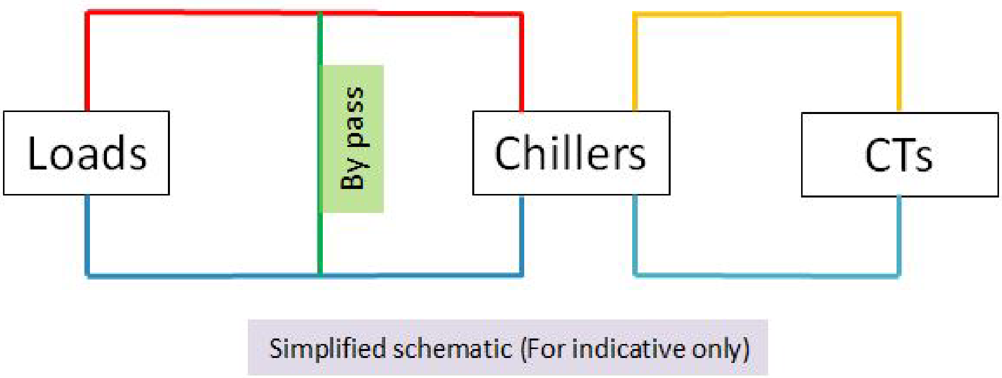


Fig. A.6(a) Block diagram for a plant system

Facility / Equipment:

Cooling towers and condensing water pumps

Site Measurement, Observation and Findings:

The approach temperature of cooling towers ranges from 6°C to 12°C. While the condensing water entering temperature has not dropped to below 26°C even when the wet-bulb temperature falls to below 20°C in Fig. A.6(b) & Fig. A.6(c).

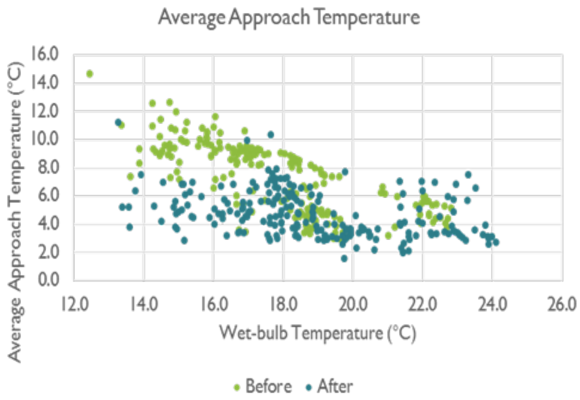
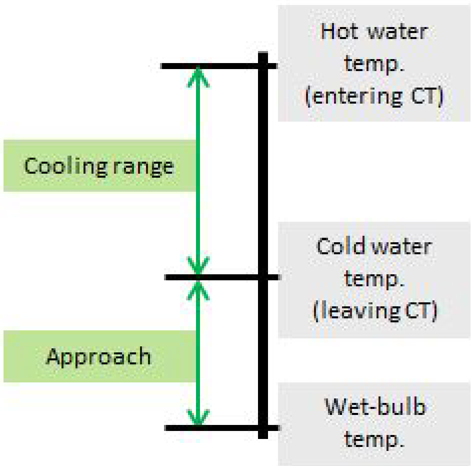


Fig. A.6(b) Average approach temperature vs wet-bulb temperature



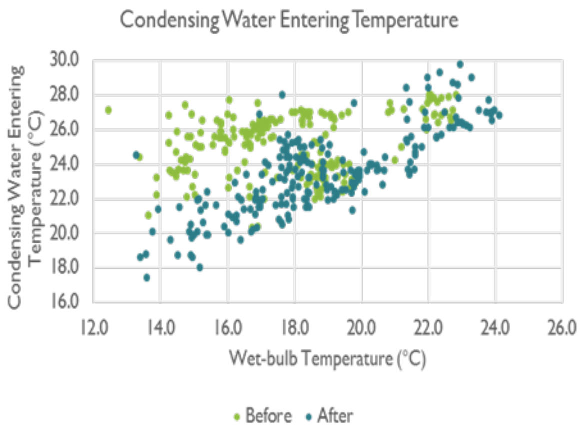


Fig. A.6(c) Condensing water entering temperature vs wet-bulb temperature

Recommendation:

The objective is to decrease the approach temperature during periods with lower wet-bulb (e.g. 14°C to 28°C) to within the proposed 2°C to 8°C. The condensing water entering temperature, which equals to the sum of wet-bulb temperature and the approach temperature of cooling tower, should be able to drop from 30°C (28+2) to 22°C (14+8).

To achieve the lowering of the approach temperature, it is recommended to control the condensing water entering temperature from 30°C to 22°C by varying the number of cooling towers (instead of on one to one base) and the speed of the cooling tower fans.

A proposed value of the approach temperature is worked out based on the performance data of the cooling towers. When the average approach temperature is higher than the recommended value, one more cooling tower will be called on and the cooling tower fan speed will start from 30 Hz and will be increased when the approach temperature still cannot meet the recommended value.

Energy Saving Estimation:

After the implementation of the above strategy, the power of the cooling towers was increased by 5kW on average as shown in Fig. A.6(d) and the chiller power consumption was reduced by 10kW as shown in Fig. A.6(e). The estimated annual energy saving of 3.2% of the chiller plant can be achieved annually.

There is still room for further adjustments in the coming months which may increase the energy savings of this strategy.

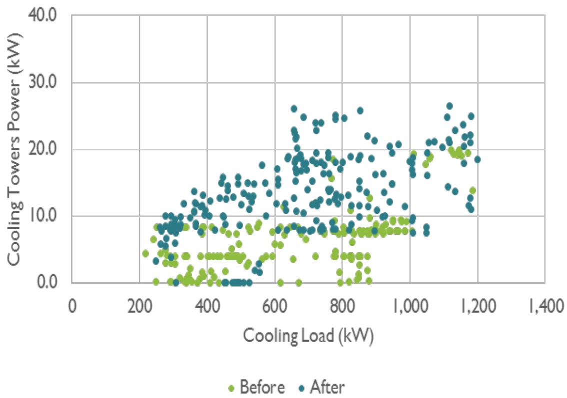


Fig. A.6(d) Cooling tower power vs cooling load

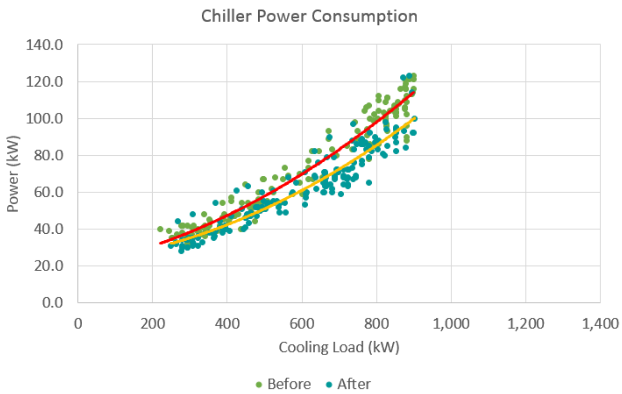


Fig. A.6(e) Chiller power vs cooling load

Example 7 - Air-conditioning (Air-side System)

Energy Saving Opportunity:
To adjust indoor room air temperature thermostat

Background Information:

In an office, VAV system is served to the perimeter zone while CAV system is for internal zone. The AHU supply air temperature is 15°C while the thermostats for the space are set at 25°C.

Facility / Equipment:

Indoor air temperature thermostat

Site Measurement, Observation and Findings:

-Trend logging of indoor air temperature

Indoor air temperatures are plotted against time in Fig. A.7(a). It is found that the indoor air temperature in average is lower than the suggested set point of 24 - 25.5°C. (Green Part indicates the office hour). It is also found that some users block the air diffusers in certain zones due to too low supply air temperature.

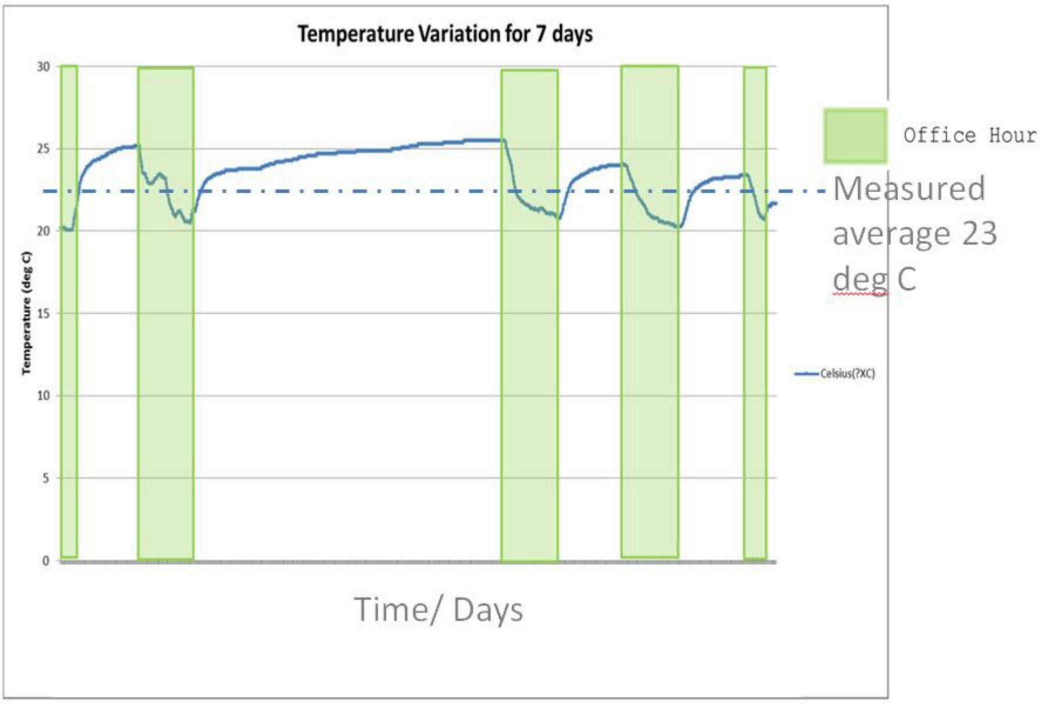


Fig. A.7(a) Temperature variation graph of a typical office for 7 days

Recommendation:

It is recommended to adjust indoor air temperature by setting the thermostats at 24°C while the AHU supply air temperature remain unchanged, the AHU motor reduces its speed so as to reduce the flow rate of the supply air. Thus, energy consumption of AHU can be reduced.

Energy Saving Estimation:

Current Situation:

AHU supply air temperature: 15°C

Measured average return air temperature: 23°C

DT_1 = 23°C – 15°C = 8°C

Proposed Situation:

AHU supply air temperature: 15°C

Target return air temperature: 24°C

DT_2 = 24°C – 15°C = 9°C

According to ASHRAE Standard 90.1-2022 Table G3.1.3.15, their part load performance characteristics should be modelled as below.

Fan Part-Load Ratio	Fraction of Full-Load Power
0.00	0.00
0.10	0.03
0.20	0.07
0.30	0.13
0.40	0.21
0.50	0.3
0.60	0.41
0.70	0.54
0.80	0.68
0.90	0.83
1.00	1.00

where Fan Part-Load Ratio means (Current Flow (L/s) / Rated Flow (L/s))

Table A.7(a) ASHRAE standard 90.1-2022 fan motor part load performance characteristics

	Before RCx	After RCx
Measured Current Flow (L/s)	4450	3600
Fan Rated Flow (L/s)	4600	4600
Fan Part-Load Ratio	0.97	0.78
Fraction of Full Load Power	~0.95	~0.65

Table A.7(b) AHU air flow comparison before and after RCx

Measured electricity consumption of all AHUs in that measurement hour (before RCx)
= **590kW** - (1)

Calculated electricity consumption of all AHUs in an hour by adjusting indoor air temperature set point hence reduces the AHU flowrate:

Hourly Electricity Consumption:
= Adjusted power before RCx (rated load power) x Fraction of Full Load Power after RCx

$$= \frac{590}{0.95} \text{ x } 0.65 = \mathbf{404\ kW} \ - \ (2)$$

Assume AHU operation from Monday to Friday, 8:00 to 18:00.
Number of hours that can adopt similar cooling loads: 662 hours

- Calculated annual electricity saving of all AHUs after RCx:
  = ((1) – (2)) x 662 hours
  = (590 kWh – 404 kWh) x 662 = 123,132 kWh– (A)

- Measured annual electricity consumption saving of all AHUs before RCx:
  = 1,348,950 kWh – (B)

Annual AHU electricity consumption saving is around (A) / (B) x 100% = 9%.

Example 8 - Air-conditioning (Air-side System)

Energy Saving Opportunity:
To adjust operation hours of Primary Air Handling Units

Background Information:

AHUs serving conditioned spaces start operating from 8:00a.m. on Tuesday to Friday and from 7:30a.m. on Monday for morning start pre-cooling.

Facility / Equipment: AHU / PAU

Air Handling Units (AHUs) and Primary Air Handling Units (PAUs)

Photo A.8 Air handling unit

Site Measurement, Observation and Findings:

By checking the control logic, it was found that the PAUs were interlocked with the AHUs and operating on the same time schedule.

Recommendation:

It is recommended to delay morning start-up of the PAUs in order to reduce the cooling energy required for treating the outdoor air during pre-cooling period. As such, the control logic of PAUs can be modified so that PAUs will start only 15 minutes before the normal operating hour of the building.

Energy Saving Estimation:

Assumptions:

- Potential saving of PAU fan power consumption 25kW;
- Potential saving from the chiller plant due to the reduction of cooling load from fresh air 120kW;
- Saving from operation of: -

  Mon delay start for 1.25 hours

  Tue to Fri delay start for 0.75 hours

  Mon to Friday early stop for 0.5 hours

Annual electricity consumption saving

= (Potential saving) x (Hours saving from weekly operation) x No. of weeks

= 49,000kWh

Example 9 - Air-conditioning (Air-side System)

Energy Saving Opportunity:
To review and adjust pressure setting for VAV systems

Background Information:

Review and adjust pressure setting for VAV systems

Facility / Equipment:

Air Handling Units (AHUs) and VAV boxes

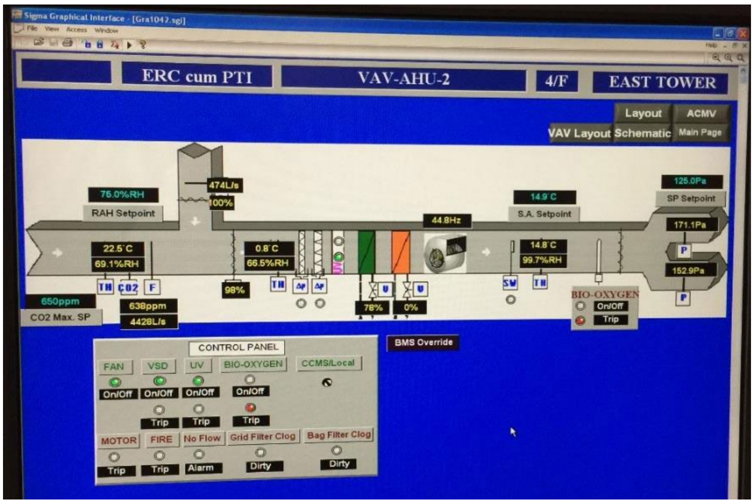


Photo A.9 AHU CCMS interface

Site Measurement, Observation and Findings:

No reading on the air flow of some VAV boxes was found during RCx inspection and the position of air damper in such VAV box was always fully opened. The pressure sensors may be clogged or failed or its settings may deviate from the design pressure/flow value for the VAV box.

Recommendation:

It is recommended to repair/replace faulty sensors and review the settings for VAV boxes so that conditioned air is supplied based on the actual demand. In addition, the amount of air supplied by AHUs of VAV system will also be reduced accordingly which resulted in a decrease in fan power and thus energy consumption of the VAV systems.

Energy Saving Estimation:

Assumptions:

- Estimated fan power saving from air side equipment : 18KW
- Saving from operation of 8 hours per day from Monday to Friday

Annual electricity consumption saving

= (Potential saving) x (Hours saving from daily operation) x No. of day x No. of weeks

= **36,000 kWh**

Example 10 - Air-conditioning (Air-side system)

Energy Saving Opportunities:
To use free cooling in cold season

Background information:

In cold seasons, enthalpy of outdoor air may be lower than that of indoor air. Given that the duct size, ductwork and damper arrangement and flow rate of the fan are capable of providing more outdoor air than the minimum requirement, it may be able to save energy for cooling by making use of outdoor air with some retrofit work.

In the course of RCx, the RCx Team should check the duct size from as-built drawing and the historical data of flow rate that the AHU fan (that provide fresh air) delivered. In case extra flow rate can be delivered from the AHU fan and the duct sizing is sufficient, free cooling should be adopted to save energy.

Facility / Equipment:

Air ductwork and AHU

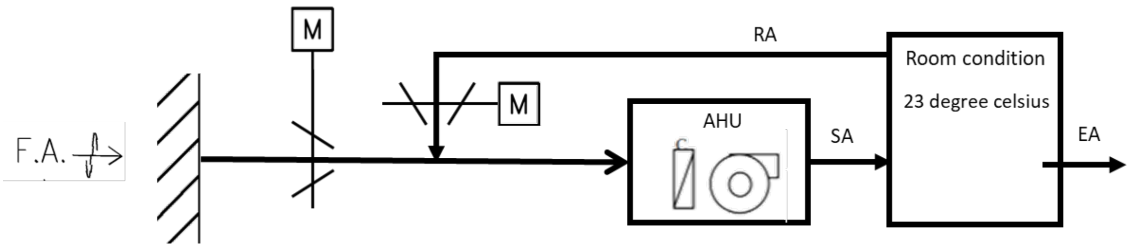


Fig. A.10 Free cooling facility

Site Measurement, Observation and Findings:

Checking the MVAC drawing to see if the duct size and place are adequate for allowing more fresh air intake and exhaust air.

Recommendation:

If the duct size and flow rate are capable of providing more outdoor air than the minimum requirement and good air balancing can be achieved for extra fresh air for free cooling, an enthalpy sensor at the fresh air intake location can be installed to control the damper position and the amount of fresh air intake.

Energy Saving Estimation:

There are in total 1,175 suitable hours for a 20-storeys building with 2 AHUs per floor, both using outdoor air for free cooling.

Assume that the cold season COP of air-cooled chiller = 3.5 &
for simplicity, assume the latent load is negligible as the humidity of cold season is low.

A= Flow rate of outdoor cooler air (m^3/s)
T_a= outdoor cooler air temperature (°C)
T_{set}= indoor setpoint temperature (°C)
ρ_a= air density (kg/m3)
C_p= Specific Heat Capacities of Air. (kJ/kg°C)

The potential energy saving from using outdoor cooler air:
= ∑(Sensible load)all hours that could conduct free cooling / COP
= ∑[A x (T_{set}-T_a) x ρ_ax C_p] all hours that could conduct free cooling / COP
= 208,580 kWh/year

Example 11 - Air-conditioning (Water–side System)

Energy Saving Opportunity:
To setback chilled water supply temperature during non-office hour operation

Background Information:

In a building, there are 2 sets of air-cooled packaged screw type chillers (1 duty & 1 standby each with 300 kW cooling capacity) for the non-office hour operation. These two chillers served the following areas: FCUs of electrical switch rooms, PABX rooms, office areas and training rooms. The chilled water supply temperature of these chillers is designed and operated at 7°C.

The operation schedule of the chillers is listed below:
Mon to Fri 00:00 to 07:00 & 21:00 to 24:00 (i.e. 50 hours)
Sat 00:00 to 07:00 & 17:00 to 24:00 (i.e. 14 hours)
Sun 00:00 to 24:00 (24 hours)

Facility / Equipment:

Non-office hour chiller (300 kW)

Photo A.11 Air cooled chiller

Site Measurement, Observation and Findings:

By checking the technical data of the chiller's performance, the amount of energy consumed by the chiller can be reduced by setting a higher chilled water supply temperature during non-office hours.

Recommendation:

It is recommended that the building operator raise the supply chilled water temperature during non-office operation. As a result, the chilled water supply temperature delivered by the chiller would be about 9°C which is 2°C higher than the original operating condition.

Energy Saving Estimation:

- One chiller unit operating for the period;
- Chilled water temperature setback by 2°C;
- Operation of non-office chiller
    - Mon to Fri 00:00 to 07:00 & 21:00 to 24:00
    - Sat 00:00 to 07:00 & 17:00 to 24:00
    - Sun 00:00 to 24:00
- Estimated saving is about 6% for the average chiller power consumption

Annual electricity consumption saving

= (Potential saving) x (Hours saving from weekly operation) x No. of weeks

~ **8,000kWh**

Example 12 - Air-conditioning (Water-Side System)

Energy Saving Opportunity:
To adjust the chilled water flowrate during non-office hours

Background Information:

Improve operation of water-side equipment by checking the temperature difference between supply and return chilled water temperature.

Facility / Equipment:

Equipment Involved: Chilled Water Pump (rated pump power 9 kW)

Photo A.12 Chilled water pump

Site Measurement, Observation and Findings:

A small temperature difference (2.7°C) was observed from the measurement result of supply and return chilled water temperature at chilled water system at night mode. The chilled water flowrate was measured at 20.7 l/s.

Based on a normal temperature difference of 5°C between supply and return chilled water temperature, the required chilled water flowrate is calculated at 11.5 l/s and the actual flowrate is nearly double that of the required chilled water flowrate.

Recommendation:

It is recommended to adjust the water flow delivered by the chilled water pump for non-office hours/period in order to reduce the chilled water flowrate and improve the performance of the water side equipment.

Energy Saving Estimation:

Assumptions:

- Pump Power reduced from 13.5kW to 8.0kW
- Savings from operation of:
  - Mon to Fri 00:00 to 07:00 & 21:00 to 24:00
  - Sat 00:00 to 07:00 & 17:00 to 24:00
  - Sun 00:00 to 24:00 (24hours)

Annual electricity consumption savings

= (Potential savings) x (Hours savings from weekly operation) x No. of weeks

= **25,000kWh**

Example 13 – Air-conditioning (Water-side system)

Energy Saving Opportunities:
To replace the insulation of chilled water pipework

Background information:

Pipe insulation for the chilled water system is important for minimizing heat loss. Proper selection of insulation material and installation are essential at the design and construction stage. However, the performance of the insulation gradually reduce throughout the life cycle by means of unintentional damage. Such defect can be improved by some retrofit work.

During RCx, the RCx Team should check the historic records and data of the temperature of chilled water along riser. In case of abnormal rising chilled water temperature along the riser, further investigation is recommended.

Facility / Equipment:

Chilled water pipework insulation

Site Measurement, Observation and Findings:

In Fig. A13, it is observed that chilled water temperature rises between the main chilled water supply at header and chilled water supply entering AHU along the main riser at different floor levels of the building.

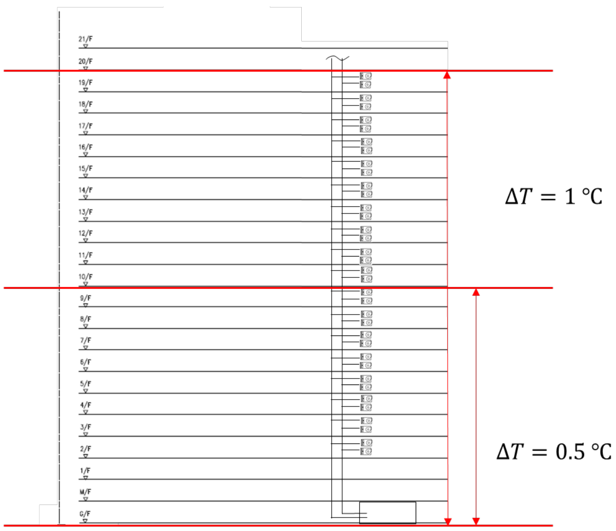


Fig. A13 Temperature rise

Checking the accuracy of the sensors is recommended to investigate the cause of increasing chilled water temperature along riser. After ruling out the possibility of sensing error, site investigation should be conducted to check the insulation of chilled water pipework.

Recommendations:

It is recommended to fix the insulation along the main riser during cold season, shut down the chiller plant and dismantle the degraded insulation on main riser. It is also recommended to install the insulation once there is no condensate on the surface on chilled water pipe.

Energy Saving Estimation:

<u>Current situation:</u>

Chilled water supply riser temperature = 7°C

10/F Tee-off chilled water temperature = 7.5°C

20/F Tee-off chilled water temperature = 8°C

<u>Proposed situation (ideal case):</u>

Chilled water supply riser temperature = 7°C

10/F Tee-off chilled water temperature = 7°C

20/F Tee-off chilled water temperature = 7°C

Assumptions:

- Constant speed pump with flow rate at each Tee-off = 5L/s
- Annual average COP of the air-cooled chiller = 3.9
- Annual operation hours =3120 hours
- The temperature rise is linear alone different floors due to the same degree of degradation of the insulation

Annual electricity consumption saving

$$= \frac{(\sum_{i=1}^{20} mc\Delta T)\times Annual\ Operation\ hours}{COP}$$

$$= \frac{(5\times4.19\times0.05+\cdots+\ 5\times4.19\times1)\times3120 hours}{3.9}$$

=42,000 kWh/year

Example 14 - Air-conditioning (Water-side system)

Energy Saving Opportunity:
To replace with VSD chilled water pumps

Background information:

A chilled water system with constant primary flow and variable secondary flow is typically used in existing building chiller plant, which means primary flow rate is constant. As a result, flow through active evaporators of chillers is constant while secondary flows vary in proportion to the cooling load to reduce part load energy consumption of pumps. Some works can be done for more energy saving under such case.

During RCx, the RCx Team should consider changing the primary constant speed drive (CSD) chilled water pump with a variable speed drive (VSD) pump and removing the secondary chilled water pump as the pump head of primary chilled water pump is sufficient to overcome the total system differential pressure requirement, to form the variable primary flow of chilled water piping configuration. With the VSD chilled water pumps the chilled water flow varies throughout the chilled-water circuit according to the cooling load, which will increase the chilled water pump energy significantly. In view of the two systems, they have their own merits and drawbacks. Primary VSD pump configuration has lower first cost, less space required and lower pump energy consumption while the control of such system is more complex than that of primary constant and secondary variable in terms of bypass and staging chillers.

Facility / Equipment:

VSD chilled water pump

Site Measurement, Observation and Findings:

It is observed that the primary chilled water flow keeps constant once the chiller system is in operation.

Recommendation:

It is recommended to replace the primary CSD chiller water pumps with VSD ones and remove the secondary chiller water pump.

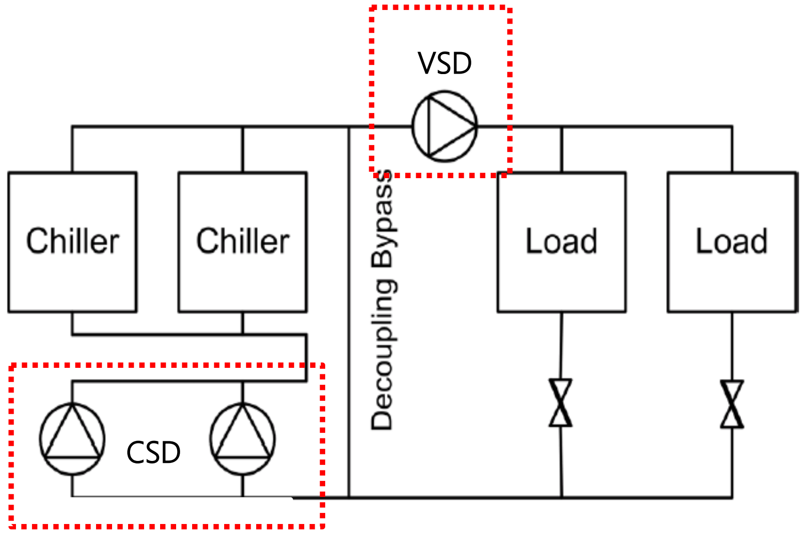


Fig. A14(a) Primary/secondary chilled water system

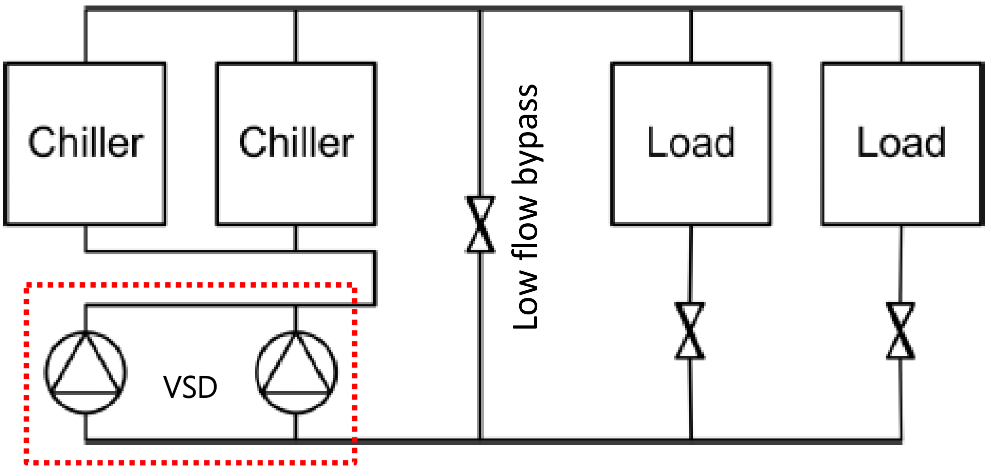


Fig. A14(b) Variable primary flow system

Energy Saving Estimation:

According to William P. BAHNFLETH 2003, variable primary chilled water system can save 24-42% in chilled water pumping energy annually, compared with primary/secondary chilled water system for an office building in Houston, USA, where the climate condition is quite similar to Hong Kong.

Reference

William P. Bahnfleth, Eric B. Peyer, (2003), 'Energy Use Characteristics of Variable Primary Flow Chilled Water Pumping Systems', International Congress Of Refrigeration 2003, Washington, D.C.

Example 15 – Electrical System

Energy Saving Opportunity:
To review power quality of electrical distribution network

Background Information:

Electrical installation includes electrical distribution network in the building from power source to final sub-circuit connected to electrical apparatus. Excessive distribution loss and poor power quality reduce efficiency of the electrical distribution network, they also cause unwanted energy losses, as well as overheating of conductors and apparatus that may impose additional cooling load for air-conditioning systems. RCx would focus on power quality of electrical distribution network to identify potential ESOs.

In the course of RCx, RCx Team should identify all available metering devices in the electrical distribution network and collect historic data. In case metering provision is not available, temporary or additional metering devices may be installed to facilitate evaluation of saving achieved by ESOs after Implementation. In the long term, it is a good practice to install permanent metering provisions and power monitoring system to keep track of the energy performance of the building.

Facility / Equipment:

Electrical distribution networks in the building is shown in Fig. A.15(a).

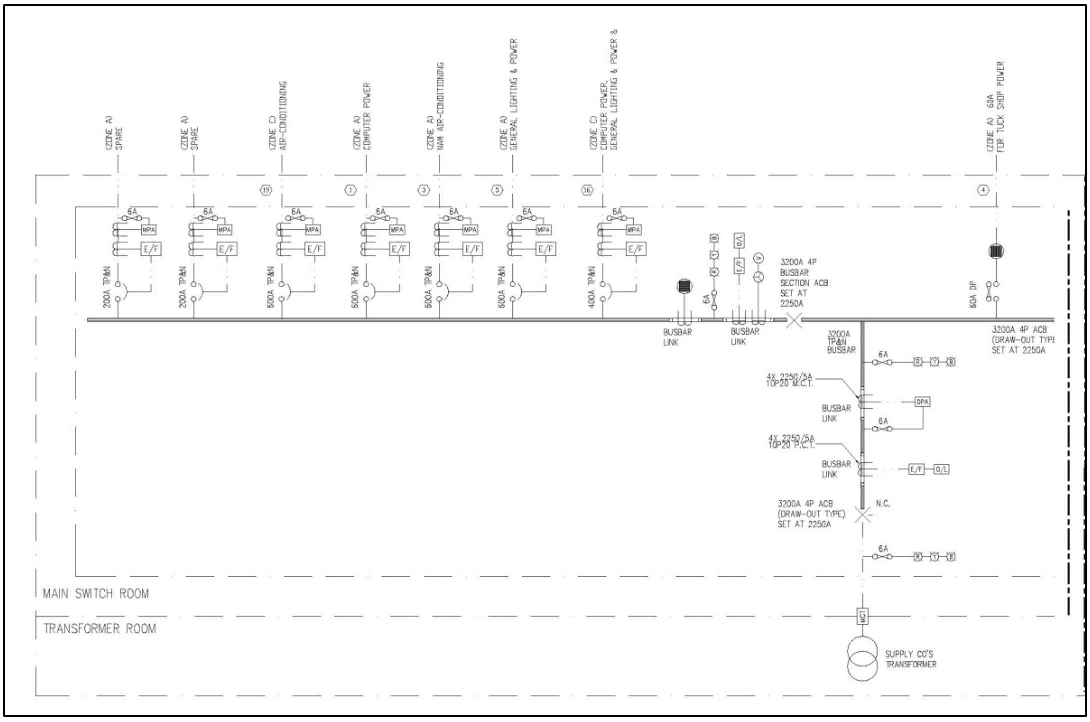


Fig. A.15(a) Electrical distribution network schematic

Site Measurement, Observation and Findings:

1. Total Power Factor (TPF)

A reactive load, such as an induction motor induces reactive power that adds to the current in the circuit, which does not do productive work. The term “power factor” - a ratio ranging from 0 to 1 - is used to describe the extent of the productive work of a load. This value is given by the ratio of real power doing productive work to the apparent power that performs both productive and non-productive work, a near- 1 power factor implies an energy efficient load.

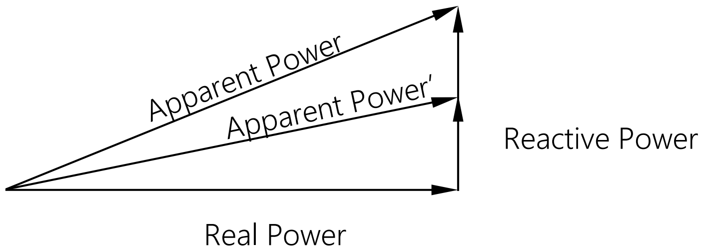


Fig. A.15(b) Power tringle for Apparent Power, Real Power and Reactive Power

(Note: Apparent Power’ refers to the apparent power after power factor correction)

When the TPF is lower than the minimum requirements of electricity suppliers, a relevant correction device should be provided. Beyond the minimum requirements, the TPF can be further enhanced with appropriate sizing of the correction device. The achievable energy savings by improving TPF of a circuit will be equal to the reduction of magnitude of the apparent power.

2. Total Harmonic Distortion (THD)

Harmonic currents, generated by non-linear loads (such as fluorescent lamp control gear, frequency invertor, personal computer etc.) installed in the building, increase energy losses in the electrical distribution network. Harmonic currents also heat up conductors and apparatus which increases cooling demand from the air-conditioning system, as well as causes other harmful effects to the electrical distribution network.

Harmonic currents can impact significantly on electrical distribution networks and waste energy. Harmonic correction devices should be provided when the THD is over the specified limits. The lower the THD, the lesser the power or energy wasted.

3. Measuring and Improving TPF and THD

If the measured TPF and THD fall into an unacceptable range, correction devices should be provided and sized according to measurement results.

Photo A.15 A metering device for a 400A circuit

In addition, identifying the size and location of reactive loads and non-linear loads should be an important part during Investigation for the electrical installation. It is much more effective to correct the power factor and harmonic currents close to the load that degrade power quality. Therefore, the RCx Team should not limit the Investigation to main, sub-main and feeder circuits. Measurement of TPF and THD to downstream and final circuits should be conducted as far as practicable. When a particular load or a group of loads (such a numbers frequency invertors) that led to a high level of power quality degradation is found, provision of correction device close to the load is preferable. On the other hand, group correction for TPF and THD is also acceptable for cost effectiveness considerations.

Improving the power quality of electrical installations reduces energy wastage in the electrical circuit and minimises associated negative effects, such as heating up of conductors and tripping of protective devices. In term of energy cost, both energy charge (kWh) and demand charge (kVA) of the building can be reduced with better power quality.

Energy Saving Estimation:

Enhancing power factor of electrical circuit reduces unwanted reactive current. The reactive current itself does not result in energy consumption. However, the reactive current increases copper losses of the electrical distribution network. The energy savings achieved by improving power factor result mainly from reduction in copper losses. Such energy savings are generally low in magnitude.

On the other hand, for buildings under the electricity tariff scheme charging by both energy charge (kWh) and demand charge (kVA), improving the TPF of the building can directly reduce demand by reducing the peak electricity demand value. This provides a significant reduction in electricity cost of the building.

Energy saving from reducing copper loss:

Copper loss = I^2R
Power Factor (PF) of a building/a circuit increases from 0.85 to 0.95 by installed and operated with appropriated power factor correction devices.

The loss fraction reduction through improving power factor is expressed by:

$[1-(PF/PF')^2] \times 100\%$ (note 1)
when:
PF = original power factor of a circuit without correction device
PF'= power factor of a electricity circuit operated with appropriated power factor correction device

As the PF improves from 0.85 to 0.95, the loss fraction reduction is:

$[1-(0.85/0.95)^2] \times 100\% = 20\%$

Assume the original copper loss of the circuit without correction device is about 2%, and the reduced copper loss is 0.4% (= original copper loss (2%) x 20%). Thus, savings of 0.4% electricity consumption can be achieved when correction devices are operated with appropriated power factor correction devices at load side.

As the building has an annual electricity bill of HKD 4,000,000, the energy charge and demand charge are about 85% and 15% of the electricity bill respectively.

When correction devices are operated with appropriate power factor correction devices, annual electricity cost savings due to reduction of copper loss are calculated below:
= $ 4,000,000 x 85% x 0.4%
= $ 13,600

Demand charge saving:
Reduction in peak demand can be calculated by:

$(1- TPF / TPF') \times 100\%$ (note2)
when:
TPF = original TPF of the building
TPF'= TPF of the building after improving of TPF

Reduction in peak demand (kVA)

= (1- 0.85/0.95) x 100% = 10.5%

As demand charge accounted for 15% of the electricity bill, annual electricity cost savings

= HKD 4,000,000 x 15% x 10.5%

= HKD 63,000

The total savings

Improving TPF of the building can directly reduce annual electricity cost: -

= $ 13,600 + 63,000

= $ 76,600

Metering and Monitoring of Electrical Distribution Network:

Electricity bills only provide overall electricity consumption of the building monthly. Understanding the power quality and electricity consumption of each installations/component is important to analyse the energy performance of a building.

Metering facilities and monitoring provisions will provide electricity consumption data and power quality data for analysis and evaluation of savings after implementation of ESOs and will assist the building owner in managing the energy performance of the building.

Example 16 – Lighting System

Energy Saving Opportunity:
To adjust lighting level

Background Information:

Check and review lighting levels of different functional area.

Facility/Equipment:

Functional areas with lighting installations

Site Measurement, Observation and Findings:

- Use lux meter to check the lighting level of the area.
- Check the measurement result against current facility requirement and international standard.
- Estimate the lighting layout and/or identify potential of de-lamping.

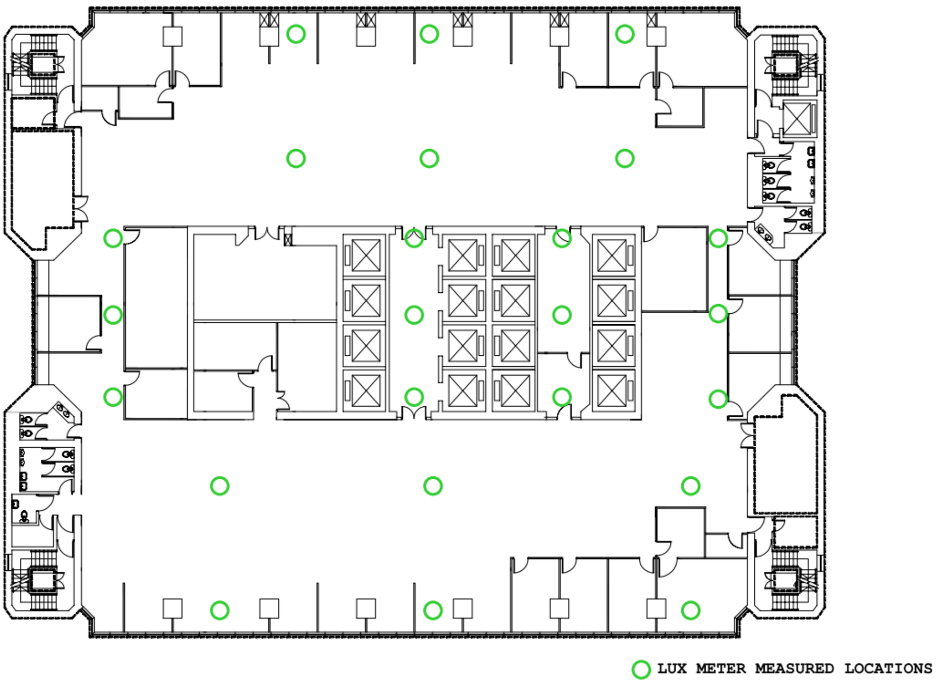


Fig. A.16 Floor Plan of a typical office

Energy Saving Estimation:

Assume there are 300 T5 fluorescent luminaires in the office and 25 of them can be taken down.

N = total number of existing lamps

N' = total number of proposed lamps to be taken down

P = power demand of each lamp (W)

D = daily operation hour (hr/day)

A = annual operation day (day)

Assume T5 1500 fluorescent luminaires = 35 W

Annual Energy Saving (kWh) = (N – N') * P * D * A

Annual Energy Saving (kWh) = (275) *35 * 8 *(240)
= 18,480 Kwh

Example 17 – Others

Energy Saving Opportunity:
To adjust equipment operational hour

Background Information:

Adjust operational hours of plants and equipment with timer control only, which are not connected to a building management system.

Facility / Equipment:

Air handling units, ventilation fans and/or lighting installations controlled by timer.

Site Measurement, Observation and Findings:

- Use power meter / amp meter with logger to measure the daily operation of facility or equipment continuous for a period.
- It is recommended that the measurement period should cover a full working day, weekly holidays and public holidays.
- Check the measurement result against the working hours of the building / functional areas to fine tune the operational hours of facilities or equipment.

Energy Saving Estimation:

$$\text{Saving} = \text{Equipment power rating} \times \text{saved operation hour}$$

Example 18 – Others

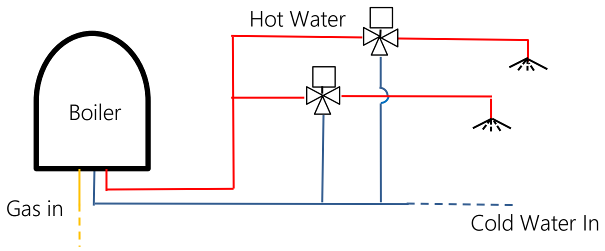
Energy Saving Opportunity:
To adjust combustion efficiency

Background Information:

Adjusting Fuel gas / air ratio in order to improve combustion efficiency of gas boiler.

Facility / Equipment: Gas Boiler:

Gas Boiler for hot water supply to shower room and washrooms, heated swimming pool, kitchen and pantry etc.



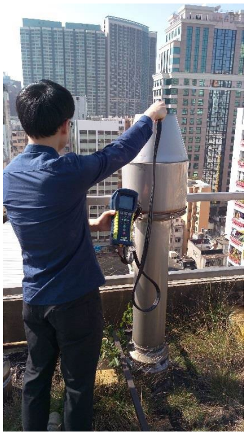


Fig. A.18(a) Hot water loop schematic

Site Measurement, Observation and Findings:

- Measure Carbon Monoxide (CO) content of flue gas at boiler exhaust and trace amount of CO;
- Incomplete combustion may occur during the boiler operation if the amount of CO content in flue gas is high;
- Adjust gas to air ratio to achieve better combustion efficiency such that the flue gas features a maximal amount of CO_2 and a minimal amount of CO.
- A theoretical combustion ratio can be referred to Fig. A.18(b).

Energy Saving Estimation:

% of CO $_{\text{(Produced from combustion)}}$ = (Measured CO $_{\text{in ppm}}$ / CO density $_{\text{in kg/m3}}$) /1000 - % of CO $_{\text{(from Gas)}}$

% excess fuel gas $_{\text{in combustion}}$ = % of CO $_{\text{(Produced from combustion)}}$

Annual Fuel gas saving = (Annual consumption of fuel gas) x (% excess fuel gas $_{\text{in combustion}}$)

Case Study:

The Boiler's annual gas consumption is about 18,195 units and spendings are about $221,311 per annum.

According to site measurements, the measured concentration of CO is 78 ppm.

% of CO $_{\text{(Produced from combustion)}}$ = (78 / 1.4[*1]) /1000 – 2.1%[*2]
= 5.3% – 2.1%
= 3.2%

% excess fuel gas $_{\text{in combustion}}$ = 3.2%

Annual Fuel gas saving = (Annual gas consumption) x (% excess fuel gas $_{\text{in combustion}}$)

Annual Fuel gas saving = 18,195 x 3.2%
= 582 unit
= 27,936MJ[*3]
~ $ 7,000

Remark:-

[*1] *CO density $_{in\ kg/m3}$ = 1.14kg/m^3*

[*2] *In the study, the concentration of CO in fuel gas is ranged from 1% to 3.1%. The average value of CO concentration is 2.1%.*

[*3] *Each unit of fuel gas represents a heat value of 48MJ*

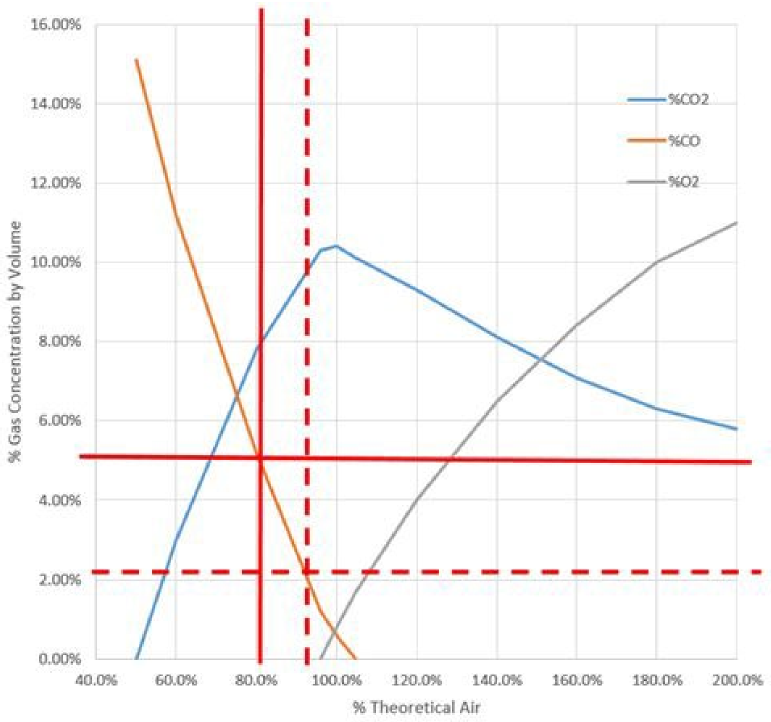


Fig. A.18(b) Theoretical Combustion

Example 19 – Others (By Computer Simulation)

Energy Saving Opportunity:
To adopt the use of daylighting (by computer simulation)

Background Information:

Electrical lighting can be a major source of energy consumption for an office building. For an example building, lighting energy accounts for almost 20% of overall electrical consumption. At present, no daylighting sensor is installed in the building except for the main entrance lobby. Consequently, lighting fixtures keep on operating even when a space is well illuminated due to transmission of visible light during daytime.

Facility / Equipment:

Lighting in Carpark Area

Photo A.19 Carpark lighting

Site Measurement, Observation and Findings:

(1) Collect trend logged data

There is no sub-meter to monitor and log the lighting power consumption for each floor. The lighting is controlled according to pre-set operating schedules in Table A.19(a).

Location	Operation schedule
Office Area, Canteen, Mess Canteen, Lift Lobby, Toilet, Carpark	24 hours
Landscape Area	18:15 - 06:15 (Mon - Sun)
Corridor	06:00 - 24:00 (Mon - Fri)
Fitness Room	08:00 - 24:00 (Mon - Sun)

Table A.19(a) Example of Lighting operating schedule

(2) Analyse the collected trend logged data by simulation

The operating schedules were entered in the 3D simulation model together with the light fitting numbers and lamp type to simulate lighting operation in real life. The simulated lighting power consumption per month is shown in Fig. A.19(a).

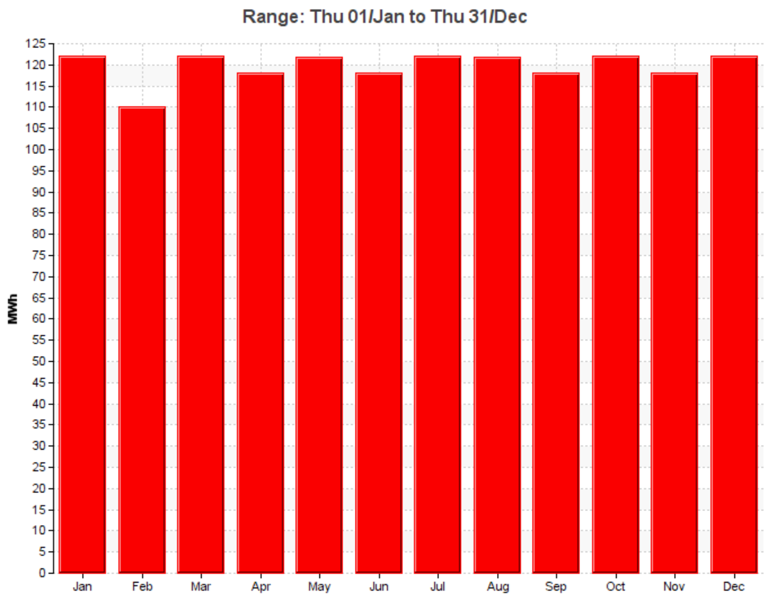


Fig. A.19(a) Example of simulated lighting monthly power consumption

(3) Identify Energy Saving Opportunities (ESOs)

It is proposed to install daylighting sensors in all of the perimeter spaces and the parking area that receive direct solar radiation during the daytime. These daylight sensors will perceive the illuminance level inside a space and turn off the electrical lighting when the lux level inside the space exceeds the permissible limit. In this way, both lighting energy as well as energy consumed for space cooling of the space can be saved. The permissible lux level recommended for the applicable spaces is given in Table A.19(b).

Space Type	Typical illuminance level (lux)
Offices	300-500*
Parking	50**
Corridor	100***
Dinning	200***
Changing room	200***

* CIBSE (Chartered Institute of Building Services Engineers) Lighting Guide 07: Offices (2005)

** Labor Department HKSAR Guidelines for Good Occupational Hygiene Practice in a Workplace (2011).

*** British Standard BSEN 12464-1:2011 Light and lighting – Lighting of work places

Table A.19(b) Example of illuminance level for lighting control switch

(4) Principal

Daylight sensors are connected to the electrical lighting switches. When sufficient illuminance level is detected at the sensors location, an electrical signal will be sent to the lighting switches to turn off the lighting automatically.

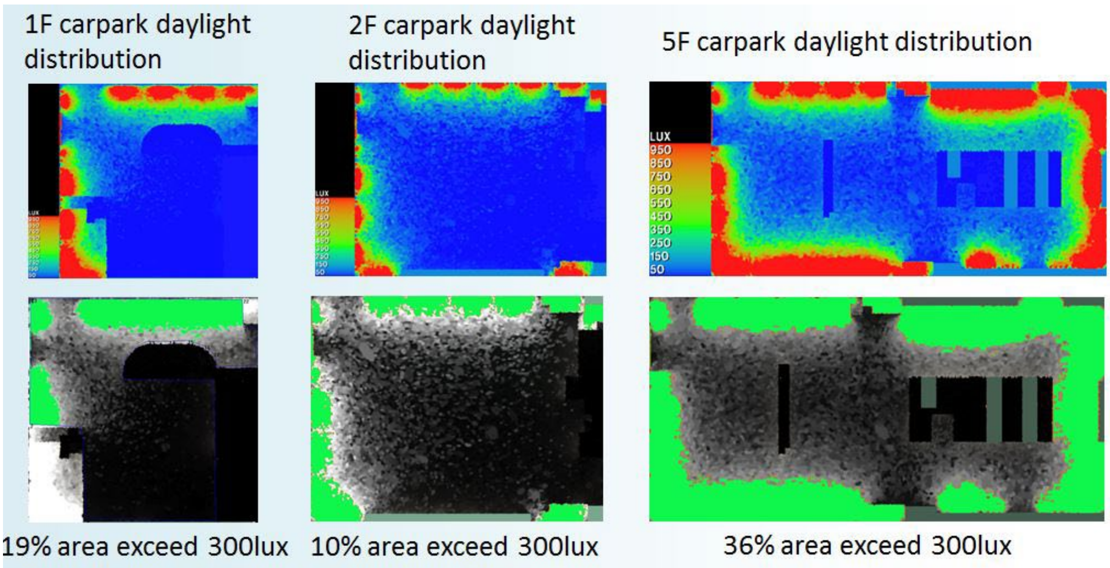


Fig. A.19(c) Daylight simulation result for carpark

Energy Saving Estimation:

The estimated energy savings (kWh) is around 1-3% on lighting power consumption.

Example 20 – Others (By Computer Simulation)

Energy Saving Opportunity:
To improve the chiller plant performance by resetting the condensate water temperature (by computer simulation)

Background Information:

There are two heat recovery VSD centrifugal chillers and two VSD centrifugal chillers all with ~1,900kW cooling capacity installed. There is also one small screw chiller (~800kW) and one small air-cooled chiller (~500kW), mainly to serve low load condition.

The operation control of the chillers is based on the building load demand (ranged from 300kW to 3,500kW) and the operating hours of the chillers. According to data and description of on-site maintenance staffs, one to two large chillers will be sufficient to fulfil the building load demand throughout the year. With the small screw chiller used to serve the building during night time.

The chillers are linked with one set of chilled water pump and condenser water pump. There are four cooling towers in the condenser water loop. According to data and description of on-site maintenance staffs, a maximum of two cooling towers will be sufficient to provide heat rejection throughout the whole year.

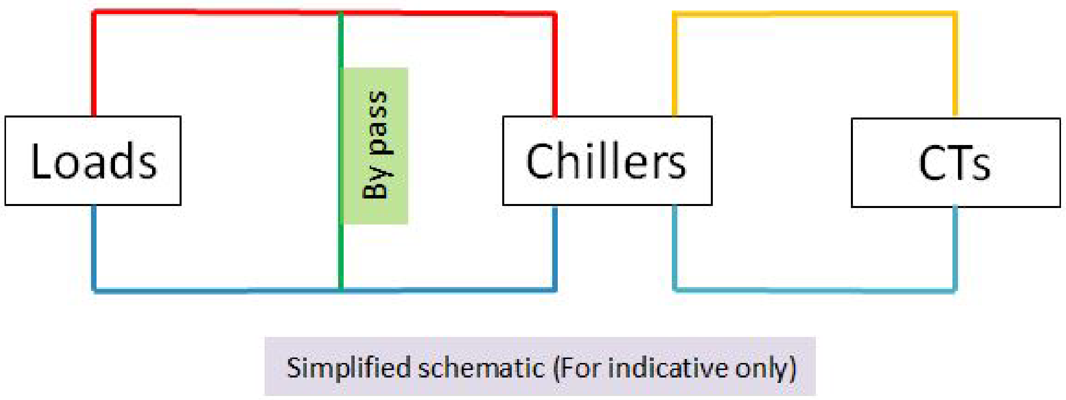


Fig. A.20(a) Block diagram of a plant system

Facility / Equipment:

Chillers, Chiller pumps, Cooling Towers, Condensate Water Pumps

Photo A.20 Chiller plant equipments

Site Measurement, Observation and Findings:

The CCMS does not have the capability for trend logging at the moment, five days of data has been extracted manually on-site for some quick investigation. The data that has been extracted includes the following:

- Chilled water flow rate
- Chilled water temperature differential
- Condenser water flow rate
- Condenser water temperature differential
- Cooling towers, condenser water and chilled water pumps power consumption
- Chiller power input

(1) Analyse the collected trend logged data

Due to limited real-life data availability, a 3D simulation model is used to reflect the operation of the building as closely as possible. For chiller plant adjustment, the following analysis has been carried out.

- Building cooling load profile analysis.
- Chiller part load performance curve analysis.
- Variation of condenser water temperature.
- Sequencing adjustment.
- Multiple cooling towers configuration.

The example building operates 24 hours for most floors, the cooling load demand ranged from 300kW to 3,500kW. The profile is shown below.

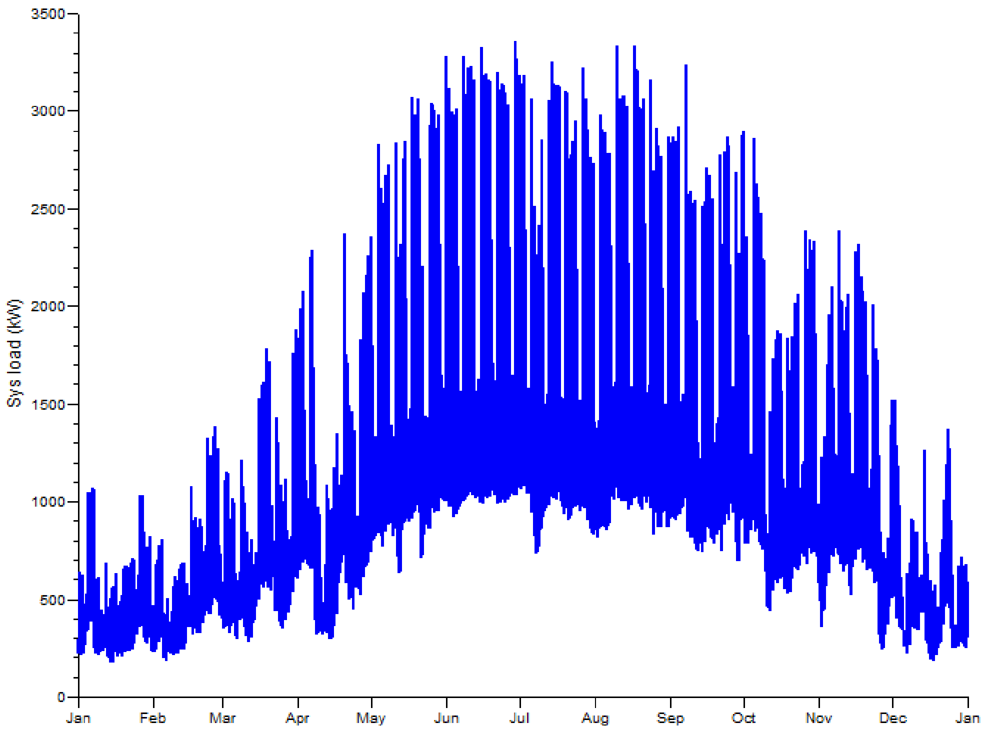


Fig. A.20(b) Example of a building cooling load profile

The monthly cooling load demand is shown in Fig. A.20.

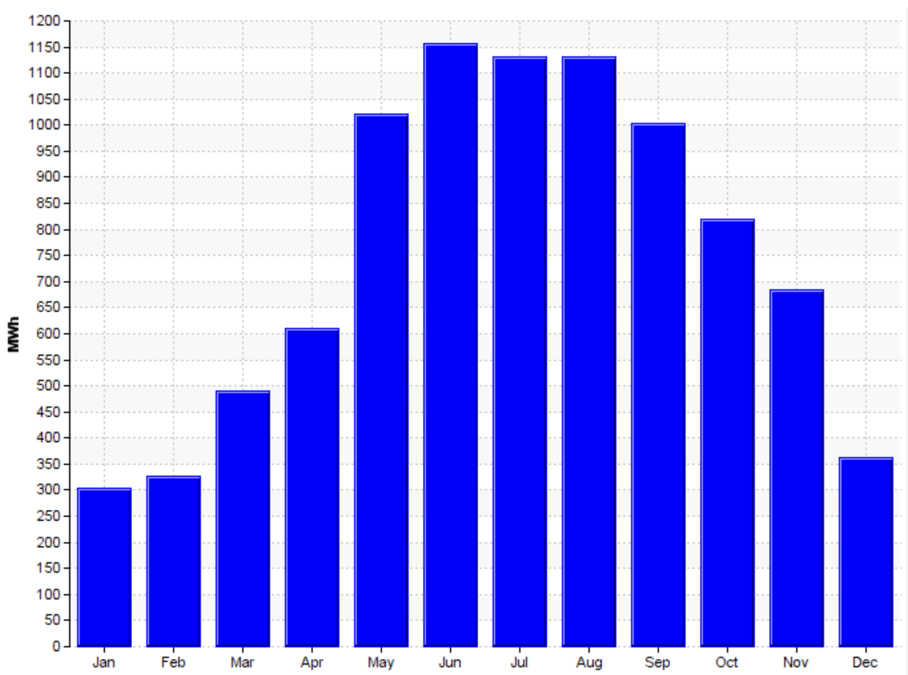


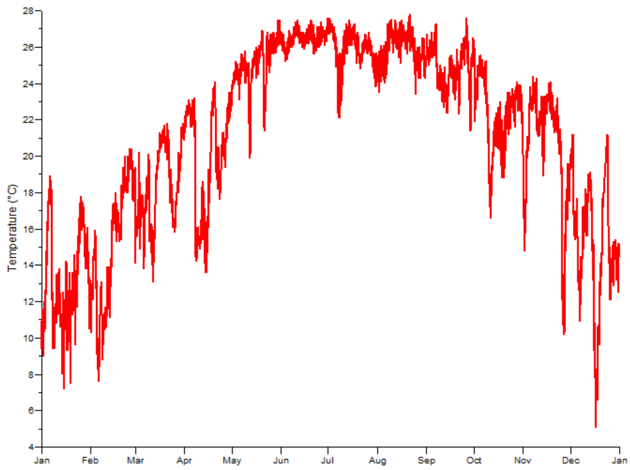
Fig. A.20(c) Example of a building monthly cooling load

(2) Identify Energy Saving Opportunities (ESOs)

<u>Condenser water temperature control</u>

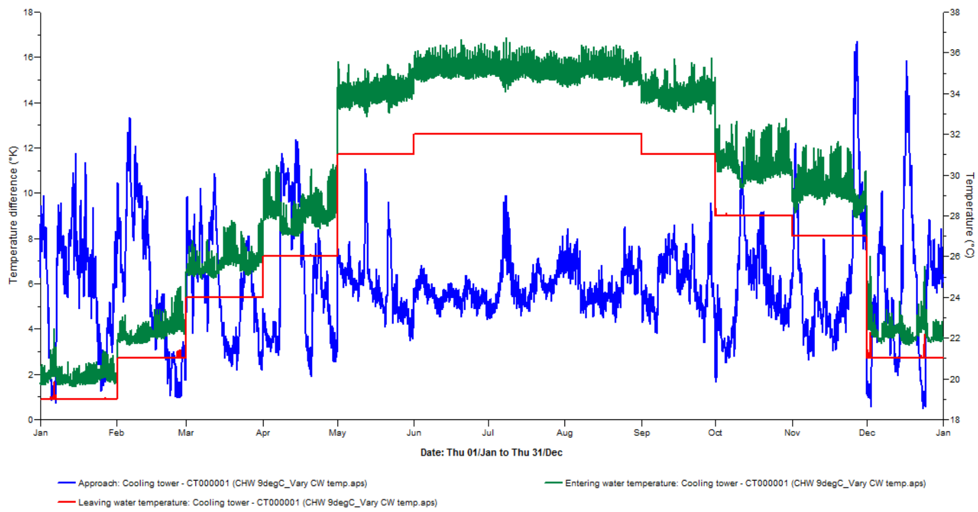
Condenser water entering temperature is currently uncontrolled and simply depends on external weather conditions. There is an opportunity for energy saving by further lowering the condenser water temperature during winter and spring period when the outdoor wet bulb temperature is low.

The target is to achieve an approach temperature of 2°C to 6°C, this will allow the chiller to operate at higher efficiency without pushing the limit of the cooling towers. The external wet bulb temperature for 2015 is shown in Fig. A.20(d).



<u>Fig. A.20(d) Example of external wet bulb temperature</u>

Fig. A.20(e) compares the approach temperature (blue line) and the target condenser water entering temperature (red line).



Approach Temperature

<u>Fig. A.20(e) Example of condenser water temperature and approach temperature</u>

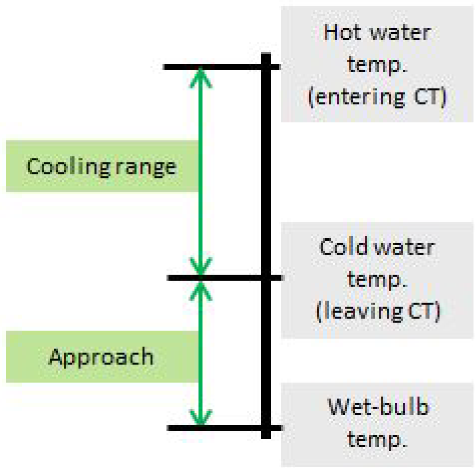


Fig. A.20(f) Approach temperature explanation

The ***Approach Temperature*** is the difference in temperature between the cooled water temperature and the entering air wet bulb temperature

Cooling tower configuration

In order to maximize the effect of the Variable Speed Drive (VSD) in the cooling towers, it is proposed to operate two cooling towers even when only one chiller is operating (N+1 arrangement); by doing so the cooling towers fans will run at low speed increasing efficiency and reducing the fan power consumption.

Principal

Depending on the external wet bulb temperature, it is recommended to consider adjusting the condenser water entering temperature accordingly to maximize the efficiency of the chiller.

Based on the characteristic of VSD fan in the cooling towers, it is recommended to consider running the cooling tower fans at lower fan speed. This can be achieved by running multiple cooling towers even during low load condition.

Chiller sequencing

The cooling load range distribution for each month is estimated as follow. The graph show how frequent each cooling load range happen during the month.

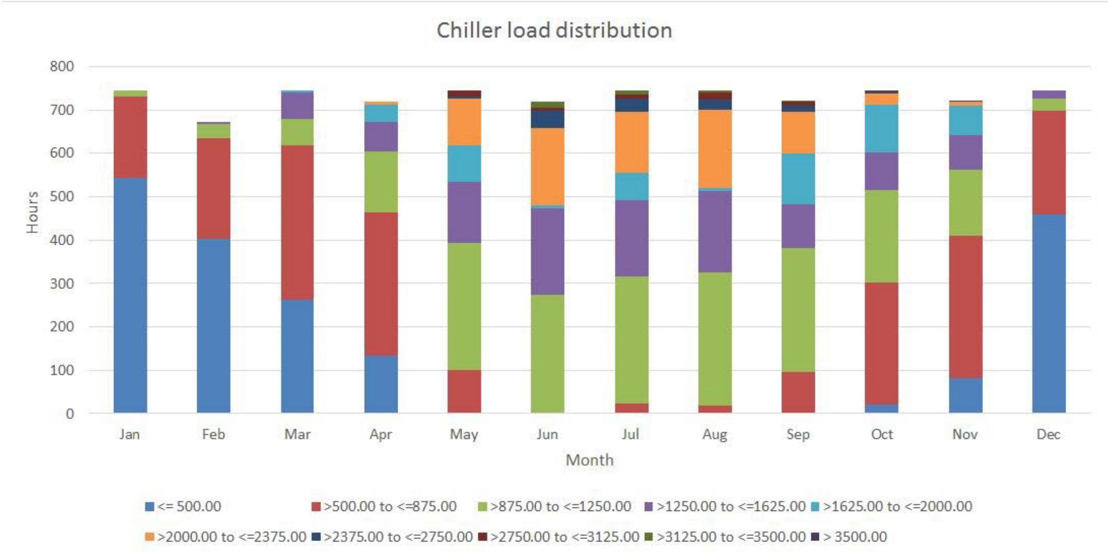


Fig. A.20(g) Monthly cooling load range (% hrs)

The graph above is used to analyse the opportunity for different chiller sequencing mode. This will need to be analysed in conjunction with the chiller part load performance graph (Fig. A.20(h)) for better understanding of how to operate the chiller at its most efficient condition.

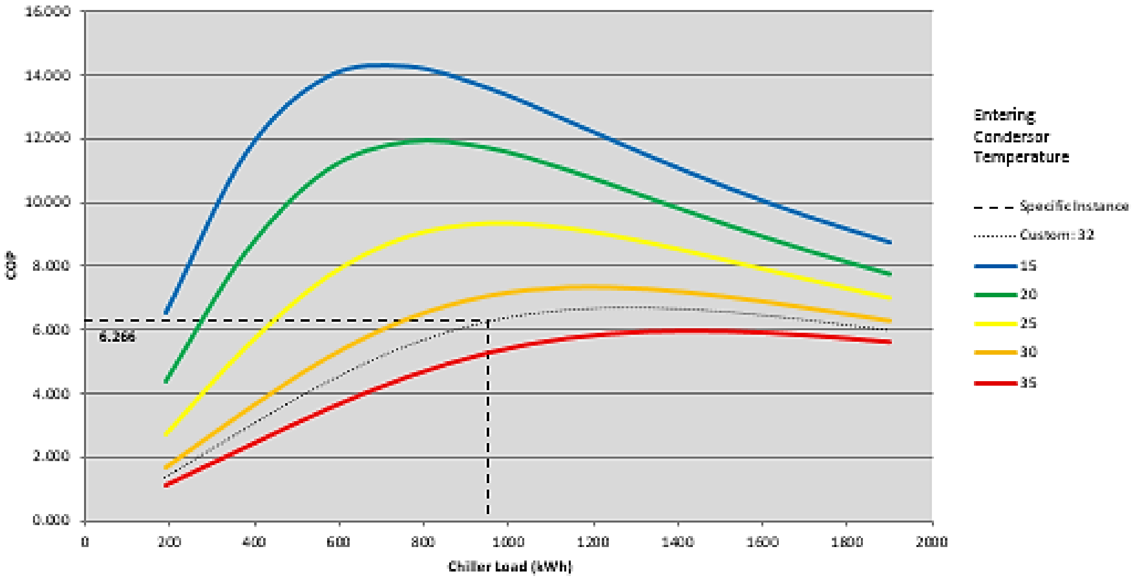


Fig. A.20(h) Generic VSD chiller performance curve

From the chiller curve above, it is noticed that the optimised chiller load range in different seasons will be as follow.

Season period	Condenser water temperature (°C)	Optimal cooling load range (kW)
Spring (March to May)	24 – 29	900 – 1200
Summer (June to August)	31	1200 – 1400
Autumn (September to November)	28 - 30	1100 – 1200
Winter (December to February)	20 - 22	750 – 900

Table A.20(a) Optimal cooling load range

It is proposed to run one large VSD chiller during low load conditions (up to 1,700kW), two large VSD chillers at medium load conditions (1,700kW – 3,000kW) and three large VSD chillers at high load conditions (3,000kW and above).

To fully utilize the benefit of VSD chiller high efficiency characteristic at low load condition. It is proposed to use the two VSD WCCs and two VSD HRCs to provide cooling to the building in the future even at low load condition. WCC1 and ACC should act as standby chillers only.

Operation Mode	Building load	No. of chiller reuiqred	Chiller to operate	No of cooling tower to operate
A	< 500kW	1	WCC1	2
B	500kW < and < 1700kW	1	HRC1/HRC2/WCC2/WCC3	2
C	1700kW < and < 3000kW	2	HRC1/HRC2/WCC2/WCC3 and HRC1/HRC2/WCC2/WCC3	3
D	> 3000kW	3	HRC1/HRC2/WCC2/WCC3 and HRC1/HRC2/WCC2/WCC3 and HRC1/HRC2/WCC2/WCC3	4

Table A.20(b) Chillers operation modes schedule

	Loading range	Suggested operation mode	Loading range	Suggested operation mode	Loading range	Suggested operation mode	Remarks
January	< 500kW	A	500kW < and < 1700kW	B	> 1700kW	B	Note 1
February	< 500kW	A	500kW < and < 1700kW	B	> 1700kW	B	Note 1
March	< 500kW	A	500kW < and < 1700kW	B	> 1700kW	B	Note 1
April	< 500kW	A	500kW < and < 1700kW	B	> 1700kW	B	Note 1
May	500kW < and < 1700kW	B	1700kW < and < 3000kW	C	> 3000kW	C	-
June	500kW < and < 1700kW	B	1700kW < and < 3000kW	C	> 3000kW	C	-
July	500kW < and < 1700kW	B	1700kW < and < 3000kW	C	> 3000kW	D	-
August	500kW < and < 1700kW	B	1700kW < and < 3000kW	C	> 3000kW	D	-
September	500kW < and < 1700kW	B	1700kW < and < 3000kW	C	> 3000kW	D	-
October	< 500kW	A	500kW < and < 1700kW	B	> 1700kW	B	Note 1
November	< 500kW	A	500kW < and < 1700kW	B	> 1700kW	B	Note 1
December	< 500kW	A	500kW < and < 1700kW	B	> 1700kW	B	Note 1

Notes
1. If loading more than 1 chiller capacity, extra chiller to be kick in

Table A.20(c) Chillers monthly operation modes schedule

For example, it is estimated that the building load in May will range between 2,000 and 2,800kW during daytime and 600-1,000kW during night time. Therefore, it is proposed to operate two VSD chillers during the day and one VSD chiller at night throughout the implementation stage.

Energy Saving Estimation:

The estimated energy savings (kWh) is around 5%-10% overall on chiller system.

Supplementary Information
Forms for Stage 1 to Stage 4

Forms for Stage 1 to Stage 4

Form 1.1 - Building Design and Operational Information Checklist

(A)	General Building Attributes			
	Type of Building			
	Building Plans		☐ Yes	☐ No
	Occupancy Schedule		☐ Yes	☐ No
	Gross Floor Area (m2)			
	OP Certified Date (DD/MM/YY)			
	Recent Major Renovation (DD/MM/YY)			
	Contact Person for Information Collection			
(B)	Building Services System Information			
	As-fitted BS Drawings (Schematic Daigrams and Services Layout Plans)			
	Air-conditioning System		☐ Yes	☐ No
	Electrical System		☐ Yes	☐ No
	Lighting System		☐ Yes	☐ No
	Plumbing System		☐ Yes	☐ No
	Lift and Escalator		☐ Yes	☐ No
	AA&I Work (Schematic Diagrams and Services Layout Plans)			
	Air-conditioning System		☐ Yes	☐ No
	Electrical System		☐ Yes	☐ No
	Lighting System		☐ Yes	☐ No
	Plumbing System		☐ Yes	☐ No
	Lift and Escalator		☐ Yes	☐ No

Note: Please amend the form to suit individual case

	Air conditioning System			
	Air-cooled Chiller	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Water-cooled Chiller	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Chilled Water Pump	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Cooling Tower	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Condenser Water Pump	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Sea Water Pump	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	VRV System	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Split-type System	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	PAU / AHU	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Other AC Equipment	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Lighting System			
	Lighting Fitting Schedule		☐ Yes	☐ No
	Lighting operation Schedule		☐ Yes	☐ No
	Lighting Control Devices	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Lift and Escalator System			
	Passenger Lift	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Goods Lift	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Escalator	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Plumbing System			
	Water Pump	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Electrical System			
	Metering	Equipment Info:	☐ Yes	☐ No
		Catalogue:	☐ Yes	☐ No
	Total Harmonic Distortion and Power Factor Correction Devices Installed		☐ Yes	☐ No
	Variable Speed Drives Installed		☐ Yes	☐ No

Note: Please amend the form to suit individual case

	General			
	Equipment Operating Schedule		☐ Yes	☐ No
	Trend Log Data for Chillers / Pumps / PAU / AHU / etc		☐ Yes	☐ No
	T&C Records		☐ Yes	☐ No
		If No, please specify:		
	Routine Mintenance Records for las 36 months		☐ Yes	☐ No
		If No, please specify:		
	O&M Manuals		☐ Yes	☐ No
	Electricity Bill for last 36 months		☐ Yes	☐ No
		If No, please specify:		
	Gas Consumption Bill for last 36 months		☐ Yes	☑ No
		If No, please specify:		
	BMS Data for at least 3 months		☐ Yes	☐ No
		If No, please specify:		
	Recent Energy Audit Rerpot		☐ Yes	☐ No
	IAQ Certification		☐ Yes	☐ No
		If No, please specify:		

Note: Please amend the form to suit individual case

Form 1.2 – Current Facilities Requirements Form

Floor	Floor Description	Air Conditioning Provision				MV Provision				Lux Level	Area Operating Schedule for Occupancy	
		Temperature (°C)		Humidity (%)		Fresh Air Intake Rate (l/s)		Exhaust Rate (l/s)				
		Current User Requirement		Current User Requirement		Current User Requirement		Current User Requirement		Current User Requirement	Current User Requirement	
		Season:		Season:		Season:		Season:			Season:	
											Weekday:	
											Saturday:	
											Sunday:	
		Season:		Season:		Season:		Season:			Season:	
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Note: Please amend the form to suit individual case

Form 1.3 – Building Walk-Through Checklist

Water-cooled / Air-cooled Chiller / Heat Pump:

Site Walk Through Checklist

☐ Central Chiller Plant

Water-cooled / Air-cooled Chiller / Heat Pump:

Equip. Designation	Installed year	Location	Installed Capacity (RTon)	Chiled water temp. (℃) Supply	Chiled water temp. (℃) Return	Flow Rate (L/s)	Evaporator Pressure (kPa)	Condenser Pressure (kPa)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD/VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects (such as cannot achieve setpont, out of range conrol, sensor error, missing of monitoring instrument, wear and tear of control devices, inappropriate star/stop of equipment etc:

1	
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Note: Please amend the form to suit individual case

Chilled Water Pumps:

Site Walk Through Checklist

☐ Central Chiller Plant

Chilled Water Pumps:

Equip. Designation	Installed year	Location	Rated Flow Rate (l/s)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD / VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

Heat Rejection Equipment:

Site Walk Through Checklist

☐ Heat Rejection Plant

Heat Rejection Equipment:

Equip. Designation	Installed year	Location	Type (e.g. Cooling Tower / Indirect Sea Water Cool / Direct Sea Water Cool)	Heat Rejection (kW)	Fan Motor Rated (kW)	Brand	Model No.

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

Condensing Water Pumps:

Site Walk Through Checklist

☐ Heat Rejection Plant

Condensing Water Pumps:

Equip. Designation	Installed year	Location	Rated Flow Rate (l/s)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD / VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

Central Hot Water Equipment:

Site Walk Through Checklist

☐ Central Hot Water Plant

Central Hot Water Equipment:

Equip. Designation	Installed year	Location	Type (e.g. Boiler / Heat Pump)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD / VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

Hot Water Pumps:

Site Walk Through Checklist

☐ Central Hot Water Plant

Hot Water Pumps:

Equip. Designation	Installed year	Location	Rated Flow Rate (l/s)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD / VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

PAU / AHU:

Site Walk Through Checklist

☐ PAU / AHU

PAU / AHU:

Equip. Designation	Installed year	Location	Rated Flow Rate (l/s)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD / VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:	
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Note: Please amend the form to suit individual case

VRV / Split Type AC:

Site Walk Through Checklist

☐ VRV / Split Type AC

VRV / Split Type AC:

Equip. Designation	Installed year	Location	Installed Cooling (kW)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD / VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

Potable Water / Flushing Water Pump Room:

Site Walk Through Checklist

☐ Potable Water / Flushing Water Pump Room

Potable Water / Flushing Water Pump Room:

Equip. Designation	Installed year	Location	Type (e.g. Potable / Flushing)	Rated Flow Rate (l/)	Rated Power (kW)	Brand	Model No.	Type of Drive (CSD / VSD)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

Lift Machine Room / Escalator Room:

Site Walk Through Checklist

☐ Lift Machine Room / Escalator Room

Lift Machine Room / Escalator Room:

Equip. Designation	Installed year	Location	Load Capacity (kg)	Rated Power (kW)	Brand	Model No.	Type of Drice (e.g. VVVF / DC)	Idling Function (Y / N)	Speed Reducing Device (Y / N)

Note: Please amend the form to suit individual case

Site Photo Record for Equipment:

Any Visual Inspected Defects:

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Note: Please amend the form to suit individual case

Retro-Commissioning Plan
at
[Building Name]

[Date]

Document No.:
[XXXXXXXXXXX]

TABLE OF CONTENTS

1. Introduction

1.1 Executive Summary

This paragraph should include as a minimum:

- Summary of the preliminary findings in this stage
- Propose potential energy saving areas
- Propose the time frame and resources for the next stage

1.2 General Description of the Building

This paragraph should include as a minimum:

- Building location
- Year of completion
- No. of storeys
- Total installed cooling capacity of central chiller plant under different heat rejection methods.
- Brief description of the central chiller plant

Photo showing the location of the building

Figure 1.1a: [Location of Building]

1.3 Objectives of RCx

This paragraph should include as a minimum:

- Brief description of RCx
- Purpose of RCx

1.4 Scope of Work in Planning Phase

This paragraph should include as a minimum:

- Commencement Date of the Project
- Scope of work in planning phase

1.5 RCx Team

Members participating in the Retro-Commissioning are as below;

Members	Name	Contact No.	Company
Building Owner			
Building Manager			
O&M Staff			
Contractor			
RCx Service Provider			

Table 1.4a: Table of RCx Team Members

1.6 Master Programme of RCx

A master programme of RCx should be attached here.

2. Overview of Major Energy Consumption Systems

2.1 Annual Energy Performance

This paragraph should include as a minimum:

- Description of current annual energy performance (by electricity bill)
- Description of current annual energy performance (by simulation) [Optional]
- Description of the breakdown of total energy consumption

	Air Conditioning Installation	Lighting and Small Power Installation	Lift Installation	Plumbing and Drainage Installation	Others	Total
Energy Consumption (MJ)						
Percentage						

Table 2.1a: Breakdown of Total Energy Consumption in the past 12 months

	Air Conditioning Installation	Lighting and Small Power Installation	Lift Installation	Plumbing and Drainage Installation	Others	Total
Energy Consumption (MJ)						
Percentage						

Table 2.1b: Breakdown of Total Energy Consumption in the past 12 months (By Simulation) [Optional]

Breakdown of Total Energy Consumption

Figure 2.1a: Breakdown of Total Energy Consumption

2.2 HVAC System

Central Chiller Plant

This section should include as a minimum:

- Detailed description of the Central Chiller Plant (i.e. No. of water-cooled/ air-cooled chiller/ heat pump / etc., Cooling capacity of respective chillers, Operation Time of the plant, Served Area, Central Chiller Plant Control System)
- Existing schematic piping diagram of the building
- Summary of existing chillers (Refer to Table 2.2a)
- Summary of existing chilled water pumps (Refer to Table 2.2b)
- Operating schedule of existing chillers (e.g. control setting / setpoint under different operation modes / seasonal conditions) (Refer to Table 2.2c)
- Detailed description of different operation modes
- Cooling capacity under different operation modes
- Areas served under different operation modes

Equipment No.	Location	Installed Capacity (Ton)	Chilled Water Temp. (°C)		Flow Rate (L/s)	Evaporator Pressure (kPa)	Condenser Pressure (kPa)	Rated Power (kW)	Brand	Model No.	Type of Drive (e.g.CSD/VSD)
			Supply	Return							

Table 2.2a: Summary of existing chillers

Equipment No.	Location	Flow Rate (L/s)	Rated Power (kW)	Brand	Model No.	Type of Drive (e.g.CSD/VSD)

Table 2.2b: Summary of existing chilled water pumps

Table 2.2c: Operating schedule of existing chillers

Existing Water-Side Schematic Diagram
for Central Chiller Plant

Figure 2.2a: Existing Water-Side Schematic Diagram for Central Chiller Plant

2.3 Electrical System

Electrical installation

This paragraph should include as a minimum:

- Description of existing electrical system including the description of electrical schematic
- Identification of major items served by the transformers / generator
- Description of capacitor bank used
- Identification of capacitor bank location
- Description of harmonic filter used
- Identification of harmonic filter location

Electrical Schematic Wiring Diagram

Figure 2.3a: Electrical Schematic Wiring Diagram

2.4 Lighting System

2.4.1 Lighting Installation

This paragraph should include as a minimum:

- Description of existing lighting system including typical type of lamps
- Description of existing lighting control system
- Identification of any energy saving measures adopted such as motion and daylight sensor

Lighting Layout

Figure 2.4a: Lighting Layout

Figure 2.4b: Lighting Schedule

2.5 Lift and Escalator System

Lift and Escalator Installation

This paragraph should include as a minimum:

- Description of existing lift and escalator system including the number of lifts and escalators, types of drives and serving floors
- Identification of any energy saving measures adopted

2.5.1 Lift Installation

Equipment No.	**Brand**	**Load Cap (Kg)**	**Speed (m/s)**	**Serving Floors**	**Power (kW)**	**Operation Hours**	**Type of Drive (e.g. VSD/ VVVF)**	**Idling Function (Y/N)**	**Speed Reducing Device (Y/N)**

2.5.2 Escalator Installation

Equipment No.	**Brand**	**Load Cap (Kg)**	**Speed (m/s)**	**Serving Floors**	**Power (kW)**	**Operation Hours**	**Type of Drive (e.g. VSD/ VVVF)**	**Idling Function (Y/N)**	**Speed Reducing Device (Y/N)**

2.6 Plumbing and Flushing System

2.6.1 Plumbing System

This paragraph should include as a minimum:

- Description of existing plumbing system

Equipment No.	**Brand/Model**	**Location**	**VSD (Y/N)**	**Flow Rate (L/s)**	**Head (m)**	**Input Power (kW)**	**Efficiency (%)**	**Operation Hours**	**Remarks**

2.6.2 Flushing System

This paragraph should include as a minimum:

- Description of existing flushing system

Equipment No.	**Brand/Model**	**Location**	**VSD (Y/N)**	**Flow Rate (L/s)**	**Head (m)**	**Input Power (kW)**	**Efficiency (%)**	**Operation Hours**	**Remarks**

3. Current Facilities Requirements

This paragraph should include as a minimum:

- Description of current user required information under Air Conditioning Provision and Mechanical Ventilation Provision (Temperature, Humidity, Exhaust Rate)
- Description of current user required information under Lighting Provision (Lux Level)
- Description of area operating schedule for occupancy

For details, please refer to Form 1.2 – Current Facilities Requirements Form.

4. Preliminary Analysis and Findings

4.1 Existing Chiller Efficiency Analysis

This paragraph should include as a minimum:

- Description of building cooling load profile
- Description of energy consumption
- Description of existing chillers' performance and its COP values

Building cooling load profile

Figure 4.1a: Building cooling load profile

Efficiency of existing chiller showing its COP value

Figure 4.1b: Efficiency of existing chiller plant

4.2 Summary of Plant Cooling Load

4.2.1 Daytime Peak Cooling Load

This paragraph should include as a minimum:

- Cooling load profile of the central chiller plant
- Peak cooling load throughout the year
- Summary of summer and winter cooling load

Summary of peak cooling load

Figure 4.2.1a: Summary of peak cooling loading

4.2.2 Overall Load Factor against Total Installed Capacity

This paragraph should include as a minimum:

- Load factor of the central chiller plant throughout the year
- Load factor of the central chiller plant for each chiller
- Analysis of chiller and corresponding accessories (e.g. pumps, heat rejection/exchange devices etc.) sequencing of operation.

Overall peak load factor against total installed capacity

Figure 4.1.2a: Overall peak load factor against total installed capacity

Load factor of each chiller against total installed capacity

Figure 4.1.2b: Load factor of each chiller against total installed capacity

<table>
<tr><th>Plant Location</th><th>Peak Cooling Load
(kW)</th><th>Total Installed Cooling Capacity (kW)</th><th>Load Factor</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Breakdown</td><td>Cooling Capacity
(kW)</td><td colspan="2">Load Factor of its Installed Capacity</td></tr>
<tr><td>Chiller A</td><td></td><td colspan="2"></td></tr>
<tr><td>Chiller B</td><td></td><td colspan="2"></td></tr>
<tr><td>Chiller C</td><td></td><td colspan="2"></td></tr>
<tr><td>Chiller D</td><td></td><td colspan="2"></td></tr>
</table>

Table 4.1.2c: Peak load factor of chillers

4.2.3 Average Load Factor of Each Chiller

This paragraph should include as a minimum:

- Description and analysis of load factor of each chiller throughout the year

Average load factor of each chiller under its capacity

Figure 4.2.3a: Average Load factor of each chiller under its capacity

Plant Location	**Chiller**	**Average Load Factor (Summer Period : Jun - Sept)**

Figure 4.2.3b: Average Load factor of each chiller during summer period

4.3 Occurrence Time of Cooling Load

4.3.1 This paragraph should include as a minimum:

- Description and analysis of cooling load occurrence time

Percentage of cooling load occurrence time in daytime

Figure 4.3.1a: Percentage of cooling load occurrence time in daytime

5. Preliminary Analysis and Findings (Energy Modelling)

5.1 Simulation Plan

This paragraph should include as a minimum:

- Description of the whole simulation plan in 6 phases:
  Step 1: Information Collection
  Step 2: Calibration on energy model (First stage analysis)
  Step 3: Calibration on the utilities bills
  Step 4: Simulate the recent performance of building (Second stage analysis)
  Step 5: Gap detection
  Step 6: On-going Retro-Commissioning

5.2 Input Parameters

- Sample of input

	Model Input Component
Building Envelop	
1	Exterior wall U-value (W/m^2.K)
2	Roof U-value (W/m^2.K)
3	Fenestration U-value(W/m^2.K)
4	Fenestration SC
5	Windows to wall ratio (overall)(%)
Internal Load	
6	Occupancy Density (m^2/pax)
7	Lighting Power Density (W/m^2)
8	Office Receptacle equipment (W/m^2)
HVAC System	
8	Chiller Plant System
9	Chilled Water Distribution System
10	Indoor Design Temperature (°C)
11	Chiller Capacity (kW)
12	Chiller COP
13	Pump & Fan Flow Rate and Power
14	Split unit COP

5.3 Simulation Findings

This paragraph should include as a minimum:

- Description of the simulation findings, including the ambient temperature comparison between the energy audit report and simulation model (if there is no energy audit report, annual energy consumption should be used by logged data)
- Description of annual Energy Performance Comparison between energy audit report and simulation model (if there is no energy audit report, annual energy consumption should be used by logged data)

(kWh)	Air Conditioning Installation	Lighting and Small Power Installation	Lift Installation	Plumbing and Drainage Installation	Others	Total
Simulation						
Energy Audit Report						
Deviations						

Figure 5.3c: Annual Energy Performance Comparison between Simulation and Audit Report

Breakdown of Total Energy Consumption

Figure 5.3d: Breakdown of Total Energy Consumption

6. Data Verification and Site Measurement Plan

6.1 Data Verification

Data Verification aims to verify the sensor accuracy and to check whether the measured data deviates much from readings. If this situation happens, a correction factor needs to be applied on the log sheet data and its analysis.

This paragraph should include as a minimum:
- Clarify the necessity of verifying the data
- List out the necessary verified data in the site measurement plan which should be attached in this section

6.2 Data Collection

Data Collection aims at collecting and storing the point list items that CCMS or O&M staff require to record for the purpose to understand the performance of equipment / system. This data is needed for further analysis to see if there is any abnormality or potential improvement in the system.

This paragraph should include as a minimum:
- Clarify the necessity of collecting data
- List out the necessary data to be collected in the site measurement plan which should be attached in this section

6.3 Site Measurement Plan

Site Measurement Plan aims at gathering a list of items that need to be verified and collected. Some items can be developed from preliminary analysis and collected materials.

A site measurement plan should consider the following aspects under different modes of operation:

- Water Cooled Chiller and Chilled Water Circuit
- Heat Rejection Circuit
- Air Side Circuit
- Electrical System
- Lighting System
- Lift and Escalator System
- Plumbing and Flushing System

A sample site measurement plan is provided on the next page.

Site Measurement Plan
Revision:
Date of Revision:

Item	Measurement List	Purpose	Methodologies	Equipment Used	Measuring Period	Location	Date	Remarks
A. Water Cooled Chiller and Chilled Water Circuit (at LG4/F)								
B. Heat Rejection System								
C. High Zone Chilled Water Circuit								
D. Night Mode (Air Cooled Chilled Water Circuit)								
E. Air Side Circuit								
F. Lighting System								
G. Electrical System								
H. Lift and Escalator System								
H. Plumbing and Flushing System								

Form 2.1 – Instrumentation for Data Collection using Portable Data Logger

(A)	HVAC Measurement Instruments	Measured Parameter / Remarks	Measure Range	Accuracy	Resolution	Operation & Maintenance Staffs	Contractors	RCx Service Provider
	Voltmeter	Voltage	0 to 600V	±2% of reading	1V	✓	✓	✓
	Ammeter	Current	0 to 400 A	±2% of reading	0.1 A	✓	✓	✓
	Wattmeter	Active Power (kW)	Depending on the measured equipment, user should decide the appropriate instrument size	± 1.5% of reading	0.1kW		✓	✓
	Power factor meter	Power Factor / Apparent power (kVA) calculation	0 to 1	±0.06	0.01			✓
	Power quality analyser	Harmonic contents / Other electrical parameters	1,000V	± 1.5% of reading	0.1V			✓
			2,500A	± 3% of reading	0.1A			
			60,000Ω	± 1% of reading	0.1Ω			
			500Hz	± 0.5% of reading	01Hz			
	Pitot static tube manometer	Air flow pressure and velocity	0 to 2kPa	±0.5% of reading	5Pa		✓	✓
	Digital type anemometer	Air flow velocity	0.25 to 12.5 m/s	±5% of reading	0.1 m/s		✓	✓

	Vane type anemometer	Air velocity through a coil, air intake, or discharge, for flows that are not dynamically unstable, typical flow velocity 0.25m/s to 15m/s	0.25 to 15 m/s	±5% of reading	0.1 m/s		✓	✓
	Hood type anemometer	Flow rate of air grille	Depending on the size of the air grille, user should select the appropriate hood size for air flow measurement	±5% of reading	0.5 l/s		✓	
	Pressure gauge	Liquid pressure	0 to 7,000kPa	±0.5% of reading	100kPa		✓	
	Ultrasonic flow meter with pipe clamps	Liquid flow / velocity	0 to 9 m/s	±1% of reading	0.0001 m/s			✓
	Thermometer	Dry bulb temperature (°C)	0°C to 50°C	±1% of reading	0.1°C	✓		
	Sling Psychrometer (thermometer)	Dry and wet bulb temperature (°C)	0°C to 50°C	±1% of reading	NA	✓		
	Portable electronic thermometer		0°C to 50°C	±1% of reading	0.1°C	✓		
	Infrared remote temperature sensing gun	Useful to sense energy losses due to improper insulation or leakage	0°C to 80°C	±1% of reading	0.1°C			✓

	Digital thermometer with temperature probe	Temperature inside a stream of normally hot air / steam (platinum probe for temperature from 0 to 100°C, and thermocouple probe for high temperatures as much as 1,200°C)	0°C to 100°C	±1% of reading	0.1°C		✓	✓
	CO_2 sensor	Concentration of carbon dioxide (ppm)	0 to 2,500 ppm	±50 ppm	1 ppm			✓
(B)	**Electrical Measurement Instruments**	**Measured Parameter / Remarks**	**Range**	**Accuracy**	**Resolution**	**Operation & Maintenance Staffs**	**Contractors**	**RCx Service Provider**
	Voltmeter	Voltage	0 to 600V	±2% of reading	1V	✓	✓	✓
	Ammeter	Current	0 to 100 A	±2% of reading	0.1 A	✓	✓	✓
	Wattmeter	Active Power (kW)	Depending on the measured equipment, user should decide the appropriate instrument size	± 1.5% of reading	0.1kW			✓
	Power factor meter	Power Factor / Apparent power (kVA) calculation	0 to 1	±0.06	0.01			✓
	Power quality analyser	Harmonic contents / Other electrical parameters	1,000V	± 1.5% of reading	0.1V			✓
			2500A	± 3% of reading	0.1A			
			60,000Ω	± 1% of reading	0.1Ω			
			500Hz	± 0.5% of reading	01Hz			

(C)	Lighting Measurement Instruments	Measured Parameter / Remarks	Range	Accuracy	Resolution	Operation & Maintenance Staffs	Contractors	RCx Service Provider
	Light meter (lux meter)	Lighting level in lux (illuminance / illumination level)	0 to 9,999 lux	±4% of reading (0-9,999 lux)	1 lux	✓		✓
			≥ 10,000 lux	±5% of reading (≥ 10,000 lux)	10 or 100 lux			
(D)	**Lift and Escalator Measurement Instruments**	**Measured Parameter / Remarks**	**Range**	**Accuracy**	**Resolution**	**Operation & Maintenance Staffs**	**Contractors**	**RCx Service Provider**
	Voltmeter	Voltage	0 to 600V	±2% of reading	1V	✓	✓	✓
	Ammeter	Current	0 to 100 A	±2% of reading	0.1 A	✓	✓	✓
	Wattmeter	Active Power (kW)	Depending on the measured equipment, user should decide the appropriate instrument size	± 1.5% of reading	0.1kW			✓
	Power factor meter	Power Factor / Apparent power (kVA) calculation	0 to 1	±0.06	0.01			✓
	Power quality analyser	Harmonic contents / Other electrical parameters	1,000V	± 1.5% of reading	0.1V			✓
			2,500A	± 3% of reading	0.1A			
			60,000Ω	± 1% of reading	0.1Ω			
			500Hz	± 0.5% of reading	01Hz			

(E)	**Plumbing and Flushing Measurement Instruments**	**Measured Parameter / Remarks**	**Range**	**Accuracy**	**Resolution**	**Operation & Maintenance Staffs**	**Contractors**	**RCx Service Provider**
	Voltmeter	Voltage	0 to 600V	±2% of reading	1V	✓	✓	✓
	Ammeter	Current	0 to 100 A	±2% of reading	0.1 A	✓	✓	✓
	Wattmeter	Active Power (kW)	Depending on the measured equipment, user should decide the appropriate instrument size	± 1.5% of reading	0.1kW			✓
	Power factor meter	Power Factor / Apparent power (kVA) calculation	0 to 1	±0.06	0.01			✓
	Power quality analyser	Harmonic contents / Other electrical parameters	1,000V	± 1.5% of reading	0.1V			✓
			2,500A	± 3% of reading	0.1A			
			60,000Ω	± 1% of reading	0.1Ω			
			500Hz	± 0.5% of reading	01Hz			

It is recommended to recalibrate all measurement equipment every 12 months to ensure good accuracy.

Please note that all installations of data loggers and on-site measurement should be carried out by certified professionals and comply with Health and Safety regulations.

Form 2.2a – Chilled Water Plant – Chiller Plant Data Collection Form

Chilled Water Plant - Chilled Specification

Designation:		
Location:		
Model no.:		
Description:	Design Value:	
	CHWST:	
	CHWRT:	

Chiller Data Collected by BMS Logged Data / On-site Measurement

Date (DD/MM/YYYY):		**Ambient Air Temperature (°C)**			**Mean:**		**Max:**		**Min:**		**Relative Humidity:**
Time Interval	Evaporator (no. of operating unit____________)					Chiller Electrical Data		Condenser (water cooled)			Condenser (air cooled)
	Chilled Water							Condenser Water			
	Temperature (°C)		Flow rate (l/s)	Hourly cooling load (kW)	Recorded cooling load (kW)	Running Current (A)	Power Input (kW)	Temperature (°C)		Flow rate (l/s)	Fan Running Current (A)
	Supply	Return						Supply	Return		
				0							
				0							
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Note: Please amend the form to suit individual case

Form 2.2b – Chilled Water Plant – Chilled Water Pump Data Collection Form

Chilled Water Plant - Chilled Water Pump Specification

Designation:	
Location:	
Model no.:	

Chilled Water Pump Data Collected by BMS Logged Data / On-site Measurement

Date (DD/MM/YYYY):		**Ambient Air Temperature (°C)**			**Mean:**		**Max:**		**Min:**		**Relative Humidity (%):**					
Time Interval	Chilled Water Pump 01				Chilled Water Pump 02				Chilled Water Pump 03				Overall Chilled Water Pump			
	Flow rate (l/s)	Running Current (Amp)	Diffferential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)

Note: Please amend the form to suit individual case

Form 2.2c – Heat Rejection Plant – Cooling Tower Data Collection Form

Heat Recjection Plant Specification

Designation:	
Location:	
Model no.:	

Heat Rejection Plant Data Collected by BMS Logged Data / On-site Measurement

Date (DD/MM/YYYY):		**Ambient Air Temperature (°C)**	**Mean:**		**Max:**		**Min:**		**Relative Humidity (%):**	

Time Interval	Cooling Tower Electrical Data (no.of operating unit____________)		Condenser Water		
	Input Current (Amp)	Consumed Power (kW)	Temperature (°C)		Flow Rate (l/s)
			Supply	Return	

Note: Please amend the form to suit individual case

Form 2.2d – Heat Rejection Plant – Condensing Water Pump Data Collection Form

Heat Rejection Plant - Condenser Water Pump Specification

Designation:	
Location:	
Model no.:	

Condenser Water Pump Data Collected by BMS Logged Data / On-site Measurement

Date (DD/MM/YYYY):		**Ambient Air Temperature (°C)**			**Mean:**		**Max:**		**Min:**		**Relative Humidity:**					
Time Interval	Condensing Water Pump 01				Condensing Water Pump 02				CondensingWater Pump 03				Overall Condensing Water Pump			
	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)

Note: Please amend the form to suit individual case

Form 2.2e – Central Hot Water Plant Data Collection Form

Central Hot Water Plant Specification

Designation:	
Location:	
Model no.:	

Central Hot Water Plant Data Collected by BMS Logged Data / On-site Measurement

Date (DD/MM/YYYY):		**Ambient Air Temperature (°C)**	**Mean:**		**Max:**		**Min:**		**Relative Humidity (%):**	

Time Interval	Central Hot Water Plant Electrical Data				Hot Water		
	COP	Steam Supply Pressure (kPa)	Boiler Input Current (Amp)	Boiler Consumed Power (kW)	Temperature (°C)		Flow Rate (l/s)
					Supply	Return	

Note: Please amend the form to suit individual case

Form 2.2f – Central Hot Water Plant – Hot Water Pump Data Collection Form

Central Hot Water Plant - Hot Water Pump Specification

Designation:	
Location:	
Model no.:	

Hot Water Pump Data Collected by BMS Logged Data / On-site Measurement

Date (DD/MM/YYYY):		**Ambient Air Temperature (°C)**			**Mean:**		**Max:**		**Min:**		**Relative Humidity:**					
Time Interval	Hot Water Pump 01				Hot Water Pump 02				Hot Water Pump 03				Overall Hot Water Pump			
	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)	Flow rate (l/s)	Running Current (Amp)	Differential Pressure (kPa)	Power Input (kW)

Note: Please amend the form to suit individual case

Form 2.2g – Air Side System – AHU / PAU / FCU / Indoor Unit Data Collection Form

Air Side System (AHU / PAU / FCU / Indoor Unit) Specification

Designation:		
Location:		
Model no.:		
Description:	Design Value:	
	CHWST:	
	Supply Air Temp.:	

Air Side Data (AHU / PAU / FCU / Indoor Unit) Collected by BMS Logged Data / On-site Measurement

Date (DD/MM/YYYY):		Ambient Air Temperature (°C)	Mean:		Max:		Min:		Relative Humidity:	

Time Interval	AHU / PAU / FCU / Indoor Unit								
	Chilled Water		Air					Fan Running Current (Amp)	Fan Running Power (kW)
	Temperature (°C)		Temperature (°C)		Flow rate (l/s)		Thermal Wheel / Heat Recovery Unit (ON/OFF)		
	Supply	Return	Supply	Return	Supply	Return			

Note: Please amend the form to suit individual case

Form 2.3 – List of Proposed Energy Saving Opportunities (ESOs)

System Tuning Works

Item	Description of ESO (including) intend results and energy baselines)	Estimated Annual Energy Saving (kWh)	Proposed Work Agent	Implementation Duration	Payback Period	Measurement and Verification Methodology (*)	Stiribution to Existing System	Implementation	
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No

Upgrading Works

Item	Description of ESO (including) intend results and energy baselines)	Estimated Annual Energy Saving (kWh)	Proposed Work Agent	Implementation Duration	Payback Period	Measurement and Verification Methodology (*)	Stiribution to Existing System	Implementation	
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No
								☐ Yes	☐ No

Note: Please amend the form to suit individual case

Overall Annual Energy Saving (kWh):
Note: (a) By Comparing the Electricity Bills
(b) By Measurement
(c) By Energy Modelling Simulation
(d) Others

Form 2.4 – List of Proposed Repairing Items

Repair Works

Item	Description of Repairing Items	Justification on its effect in conducting RCx	Proposed Work Agent	Implementation Duration

Note: Please amend the form to suit individual case

Investigation Report
at
[Building Name]

[Date]

Document No.:
[XXXXXXXXXXX]

TABLE OF CONTENTS

M&V plan template

[Name of the ESO]
M&V Plan
[Date]

The situation

In this section, a description of the status of the facility should be included. This will include a high-level description of each ESO, the expected effects, and savings after the implementation. The current limitations should be highlighted and include pictures and other relevant ESO information.

The plan

ESO Intent

Describe how the ESO is intended to reduce energy consumption. Include potential impact on operations.

IPMVP Option and measurement boundaries

Describe the option (A, B, C or D) and the measurement boundaries. Identify how impacts on energy consumption outside of the measurement boundaries will be considered.

Baseline Period

The length of the baseline period and include a list of the independent variables.

Reporting Period

The length of the reporting (or post retrofit) period. Include responsible for data collection.

Basis for adjustment

Weather-independent operational change.

Analysis procedure

Description of the calculation method. Example:

$$S = ABL - Actual \ \pm Non - routine \ \ adjustments$$

Where:
$S =$ Saved energy use, in kWh

$ABL =$ Adjusted baseline, usually by weather and operational hours

$Actual =$ Actual energy consumption

$Non - routine \ \ adjustments$ = Adjustments in building operations that impact energy use that are not considered in the adjusted baseline.

$$Cost \ \ saved = S * Energy \ \ price \ \ schedule$$

Energy price schedule used

Include peak and off-peak period costs.

Meter specifications

Characteristics of meters used for the M&V process. Include accuracy, reading responsible and frequency. Include actions to take in case of missed/incorrect data readings.

Monitoring responsibilities

Specify who is the responsible of monitoring the correct functioning of the select ESO.

Define stakeholders

Stakeholders involved in the selected ESO.

Expected accuracy

List sources of uncertainty. Compute precision and confidence.

Budget

Include costs of meters, maintenance, labour and reporting costs.

Report format

Report used to present savings at the agreed reporting period.

Quality assurance procedures

List primary risks in the M&V process including data gaps, undocumented non-routine adjustments.

For option A include:

- Justification of the key and non-key parameters used.
- Equipment inspection schedule.

For option D include:

- Name and version of selected software
- Input data and method of measuring any parameters
- Relevant output data from simulation.
- Accuracy achieved, consider ASHARE Guidelines 14.

M&V Report template

Executive summary

Overview of the report including a table showing estimated savings.

	Total energy consumption savings (kWh per annum)	**Total energy cost savings ($ per annum)**
Proposed Savings		
Current Report Verified Savings		

Background

Project information:

Project:	
Client Name	
Site Location	
Facility Description	
Funding partner (if any)	
ESO(s)	

M&V Information:

Framework	
M&V Plan	Reference the document containing M&V plan
IPMVP Option	Define M&V Option
Measurement	
Measurement Strategy	Temporary loggers/ Submetering/ Utility bills/ etc.
Measurement Boundary	Clear measurement boundary
Monitoring Period	I.e. 12 months
Analysis	
Savings determination	Avoided energy/Normalised energy
Basis of Routine Adjustments	Cooling degree days, operation hours, etc.
Target uncertainty	Confidence/Accuracy (i.e.90/10)
Reporting	
Reporting schedule	Example: Year 0 Report – immediately following ESO completion. Year 1 Report – 12 months after ESO completion. Year 2 Report – 24 months after ESO completion.

Savings information:

	Total energy consumption savings (kWh per annum)	**Total energy cost savings ($ per annum)**
Proposed Savings		
Report 0 Verified Savings		
Report 1 Verified Savings		
…		

Project Savings Verification

Measurement and reporting periods
These periods should align with the M&V plan

Analysis overview

Include information used for baseline adjustments (i.e. weather) and Non-Routine Baseline Adjustments (i.e. set points temperatures). Also, update the energy price schedule used.

Observed data and energy savings calculation

Present data in form of tables or graphs.

Interval	Independent variable(s)	Measured energy use (kWh)	Adjusted Baseline Energy use (kWh)	Energy Savings (kWh)	Avoided costs ($)	Comments/ Corrections
January						
February						
…						

Conclusions

Discuss the results and detected operational issues. Define whether the actual savings are aligned with the predicted values. Provide recommendations for the following reporting period.

Appendix A: Raw observed data

Contains all the logged data used for the estimations of savings.

Appendix B: Savings calculation

Contains all the calculations undertaken in determining savings due to the ESO.

Implementation Report
at
[Building Name]

[Date]

Document No.:
[XXXXXXXXXXX]

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On-going Commissioning Report
at
[Building Name]

[Date]

Document No.:
[XXXXXXXXXXX]

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