Department of Electrical and Electronic Engineering

The University of Hong Kong

Final Report

on

Research on Energy Management and Power Quality

in

Tseung Kwan O Hospital

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1. Introduction

This is a collaborative research project between EMSD and HKU to seek synergism in facilitating energy saving and elevating power quality in Tseung Kwan O Hospital. This report outlines the objectives and the scope of study, study on energy consumption pattern, power quality analysis and solution recommendations.

a. Objectives

An energy consumption study involves the systematic review of the energy consuming equipment/systems in a building, which delivers comprehensive information for the building owner to decide on and implement the energy saving measures for environmental consideration and economic benefits. A power quality analysis involves detailed study on different parameters in the electrical system in a building, hence developing solutions and recommendations on the possible power problems discovered, which provides strategies for building owner to improve the power quality in the building.

b. Scope of Study

In energy consumption study, the following scope of study is included:

- Coordinating with operation and maintenance staff on collecting building information;
- Identifying of all building services operating systems such as air-conditioning systems, lighting system, electrical system and other system;
- Studying on the energy consumption report provided from EMSD;
- Conducting site measurement of system with tools and meters as appropriate;
- Studying and analyzing the measuring data and estimating energy efficiency;
- Making recommendation on energy consumption for future implementation.

The following methodology/ assumptions are also included:

I. Electricity Consumption Study
   a) Study the incoming mains distribution and electricity meter(s).
   b) Study the electricity consumption for
      - Air-conditioning
      - Public lightings (normal and essential)
      - Lift and escalators
      - Plumbing

II. Power Quality Analysis
   a) Study the electrical schematics and MCB schedule.
   b) Study the power quality of
      - Transformer TA1 (Tx4)
      - Transformer TA2 (Tx5)
      - Transformer TB3 (Tx6)
      - Transformer TB4 (Tx1)
      - Transformer TC5 (Tx2)
      - Transformer TC6 (Tx3)

III. Site Measurements

a) For air-conditioning and lighting system:

- Raw data collection from energy monitoring devices and Central Control Monitoring System (CCMS).
- Perform site measurements for 2 half day using lux meter and indoor thermometer.
- Perform site measurement for 3 weeks (2 times separately, 1+2 weeks) using power analyzer.
- After 2 site measurements, the data shall be input to computer and organized for analysis.

IV. Analysis

a) Obtain the recorded energy consumption data from building management staff and site measurement.
b) In macroscopic approach, reflecting the performance of the whole building is the greatest consideration.
c) In microscopic approach, tackling the particular source of problem in the building is prioritized.
d) For air-conditioning, compare site measured data with the optimum indoor temperature to estimate the efficiency.
e) For lighting, compare site measured data with desire illuminance level to project the efficiency.
f) Establish the percentage annual energy consumption of system types for comparison / suggestions.
g) Track the variation of different parameters for problem identification / evaluation.

V. Assumptions and Estimating Methods

a) The daily energy consumption of lighting system and air-conditioning system was assumed to be constant throughout the year.
b) The lightings for plant rooms were seldom used and their energy consumptions were negligible to take into account of total energy consumption.

c. Instrument Available for Measurement

I. Power Analyzer (Model: Fluke 1738 Power Logger)
II. Lux Meter (Model: CEM Light Meter)
III. Indoor Thermometer (Model: Fluke t3000 FC K-Type Thermometer)

d. Member of the Research Team

Principal investigator: Dr. Philip W.T. Pong

Co-investigator: Dr. K. H. Lam

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2. Building Characteristics

Tseung Kwan O Hospital Ambulatory Care Block is located at 2 Po Ning Lane, Hang Hau, Tseung Kwan O, Kowloon. Table 2.1 and Table 2.2 summarize the building characteristics and the major types of functional areas in the building respectively.

Table 2.1 Building Characteristics

Name of Building			Tseung Kwan O Hospital Ambulatory Care Block
Location			2 Po Ning Lane, Tseung Kwan O, Kowloon
Usage of building			Hospital
Internal Floor area of building			36,893 m^2
Nos. of floor			10 + Roof
Operating Characteristics	LG/F		24 hours/day
	G/F	Psychiatric Centre	15 hours/day (Mon-Fri); 5 hours/day (Sat, Sun & Public Holiday)
		MRI, Security & CCMS Room	24 hours/day
		Specialist Outpatient Appointment Booking Office & Shroff & Enquiry	15 hours/day (Mon – Fri); 6.5 hours/day (Sat)
	1/F	Blood Taking Station	10 hours/day (Mon – Fri); 6 hours/day (Sat)
		Fever Triage Room	13 hours/day (Mon – Fri); 8 hours/day (Sat, Sun & Public Holiday)
		Minor O.T	24 hours/day
		Family Medicine & Primary Health Care	10.5 hours/day (Mon – Fri); 6.5 hours/day (Sat)
		Health Resources Centre & Function Room	12 hours/day (Mon – Fri); 8 hours/day (Sat)
	2/F	Obstetrics & Gynecology Clinic, Fever Triage Room	12 hours/day (Mon – Fri); 8 hours/day (Sat, Sun & Public Holiday)
		Registration Counter & Office	12 hours/day (Mon – Fri); 8 hours/day (Sat)
		Surgical Clinic Orthopedics & Traumatology Clinic	12 hours/day (Mon – Fri); 8 hours/day (Sat, Sun & Public Holiday)
	3/F	Pediatrics & Adolescent Medicine Clinic	12 hours/day (Mon – Fri); 8 hours/day (Sat, Sun & Public Holiday)
		Fever Triage Room	13 hours/day (Mon – Fri); 8 hours/day (Sat, Sun & Public Holiday)
		Registration Counter & Office	12 hours/day (Mon – Fri); 8 hours/day (Sat)

Operating Characteristics	3/F	Eye, Ear, Nose & Throat Clinic, Minor O.T.	24 hours/day
	4/F	HDC / Integrated Rehabilitation Services	10.5 hours/day (Mon – Fri)
		Electrographic Diagnostic Unit	12 hours/day (Mon – Fri); 9 hours/day (Sat. Sun & Public Holiday)
		Pulmonary Function Room	12 hour/day (Mon – Fri); 8 hours/day (Sat, Sun & Public Holiday)
		Geriatric Day Hospital, Diabetes Centre	12 hours/day (Mon – Fri); 10 hours/day (Sat & Sun)
		Nurse Office, Equipment Room	12 hours/day (Mon – Fri); 9 hours/day (Sat & Sun)
	5/F		24 hours/day
	6/F	Chinese Medicine Clinic & Staff Fitness Room, Common Room	24 hours/day
		Fever Triage Room	13 hours/day (Mon – Fri); 9.5 hours/day (Sat) 8 hours/day (Sun & Public Holiday)
		SOPD Administration	12 hours/day (Mon – Fri)
	7/F		24 hours/day
	8/F		12 hours/day (Mon – Sat)

Table 2.2 Major Types of Functional Areas in the Building

Floor No.	Major Types of Functional Areas
LG/F	HIRD, Pharmacy
G/F	Psychiatric Centre, MRI, Security Room, CCMS Room, Specialist Outpatient Appointment Booking Office, Shroff, Enquiry
1/F	Blood Taking Station, Fever Triage Room, Minor O.T, Medical Clinic, Family Medicine & Primary Health Care, Health Resources Centre and Function Room
2/F	Obstetrics & Gynecology Clinic, Registration Counter & Office, Surgical Clinic Orthopedics & Traumatology Clinic, Fever Triage Room
3/F	Pediatrics & Adolescent Medicine Clinic, Fever Triage Room, Registration Counter & Office, Eye, Ear, Nose & Throat Clinic, Minor O.T.
4/F	HDC / Integrated Rehabilitation Services, Electrographic Diagnostic Unit, Pulmonary Function Room, Geriatric Day Hospital, Diabetes Centre, Nurse Office, Equipment Room
5/F	Day Medical Centre, Minor O.T. in DMC, Ambulatory Surgery Centre, O.T.
6/F	Chinese Medicine Clinic, Fever Triage Room, SOPD Administration, Staff Fitness Room, Common Room
7/F	Library, Overnight Room
8/F	Administration Offices, Lecture Theatre
R/F	Exhaust Fan Room, MCC Room, Lift Machine Room, A/C Plant Room

3. Study on Energy Consumption Pattern

a. General Description of Systems in Ambulatory Care Block (ACB)

From the information obtained from the technical staff of the building, the information of E/M schedule is summarized as follows:-

I. Air-Conditioning System

Equipment Description

For the air-conditioning system, there are 10 nos. of air-cooled chillers and 18 nos. of chilled water pumps. The technical data of the chillers and chilled water pumps are summarized in Table 3.1.1.1 and Table 3.1.1.2 respectively

Table 3.1.1.1 Summary of Chillers

Designation no.	Brand	Model	Type	Refrige -rant type	Rated cooling capacity (kW)	Rated input power (kW)	Qty	Location	Daily operation hours
OFAC-R-1 To OFAC R-6	Smardt	A082.3 BH6	Air-cooled (Centrifugal)	R134a	820	269	6	R/F	24
HRC-R-1 & HRC-R-2	Mcquary	ALS 241.2 XE SR3	Air-cooled (Screw)	R134a	870	293.1	2	R/F	24
CHP-R-01 to 02	Mcquary	MHS 260.2 FST4	Air-cooled (Screw)	R134a	870	287.5	2	R/F	24

Table 3.1.1.2 Summary of Chilled Water Pumps

Designation no.	Primary or Secondary circuit?	Pump rated motor power (kW)	Pump rated flow (L/s)	Qty	Location	Daily operation hours
PCHWP-1 to PCHWP-1	Primary	11	35.7	7	R/F	24
PCHWP-8 to PCHWP-11	Primary	11	37.8	4	R/F	24
SCHWP-1 to SCHWP-4	Secondary	30	80.5	4	R/F	24
SCHWP-5 to SCHWP-7	Secondary	11	26.1	3	R/F	24

The building is served by air handling units (AHUs), primary air units (PAUs) and fan coil units (FCUs). The technical data of air handling units (AHUs), primary air units (PAUs) and fan coil units (FCUs) are summarized in Table 3.1.1.3, Table 3.1.1.4 and Table 3.1.1.5 respectively.

Table 3.1.1.3 Summary of Air Handling Units (AHUs)

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
AHU-LG-1	Savier	15	6,613	1	LG/F	24
AHU-LG-2	Savier	11	4,355	1	LG/F	24
AHU-G-1	Savier	11	3,934	1	G/F	24
AHU-G-2	Savier	11	4,656	1	G/F	24
AHU-G-3	Savier	11	4,291	1	G/F	24
AHU-G-4	Savier	11	4,987	1	G/F	24
AHU-1-1	Savier	5.5	2,722	1	1/F	24
AHU-1-2	Savier	5.5	2,548	1	1/F	24
AHU-1-3	Savier	7.5	3,426	1	1/F	24
AHU-1-4	Savier	11	4,167	1	1/F	24
AHU-2-1	Savier	7.5	3,214	1	2/F	24
AHU-2-2	Savier	7.5	3,061	1	2/F	24
AHU-2-3	Savier	11	4,214	1	2/F	24
AHU-3-1	Savier	5.5	2,634	1	3/F	24
AHU-3-2	Savier	5.5	2,571	1	3/F	24
AHU-3-3	Savier	7.5	2,878	1	3/F	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
AHU-4-1	Savier	11	4,003	1	4/F	24
AHU-4-2	Savier	5.5	2,151	1	4/F	24
AHU-4-3	Savier	4	1,300	1	4/F	24
AHU-4-4	Savier	7.5	3,930	1	4/F	24
AHU-4-5	Savier	7.5	2,663	1	4/F	24
AHU-4-6	Savier	4	1,782	11	4/F	24
AHU-5-1	Savier	11	4,374	1	5/F	24
AHU-5-2	Savier	18.5	8,591	1	5/F	24
AHU-6-1	Savier	11	3,910	1	6/F	24
AHU-6-2	Savier	3	1,310	1	6/F	24
AHU-6-3 to AHU-6-6	Savier	7.5	1,900	4	6/F	24
AHU-6-7	Savier	5.5	2,180	1	6/F	24
AHU-6-8	Savier	5.5	2,710	1	6/F	24
AHU-8-1	Savier	15	5,630	1	8/F	24
AHU-8-2	Savier	5.5	2,580	1	8/F	24
AHU-8-3	Savier	7.5	2,820	1	8/F	24
AHU-R-1	Savier	2.2	350	1	R/F	24
AHU-R-2	Savier	1.5	390	1	R/F	24

Table 3.1.1.4 Summary of Primary Air Units (PAUs)

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
PAU-7-1	Savier	11	4,235	1	7/F	24

Table 3.1.1.5 Summary of Fan Coil Units (FCUs)

Designation no.	Brand	Model	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
FCU-08H	McQuary	MCW800AC5	0.162	310	1	LG/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	3	LG/F	24
FCU-08H	McQuary	MCW800AC5	0.162	310	3	G/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	1	G/F	24
FCU-14H	McQuary	MCW1400AC5	0.279	542	3	G/F	24
FCU-04	McQuary	MCW400AC3	0.072	155	1	1/F	24
FCU-08H	McQuary	MCW800AC5	0.162	310	2	1/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	1	1/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	2	2/F	24
FCU-08H	McQuary	MCW800AC5	0.162	310	1	3/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	1	3/F	24
FCU-04	McQuary	MCW400AC3	0.072	155	1	4/F	24
FCU-08H	McQuary	MCW800AC5	0.162	310	3	4/F	24

Designation no.	Brand	Model	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
FCU-10H	McQuary	MCW1000AC5	0.187	387	1	4/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	1	5/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	3	6/F	24
FCU-04S	McQuary	MCW400AC3	0.077	155	50	7/F	24
FCU-06S	McQuary	MCW600AC3	0.107	232	11	7/F	24
FCU-08H	McQuary	MCW800AC5	0.162	310	2	7/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	1	7/F	24
FCU-12	McQuary	MCW1200AC3	0.217	465	3	7/F	24
FCU-08	McQuary	MCW800AC3	0.142	310	1	8/F	24
FCU-10H	McQuary	MCW1000AC5	0.187	387	1	8/F	24
FCU-10L	McQuary	MCW800AC5	0.183	387	1	8/F	24
FCU-08H	McQuary	MCW800AC5	0.162	310	2	R/F	24
FCU-08L	McQuary	MCW800AC5	0.162	310	2	R/F	24
FCU-14H	McQuary	MCW1400AC5	0.279	542	1	R/F	24
FCU-14L	McQuary	MCW1400AC5	0.279	542	2	R/F	24

II. Ventilation System

For the ventilation system, there are 115 nos. of ventilation fans serving the building. The technical data of the ventilation fans is summarized in Table 3.1.2.1.

Table 3.1.2.1 Summary of Ventilation Fans

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
FAF-B-1 & FAF-B-2	Plymovent	7.5	6,500	2	B/F Fan Room	24
EAF-B-1	Systemair	2.2	1,440	1	B/F PD Pump and Tank Rm (GL 26, AB) and Fan Room (GL 12, BC)	24
EAF-B-2	Systemair	0.9	140	1	B/F Fan Room (GL 57, BC)	24
EAF-B-3	Plymovent	7.5	6,500	1	B/F PD Pump and Tank Rm (GL 26, AB)	24
EAF-LG-1 & EAF-LG-2	Plymovent	7.5	6,500	2	LG AHU Rm (GL 79, CE)	24
EAF-LG-3	Systemair	0.373	340	1	LG AHU Rm (GL 79, CE)	24
EAF-LG-4	Systemair	2.2	1,890	1	LG FS Pump and Tank Rm (GL 68, EG)	24
EAF-LG-5	Systemair	0.64	470	1	LG AHU Rm (GL 79, CE)	24
EAF-LG-6	Systemair	0.373	160	1	LG Public Lav. (Dis)	24
EAF-LG-7	Systemair	0.64	550	1	LG Genset Rm (GL 13, GH)	24
EAF-LG-8	Systemair	1.5	1,250	1	LG Carpark for Neats’ Vehicles (GL 45, HJ)	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
EAF-LG-9	Systemair	0.373	265	1	LG Staff Lav.	24
EAF-LG-10	Systemair	2.2	1,890	1	LG FS Pump and Tank Rm (GL 68, EG)	24
EAF-G-1	Systemair	0.373	268	1	G/F AHU Rm (GL 24, FH)	24
EAF-G-2	Systemair	0.373	113	1	G/F AHU Rm (GL 24, FH)	24
EAF-G-3	Systemair	0.373	372	1	G/F Patient Lav. (F) (04.8)	24
EAF-G-4	Systemair	0.373	434	1	G/F AHU Rm (GL 79, GH)	24
EAF-G-5	Systemair	0.64	741	1	G/F AHU Rm (GL 79, GH)	24
EAF-G-6	Systemair	0.373	73	1	G/F AHU Rm (GL 79, GH)	24
EAF-G-7	Systemair	0.373	336	1	G/F AHU Rm (GL 79, GH)	24
EAF-G-8	Systemair	0.373	215	1	G/F AHU Rm (GL 79, GH)	24
EAF-G-9	Systemair	0.64	710	1	G/F AHU Rm (GL 79, HJ)	24
EAF-G-10	Systemair	1.5	1,170	1	G/F Genset Rm (GL 46, GL)	24
EAF-G-11	Systemair	0.373	165	1	G/F Plant Room for MRI Suite	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
EAF-1-1	Systemair	2.2	1,440	1	1/F AHU Rm (GL 24, FH)	24
EAF-1-2	Systemair	0.9	140	1	1/F AHU Rm (GL 24, FH)	24
EAF-1-3	Systemair	2.2	1,250	1	1/F AHU Rm (GL 24, FH)	24
EAF-1-4	Systemair	0.373	340	1	1/F Patient Lav. (Dis) (GL 13, BC)	24
EAF-1-5	Systemair	2.2	1,890	1	1/F Patient Lav. (Dis) (GL 13, CD)	24
EAF-1-6	Systemair	0.64	470	1	1/F AHU Rm (GL 79, GH)	24
EAF-1-7	Systemair	0.373	160	1	1/F AHU Rm (GL 79, GH)	24
EAF-1-8	Systemair	0.64	550	1	1/F AHU Rm (GL 79, GH)	24
EAF-2-1	Systemair	0.373	461	1	2/F AHU Rm (GL 79, FH)	24
EAF-2-2	Systemair	0.373	482	1	2/F AHU Rm (GL 79, FH)	24
EAF-2-3	Systemair	0.373	303	1	2/F Public Lav. (M) (026.2)	24
EAF-2-4	Systemair	0.373	572	1	2/F AHU Rm (GL 79, GH)	24
EAF-2-5	Systemair	0.373	332	1	2/F AHU Rm (GL 79, GH)	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
EAF-2-6	Systemair	0.373	266	1	2/F AHU Rm (GL 79, GH)	24
EAF-3-1	Systemair	0.64	654	1	3/F AHU Rm (GL 24, FH)	24
EAF-3-2	Systemair	0.373	243	1	3/F AHU Rm (GL 24, FH)	24
EAF-3-3	Systemair	0.373	506	1	3/F AHU Rm (GL 24, FH)	24
EAF-3-4	Systemair	0.64	720	1	3/F Public Lav. (F) (026.1)	24
EAF-3-5	Systemair	0.373	161	1	3/F AHU Rm (GL 79, GH)	24
EAF-3-6	Systemair	0.373	538	1	3/F AHU Rm (GL 79, GH)	24
EAF-3-7	Systemair	0.373	266	1	3/F AHU Rm (GL 79, GH)	24
EAF-4-1	Systemair	0.373	220	1	4/F AHU Rm (GL 24, FH)	24
EAF-4-2	Systemair	0.373	256	1	4/F AHU Rm (GL 24, FH)	24
EAF-4-3	Systemair	0.373	117	1	4/F AHU Rm (GL 24, FH)	24
EAF-4-4	Systemair	0.373	210	1	4/F AHU Rm (GL 24, FH)	24
EAF-4-5	Systemair	0.373	338	1	4/F Public (026.2)	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
EAF-4-6	Systemair	0.64	556	1	4/F AHU Rm (GL 79, GH)	24
EAF-4-7	Systemair	0.373	343	1	4/F AHU Rm (GL 79, GH)	24
EAF-4-8	Systemair	0.373	534	1	4/F AHU Rm (GL 79, GH)	24
EAF-4-9	Systemair	0.373	338	1	4/F AHU Rm (GL 79, GH)	24
EAF-4-10	Systemair	0.373	234	1	4/F AHU Rm (GL 79, GH)	24
EAF-5-1	Systemair	0.373	234	1	5/F AHU Rm (GL 24, FH)	24
EAF-5-2	Systemair	0.373	389	1	5/F AHU Rm (GL 24, FH)	24
EAF-5-3	Systemair	0.9	761	1	5/F Public Lav. (026.2)	24
EAF-5-4	Systemair	0.373	290	1	5/F AHU Rm (GL 79, GH)	24
EAF-5-5	Systemair	0.9	793	1	5/F AHU Rm (GL 79, GH)	24
EAF-5-6	Systemair	0.9	973	1	5/F AHU Rm (GL 79, GH)	24
FAF-6-1	Plymovent	3	3,600	1	6/F AHU Rm (GL 789, GH)	24
FAF-6-2	Plymovent	4	3,600	1	6/F AHU Rm (GL 789, GH)	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
FAF-6-3	Plymovent	7.5	5,800	1	6/F AHU Rm (GL 789, GH)	24
EAF-6-1	Systemair	0.373	266	1	6/F AHU Rm (GL 24, FH)	24
EAF-6-2	Systemair	0.373	337	1	6/F AHU Rm (GL 24, FH)	24
EAF-6-3	Systemair	0.373	381	1	6/F Public Lav. (026.2)	24
EAF-6-4	Systemair	0.373	342	1	6/F AHU Rm (GL 79, GH)	24
EAF-6-5	Systemair	0.373	122	1	6/F AHU Rm (GL 79, GH)	24
EAF-6-6	Systemair	0.373	521	1	6/F AHU Rm (GL 79, GH)	24
EAF-6-7	Systemair	0.373	270	1	6/F AHU Rm (GL 24, FH)	24
EAF-7-1	Systemair	0.373	387	1	7/F AHU Rm (GL 24, FH)	24
EAF-7-2	Systemair	0.373	237	1	7/F AHU Rm (GL 24, FH)	24
EAF-7-3	Systemair	1.5	947	1	7/F AHU Rm (GL 24, FH)	24
EAF-8-1	Systemair	1.5	1,424	1	8/F A/C Rm (GL 12, BC)	24
EAF-8-2	Systemair	0.373	693	1	8/F AHU Rm (GL 24, FH)	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
EAF-8-3	Systemair	0.64	683	1	8/F AHU Rm (GL 24, FH)	24
EAF-8-4	Systemair	1.5	813	1	8/F AHU Rm (GL 24, FH)	24
EAF-8-5	Systemair	0.373	285	1	8/F AHU Rm (GL 24, FH)	24
EAF-8-6	Systemair	0.373	384	1	8/F AHU Rm (GL 79, FH)	24
EAF-8-7	Systemair	0.373	78	1	8/F Lift Machine Rm (GL 78, BC)	24
EAF-R-1	Plymovent	7.5	3,896	1	R/F Clean Exhaust Fan at R/F (GL 24, FH)	24
EAF-R-2	Plymovent	11	7.987	1	R/F Dirty Exhaust Fan at R/F (GL 24, FH)	24
EAF-R-3	Plymovent	5.5	4,377	1	R/F Clean Exhaust Fan at R/F (GL 24, BC)	24
EAF-R-4	Plymovent	3	2,726	1	R/F Clean Exhaust Fan at R/F (GL 79, GH)	24
EAF-R-5	Plymovent	7.5	6,459	1	R/F Dirty Exhaust Fan at R/F (GL 79, GH)	24
EAF-R-6	Plymovent	4	3,162	1	R/F Independent Exhaust (Refuse Room)	24
EAF-R-7	Plymovent	1.5	1,600	1	R/F Independent Exhaust (Herbs Preparation)	24
EAF-R-8	Plymovent	1.5	1,600	1	R/F Independent Exhaust (Herbs Preparation)	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
EAF-R-9	Plymovent	1.5	567	1	R/F Independent Exhaust (Grown Down Area)	24
EAF-R-10	Plymovent	1.5	567	1	R/F Independent Exhaust (Grown Down Area)	24
EAF-R-11	Plymovent	1.5	939	1	R/F Independent Exhaust (MRI)	24
EAF-R-12	Plymovent	1.5	939	1	R/F Independent Exhaust (MRI)	24
EAF-R-13	Plymovent	1.1	960	1	R/F Independent Exhaust (Cleansing Room)	24
EAF-R-16	Plymovent	2.2	540	1	R/F Independent Exhaust (Cleansing Room)	24
EAF-R-17	Plymovent	2.2	540	1	R/F Independent Exhaust (Cleansing Room)	24
EAF-R-20	Plymovent	11	7,250	1	R/F Exhaust Fan Room (78, GH)	24
EAF-R-21	Plymovent	2.2	1,813	1	R/F Elect Rm Exhaust Fan at R/F (GL 24, HJ)	24
EAF-R-22	Systemair	7.5	5,600	1	R/F Chilled Water Pump Rm (78, BH)	24
EAF-R-23	Systemair	0.373	532	1	R/F Lift Mech Rm (GL 78, AB)	24
EAF-R-24	Systemair	2.2	2,183	1	R/F Lift Mech Rm (GL 78, BC)	24
EAF-R-25	Systemair	2.2	1,202	1	R/F Boiler Rm (GL 67, BC)	24

Designation no.	Brand	Fan rated motor power (kW)	Fan rated flow (L/s)	Qty	Location	Daily operation hours
EAF-R-26	Systemair	1.5	834	1	R/F Water Tank Rm (GL 78, BH)	24
EAF-R-27	Systemair	2.2	1,590	1	R/F PV Control Room	24
EAF-R-28	Systemair	0.373	136	1	R/F Fan Room	24
EAF-R-30	Systemair	1.5	945	1	R/F Independent Exhaust (POP Room)	24
EAF-R-31	Systemair	0.373	180	1	R/F Elect Rm Exhaust Fan at R/F (GL 78, GH)	24
EAF-R-32	Systemair	0.373	488	1	R/F Elect Rm Exhaust Fan at R/F (GL 78, HJ)	24
EAF-R-33	Systemair	0.373	524	1	RMF Lift Machine Room (GL 24, J)	24
EAF-R-34	Systemair	0.373	420	1	RMF PV Control Room	24
EAF-R-35	Systemair	0.373	84	1	RMF Exhaust Fan Room (GL 24, GJ)	24
EAF-R-36	Systemair	0.64	914	1	R/F BRI Room (GL 78, BH)	24
FAF-R-3	Systemair	0.373	74	1	R/F Elect. Rm Exhaust Fan Room (GL 79, FH)	24

III. Lighting System

Equipment Description

The types of lighting is used in Tseung Kwan O Hospital Ambulatory Care Block are summarized in Table 3.1.3.1. The quantities of luminaires are summarized in Table 3.1.3.2.

Table 3.1.3.1 Summary of Ventilation Fans

Lighting No.	Types of Luminaire
L01	1x14W T5 Fluorescent Lamp
L02	2x14W T5 Fluorescent Lamp
L03	3x14W T5 Fluorescent Lamp
L04	1x 28W T5 Fluorescent Lamp
L05	2x28W T5 Fluorescent Lamp
L06	2x28W T5 Weatherproof Fluorescent Lamp
L07	1x35W T5 Fluorescent Lamp
L08	1x36W T8 Fluorescent Lamp
L09	2x18W Compact Fluorescent Lamp
L10	2x18W Compact Fluorescent Lamp
L11	1x26W Compact Fluorescent Lamp
L12	2x26W Compact Fluorescent Lamp
L13	1x28W Compact Fluorescent Lamp
L14	1x32W Compact Fluorescent Lamp
L15	1x20W LED Downlight
L16	1x3W LED Exit Sign

Table 3.1.3.2 (a) Lighting Quantity for Building

Floor	L01	L02	L03	L04	L05	L06	L07	L08
LG/F		29		16	410			21
G/F	4	27		200	286	4		
1/F	5	18		126	370	40		
2/F	4	26		43	302	47		
3/F	3	29		36	335	31		
4/F	5	14		195	240	63		
5/F	6	19		49	308	28		
6/F	2	13		23	149	122		
7/F	103	18	1	99	154	21		
8/F	3	16		39	202	43	14	
R/F					3	240		
RM/F		1			3	248		
Total	**135**	**210**		**826**	**2762**	**887**		

Table 3.1.3.2 (b) Lighting Quantity for Building

Floor	L09	L10	L11	L12	L13	L14	L15	L16
LG/F		72		45	18	9	12	15
G/F		88	10	17	27	25	12	24
1/F		82		13	27	73	12	37
2/F		80		25	27	42	12	31
3/F		73		24	27	74	12	24
4/F		112		24	27	31	12	27
5/F		72		33	27	63	12	30
6/F	28	27		13	27	29	12	19
7/F		51		13	27	64	12	20
8/F		30		17	27	49	12	16
R/F					24			10
RM/F					13			4
Total	**28**	**687**	**10**	**224**	**298**	**459**	**120**	**257**

IV. Electrical System

The incoming power of the building is supplied by the transformer from CLP Power Hong Kong Limited (CLP) which is located at the transformer room at LG/F. The L.V switchboards are located in the switch and meter room at LG/F. The L.V switchboards received electrical power from transformers is then distributed to all electrical main and sub-main of the entire building.

The power supply from L.V switchboards supplied by transformer is to provide power for Tseung Kwan O Hospital Ambulatory Care Block, chillers, AHUs, PAUs, FCUs, lift and escalator, lighting system and general power, etc.

[Refer to Appendix for the Electrical Schematic Wiring Diagram]

V. Lift and Escalator System

Equipment Description

There are 11 nos. of lifts and 8 nos. of escalators serving the building. The technical data of lift and escalator system is summarized in Table 3.1.5.1 and Table 3.1.5.2**.**

Table 3.1.5.1 Summary of Lift System

Designation no.	Brand	Drive Type	Served floors	Rated motor power (kW)	Qty	Location	Daily operation hours
L1	ABB	ACVVVF	LG/F, G/F, 1/F-8/F	25	1	R/F	24
L2 & L3	ABB	ACVVVF	LG/F, G/F, 1/F-8/F	25	2	R/F	24
L4 to L9	ABB	ACVVVF	LG/F, G/F, 1/F-8/F	25	6	R/F	24
L10 & L11	ABB	ACVVVF	LG/F, G/F, 1/F-8/F	25	1	R/F	24

Table 3.1.5.2 Summary of Escalator System

Designation no.	Brand	Drive Type	Served floors	Rated motor power (kW)	Qty	Location	Daily operation hours
E1 & E2	Kone	AC	LG/F, G/F	6.6	2	R/F	24
E3 & E4	Kone	AC	G/F, 1/F	6.6	2	R/F	24
E5 & E6	Kone	AC	1/F, 2/F	6.6	2	R/F	24
E7 & E8	Kone	AC	2/F, 3/F	6.6	2	R/F	24

VI. Plumbing System

Equipment Description

There are 26 nos. of water pumps serving the building, including fresh water, flushing water, cleansing water, clinical water etc. The details of the plumbing system are summarized in Table 3.1.6.1.

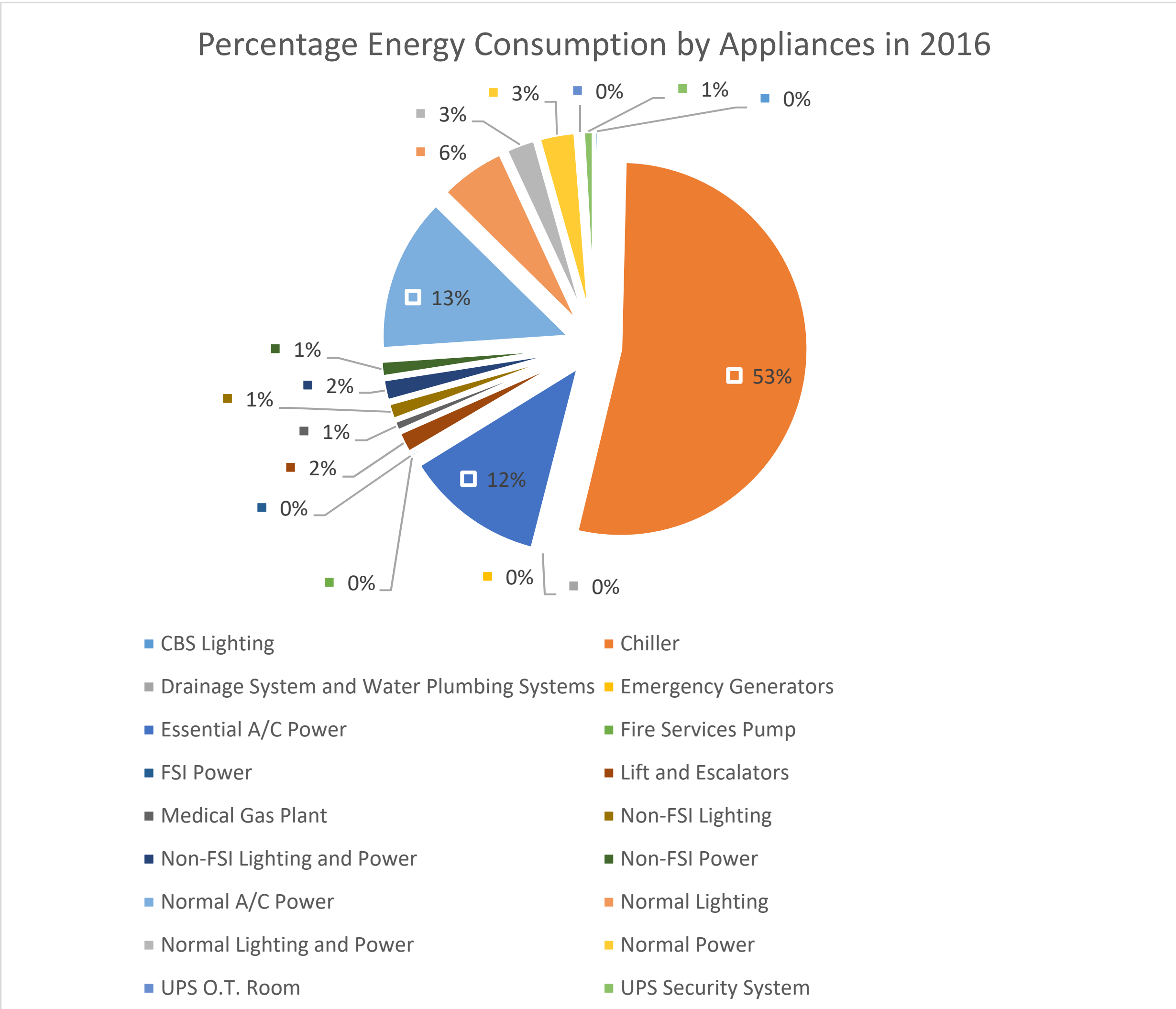
Table 3.1.6.1 Summary of Pumps

Designation no.	Services	Brand	Rated motor power (kW)	Location	Qty	Daily operation hours
RRP-R-01 & RRP-R-02	Rain Water Recycling Pumps	Apolo	2.2	R/F	2	On demand
IRP-B-01 & IRP-B-02	Irrigation Water Upfeed Pumps	Apolo	1.1	R/F	2	On demand
IRP-R-01 to IRP-R-03	Irrigation Water Pumps	Apolo	1.1	R/F	2	On demand
FP-B-01 & FP-B-02	Flushing Water Upfeed Pumps	Apolo	7.5	B/F	2	On demand
FP-R-01 & FP-R-02	Flushing Water Booster Pumps	Apolo	7.5	R/F	2	On demand
CP-B-01 & CP-B-02	Portable Cold Water Upfeed Pumps	Apolo	2.2	B/F	2	On demand
CP-R-01 & CP-R-02	Portable Cold Water Booster Pumps	Apolo	2.2	R/F	2	On demand
CMC-R-01 & CMC-R-02	Chinese Medicine Portable Cold Water Pumps	Apolo	0.75	R/F	2	On demand
NCP-B-01 & NCP-B-02	Clinical Water Upfeed Pumps	Apolo	1.1	B/F	2	On demand
NCP-R-01 & NCP-R-02	Clinical Water Pumps	Apolo	1.1	R/F	2	On demand
CLP-R-01 to CLP-R-04	Cleansing Water Pumps	Apolo	1.1	R/F	4	On demand
CLP-B-01 & CLP-B-02	Cleansing Water Upfeed Pumps	Apolo	1.1	B/F	2	On demand

b. Preliminary analysis of Energy Consumption in Different Sectors

There are 18 different categories of appliances in ACB, the percentage energy consumption by appliances in 2016 are shown in Figure 3.2.1.

Figure 3.2.1: Percentage Energy Consumption by Appliances in 2016



According to Figure 3.2.1, among the 18 groups of appliances in the building, the most-energy-consumed sector is the chiller, more than half of the total energy consumption is attributed to chiller operation. It is followed by the two A/C power consumption (Normal A/C and Essential A/C), which combined accounts for a quarter of the energy consumption of the whole building. The great portion of the three sectors suggests the large influence of them on the building energy consumption pattern.

The exact numbers of energy consumption in kWh is shown in Table 3.2.1.

Table 3.2.1: Energy Consumption by appliances in kWh in 2016

Categories/Month in 2016	Jan	Feb	Mar	Apr	May	Jun
CBS Lighting	2,841	2,712	3,260	3,147	3,334	3,213
Chiller	200,640	135,197	217,600	453,906	622,337	745,195
Drainage and Water Plumbing	2,017	1,925	2,130	1,952	2,013	2,077
Emergency Generators	0	0	0	0	0	0
Essential A/C Power	109,674	99,409	105,140	107,059	108,266	108,287
Fire Services Pump	75	0	0	21	7	0
FSI Power	3,365	3,129	3,282	2,982	2,986	2,937
Lift and Escalators	15,342	13,714	15,927	15,729	16,044	16,382
Medical Gas Plant	7,612	7,387	8,651	7,528	7,509	7,725
Non-FSI Lighting	12,760	11,422	12,701	12,569	12,778	12,655
Non-FSI Lighting and Power	17,076	15,923	17,271	17,143	17,473	17,495
Non-FSI Power	12,514	11,672	12,117	11,989	12,465	12,231
Normal A/C Power	128,474	125,090	128,145	118,504	117,150	116,580
Normal Lighting	51,334	46,266	50,607	49,441	49,688	49,591
Normal Lighting and Power	22,489	21,341	22,526	23,520	22,612	21,192
Normal Power	26,822	24,402	27,145	27,069	28,033	28,277
UPS O.T. Room	2,136	1,958	2,065	1,968	2,182	2,290
UPS Security System	8,077	7,577	8,078	7,818	7,965	7,794

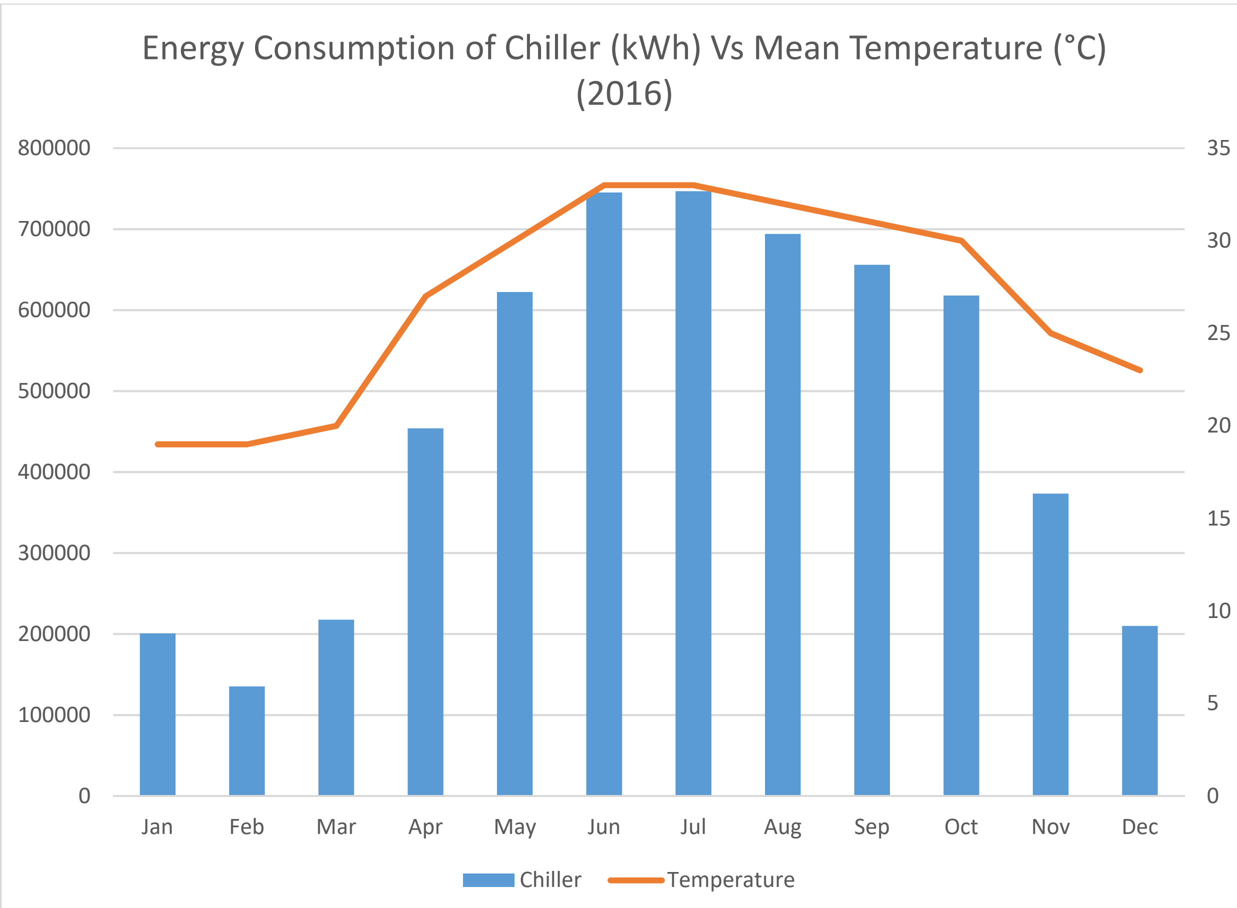
Categories/Month in 2016	Jul	Aug	Sep	Oct	Nov	Dec
CBS Lighting	3,402	3,422	3,362	3,482	3,448	3,291
Chiller	746,750	693,956	655,882	618,005	373,427	209,987
Drainage and Water Plumbing	2,152	2,141	2,029	1,943	2,029	1,910
Emergency Generators	0	0	0	0	0	0
Essential A/C Power	111,758	109,177	105,884	110,506	111,001	113,239
Fire Services Pump	7	1	5	8	1	1
FSI Power	3,047	3,016	2,916	3,004	3,081	2,731
Lift and Escalators	16,371	17,044	16,543	16,180	18,193	16,928
Medical Gas Plant	8,338	8,296	7,186	7,278	8,192	9,078
Non-FSI Lighting	12,938	12,706	12,998	12,393	13,004	12,611
Non-FSI Lighting and Power	16,425	16,289	15,626	15,804	15,513	14,755
Non-FSI Power	12,482	12,605	12,091	11,940	11,794	11,943
Normal A/C Power	119,475	118,598	116,058	115,453	111,701	113,672
Normal Lighting	50,391	50,809	51,170	50,765	53,790	52,382
Normal Lighting and Power	23,788	22,330	22,169	22,881	22,699	24,392
Normal Power	28,482	28,861	27,646	27,872	29,345	28,599
UPS O.T. Room	2,394	2,385	1,946	2,910	10,956	2,518
UPS Security System	8,050	8,019	7,755	7,996	7,823	7,965

c. **Energy Consumption and Performance Evaluation**

I. **Energy Consumption Pattern of ACB (2015-2017)**

As the dominant sector in energy consumption, the variation of energy consumption in chiller part is assumed to affect the whole picture of the building energy consumption tremendously. Figure 3.2.2 illustrates the trend of variation of the chiller energy consumption with the mean temperature.

Figure 3.3.1.1: Comparison between chiller energy consumption and mean temperature (2016)



From figure 3.3.1.1, the energy consumption of chiller varies greatly throughout a year, the highest energy consumption is around 5 times of the lowest one. The variation of the chiller energy consumption is directly related to the change in mean outdoor temperature. The period with chiller energy consumption higher than 500,000 kWh is mainly in summer time, while in winter time, the chiller energy consumption reduced to below 500,000 kWh. Table 3.2.2 concluded the average chiller energy consumption in summer and winter time.

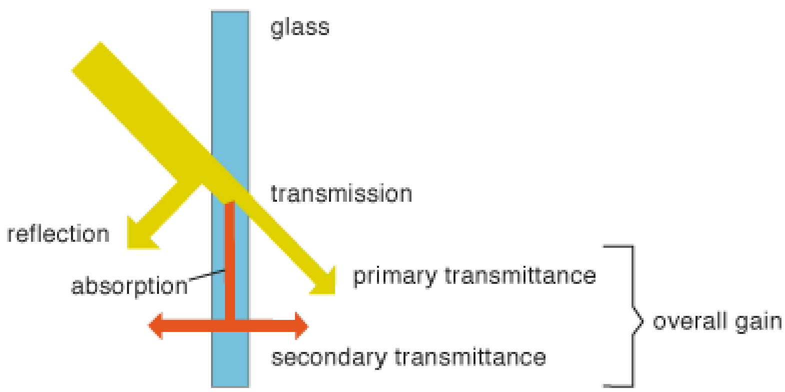
Table 3.3.1.1 Average energy consumption of chiller in different seasons

	Summer time	Winter time	% Difference
Average Chiller Energy Consumption	680,354 kWh	265,126 kWh	156.6%

Note: For simplicity, May to October is regarded as summer time, while November to April is regarded as winter time.

Table 3.3.1.1 suggests the influence of seasonal factor on energy consumption pattern. In summer time, excessive solar radiation will directly heat up the inner part of the building and cause the high outdoor air temperature. This condition will increase the heat transfer from external to internal by conduction, convection and radiation. Apart from the difference between the indoor and outdoor temperature, the building envelope such as window type (single glazed, double glazed or chromogenic window), window size and existing of interior shades, building material (green roof) and shape, building location and orientation also affect the amount of external thermal load entering. Figure 3.1.1.2 explains the mechanism of the solar absorption through a window of a building.

Figure 3.1.1.2 Solar absorption through a window



Part of the solar energy is directly transmitted to indoor area and part of solar energy is absorbed then re-transmit as secondary transmittance by convection and radiation. About 50% of solar-radiation can be admitted while the remaining 50% will be rejected through a standard double-glazing window.

Consider a double glass window filled with argon gas, the overall thermal resistance is

$R_{total} = R_{th1} + R_{th2} + R_{th3} + \ldots + R_{thn}$

Heat transfer due to convection, $R_{th,\ convection} = 1/hA$

Heat transfer due to conduction, $R_{th,\ conduction} = x/kA$

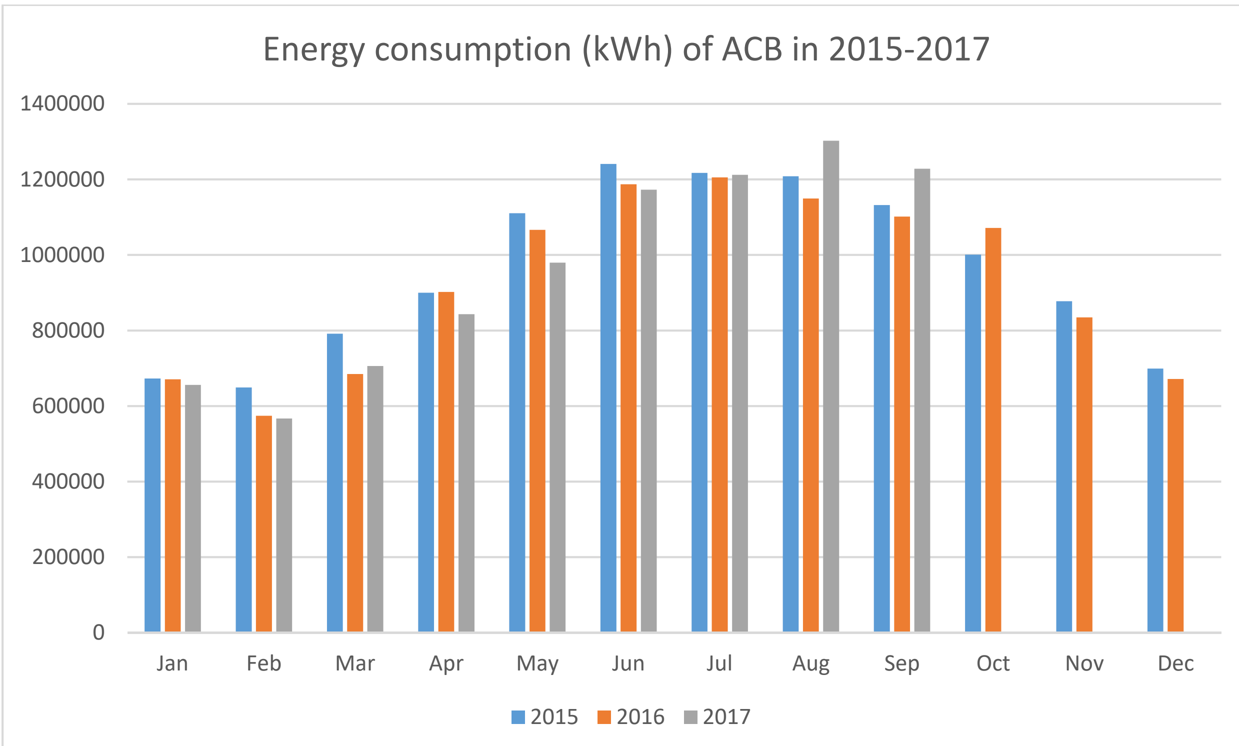
h ($Wm^{-2}K^{-1}$) is the heat transfer coefficient; k ($Wm^{-1}K^{-1}$) is the thermal conductivity

Overall thermal resistance, $R_{total} = \frac{1}{h_1 A} + \frac{x}{k_1 A} + \frac{x}{k_2 A} + \frac{1}{h_2 A}$

Rate of heat transfer, $\dot{Q} = \Delta T / R_{total}$

The chiller energy consumption in summer is more than two times of that in the winter time, which is hypothesized to be reflected on the energy consumption pattern of the entire building. Figure 3.3.1.3 shows the variation of the total energy consumption of the ACB among three years (2015 – 2017).

Figure 3.3.1.3: Trend of Energy Consumption (kWh) of ACB in 2015-2017



Note: The data in 2017 only covers the period from January to September.

Figure 3.1.1.3 displays a similar trend as the variation of the chiller energy consumption shown in figure 3.1.1.1, which confirms the effect of seasonal factor on building energy consumption. It can be concluded that the energy consumption trend of the whole building throughout a year is greatly depended on the chiller energy consumption, which is directly related to the mean outdoor temperature. If the amount of chiller energy consumption can be reduced, it will save a large portion of energy for the whole building, and hence a huge amount of money can be saved. Table 3.3.1.3 shows the energy consumption of the whole building from 2015 to 2017, and table 3.3.1.3 displays the approximated tariff for that amount of energy consumption.

Table 3.3.1.2 Energy Consumption (kWh) of ACB in 2015-2017

kWh	Jan	Feb	Mar	Apr	May	Jun
2015	672,616	648,823	791,222	899,607	1,110,451	1,240,951
2016	670,794	574,015	684,473	901,736	1,066,144	1,186,832
2017	655,904	566,673	705,657	842,869	979,299	1,172,668

kWh	Jul	Aug	Sep	Oct	Nov	Dec
2015	1,217,286	1,208,125	1,132,107	1,000,485	877,419	698,971
2016	1,205,209	1,149,510	1,101,353	1,071,286	834,379	671,603
2017	1,212,110	1,302,291	1,228,244			

Table 3.3.1.3 Approximated Tariff of ACB in 2015-2017

	2015	**2016**	**2017 (Jan – Sep)**
Amount of tariff accumulated	$12,072,966.2	$11,673,200.7	$9,099,000.75

Note: For simplicity, tariff rate is assumed to be $1.05/kWh.

As chiller energy consumption contributes the major portion of the energy consumption of the whole building, it is essential to evaluate the coefficient of performance (COP) of each individual chiller. The details will be included in "Chapter 3.c.III Identification of Problems". Regular checking and maintenance of chiller water pipe insulation can reduce energy consumption due to the heat loss to surrounding in the complete loop of the refrigeration cycle. According to EMSD *Code of Practice for Energy Efficiency of Air Conditioning Installations* 2017 Edition, the minimum insulation thickness for chilled water pipes could be determined by the following equations.

$$X = \frac{10^3 \times \lambda}{h} \times \frac{\theta_d - \theta_1}{\theta_m - \theta_d}$$

$$X = 0.5\,(d_o + 2L) \times \ln 1 + \frac{2L_a}{d_o}$$

L_a = Actual minimum thickness (mm)

d_o = Outside diameter of pipe (mm)

θ_d = Dew point temperature (°C)

θ_1 = Temperature of cold surface (line temperature) (°C)

θ_m = Temperature of the ambient still air (°C)

The above reflects the overall picture of energy consumption of the whole building. In the analysis, climate – mainly outdoor temperature, and building service equipment – mainly chiller water system are the major influencing factors of building energy consumption. To have a comprehensive analysis on energy consumption pattern, the energy consumption in terms of floors and department is studied. Table 3.3.1.4 includes the data of chilled water consumption which is process from the data taken in the period from 08 July 2017 to 09 August 2017, and explains the energy consumption pattern of the major appliances in the departments on each floor.

Table 3.3.1.4 Chilled Water Consumption (08 July 2017 – 09 August 2017)

Floor	Department	On-peak Consumption (kWh) (A)	Off-peak Consumption (kWh) (B)	Sub-total Consumption (kWh) (A + B)	% of Total Consumption
R/F	Chinese Medicine Clinic	1,711.07	391.95	2,103.02	6.51%
	Common Area	14,262.73	8,035.77	22,298.50	69.00%
	Community PSY Liaison Office	1,026.64	235.17	1,261.81	3.90%
	Electro-Diagnostic Unit	3,568.88	563.17	4,132.05	12.79%
	Medical SOPD	1,026.64	235.17	1,261.81	3.90%
	Pediatrics and Adolescent Medicine Clinic	1,026.64	235.17	1,261.81	3.90%
R/F Total		**22,622.60**	**9,696.40**	**32,319.00**	**3.27%**
8/F	Common Area	9,312.92	1,522.07	10,834.99	22.77%
	Lecture Theatre	5,463.70	666.45	6,130.15	12.88%
	Nursing Services Division, Administrative Services Division, Finance Department and Patients and Community Relations Department	27,698.53	2,922.03	30,620.56	64.35%
8/F Total		**42,475.15**	**5,110.55**	**47,585.70**	**4.82%**
7/F	Common Room and Gymnasium Fitness Room	10,179.03	14,376.01	24,555.04	80.47%
	Common Area	93.66	130.49	224.15	0.73%
	Overnight Room and Staff Changing Room	2,144.07	2,607.35	4,751.42	15.57%
	Staff Library	884.10	100.52	984.62	3.23%
7/F Total		**13,300.86**	**17,214.37**	**30,515.23**	**3.09%**

Floor	Department	On-peak Consumption (kWh) (A)	Off-peak Consumption (kWh) (B)	Sub-total Consumption (kWh) (A + B)	% of Total Consumption
6/F	Ambulatory Surgery Centre	83.04	111.76	194.80	0.25%
	Chinese Medicine Clinic	1,508.46	1,709.52	3,217.98	4.07%
	Common Room and Gymnasium Fitness Room	3,629.94	4,198.17	7,828.11	9.89%
	Common Area	22,739.48	12,241.08	34,980.56	44.21%
	Electro-Diagnostic Unit	1,333.02	2,481.85	3,814.87	4.82%
	Family Medicine and Primary Health Care	9,357.36	12,673.38	22,030.74	27.84%
	Staff Library	6,392.87	666.51	7,059.38	8.92%
6/F Total		**45,044.17**	**34,082.27**	**79,126.44**	**8.02%**
5/F	Ambulatory Surgery Centre	17.48	26.23	43.71	0.07%
	Common Area	10,639.51	12,474.50	23,114.01	34.84%
	Day Medical Centre	19,936.29	23,252.30	43,188.59	65.10%
5/F Total		**30,593.28**	**35,753.03**	**66,346.31**	**6.72%**
4/F	Common Area	20,117.93	6,935.58	27,053.51	22.44%
	Community PSY Liaison Office	5,267.14	7,257.31	12,524.45	10.39%
	Day Medical Centre	5,267.14	7,257.31	12,524.45	10.39%
	Electro-Diagnostic Unit	16,916.56	5,719.81	22,636.37	18.78%
	Hemodialysis Centre	7,239.52	1,529.69	8,769.21	7.27%
	Integrated Care and Discharge Support for Elderly Patients / Diabetes Centre	11,247.38	2,967.17	14,214.55	11.79%
	Integrated Rehabilitation Services	4,866.61	1,268.40	6,135.01	5.09%
	Medical SOPD	3,511.43	4,838.21	8,349.64	6.93%
	Ophthalmology Clinic	3,511.43	4,838.21	8,349.64	6.93%
4/F Total		**77,945.14**	**42,611.69**	**120,556.83**	**12.22%**
3/F	Common Area	22,094.42	2,606.10	24,700.52	21.49%
	Ear, Nose and Throat Clinic	21,543.10	26,246.46	47,789.56	41.58%
	Ophthalmology Clinic	14,551.46	14,129.39	28,680.85	24.96%
	Pediatrics and Adolescent Medicine Clinic	11,227.34	2,530.55	13,757.89	11.97%
3/F Total		**69,416.32**	**45,512.50**	**114,928.82**	**11.64%**

Floor	Department	On-peak Consumption (kWh) (A)	Off-peak Consumption (kWh) (B)	Sub-total Consumption (kWh) (A + B)	% of Total Consumption
2/F	Common Area	33,293.04	7,293.21	40,586.25	45.64%
	Obstetric and Gynecology Clinic	19,574.48	4,314.99	23,889.47	26.86%
	Surgical Clinic and Orthopedics and Traumatology Clinic	22,205.55	2,255.21	24,460.76	27.50%
2/F Total		**75,073.07**	**13,863.41**	**88,936.48**	**9.01%**
1/F	Blood Taking Station	2.149.38	343.84	2,493.22	4.03%
	Common Area	22,233.94	3,783.85	26,017.79	42.01%
	Family Medicine and Primary Health Care	11,645.04	2,755.32	14,400.36	23.25%
	Health Resources Centre	9,038.32	1,915.55	10,953.87	17.69%
	Medical SOPD	7,256.99	808.56	8,065.55	13.02%
1/F Total		**52,323.67**	**9,607.12**	**61,930.79**	**6.28%**
G/F	Common Area	30,215.28	31,762.09	61,977.37	36.16%
	Community PSY Liaison Office	12,385.53	2,095.25	14,480.78	8.45%
	MRI Centre	34,597.96	46,828.03	81,425.99	47.50%
	Security Department / CCMS Room	0.00	0.00	0.00	0.00%
	Shroff	5,315.10	4,508.17	9,823.27	5.73%
	Specialist Out-patient Department, Appointment Booking Office, Patient Relations Office	1,954.64	1,749.34	3,703.98	2.16%
G/F Total		**84,468.51**	**86,942.88**	**171,411.39**	**17.37%**
LG/F	Common Area	36,495.38	48,434.54	84,929.92	50.52%
	Health Information and Records Department	35,111.76	43,300.22	78,411.98	46.64%
	Security Department / CCMS Room	2,191.59	2,581.25	4,772.84	2.84%
LG/F Total		**73,798.73**	**94,316.01**	**168,114.74**	**17.03%**
B/F	Common Area	2,203.39	2,968.24	5,171.63	100.00%
B/F Total		**2,203.39**	**2,968.24**	**5,171.63**	**0.52%**
Expansion of TKO Hospital Total (Chiller Plant)		**589,264.89**	**397,678.47**	**986,943.36**	**100%**

Note: On-peak hours: 0900 to 2100 (Monday to Saturday, excluding General Holidays); off-peak hours: all hours other than on-peak hours.

Table 3.3.1.4 shows the chilled water consumption of departments at different floors in the building, demonstrating that the energy consumption of chilled water at G/F, LG/F and 4/F are the highest from 08 July 2017 to 09 August 2017 with 17.37%, 17.03% and 12.22% respectively among the total chilled water consumption. There are offices and centres of diverse functions on both G/F and 4/F. For example, the community PSY Liaison Office and MRI Centre are located on G/F, where the Electro-diagnostic Unit and Elderly Patients / Diabetes Centre can be found on 4/F. Those are all high energy consuming facilities of the building. There is a large common area located on each floor which is an open area for all occupants in the building, for instance, lobbies, corridors, stairways, washrooms, elevators and store rooms. In the common area, the total energy consumption is almost the highest at each floor. Those areas are large and cater the largest number of occupants, thus the thermal loads of those areas are usually high.

Apart from chiller water equipment of HVAC system, normal lighting equipment is also indispensable in hospital. In modern lighting fixture, most of the types such as Compact Fluorescents Lamps (CFLs) and Light Emitting Diodes (LEDs) has low circuit wattage and control gear loss per luminaire hence achieving high energy efficiency. However, because of the large gross cover area of lighting system in a building, it usually contributes a significant portion of total energy consumption. In hospital, some operation like surgical operation and dissection operation requires some special lighting and long operation time. These are part of the reasons for high energy consumption. Table 3.3.1.5 summarizes the lighting energy consumption of departments on different floors in the building.

Table 3.3.1.5 Normal Lighting Consumption (08 July 2017 – 09 August 2017)

Floor	**Department**	**On-peak Consumption (kWh) (A)**	**Off-peak Consumption (kWh) (B)**	**Sub-total Consumption (kWh) (A + B)**	**% of Total Consumption**
R/F	Chinese Medicine Clinic	0.00	0.00	0.00	0.00%
	Common Area	2,361.97	3,136.81	5,498.78	100.00%
	Community PSY Liaison Office	0.00	0.00	0.00	0.00%
	Electro-Diagnostic Unit	0.00	0.00	0.00	0.00%
	Medical SOPD	0.00	0.00	0.00	0.00%
	Pediatrics and Adolescent Medicine Clinic	0.00	0.00	0.00	0.00%
R/F Total		**2,361.97**	**3,136.81**	**5,498.78**	**10.84%**

Floor	Department	On-peak Consumption (kWh) (A)	Off-peak Consumption (kWh) (B)	Sub-total Consumption (kWh) (A + B)	% of Total Consumption
8/F	Common Area	560.05	375.25	935.30	27.96%
	Lecture Theatre	350.27	258.49	608.76	18.20%
	Nursing Services Division, Administrative Services Division, Finance Department and Patients and Community Relations Department	1,359.24	441.43	1,800.67	53.84%
8/F Total		**2,269.56**	**1,075.17**	**3,344.73**	**6.59%**
7/F	Common Room and Gymnasium Fitness Room	0.00	0.00	0.00	0.00%
	Common Area	668.69	703.66	1,372.35	31.78%
	Overnight Room and Staff Changing Room	1,073.28	1,474.13	2,547.41	58.99%
	Staff Library	367.75	31.22	398.97	9.24%
7/F Total		**2,109.72**	**2,209.01**	**4,318.73**	**8.51%**
6/F	Ambulatory Surgery Centre	0.00	0.00	0.00	0.00%
	Chinese Medicine Clinic	664.32	72.43	736.75	44.21%
	Common Room and Gymnasium Fitness Room	320.30	289.08	609.38	36.57%
	Common Area	118.01	114.88	232.89	13.98%
	Electro-Diagnostic Unit	0.00	0.00	0.00	0.00%
	Family Medicine and Primary Health Care	43.08	44.33	87.41	5.25%
	Staff Library	0.00	0.00	0.00	0.00%
6/F Total		**1,145.71**	**520.72**	**1,666.43**	**3.28%**
5/F	Ambulatory Surgery Centre	1,480.37	2,025.44	3,505.81	61.86%
	Common Area	673.07	473.89	1,146.96	20.24%
	Day Medical Centre	870.36	144.23	1,014.59	17.90%
5/F Total		**3,023.80**	**2,643.56**	**5,667.36**	**11.17%**

Floor	Department	On-peak Consumption (kWh) (A)	Off-peak Consumption (kWh) (B)	Sub-total Consumption (kWh) (A + B)	% of Total Consumption
4/F	Common Area	695.54	417.08	1,112.62	30.58%
	Community PSY Liaison Office	0.00	0.00	0.00	0.00%
	Day Medical Centre	0.00	0.00	0.00	0.00%
	Electro-Diagnostic Unit	575.67	123.62	699.29	19.22%
	Hemodialysis Centre	0.00	0.00	0.00	0.00%
	Integrated Care and Discharge Support for Elderly Patients / Diabetes Centre	1,038.95	351.51	1,390.46	38.22%
	Integrated Rehabilitation Services	344.65	91.16	435.81	11.98%
	Medical SOPD	0.00	0.00	0.00	0.00%
	Ophthalmology Clinic	0.00	0.00	0.00	0.00%
4/F Total		**2,654.81**	**983.37**	**3,638.18**	**7.17%**
3/F	Common Area	1,531.57	728.63	2,260.20	56.83%
	Ear, Nose and Throat Clinic	1,037.70	180.44	1,218.14	30.63%
	Ophthalmology Clinic	450.79	48.08	498.87	12.54%
	Pediatrics and Adolescent Medicine Clinic	0.00	0.00	0.00	0.00%
3/F Total		**3,020.06**	**957.15**	**3,977.21**	**7.84%**
2/F	Common Area	1,379.85	757.98	2,137.83	58.34%
	Obstetric and Gynecology Clinic	558.80	48.08	606.88	16.56%
	Surgical Clinic and Orthopedics and Traumatology Clinic	805.43	114.26	919.69	25.10%
2/F Total		**2,744.08**	**920.32**	**3,664.40**	**7.22%**
1/F	Blood Taking Station	0.00	0.00	0.00	0.00%
	Common Area	1,131.35	1,025.20	2,156.55	62.25%
	Family Medicine and Primary Health Care	0.00	0.00	0.00	0.00%
	Health Resources Centre	213.54	0.62	214.16	6.18%
	Medical SOPD	984.62	109.27	1,093.89	31.57%
1/F Total		**2,329.51**	**1,135.09**	**3,464.60**	**6.83%**

Floor	Department	On-peak Consumption (kWh) (A)	Off-peak Consumption (kWh) (B)	Sub-total Consumption (kWh) (A + B)	% of Total Consumption
G/F	Common Area	2,008.58	1,666.43	3,675.01	62.21%
	Community PSY Liaison Office	688.07	408.34	1,076.41	18.22%
	MRI Centre	348.40	113.63	462.03	7.82%
	Security Department / CCMS Room	166.08	100.52	266.60	4.51%
	Shroff	0.00	0.00	0.00	0.00%
	Specialist Out-patient Department, Appointment Booking Office, Patient Relations Office	374.00	53.07	427.07	7.23%
G/F Total		**3,565.13**	**2,341.99**	**5,967.12**	**11.64%**
LG/F	Common Area	1,828.15	1,523.44	3,351.59	55.62%
	Health Information and Records Department	1,921.80	752.36	2,674.16	44.38%
	Security Department / CCMS Room	0.00	0.00	0.00	0.00%
LG/F Total		**3,749.95**	**2,275.80**	**6,025.75**	**11.88%**
B/F	Common Area	1,535.93	2,031.06	3,566.99	100%
B/F Total		**1,535.93**	**2,031.06**	**3,566.99**	**7.03%**
Expansion of TKO Hospital Total (Chiller Plant)		**30,510.23**	**20,230.05**	**50,740.28**	**100%**

Note: On-peak hours: 0900 to 2100 (Monday to Saturday, excluding General Holidays); off-peak hours: all hours other than on-peak hours.

The results displayed on Table 3.3.1.5 resonates that on Table 3.3.1.4. LG/F and G/F combined contribute almost a quarter of the total energy consumption of normal lighting because of the common area, which accounts for more than half of the energy use on the corresponding floor. The amount of lighting energy use of 5/F is close to that of LG/F and G/F, accounting for 11.17% of the total lighting energy. In contrary to the case of LG/F and G/F, common area on 5/F does not contribute the greatest portion of the lighting energy use, it is the Ambulatory Surgery Centre which takes the dominance.

According to the results from Table 3.3.1.4 and Table 3.3.1.5, common area is at paramount importance when it comes to energy saving, since it contributes the greatest portion of the energy consumption each floor. There are still some exceptions, some building service energy consumption pattern depends on the nature and operation of departments. For instance, it is expected that surgery operation consumes more energy for lighting but not chilled water, while Electro-Diagnostic Unit and MRI Centre use greater portion of energy in terms of chilled water, which is because of the temperature and humidity requirements for the rooms.

II. Site Measurement on Indoor Environmental Quality

Indoor Temperature

The indoor temperature represents the comfort level at the building. The data was measured on 4th June, 17th July and 8th August 2018 with an outdoor temperature ranging from 31°C to 34°C (data from the Hong Kong Observatory).

The average measured indoor temperature for different functional areas with the recommended temperature are shown in Table 3.3.2.1.

Table 3.3.2.1 Indoor Temperature

Floor	Location	Measured average temperature (°C)	Recommended average temperature (°C)
G/F	CCMS Room	24.0	23-25
	Lift Lobby	23.4	23-25
	Enquiry	23.1	23-25
	Shroff	22.6	23-25
	Corridor	22.2	23-25
	Entry	23.0	23-25
	MRI	20.9	23-25
1/F	Public Foyer	23.0	23-25
	Lift Lobby	21.8	23-25
2/F	Public Foyer	23.3	23-25
	Obstetrics & Gynecology Clinic	22.5	23-25
	Lift Lobby	22.8	23-25
3/F	Public Foyer	23.3	23-25
	Pediatrics & Adolescent Medicine Clinic	21.1	23-25
	Lift Lobby	22.2	23-25
4/F	Public Foyer	23.6	23-25
	Lift Lobby	23.2	23-25
	Electrographic Diagnostic Unit	22.0	23-25
	Geriatric Day Hospital & Diabetes Centre	22.7	23-25
	Corridor	22.2	23-25
5/F	Lift Lobby	23.2	23-25
	Public Foyer	23.1	23-25
6/F	Lift Lobby	23.8	23-25
	Public Foyer	22.8	23-25
7/F	Lift Lobby	23.5	23-25
	Public Foyer	24.0	23-25
8/F	Lift Lobby	22.2	23-25
	Public Foyer	22.0	23-25

Note: For measured error that cannot be avoided, deviation to the recommended temperature setting is acceptable.

If the measured indoor temperature of any specific area is deviated from the recommended temperature, the set point temperature for the specific area shall be checked and, if applicable, re-adjusted so as to meet with recommended temperature.

Illuminance Level

The illuminance level was measured on 4th June, 17th July and 8th August 2018. According to the CIBSE Lighting Guide, the design illuminance level of different locations are shown in Table 3.3.2.2.

Table 3.3.2.2 Measured Illuminance Level

Floor	Location	Measured average lux level (lx)	Desire lux level (lx)
G/F	Lift Lobby	250	200
	Shroff	401	500
	Corridor	192	150
	Entry	585	500
	Waiting Area	786	500
1/F	Public Foyer	243	500
	Lift Lobby	169	200
2/F	Public Foyer	214	500
	Escalator	342	150
	Lift Lobby	167	200
3/F	Public Foyer I	229	500
	Public Foyer II	516	500
	Lift Lobby	227	200
4/F	Public Foyer	694	500
	Lift Lobby	842	200
	Corridor I	246	150
	Corridor II	287	150
	Staff Lift Lobby	194	200
5/F	Lift Lobby	585	200
	Public Foyer	510	500
	Corridor I	366	150
	Corridor II	277	150
	Staff Lift Lobby	212	200
6/F	Lift Lobby	559	200
	Public Foyer	528	500
7/F	Lift Lobby	707	200
	Public Foyer	432	500
8/F	Lift Lobby	844	200
	Public Foyer	614	500

The processed data and the comments on the measure illuminance level are displayed in Chapter 3.c.III.

III. Identification of Problems

In ACB, two types of chillers are mainly in use – Oil free Cooled Centrifugal and Air Cooled Heat Recovery Chiller. According to *Code of Practice for Energy Efficiency of Air Conditioning Installations* (2007 edition), the minimum coefficient of performance (COP) for air-cooled centrifugal and screw chillers are 2.8 and 2.9 respectively. Table 3.3.3.1 displays the performance of the chillers on August 2017.

Table 3.3.3.1 COP Analysis of individual Chillers (August 2017)

Chiller	Electricity Consumption (kWh)			Chilled Water Energy (kWh)	Calculated COP
	On-peak Hrs	Off-peak Hrs	Total	CCMS Data	
OFAC_RF2_04	0.00	400.00	400.00	0.00	0.00
OFAC_RF2_02	900.00	100.00	1,000.00	2,450.00	2.45
OFAC_RF2_01	57,800.00	22,300.00	80,100.00	198,185.00	2.47
OFAC_RF1_06	59,400.00	42,400.00	101,800.00	303,925.00	2.99
OFAC_RF1_05	9,200.00	11,200.00	20,400.00	65,669.00	3.22
OFAC_RF1_03	72,600.00	31,200.00	103,800.00	354,526.00	3.42
HRC_RF_02	95,300.00	97,400.00	192,700.00	192,690.00	1.00
HRC_RF_01	56,500.00	64,000.00	120,500.00	291,196.00	2.42

Table 3.3.3.1 outlines an unsatisfactory picture of the chiller performance. OFAC_RF2_04 and HRC_RF_02 are working unsatisfactorily, the coefficient of performance (COP) of HRC_RF_02 is 1.00 (highlighted in red), which is way below the required COP; while OFAC_RF2_04 is reported as malfunctioned and turned off. HRC_RF_02 contributes nearly one-third of the total electricity consumption of the chiller plant, which leads the chillers in terms of electricity consumption, the low COP of the chiller increased the burden on the chiller energy consumption. If the COP of HRC_RF_02 can be maintained at around 3, the amount of electricity consumption for the same chilled water energy output will be reduced by 200%. Table 3.3.3.2 displays the electricity consumption and the corresponding tariff by chiller with 200,000 kWh chilled water energy output under different COP.

Table 3.3.3.2 Electricity Consumption and Tariff of Chiller with Different COP

COP	Electricity Consumption (kWh)	Approximated Electricity Tariff ($)
1.00	200,000	210,000
1.50	133,333	140,000
2.00	100,000	105,000
3.00	66,667	70,000

Note: For simplicity, tariff rate is assumed to be $1.05/kWh.

In the case of HRC_RF_02, if the COP can be maintained at around 3 throughout the whole year, around $140,000 can be saved per month, which is more than 1,500,000 per year, the amount of money saved can be used to improve other facilities in the building.

Table 3.3.3.3 is formulated from the measured data from Table 3.3.2.2 and displays the percentage difference between the actual and the ideal illuminance level in the building.

Table 3.3.3.3 Percentage Difference between Desired and Measured Lux Level

Floor	Location	% Difference between Desire and Measured Lux
G/F	Lift Lobby	+25.0%
	Shroff	-19.8%
	Corridor	+28.0%
	Entry	+17.0%
	Waiting Area	+57.2%
1/F	Public Foyer	-51.4%
	Lift Lobby	-15.5%
2/F	Public Foyer	-57.2%
	Escalator	+128.0%
	Lift Lobby	-16.5%
3/F	Public Foyer I	-54.2%
	Public Foyer II	+3.2%
	Lift Lobby	+13.5%
4/F	Public Foyer	+38.8%
	Lift Lobby	+321.0%
	Corridor I	+64.0%
	Corridor II	+91.3%
	Staff Lift Lobby	-3.0%
5/F	Lift Lobby	+192.5%
	Public Foyer	+2.0%
	Corridor I	+144.0%
	Corridor II	+84.7%
	Staff Lift Lobby	+6.0%
6/F	Lift Lobby	+179.5%
	Public Foyer	+5.6%
7/F	Lift Lobby	+253.5%
	Public Foyer	-13.6%
8/F	Lift Lobby	+322.0%
	Public Foyer	+22.8%

Note: Values of percentage difference larger than +/- 50% are highlighted in red.

According to the *Code of Practice for Energy Efficiency of Lighting Installations* published by EMSD, the design requirements of different parameters are clearly listed, such as luminous efficacy, maximum allowable power consumption and lighting power density for indoor lighting with various specific functions.

From the result displayed on Table 3.3.3.3, some public area, for example, the lift lobby, can borrow natural sunlight during daytime as there are transparent windows in the surroundings. The advanced control of those areas is important to achieve energy saving lighting inside the building, given that lighting contributes nearly half of a quarter of the total energy consumption of the building.

4. Power Quality Analysis

a. General Description of the Power System in ACB

The building is classified into multiple electrical zones. Table 4.1.1 describes the electrical zoning of different floors in the building.

Table 4.1.1 Electrical Zoning of Different Floors in ACB

FLOOR	DEPARTMENTS AND ROOMS					
LG/F	18 (IT Dept. – TC Room)	14 (Health Information and Management Dept.)				
G/F	18 (IT Dept. – TC Room)	4 (Psychiatric Centre)	13 (Security Dept.)	24 (Communication)	7 MRI 25 PACs	2C (Specialist Out-patient Dept. – Appointment Booking Office) 19 (Domestic and Transportation) 12 (Patient Relations Office) 15 (Information Counter) 16 (Shroff)
1/F	18 (IT Dept. – TC Room)	2B (Medical SOPD)	11 (Health Resources Centre)	Shared Facility 2A (Specialist Out-patient Dept.) 2C (Blood Taking Station + Communal)	Shared Facility 2A (Common Areas + Communal)	
2/F	18 (IT Dept. – TC Room)	Shared Facility 2E (Common Areas + Communal)	2H (Obstetric and Gynecology)		2G (Orthopedics and Traumatology Clinic) 2F (Surgical Clinic) 2E (Common Area)	
3/F	18 (IT Dept. – TC Room)	Shared Facility 2I (Common Areas + Communal)	2L (Pediatric and Adolescent Medicine Clinic)		2J (Ophthalmology Clinic) 2K (Ear, Nose and Throat Clinic)	

FLOOR	DEPARTMENTS AND ROOMS				
4/F	18 (IT Dept. – TC Room)	6B (Integrated Rehabilitation Services Area)		5 (Geriatric Day Hospital) 6A (Diabetes Square) 6C (Common Area)	8 (Electro-diagnostic Unit)
5/F	18 (IT Dept. – TC Room)	3 (Day Medical Centre)	1 (Ambulatory Surgery Centre)		
6/F	18 (IT Dept. – TC Room)	21A (Common Areas) 21B (Gymnasium)		2D (SOPD Admin Office)	9 (Chinese Medicine Clinic)
7/F	18 (IT Dept. – TC Room)	22 (Staff Overnight Room) 23 (Male Staff Changing Room)			17 (Library)
8/F	18 (IT Dept. – TC Room)	10A (General Admin Office) 10B (Nursing Admin Office) 10C (Finance Office)	10A (General Admin Office) 10D (Patient and Community Relations Office)	20 (Lecture Theatre)	10E (Shared Facility + Communal)

The incoming power of the building is supplied by 6 transformers from CLP, which are located in 3 different transformer rooms on LG/F. The general description of the transformers is as follows:-

I. Transformer TB4 (Tx1)

Tx1 is located in Transformer Room B, its incomer is denoted as "Tx1/TB4 (6D/3200A)". Table 4.1.1.1 concludes the main connection and schedule of Tx1.

Table 4.1.1.1 Main connection of Tx1 (TB4)

Floor	Served Equipment
LG/F	Transient Voltage Surge Suppressor, Cap. Bank, Active Harmonic Filter, Lighting, FSU and Socket Power, Low-voltage Switchboard
G/F	Lighting, FSU and Socket Power
1/F	Lighting, FSU and Socket Power
2/F	Lighting, FSU and Socket Power
3/F	Lighting, FSU and Socket Power
4/F	Lighting, FSU and Socket Power
5/F	Lighting
6/F	Lighting, FSU and Socket Power
7/F	Lighting, FSU and Socket Power
8/F	Lighting, FSU and Socket Power
R/F	Lift and Lighting
B/F	Water Pump System

II. Transformer TC5 (Tx2)

Tx2 is located in Transformer Room C, its incomer is denoted as "Tx2/TC5 (8D/3200A)". Table 4.1.2.1 concludes the main connection and schedule of Tx2.

Table 4.1.2.1 Main connection of Tx2 (TC5)

Floor	Served Equipment
LG/F	Transient Voltage Surge Suppressor, Cap. Bank, Active Harmonic Filter, Lighting, FSU and Socket Power, Escalator, Low-voltage Switchboard, Genset Heater, Battery Charger, Lift and Automatic Door
G/F	Lighting, FSU, Socket Power, Genset Charger and Escalator
1/F	Lighting, FSU, Socket Power, Storage Power (AV Equipment) and Escalator
2/F	Lighting, FSU, Socket Power and Escalator
3/F	Lighting, FSU and Socket Power
4/F	Lighting, FSU and Socket Power
5/F	Lighting
6/F	Lighting, FSU and Socket Power
7/F	Lighting, FSU and Socket Power
8/F	Lighting, FSU, Socket Power and Lift
9/F	Lighting and Socket Power
R/F	Lift and Lighting

III. Transformer TC6 (Tx3)

Tx3 is located in Transformer Room C, its incomer is denoted as "Tx3/TC6 (16G/3200A)". Table 4.1.3.1 concludes the main connection and schedule of Tx3.

Table 4.1.3.1 Main connection of Tx3 (TC6)

Floor	Served Equipment
LG/F	Transient Voltage Surge Suppressor, Cap. Bank, Active Harmonic Filter, Low-voltage Switchboard and Hospital Equipment
G/F	Lighting, FSU and Socket Power
1/F	Socket Power
2/F	Socket Power
3/F	Socket Power
4/F	Lighting, FSU and Socket Power
5/F	Lighting, FSU Socket Power and Automatic Door
6/F	Socket Power
7/F	Socket Power
8/F	Socket Power
R/F	Water Pump System

IV. Transformer TA1 (Tx4)

Tx4 is located in Transformer Room A, its incomer is denoted as "Tx4/TA1 (1D/3200A)". Table 4.1.4.1 concludes the main connection and schedule of Tx4.

Table 4.1.4.1 Main connection of Tx4 (TA1)

Floor	Served Equipment
LG/F	Transient Voltage Surge Suppressor, Cap. Bank, Active Harmonic Filter
G/F	FSU, Air-conditioning System and AC Power
1/F	AC, FSU Power, Air-conditioning, Ventilation System
2/F	FSU, Ventilation System and AC Power
3/F	FSU, Ventilation System and ELV system
4/F	FSU and Air-Conditioning System
5/F	Nil (Spare)
6/F	FSU Power, Air Conditioning and Ventilation System
7/F	FSU Power
8/F	FSU Power, Air Conditioning and Ventilation System
9/F	Ventilation and PV System
R/F	OFAC_RF1_05 Chiller and Pump, OFAC_RF1_06 Chiller and Pump, HRC_RF_01 Chiller and Pump, HRC_RF_02 Chiller and Pump

V. Transformer TA2 (Tx5)

Tx5 is located in Transformer Room A, its incomer is denoted as "Tx5/TA2 (6D/3200A)". Table 4.1.5.1 concludes the main connection and schedule of Tx5.

Table 4.1.5.1 Main connection of Tx5 (TA2)

Floor	Served Equipment
LG/F	Active Harmonic Filter, FSU Power, Ventilation System and UPS
G/F	Cap Bank, FSU Power, Air-conditioning, Ventilation System and UPS
1/F	FSU Power, AC Power
2/F	FSU Power and Air-conditioning System
3/F	FSU Power
4/F	FSU Power, Air-conditioning and Ventilation System
5/F	FSU Power and UPS
6/F	FSU Power, Air-conditioning System and UPS
7/F	FSU Power
8/F	FSU Power and Air-conditioning and Ventilation System
R/F	OFAC_RF2_02 Chiller and Pump, OFAC_RF1_03 Chiller and Pump,

VI. Transformer TB3 (Tx6)

Tx6 is located in Transformer Room B, its incomer is denoted as "Tx6/TB3 (14D/3200A)". Table 4.1.6.1 concludes the main connection and schedule of Tx6.

Table 4.1.6.1 Main connection of Tx6 (TB3)

Floor	Served Equipment
LG/F	Transient Voltage Suppressor, Cap Bank Active Harmonic Filter, Low-voltage Switchboard
G/F	AC, FSU Power, Air-conditioning and Ventilation System
1/F	FSU Power, Air-conditioning and Ventilation System
2/F	FSU Power, Air-conditioning and Ventilation System
3/F	FSU Power, Air-conditioning and Ventilation System
4/F	AC, FSU Power, Air-conditioning and Ventilation System
5/F	AC, FSU Power, Air-conditioning and Ventilation System
6/F	FSU Power and Ventilation System
7/F	FSU Power, Air-conditioning and Ventilation System
8/F	FSU Power, Air-conditioning and Ventilation System
R/F	Ventilation System OFAC_RF2_01 Chiller and Pump, OFAC_RF2_04 Chiller and Pump,

b. Introduction of the Parameters Used in Analysis

Power quality is a sub-category under electricity quality, which is the combination of voltage and current quality. Power quality issues may lead to interruption on the service of the building and cause adverse effect on occupant experience. The focus of power quality analysis is mainly on 6 different parameters, the description of the parameters are listed as follows, plots of the transformer data are used for detailed explanations:-

I. Voltage

Voltage quality is concerned with deviations of the voltage from the ideal. The ideal voltage is a single frequency sine wave of constant amplitude and frequency. The common voltage includes three-phase voltage unbalance, sag and swell, amplitude fluctuations and transient. Figure 4.2.1.1 shows a normal voltage waveform from one of the transformers of the building.

Figure 4.2.1.1 Normal Voltage Waveform of ACB (TB3, January 2017)

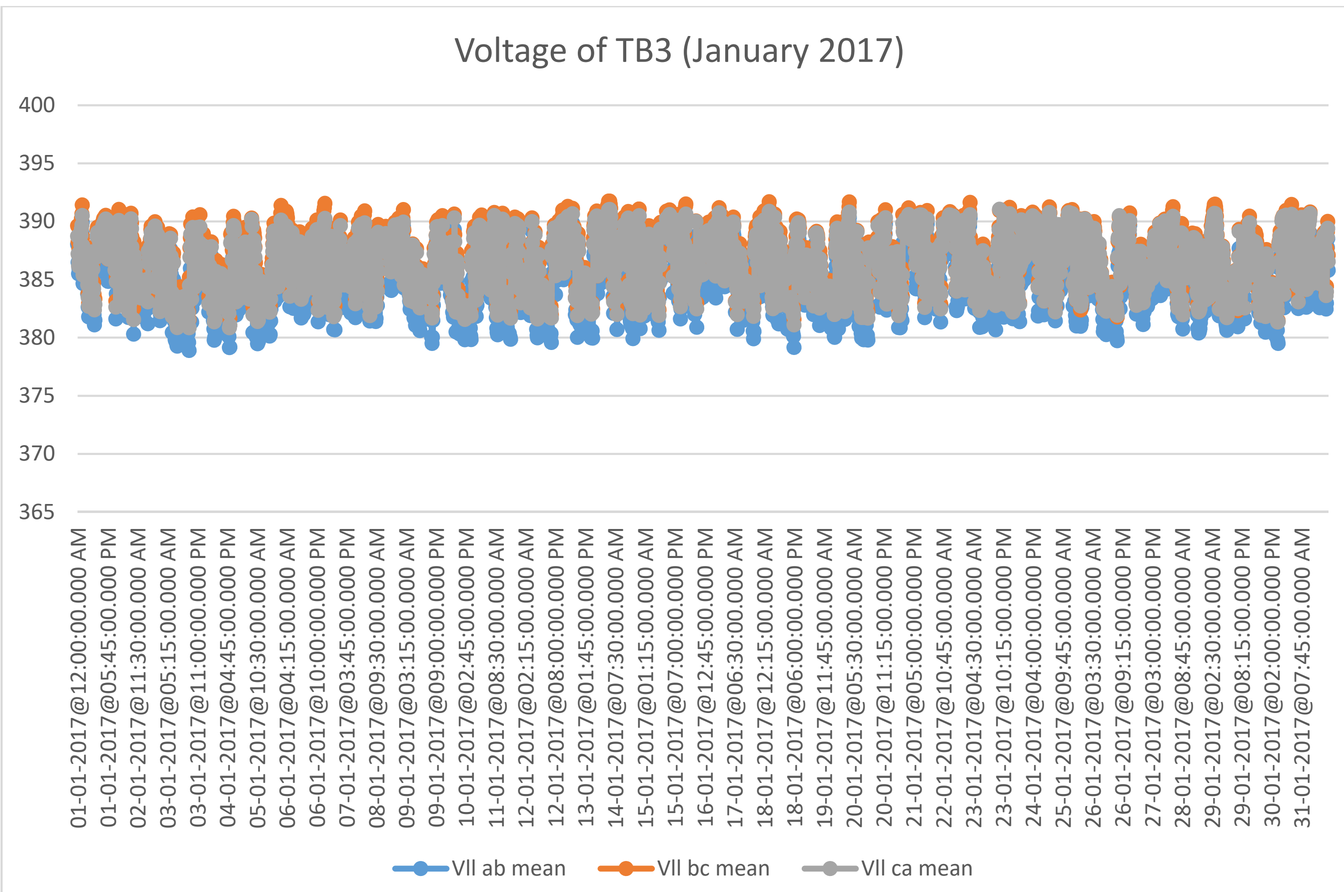
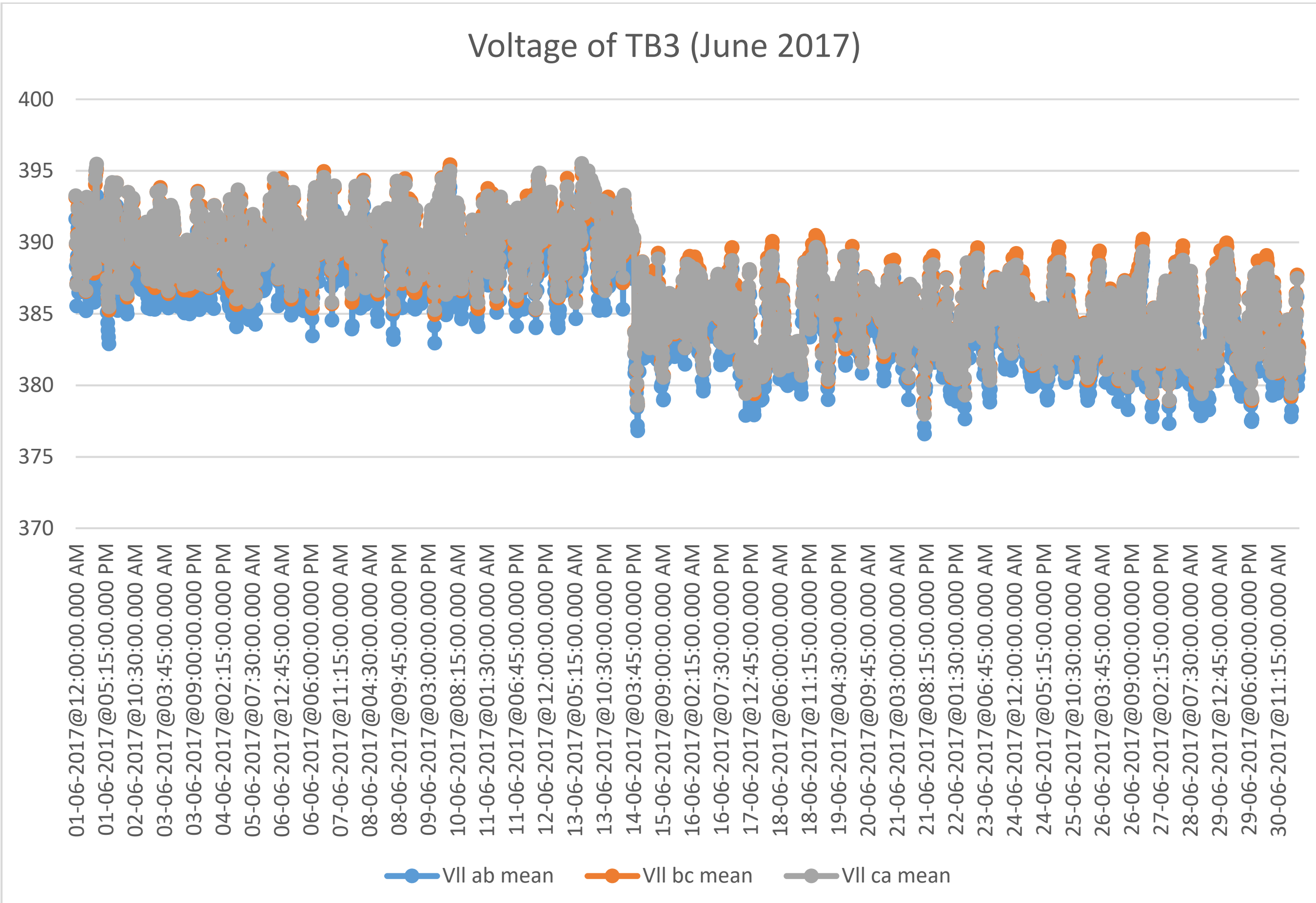


Figure 4.2.1.1 displays the voltage waveform of all the three phases, the three waveform perfectly overlap each other, which implies the voltage of the three phases is completely balanced. The range of voltage amplitude is steady, all of the values lie between 390V and 380V, it can be concluded that there is no voltage fluctuation this month.

For comparison, Figure 4.2.1.2 shows an abnormal voltage waveform of the same transformer in the same year.

Figure 4.2.1.2 Abnormal Voltage Waveform of ACB (TB3, June 2017)



The waveform in Figure 4.2.1.2 displayed a noticeable step-down in the voltage amplitude, the average value of the voltage amplitude decreased from 390V to 385V, in which the percentage difference between maximum and minimum value is around 4%.

As indicated in Figure 4.2.1.1, the normal range of voltage amplitude is 390V to 380V, so the voltage amplitude is higher than normal in the first half of the month, and returned to normal in the second half of the month. Even though the extent of the voltage surge will not cause severe problem to the power system, the long duration of this surge indicates a presence of abnormality in the power system.

Despite the long-lasting voltage surge, the voltage of the three phases are perfectly balanced, which is shown from the perfectly overlapped waveforms of the three phases.

II. Current

Current quality is the complementary term to voltage quality: it is concerned with the deviation of the current from the ideal. The ideal current is a single-frequency sine wave of constant amplitude and frequency and the current sine wave should be in phase with the voltage sine wave. One of the common current quality issues is three-phase current unbalance. Figure 4.2.2.1 shows a normal current waveform from one of the transformer of the building.

Figure 4.2.2.1 Normal Current Waveform of ACB (TB4, March 2017)

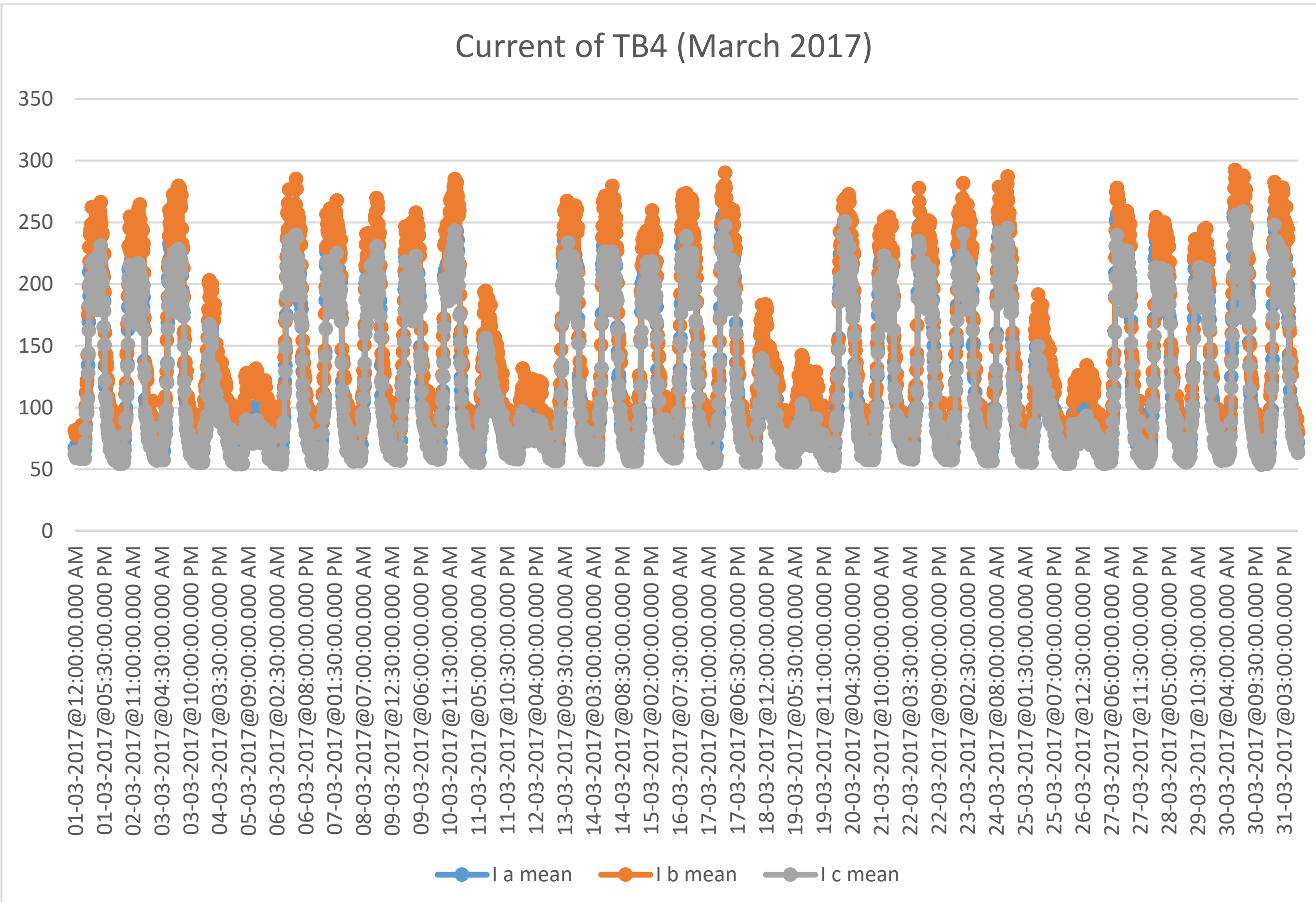
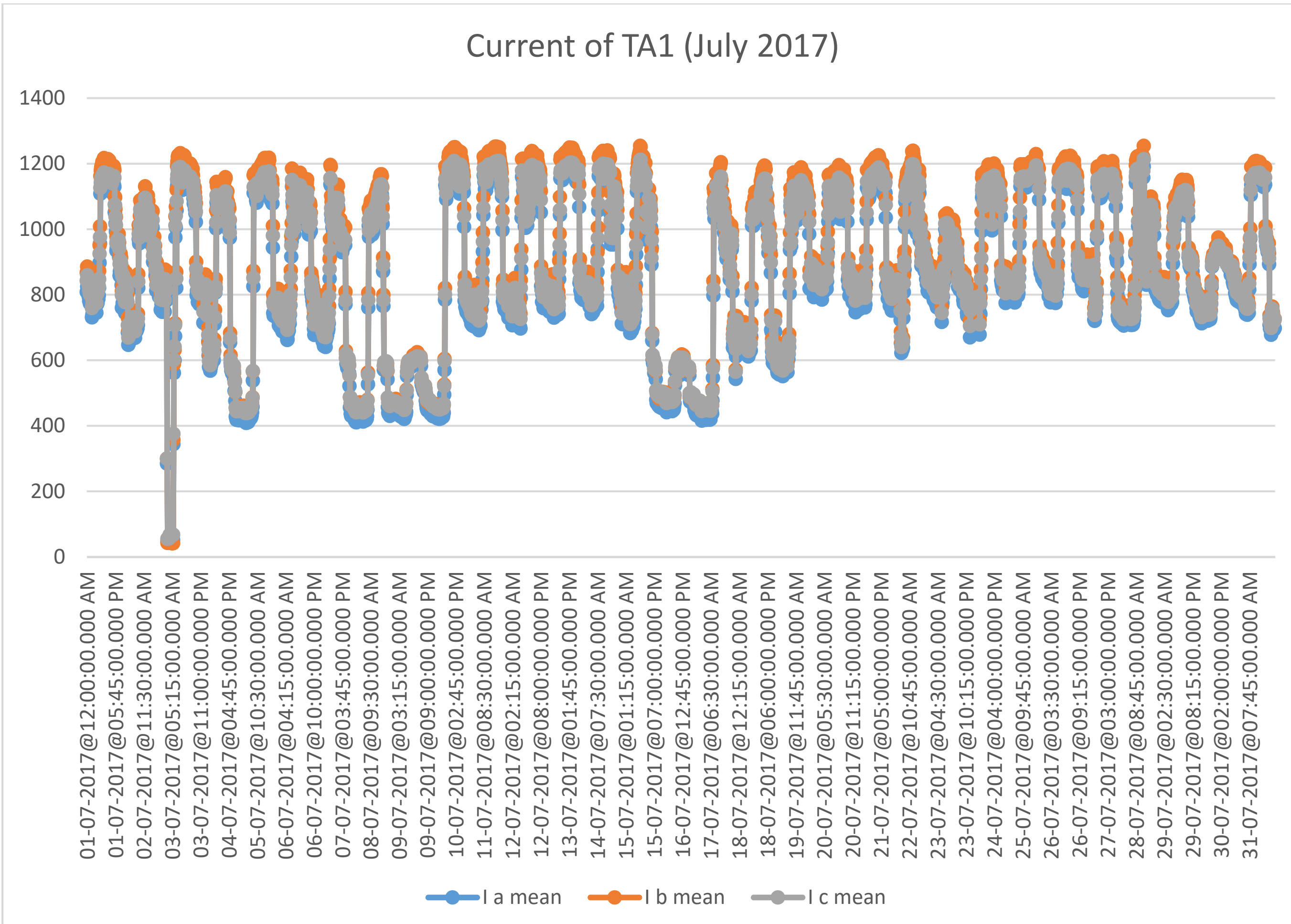


Figure 4.2.2.1 displays a periodic waveform, following a cycle of 5 high crest and 2 lower crest, which resonates with the operating schedule of the building. On weekdays (Monday to Friday), the building operates for the whole day, which results in higher current level. On Saturday, the building operates for half of the day, so the crest on Saturday will be lower than that on weekdays. On Sunday, the building is closed and only part of the equipment operates, which is represented by the lowest crest.

Figure 4.2.2.1 displays the ideal current waveform of the transformer; however, the shape of the current waveform is easily distorted by multiple parameters. Figure 4.2.2.2 shows a distorted current waveform from a different transformer of the building.

Figure 4.2.2.2 Distorted Current Waveform of ACB (TA1, July 2017)



The waveform in Figure 4.2.2.2 is severely distorted, there are multiple times of decrease in magnitude, the percentage of reduction is up to 200%. On 3 July 2017, there was a sudden drop of current amplitude to a level below 60A.

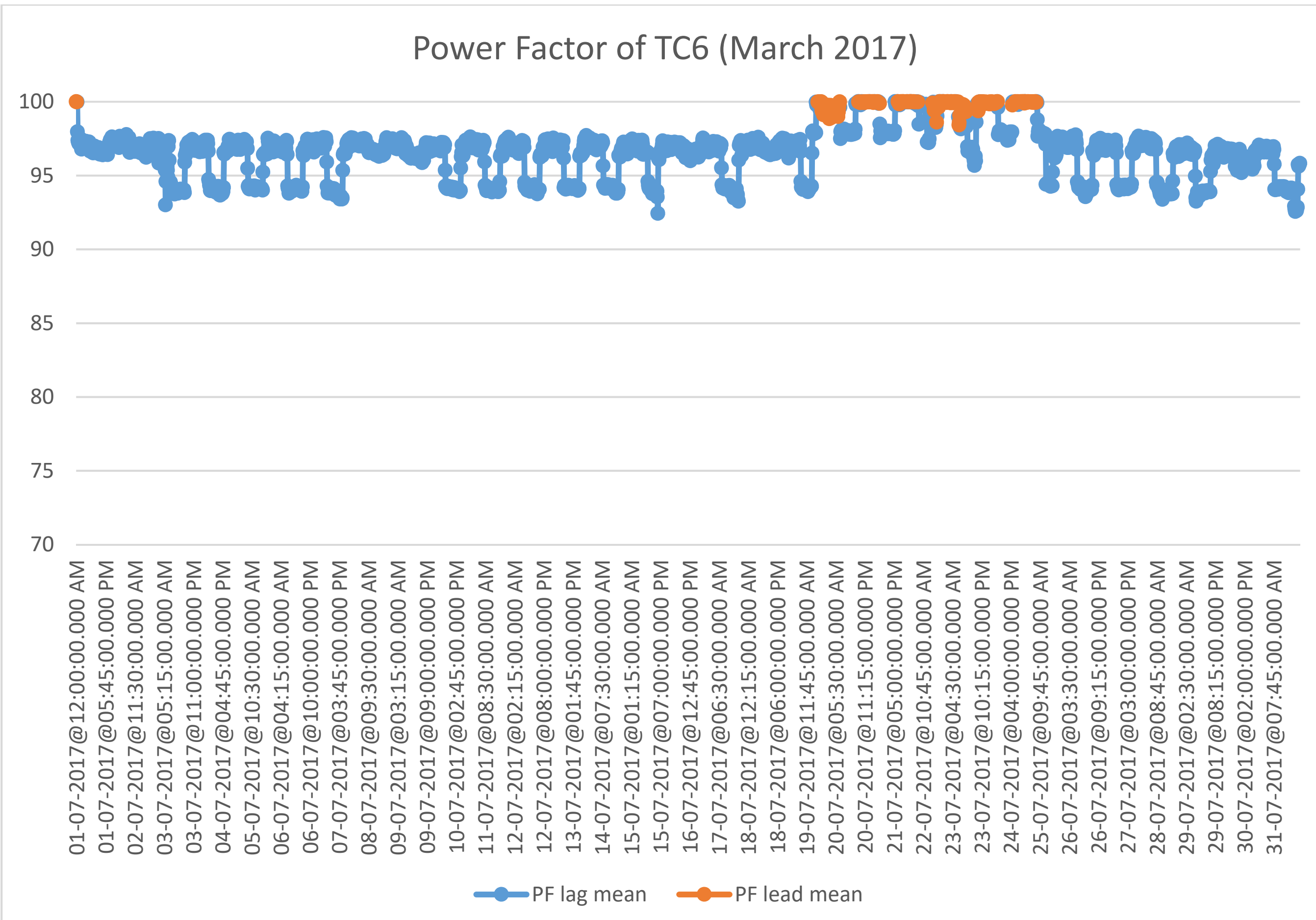
There are several possible reasons causing the distortion of the current waveform, including the fault and maintenance events in the building, the change in operation of the served equipment, etc. The maintenance events in the building includes periodic inspections, reset of the power system, those events will interrupt the power supply and cause the decrease in current level. Among all served equipment, the operation of chiller is the major factor on the current distortion, the variation of chiller current during operation will affect the current amplitude of transformer.

Apart from the current waveform, additional information (for instance, maintenance log, fault log) is required for thorough investigation of the distorted waveform.

III. Power and Power Factor

Power quality is the combination of both voltage and current quality. Power factor is the main focus of studying power quality, as it can reflect any abnormality in voltage, current or power. Common power quality problems include low power factor, leading power factor, etc. Figure 4.2.3.1 shows a plot of normal power factor from one of the transformer of the building.

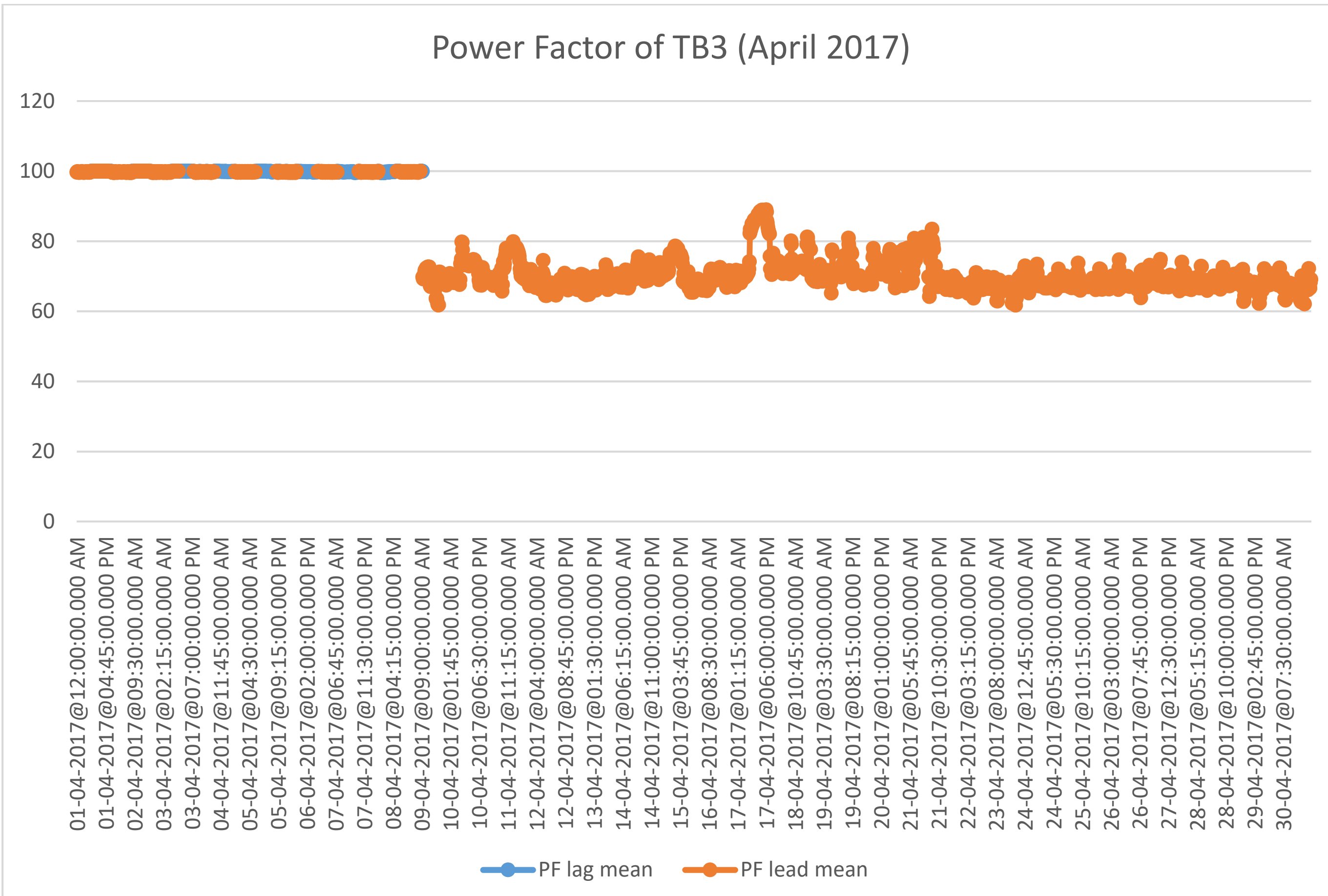
Figure 4.2.3.1 Normal Power Factor of ACB (TC6, March 2017)



As shown in Figure 4.2.3.1, the fluctuation of the power factor is within the range of 0.92 to 1, in which the percentage decrease is below 10%. The plot does not show any sign of low power factor, and leading power factor only appears in short time, the power factor values are close to unity. Given that TC6 is serving multiple equipment, which may cause reduction in power factor, resulting in overall power factor higher than 0.92 is very satisfactory for this transformer.

Transformers serving chillers have greater chance of fluctuating power factor, the fluctuation of power factor is supposed to be compensated by the corresponding capacitor bank. If the power factor drop below the desire level, the capacitor bank turns on and supplies power to retrieve the normal power factor. However, in some cases, the retrieval of power factor will cause leading power factor. Figure 4.2.3.2 shows a plot of continuous leading power factor of one of the transformers in the building.

Figure 4.2.3.2 Continuous Leading Power Factor of TB3 (April 2017)



According to Figure 4.2.3.2, the leading power factor in TB3 continues for more than half of the month. On 9 July 2017, the power factor changed to 0.7 capacitive, and it did not resume the value to near unity or return to inductive power factor in the remaining days of the month.

The retrieval of power factor mainly depends on the operation of capacitor bank, and the control algorithm of the capacitor bank determines the mode of operation of the capacitor bank. If the capacitor bank is programmed with desire power factor as inductive, it can only retrieve the power factor when it is inductive and lower than the desire value. On the other hand, the capacitor bank will not operate if the power factor is leading, due to the control algorithm. The technical details of the capacitor bank used in the building will be described in Chapter 4.d.I.

IV. Harmonics

Harmonics appears when there is presence of frequencies at integer multiples of the fundamental system frequency. Harmonics combine with the fundamental voltage or current, and produce waveform distortion. Previously, distorted waveforms and associated harmonics were of little concern, rapidly increasing use of power rectifier circuitry and other power electronic devices made harmonic distortion a significant source of power quality problems. When it comes to harmonic distortion, voltage total harmonic distortion (THD), current harmonic distortion and K-factor are the major parameters to study. Figure 4.2.4.1, Figure 4.2.4.2 and Figure 4.2.4.3 display the voltage THD, the current THD and the K-factor of one of the transformers in the building.

Figure 4.2.4.1 Voltage THD of TC6 (June 2017)

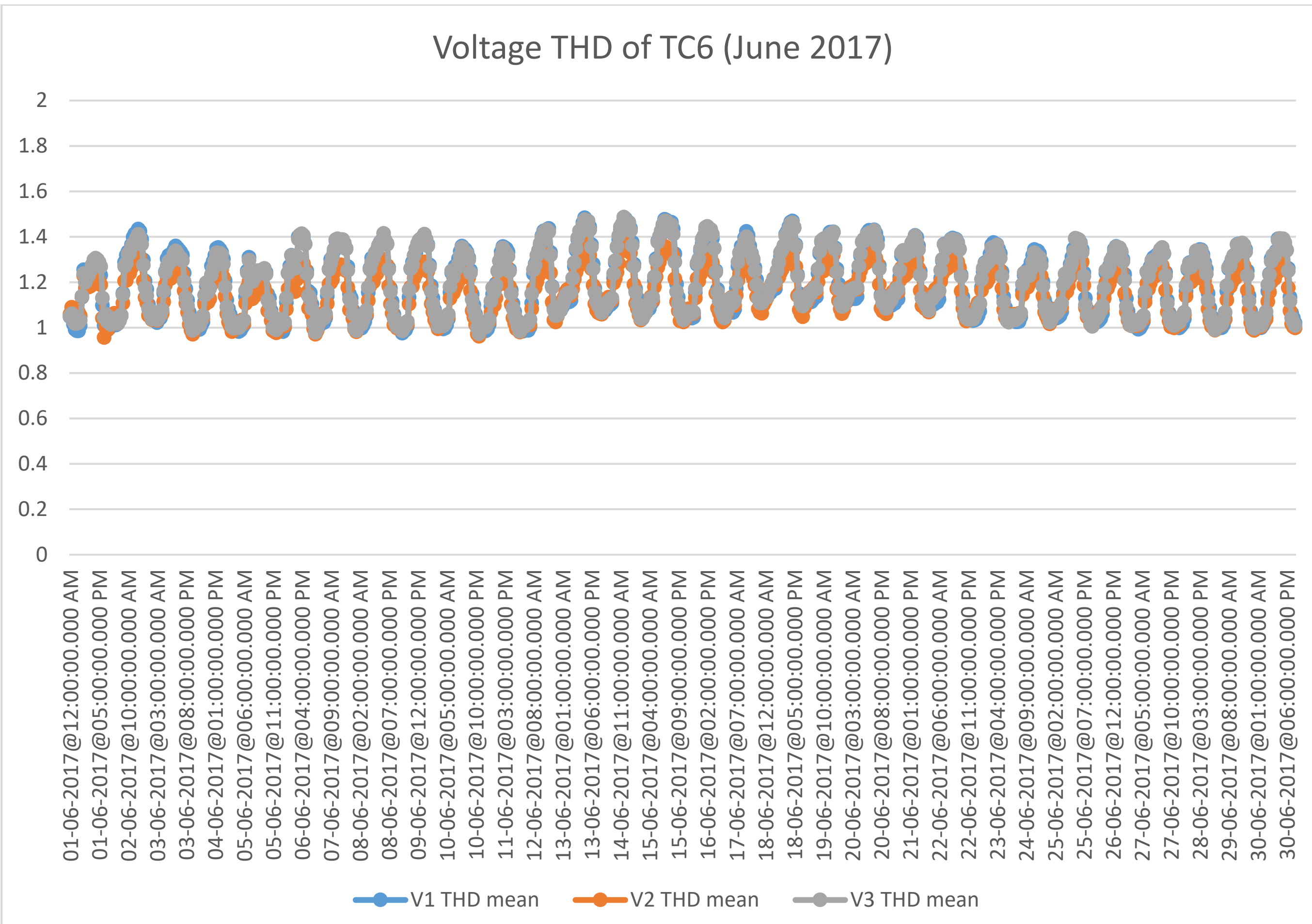


Figure 4.2.4.2 Current THD of TC6 (June 2017)

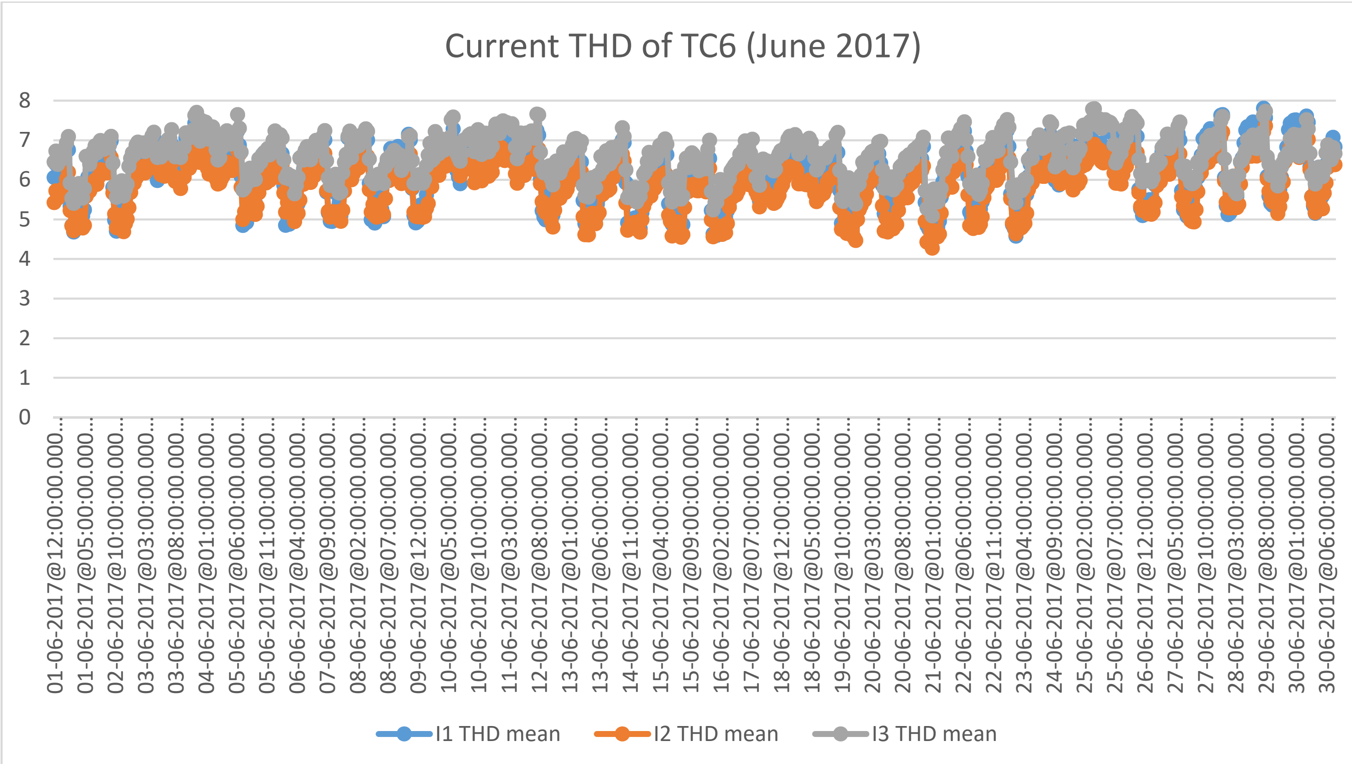
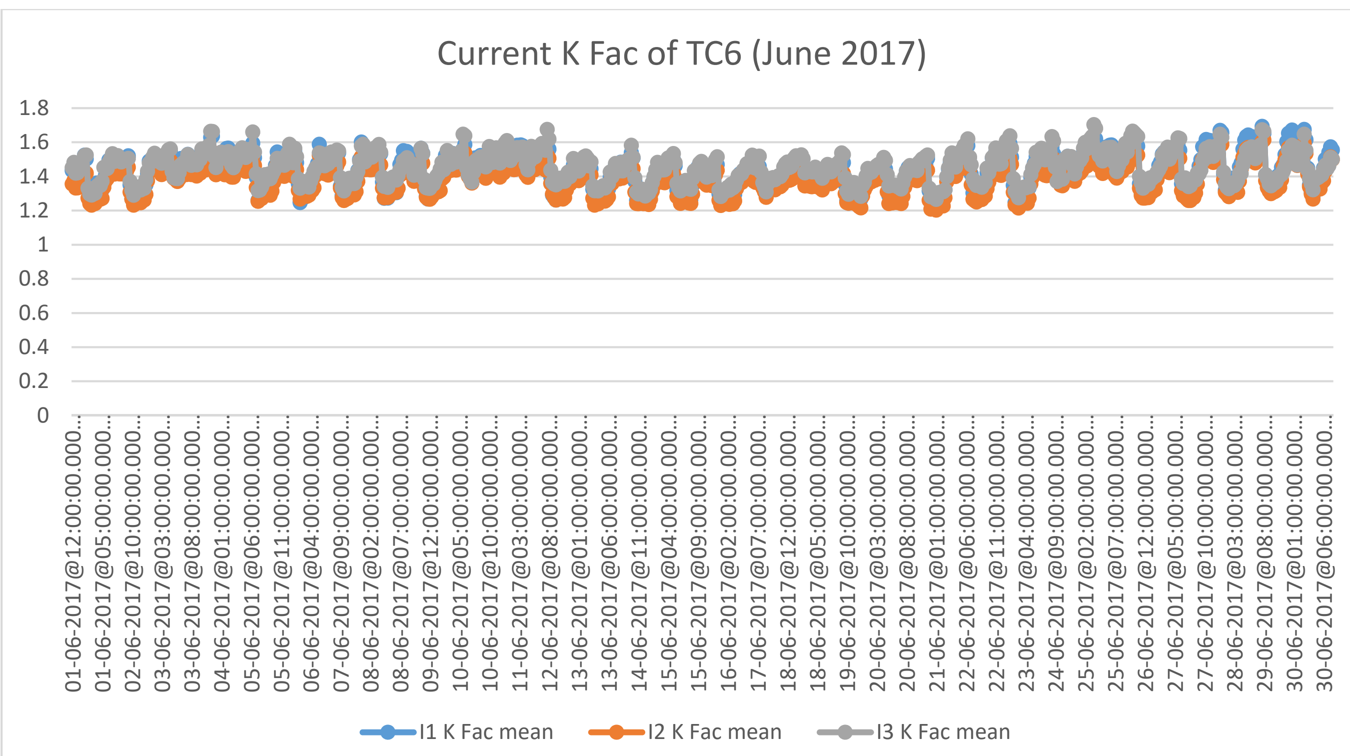


Figure 4.2.4.3 Current K-factor of TC6 (June 2017)

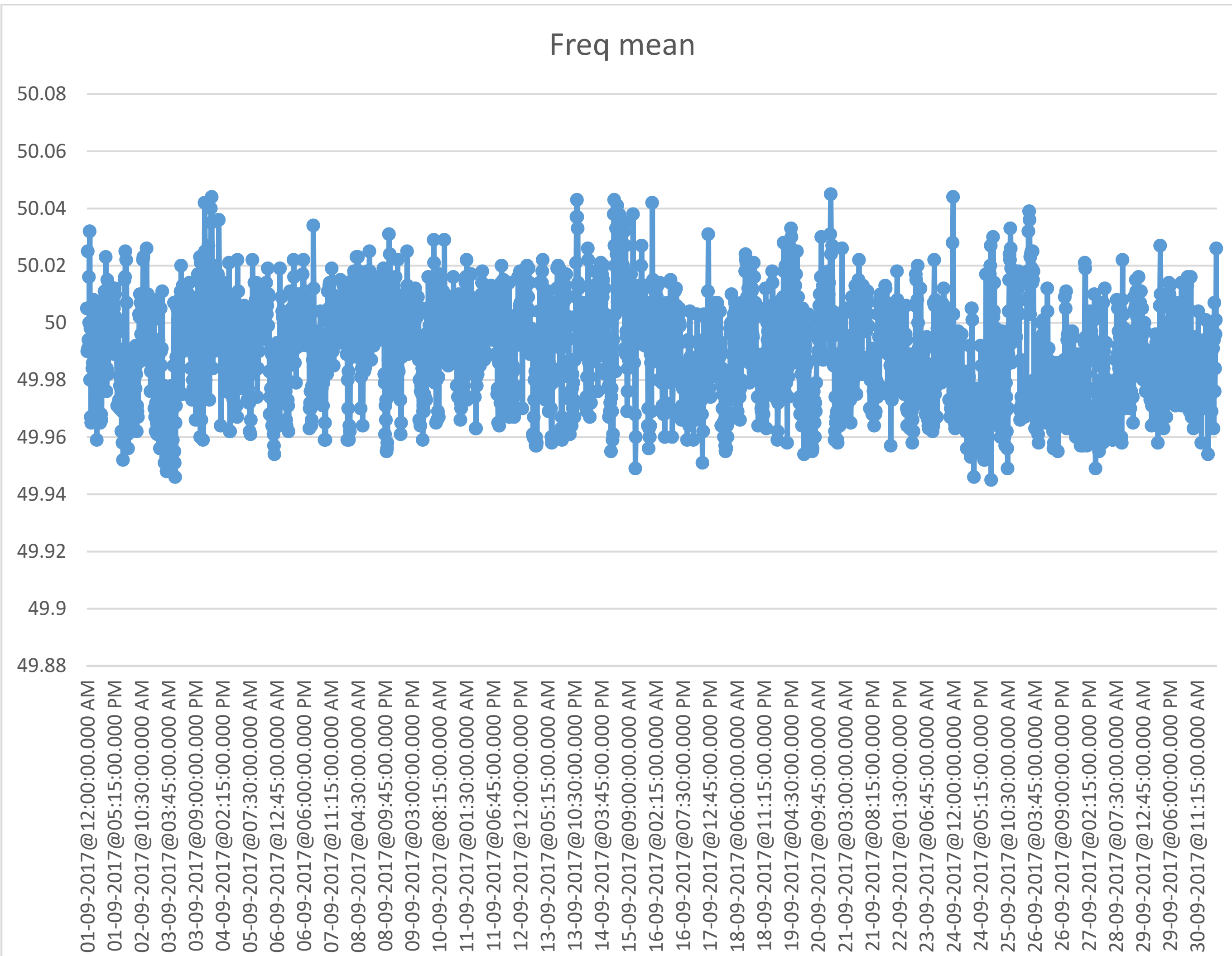


V. Frequency

Frequency deviation is mainly caused by the generator sets and could affect normal operation of power electronic equipment, but not affect purely resistive loads.

Frequency deviation is seldom a problem with utility-supplied power network nowadays. Frequency rarely varies more than 0.5 Hz from 50 Hz in Hong Kong, and is averaged out over 24-hour period because of large number of clocks and other time-based devices which depend for accuracy on constant frequency from the mains. Figure 4.2.5.1 shows a plot of frequency of one of the transformers of the building.

Figure 4.2.5.1 Frequency of TC5 (February 2017)



c. Macroscopic Analysis

Macroscopic approach is adopted to process the data in general, and to reflect the overall picture of the power consumption in ACB. In macroscopic analysis, the raw data of the transformer incomers are analysed, which are used to reflect to power quality in the whole building.

I. Plots from PQM data of transformers (2016 and 2017)

Macroscopic analysis is based on the PQM raw data provided by the technical staff in the building, which includes different parameters from the 6 transformers. Table 4.3.1.1 classifies the types of data included in the data file.

Table 4.3.1.1 Classification of Parameters in PQM Raw Data

Parameters	Data included
Voltage	$V_{average}$ (Mean, Highest, Lowest)
	V_{ab} (Mean, Highest, Lowest)
	V_{bc} (Mean, Highest, Lowest)
	V_{ca} (Mean, Highest, Lowest)
	$V_{unbalance}$ (Mean, Highest, Lowest)
Current	$I_{average}$ (Mean, Highest, Lowest)
	I_a (Mean, Highest, Lowest)
	I_b (Mean, Highest, Lowest)
	I_c (Mean, Highest, Lowest)
	I_n (Mean, Highest, Lowest)
Power	Real Power, kW (Mean, Highest, Lowest)
	Apparent Power, kVA (Mean, Highest, Lowest)
	Reactive Power, kVAR (Mean, Highest, Lowest)
Power Factor	Leading Power Factor (Mean, Highest, Lowest)
	Lagging Power Factor (Mean, Highest, Lowest)
Frequency	Frequency (Mean, Highest, Lowest)
Harmonics	V_{ab} THD (Mean, Highest, Lowest)
	V_{bc} THD (Mean, Highest, Lowest)
	V_{ca} THD (Mean, Highest, Lowest)
	I_a THD (Mean, Highest, Lowest)
	I_b THD (Mean, Highest, Lowest)
	I_c THD (Mean, Highest, Lowest)
	I_a K-factor (Mean, Highest, Lowest)
	I_b K-factor (Mean, Highest, Lowest)
	I_c K-factor (Mean, Highest, Lowest)

From the PQM raw data, multiple plots of different parameters are constructed. For simplicity, only plots with noticeable problem are displayed.

Figure 4.3.1.1 to Figure 4.3.1.4 shows the variation of power factor of TA1 from March to June 2016. Figure 4.3.1.5 displays the change in power factor of TA2 in March 2017. Figure 4.3.1.6 to Figure 4.3.1.8 depicts the continuous leading power of TB3 during the period between April and June in 2017. The elaboration of the plots and the identification of problems are included in Chapter 4.C.II.

Figure 4.3.1.1 Power Factor of TA1 (March 2016)

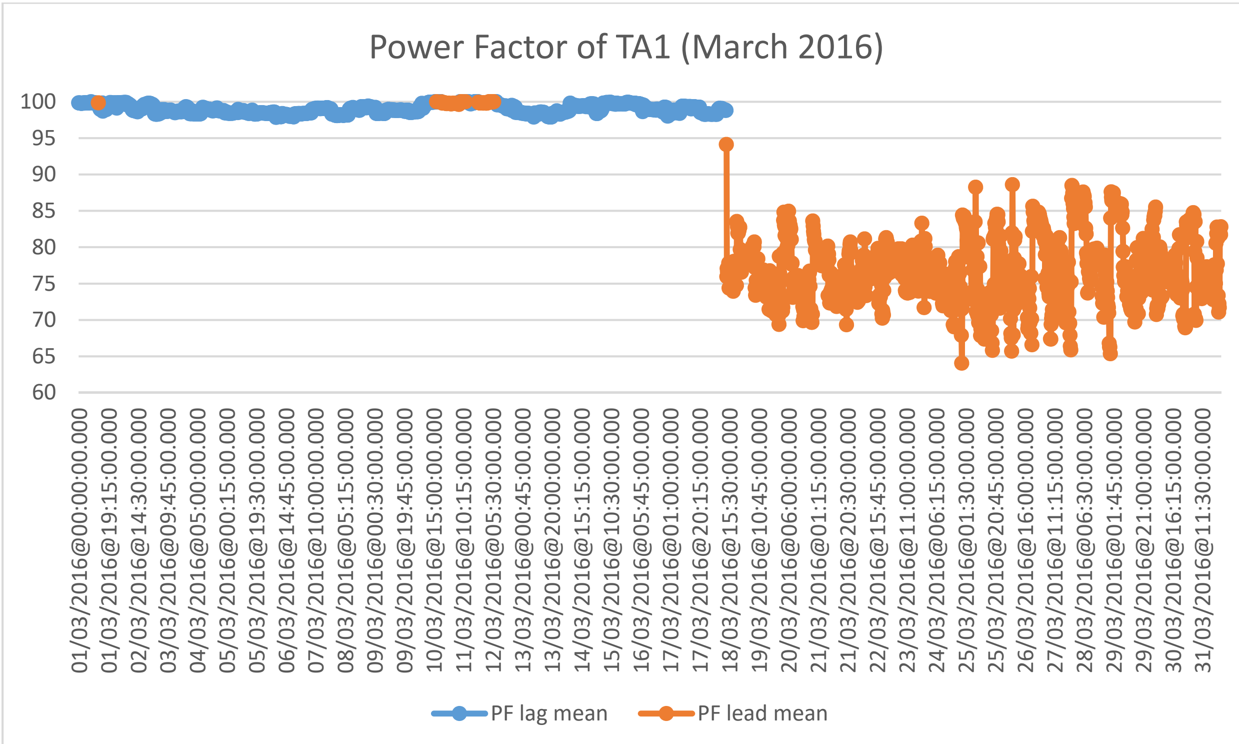


Figure 4.3.1.2 Power Factor of TA1 (April 2016)

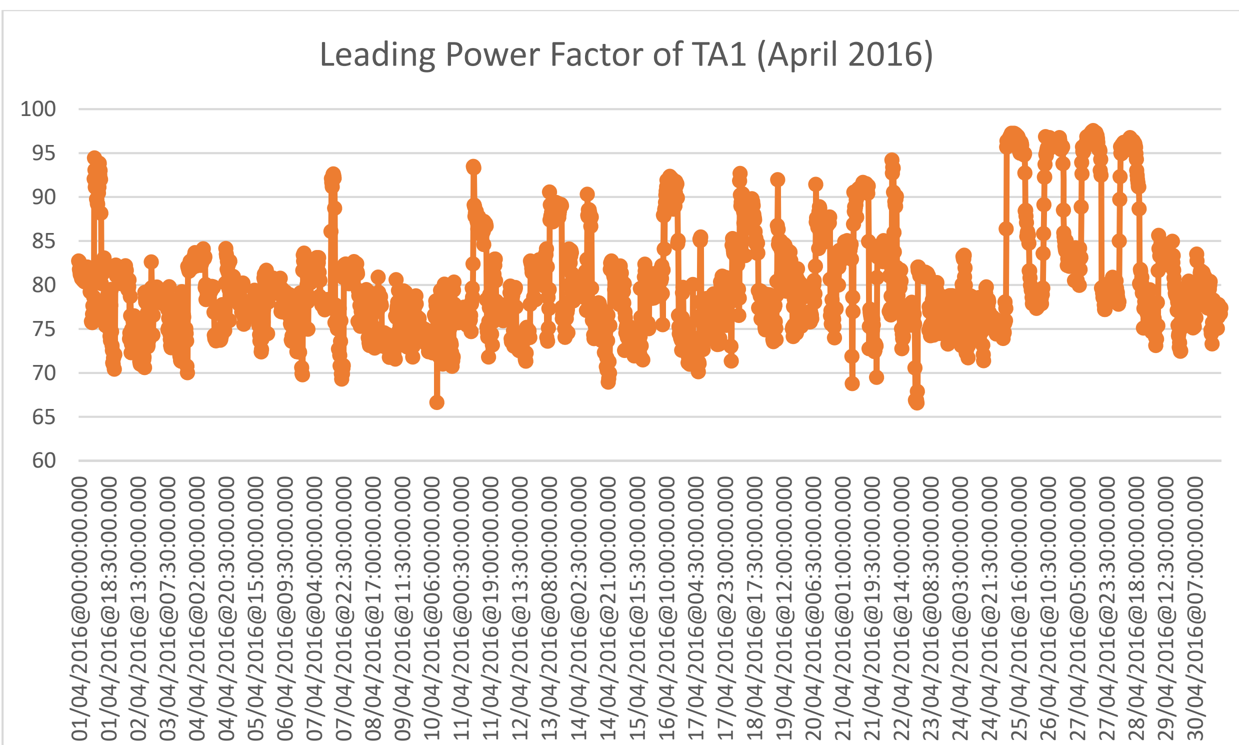


Figure 4.3.1.3 Power Factor of TA1 (May 2016)

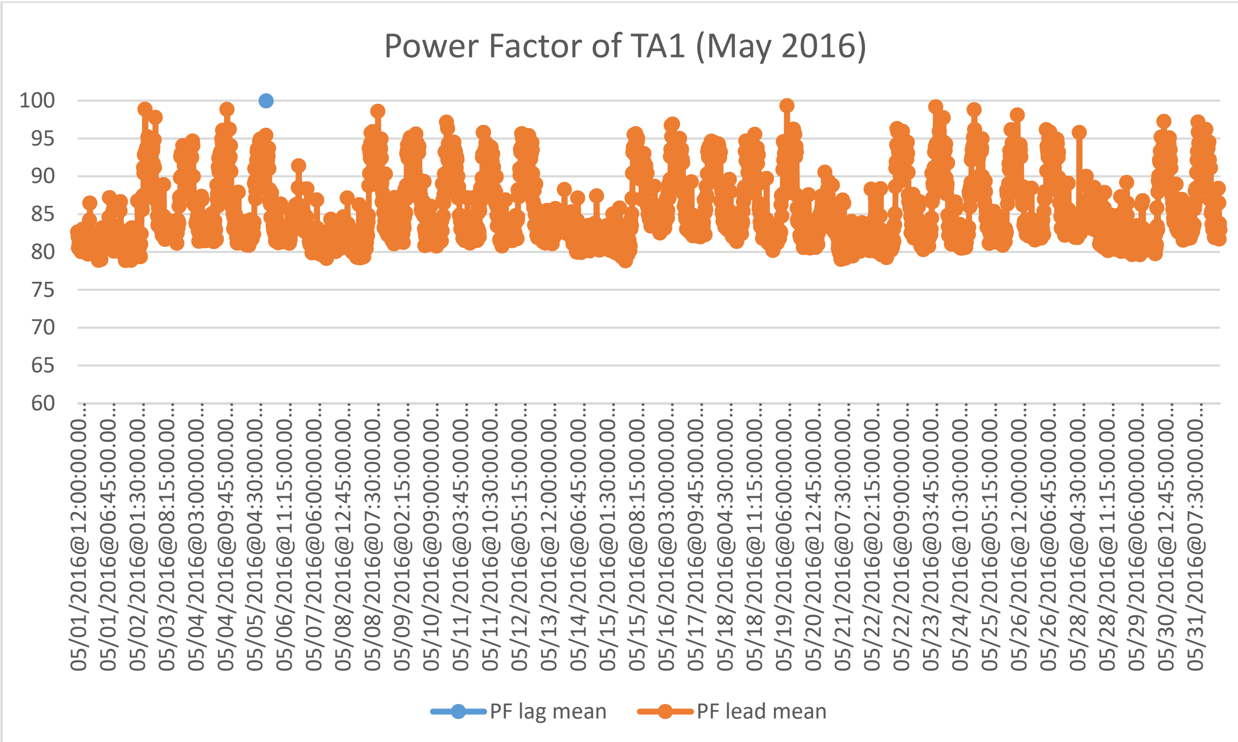


Figure 4.3.1.4 Power Factor of TA1 (June 2016)

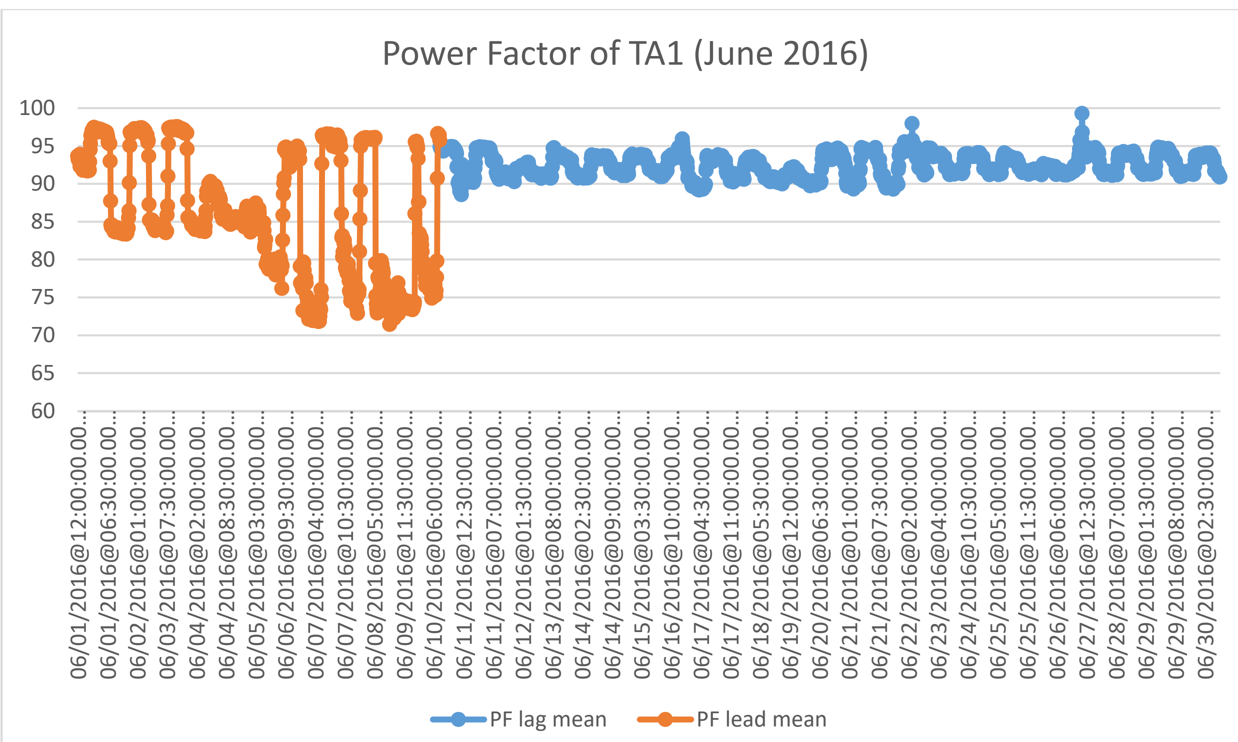


Figure 4.3.1.5 Power Factor of TA2 (March 2017)

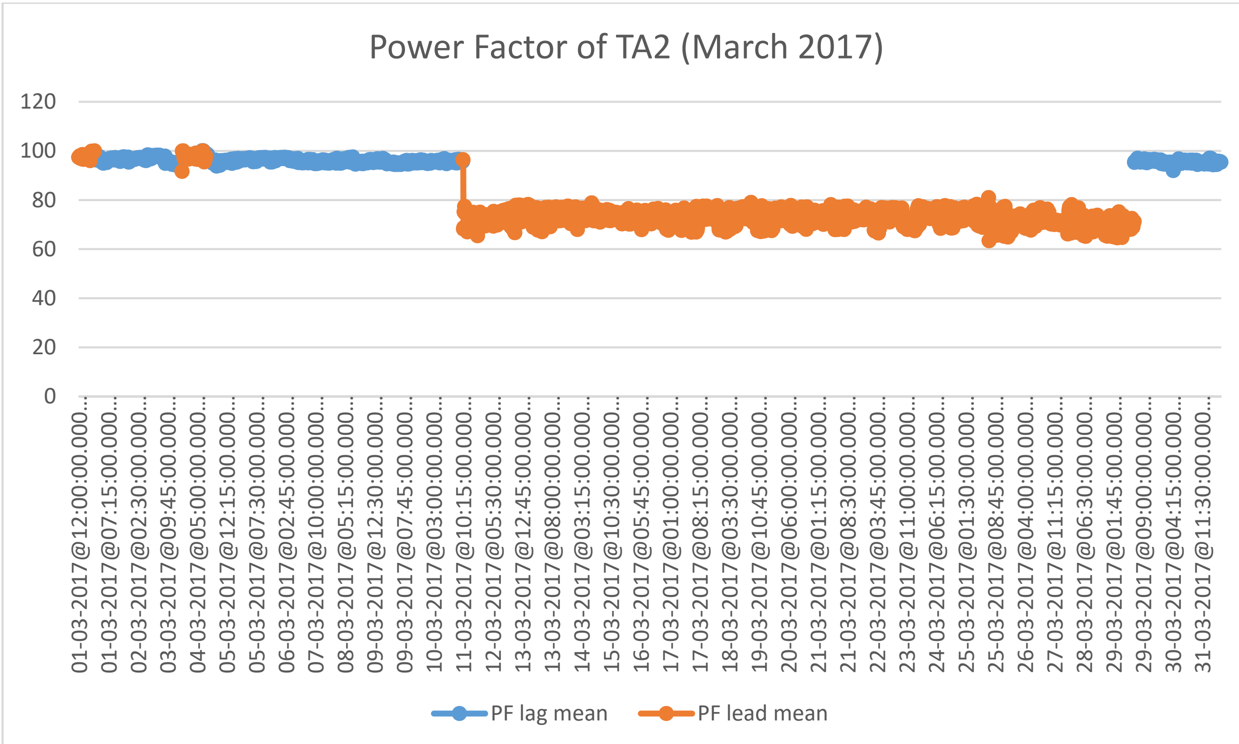


Figure 4.3.1.6 Power Factor of TB3 (April 2017)

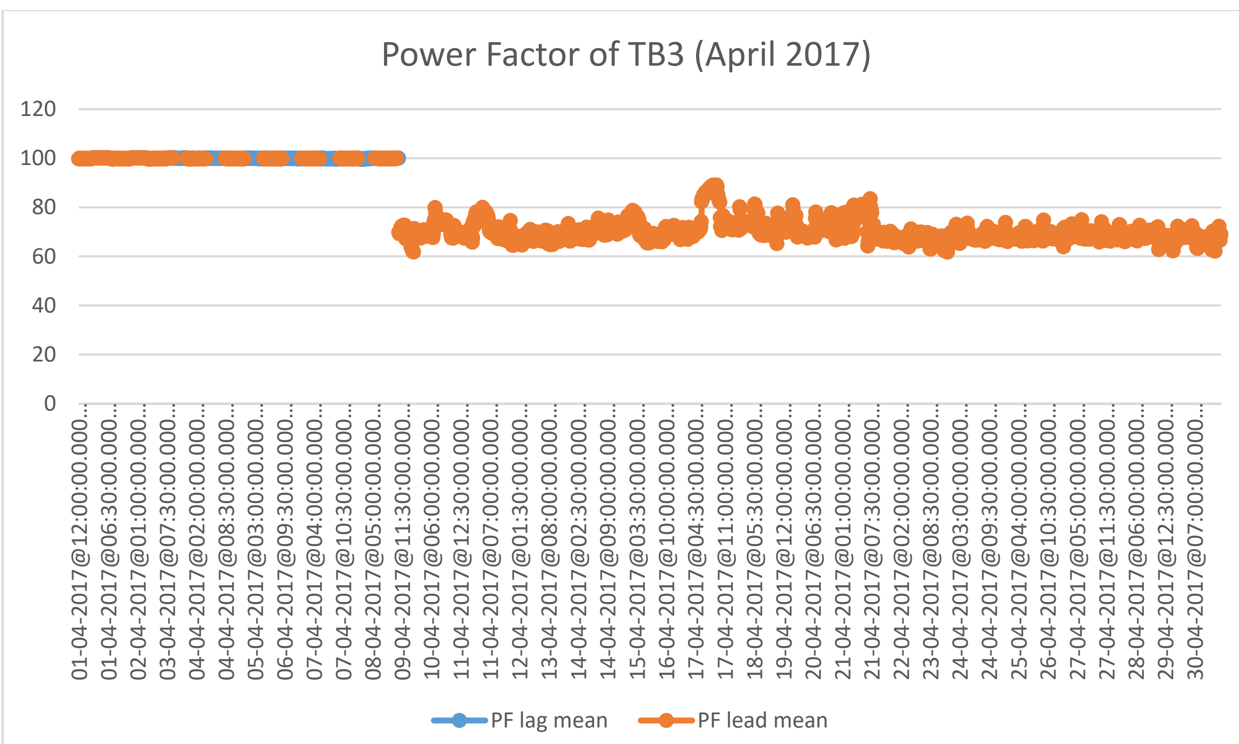


Figure 4.3.1.7 Power Factor of TB3 (May 2017)

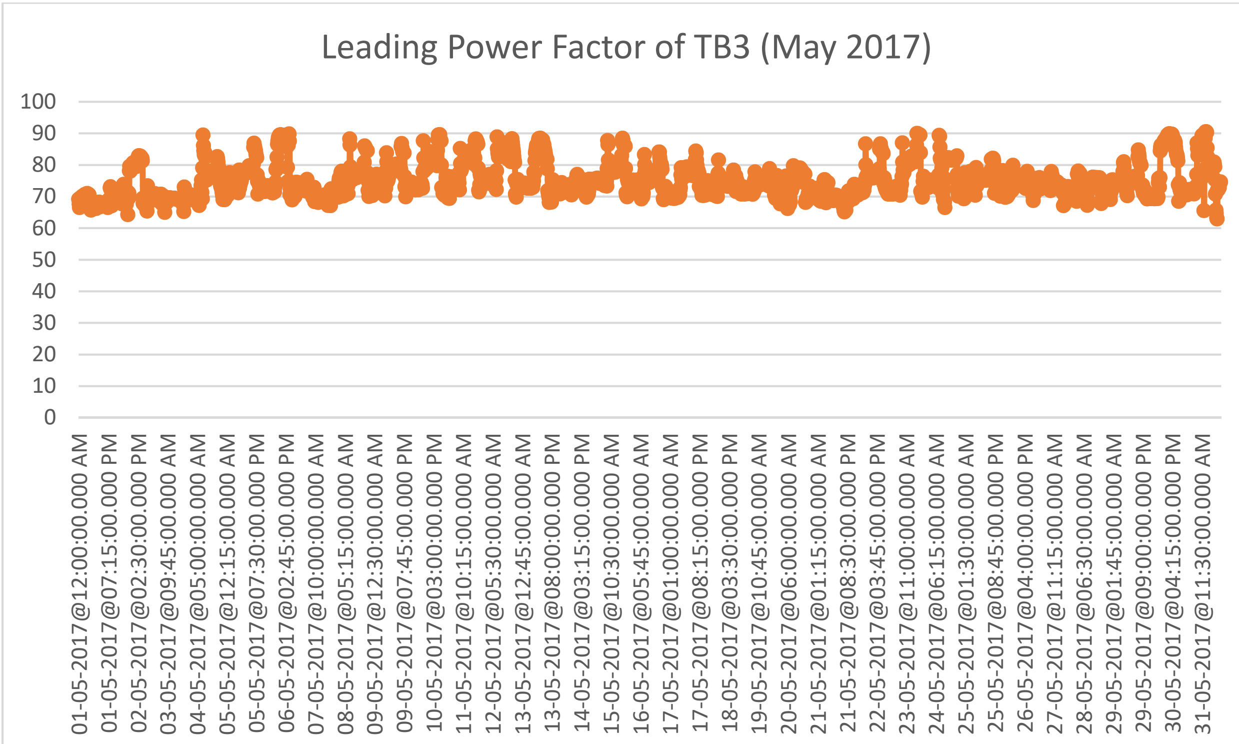
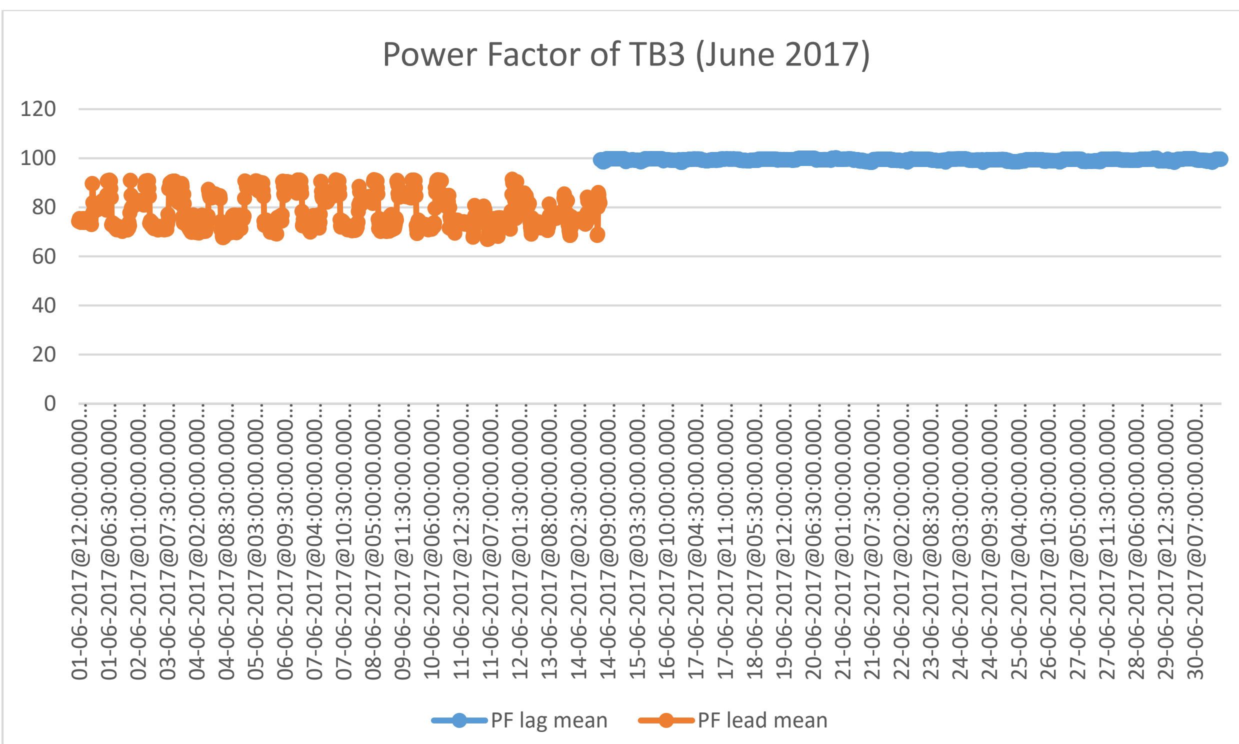


Figure 4.3.1.8 Power Factor of TB3 (June 2017)



II. Identification of Problems

The problem of leading power factor is noticed in half of the 6 transformers, namely transformer TA1 (Tx4), transformer TA2 (Tx5) and transformer TB3 (Tx6). The leading power factor problem is serious, in terms of the duration and the level of the change in magnitude.

According to Figure 4.3.1.1, the power factor of TA1 abruptly switched from inductive to capacitive on 18th March 2016. After the unexpected switch, the existence of the leading power became continuous. Leading power factor of TA1 is noticed in Figure 4.3.1.1, Figure 4.3.1.2, Figure 4.3.1.3 and Figure 4.3.1.4, which include a 4-month period in 2016. Among the 4-month time, the leading power factor existed for around 3 months, with the average value of 0.8 capacitive. On 10th June 2016, the power factor returned to inductive, with an average value 0.92 lagging, which is probably due to the reset in the power system.

From Figure 4.3.1.5, the power factor of TA2 switched from inductive to capacitive on 11th March 2017. The leading power factor in TA2 continued for more than half of the month, with the average value of 0.7 capacitive, the level of change magnitude is the highest among the 3 transformers. On 29th March 2017, the power factor retrieved to inductive, with the average amplitude close to unity, this retrieval can be explained by the reset in the power system.

Figure 4.3.1.6, Figure 4.3.1.7 and Figure 4.3.1.8 displays the variation of the power factor for transformer TB3, in the period from April to June in 2017. In the beginning of April 2017, multiple switching of power factor between inductive and capacitive are noticed. Leading power factor is observed in the period from 9th April 2017 to 14th June 2017, with the average value of 0.75 capacitive. After 14th June 2017, the power factor resumed to inductive, with the average value close to unity.

Table 4.3.2.1 summarizes the problem of leading power factor of the 3 transformers in 2016 and 2017.

Table 4.3.2.1 Summary of Leading Power Factor Problem in TA1, TA2 and TB3

Transformer	Year of Occurrence	Duration	Average Leading PF
TA1 (Tx4)	2016	84 Days	0.8
TA2 (Tx5)	2017	19 Days	0.7
TB3 (Tx6)	2017	67 Days	0.75

In ideal case, the value of power factor is assumed to be unity; however, in actual practice, the power factor in the building seldom approaches unity, due to the operation of some particular equipment (for instance, chiller). The issue of leading power factor could be due to the interaction between the loads and capacitor bank. It can be resolved by adjusting the settings of control circuits for capacitor banks.

d. **Microscopic Analysis**

Microscopic approach is adopted to process the data from a particular point, in order to study and locate any possible problem in smaller perspectives. In microscopic analysis, the apparently abnormal parts will be studied, in which the control algorithm behind and the operation performance will be studied.

In Chapter 4.c.II, the problem of leading power factor is found to occur persistently. The first instinct for the issue is the error in the capacitor bank. Capacitor bank is one of the major devices that can be used to compensate the low power factor, the error in sensor or control algorithm can cause overshooting and resulting in leading power factor. The technical details and the operation of the capacitor bank should be analysed to find out the cause of problem.

I. **Technical Details of the Capacitor Bank**

An 8-step capacitor bank is connected to each transformer in the building, at the 3200A busbar after the transformer. Figure 4.4.1.1 illustrates the connection of the capacitor bank in a schematic diagram. Table 4.4.1.1 summarizes the technical characteristics of the capacitor bank used in the building. Table 4.4.1.2 displays the programed setting for the controller of the capacitor bank.

Figure 4.4.1.1 Connection of Capacitor Bank (Main Distribution System Schematic)

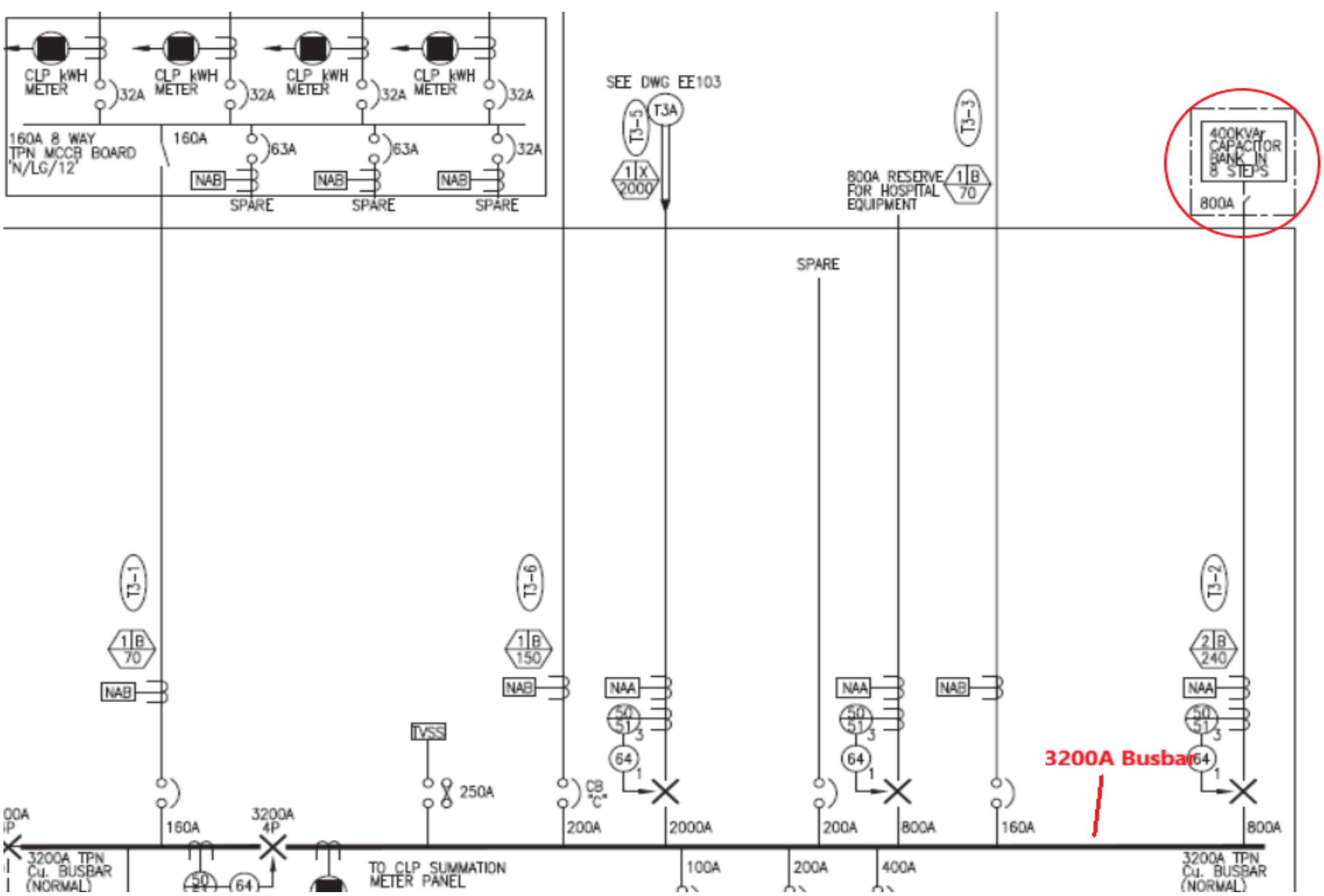


Table 4.4.1.1 Summary of Technical Characteristic of Capacitor Bank

Technical Characteristic	Value
Rated Voltage	380 V
Rated Power	400 kVAR
Rated Current	608 A
Design Voltage	440 V
Design Power	448 kVAR
Maximum Continuous Current	796 A
Rated Frequency	50 Hz
Insulation	0.69 kV
Calculated Losses	2000 W
Tuning	215 Hz
Indoor Type	IP31
Standard	IEC 439
Temperature Range	-5 / +40 °C
Average Temperature over 24 Hours	35 °C
Average Annual Temperature	25 °C

Table 4.4.1.2 Programed Setting of the Capacitor Bank Controller

Setting	Programed Value / Option
Power Factor Upper Limit	0.96 Inductive
Power Factor Lower Limit	0.89 Inductive
Current Transformer Ratio	500
Learning of Connection Configuration	OFF
Stage Power of the First Stage	50 kVAR
Stage Ratio	1, 1, 1, 1
Number of Switching Outputs	8
Delete Peak Values	Del
Expanded Programming	Pro.

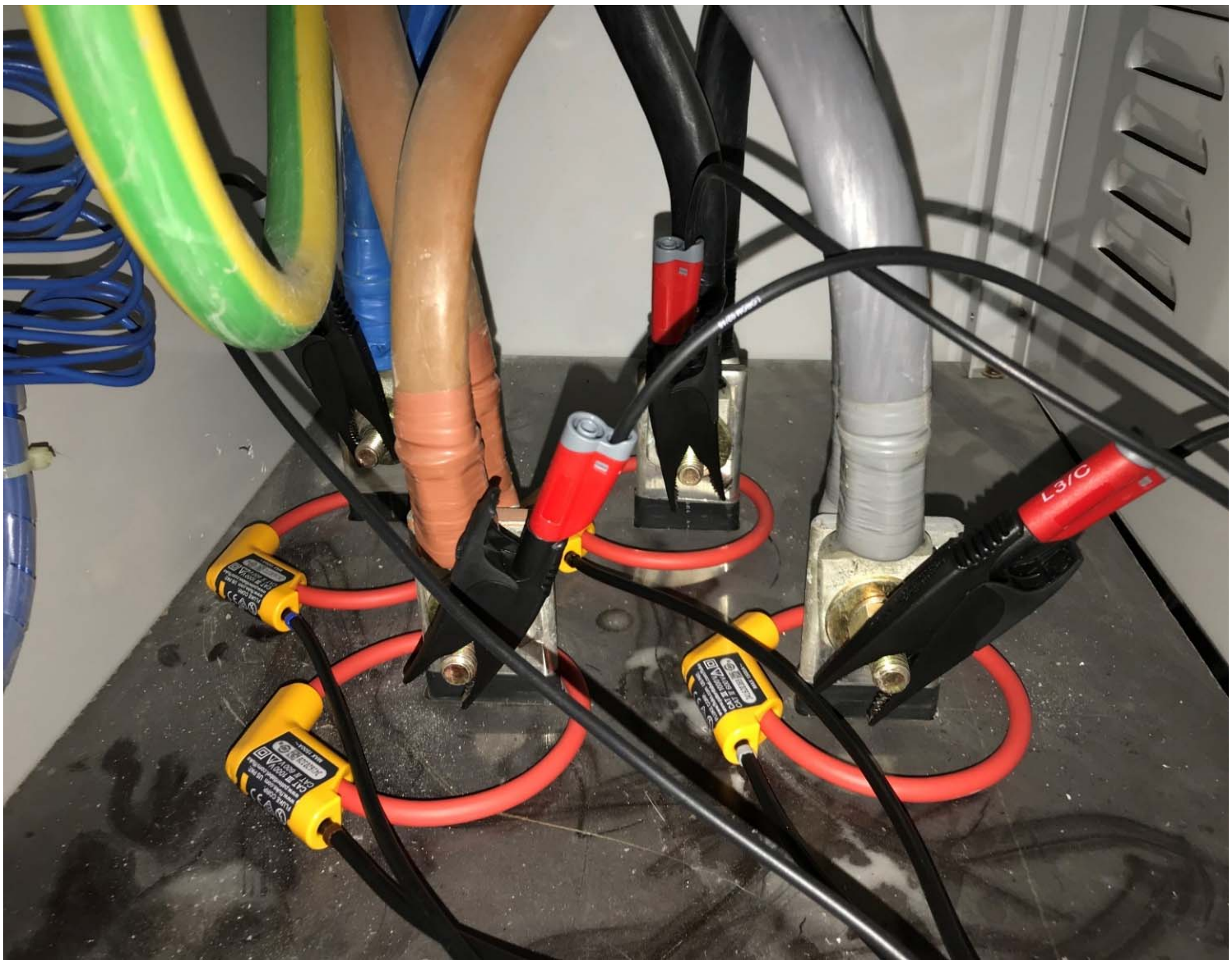
From the program displayed in Table 4.4.1.2, the target power factor is restricted within the range from 0.96 inductive to 0.89 inductive. If the detected power factor is below 0.89 inductive, the controller will start the operation of the capacitor bank – the capacitor bank will supply reactive power and compensate the reduced power factor. The operation will be terminated when the power factor level approached 0.96 inductive. Every capacitor bank consists a total of 8 steps, with evenly distributed power (50 kVAR), the number of step operating depends on the difference between the target and the detected power factor level.

If the operation of the capacitor bank follows the design intent of the program, the power factor should be within the range from 0.96 to 0.89 inductive. The existence of leading power factor suggests the possibility of errors in the capacitor bank, site measurement is then conducted to examine the performance of the capacitor bank.

II. Site Measurement on Capacitor Bank Performance

Two site measurements are conducted on 17th July and 8th August 2018, power analyzer is connected to the capacitor bank to record the electrical parameters for one week and two weeks respectively. As advised by the technical staff in the building, the data of capacitor bank for Tx2 and Tx3 are measured. Figure 4.4.2.1 shows the set up and connection in the capacitor bank during the measurement.

Figure 4.4.2.1 Set Up for Capacitor Bank Measurement



During the two site measurement, there is no specific findings and the data obtained shows that there is no connection and usage of the capacitor bank. As reported by the technical staff of the building, the upper limit of the target power factor is changed to 0.93 inductive, to prevent overshoot after the operation of capacitor bank. Seemingly with the new setting of the upper limit in the control algorithm, the capacitor banks are operating satisfactorily and no subsequent problems have been reported.

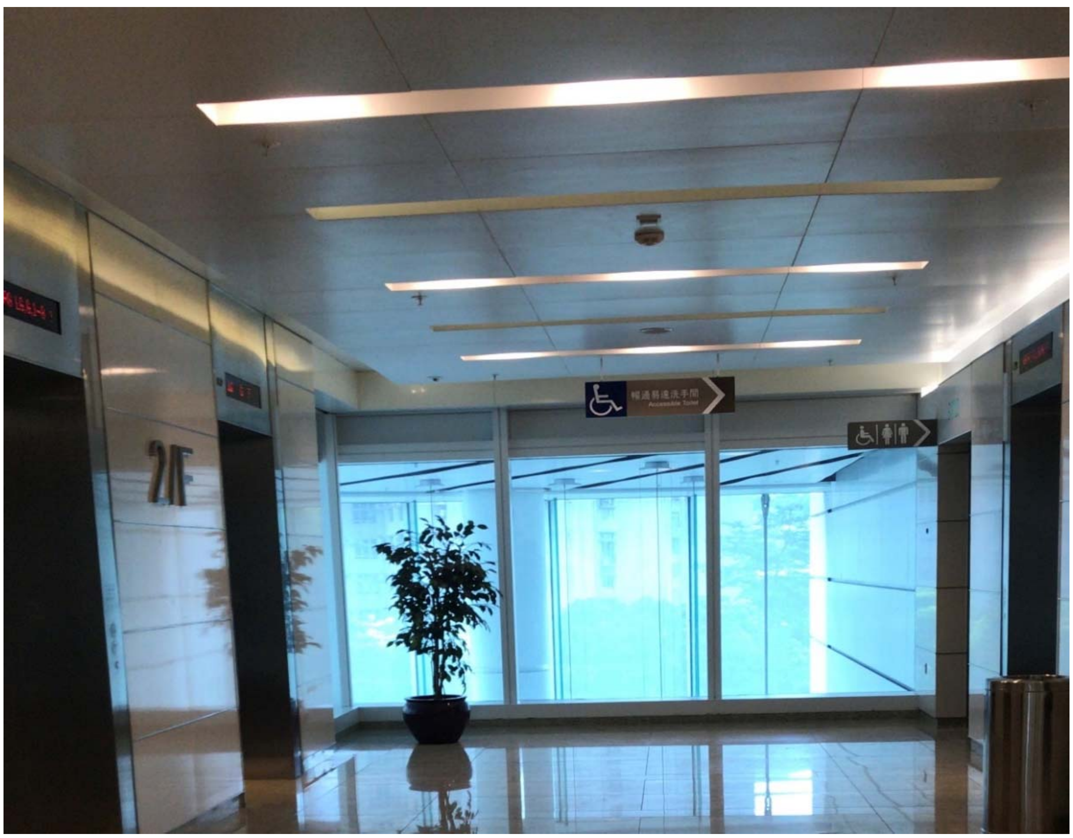
5. Systems Evaluation

According to the result from energy consumption study and power quality analysis, multiple issues are noticed in three different systems, namely the lighting system, the air-conditioning system and the power system. In this chapter, multiple possibilities of causes and explanations to the identified issues will be discussed.

a. Issues in Lighting System

According to the formulated illuminance data and description included in Chapter 3.c.III, there is a noticeable difference between the desirable and the actual illuminance level, in which the illuminance level of areas near transparent windows is much higher than the optimal level. From short interviews with occupants in the building, the interviewee comments that natural light through the window is already sufficient in most of the time, which resonates with the data obtained from site measurement, indicating the excessive lighting in the building. Figure 5.1.1 shows the excessive lightings near transparent windows.

Figure 5.1.1 Excessive Lightings near Transparent Windows



As shown in Figure 5.1.1, the 3 operating luminaires in the area are seemingly dissipating similar amount of lighting power, despite the entrance of natural light from the transparent window. For maximum utilization of natural light, the lighting power from luminaire should depend on the amount of natural light reached. In this case, the luminaire which is nearest to the transparent window should be dimmed or switched off. If advanced lighting control system is implemented in the building, the lights in the building can be dimmed whenever there is sufficient natural light detected, the saving in annual lighting power will be noticeable.

Apart from excessive lighting, redundant luminaire is one of the possible reasons causing immoderate illuminance level. In site visit conducted on 8th August 2018, some redundant luminaires are noticed in the building. Figure 5.1.2 shows an example of redundant luminaires found in the building.

Figure 5.1.2 Redundant Luminaires Spotted in ACB

Apart from showing the luminaires, Figure 5.1.2 shows the exterior design of the building, which make good use of glass facade. This facade design allows natural light from broader directions to enter, so as to reduce the use of power in lighting system. The luminaires shown are not useful during sunny daytime, as the natural light is adequate for occupants; while at cloudy daytime or at night, the light from these luminaires would perform their intended functions. The luminaires identified are recommended to remain power-off when there is sufficient natural lighting. The detailed recommendations will be explained in Chapter 6.c.

b. Issues in Air-conditioning System

As the largest portion of energy consumption in the building, the malfunctioning of chillers and inefficient performance of chillers will tremendously affect the whole building. The performance evaluation of individual chillers is included in Chapter 3.c.III, indicating the malfunction of OFAC_RF2_02 and OFAC_RF2_04.

According to the information provided by the technical staff in the building, the oil-free chillers installed in the building seldom worked simultaneously. The oil-free chillers have been installed in the building since 2012, the chiller energy consumption is proposed to reduce by 20-30%, which is equivalent to 5% of the total consumption in the building, hence saving around $1M in electricity tariff annually. Compared to the expected life span and the expected COP of centrifugal chillers, the situation of the malfunctioned chillers is unsatisfactory.

The chiller OFAC_RF2_04 and OFAC_RF2_01 are reported to have a long period of malfunctioning during the period from 2016 – 2017. During the site visit dated 4th June 2018, the chiller OFAC_RF2_04 is still not functioning, some functional parts of that chiller is used to replace the malfunctioning part of OFAC_RF2_01. Figure 5.2.1 is a photo of OFAC_RF2_04 taken on 4th June 2018, showing a tag "pending for maintenance" is attached to the chiller.

Figure 5.2.1: Photo of OFAC_RF2_04 on 4th June 2018

The prolonged malfunctioning of OFAC_RF2_04 is affecting the loading distribution of the whole chiller system. Given the energy saving in the long run together with the longer life expectancy of equipment, it is recommended that the malfunctioning chiller should be repaired as soon as possible.

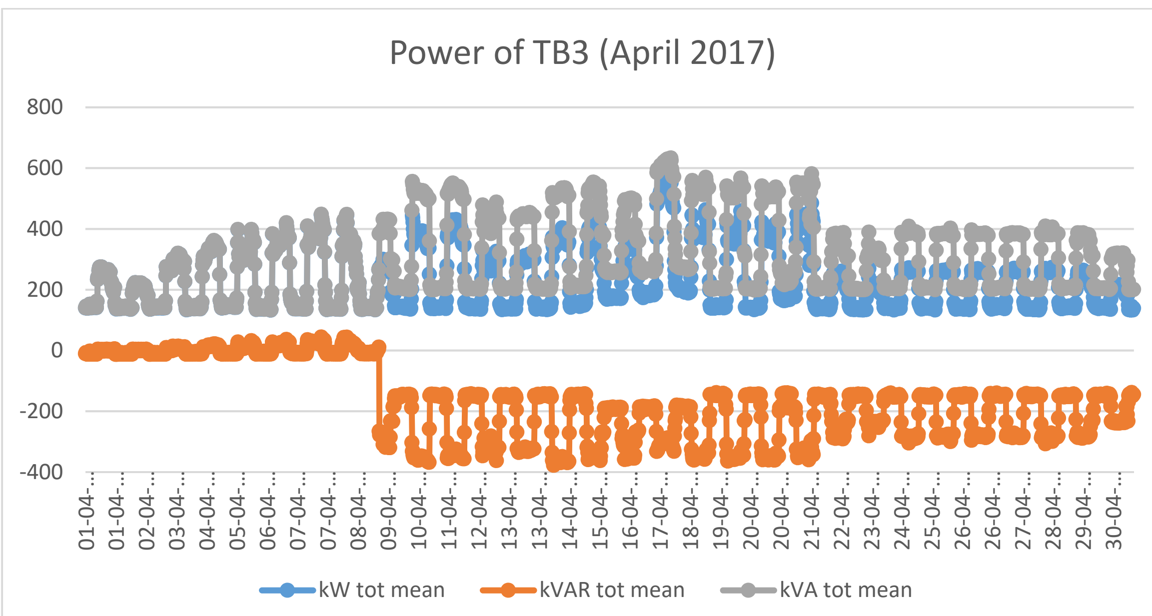
c. Issues in Power System

In Chapter 4.c.II, the problem of leading power factor is identified in multiple transformers in the building, transformer TA1 (Tx4), TA2 (Tx5) and TB3 (Tx6) are noticed to have continuous leading power factor sustained for more than half of a month. With reference to the description to the power system in Chapter 4.a, the 3 transformers are connected and supplying power to air-conditioning system, hence the problem of leading power factor is believed to be related to the abnormality discovered in air-conditioning system. The operation of chillers reduces the level of power factor, when the power factor level decrease below certain level, the program in capacitor bank will initiate the power-compensating operation. The problem of leading power factor is majorly due to the overcompensation by capacitor bank, which can be caused by overpowering or fault in control algorithm in the capacitor bank.

From April to June 2017, leading power factor is noticed in transformer TB3, while at the same period, OFAC_RF2_04 is reported to be malfunctioned. The malfunctioning of a chiller greatly reduce the amount of true power supplied from the transformer, hence the original setting in the capacitor bank will possibly overpowered and causing overcompensation.

Consider the data in April 2017, the total energy consumption of transformer TB3 is 167,383 kWh, the average power supplied by the transformer is around 232.5 kW. Figure 5.3.1 displays the variation of the power level of transformer TB3 in April 2017.

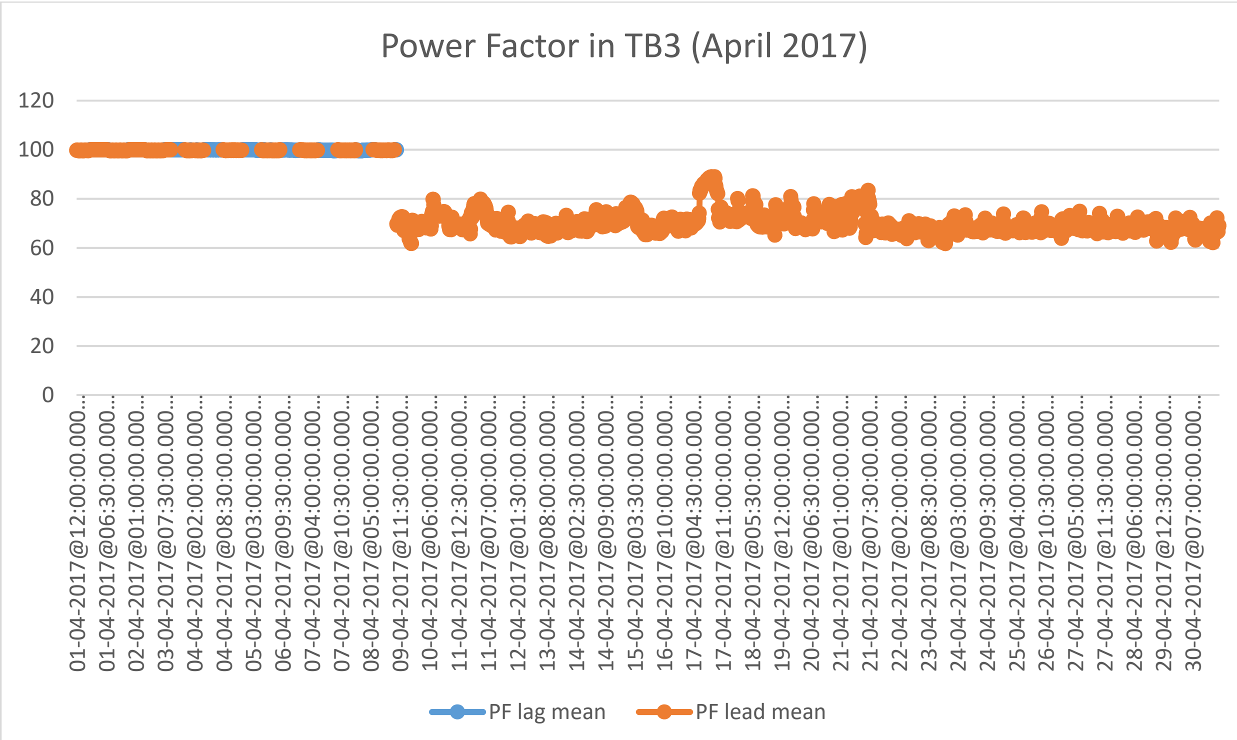
Figure 5.3.1 Power Level of TB3 in April 2017



Consider the same true power dissipation, if the power factor decreases to a level just below the lower boundary programed in the capacitor bank (0.89 inductive), the apparent power is calculated to be 261.2 kVA, with reactive power of 119.1 kVAR. In this case, the capacitor bank will supply capacitive reactive power to rectify the power factor level. According to the capacitor rating in Chapter 4.d.I, power rating of each step of the capacitor bank is 50 kVAR. To compensate inductive reactive power of 119.1 kVAR, 2 or 3 steps in the capacitor bank will be switched on. In the case of 3-step operation, which is equivalent to 150 kVAR, the power factor will be overcompensated and hence resulting in leading power factor.

Apart from over-sized capacitor bank, fault in the control algorithm is another possible explanation of the leading power factor problem. From the plots in Chapter 4.c.I, leading power factor occurs without any precedent signal. Figure 5.3.2 recalls the sudden change in power factor in TB3 in April 2017.

Figure 5.3.2 Power Factor in TB3 (April 2017)



In normal power-compensating operation, the change in power factor level should be continuous, the power factor is first decrease to below target level, then rectify to level close to unity. The sudden and abnormal change in power factor suggests the possibility of existing fault in the capacitor bank control. After acknowledging the possibility of fault in capacitor bank control, the technical staff in the building modified the control program. With the upper boundary of target power factor changed to 0.93, the power factor level is reported to be normal afterwards, which resonates with the hypothesis of existing problem in capacitor bank control.

As shown in Figure 5.3.2, the power factor level of TB3 on the first 10 days in April 2017 is very close to unity, which is not likely to happen in actual practice. The operation of chillers will cause inductive reactive power to the system, which will reduce the power factor level. However, as a chiller-serving transformer, TB3 does not display any signal of reducing power factor on the first 10 days in April 2017. This abnormal performance suggests the possibility of problem existing in the PQM sensor.

As the site measurement with power analyzer failed to obtain comprehensive data of the capacitor bank, and further data is not available, further investigation of the possible issues in capacitor bank or PQM can only be achieved if further investigation opportunity is accessible.

6. Solutions Recommendation

a. Energy Management Opportunities

The Energy Management Opportunity (EMO) is a systematic way to classify the level of energy enhancement methods. Clients can use their existing cost and resources to optimize and choose different kinds of energy saving method. There are basically 3 categories under concept and defined by the cost of investment.

- Category 1: It involves zero cost and just enhance energy usage by housekeeping methods and general policy
  e.g. energy saving policy of individual party

- Category 2: It needs small amount of investment cost without major changing
  e.g. replacement of some energy saving appliances

- Category 3: It needs high cost and a more complete changing is required.
  e.g. changing the arrangement or configuration of chiller water plant

Obviously, category 3 is the most effective way of improvement but it involves extensive investment that requires careful consideration. Category 1 is the simplest method but it is hard to have sharp changes of improvement in a short period of time.

In this chapter, the energy saving proposal at different perspectives are described for consideration. The energy measures are basically classified macroscopically (for the whole building) and microscopically (targeted for the issues), with supplement of engineering policy. Some indicative figures on the investments will be given in the selected recommendations.

b. ACB-oriented Recommendations

ACB-oriented recommendations focus on the whole building, building envelope in one of the greatest factors affecting the lighting system and cooling load. As discussed in 3.c.I, the heat transfer equation of double-glazing windows explains the heat gain and loss between outdoor and indoor area due to convection and radiation. Comparing to conventional building material, the use of double-glazing window increases thermal load and energy loss inside the building and affects the thermal comfort of occupants. As this is not possible to change the appearance of the whole building, the following suggestions act as the supplement of the flaw of building envelope and are as follows:-

Category 1

1. Close the windows or any openings especially between the spaces having different thermal conditions. It can prevent any unnecessary thermal flow.

Category 2

1. Automatic control or mechanism can be added to control the opening or closing of windows and doors having the thermal flow at particular time.
2. Regular checking and replacement of sealing joint of window frame, door frame, ventilation louvers, etc. to prevent air leakage between outdoor and indoor area.
3. Installations of solar films onto the façade to reduce solar heat gain. The expected investment will only be around HK$120,000 for most of the South-facing façade. Assuming that the OTTV of the glass facade to be 114.8 W/m^2, then the expected saving in thermal loads will be over 36,500kWh per year. Hence the simple payback period will be just 3.3 years.

Category 3

1. Building the green roof at the top of the building which can serve as some purpose:-
    - It acts as the insulation layer for the building and it is good for heat and rainwater absorption.
    - The plant can help absorbing CO_2 and reduce CO_2 level of the city
    - The heat island effect between urban and rural area can be improved

2. Adoption of renewable energy system at the building envelope such as exterior wall, window and at roof can be considered. The renewable energy system like additional solar panels or wind turbine can either be a grid connected or standalone system for small electricity use of the building such as USB charging port, the electricity supply for security devices. This can help to promote the importance of energy efficiency and becoming a green building.

c. Problem-oriented Recommendations

From the discussion in Chapter 3.c.III and 4.c.II, the problems are mainly from air-conditioning, lighting and power system, which are the focuses of the recommendations proposed in this session.

I. Air-conditioning System

Category 1

1. Open the doors and windows during winter time to enhance natural ventilation and reduce the use of air conditioning system while the thermal comfort of the occupants can be achieved.
2. Carry out the calibration of the measuring equipment and corresponding signal and control system. The poor measurement will give a wrong signal of control thus reducing the energy efficiency.

Category 2

1. Regular checking, inspection and maintenance of chillers, heat exchangers, refrigeration tower, insulation of chilled water pipework, weld joint and fitting of pipework and air-side component like humidifier and heater.
2. Replacement of aged equipment of the air-conditioning system, for example, air handling unit and blower to lower the energy consumption and enhance the energy efficiency.
3. Periodic cleaning pipework of connecting components for refrigeration cycle, blower fan and air filter to ensure the heat transfer efficiency of the components.
4. Periodic cleaning of condenser and heat exchanger tube to enhance the heat exchange during the cooling or heating process. Inspect the tube leakage, a major cause of low efficiency of condenser and heat exchanger, some useful working fluid at designated temperature is lost because of that.
5. Installation of advanced thermostats and regulatory valve to have a more precise control of indoor conditions.

Category 3

1. Combine the Building Management System with the electronic control or digital controller to optimize the temperature, humidity and flow of cooling air at different locations and functions. This is achieved by the real-time data collected by the BMS system. A more advanced consideration is to link up with other building service system like lighting system for triggering turn-on or turn-off.
2. Carry out a building service system review and reroute the air-conditioning system piping to reduce the distance of travel thus reducing the energy loss during the process.

II. Lighting System

Category 1

1. As there are natural sun radiation entering through the double glass window in many areas, some luminaires are actually not required and this can definitely reduce the total energy consumption. Instead of permanently removing the luminaires, the excessive lightings or redundant luminaires should be switched off.

Category 2

1. Recondition of internal surface of some old lamps and a layer of painting can be used to make the lighting brighter.

2. Replacement of lighting with higher luminous efficiency and efficacy (e.g. Lighting Emitting Diode, LED, or compact fluorescent tubes) especially for the areas with prolonged lighting usage. The arrangement and coverage of lighting can be reassessed by using lux meter data obtained in site measurement and calculate the light power density with the required standard stated in EMSD Code of Practice.

3. Control the lighting system with some additional installed sensor, timer, and dimmers, and increase the number of switches, these can optimize the lighting usage inside the building with energy saved. The re-wiring and installation of new sensors can involve an investment of over HK$250,000. But the energy saving can be about 60,000kWh per year. The simple payback period will be just 3.3 years.

Category 3

1. Combine the Building Management System with the electronic control or digital controller to optimize the lighting level at different locations and functions. This is achieved by the real-time data collected by the BMS system. A more advanced consideration is to link up with other building service system like air-conditioning system for triggering turn-on or turn-off.

III. Power System

Category 1

1. Study and modify the control program of capacitor bank to prevent overcompensation to the power factor value. (e.g. modify the target range of power factor)

Category 2

1. Inspection on the control system of capacitor bank, to identify problem in the capacitor bank. Further maintenance should be carried out if any problem is noticed.

2. Inspection on PQM in the power system, to identify to problem in the capacitor bank. Further maintenance should be carried out if any problem is noticed.

d. Administration Policy

Category 1

1. Grade 1 energy label appliances should be used as it is a good reference when we are going to purchase an electrical item. By using those appliances, the energy saving and efficiency can be maximized comparing with the grade 5 energy label. Table 6.4.1 shows the energy saving comparison between different energy labels. There is a general 40% difference in electricity saving between grade 1 and grade 5 labels.

Table 6.4.1 Energy Labelled Appliances Electricity Saving

Grading Level of Energy Level	Electricity Saving	
	1 vs 3	1 vs 5
Room Cooler	15%	30%
Refrigerator	35%	45%
Washing Machine	20%	40%
Electric Storage Water Heater (Standby)	25%	40%
Electric Clothes Dryer	20%	40%

2. Develop a good practice of energy saving, for example, turning off all unnecessary equipment when it is not used.

3. The hospital should actively participate in different green projects or energy saving activities hosted by Hong Kong Government or private sectors. For example, Energy Saving Charter 2018 and 4Ts Charter organized by Government and Eco Building Fund Communication Workshop organized by CLP Power Hong Kong Limited. By joining these kind of activities, energy saving and efficiency for the building can be promoted with raising community awareness.

7. Suggestions on Central Control and Monitoring Systems (CCMS)

a. Inadequacy of Central Control and Monitoring System

The following items are the inadequacy of the Building Management System:

I. It does not provide instant benchmark comparison on energy consumption.
II. There are no fault alarm when poor energy performance were recorded.
III. The maintenance records did not enter into the system and cannot be easily retrieved.

b. Improvement of Central Control and Monitoring System

I. Integrated Energy Management System

The system can provide access to every metered energy loads in the building including electricity, gas, oil, steam, chilled water and water meters. Also it should convert to analyze, compare and normalize energy consumption data for a single building, annotate data using heating/cooling degree days, occupied/ unoccupied usage, and min-average-max values for better comparison. Furthermore it can normalize consumption data by building area, occupancy and/ or occupied hours.

Also, it can produce benchmark consumption data by year, meter target or building type energy benchmarks so as to remind the occupant about energy savings in buildings.

II. Real-time weather forecast

An on-line real-time weather forecast with sunrise and sunset time, wind direction, wind speed, humidity and temperature etc., can help those weather related systems, such as chiller plant operation, lighting installation, etc. to predict the building load so as to optimize the operations.

III. Real Time Database for Collection and Storage of Continuous Data

Continuous indoor data (for instance, indoor temperature and lux level) can be recorded and stored in a real time database, for evaluation of the system performance. Combined with the real-time weather forecast system, the operation of the lighting and air-conditioning system can be optimized.

IV. Building Services Optimization

The system should be self-learning so that it could base on the daily collected data to determine the optimal on/off time and period of the Equipment.

V. Alarm pop up with event log

The important alarm messages could be appeared with event log queries to be reported by housekeeping staff. When there is alarm, it could be assisted by CCTV which will be pop up automatically to allow the operator to have a full picture of the alarm within seconds. The fault and the event log could be integrated into the data logging system, this provides convenience for data analysis.

Appendix I:

ELECTRICAL SCHEMATIC WIRING DIAGRAM

(Reserved)

Appendix II:
ACB SCHEDULE OF TX1 – TX6
(Reserved)

Appendix III:

PLOTS OF PQM DATA FROM TRANSFORMER INCOMER (2017)

(Reserved)

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