Building and Construction Authority

CODE ON
ENVIRONMENTAL SUSTAINABILITY MEASURES
FOR
EXISTING BUILDINGS

Edition 2.0

History of Amendments

S/N	Brief description of changes	Revision date
1	Edition 1.0 –first issue	1st July 2013
2	Edition 1.1 –first revision The purpose of the amendment is to align with the changes to the Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations 2016 to extend Minimum Environmental Sustainability Standards to more medium-sized buildings. “Scope” in Page 2 of the Code shall be replaced as : The Code shall be applicable to all prescribed buildings stated in the Building Control (Environmental Sustainability Measure for Existing Buildings) (Amended) Regulations 2016 except the following Type A and Type B Buildings: Type A (a) Data centres; (b) Religious buildings; (c) Residential buildings (other than serviced apartments); or (d) Utility buildings; Type B (e) Industrial buildings; (f) Railway premises; (g) Port services and facilities; or (h) Airport services and facilities. (i) Any mixed-used developments which includes industrial buildings, railway premises, ports services and facilities or airport services and facilities.”	1st July 2016
3	Edition 2.0 – second issue Amendment to the scoring method for determining the level of environmental sustainability in complying with the Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations 2016, and align the sustainable requirements with the Green Mark for Existing Non-Residential Buildings 2017 at the Certified level.	1 April 2019

Contents

CODE ON ENVIRONMENTAL SUSTAINABILITY MEASURES FOR EXISTING BUILDINGS (EDITION 2.0)

Dated: 01 April 2019

INTRODUCTION

In 2009, BCA rolled out its 2nd Green Building Masterplan, a roadmap that covers both new and existing buildings and sets out specific initiatives to achieve a truly sustainable built environment in Singapore. Under this Masterplan, the target set by the Inter-Ministerial Committee on Sustainable Development (IMCSD) is to green at least 80% of the buildings in Singapore by 2030 through the BCA Green Mark Certified rating. The current challenge is on greening the existing stock of buildings and legislation has been identified as one of the avenue to meet this target.

Since April 2008, BCA implemented the Building Control (Environmental Sustainability) Regulations which require new developments to meet a minimum environmental sustainability standard. However, this measure for new developments alone is not sufficient to greatly improve the sustainability of our built environment. Therefore, BCA has introduced some regulatory measures in Dec 2012 to require owners of existing buildings to improve the minimum environmental sustainability standards of existing buildings as and when the building owners install or replace their building cooling system. These buildings will need to meet the minimum Green Mark standards for existing buildings.

Besides meeting minimum standards, these buildings need to continue to operate at the optimum performance level, so that they will be able to reap the most benefits out of their retrofits. Thus, building owners are also required to conduct three-yearly audit on their building cooling systems in these buildings.

The intent of this Code for Environmental Sustainability Measures for Existing Buildings (referred to as “this Code”) is to guide owners of existing buildings to improve the minimum sustainability standards of existing buildings and establish environmentally friendly practices in the operation and retrofitting of existing buildings.

This Code is not intended to abridge safety, health, environmental or related requirements contained in other applicable laws, codes or policies administered by relevant authorities. Where there is a conflict between a requirement of this Code and such other laws affecting the design and construction of the building, the laws shall take precedence.

If you need clarification on any aspect of this Code, please contact the Building and Construction Authority, Singapore (BCA).

1 SCOPE

This Code sets out the minimum environmental sustainability measures for existing buildings and the administrative requirements in complying with the Building Control (Environmental Sustainability Measures for Existing Buildings) Regulations 2016. It includes the compliance method for determining the level of environmental sustainability of an existing building.

The Code shall be applicable to all prescribed buildings stated in the Building Control (Environmental Sustainability Measure for Existing Buildings) (Amended) Regulations 2016 except the following Type A and Type B Buildings:

Type A

(j) Data centres;
(k) Religious buildings;
(l) Residential buildings (other than serviced apartments); or
(m) Utility buildings;

Type B

(n) Industrial buildings;
(o) Railway premises;
(p) Port services and facilities; or
(q) Airport services and facilities.
(r) Any mixed-used developments which includes industrial buildings, railway premises, ports services and facilities or airport services and facilities.

For more details on the applicable building types, please refer to the “Building Control (Environmental Sustainability Measures for Existing Building) (Amendment) Regulations 2016”.

The referenced codes, standards and other documents referred in this Code shall be considered part of the requirements of this Code to the extent as prescribed.

2 DEFINITIONS

For the purpose of this Code, the following definitions shall apply:

As-built Submission	The submitted as-built score for a prescribed building that has completed the major energy-use change
BC Act	The Building Control Act (Chapter 29)
BCA	The Building and Construction Authority
Chilled Water Plant	A building's centralised air conditioning system which makes use of chilled water as the medium for removing the heat from the buildings. This includes the chillers and its ancillary equipment, including pumps and cooling towers where applicable.
Design Submission	The submitted design score for a prescribed building undergoing a major energy-use change
Gross Floor Area (GFA)	The "gross floor area" has the same meaning as "floor area" in the Planning (Development Charges) Rules (Cap.232, R 5)
Minimum Green Mark Score	The lowest Green Mark score that would meet the minimum environmental performance required for existing buildings.
Operational System Efficiency (OSE)	The measured system efficiency of the building's chilled water plant during its normal operating hours.
PE(Mech)	A person who is registered under the Professional Engineers Act (Cap. 253) in the mechanical engineering discipline and who has in force a practising certificate issued under that Act authorising him to engage in mechanical engineering.
Unitary Air Conditioning System	One or more factory-made assemblies that normally include an evaporator or cooling coil and a compressor combination. Units that perform a heating function area are also included.
Regulations	The Building Control (Environmental Sustainability Measures for Existing Building) (Amendment) Regulations 2016
Government Land Sales (GLS)	Whole or part of any building that is on land within areas stipulated under the First and Second Schedules to the 2008 Regulations (and such other schedules to the 2008 Regulations as gazetted from time to time)

In instances where terms are not expressly stated in this Code and are defined in other referenced documents, such terms shall have the meanings as determined in those documents.

3 STATUTORY REQUIREMENTS

3.1 Act and Regulations

The following Act and Regulations have relevance:

a. the BC Act; and

b. the Regulations.

3.2 Referenced Codes and Standards

The following codes and standards have relevance:

a. SS 530 : 2006 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment

b. CP38 : 1999 – Artificial Lighting in Building

c. SS 531 – 1 : 2006 – Code of Practice for Lighting of Workplaces

d. SS 553 : 2009 - Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings

e. SS 554 : 2016 - Code of Practice for Indoor Air Quality for Air-conditioned Buildings

f. NEA's Guidelines for Good Indoor Air Quality in Office Premises

g. AHRI Standard 550/590 – Performance Rating of Water Chilling and Heat Pump Water–Heating Packages Using the Vapour Compression Cycle by Air-Conditioning, Heating and Refrigeration Institute(AHRI)

h. Singapore Standard 591 – Code of Practice for long term measurement of central chilled water system energy efficiency

i. BCA – FAQs on instrumentation for permanent M&V for chilled-water plant system

3.3 Responsibility

To comply with the minimum environmental sustainability measures stipulated in the Regulations, the building shall comply with all the requirements listed in the Code. Before commencement of the replacement or retrofitting works, the building owner shall appoint a PE(Mech) to assess the design of the retrofitting works, prepare the Design Submission, and provide the documentation of the design submission that meets the minimum environmental sustainability standard and such other documents required in the Regulations.

The building owner shall then submit the Design Submission and supporting documents to BCA for approval before the commencement of the retrofitting works. He must also commence and complete the installation/replacement works not later than the period prescribed in the Regulations.

Upon completion of the installation or replacement works, the PE(Mech) shall assess and prepare the As-built Submission that meets the minimum environmental sustainability standard, and provide to the building owner the documentation of the As-

built Submission, completion certificate and such other documents required in the Regulations.

The building owner shall submit the As-built Submission, declaration by PE(Mech) and supporting documents to BCA for approval not later than the period prescribed in the Regulations.

3.4 Minimum Environmental Sustainability Measures

3.4.1 Buildings that comply with all the sustainable requirements as specified in the Code are deemed to have met the minimum environmental sustainability standard of 50 points as prescribed in the Regulations.

4 COMPLIANCE METHOD

4.1 Environmental Sustainability Standard

4.1.1 The environmental sustainability standard of an existing building shall be determined by the compliance with all the requirements as specified herein.

4.1.2 The seven (7) compliance requirements are:

a) Energy consumption monitoring
b) Air-conditioning system minimum operating efficiency
c) Energy improvement on lighting system
d) Water consumption monitoring
e) Chiller plant measurement and verification (M&V) instrumentation
f) Indoor temperature
g) Indoor air quality (IAQ) surveillance audit

T**able 4.1.1 : Compliance requirements for Existing Non-residential Building**

a) **ENERGY CONSUMPTION MONITORING**

To compute and monitor the building's Energy Use Intensity (EUI) for the past 3 years and review its Energy Efficiency Improvement Plan, where necessary

b) **AIR CONDITIONING SYSTEM MINIMUM OPERATING EFFICIENCY**

(i) For Buildings using Water-cooled Chilled-water Plant

Green Mark Rating	**Building Cooling Load (RT)**	
	< 500	**≥ 500**
	Minimum Efficiency (kW/RT)	
Certified	0.8	0.75
Gold	0.75	0.70
Gold^{PLUS}	0.7	0.68
Platinum	0.68	0.65

(ii) For Buildings using Air-cooled Chilled-water Plant or Unitary Air-Conditioners

Green Mark Rating	**Building Cooling Load (RT)**	
	< 500	**≥ 500**
	Minimum Efficiency (kW/RT)	
Certified	1.1	1.0
Gold	1.0	*N.A
Gold^{PLUS}	0.85	
Platinum	0.78	

*For buildings with cooling load of more than 500 RT, the air-cooled chilled-water plant or unitary air-conditioners will be assessed on a case-by-case basis. It will only be considered when it meets the same efficiency requirement as stipulated in 2(i).

Note: Performance of the overall air-conditioning system for the building is based on the Operating System Efficiency (OSE) of the system during standard building operating hours as defined below:

Office Building: Monday to Friday: 9am to 6pm Retail Mall: Monday to Sunday: 10am to 10pm	Hotel and Hospital: 24-hour Industrial Building and Other Building Types: To be determined based on its normal operating hours

c) **ENERGY IMPROVEMENT ON LIGHTING SYSTEM**

To demonstrate at least 20% improvement in the lighting power budget for common areas over the baseline stated in annex A

d) **WATER CONSUMPTION MONITORING**

To compute and monitor the building's yearly water consumption (m^3/GFA(m^2)) for the past 3 years and review its Water Efficiency Improvement Plan, where necessary

e) **CHILLER PLANT MEASUREMENT AND VERIFICATION (M&V) INSTRUMENTATION**

To provide permanent measuring instruments for monitoring of chilled water system operating efficiency. The installed instrumentation shall have the capability to calculate the resultant operating system efficiency (i.e. kW/RT) within 5% of its true value and in accordance with SS 591. Each measurement system shall include the sensor(s), any signal conditioning, the data acquisition system and wiring connecting these components.

A heat balance substantiating test for water-cooled chilled-water system is to be computed in accordance to SS 591 for verification of the accuracy of the M&V instrumentation. The heat balance shall be computed over the entire normal operating hours with more than 80% of the computed heat balance within ±5% over a 1-week period.

f) **INDOOR TEMPERATURE**

To maintain the indoor dry-bulb temperature at 23 °C and above to prevent overcooling

7. INDOOR AIR QUALITY (IAQ) SURVEILLANCE AUDIT

The audit shall be conducted by an accredited laboratory under Singapore Accreditation Council with respect to the recommended IAQ parameters and acceptable limits stated in Table 1 of *SS 554 : 2016 Code of Practice for Indoor Air Quality for Air-Conditioned Buildings* or in Annex E of NEA's *Guidelines for Good Indoor Air Quality in Office Premises*.

Annex A: Maximum Lighting Power Budget (including ballast loss)

Type of Usage	Maximum Lighting Power Budget (W/m^2)
Offices	15
Classrooms	15
Hotel guest room	15
Lecture theatres	15
Auditoriums / Concert halls	10
Shops / Supermarkets / Departmental stores (including general, accent & display lighting)	25
Restaurants	15
Lobbies / Atriums / Concourse	10
Stairs	6
Corridors	10
Toilets	15
Car parks	5
Electronic manufacturing and fine detail / Assembly industries	20
Medium and heavy industries	15
Warehouses / Storage areas	10

5 SUBMISSION PROCEDURES

5.1 General

Under the Regulations, buildings which are required to comply with the minimum environmental sustainability measures, shall comply with all the requirements as specified in the Code. The evidence documents must be submitted by the PE(Mech) at the following stages:-

(a) before the commencement of the retrofitting works; and

(b) after the completion and commissioning of the retrofitting works.

5.2 Submission before commencement of retrofitting works

Before the commencement of the retrofitting works, the building owner shall appoint a PE(Mech) to assess and prepare the Design Submission for the building. The PE(Mech) shall encrypt and submit electronically the following forms / documents to BCA via CORENET e-submission system:-

(a) Form BCA-EB-NAPPPE01 – "Notification of Appointment / Authorization of Mechanical Engineer;

(b) Form BCA-EB-RWAPPV01 – "Application for Approval of Retrofitting Plans – Environmental Sustainability Measures for Existing Buildings"; and

(c) Supporting documents listed in Form BCA-EB-RWAPPV01:
- Audit report on current air-conditioning system before retrofitting works
- Cooling load calculations (if there is a change in cooling load or unitary air-conditioning systems installed)
- Design schematic drawing of proposed air-conditioning system (water-side)
- Chiller plant room layout drawing including position of M&V instruments using symbol and color scheme
- Chiller part-load performance data sheet from equipment supplier
- Chilled water pump selection data sheet and pump curves showing design flow and head, pump hydraulic efficiency, motor absorbed power and efficiency
- Condenser water pump selection data sheet and pump curves showing design flow and head, pump hydraulic efficiency, motor absorbed power and efficiency
- Cooling tower selection data sheet and location plans
- Project schedule for retrofitting works is attached
- Worksheet for chiller plant efficiency computation
- Worksheet for the lighting power budget computation
- The building's past three years Energy Use Intensity (EUI) and projected post-retrofit EUI
- The building's past three years water consumption [m^3/GFA(m^2)]

BCA will issue Notice of Approval if the submissions are in order.

5.3 Submission after completion of the retrofitting works

Upon completion of the retrofitted works and system commissioning, the PE(Mech) shall assess and prepare the As-built Submission, encrypt and submit electronically the following forms / documents to BCA via CORENET e-submission system:-

(a) Form BCA-EB-NAPPPE01 – "Notification of Appointment / Authorization of Mechanical Engineer;

(b) Form BCA-EB-RWCW01 – “Application for Approval of Completion of Retrofitting Works & Operating System Efficiency of Building Cooling System”; and

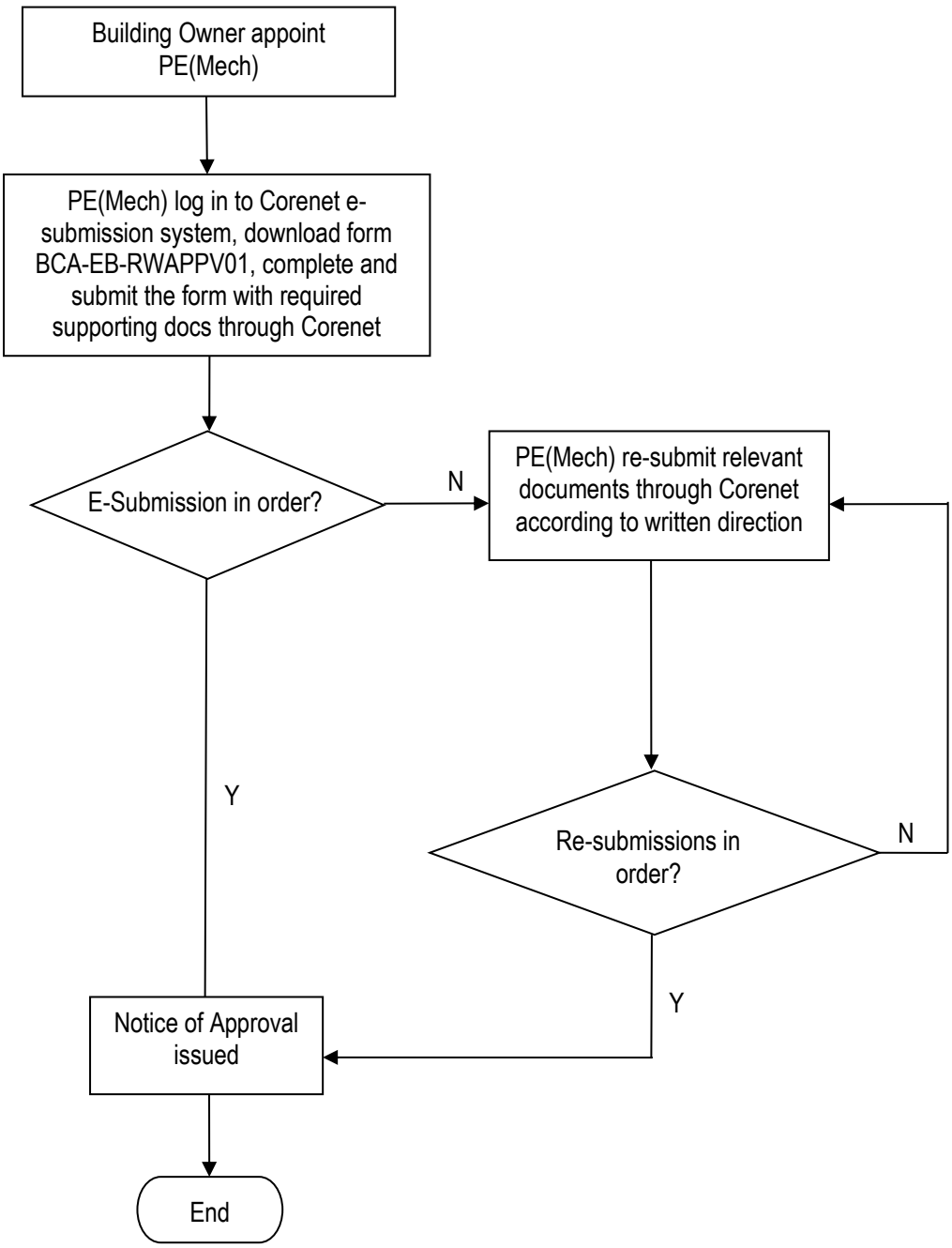
(c) Supporting documents listed in Form BCA-EB-RWCW01:
- As-built schematic drawing of air-conditioning system (water-side)
- As-built chiller plant room layout drawing indicating position of M&V instruments using symbol and color scheme
- As-built chiller part-load performance data sheet from equipment supplier
- As-built chilled water pump selection data sheet and pump curves showing design flow and head, pump hydraulic efficiency, motor absorbed power and efficiency
- As-built condenser water pump selection data sheet and pump curves showing design flow and head, pump hydraulic efficiency, motor absorbed power and efficiency
- As-built cooling tower selection data sheet and location plans
- Instruments’ calibration certificates from accredited laboratory (temperature sensors) and batch calibration certificates from manufacturers (other M&V instruments)
- Construction drawings of the instruments showing the details of installation
- 2 week raw data of the following data points in excel format (.xls) with date and time stamp: chilled water supply temperature (°C); chilled water return temperature (°C); condenser water supply temperature (°C); condenser water return temperature (°C); chilled water flow rate (l/s); condenser water flow rate (l/s); electrical power of chiller(s), chilled water pump(s), condenser water pump(s) & cooling tower(s) (kW). The excel file should include all the chart plots specified in Annex B of the Code on Periodic Energy Audit of Building Cooling Systems
- Energy Audit report (format in accordance to Annex B of “Code on Periodic Energy Audit of Building Cooling Systems”)
- As-built lighting power budget computation
- The building’s post retrofitted Energy Use Intensity (EUI)
- The building’s past three years water consumption (m^3/GFA(m^2))
- An post-retrofit IAQ surveillance audit based on the indicative methods according to SS 554 : 2016 Code of Practice for Indoor Air Quality for Air-Conditioned Buildings or demonstrate good IAQ performance according to NEA’s Guidelines for Good Indoor Air Quality in Office Premises

The Notice of Approval for completion of the retrofitting works will be given if the retrofitting works is successfully commissioned and the submissions are in order.

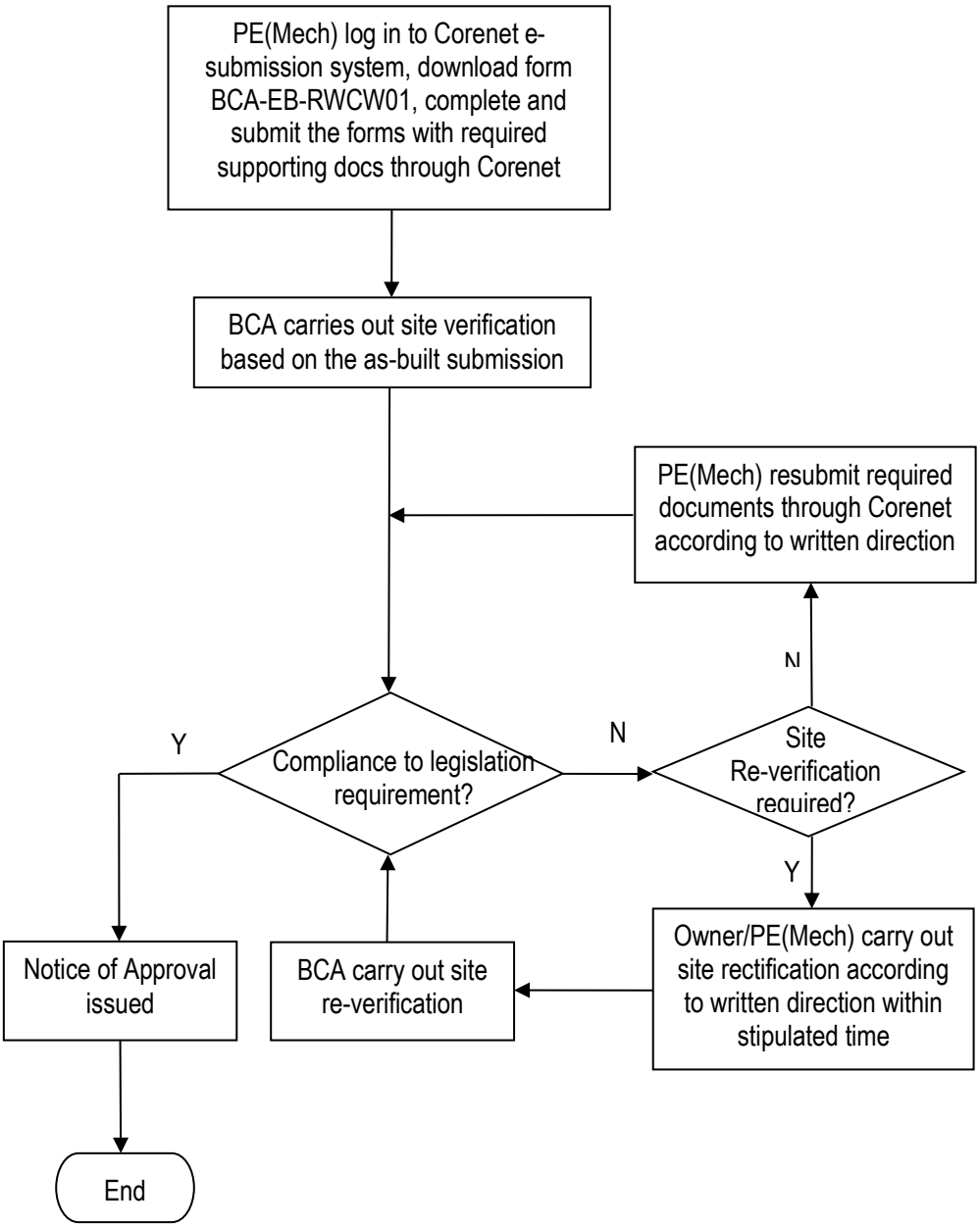
5.4 Documentary Evidence

The details of the documentary evidences required can be found in the Part 6: Methodology & Documentation for compliance. Building Owner / PE(Mech) shall ensure that these documents and records are available as evidences to demonstrate compliance with the environmental sustainability standard and criteria.

Submission Flowchart - Before commencement of retrofitting works



Submission Flowchart - After Completion of the retrofitting works



Part 6

METHODOLOGY & DOCUMENTATION

Requirements

1. ENERGY CONSUMPTION MONITORING

<table>
<tr><td>Objective</td><td>To encourage the building owner to monitor the building's energy consumption trend in the past 3 years and review its Energy Efficiency Improvement Plan, where necessary.</td></tr>
<tr><td>Applicability</td><td>Applicable to all buildings.</td></tr>
<tr><td rowspan="2">Methodology/ Baseline Standard</td><td>The building's Energy Use Intensity (EUI) for the past 3 years shall be calculated and submitted. It shall be calculated based on actual utility bills. EUI = Annual Total Building Energy Consumption (kWh)/GFA(m^2). Any abnormal trends or significant increase in EUI should be investigated and corrective actions should be carried out to address any wastage.</td></tr>
<tr><td>• Calculation of EUI = TBEC / GFA

Where
TBEC : Total building energy consumption (kWh/year)
GFA : Gross floor area (exclude car park area) (m2)

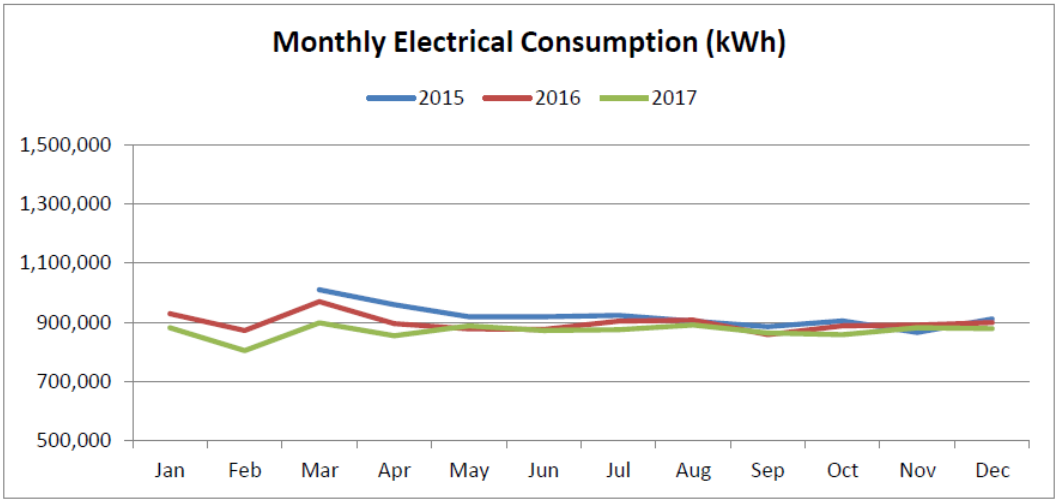
• The building's past 3 years utility bill shall be submitted</td></tr>
<tr><td>References</td><td>Nil</td></tr>
<tr><td>Worked Example</td><td><u>Background info:</u>

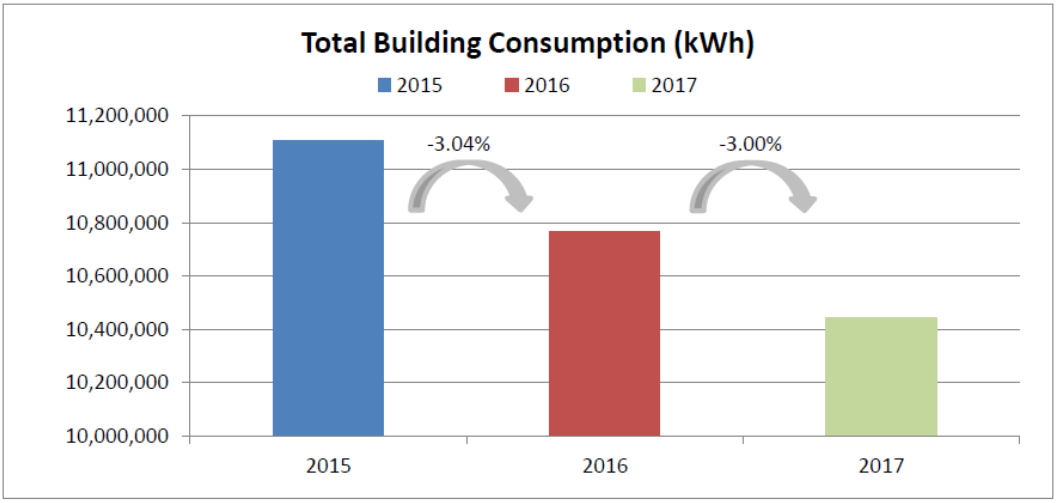
Assume an existing building with GFA of 31,540 m^2.

<table>
<tr><th>Month</th><th>Electricity Bill (2015)</th><th>Electricity Bill (2016)</th><th>Electricity Bill (2017)</th></tr>
<tr><td>January</td><td>846,332.05</td><td>928,990.22</td><td>881,538.18</td></tr>
<tr><td>February</td><td>1,059,170.28</td><td>872,425.01</td><td>803,967.48</td></tr>
<tr><td>March</td><td>1,009,784.15</td><td>969,407.75</td><td>898,125.78</td></tr>
<tr><td>April</td><td>959,061.17</td><td>895,217.92</td><td>854,398.27</td></tr>
<tr><td>May</td><td>918,719.73</td><td>877,730.64</td><td>888,123.20</td></tr>
<tr><td>June</td><td>918,339.21</td><td>876,166.72</td><td>871,571.00</td></tr>
<tr><td>July</td><td>922,716.52</td><td>903,425.78</td><td>874,511.78</td></tr>
<tr><td>August</td><td>903,851.85</td><td>907,715.70</td><td>890,246.84</td></tr>
<tr><td>September</td><td>885,180.49</td><td>858,509.93</td><td>863,458.04</td></tr>
<tr><td>October</td><td>904,567.52</td><td>888,244.20</td><td>858,307.30</td></tr>
<tr><td>November</td><td>865,289.02</td><td>890,177.01</td><td>881,028.54</td></tr>
<tr><td>December</td><td>911,383.18</td><td>898,669.48</td><td>878,565.07</td></tr>
<tr><td>TOTAL (kWH/yr)</td><td>11,104,395.15</td><td>10,766,680.34</td><td>10,443,841.48</td></tr>
</table>
</td></tr>
</table>

EUI Calculation

	2015	2016	2017
Total (kWH/yr)	11,104,395.15	10,766,680.34	10,443,841.48
GFA (m^2)	31,540	31,540	31,540
EUI (kWH/yr/m^2)	**352.07**	**341.37**	**331.13**
Deviation (%)	**-**	**- 3.04%**	**- 3%**





2. AIR-CONDITIONING SYSTEM MINIMUM OPERATING EFFICIENCY

<table>
<tr><td>Objective</td><td>To optimise a building’s total system performance and reduce its overall energy consumption through the use of energy efficient and appropriately sized air-conditioning systems.</td></tr>
<tr><td>Applicability</td><td>Applicable to air-conditioning systems serving the building’s comfort cooling needs and the building’s aggregate air-conditioned areas exceed 500 m2.</td></tr>
<tr><td>Methodology/ Baseline Standard</td><td>The system efficiency shall not exceed the following limits indicated in the tables below. Performance of the overall air-conditioning system for the building is based on the Operating System Efficiency (OSE) of the system during standard building operating hours as defined below:
<table>
<tr><td><u>Office Building:</u>
Monday to Friday: 9am to 6pm
<u>Retail Mall:</u>
Monday to Sunday:
10am to 10pm</td><td><u>Hotel and Hospital:</u>
24-hour
<u>Industrial Building and Other Building Types:</u>
To be determined based on its normal operating hours</td></tr>
</table>
<u>1-2(a) Water Cooled Chilled-Water Plant</u>
<table>
<tr><th rowspan="2">Baseline</th><th colspan="2">Building Cooling Load</th></tr>
<tr><th>< 500 RT</th><th>≥ 500 RT</th></tr>
<tr><td><u>Pre-requisite Requirements for regulated buildings</u>
Minimum System Efficiency for Water-cooled Chilled Water Plant</td><td>0.80 kW/RT</td><td>0.75 kW/RT</td></tr>
<tr><td><u>Pre-requisite Requirements for GLS Goldplus projects</u>
Minimum system efficiency of central chilled-water plant</td><td>0.7 kW/RT</td><td>0.65 kW/RT</td></tr>
<tr><td><u>Pre-requisite Requirements for GLS Platinum projects</u>
Minimum system efficiency of central chilled-water plant</td><td>0.7 or 0.68* kW/RT</td><td>0.65 kW/RT</td></tr>
</table>
<u>* for projects with GLS tender closing date on or after 1 December 2016</u></td></tr>
</table>

1-2(b) Air Cooled Chilled-Water Plant/ Unitary Air-Conditioners

Baseline	Building Cooling Load	
	< 500 RT	**≥ 500 RT**
Pre-requisite Requirements Minimum System Efficiency for Air Cooled Chilled-Water Plant or Unitary Air-Conditioners	1.1 kW/RT	1.0 kW/RT
Pre-requisite Requirements for GLS Goldplus projects Minimum System Efficiency for Air Cooled Chilled-Water Plant or Unitary Air-Conditioners	0.85 kW/RT	Not Applicable
Pre-requisite Requirements for GLS Platinum projects Minimum System Efficiency for Air Cooled Chilled-Water Plant or Unitary Air-Conditioners	0.78 kW/RT	Not Applicable

Documentation Requirements

- Latest Energy Audit report on the chiller plant before retrofit.
- Detailed calculations of the proposed equipment efficiency of the retrofitted chiller plant as shown in the worked examples,
- Drawings showing the proposed chilled water schematic of the retrofitted chiller plant;
- Drawings showing the proposed layout of the retrofitted chiller plant equipment;
- If there is addition or reduction of cooling load, cooling load simulation report shall be submitted.
- Chiller plant equipment (i.e. chillers, pumps, cooling towers) technical schedule and specifications.
- Chiller plant equipment schedule to be presented in following format:

ID	Description	Name plate motor (kW)	Pump Head (m)	Flow rate (L/S)	Pump / Fan efficiency	Motor Efficiency
CHWP-1	Chilled water pump 1	55 kW	30m	151.2	85%	95%
CHWP-2	Chilled water pump 2	30 kW	30m	75.6	85%	95%
CWP-1	Condenser water pump 1	45 kW	20m	189	85%	95%
CWP-2	Condenser water pump 2	22 kW	20m	94.5	85%	95%
CT-1	Cooling tower 1	45 kW	-	130	75%	92%
CT-2	Cooling tower 2	45 kW	-	130	75%	92%

ID	Description	Type	Name plate motor (kW)	Cooling Capacity (RT)	Chilled water LWT	Chilled water ΔT	Efficiency kW/RT
CH-1	Chiller 1	Centrifugal	550	1000	6.7 °C	5.5°C	0.55
CH-2	Chiller 2	VSD Screw	260	500	6.7 °C	5.5°C	0.52

References

- SS 530 : 2006 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment
- SS 553 : 2009 - Code of Practice for Air-Conditioning and Mechanical Ventilation in Buildings
- AHRI Standard 550/590 – Performance Rating of Water Chilling and Heat Pump Water–Heating Packages Using the Vapour Compression Cycle by Air-Conditioning, Heating and Refrigeration Institute(AHRI)

Worked Example

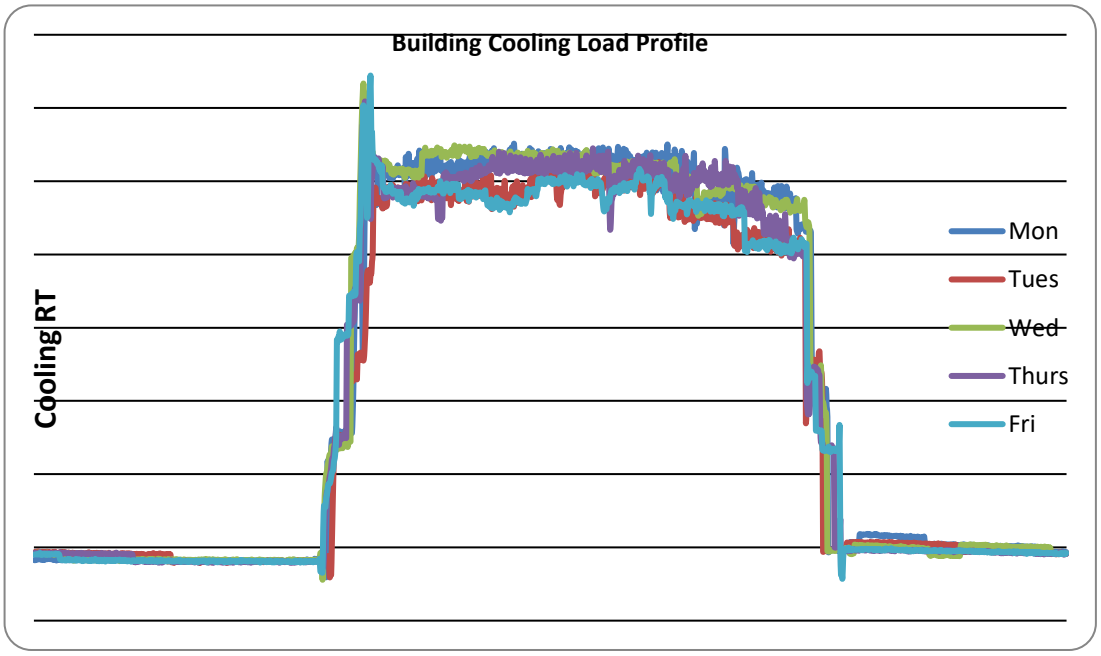
Determining the System Efficiency for Central water-cooled chiller system

Background info

- Office building air-conditioned floor area = 70,000 m^2
- Building operating hours : 8 am to 6pm
- The building cooling load profile is determined from the energy audit on the chiller plant before retrofitting; the result is shown below.

Step 1 : Building cooling load profile (from audit measurements)

Based on the measured building cooling load profile for the building operation hours from 8:00 to 18:00, the cooling load is **1200 RT**.



From energy audit, the building cooling load profile is shown:-

Time	Average Cooling Load (RT)
0:00	190
1:00	190
2:00	190
3:00	190
4:00	190
5:00	190
6:00	190
7:00	1400
8:00	1200
9:00	1200
10:00	1200
11:00	1200
12:00	1200
13:00	1200
14:00	1200
15:00	1200
16:00	1150
17:00	1150
18:00	1150
19:00	190
20:00	190
21:00	190
22:00	190
23:00	190

The chiller plant system efficiency will be computed based on the following cooling loads measured during the specified operating hours i.e. 0900 to 1800 hrs (office building):

(a) 0900 to 1600 hrs : 1200 RT

(b) 1600 to 1800 hrs : 1150 RT

Step 2 : Proposed Chiller Plant Equipment configuration

Proposed chiller plant equipment configuration:-

Equipment	Office hours (0900 to 1800 hrs)	After Office hours (1800 to 0900 hrs)
Chillers	3 nos. x 700 RT (2 in operation & 1 stand-by)	2 nos. x 200 RT (1 in operation & 1 stand-by)
Chilled Water Pumps	3 nos. x 45 kW (2 in operation & 1 stand-by)	2 nos. x 15 kW (1 in operation & 1 stand-by)
Condenser Water Pumps	3 nos. x 55 kW (2 in operation & 1 stand-by)	2 nos. x 18.5 kW (1 in operation & 1 stand-by)
Cooling Towers	3 nos. x 900 RT, each having 3 fans x 7.5 kW	

Important notes :

(1) It is important to design the air-conditioning plant configuration for other load conditions that are not within the building operating hours specified, although this is not required for point scoring purpose.

(2) The estimated operating pump and motor power of the various components at part-load condition as illustrated in Step 4 & 5 are based on the affinity laws assuming that the system curve remains unchanged.

Step 3 : Water-cooled Chillers' Performance

Chillers in operation are 2 nos. x 700 RT during office hours and 1 no. x 200 RT for after office hour operation.

Performance data for selected chillers (700 RT) as given by chiller suppliers is shown below:-

% Load	Capacity (RT)	Chiller Input Power (kW)	Chiller Efficiency kW/RT	Evaporator		Condenser	
				CHWST (°C)	CHWRT (°C)	CWRT (°C)	CWST (°C)
100	700	363	0.519	6.67	12.31	34.80	29.68
90	630	329	0.522	6.67	12.31	34.29	29.68
80	560	291	0.520	6.67	12.31	33.78	29.68
70	490	260	0.533	6.67	12.31	33.28	29.68
60	420	227	0.543	6.67	12.31	32.77	29.68
50	350	195	0.563	6.67	12.31	32.27	29.68
40	280	165	0.596	6.67	12.31	31.76	29.68
30	210	135	0.652	6.67	12.04	31.25	29.68
20	140	104	0.750	6.67	10.27	30.75	29.68
15	105.3	87	0.836	6.67	9.39	30.50	29.68

Cooling load (RT)	No. of Chillers in operation	% Load	kW/RT	Total Chiller Power (kW)
A	B	C	D	E = A x D
1200 RT	2 nos. x 700RT	85.7%	0.521	625.2
1150 RT	2 nos. x 700RT	82.1%	0.520	598.0

Step 4 : Chilled Water Pumps' Performance

(i) 2 nos. x 45 kW pumps will be in operation during office hours and are installed with Variable Speed Drives (VSD)

(ii) Operating pump head = 28 m (from energy audit)

(iii) Pump efficiency = 86.8 % at design operation condition

(iv) Motor efficiency = 94.2 % at design operation condition

(v) Motor absorbed power (kW) is calculated from = $\frac{(Q)(\rho)(g)(h)}{(10^6)(\eta_p)(\eta_m)}$

where

Q=water flow rate in L/s
ρ=density of water = 1000 kg/m^3
g=gravitational acceleration = 9.81 m/s^2
h=static pressure head m
η_p= pump efficiency
η_m=motor efficiency

Chilled Water Pump 1 & 2 (45 kW)					
% Load	A	B	C	D	E = (A x 1000 x 9.81 x B) / (10^6 x C x D)
	Rated Flow (l/s)	Rated Head (m)	Motor Efficiency (%)	Pump Efficiency (%)	Pump input power (kW)
100	106.1	28	94.2	86.8	35.64
90	95.49	22.68	94.2	84.2	26.76
85.7	90.9	20.56	94.2	84	23.17
82.1	87.1	18.87	94.2	83.7	20.45
80	84.88	17.92	94.2	83.3	19.00
70	74.27	13.72	94.2	79.9	13.27
60	63.66	10.08	94.2	77.3	8.64

For total cooling requirement of 1200 RT, the 2 nos. CHW pumps will operate at part-load i.e. 1200RT / 1400RT i.e. 85.7%.

Cooling load (RT)	No. of CHW pumps in operation	% Load	Pump input power (kW)	Total CHW Pump Power (kW)
A	B	C	D	E = B x D
1200	2 nos.	85.7%	23.17	46.34
1150	2 nos.	82.1%	20.45	40.9

Note: It is recommended to limit the speed of the pump to a minimum of 60% of the load.

Step 5 : Condenser Water Pumps' Performance

(i) 2 nos. x 55 kW will be in operation during office hours and all pumps are installed with Variable Speed Drives (VSD)

(ii) Operating pump head = 32 m (from energy audit)

(iii) Pump efficiency = 88.5 % at design operation condition

(iv) Motor efficiency = 94.7 % at design operation condition

Condenser Water Pump 1 & 2 (55 kW)					
% Load	A	B	C	D	E = (A x 1000 x 9.81 x B) / (10^6 x C x D)
	Rated Flow (L/s)	Rated Head (m)	Motor Efficiency (%)	Pump Efficiency (%)	Pump input power (kW)
100	132.51	32	94.7	88.5	49.63
90	119.26	25.92	94.7	85.9	37.28
85.7	113.56	23.5	94.7	85.5	32.33
82.1	108.8	21.57	94.7	85.2	28.53
80	106.01	20.48	94.7	85	26.46
70	92.76	15.68	94.7	81.4	18.51
60	79.51	11.52	94.7	78.8	12.04

For total cooling requirement of 1200 RT, the 2 nos. CW pumps will operate at part-load i.e. at 1200 / 1400 RT i.e. 85.7%.

Cooling load (RT)	No. of CW pumps in operation	% Load	Pump input power (kW)	Total CW Pump Power (kW)
A	B	C	D	E = B x D
1200	2 nos.	85.7%	32.33	64.66
1150	2 nos.	82.1%	28.53	57.06

Note: It is recommended to limit the speed of the pump to a minimum 60% of the rated capacity.

Step 6 : Operating efficiency for Cooling Towers

(i) 2 nos. cooling towers will be in operation with Variable Speed Drives (VSD)

(ii) Heat rejection capacity per cooling tower = 900 RT

(iii) Total heat rejection for 2 nos. cooling towers = 900 RT x 2 = 1800 RT

(iv) Each tower with 3 fan cells, each fan motor = 7.5 kW

(v) Fan Motor efficiency = 92 %

(vi) Fan motor input power for each tower = (7.5 kW x 3 fans.) / 92% = 24.46 kW

(vii) Total power for 2 nos. cooling towers = 24.46 kW x 2 = 48.92 kW

Cooling load (RT)	Chiller Input Power (kW)	Required Heat Rejection (RT)
A	B	C = A + (B / 3.517)
1200	625.2	1377.77
1150	598	1320.03

Cooling load (RT)	No. of CT in operation	Total CT Heat Rejection Capacity (RT)	Percentage Loading for Required & Available Heat Rejection (RT)
A	B	D	E = C / D
1200	2	1800	76.5 %
1150	2	1800	73.3 %

At full speed (100%), total cooling tower (2 nos.) power consumption = 24.46 x 2 = 48.92 kW

Based on the fan law,

$$\frac{\text{Fans Power}_{@\ 76.6\%}}{\text{Fans Power}_{@\ 100\%}} = \left(\frac{\text{Fans Speed}_{@\ 76.6\%}}{\text{Fans Speed}_{@\ 100\%}}\right)^3$$

At 76.6% speed (via VSD), total cooling towers' fans power = 48.92 x $(0.765)^3$ = **21.90 kW**

Similarly, at 73.4% speed, total cooling towers' fans power = 48.92 x $(0.733)^3$ = **19.27 kW**

Cooling Load (RT)	Required Part load % for CT	Total Fan Motor Power at required part load (kW)
1200 RT	76.5%	21.90
1150 RT	73.3%	19.27

Step 7 : System Efficiency

The chiller plant system efficiency at various cooling loads is tabulated below.

Time	Average Cooling Load (RT)	Chillers Power Input (kW)	CHW Pumps Power (kW)	CW Pumps Power (kW)	CT power (kW)	Total Power Input (kW)
9:00	1200	625.2	46.34	64.66	21.90	758.1
10:00	1200	625.2	46.34	64.66	21.90	758.1
11:00	1200	625.2	46.34	64.66	21.90	758.1
12:00	1200	625.2	46.34	64.66	21.90	758.1
13:00	1200	625.2	46.34	64.66	21.90	758.1
14:00	1200	625.2	46.34	64.66	21.90	758.1
15:00	1200	625.2	46.34	64.66	21.90	758.1
16:00	1150	598	40.9	57.06	19.27	715.23

17:00	1150	598	40.9	57.06	19.27	715.23
18:00	1150	598	40.9	57.06	19.27	715.23
Total (0900 to 1800)	$\sum CL_i$ = 11850	6170.4	447.08	623.8	211.11	$\sum TPL_i$ = 7452.39
Efficiency kW/RT		0.521	0.038	0.053	0.018	**0.629**

To summarize, the chiller plant system efficiency for this office building is :

Equipment	Efficiency (kW/RT)
Chillers	0.521
Chilled water pumps	0.038
Condenser water pumps	0.053
Cooling towers	0.018
Total	**0.629**

< 0.75 kW/RT

Determining the System Efficiency for Unitary Air-Conditioners/ Condensing Units - VRF System

For variable refrigerant flow (VRF) system, the efficiency can be computed based on the following formula from NEA:

$COP_{weighted} = 0.4 \times COP_{100\%} + 0.6 \times COP_{50\%}$

$COP_{100\%}$ is defined as the ratio of the cooling capacity to effective power input at full load cooling capacity
$COP_{50\%}$ is defined as the ratio of the cooling capacity to effective power input at 50% cooling capacity

System no.	System Qty	CU model	Specification of Condensing Unit				Efficiency ($COP_{weighted}$)
			Total Cooling Capacity (kW)		Power Input (kW)		
			100%	50%	100%	50%	
System – 1a	1	24HP	67.20	33.60	14.70	5.73	5.35
System – 1b	1	24HP	67.20	33.60	14.70	5.73	5.35
System – 1c	1	24HP	67.20	33.60	14.70	5.73	5.35
System – 2a	1	20HP	54.40	27.20	11.70	4.57	5.43
System – 2b	1	20HP	54.40	27.20	11.70	4.57	5.43
		Total:	**310.4**	**155.2**	**67.5**	**26.33**	**5.376**

VRF system efficiency: 3.517 ÷ 5.376 = **0.65 kW/RT** < 1.1kW/RT

3. ENERGY IMPROVEMENT ON LIGHTING SYSTEM

Objective	To reduce the energy needed to illuminate a space through the use of energy efficient lightings with adequate control strategies.
Applicability	Applicable to lighting provisions for the type of usage specified in *SS 530 : 2006 – Code of Practice for Energy Efficiency Standard for Building Services and Equipment*.
Methodology/ Baseline Standard	To demonstrate at least 20% improvement in the lighting power budget for common areas over the baseline stated in Annex A.
Documentation Requirements	• Lighting layout plan; • Calculation of the lighting power budget showing individual locations with area in m^2, fittings type, power consumption in watt, ballast loss, no. of lamps, total power consumption in watt, power density watt/m^2, reference power density watt/m^2, reference total power consumption and the percentage improvement in the prescribed tabulated format as shown in the worked example 1-4; • Technical product information of the lighting luminaries used.
References	• SS 531 – 1 : 2006 – Code of Practice for Lighting of Workplaces Part 1 – Indoor Lighting or CP 38 : 1999 Code of Practice for Artificial Lighting in Buildings • Annex A specified in this Code.
Worked Example	▪ Determine the total power consumption based on the lighting layout design for each area and light fitting types used. ▪ Calculate the total power consumption based on the maximum lighting power budget stated in the References. ▪ Calculate the percentage improvement in the total power consumption. **Table 1: Total power consumption based on each fitting type**

Description	Areas (m^2) (A)	Light Fitting Type (B)	Power Consumption per fitting (W) (C)	Ballast Loss (W) (D)	No. of Fittings (E)	Total power consumption based on fitting type [(C+D) x (E)]
Corridors Type 1	150	T5	28	3	40	1,240
Corridors Type 2	205	T5	28	3	40	1,240
		Surface downlight	70	3	10	730
Atrium	850	T8	28	6	174	5,916
		Surface downlight	150	3	10	1,530
Carparks	7,500	T5	28	3	870	26,970
Staircase	300	T5	28	3	40	1,240
Male toilets	45	PLC	13	3	15	240
Female toilets	45	PLC	13	3	15	240
					Total	**39,346**

Table 1 : Total power consumption based on design and SS 530 requirements

Description	Areas (m^2) (A)	Design Data		SS 530 Requirements	
		Total Power Consumption (by area)(W) (F)	Design Lighting Power Budget (W/m^2) (F/A)	Reference Lighting Power Budget (W/m^2) (H)	Reference Total Power Consumption (by area) (W) (H x A)
Corridors Type 1	150	1,240	8.27	10	1500
Corridors Type 2	205	1,970	9.61	10	2050
Atrium	850	7,446	8.76	10	8,500
Carparks	7,500	26,970	3.60	5	8500
Staircase	300	1,240	4.13	6	1,800
Male toilets	45	240	5.33	15	37500
Female toilets	45	240	5.33	15	1800
Total		**39,346**			**52,700**

% improvement = $[\Sigma(HxA) - \Sigma(F)] \div \Sigma(HxA) \times 100\%$

= (52,700 - 39,346) ÷ 52,700 x 100%

= 25.34% (>20% improvement)

4. WATER CONSUMPTION MONITORING

<table>
<tr><td>Objective</td><td>To encourage the building owner to monitor the building's water consumption trend in the past 3 years and review its Water Improvement Plan, where necessary.</td></tr>
<tr><td>Applicability</td><td>Applicable to all buildings.</td></tr>
<tr><td>Methodology/ Baseline Standard</td><td>The building's yearly water consumption (m³/GFA(m²)) for the past 3 years shall be calculated and submitted. It shall be calculated based on actual utility bills.</td></tr>
<tr><td></td><td>• Calculation of Water Usage Index (WUI) = TBWC / GFA

Where
TBWC : Total building water consumption (m^3/year)
GFA : Gross floor area (exclude car park area) (m^2)

• The building's past 3 years water bill shall be submitted</td></tr>
<tr><td>References</td><td>Nil</td></tr>
<tr><td>Worked Example</td><td><u>Background info :</u>

Assume an existing building with GFA of 31,540 m^2.

<table>
<tr><th>Month</th><th>Water Bill (2015)</th><th>Water Bill (2016)</th><th>Water Bill (2017)</th></tr>
<tr><td>January</td><td>4,887.00</td><td>4,576.70</td><td>3,639.60</td></tr>
<tr><td>February</td><td>4,360.00</td><td>1,949.80</td><td>4,021.00</td></tr>
<tr><td>March</td><td>4,610.00</td><td>4,135.20</td><td>3,578.80</td></tr>
<tr><td>April</td><td>5,248.00</td><td>4,615.10</td><td>4,153.50</td></tr>
<tr><td>May</td><td>4,505.00</td><td>4,516.00</td><td>4,084.80</td></tr>
<tr><td>June</td><td>4,746.00</td><td>3,794.00</td><td>3,522.10</td></tr>
<tr><td>July</td><td>4,979.00</td><td>4,405.00</td><td>3,777.50</td></tr>
<tr><td>August</td><td>4,328.00</td><td>4,611.80</td><td>4,502.40</td></tr>
<tr><td>September</td><td>4,916.00</td><td>4,949.00</td><td>4,289.90</td></tr>
<tr><td>October</td><td>5,066.00</td><td>4,228.40</td><td>4,712.70</td></tr>
<tr><td>November</td><td>5,194.00</td><td>4,701.80</td><td>4,561.50</td></tr>
<tr><td>December</td><td>5,361.00</td><td>4,674.50</td><td>4,377.40</td></tr>
<tr><td>TOTAL (m^3/yr)</td><td>58,200.00</td><td>51,157.30</td><td>49,221.20</td></tr>
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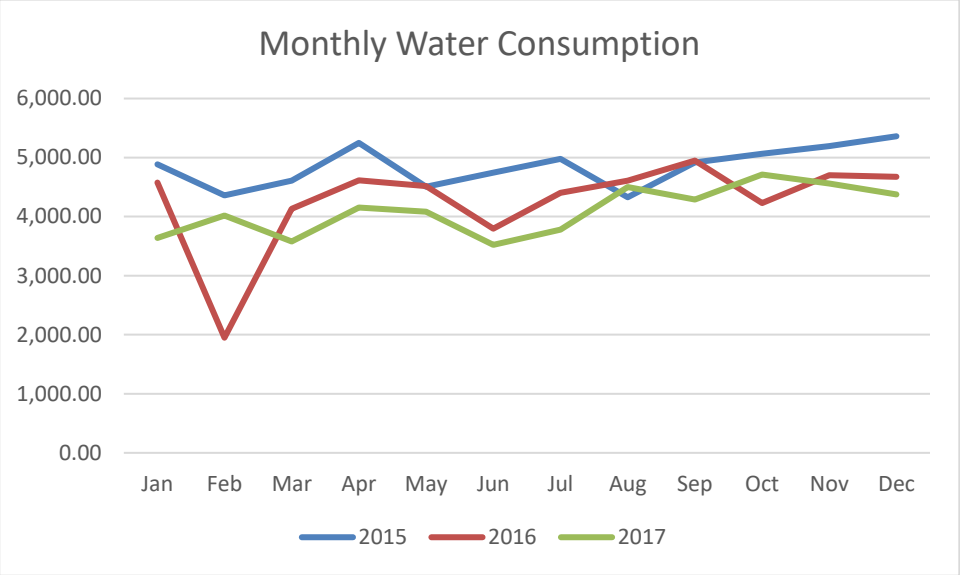
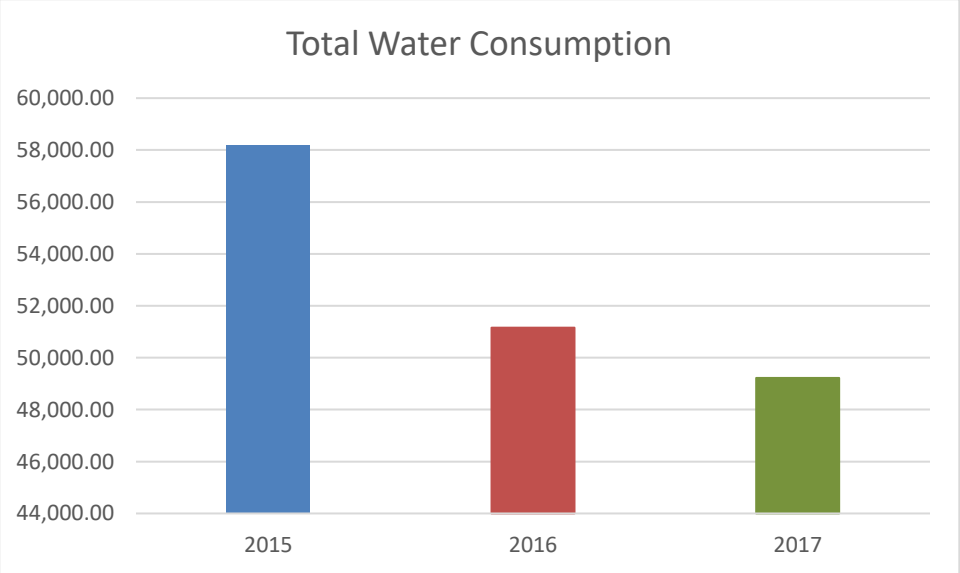
	2015	2016	2017
Total (m^3/yr)	11,104,395.15	10,766,680.34	10,443,841.48
GFA (m^2)	31,540	31,540	31,540
EUI (kWH/yr/m2)	**352.07**	**341.37**	**331.13**
Deviation	**-**	**- 12%**	**- 4%**





5. PERMANENT INSTRUMENTATION FOR THE MEASUREMENT AND VERIFICATION OF CHILLED WATER AIR CONDITIONING SYSTEMS

Objective	To continually monitor and verify the performance of a building's chiller plant with accurate permanent measuring instruments, detect operational anomalies and realise its optimisation potential through analysis of usage patterns.
Applicability	Applicable to all chilled-water air-conditioning systems.
Methodology/ Baseline Standard	Permanent measuring instruments for monitoring of chilled-water system operating efficiency shall be provided. The installed instrumentation shall have the capability to calculate the resultant operating system efficiency (i.e. kW/RT) within 5% of its true value and in accordance with SS591. Each measurement system shall include the sensor(s), any signal conditioning, the data acquisition system and wiring connecting these components. The permanent instrumentation shall comply with the following: • Location and installation of the measuring devices to meet the manufacturer's recommendation; location of temperature sensors should be within reach to facilitate site verification • All data logging with capability to trend at 1-minute sampling time interval, and recorded to the 3rd decimal digit • Computation and display of water-side efficiency • Magnetic in-line flow meter, with 1% uncertainty and capable of electronic in-situ verification to within ±2% of its original factory calibration. If installation of magnetic in-line meters is not possible, ultrasonic flow meters may be used • Temperature sensors are to be provided for chilled water and condenser water loop and shall have an end-to-end measurement uncertainty not exceeding ±0.05°C over the entire measurement range. Provisions shall be made for each temperature measurement location to have test plugs or additional thermo-wells located before and after each temperature sensor for verification of measurement accuracy. All thermo-wells are recommended to be installed in a manner that ensures the sensors can be in direct contact with the fluid flow. There shall be valid justification if direct immersion of the temperature sensor(s) is/are not possible. Such projects will be assessed on a case-by-case basis • Dedicated power meters of accuracy Class 1 or better and metering current transformers, where applicable, of Class 1 or better, are to be provided for each of the following groups of equipment: chillers, chilled water pumps, condenser water pumps and cooling towers fans • A heat balance substantiating test for the water-cooled chilled-water system is to be computed in accordance to SS 591 for verification of the accuracy of the M&V instrumentation. The heat balance shall be computed over the

	entire normal operating hours with more than 80% of the computed heat balance within ± 5% over a 1-week period

Documentation Requirements	• Calculation of total uncertainty of resultant operating system efficiency using the following root sum square formula:
	$$Error_{rms} = \sqrt{\sum (U_N)^2}$$
	Where
	$U_N = \text{Individual uncertainty of variable N (\%)}$
	N = Mass flow rate, electrical power input or delta T
	In deriving the measurement errors contributed by flow meter, an additional 1% is to be included in the computation.
	• Detailed schematic drawings of the instruments and test plugs locations
	• Technical specifications and/or sample data sheets/ product information for instruments and meters
	• Detailed drawings and schematics of the power measurement strategies for the air conditioning system
	• Purchase orders and delivery orders of the instrumentation and power meters installed
	• Instrumentation calibration certificates
	• BMS screenshots showing the relevant calibration inputs have been entered for temperature measurement
	• Site requirement: To determine the chilled-water plant efficiency using the following operation data/ installations to demonstrate compliance with design specifications:
	  ○ From Building Management System
	  ▪ Chilled-water plant kW/RT
	  ▪ Chilled water/ Condenser water supply & return temperatures of the header to be checked for consistency against the temperatures of individual chillers and/or individual branches.
	  ▪ Chilled-water/ Condenser water header flow rate to be checked for consistency against the flow rate(s) of individual branches
	  ▪ The accuracy of the programmed formula for the computation of kW/RT of the various parameters
	  ○ From operating chiller panel
	  ▪ Chilled water/ Condenser water supply & return temperatures to be checked for consistency against the BMS data
	  ▪ Approach of chilled water supply- refrigerant evaporating temperature
	  ▪ Approach of chilled water return- refrigerant condensing temperature
	  ▪ Location of the chilled-water flow meter(s) installed to comply with manufacturer's recommendations

References	• Singapore Standard 591 – Code of Practice for long term measurement of central chilled water system energy efficiency

Worked Example

<u>Computation of overall uncertainty in the resulting chilled-water plant efficiency</u>

As instrumentation measurement uncertainties stated in calibration certificates and technical specifications are based on controlled conditions in a laboratory, it is necessary to allow for on-site deviations and measurements. The overall measurement system comprising the temperature, flow and power measurement shall be capable of calculating resultant chiller-water plant efficiency with the uncertainty within ±5% for on-site measurement. Each measurement shall include the sensor, any signal conditioning (if available), the data acquisition system and the wiring connecting them. The following example illustrates the computation of the uncertainty of the overall measurement system installed.

Item	Measurement System	End-to-End Measurement Uncertainty (% of reading)
1	Temperature	$\frac{\sqrt{0.05^2 + 0.05^2}}{5.5} = 1.3\%$ see note (1)
2	Flow	1% see note (2) + 1% (i.e. 2%)
3	Power	$\sqrt{1^2+1^2}$ = 1.4% see note (3)

Note:

(1) Temperature measurement system shall have an end-to-end measurement uncertainty of ± 0.05°C over the entire measurement range. The combined uncertainty for ΔT is computed based on the root-sum square formula with ΔT assumed to be 5.5 °C as illustrated above.

(2) An additional 1% to be included in the computation of measurement errors for flow meter.

(3) Uncertainty of power measurement system shall include that of the current transformer where applicable. It is recommended that 3rd party verified power meter be specified to ensure accuracy.

The overall uncertainty of the measurement system shall be the combination of the individual uncertainty of each measurement system. Based on the above information, the overall uncertainty of measurement is as shown in the following :

$Error_{rms} = \sqrt{(\sum (U_N)^2)}$ where U_N = individual uncertainty of variable N (%)

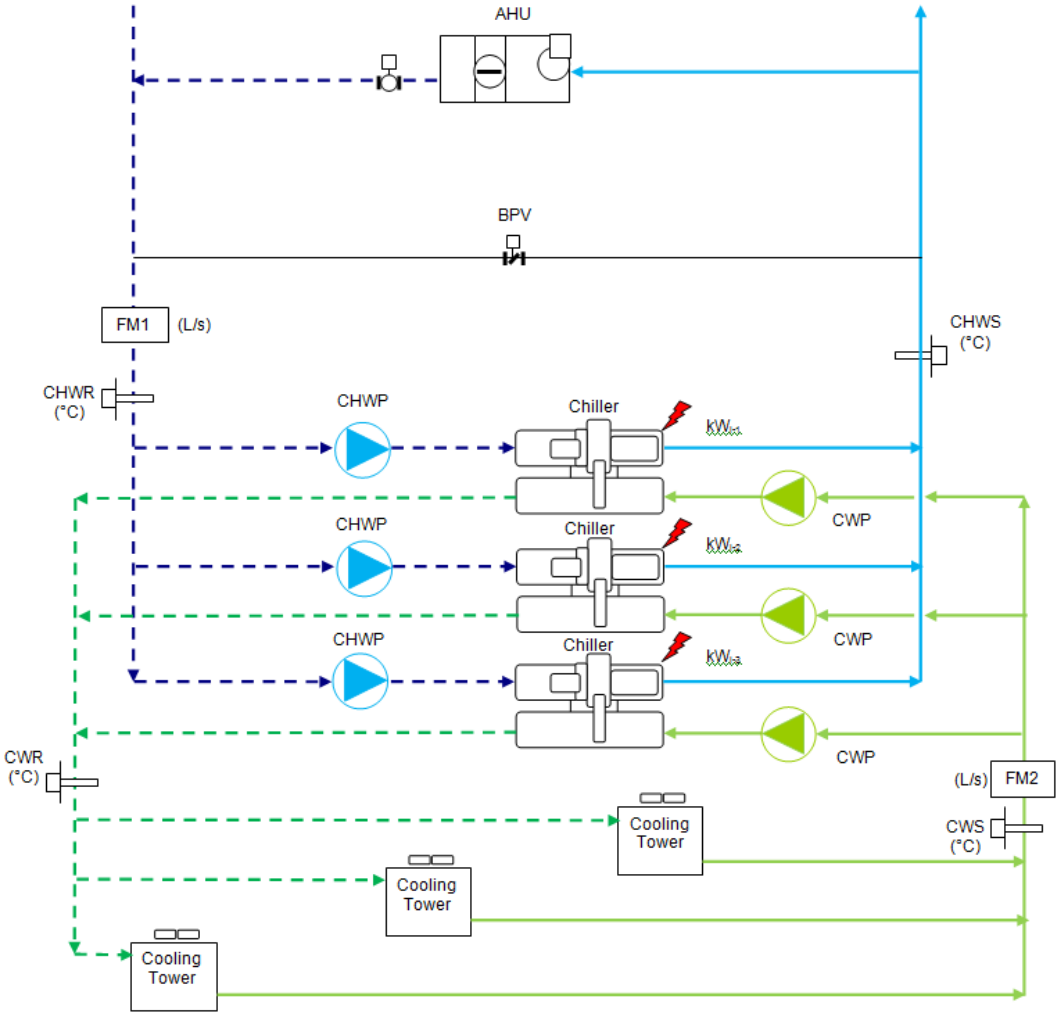
$= \sqrt{(1.3^2 + 2^2 + 1.4^2)}$ N = mass flow rate, electrical power input or delta T

= 2.8 %

Therefore, the total uncertainty for the calculated chilled-water plant efficiency (kW/RT) is 2.8 %, which falls within the 5% of the true value.

Determining Heat Balance for Different Plant Configurations

Plant A – Constant Primary Chilled-Water System



A: $q_{evaporator}$ = m x Cp x ΔT = FM1 x Cp x (CHWR - CHWS)

B: $q_{condenser}$ = m x Cp x ΔT = FM2 x Cp x (CWR - CWS)

C: W_{input} = kW_{i-1} + kWi_{-2} + kWi_{-3}

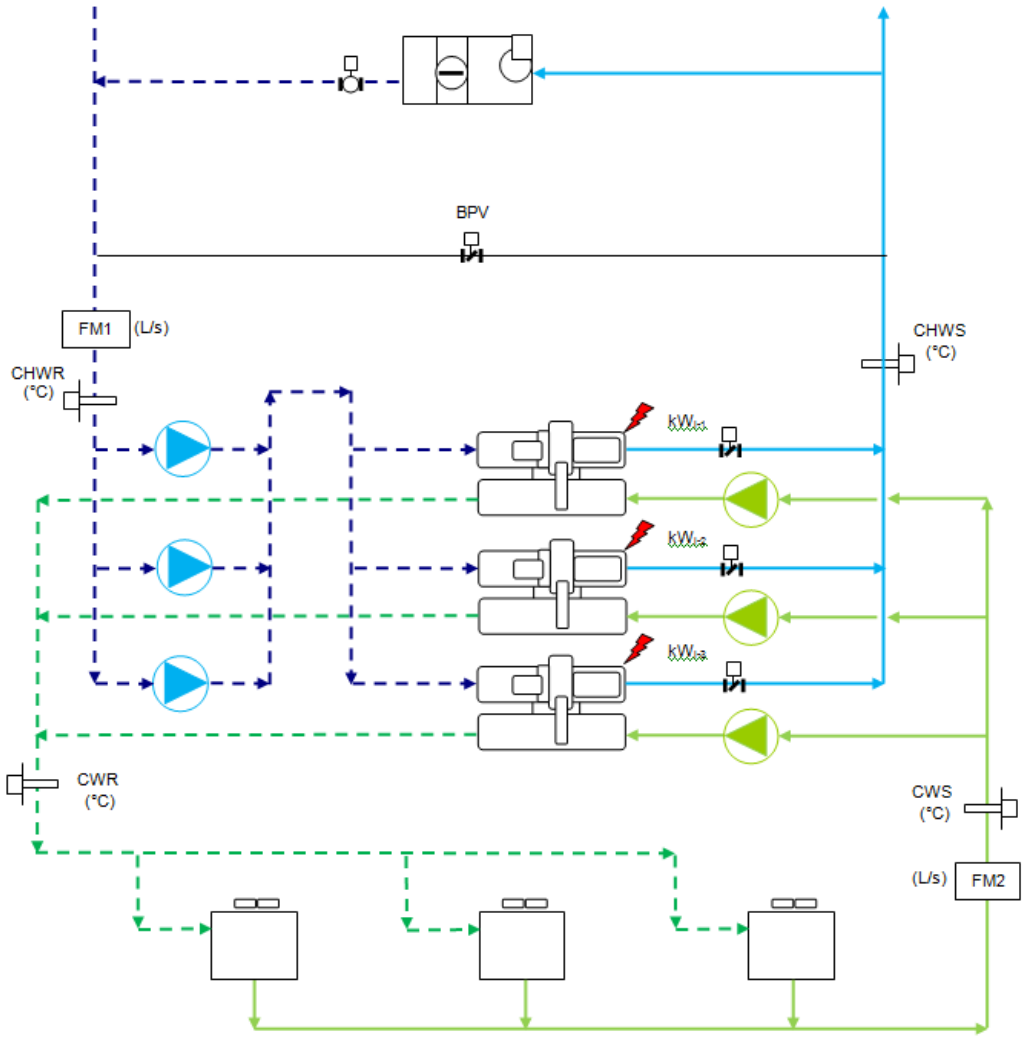
where Cp = 4.19 kJ/kg.ºC & density of chilled water is assumed to be 1kg/l

Percent heat balance = [(A + C) – B] / B x 100%

Note : In the event where hydraulic losses of pumps constitute substantial heat gain, W_{input}/ $q_{condenser}$ may be adjusted to account for these additional heat gain. The value shall be determined from variable speed drive losses, motor efficiency and pump efficiency values certified by the manufacturer.

Determining Heat Balance for Different Plant Configuration

Plant B – Variable Primary Chilled-Water System



A: $q_{evaporator}$ = FM1 x Cp x (CHWR - CHWS)

B: $q_{condenser}$ = FM2 x Cp x (CWR - CWS)

C: W_{input} = kW_{i-1} + kWi_{-2} + kWi_{-3}

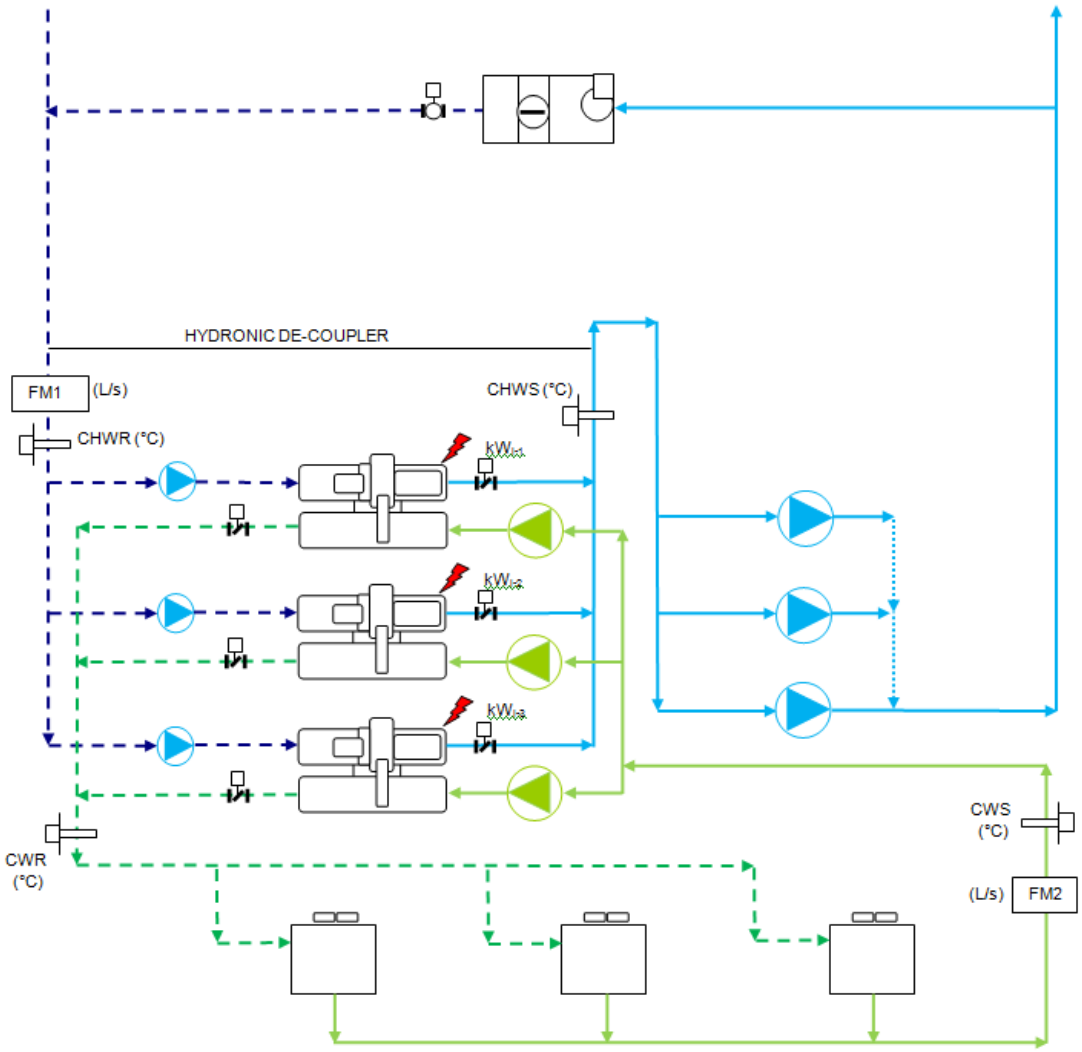
where Cp = 4.19 kJ/kg.ºC & density of chilled water is assumed to be 1kg/l

Percent heat balance = [(A + C) – B] / B x 100%

Note: In the event where ~~h~~hydraulic losses of pumps constitute substantial heat gain, W_{input}/ $q_{condenser}$ may be adjusted to account for these additional heat gain. The value shall be determined from variable speed drive losses, motor efficiency and pump efficiency values certified by the manufacturer.

Determining Heat Balance for Different Plant Configuration

Plant C – Constant Primary & Variable Secondary Chilled-Water System



A: $q_{evaporator}$ = FM1 x Cp x (CHWR – CHWS)

B: $q_{condenser}$ = FM2 x Cp x (CWR - CWS)

C: W_{input} = kW_{i-1} + kW_{i-2} + kW_{i-3}

where Cp = 4.19 kJ/kg.ºC & density of chilled water is assumed to be 1kg/l

Percent heat balance = [(A + C) – B] / B x 100%

Note: In the event where hydraulic losses of pumps constitute a substantial heat gain, W_{input}/ $q_{condenser}$ may be adjusted to account for these additional heat gain. The value shall be determined from variable speed drive losses, motor efficiency and pump efficiency values certified by the manufacturer.

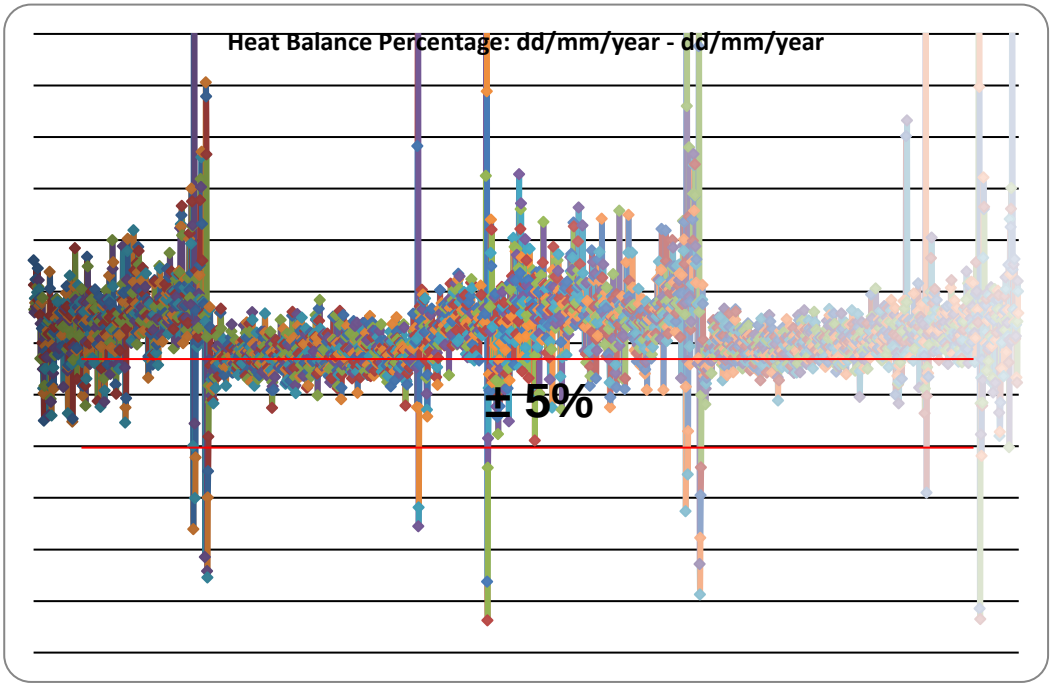
	(a) Chilled water supply temperature	(b) Chilled water return temperature	(c) Chilled water flow rate	(d) Condenser water supply temperature	(e) Condenser water return temperature	(f) Condenser water flow rate	(g) Chiller kWe	(h) Heat Gain	(i) Heat Rejected	(j) Percent Heat Balance
dd/mm/yyyy hh:mm	°C	°C	L/s	°C	°C	L/s	kW	RT	RT	%
16/6/2012 15:00	6.70	12.60	84.10	29.4	35.5	97.65	308	591.14	709.65	-4.36
16/6/2012 15:01	6.71	12.50	84.20	29.5	35.4	97.60	309	580.81	686.03	-2.53
16/6/2012 15:02	6.72	12.30	84.30	29.6	35.3	97.55	310	560.41	662.44	-2.10
16/6/2012 15:03	6.73	12.10	84.20	29.7	35.2	97.50	311	538.68	638.86	-1.84
16/6/2012 15:04	6.74	12.20	84.10	29.8	35.1	97.55	312	547.05	615.95	3.22
16/6/2012 15:05	6.75	12.00	84.00	29.9	35	97.60	311	525.39	593.01	3.51
16/6/2012 15:06	6.74	12.30	84.10	29.8	35.1	97.65	310	557.07	616.58	4.64
16/6/2012 15:07	6.73	12.10	84.20	29.7	35.2	97.60	309	538.68	639.52	-2.03
16/6/2012 15:08	6.72	12.10	84.30	29.6	35.3	97.55	308	540.32	662.44	-5.21
16/6/2012 15:09	6.71	12.20	84.20	29.5	35.4	97.50	309	550.71	685.33	-6.82
16/6/2012 15:10	6.70	12.40	84.10	29.4	35.2	97.55	310	571.10	674.06	-2.20
16/6/2012 15:11	6.70	12.60	84.10	29.4	35.5	97.65	308	591.14	709.65	-4.36
16/6/2012 15:12	6.71	12.50	84.20	29.5	35.4	97.60	309	580.81	686.03	-2.53
16/6/2012 15:13	6.72	12.30	84.30	29.6	35.3	97.55	310	560.41	662.44	-2.10
16/6/2012 15:14	6.73	12.10	84.20	29.7	35.2	97.50	311	538.68	638.86	-1.84
16/6/2012 15:15	6.74	12.20	84.10	29.8	35.1	97.55	312	547.05	615.95	3.22
16/6/2012 15:16	6.75	12.00	84.00	29.9	35	97.60	311	525.39	593.01	3.51
16/6/2012 15:17	6.74	12.30	84.10	29.8	35.1	97.65	310	557.07	616.58	4.64
16/6/2012 15:18	6.73	12.10	84.20	29.7	35.2	97.60	309	538.68	639.52	-2.03
16/6/2012 15:19	6.72	12.10	84.30	29.6	35.3	97.55	308	540.32	662.44	-5.21
16/6/2012 15:20	6.71	12.20	84.20	29.5	35.4	97.50	309	550.71	685.33	-6.82
16/6/2012 15:21	6.70	12.40	84.10	29.4	35.2	97.55	310	571.10	674.06	-2.20
Total							**6814**	**12,202.71**	**14,367.72**	**32.36**
									Total data count	**22**
									Data Count > +5% error	**0**
									Data Count < -5% error	**4**
									Percentage of heat balance within ± 5%	**82%**

Heat Gain (h) = m x Cp x ΔT = (c) x 4.19kJ/kg.ºC x [(b) – (a)] / 3.517

Heat Rejected (i) = (f) x 4.19 kJ/kg ºC x [(e) – (d)] / 3.517

Percent Heat Balance (j) = [(g) / 3.517 + (h) – (i)] / (i) x 100%

System level heat balance plot (example)



Summary of Heat Balance (example)

	Quantity	Unit	Formula
Sum of total electrical energy used	6814	kWh	(A)
Sum of total cooling produced	12,202	RTh	(B)
Sum of total heat rejected	14,367	RTh	(C)
Chiller Plant Efficiency	0.56	kW/RT	(A) / (B)
Total Heat Balance Data Count	22	-	(D)
Data Count > 5% error	0	-	(E)
Data Count < 5% error	4	-	(F)
Data Count within ±5% error	18	-	(G) = (D) – (E) – (F)
% Heat Balance within ±5% error	82	%	(G) / (D) x 100%

Based on the above example, 82% of the heat balance calculation falls within ± 5% which fulfills the criterion of 80%.

Note : Actual heat balance shall be conducted over the entire normal operating hours with more than 80% of the computed heat balance within ±5% over one (1) week period.

Abbreviations used in Worked Example

CH	Chiller	--
CHWP	Chilled Water Pump	-
CWP	Condenser Water Pump	-
CT	Cooling Tower	-
CHWS	Chilled Water Supply Temperature	^oC
CHWR	Chilled Water Return Temperature	^oC
CWS	Condenser Water Supply Temperature	^oC
CWR	Condenser Water Return Temperature	^oC
KW	Electrical Power Consumption	kW
$q_{evaporator}$	Cooling Load	kW or RT
$q_{condenser}$	Heat Rejection	kW or RT
W_{input}	Energy Input	kW
AHU	Air Handling Unit	
BP	Bypass Line	
BPV	Bypass Valve (2-Way Modulating)	
Cp	Specific Heat Capacity of Water	4.19 kJ/kg.^oC

6. INDOOR TEMPERATURE

Objective	To prevent overcooling of air-conditioned premises in order to save energy and provide thermal comfort to the building occupants.
Applicability	Applicable to occupied air-conditioned spaces.
Methodology/ Baseline Standard	The normal dry-bulb temperature for comfort air-conditioning shall be maintained at 23ºC and above.
Documentation Requirements	IAQ surveillance audit report (hardcopy and softcopy in excel template) endorsed by an accredited laboratory
References	• SS 554:2016 - Code of Practice for Indoor Air Quality for Air-conditioned Buildings IAQ management programme.

7. INDOOR AIR QUALITY (IAQ) SURVEILLANCE AUDIT

Objective	To ensure a comfortable and healthy indoor environment for occupants through the testing and evaluation of IAQ parameters within an occupied air-conditioned space.
Applicability	Applicable to all air-conditioned premises where air-conditioning is used intermittently or continuously, with the exception of residential premises, factory production areas, hospitals, polyclinics and laboratories.
Methodology/ Baseline Standard	To conduct an IAQ surveillance audit based on the indicative methods according to *SS 554 : 2016 Code of Practice for Indoor Air Quality for Air-Conditioned Buildings* or demonstrate good IAQ performance according to NEA's *Guidelines for Good Indoor Air Quality in Office Premises*.
Documentation Requirements	IAQ surveillance audit report (hardcopy and softcopy in excel template) endorsed by an accredited laboratory
References	• NEA's Guidelines for Good Indoor Air Quality in Office Premises • SS 554:2016 - Code of Practice for Indoor Air Quality for Air-conditioned Buildings.