78066

BCA ACADEMY

Certification Course for Green Mark Facilities Professional (GMFP)

(Core Module)

Retro Commissioning and Performance Contracting

180,000 - 10,000 × 7V27A
7V17A = 15 (6%)

BCA ACADEMY

Certification Course for Green Mark Facilities Professional (GMFP) (Core Module)

Retro Commissioning and Performance Contracting

Objective

The aim of the course is to impart valuable knowledge on Retro Commissioning and Performance Contracting to the participants. Upon completion of the course, participants will better understand in detail what retro commissioning and performance contracting entails and would develop a greater appreciation of their importance and benefits. Participants would be able to identify the different stages in retro commissioning, develop a performance contracting plan, and implement a performance contract. The different mechanism in financing a performance contract would be discussed.

Assessment and Certificates

All core and elective modules are assessment-based. To pass a module, the participant has to fulfil these requirements:

a. Achieve at least 75% class attendance, and
b. Pass all assessment(s) of the respective module.

A Certificate of Successful Completion (CSC) for the module will be issued to participants who have fulfilled the attendance and assessment requirements of the module.

Lesson	Lecturer	Time / Duration
Day 1		
Introduction – Retro Commissioning	C.V. Kumar	9.00am – 10.00am (1.0 hour)
Break		10.00am – 10.30am (0.5 hour)
Introduction – Retro Commissioning (cont'd)	C.V. Kumar	10.30am – 12.00pm (1.5 hour)
Lunch		12.00pm – 1.00pm (1.0 hour)

Lesson	Lecturer	Time / Duration
Identification of the need for Retro Commissioning	C.V. Kumar	1.00pm – 3.00pm (2.0 hour)
Break		3.00pm – 3.30pm (0.5 hour)
Identification of the need for Retro Commissioning (cont'd)	C.V. Kumar	3.30pm – 5.00pm (1.5 hour)
Day 2		
Stages in Retro-Commissioning	C.V. Kumar	9.00am – 10.00am (1.0 hour)
Break		10.00am – 10.30am (0.5 hour)
Stages in Retro-Commissioning (cont'd)	C.V. Kumar	10.30am – 12.00pm (1.5 hour)
Lunch		12.00pm – 1.00pm (1.0 hour)
Introduction to Performance Contracting	Er. Patrick Foong	1.00pm – 3.00pm (2.0 hour)
Break		3.00pm – 3.30pm (0.5 hour)
Economic Analysis Tools of the Energy Efficient Projects (EEP)	Er. Patrick Foong	3.30pm – 5.00pm (1.5 hour)
Day 3		
Measurement & Verification in EEP	Er. Patrick Foong	9.00am – 10.00am (1.0 hour)
Break		10.00am – 10.30am (0.5 hour)
Measurement & Verification in EEP (cont'd)	Er. Patrick Foong	10.30am – 12.00pm (1.5 hour)
Lunch		12.00pm – 1.00pm (1.0 hour)

Lesson	Lecturer	Time / Duration
Legal Documentation of Performance Contract	Er. Patrick Foong	1.00pm –2.00pm (1.0 hour)
Development of an Performance Contracting Plan, Process & Implementation	Er. Patrick Foong	2.00pm – 3.00pm (1.0 hour)
Break		3.00pm – 3.30pm (0.5 hour)
Case Study	Er. Patrick Foong	3.30pm – 4.00pm (0.5 hour)
Assessment	BCAA	4.30pm – 5.00pm (0.5 hour)

BCA ACADEMY

Certification Course for Green Mark Facilities Professional (GMFP)

(Core Module)

Retro Commissioning and Performance Contracting

BCA ACADEMY

Course Overview

Part I : Retro Commissioning

Day 1 (am/pm) & Day 2 (am)

- Introduction to Retro Commissioning
- Identification of the need for Retro Commissioning
- Stages in Retro-Commissioning
  - Services need retro-commissioning in buildings
  - Retro-commissioning opportunities in ACMV systems
  - Results of retro-commissioning
  - Retro-commissioning stages and implementation
- Conclusion

Trainer Profile

- More than 24 years of expertise in HVAC, Electrical, Controls and Instrumentation space.
- Managed various jobs in Singapore, China, Malaysia and Thailand
  - Testing and Commissioning
  - Design and built of HVAC systems, TES and Tri-generation plants
  - Operation and Maintenance
  - Energy Performance Contracting
- BCA Registered Energy Auditor and QuESS
- Member of American Society of Refrigerating and Air-Conditioning Engineer (ASHRAE)
- Senior Member of Association of Energy Engineers (AEE).
- BCA certified Green Mark Facility Manager



C.V. Kumar
COO

Barghest Building Performance Pte Ltd
150 Cantonment Road
#01-06
Singapore 089762
Mobile: 98203976
Tel: +65-66351679,
Fax: +65-66351680
Email: cvkumar@bbp.sg

BCA ACADEMY

Introduction to Retro Commissioning

BCA ACADEMY

Energy in building and its impact

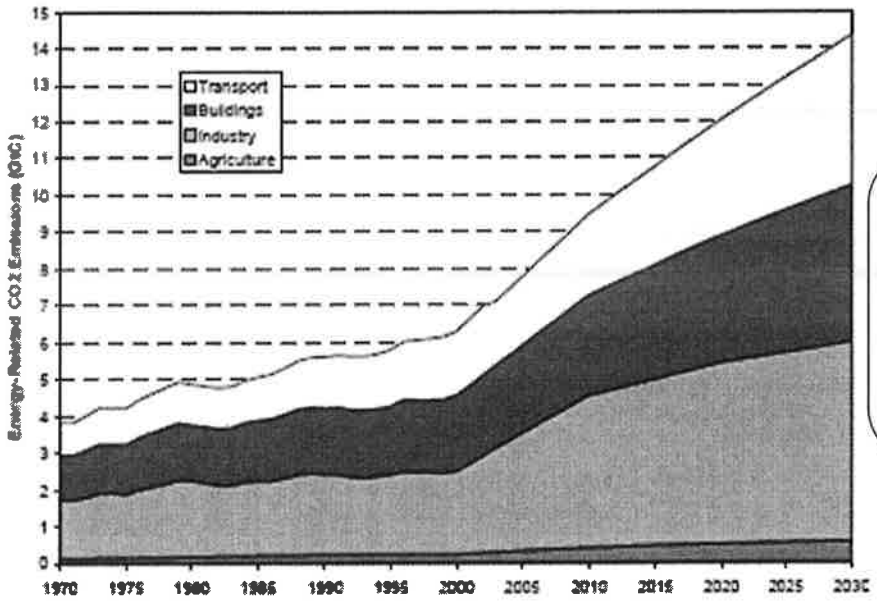
Building Sector globally accounts for **40%** of Energy Consumption and **33%** of Greenhouse Gas Emissions (Price et al, 2006)



BCA ACADEMY

Energy in building and its impact

Buildings are a significant part of world energy consumption, and Greenhouse Gas (GHG) emissions from Building sector is projected to grow continuously



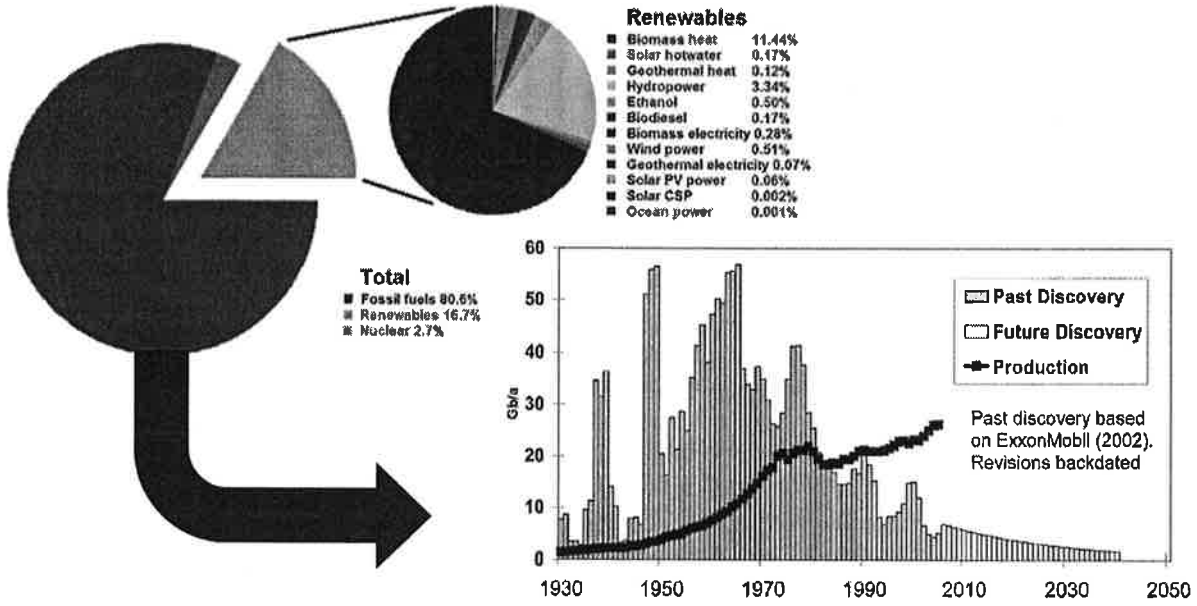
If nothing is done, greenhouse gas emissions from buildings will be more than double in the next 20 years

Source: Historical and Projected Greenhouse Gas Emissions at Various Sectors (IEA report)

80% of the Energy need is fulfilled from fossil fuels and unsustainable sources

BCA ACADEMY

Total World Energy Consumption by Source (2010)

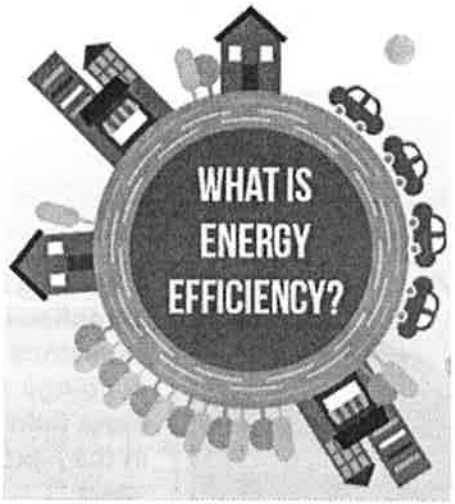


Source: ASPO

Source: Historical and Projected Greenhouse Gas Emissions at Various Sectors (IEA report)

Energy Efficiency

BCA ACADEMY



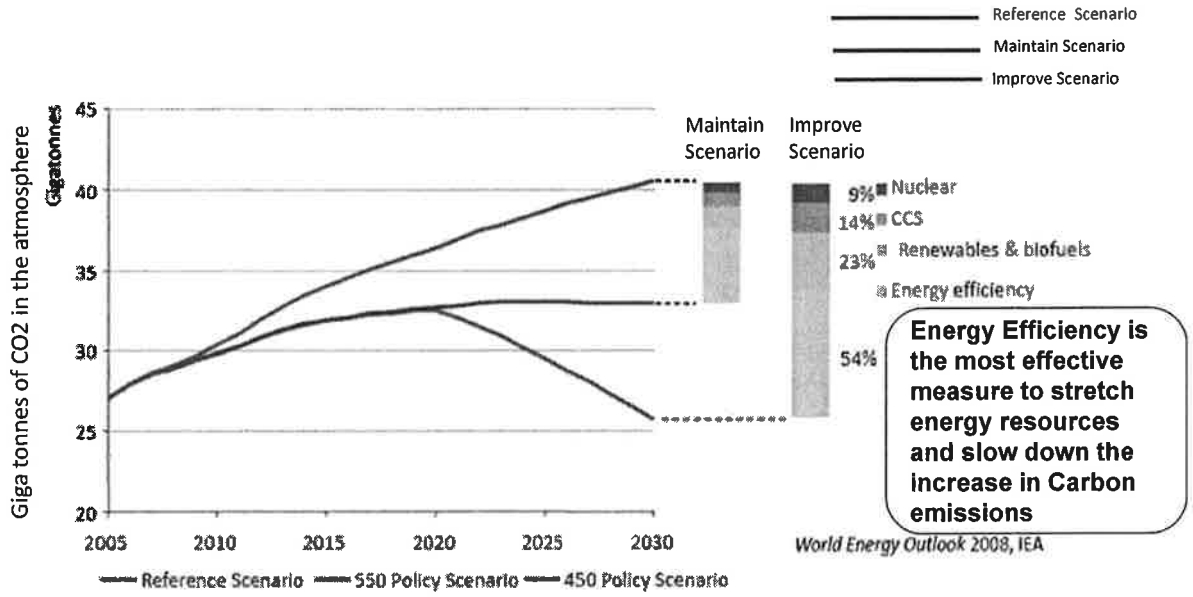
- Less input for given output
- No compromise in comfort
- Energy efficiency became a fifth fuel and alternative to convention energy sources.
- Key in sustainability agenda as well as in reducing operating costs

Earth is our **"COMMON ADDRESS"**

Energy efficiency Vs. other measures in reducing Carbon emissions

BCA ACADEMY

Impact of different measures in reducing carbon emissions



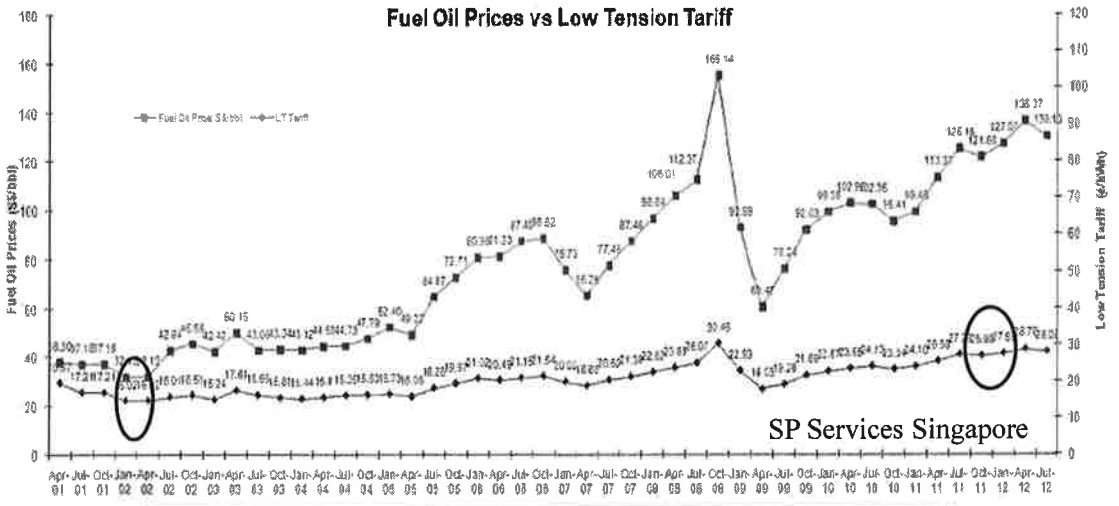
Energy Efficiency is the most effective measure to stretch energy resources and slow down the increase in Carbon emissions

Source: IEA World Energy outlook 2008, Maintain – 550 ppm, improve 450ppm

Furthermore, increasing electricity tariff has made energy efficiency an economical priority for companies and governments

BCA ACADEMY

Historical electricity tariff and its trend

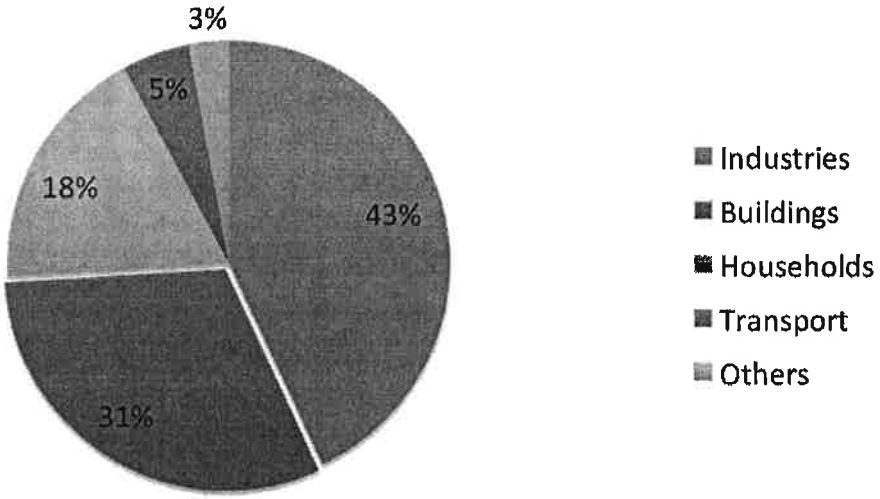


Approx. 8% annual increase over the past 10 years in electricity price

Singapore - Building Sector accounts for 31% of End-Use Electricity Consumption

BCA ACADEMY

End-Use Electricity Consumption in Singapore



Source: NEA

Singapore has been driving building sector Energy Efficiency initiatives aggressively

BCA ACADEMY

Govt. Target and Mandatory Requirements	Key Incentive Programs
• Reduce Energy Intensity by 20% by 2020 and 35% by 2030 from 2005 levels • 80% of building to be green by 2030 • Introduction of Building Control act and Mandatory requirements • In case of replacement of any Air-conditioning plant equipment need, the building must meet minimum Green Mark Score • Energy Audit to be conducted every 3 years • Mandatory submission of buildings energy consumption	• S$100 Million Green Mark Incentive Scheme (Fully committed) • Grants for EE technologies • Finance program for EE projects

Energy Efficiency is an important part of Green Building Certificate, especially in Singapore

BCA ACADEMY

Weightage/Points for the Energy Efficiency is high

Certificate	Country	Year introduced	Points	Weightage
Green Mark	Singapore	2005	**89 out of 180**	49%
LEED	USA	1998	35 out of 110	31.8%
BREEAM	UK	1990	-	26.5%

Energy Efficiency is one of the Mandatory requirements to achieve Green Building Certificate

BCA GREEN MARK

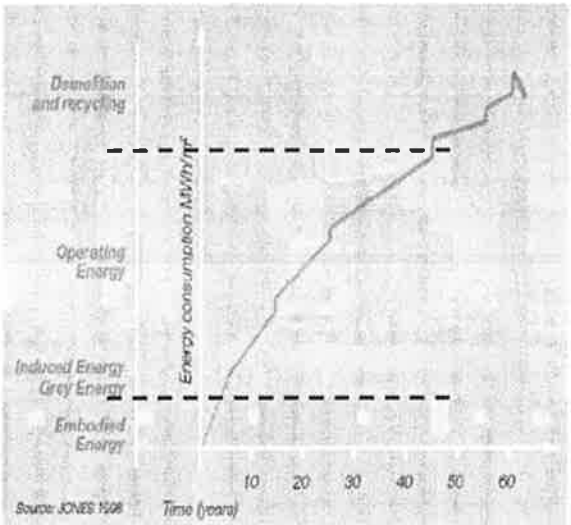
U.S. GREEN BUILDING COUNCIL LEED USGBC

BREEAM®

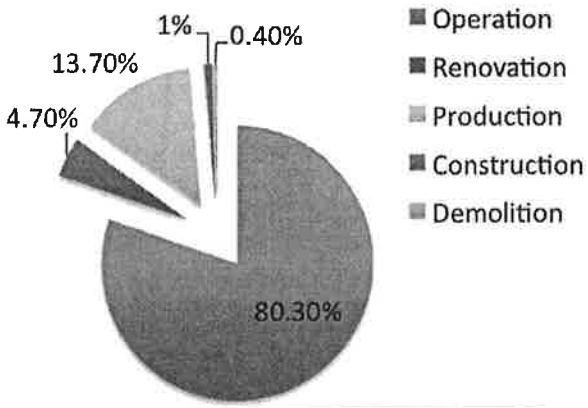
Energy consumption and Greenhouse Gas emissions (GHG)

BCA ACADEMY

Energy Consumption in various stages of a building life cycle



GHG Emission in various stages of a building life cycle



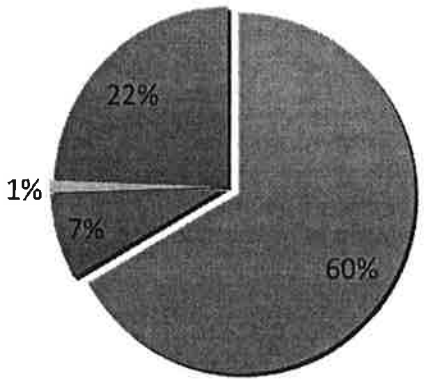
Facility Management (FM) is critical in managing the operational stage of buildings and reducing energy consumption

Source: Energy Consumption in buildings at various stages (UNEP, Building and Climate Change 2007), Energy Consumption in buildings at various stages ((Harn Wei Kua, et al, 2012))

Furthermore, energy cost is a major component in building's operating costs

BCA ACADEMY

Operating costs of typical commercial building (landlord prospective)

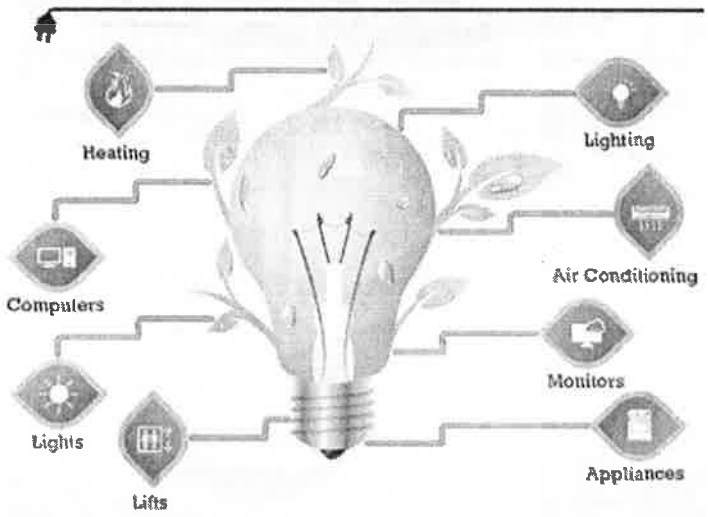


- Landlord Energy 60 %
- Security 7 %
- Cleaning 1 %
- M&E and Others 22 %

Energy is a major component of operational cost and it is instrumental in managing the operating cost of the building

Various Major Energy Consuming Systems in Building

BCA ACADEMY

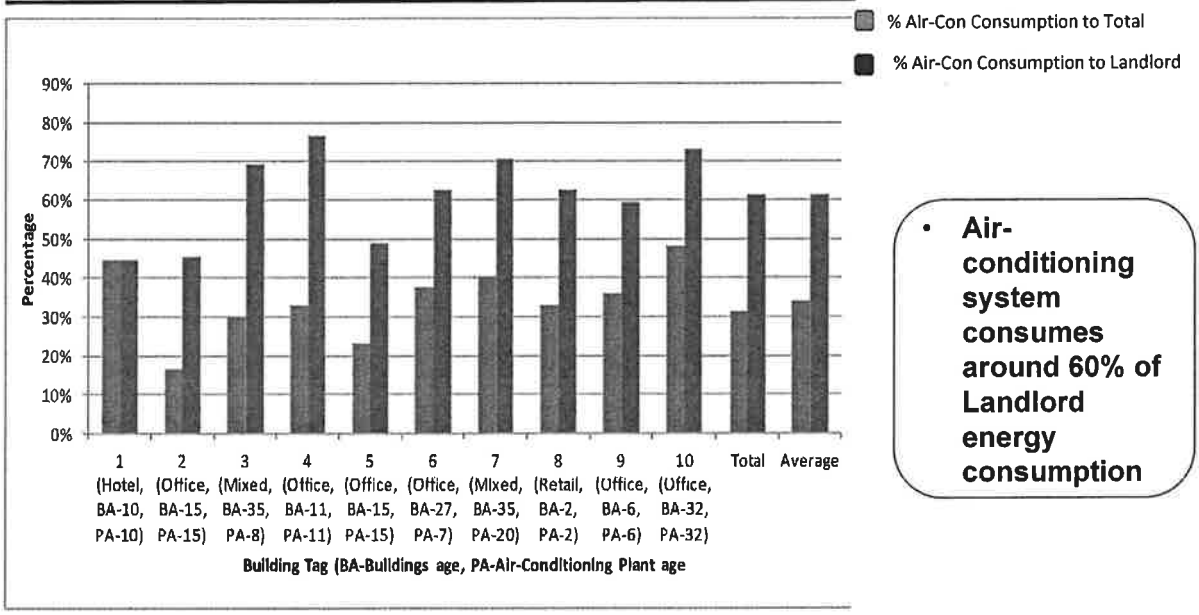


- Air-Conditioning
- Heating
- Ventilation
- Lighting
- Lifts
- IT equipments
- Appliances and Plug loads etc

AC Consumption around 60% of the landlord energy

BCA ACADEMY

Air-conditioning system consumption % to total building and landlord consumption



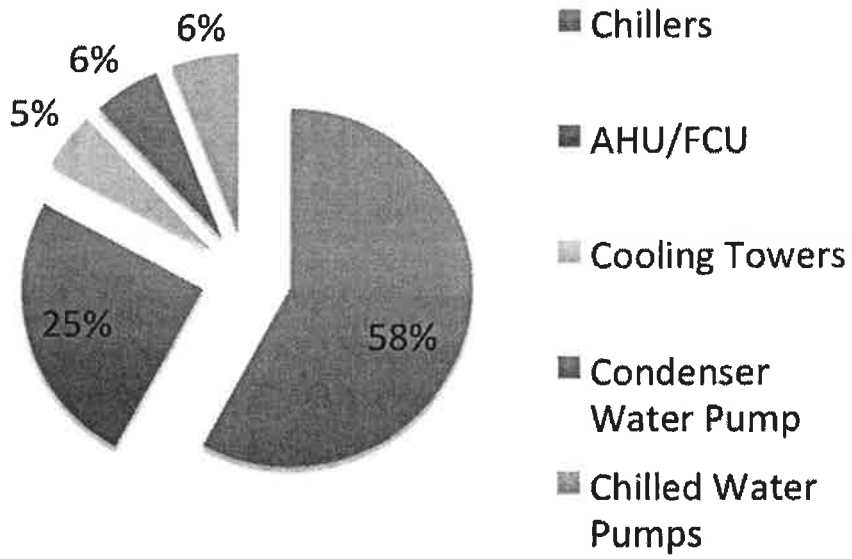
- **Air-conditioning system consumes around 60% of Landlord energy consumption**

Source: Based on study on 10 buildings in Singapore

Chiller consumes the majority of electricity in an Air-conditioning system

BCA ACADEMY

Split of electricity consumption in an Air-Conditioning System



Green Mark Points and Weightage for ACMV

BCA ACADEMY

Assessment Criteria	Green Mark Points	Weightage
Part 1 Energy Efficiency	89	49%
Part 2 Water Efficiency	24	13%
Part 3 Sustainable Operation & Management	39	22%
Part 4 Indoor Environmental Quality	18	10%
Part 5 Other Green Features (Bonus)	10	6%
Total Points	**180**	**100%**

Green Mark Points and Weightage for ACMV

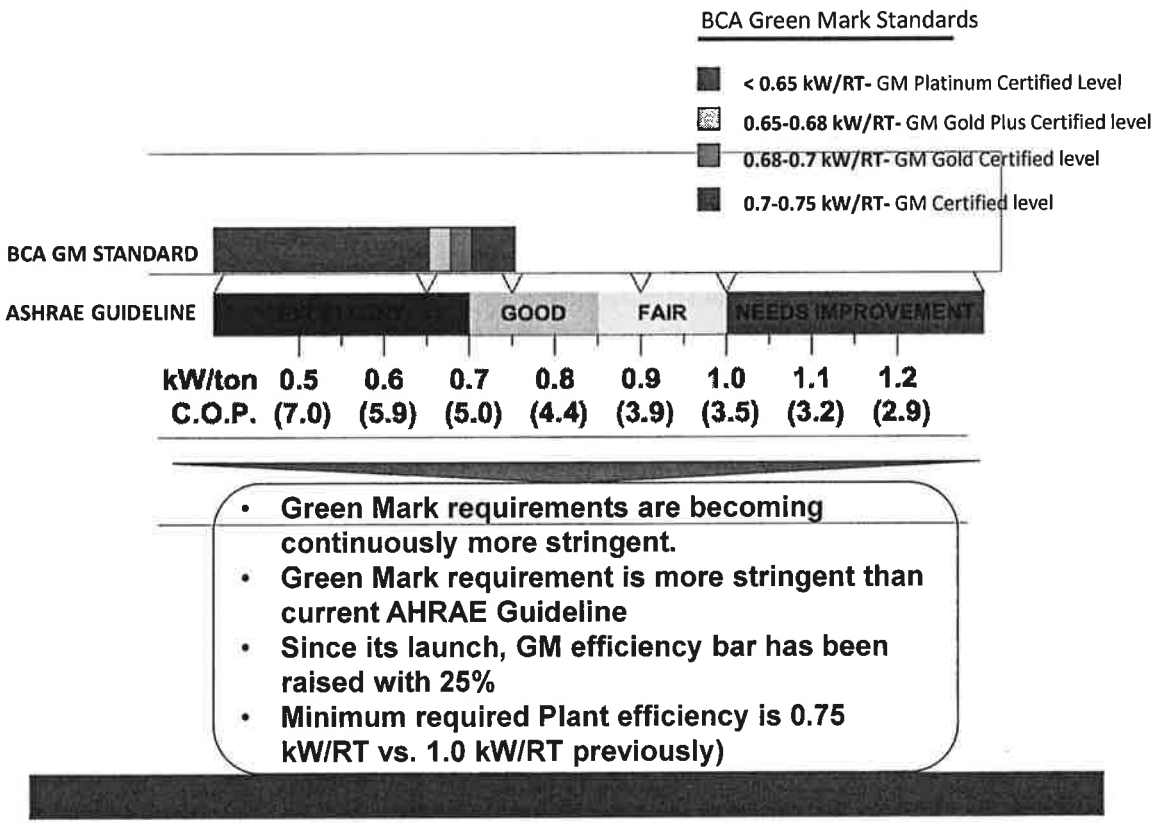
BCA ACADEMY

Part 1 – Energy Efficiency		
	Points	Weightage
1-1 Thermal Performance of Building Envelope	5	6%
1-2 Air Conditioning System	32	36% *
1-3 Natural Ventilation/Mechanical Ventilation (if no air-conditioning)	32	36%
1-4 Artificial Lighting	13	15%
1-5 Ventilation in Car parks	4	4% *
1-6 Ventilation in Common Areas	5	6% *
1-7 Lifts and Escalators	2	2%
1-8 Energy Efficient Practices & Features	12	13%
1-9 Energy Policy & Management	1	1%
1-10 Renewable Energy	15	17%
Sub Total (Part 1)	**89**	**100%**

*** 46% goes to Air-Conditioning and Mechanical Ventilation (ACMV) System**

Green Mark requirements are becoming continuously more stringent

BCA ACADEMY



- **Green Mark requirements are becoming continuously more stringent.**
- **Green Mark requirement is more stringent than current AHRAE Guideline**
- **Since its launch, GM efficiency bar has been raised with 25%**
- **Minimum required Plant efficiency is 0.75 kW/RT vs. 1.0 kW/RT previously)**

Challenges with energy efficiency in existing buildings

BCA ACADEMY

- Singapore has existing commercial building gross floor area over 210 million square meters.
- New buildings are automatically complies with better building performance by design due to code of practice but the challenge is with existing buildings stack.
- Difficult to enforce the code on the existing stack.
- Most practical way is to make the existing systems operate better and aim to meet for the new building standards when the building going for renovation.



There are a number of ways to improve Energy Efficiency

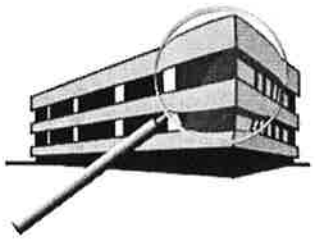
BCA ACADEMY

Type of Initiative	Challenges
New Technology	• High cost (5 to 8 years payback) • Best suitable during construction stage
Equipment Replacement	• High Cost (3-5 years payback) • Possible interruption to operation
Retro-commissioning	• Short payback (1-3 years) and no interruption to operation • Resource intensive- Team should have knowledge and capabilities in: 1. *Design of ACMV system, Controls and Automation* : In-depth knowledge in control systems and control strategies customised to operational asset 2. *Addition and Alteration Work:* To implement a new system without interruption and inconvenience when the building is in operation 3. *Simulation, Selection and in-depth knowledge of Motors, Drives, Chiller, Pumps, CT, AHU/FCU at component level*: To simulate the performance of current operating system and predict the system performance and challenges with proposed operating conditions 4. *Operation and Maintenance:* To address all operation and maintenance issues 5. *Testing and Commissioning:* To properly commission the system - cover air and water balancing, developing system checklist and KPI to maintain the savings consistently

Retro-Commissioning

BCA ACADEMY

- Retro-Commissioning is often offering the most economically viable options.
- Savings through retro-commissioning can range up to 40% and S$12.5/m^2 with average payback of around 1.5 year



Commissioning Vs. Retro-commissioning

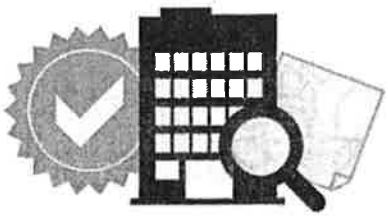
BCA ACADEMY

Commissioning:

- Commissioning is essentially a systematic quality related process for ensuring that the performance of facilities and systems meet defined criteria and efficiency objectives set by owners, tenants, and other stakeholders.
- Commissioning is **ideally implemented at the beginning of the design development phase and continues through initial occupancy and beyond**.

•Commissioning ensures that the new building operates initially as the owner intended and that building staff are prepared to operate and maintain its systems and equipment.

•Usually it will be **done by independent party**, as:



- Owner owns the facility
- Consultants design the system
- Contractor install the system
- Commissioning firm tests the system and gives report ensuring the system installation, operation and performance as per design intent

Commissioning Vs. Retro-commissioning (Cont'd)

BCA ACADEMY

Retro - Commissioning:

- Retro-commissioning is performed **several years after a building, that was previously commissioned,** has been in operation to ensure that the building and systems are meeting the original design requirements.
- Retro-commissioning is typically used to identify and correct malfunctions in a building that occur as the building ages and to ensure continued indoor air quality, employee productivity, and energy efficiency.
- Retro-commissioning can also **be used to address changes in ownership, building use patterns, and operation and maintenance practices**.

Commissioning Vs. Retro-commissioning (Cont'd)

Retro - Commissioning:

•Retro-commissioning is a systematic process to improve an existing building's performance. Retro-commissioning identify the opportunities and improvements which will reduce the energy consumption, improves the comfort level and IAQ.

•In all, **retro-commissioning improves a building's operations and maintenance (O&M) procedures to enhance overall building performance**

Commissioning Vs. Retro-commissioning (Cont'd)

BCA ACADEMY

Continuous Monitoring Vs. Commissioning:

- It involves ongoing monitoring and testing of systems as part of a regular maintenance plan to ensure continued optimum performance and enhanced equipment longevity.
- Whatever the retrofit and commissioning implemented, if its not continuously measured, monitored, analyzed and take corrective actions, system can be deteriorated within few years and real payback may not be achieved.
- Continuous monitoring and commissioning essential to any retrofit and retro-commissioning.

Need for retro-commissioning

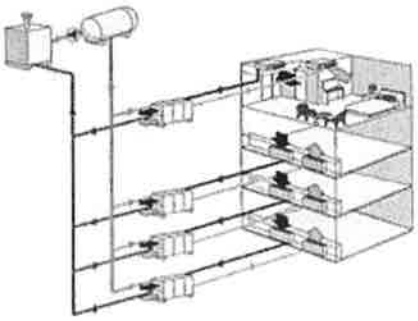
Retro-commissioning is required mainly due to the following:

- Change of use.
- Water and Air out of balance.
- A&A works
- Controls and Calibrations out of range.
- Possibility to add on new technology and drives to make existing system more efficient.
- Resolve and operational and maintenance issues

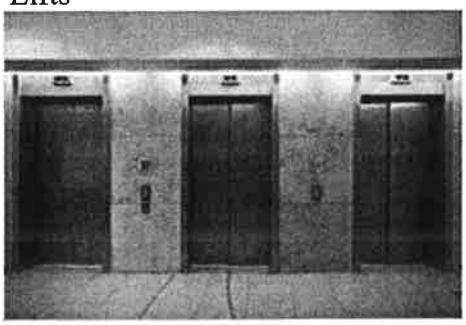
Service required retro-commissioning

- Any service which may change and react based on operation, use and weather, typically are:

a. ACMV system



b. Lifts



c. Lighting system



ACMV system is more dynamic, requires continuous monitoring and commissioning.

ACMV consumes major part of the building so more focus to be on ACMV

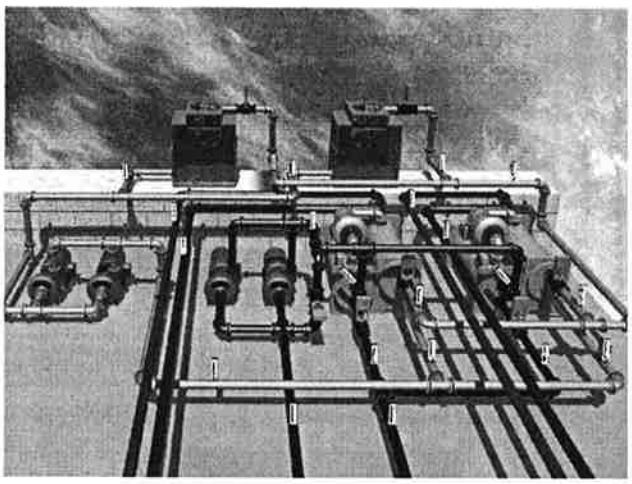
Identification of the Need for Retro-Commissioning

Air-Conditioning System – An Overview

BCA ACADEMY

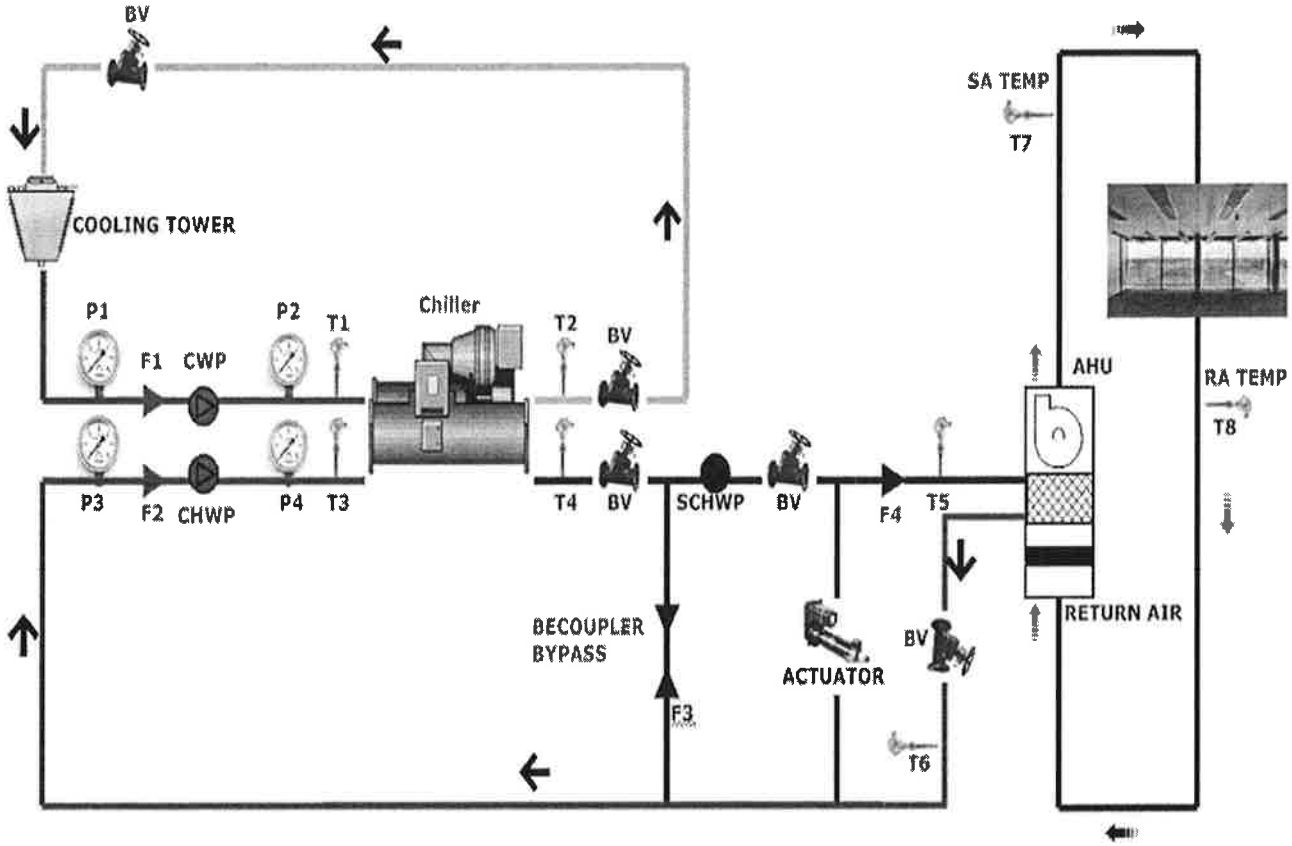
Air-Conditioning System comprises of mainly

- Chilled Water
- Condenser Water
- Refrigeration
- Air System



Air-Conditioning System – An Overview

BCA ACADEMY



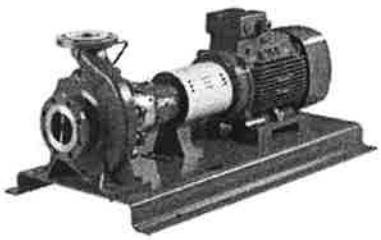
Main equipment in ACMV System

BCA ACADEMY

a. Motors



b. Pumps (i.e. CHWPs, SCHWPs, CWPs)



c. Fans (i.e. MV Fan, CT fans, AHU Fans, etc)



d. Compressors



Key parameters impact the Operation, Performance and Efficiency of the System

BCA ACADEMY

Following items are key parameters that have impact on system operation and efficiency:

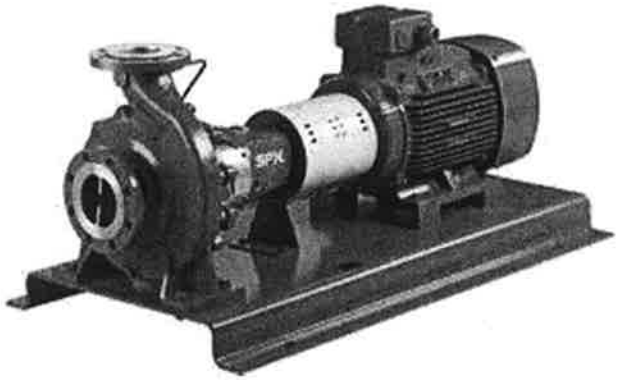
- Water Flow
- Pump Head
- Air Flow
- Fan Pressure
- Room temperature and humidity
- Outdoor air
- Efficiency of Pumps, Cooling Tower and Compressor/Chiller

Various ways to improve system efficiency through retro-commissioning

BCA ACADEMY

Same Demand (RT) - Improve the Equipment Efficiency	Reduce Water Flow and Head
	Reduce Air flow and Pressure
	Improve equipment and chiller Efficiency with optimum flow and temp
Reduce Demand (RT)	Reduce infiltration
	Balance Kitchen and Fresh air
	Demand Ventilation Control (Reduce fresh air)
	Reduce thermal losses
Both	All the above

Air conditioning system - Pump



Affinity laws of Centrifugal Pump

- **Affinity Laws** relate pump speed to:

  Flow rate, Q
  Pump head, H_p
  Fluid power, P
  Speed, N

- $N \propto Q$
- $N^2 \propto H_p$
- $N^3 \propto P$

$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2}$$

$$\left(\frac{N_1}{N_2}\right)^2 = \frac{H_{p1}}{H_{p2}}$$

$$\left(\frac{N_1}{N_2}\right)^3 = \frac{P_1}{P_2}$$

₄mp Power Calculation for given flow, Head and Efficiency

$$\text{Pump Power (HP)} = \frac{SG \times Q(\text{gpm}) \times H(\text{ft})}{3960 \times \text{Efficiency } (\eta)}$$

SG: Specific Gravity

Q: Volume flow rate (gpm)

H: Pressure head (ft)

Pump Power depends on *Flow*, *Pressure* and *efficiency.*

Improving efficiency of existing Pump (kW/RT) - for given cooling load

- Reduce the flow
- Reduce pump head
- Improve the equipment efficiency
  (Usually to be done during selection of pump)

Various methods to reduce flow

- Throttling the valves
  - Increases the head
  - Not effective in power reduction
- Reducing the speed
  - Reduces the head
  - Reduces the power
  - Very efficient method in controlling the flow

Reducing flow – how does it impact on pump power?

Example:

•Existing Hydraulic Power = 100 KW

•Existing Flow – 200 l/s

•With optimization:

A. If pump flow reduced by 20% - New flow 160 l/s
   - Pump law = $P1/P2 = (Q1/Q2)^3$
   - New Power = $100 / (200/160)^3 = 51.2$ KW

B. If flow reduced by 50% i.e. new flow = 100 l/s
   - New Power = 100 / (200/100)3 = 12.5 KW

48.8 %

- **20% reduction flow will reduce Power by 50%**
- **50% reduction flow will reduce Power by 87.5%**

$(0.8)^3 = 0.512$

$(0.5)^3 = 0.125$

Reducing flow – how does it impact on pump power?

BCA ACADEMY

Pump Speed	% Savings
100 %	No Savings
90%	27.1%
80%	48.8%
70%	65.7%
60%	78.4%
50%	87.5%
40%	93.6%
30%	97.3%

0.9^3 0.8^3 0.3^3

Reducing Head – how does it impact on pump power?

BCA ACADEMY

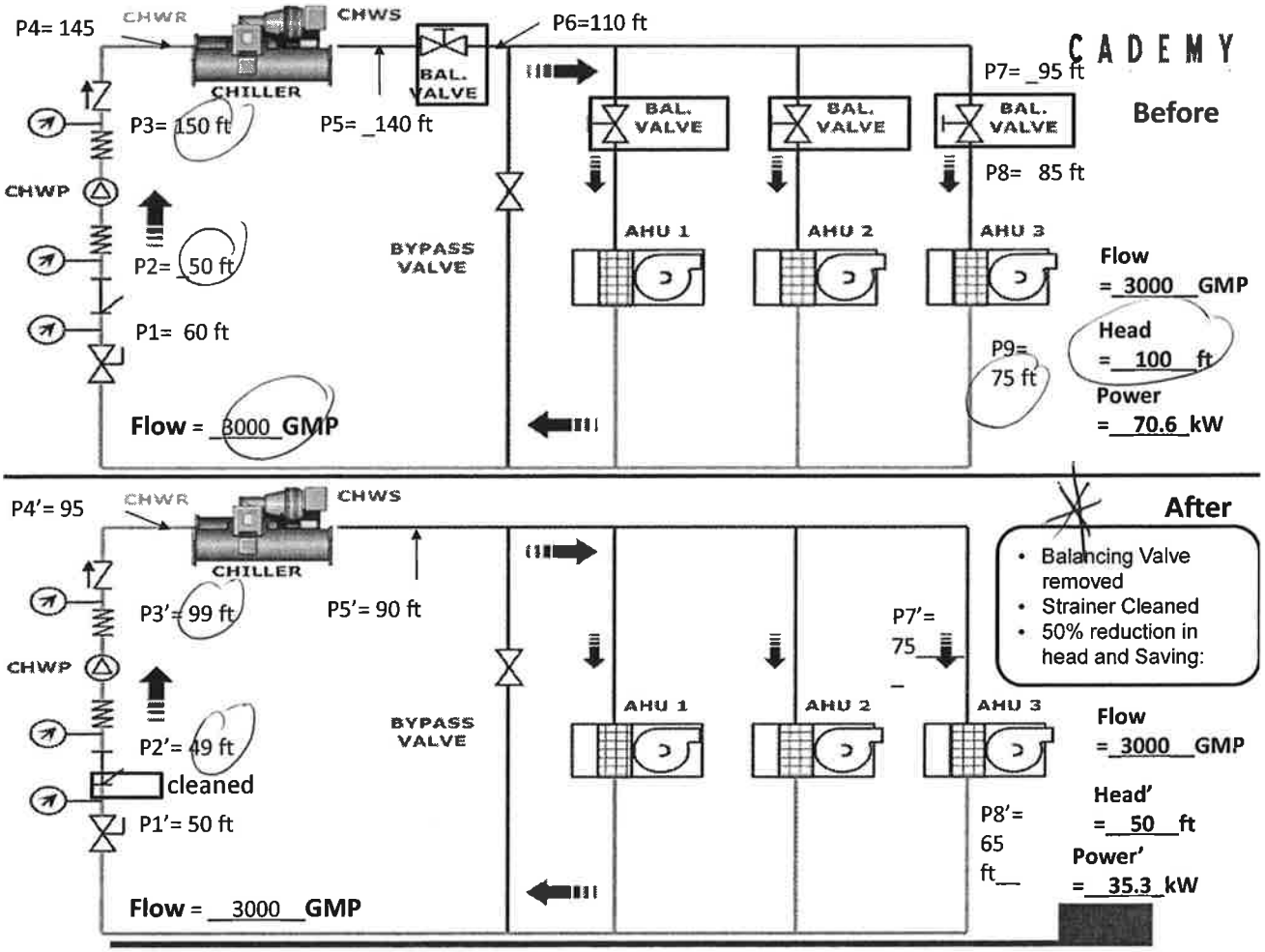
	Existing	Proposed	Savings	%
Water flow in GPM	3000	3000	0	0
Head in ft	100	50	50	50%
Pump Efficiency	80%	80%	0	Assume Efficiency no change
Pump Power in HP = SG* (Flow in GPM x Head in Ft) / (efficiency % * 3960)				
Pump Power (HP)	94.7	47.3	47.3	50%
Pump Power (KW) HP x 0.746	70.6	35.3	35.3	50%

* Specific Gravity (SG) assumed as 1

50% reduction

$HP = \frac{1 \times 3000 \times 100}{0.8 \times 3960} = 94.7\ HP$

$kW = 70.6\ kW$



Water Flow, Temperature Difference and Cooling load

BCA ACADEMY

- Cooling load (RT) = 1.2 x Water flow (l/s) x Delta T (Deg.C)

  Delta T - Temperature Difference of Return and Supply Water

- Most systems designed at 5.5 Deg.C Delta T.

- Based on the AHU capacity/Sizing it is possible to maintain even higher than 5.5 Deg.C

Balance Control Valve → Set Max. flowrate

Effect of Temperature Difference on Water flow for given Cooling load

BCA ACADEMY

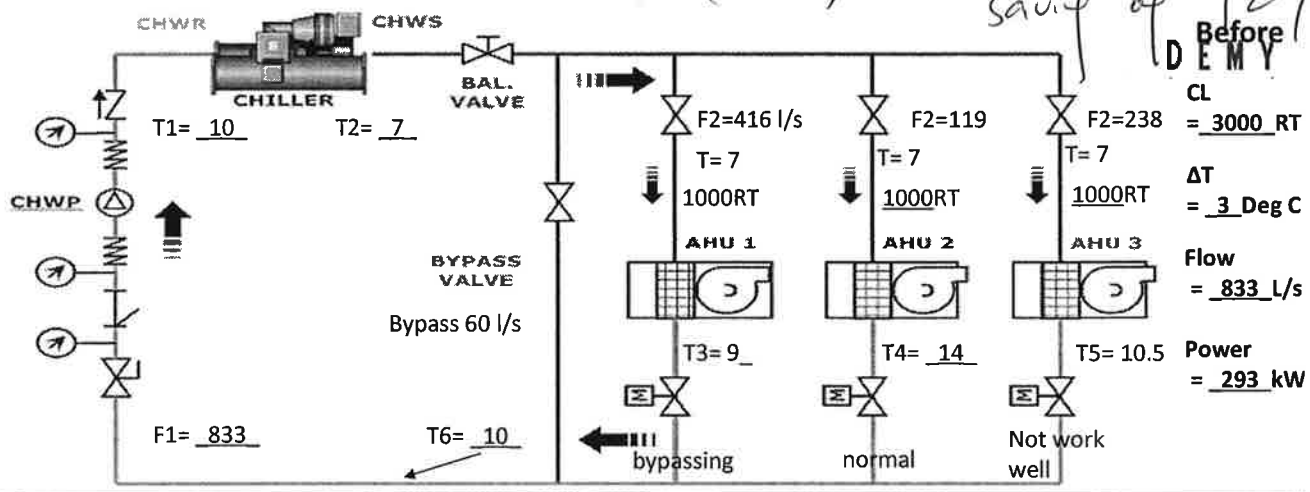
	Existing	Proposed	Savings	%
Cooling load (RT)	3000	3000	0	0
CHWS (Deg.C)	7.0	7.0	0	0
CHWR (Deg.C)	10.0	14.0	-	-
Delta T (Deg.C)	3.0	7.0	-	-
Flow (l/s) (GPM)	833 (13,288)	357 (5,658)	476 (7,544)	57%
Pump Power (KW) (HP)	293 (393)	23 (31)	270 (362)	92%

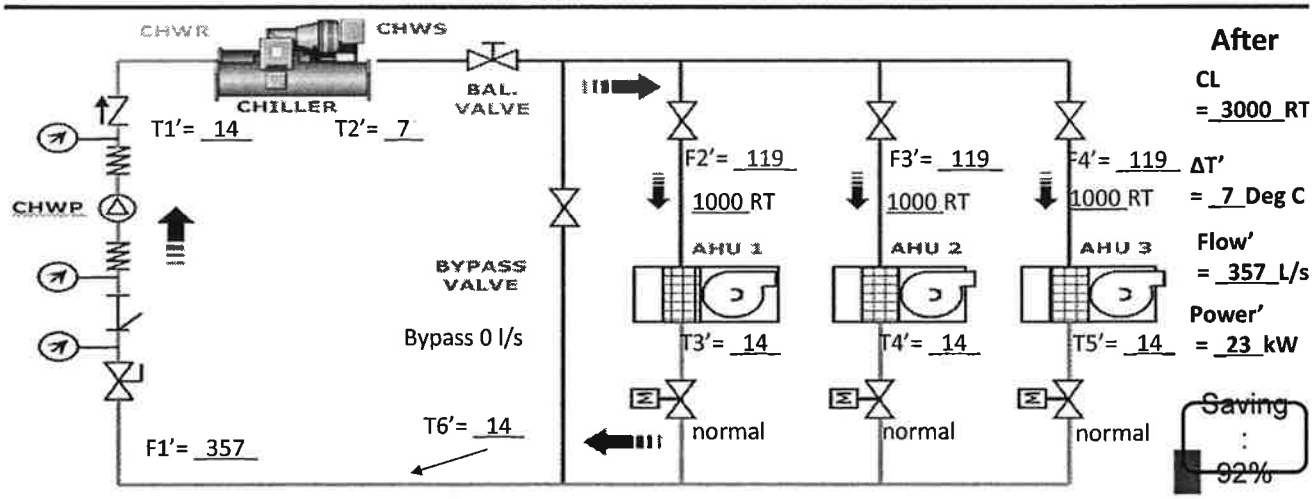
Cooling load (RT) - 1.2 x Water flow in l/s x Delta T in Deg.C

Flow was reduced by reducing speed, so using pump affinity law $P1/P2 = (Q1/Q2)^3$

Increase in temp difference from 3 to 7 Deg.C caused to reduce the flow by 57% for same cooling load

- **Power reduced by 92%**





Working Example-1

- System operating with cooling load of 2000 RT, Pump Power of 200KW, CHWS temp is 7 Deg.C and Return at 10.5 Deg.C $\Delta T = 3.5^\circ C$
- If the return water temperature increased to 12.5 Deg.C with same CHWS temperature of 7 Deg.C and Cooling load of 2000 RT calculate the following: $\Delta T = 5.5^\circ C$

1. Existing flow $RT = 1.2 \times flow \times \Delta T$ $2000 = 1.2 \times flow \times 5.5$ $\Rightarrow$ new flow = 303 L/s
2. New flow ref's flow = 476.2 L/s
3. New power using pump affinity law New power $= 200kW \times \left(\frac{303}{476.2}\right)^3 = 51.5kW$
4. Savings in KW Saving $= 200 - 51.5$ $= 148.5kW$ //

Working Example-2

- If the system operating with flow of 6000 GPM, Head 40 ft.
- Pump head reduced to 30 ft by maintaining the same flow of 6000 GPM calculate the following (Assume pump efficiency of 80% in both conditions)

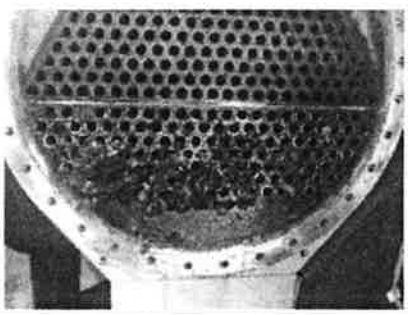
1. Existing Pump Kw
2. New Pump KW
3. Savings in KW

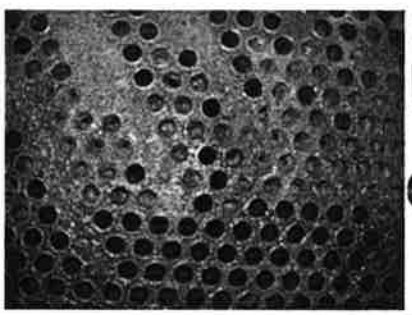
Common Issues for Lower Temperature Difference or Increased Water flow

- Improper Control Algorithms
- Control Vales are bypassed
- Valves are leaking
- Control Valves are oversized
- AHUs are fitted with 3 way valves, so water is bypassing.
- Leaked valves at AHU and Chiller
- Chiller Bypass Valves are not Working
- Improper Water balancing.
- Oversized pumps and too many pumps are running
- Plant optimization chiller control based on load not in place or not working.

Common Issues for higher pump head

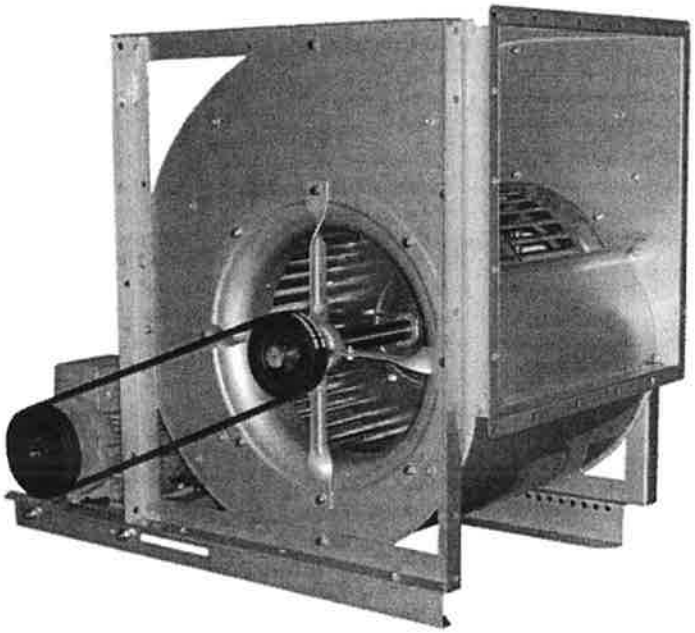
- Strainers clogged.
- Coil clogged
- Condenser scaling.
- Balancing Valves and Other Valves are throttled.
- Pumping System over sized or too many pumps are running.
- Improper Water balancing
- Controls not working and sensors are not calibrated







Air conditioning system - Fan



Affinity laws of Centrifugal Fan

- **Affinity Laws** relate fan speed to:

  Flow rate, Q
  Fan Pressure, H_p
  Fan Power, P

- $N \propto Q$
- $N^2 \propto H_p$
- $N^3 \propto P$

$$\frac{N_1}{N_2} = \frac{Q_1}{Q_2}$$

$$\left(\frac{N_1}{N_2}\right)^2 = \frac{H_{p1}}{H_{p2}}$$

$$\left(\frac{N_1}{N_2}\right)^3 = \frac{P_1}{P_2}$$

Fan Power calculation for Given flow, pressure and efficiency

BCA ACADEMY

$$\text{Fan Power (Watt)} = \frac{\text{Air Volume in } m^3/sec \times \text{Total Pressure in Pa}}{\text{Efficiency } (\eta)}$$

Fan Power depends on *Flow*, *Pressure* and *efficiency.*

Improving efficiency of existing Fan system for given cooling load

BCA ACADEMY

- Reduce the flow
- Reduce Fan Pressure
- Improve the equipment efficiency (Usually to be done during selection of pump)

Various methods to reduce flow

- Throttling the damper
  - Increases the fan pressure
  - Not effective in power reduction
- Reducing the speed
  - Reduces the head
  - Reduces the power
  - Very efficient method in controlling the flow

BCA ACADEMY

Reducing flow – How does it impact on Fan Power

•Existing Fan Power = 40 KW

•Existing Flow – 15 m^3/s

•With optimization:

A. fan flow reduced by 20% - New flow 12 m^3/s

•Fan law = $P1/P2 = (Q1/Q2)^3$

•New Power = $40 / (15/12)^3 = 20.48$ KW

B. If flow reduced by 50% i.e. new flow = 7.5 m^3/s

•New Power = $40 / (15/7.5)^3 = 5$ KW

- **20% reduction flow will reduce Power by 50%**
- **50% reduction flow will reduce Power by 87.5%**

Reducing flow – how does it impact on fan power?

BCA ACADEMY

Fan Speed	% Savings
100 %	No Savings
90%	27.1%
80%	48.8%
70%	65.7%
60%	78.4%
50%	87.5%
40%	93.6%
30%	97.3%

Identical Same as Pump

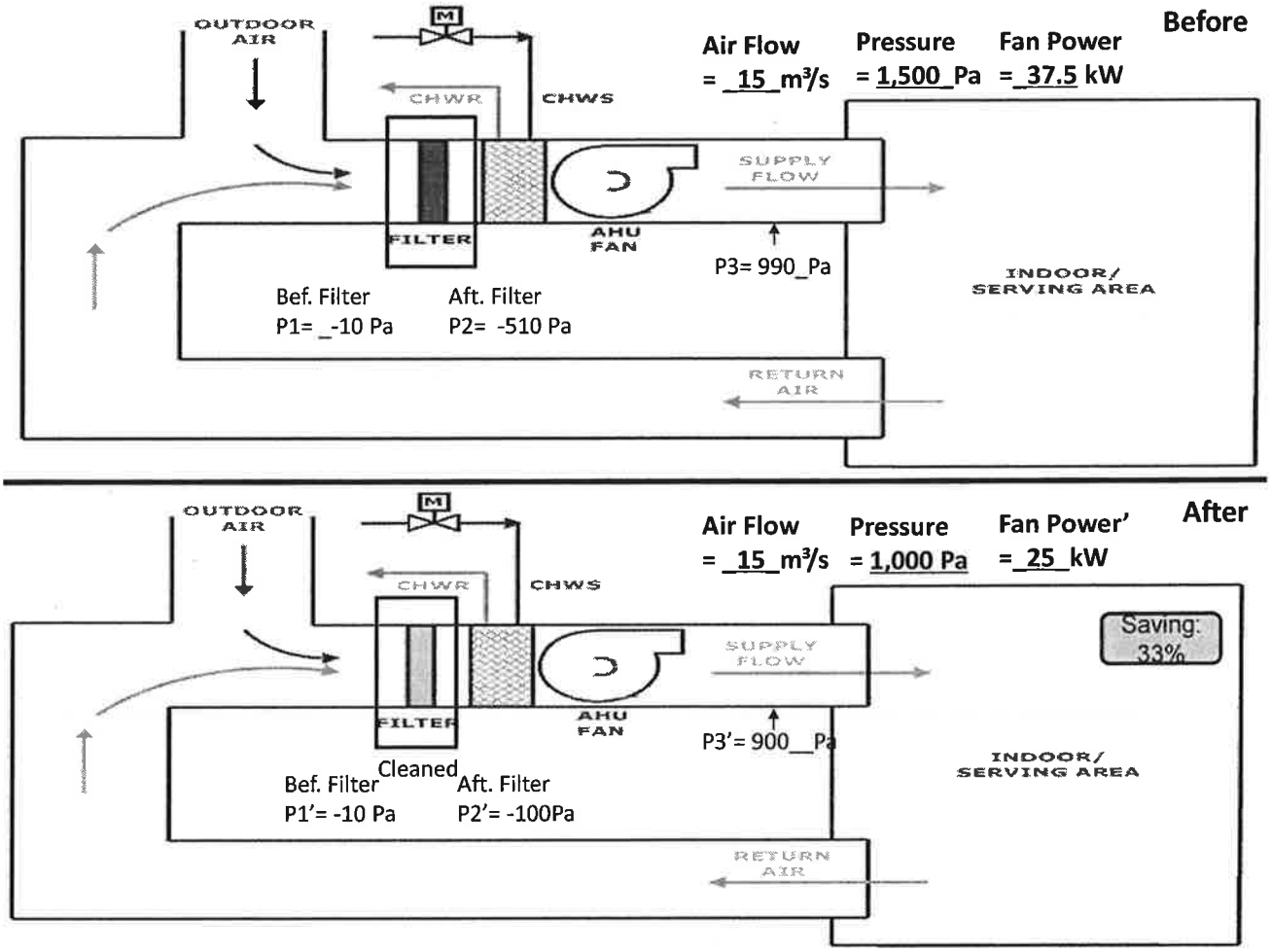
Reducing Head – How does it impact on Fan Power

BCA ACADEMY

	Existing	Proposed	Savings	%
Air Volume (m^3/s)	15	15	0	0
Total Pressure (pa)	1500	1000	500	33%
Fan Efficiency	60%	60%	0	Assume Efficiency no change
Fan Power (Kw) = (Flow in m3/s x Total Pressure in Pa) / (Efficiency * 1000)				
Fan Power (kW)	37.5	25	12.5	33%

$\frac{15 \times 1500}{0.6 \times 1000} = 37.5kW$

$\left(\frac{1000}{1500}\right)$



Air Flow, Temperature Difference and Sensible load

BCA ACADEMY

- Sensible load (Watts) = 1.23 x Airflow in l/s x Delta T

Delta T - Temperature Difference of Supply Air and Return Air

- Most systems designed at around10 Deg.C Delta T
- Based on the AHU capacity/Sizing it is possible to maintain Delta T even higher than 10 Deg.C

Effect of Temperature Difference on Airflow for given sensible load

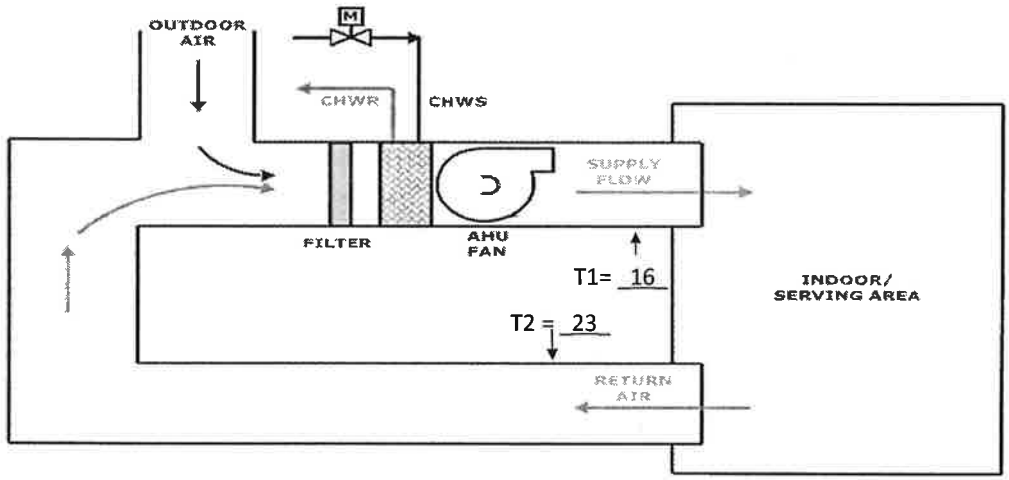
BCA ACADEMY

	Existing	Proposed	Savings	%
Sensible Cooling load (RT)	100	100	-	-
Cooling load in Watts (1 RT=3.517KW)	351,700	351,700	-	-
Supply Air Temp (Deg.C)	16	12	-	-
Return Air Temp (Deg.C)	23	23	-	-
Delta T (Deg.C)	7	11	-	-
Airflow in l/s	41,869	26,644	15,225	36%
Power (kW)	30	7.73	22.27	74%

Sensible Cooling load (Watts) - 1.23 x Airflow in l/s x Delta T in Deg.C

Flow reduced by reducing speed, so using fan affinity law $P1/P2 = (Q1/Q2)^3$

- **Increase in temp difference from 7 Deg.C to 11 Deg.C or reducing supply air by 36%**
- **Power reduced by 74%**



Before

BCA ACADEMY

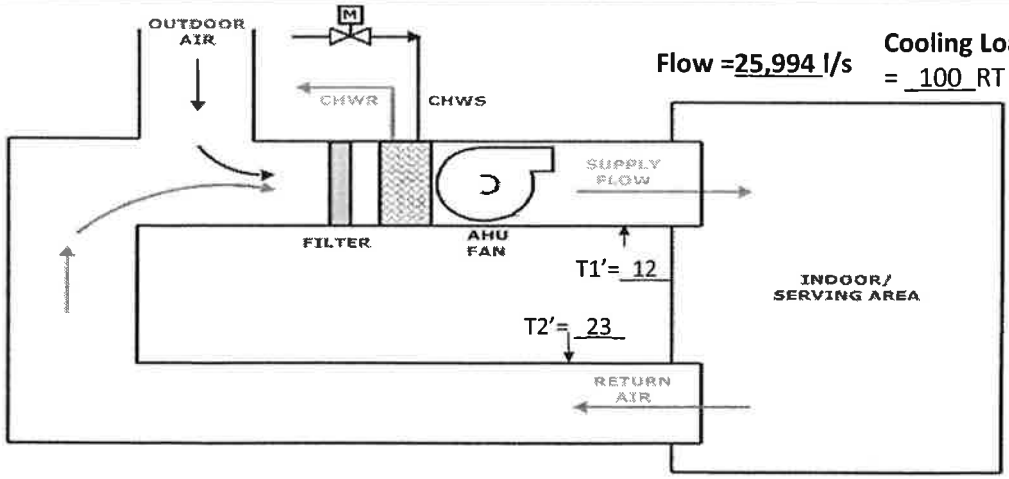
Sensible Cooling Load = 100 RT

SAT = 16 Deg C
RAT = 23 Deg C
ΔT = 7 Deg C

Flow = 41,869 L/s

Power = 30 kW

Saving: 36%



After

Flow = 25,994 l/s

Cooling Load = 100 RT

Sensible Cooling Load = 100 RT

SAT = 12 Deg C
RAT = 23 Deg C
ΔT = 11 Deg C

Flow = 26,644 L/s

Power = 7.73 kW

Working Example-3

- System operating with sensible cooling load of 50 RT, Fan Power-20 KW, Supply air temp of 17 Deg.C and Return at 23 Deg.C $\Delta T = 6^{\circ}C$
- If the Supply air temperature reduced to 12.0 Deg.C with same Return Air temperature of 23 Deg.C and same Sensible Cooling load of 50 RT, calculate the following $\Delta T = 11^{\circ}C$.

1. Existing Airflow $50 \times 3.517 \times 1000 = 1.23 \times \text{Airflow} \times 6$
   $\Rightarrow \text{Airflow} = 23827 \text{ l/s}$
2. New Airflow $\text{New Airflow} = \frac{6}{11} \times 23827 = 12997 \text{ l/s}$
3. New fan power using fan affinity law $20\text{kW} \times \left(\frac{6}{11}\right)^3 = 3.24\text{kW}$
4. Savings in KW

$20\text{kW} - 3.24\text{kW}$
$= 16.76\text{kW}$.

Working Example-4

- If the system operating with air flow of 10 m3/s, Total Pressure of 1000 pa
- Total pressure reduced to 700 Pa by maintaining the same flow of 10 m3/s, calculate the following (Assume fan efficiency of 60% in both conditions)

1. Existing Fan Kw $\frac{10 \times 1000}{0.6 \times 1000} = 16.67$
2. New Fan KW $16.67 \times \frac{700}{1000} = 11.67$
3. Savings in KW $60\text{kW} - 42\text{kW} = 18\text{ kW}$.

5

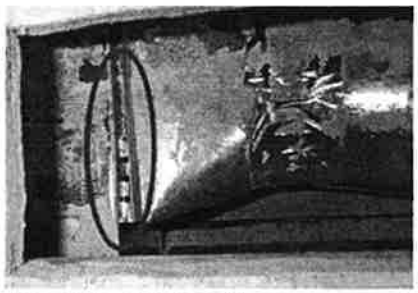
16.67
11.67
5 kW

Common Issues for Lower Temperature Difference or Increased airflow

BCA ACADEMY

- Improper Control Algorithms or Controls are not working.
- Static Pressure Sensor setting is too high for VAV system.
- VSD minimum setting are too high.
- Leaks in the system.
- Improper Air balancing.
- Oversized fans
- Sensors not calibrated









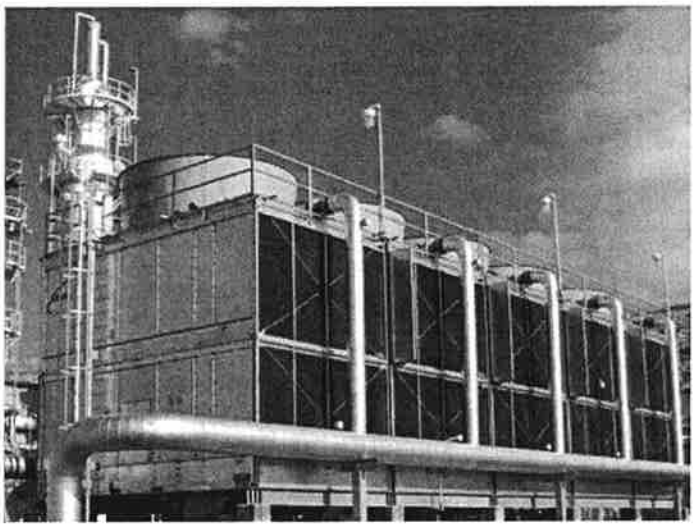
Common Issues for higher pump head

BCA ACADEMY

- Filters Clogged
- Coil clogged
- Dampers are throttled
- Improper air balancing and duct sizing
- Flexible ducting is not properly installed

Air conditioning system- Cooling Tower

BCA ACADEMY



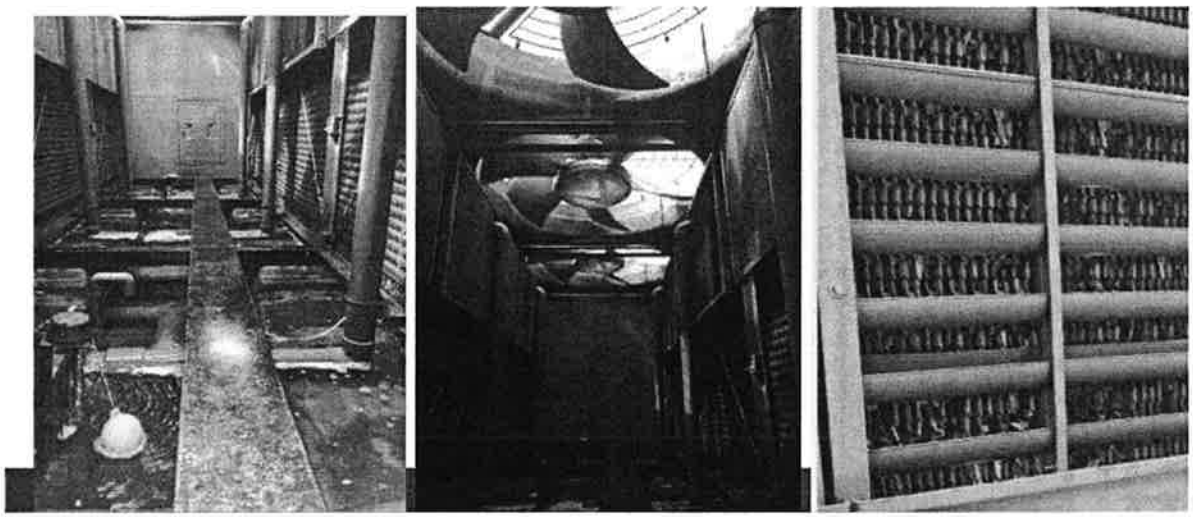
BCA ACADEMY

Cooling towers

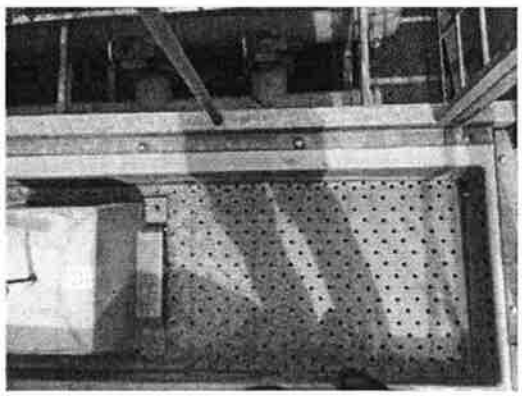
- Cooling Towers are used to remove the heat from chiller
- Most of the places cooling towers are installed with 100 to 200% standby
- By running more cooling towers with proper control strategy, it is possible to get the CWS close to Wet Bulb Temperature, on average around 27 to 28 Deg.C of CWS temperature.
- It also helps to reduce the CT fan power, as running more cooling tower reduces the flow across each CT which reduces the fan pressure and fan power.
- Similar way, it also reduces the water friction loss across the CT there by pump head.

Cooling Towers – Conditions effects the performance of CT

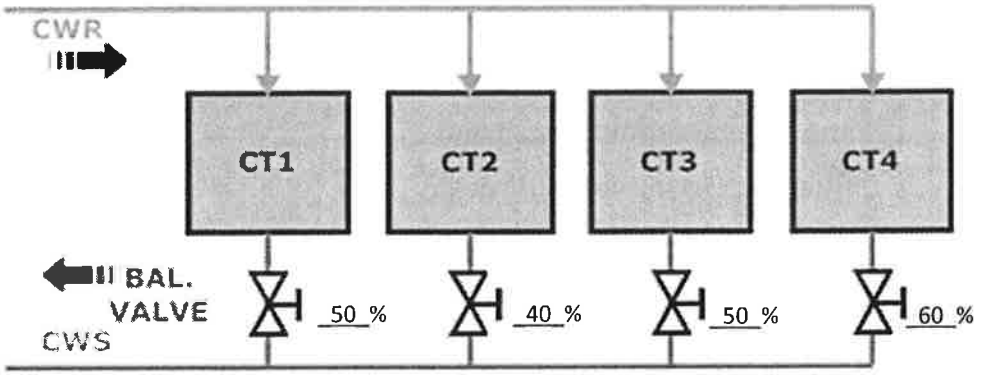
- Short cycling
- Poor maintenance.
- Infill damage
- Improper water balancing



Cooling Towers – Conditions effects the performance of CT (Cont'd)



Cooling Towers – Conditions effects the performance of CT (Cont'd)



Reduce Cooling Load without compromising comfort level

BCA ACADEMY

Main reasons contributing to increased cooling load more than real need are:

•Infiltration through Kitchen and Toilet Ventilation System

One of the main reasons for the infiltration in to the building is Exhaust and Fresh air unbalance Poor maintenance. Some time chef may switch OFF the exhaust system for the comfort of air conditioning cooled air, which will exhaust the air conditioning air and refill with ambient air through infiltration

•Infiltration through leaks and unauthorized opening of the doors

•Higher fresh air – Fresh air consumes 250 CMH/RT, where as recirculation air around 500 to 600 CMH per Ton, it is almost double, so if the system draws more fresh air for whatever reason it increases the load on chiller.

•Improper Air distribution and Controls

•Poor thermal insulation

•Sensors not calibrated or installed at wrong location

Reduce Cooling Load without compromising comfort level

BCA ACADEMY

Main reasons contributing to increased cooling load more than real need are:

- Minimum settings
  - VAV Minimum flow
  - Pump and fan minimum speed.
  - Chiller minimum water flow etc
  - Many occasions VAV minimum flow are set at over than required, which cause to over cool the space.
  - Manufacturer usually tell minimum speed at 30 Hz, sometimes AHU fans running at 30 Hz is more than required.

Reduce Cooling Load without compromising comfort level

BCA ACADEMY

Main reasons contributing to increased cooling load more than real need are:

•Minimum settings

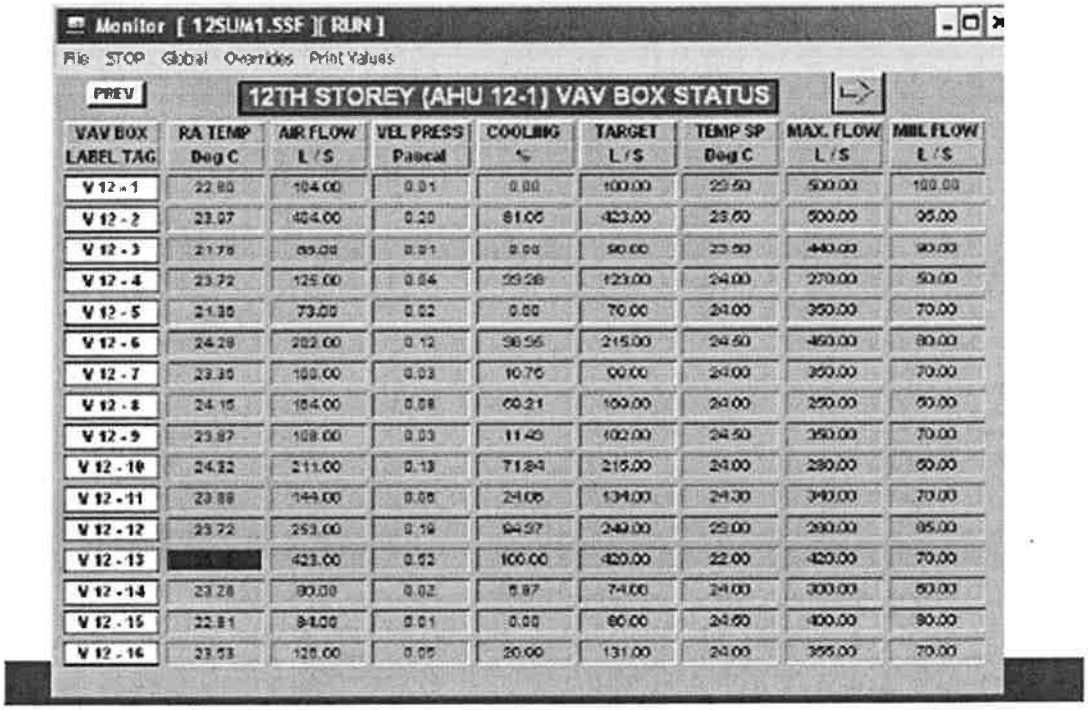
- Usually manufacturers set minimum and safety values in general and taking into general conditions, it is always good to know the reasons for limits and whether our application are in the specified conditions, if not we can adjust this limits without compromising the safety
- Example if the motor inside the AHU which is at 12 to 15 Deg.C environment do we need the minim speed to run at 30HZ?
- Adjusting minimum flow also enables to run more pumps or fans in parallel which results in low head/pressure

Reduce Cooling Load without compromising comfort level

BCA ACADEMY

Main reasons contributing to increased cooling load more than real need are:

- Minimum settings



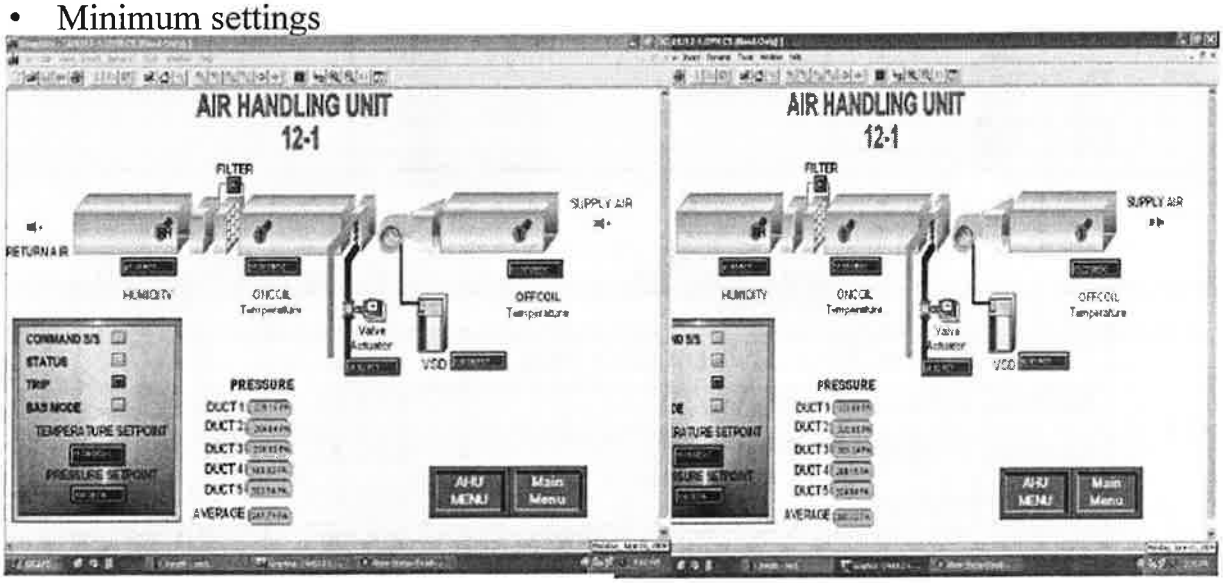
VAV BOX LABEL TAG	RA TEMP Deg C	AIR FLOW L / S	VEL PRESS Pascal	COOLING %	TARGET L / S	TEMP SP Deg C	MAX. FLOW L / S	MIN. FLOW L / S
V 12 - 1	22.80	104.00	0.01	0.00	100.00	23.50	500.00	100.00
V 12 - 2	23.07	404.00	0.20	81.00	423.00	23.50	500.00	95.00
V 12 - 3	21.76	69.00	0.01	0.00	90.00	23.50	440.00	90.00
V 12 - 4	23.72	125.00	0.04	29.29	123.00	24.00	270.00	50.00
V 12 - 5	21.30	73.00	0.02	0.00	70.00	24.00	350.00	70.00
V 12 - 6	24.29	202.00	0.12	38.56	215.00	24.50	460.00	80.00
V 12 - 7	23.35	100.00	0.03	10.75	90.00	24.00	350.00	70.00
V 12 - 8	24.15	184.00	0.08	60.21	160.00	24.00	250.00	50.00
V 12 - 9	23.87	108.00	0.03	11.49	102.00	24.50	350.00	70.00
V 12 - 10	24.32	211.00	0.13	71.84	215.00	24.00	280.00	60.00
V 12 - 11	23.89	144.00	0.05	24.06	134.00	24.30	340.00	70.00
V 12 - 12	23.72	253.00	0.19	94.97	240.00	22.00	280.00	95.00
V 12 - 13		423.00	0.02	100.00	420.00	22.00	420.00	70.00
V 12 - 14	23.28	80.00	0.02	5.87	74.00	24.00	300.00	60.00
V 12 - 15	22.81	94.00	0.01	0.00	80.00	24.50	400.00	90.00
V 12 - 16	23.53	126.00	0.05	20.00	131.00	24.00	355.00	70.00

Reduce Cooling Load without compromising comfort level

BCA ACADEMY

Main reasons contributing to increased cooling load more than real need are:

- Minimum settings

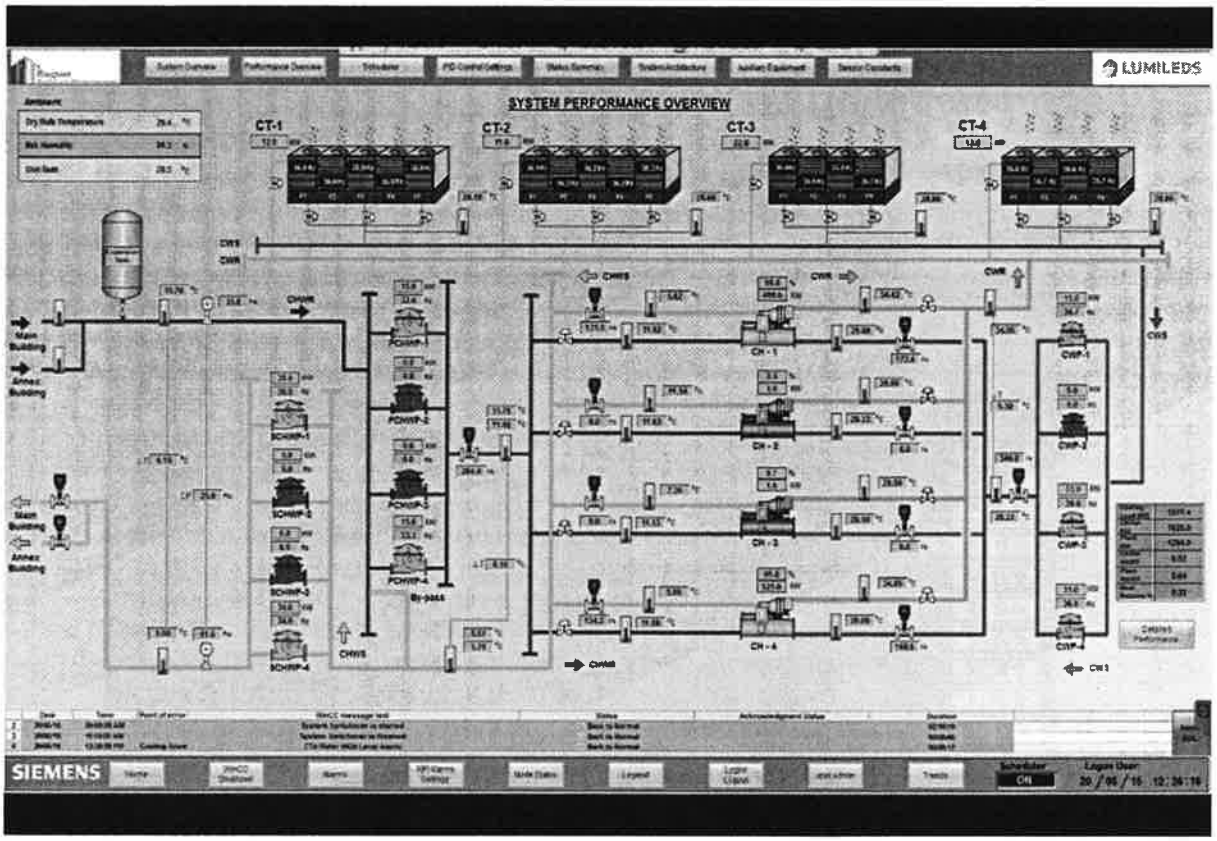


Before – VSD runs at full speed

Set static pressure never reach

After adjusting minimum speed – Static pressure reached to set point

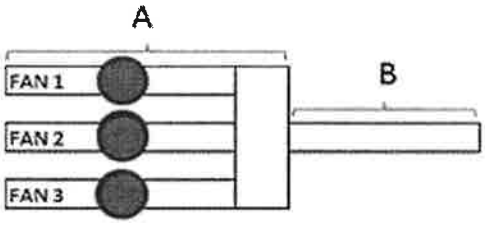
VSD runs only at 80 to 90%



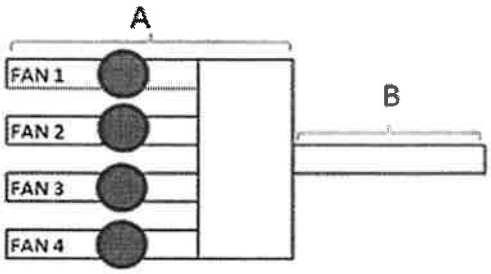
- Even with un-controlled de-coupler line, proper controls ensuring no bypass
- Running additional condenser water pumps causing low pump head

BCA ACADEMY

Existing
(CSR1 SAF)



Proposed
(CSR1 SAF)

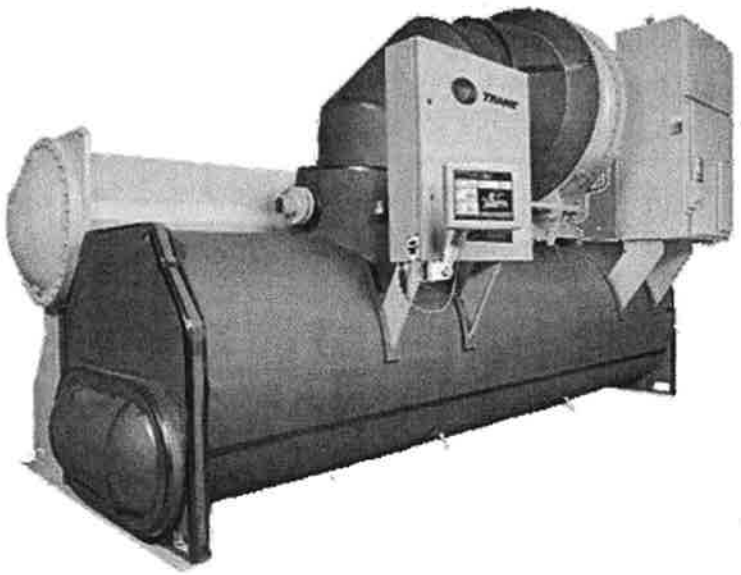


CSR1 Supply Air Fan	Existing	Proposed
Section A Flow Rate (l/s)	18.14	13.61
Section B Flow Rate (l/s) (flow to range)	**55.19**	**55.19**
Section A Pressure (Pa)	112.47	63.27
Section B Pressure (Pa)	623.00	623.00
Total Pressure	735.47	686.27
Section A Individual Fan Power (kW)	**27.69**	**19.28**
Section B Total Fan Power (kW)	**83.06**	**77.51**
Saving (kW)	**5.55**	

- Running additional fans in parallel also cause to reduced pressure and power

BCA

Air conditioning system- Chiller



BCA ACADEMY

Chillers

- Chillers are main component in Air Conditioning System
- Generally Chiller used for air-conditioning system designed at

  - CHWS - 6.7 Deg.C

  - CWS – 29.5 Deg.C

  CHW and Condenser Water Delta T of 5.5 Deg.C
- Above temperature are set at many years back based on that time material and energy cost equilibrium.
- Now the energy cost is higher than before, it is time to redesign the above parameters to possible best, even existing system can be commissioned to have **higher delta T**, **higher CHWS** and **Lower Condenser Water Temp.**
- Every Deg.C increase in Chilled Water Supply Temperature or Reduction in Condenser Water can improve around **3 to 4 %** chiller efficiency

Historical Chiller Technology and Efficiency

- Chillers designed prior to 1990s operated at ~ 0.9 KW/RT efficiency
- In 90s itself compressor technology reached to tipping point, chiller efficiency reached to ~0.55 KW/RT (i.e. over 35% improvement)
- Marginal improvement in chiller technology since 90s, today best chiller efficiency is around 0.5 KW/RT (i.e. an improvement of 10%)

Chillers

BCA ACADEMY

Key parameters and conditions effects chiller efficiency

- Condenser Water Supply Temperature (Entering Chiller)
- Chilled Water Supply Temperature (Leaving Chiller)
- Water flow and Water treatment
- Refrigerant Charge.
- Evaporator and Condenser cleanliness.
- Compressor efficiency usually selected during design stage

It is possible to maintain the above close to design condition and even better if the flow and temperatures are maintained better than design.

Chiller Efficiency Improvement at Various flow and temperature

BCA ACADEMY

			kW/ton std = 0.576 Condenser Flow Rate						IPLV std = 0.549 Condenser Flow Rate					
			2 gpm/ton	2.5 gpm/ton	3 gpm/ton	4 gpm/ton	5 gpm/ton	6 gpm/ton	2 gpm/ton	2.5 gpm/ton	3 gpm/ton	4 gpm/ton	5 gpm/ton	6 gpm/ton
Leaving Chilled Water Temp (°F)	Entering Condenser Water Temp (°F)	Lift (°F)	Required kW/ton						Required NPLV					
46	75	29	0.517	0.494	0.478	0.456	0.441	0.431	0.492	0.471	0.455	0.434	0.420	0.410
45	75	30	0.524	0.503	0.488	0.466	0.452	0.442	0.499	0.478	0.464	0.443	0.430	0.420
44	75	31	0.532	0.510	0.496	0.475	0.462	0.452	0.506	0.486	0.472	0.452	0.439	0.431
43	75	32	0.539	0.518	0.504	0.484	0.472	0.462	0.513	0.493	0.480	0.461	0.449	0.440
42	75	33	0.547	0.525	0.512	0.493	0.481	0.472	0.521	0.500	0.487	0.469	0.458	0.449
41	75	34	0.555	0.533	0.519	0.501	0.490	0.481	0.529	0.507	0.494	0.477	0.466	0.458
46	80	34	0.555	0.533	0.519	0.501	0.490	0.481	0.529	0.507	0.494	0.477	0.466	0.458
40	75	35	0.564	0.541	0.526	0.509	0.498	0.490	0.537	0.515	0.501	0.484	0.474	0.466
45	80	35	0.564	0.541	0.526	0.509	0.498	0.490	0.537	0.515	0.501	0.484	0.474	0.466
44	80	36	0.573	0.548	0.534	0.516	0.506	0.499	0.546	0.522	0.508	0.492	0.481	0.474
43	80	37	0.584	0.557	0.543	0.524	0.513	0.506	0.556	0.530	0.515	0.499	0.489	0.481
42	80	38	0.596	0.566	0.549	0.532	0.521	0.514	0.567	0.538	0.523	0.506	0.496	0.489
41	80	39	0.609	0.575	0.558	0.539	0.529	0.522	0.580	0.547	0.531	0.513	0.503	0.496
46	85	39	0.609	0.575	0.558	0.539	0.529	0.522	0.580	0.547	0.531	0.513	0.503	0.496
40	80	40	0.624	0.586	0.567	0.547	0.536	0.529	0.595	0.558	0.539	0.520	0.510	0.504
45	85	40	0.624	0.586	0.567	0.547	0.536	0.529	0.595	0.558	0.539	0.520	0.510	0.504
44	85	41	0.643	0.599	0.576	0.555	0.543	0.537	0.611	0.570	**0.549**	0.528	0.518	0.510
43	85	42	0.663	0.612	0.593	0.563	0.552	0.544	0.631	0.583	0.560	0.537	0.525	0.518
42	85	43	0.688	0.628	0.600	0.573	0.560	0.552	0.655	0.598	0.571	0.546	0.533	0.525
41	85	44	0.717	0.646	0.614	0.584	0.570	0.561	0.683	0.616	0.585	0.555	0.542	0.533
40	85	45	0.751	0.668	0.630	0.596	0.579	0.570	0.716	0.636	0.600	0.567	0.552	0.542
Condenser DT (°F)			14.04	11.23	9.36	7.02	5.62	4.68	14.04	11.23	9.36	7.02	5.62	4.68

Lift = Entering Condenser Water Temperature – Leaving Chilled Water Temperature

Condenser ΔT = Leaving Condenser Water Temperature – Entering Condenser Water Temperature

$COP_{adj} = K_{adj} \times COP_{std}$

$K_{adj} = 6.1507 - 0.30244(x) + 0.0062692(X)^2 - 0.000045595(X)^3$

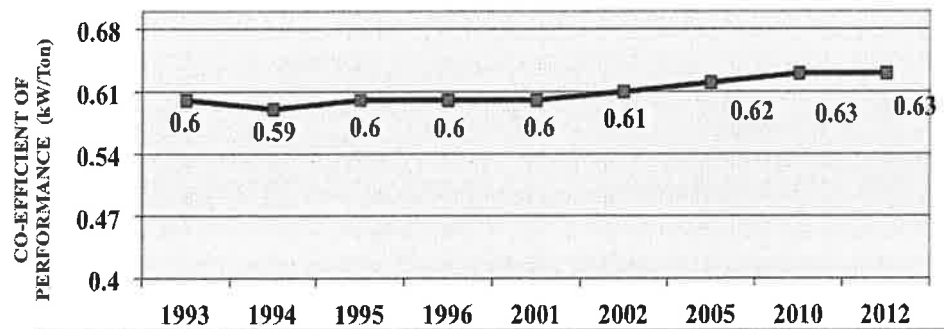
$kW/ton_{adj} = 1/(COP_{adj} \times 0.2845)$

NPLV Value at Conditions of 3 gpm/ton and 41°F Lift is IPLV

BCA ACADEMY

Life Span of chiller

- Chiller lifespan can range from 15 to 30 Years depends on environment and maintenance.
- It is possible to maintain the chiller efficiency close to design condition throughout the life span:
  - With proper preventive and predictive maintenance.
  - Monitoring the system performance on monthly/daily basis and taking immediate corrective actions if any deterioration
  - Controlling for optimized flow and using the most favourable weather conditions

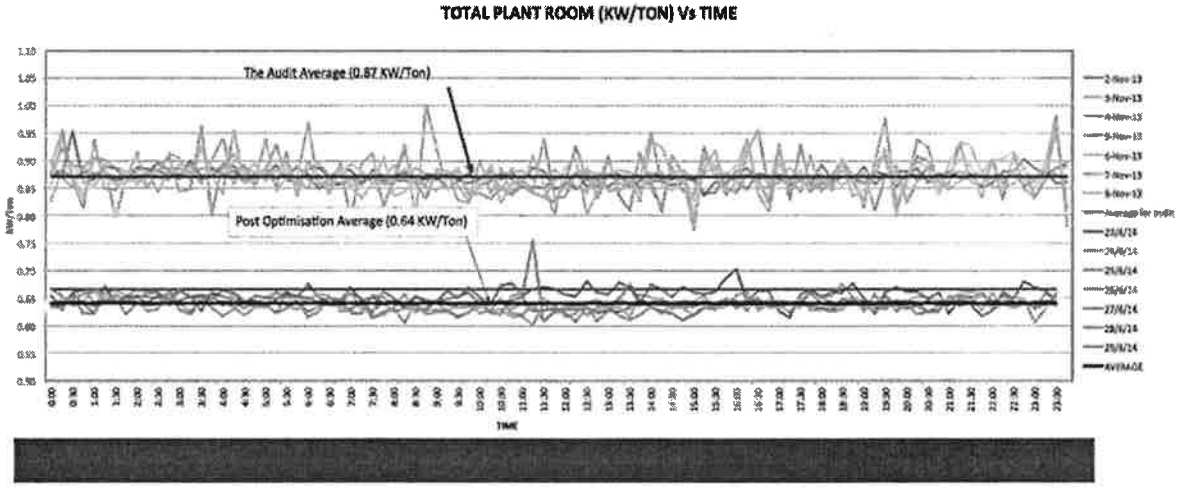


Actual chiller efficiency trend since its installation at one of the mixed use building in Singapore

Case study - 14 years old Chiller Plant efficiency reached Green Mark Platinum level without changing equipment

- 14 Years old chiller Plant.
- Chilled Water Supply at 5.8 Deg.C.
- Optimized the plant and installed intelligent control system
- **Achieved BCA Green Mark Platinum Certificate.**
- Payback less than 2 years
- Site visit can be arranged upon request
- Originally Chiller was designed at 0.55 KW/RT

		Before	After	Savings	
CHILLER	KW/RT	0.574	0.523	0.052	9%
CHWP	KW/RT	0.138	0.053	0.086	62%
CWP	KW/RT	0.104	0.031	0.072	70%
CT	KW/RT	0.057	0.034	0.022	39%
Total Plant KW/RT	KW/RT	0.873	0.641	0.232	27%



BCA ACADEMY

OPTIMIZE or REPLACE

Case Study – Chiller Replacement Vs. System Optimization

BCA ACADEMY

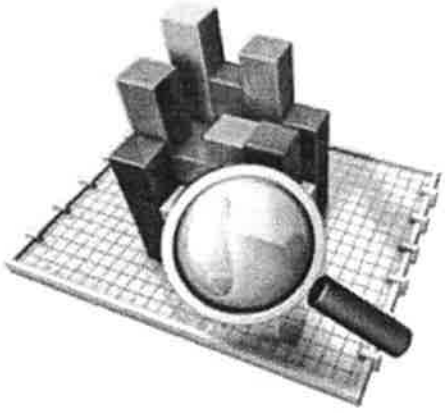
4*1100 RT System, 2 running and 2 standby

	Before	After	
		Option-1 EQUIPMENT REPLACEMENT	Option-2 System optimization (NO EQUIPMENT REPLACEMENT)
Cooling load (RT)	1,700	1,700	1,700
Operating Hours	8,760	8,760	8,760
Chiller Efficiency	0.57	0.5	0.52
Pump and CT Efficiency	0.3	0.12	0.12
Chiller Plant Efficiency	0.87	0.62	0.64
KWH	12,956,040	9,233,040	9,530,880
Energy Cost S$ (@$0.25/kWh)	2,591,208	1,846,608	1,906,176
Savings (KW/RT)		0.25	0.23
Savings in KWH		3,723,000	3,425,160
Savings (S$)		**$744,600.00**	**$685,032.00**
Investment Cost including BMS and 5 Years Performance Contracting (S$)		**$3,460,000.00**	**$1,100,000.00**
Payback (Years)		**4.65**	**1.61**

RETRO-COMMISSIONING RESULTS

BCA ACADEMY

Results of Retro-Commissioning in 10 buildings in Singapore



Case Study: Buildings types

BCA ACADEMY

Building no	Building Type	Building Age [Years]	Chiller Plant Age [Years]	Building Gross Floor Area [m^2/ft^2]	Air-conditioning System Type*
1	Hotel	10	10	23,769 / 255,847	WC
2	Office	15	15	36,196 / 389,611	WC
3	Mixed	35	8	71,200 / 766,391	WC
4	Office	11	11	28,360 / 305,265	AC
5	Office	15	15	27,699 / 298,150	WC
6	Office	27	7	95,625/ 1,029,289	WC
7	Mixed	35	20	31,977 / 344,198	WC
8	Retail	2	2	5,501 / 59,212	VRV
9	Office	6	6	35,165 / 378,513	WC
10	Office	32	32	24,368 / 262,295	WCPU

*Legend:
WC (Water Cooled Central Chiller Plant)
AC (Air Cooled Central Chiller Plant)
VRV (Variable Refrigerant Volume)
WCPU (Water Cooled Package Units)

Retro-commissioning – Focused Areas

BCA ACADEMY

- Permanent smart metering and establishing proper M&V procedures.
- Variable chilled water and condenser water flow as per demand.
- Increased Chilled Water and Condenser Water Temperature difference to optimum level.
- Reduce the friction in the system and pump head of Chilled Water and Condenser Water Pump.
- Reduce the condenser water supply temperature and optimize the cooling tower fan operation based on weather condition.
- Optimize the AHU airflow for the same comfort and cooling load and introduce Airflow and temp. dual control
- Install Demand Ventilation Controls.
- Calibrate and fine-tune HVAC plant control sensors, set points and installing intelligent controls.

All of the above was done while committing to the same comfort level

Optimization of Air-conditioning system – equipment level results

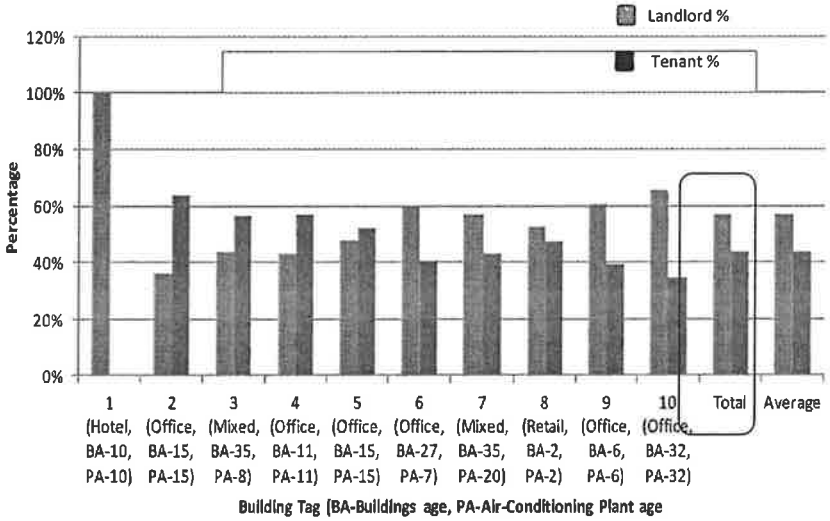
BCA ACADEMY

Efficiency		Before	After
Condenser System Head	PSI	65	18
Chilled Water System Head	PSI	60	19
Chilled Water Flow	GPM/Ton	3.7	1.88
Condenser Water Flow	GPM/Ton	4.1	3
Reduce AHU airflow	CMH/Ton	600	450
Reduce Fan Pressure	Pa	700	500
Chillers	kW/Ton	0.93	0.5
Chilled Water Pumps	kW/Ton	0.27	0.025
Condenser Water Pumps	kW/Ton	0.25	0.030
CT	kW/Ton	0.05	0.025
AHU Energy	kW/Ton	0.35	0.11

Landlord energy consumption is on average ~60% of total electricity consumption

BCA ACADEMY

Annual Building Electricity – Tenant vs. Landlord across different buildings

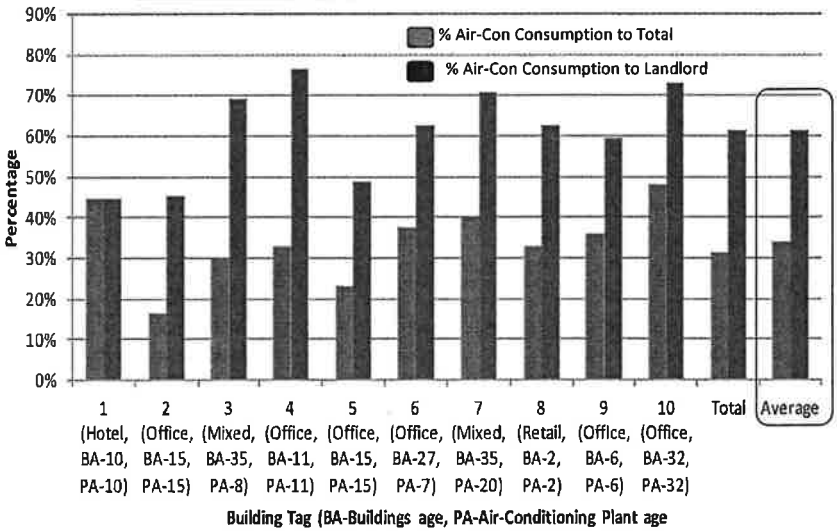


- **Typical structure in Singapore: Tenant pays for their usage: plug loads, lighting etc in their premises.**
- **Landlord pay for common facilities energy cost including Air-Condition.**

Air-Conditioning Consumption is ~60% of the landlord energy and ~35% of total building consumption

BCA ACADEMY

Air-conditioning consumption % to total building and landlord consumption

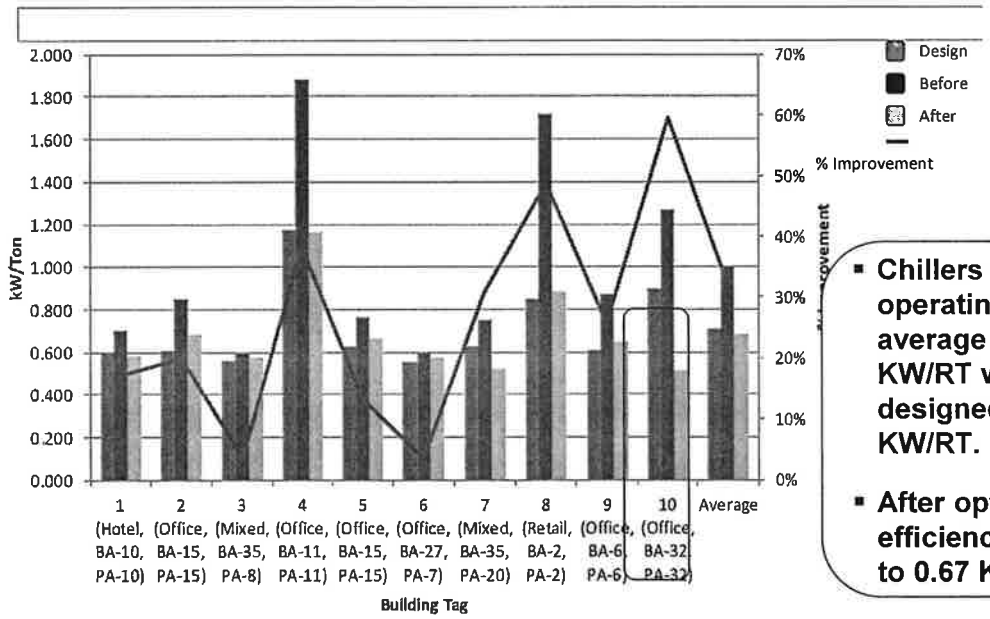


- Air-conditioning (Chiller Plant and Airside) is around 60% of Landlord Energy Consumption
- Air-Conditioning and Mechanical Ventilation Consumes around 70% of Landlord Energy Consumption

Chiller Efficiency – Able to recondition close to design efficiency

BCA ACADEMY

Chiller Efficiency Improvement – Design, Before and After retro-commissioning and % Improved

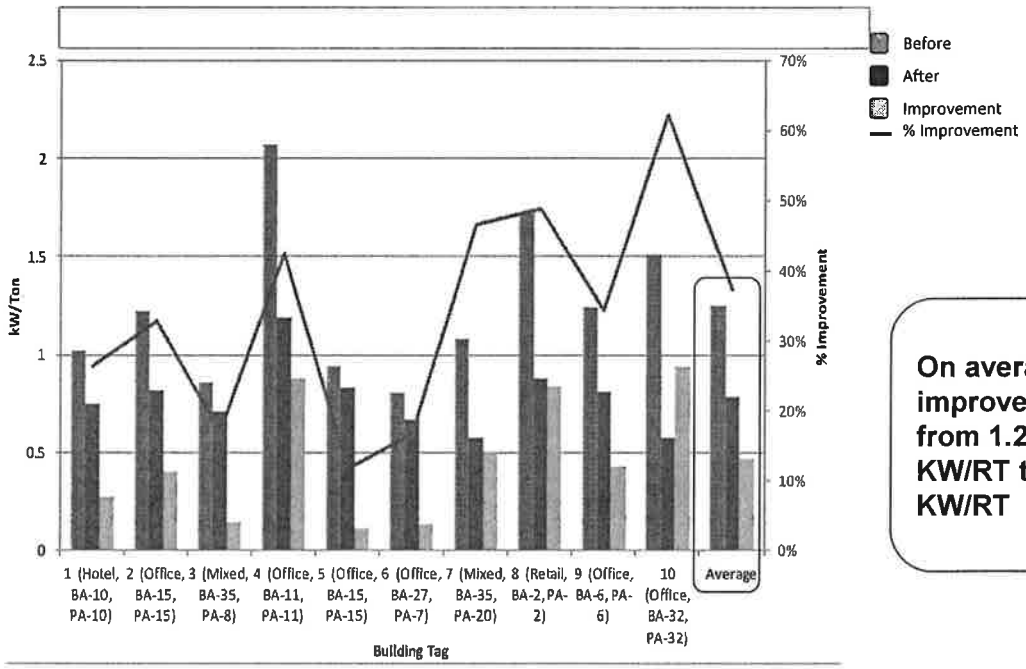


- Chillers were operating at average of 0.85 KW/RT whereas designed at 0.61 KW/RT.
- After optimisation efficiency improved to 0.67 KW/RT

Avg. 37% improvement in Plant Efficiency including Chillers, Pumps and Cooling Towers

BCA ACADEMY

Plant Efficiency Improvement by Optimization – Actual Data from building in Singapore

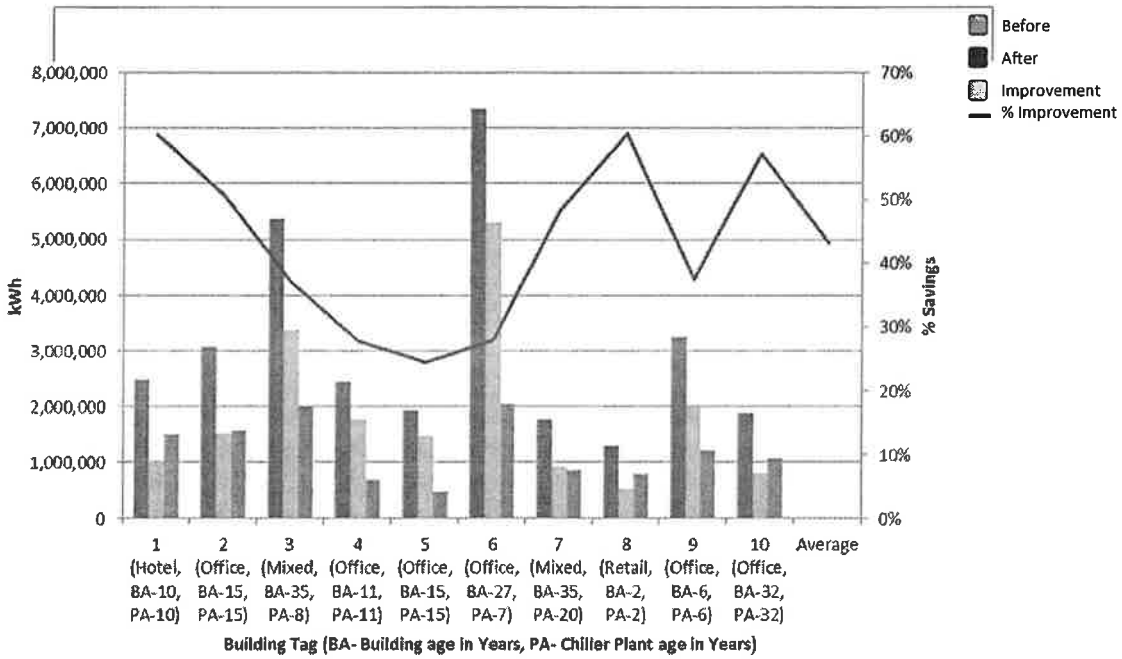


On average improvement from 1.25 KW/RT to 0.78 KW/RT

Avg. 43% savings in Air-Conditioning System kWh Consumption

BCA ACADEMY

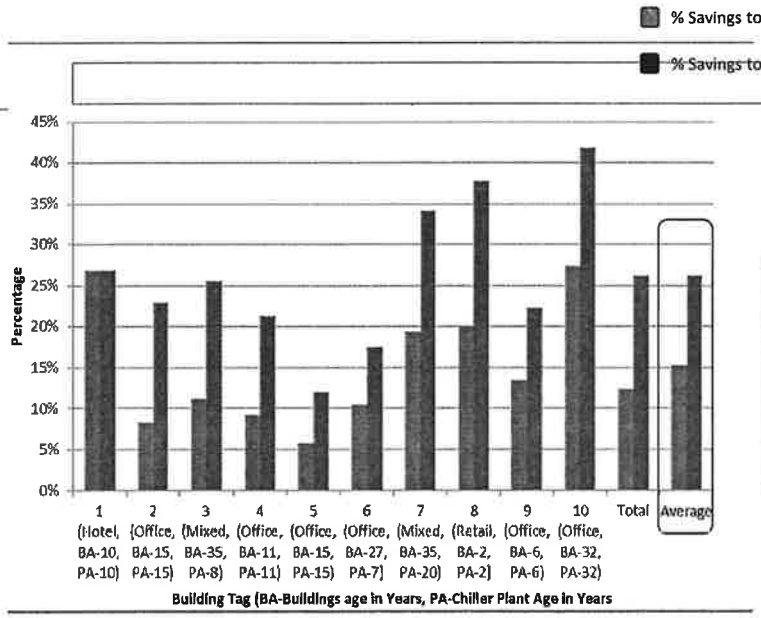
Air-Conditioning Energy Consumption (Before, After Retro commissioning, Savings and %Savings



Savings in Air-Conditioning contributes to significant reduction in landlord and total building consumption

BCA ACADEMY

% Savings in Air conditioning for landlord and total building

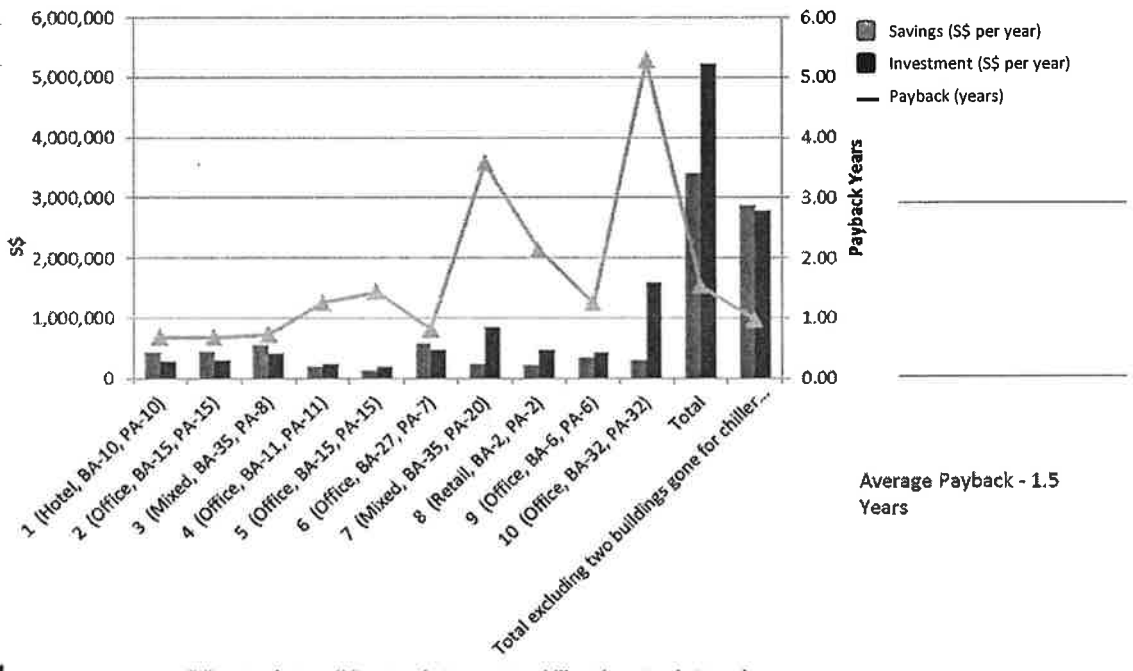


- Avg. 26% to landlord consumption
- Avg. 16% to total building consumption

Average Payback for retrofitting is 1.5 Years

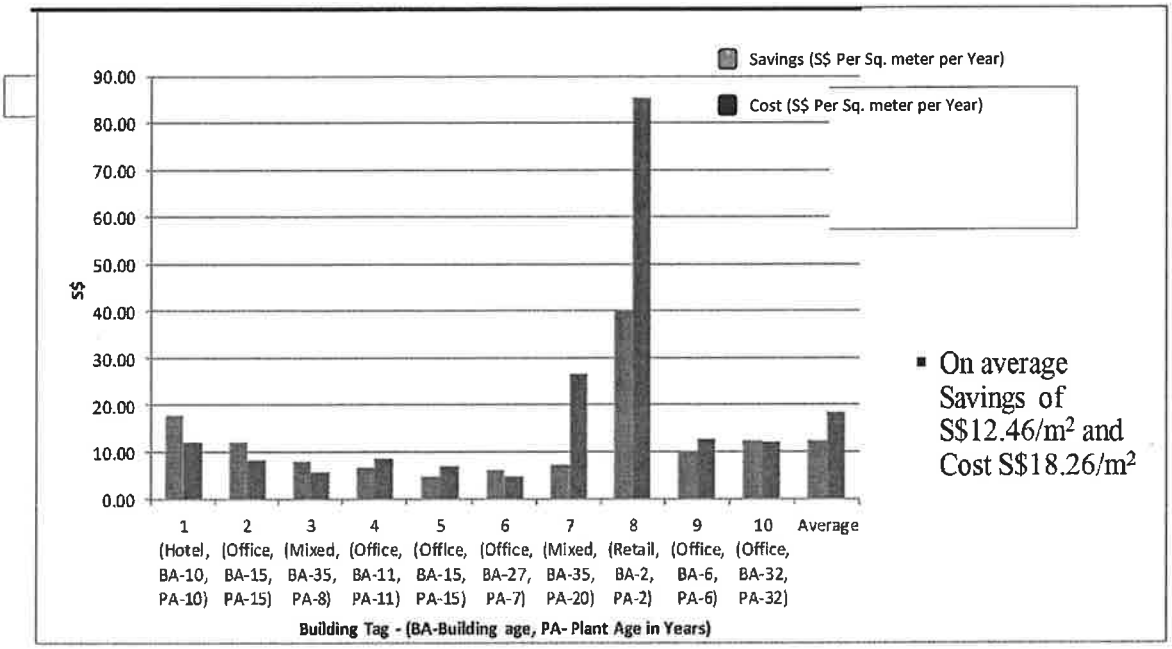
BCA ACADEMY

Investment, savings and Payback



Savings and Cost Per Square meter (GFA)

Cost and Savings per Sq.m (S$)



- On average Savings of S$12.46/m^2 and Cost S$18.26/m^2

Optimization/Retro-commissioning - Results

- Case study in Singapore buildings reveal potential savings of ~40% for optimisation of air-condition system
- It contributes to savings of S$12.46 /m^2 (GFA) with an average payback of 1.5 years.
- It is possible to achieve Green Mark Platinum level with existing equipment.
- Even at other countries retro-commissioning brings similar results
- Study conducted on building commissioning in USA reveals the savings due to retro-commissioning/optimisation was around 16% for existing building with a payback of 1.1 years (Evan Mills, 2011).
- Value of energy savings ranges $0.11 to 0.72 per Square feet ($1.18 to $7.7 per m2) (Mills, 2004)

Optimization/Retro-commissioning - Results

- **Other benefits includes:**
  - ✓ Improved system operation: beyond preventive maintenance
  - ✓ Improved equipment performance and increased life cycle
  - ✓ Increased Operation and Maintenance Staff Capabilities and Expertise
  - ✓ Increased asset value
  - ✓ Improved indoor environmental quality (IEQ)
  - ✓ Improved building documentation
  - ✓ Ability to cope with expansion and increased occupancy without installing or upgrading equipment

Barriers and available solutions for implementation of Retro-Commissioning projects

Main Barriers	Possible Solutions
High Audit Fees	- Engage the companies who do the preliminary audit **at no cost** and give proposal that can give an idea on the opportunities - Use industry standard benchmarks like kWh/m2 and RT/m2 for quick comparison
High Implementation Cost	- If we are looking for optimization of existing system the payback ranges from 1 to 2 years. - There are options available like Energy Performance Contracting where owners can enjoy 30% to 70% savings without any investment. - Use incentives and grants
How to Quantify the Savings and problem with reconciliation with energy bill	- Energy Savings measures also comes with metering, instrumentation and monitoring software. - Install the energy meters for every equipment and calculate the savings based on efficiency. - Auto reporting - If the energy saving project small scope (e.g. lighting replacement) may not reflect in the energy bills.

Barriers and available solutions for implementation of Retro-Commissioning projects (Contd.)

BCA ACADEMY

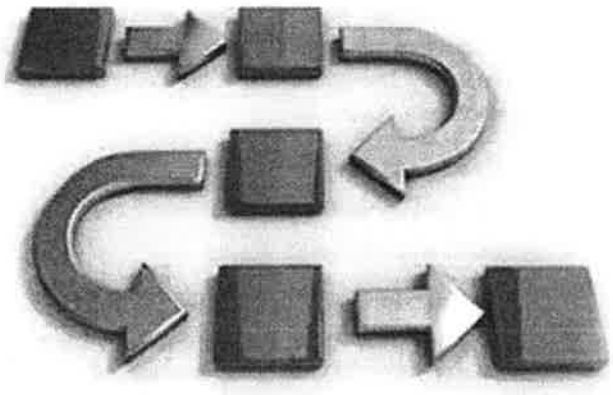
Main Barriers	Possible Solutions
Possible interruption, Complaints and failure	- Optimisation and Retro-commissioning is not straight forward approach, there are lot of quick fixes since years operation, if anyone trying to address the issues without looking at the root cause for poor performance and the right solutions it gives rise more issues and project may abandon. - For the proposed energy conservation measures of OPTIMIZATION/Retro-Commissioning to work well, having energy audit experience alone is not enough - Consultants or Energy Performance Contractors shall have experience and extensive knowledge in ✓ Operation and Maintenance ✓ Testing and Commissioning ✓ Addition and Alteration Works ✓ Design of ACMV system, Controls and Automation ✓ Simulation, Selection and in-depth knowledge of Motors, Drives Chiller, Pumps, CT, AHU/FCU at component level

Barriers and available solutions for implementation of Retro-Commissioning projects (Contd.)

BCA ACADEMY

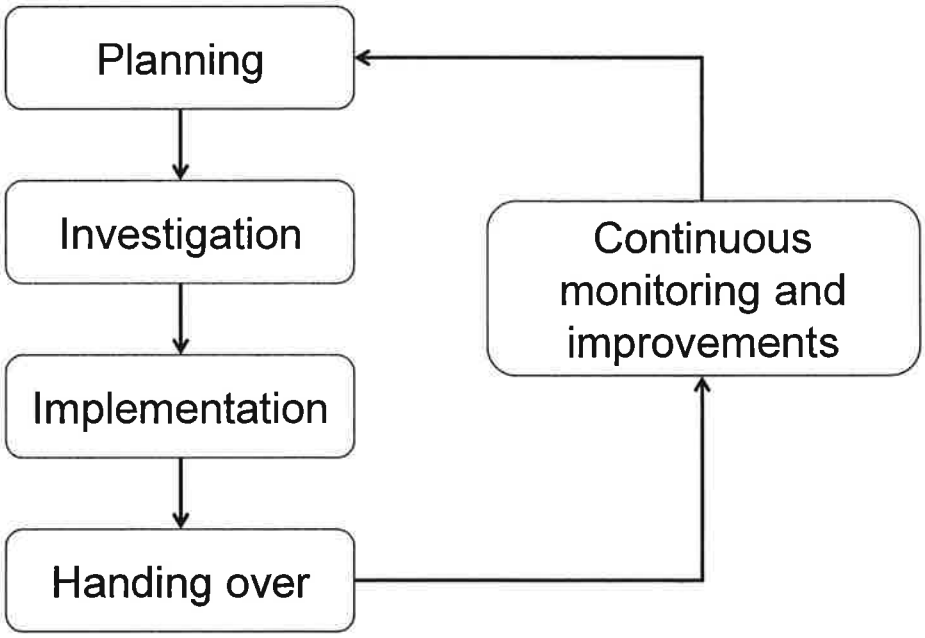
Main Barriers	Possible Solutions
Lack of expertise to create business case	- FM to be trained on how to calculate the life cycle costing. - FM to be trained to provide the report and recommendations with financial analysis (NPV or IRR) along with other intangible benefits like meeting CSR etc.
No motivation and worry	- FM to be trained how to write reports to management and present the work done in impressive way so that Management can recognize the efforts of FM. - Discuss the concerns, address it and move forward .
Lack of time	- FM team are with limited resources and busy with day to day operations. Management to provide dedicated person in-charge for the energy efficiency initiatives. - If the Energy Initiatives comes with control systems and monitoring software (KPI) it will helps o Predict failures and Reduce downtime. o Quick troubleshooting and identifying root causes. o Less complaints o All the above helps to manage FM team

Stages in Retro-commissioning



Retro-commissioning- Stages

A well-planned and executed retro-commissioning project typically occurs in five phases:



BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning

- Whenever significant changes occur in building occupancy, space utilization, equipment configuration, or maintenance practices.
- Whenever sections of buildings and systems are undergoing a significant upgrade
- When energy-use trending reveals an increase over time, which may be attributed to control drift or equipment wear.
- An older building that has been inactivated
- It is not necessary only old buildings required retro-commissioning. When the building commissioned it may not occupied fully, so retro-commissioning may even requires in the new the buildings less than 6 months of operation.

To check. Ext's Water Pressure Drop Across Ext's AHU/FCU coil if to add AHU/FCU.

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

Check list.

1. Identify the need fro retro-commissioning (Cont'd)

- Following are simple measure which FM can easily measure and analyze through maintenance activities, any of these are yes means there is need for retro-commissioning and possibility of savings
  - Chiller Operating higher than design KW/RT?
  - Chilled Water or Condenser Water Pump Head higher than 30 PSI?
  - Chilled Water Delta T lower than 5.5 or Design?
  - Condenser Water Supply temperature higher than 29 or 1.5 Deg.C higher than outdoor wet bulb temperature?
  - CHWP KW/RT higher than 0.03?
  - CWP KW/RT higher than 0.035?
  - CT higher than 0.03 KW/RT?
  - Chiller Condenser approach higher than 0.5 Deg.C?
  - Evaporator Condenser Water approach higher than 0.5 Deg?

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning (Cont'd.)

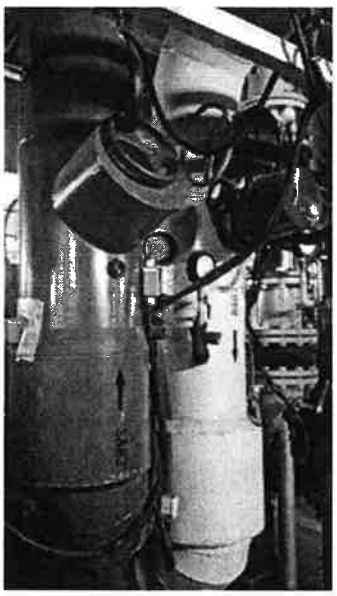
- Supply Air Temperature higher than 13 Deg.C?
- Room temperature and air entering to AHU room difference greater than 1 Deg.C?
- If the Air Entering to AHU is lower than room temperature indicates air leaks or short cycling.
- If the Air Entering to AHU is higher than room temperature indicates infiltration or some other issues above the ceiling.
- AHU Coil air pressure drop higher than 100 pa?
- AHU Filter pressure drop higher than 50 pa?
- Room temperature lower than 23 Deg.C?
- CO2 levels lower than 800 PPM?
- CO levels at car park less than 25 PPM?
- Controls are not working and sensors are not calibrated.

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples



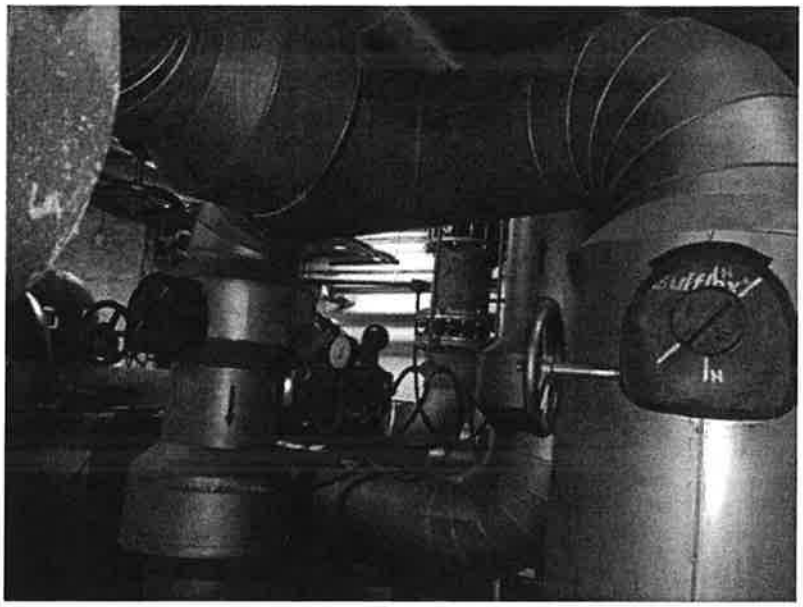


Flow restrictions – Throttled Valves and Constant flow valves etc

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples



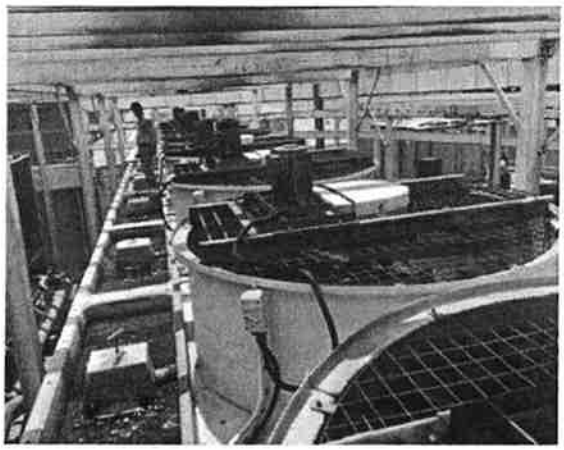
Flow restrictions – Throttled Valves and Constant flow valves etc

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples



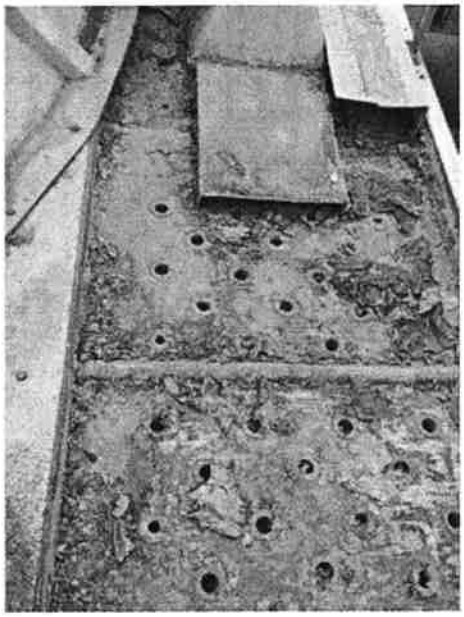


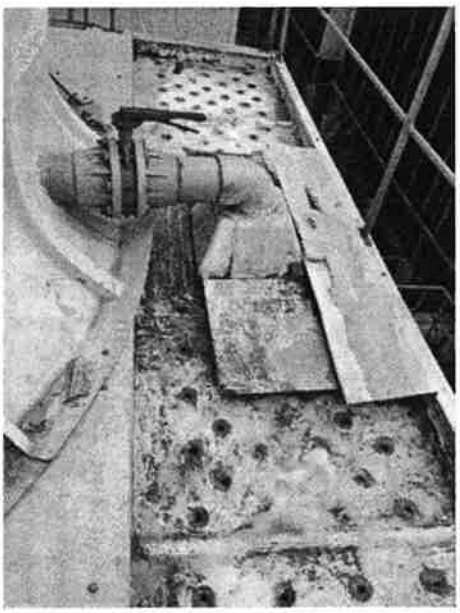
Clogged basin and In fills, Short cycling

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples





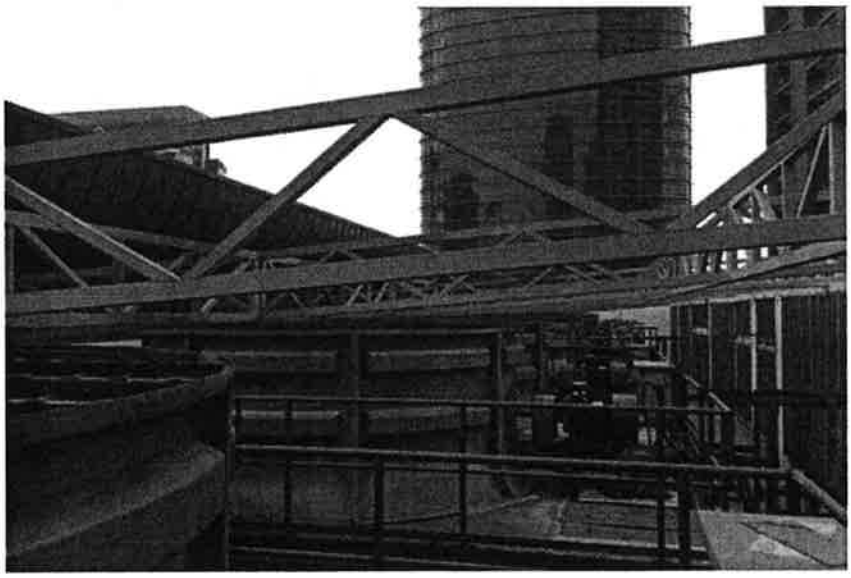
Clogged basin and Infills, Short cycling

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples

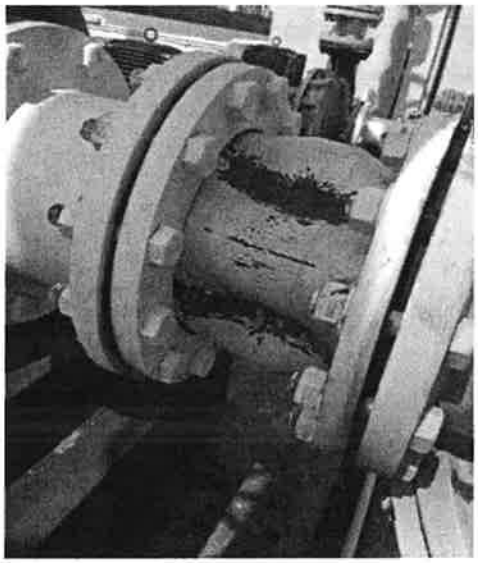


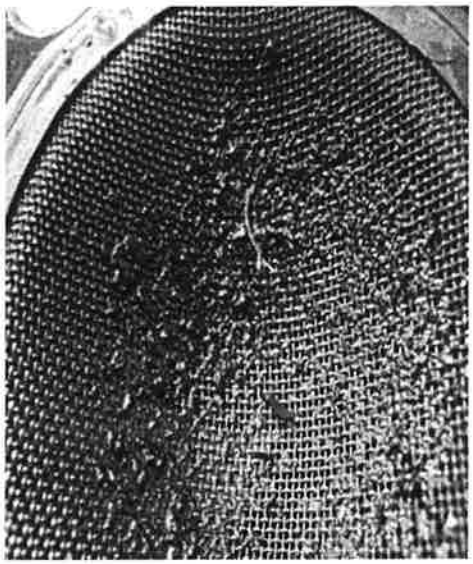
Clogged basin and Infills, Short cycling

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples





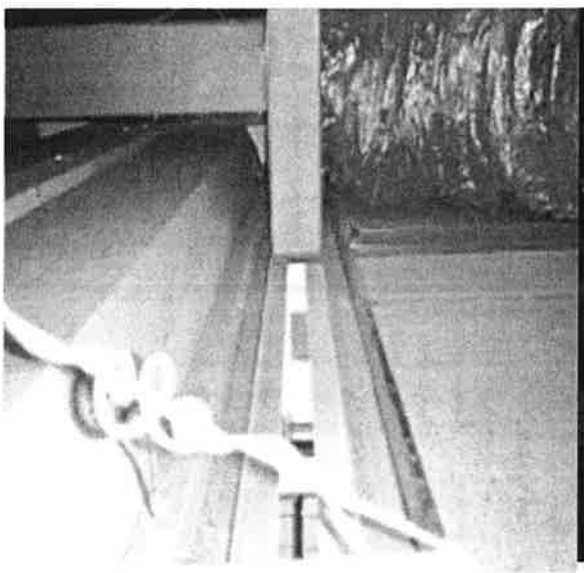
Clogged strainer and impact on flexible

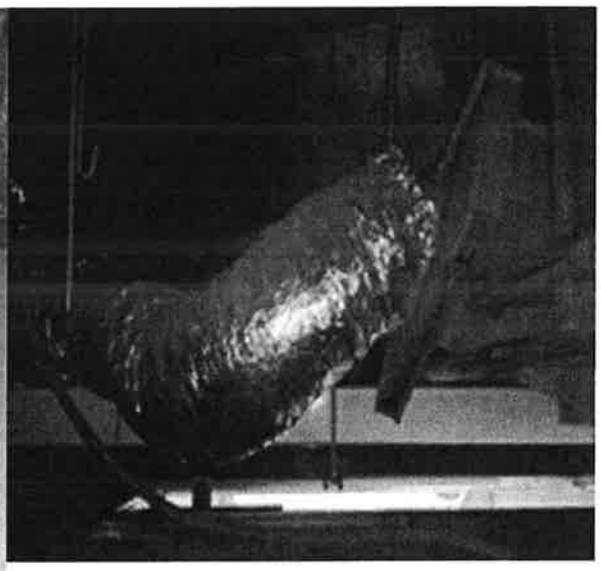
BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples





Leaks in supply air, Improper Flexibles connections

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples



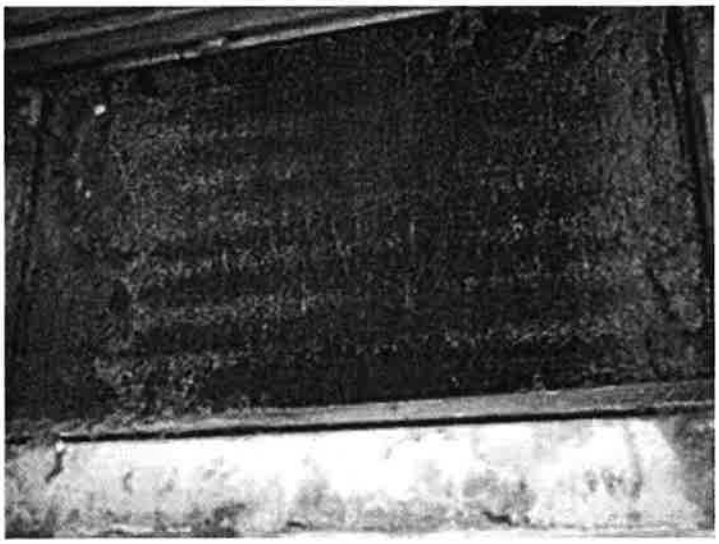
Improper location of Thermostat (Above the ceiling and blocked)

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples

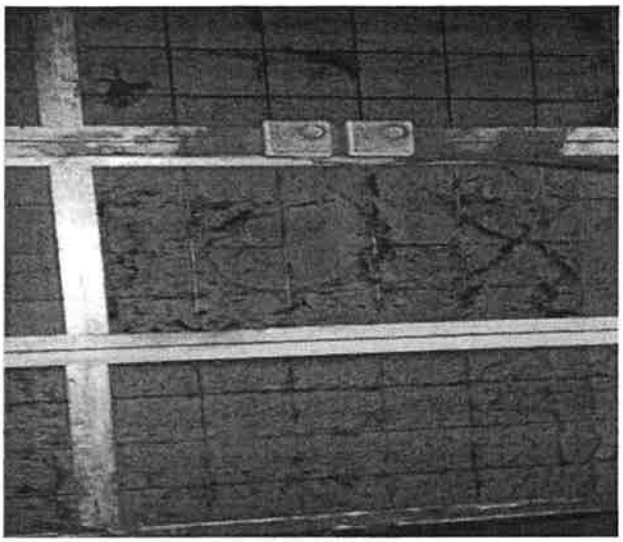


Clogged Coil

Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples



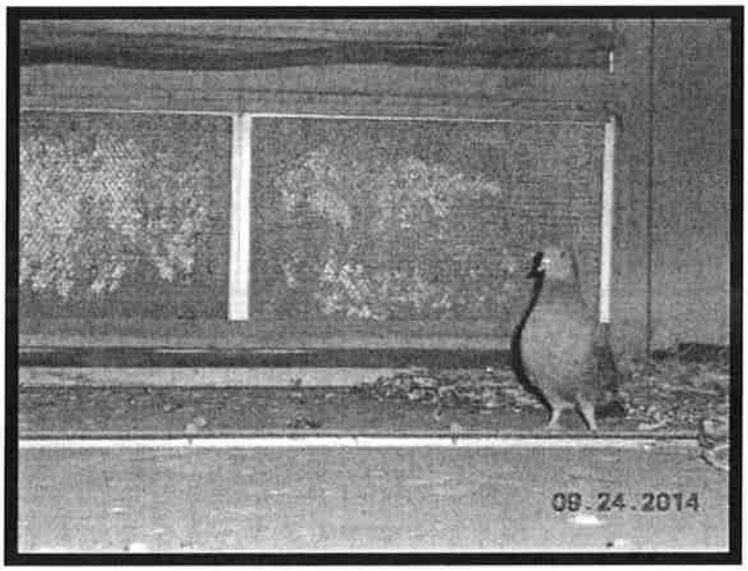
Clogged Filter

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

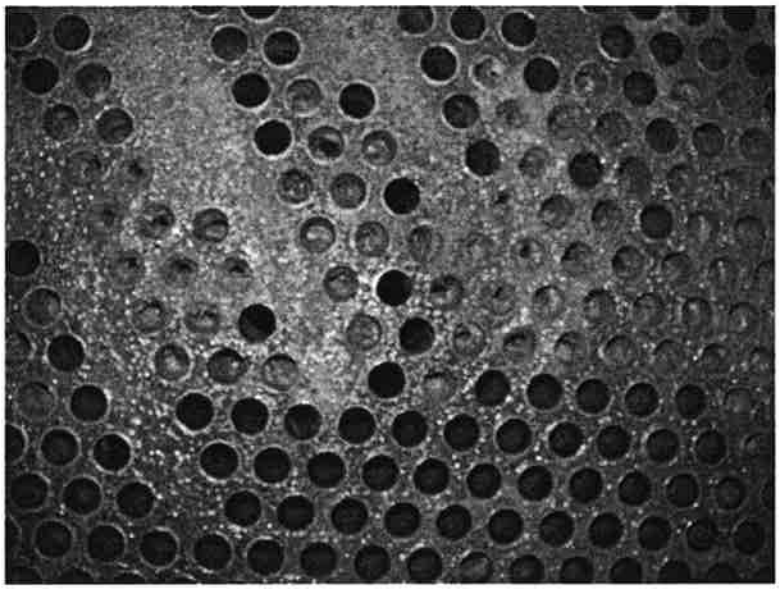
1.Identify the need for retro-commissioning - Fresh air duct



Retro-commissioning- Stages

Planning Stage

1.Identify the need fro retro-commissioning - Few Examples



Chiller Evaporator and Condenser Scaling

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

2. Select and Prioritize the facilities for retro-commissioning
   - Energy Costs
   - Maintenance Costs
   - Complaints
   - Age of the system etc

Retro-commissioning- Stages

Planning Stage

3. Equipment replacement or retro-commissioning
   - ➢ Follow step approach
     - Study the feasibility and Conduct cost and benefit analysis to bring the system to design conditions (even better) without compromising comfort level and safety.
     - From above condition (post retro-commissioning) if the new equipment gives better efficiency and makes economic sense to replace then can consider for replacement.
     - If the existing condition is very bad, corroded, equipment are obsolete and may lost less than 5 years, then its better to consider equipment replacement option straight away.

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

4. Goals of retro-commissioning
   - ➢ Energy and Cost reduction
   - ➢ Improved Comfort level and tenant satisfaction.
   - ➢ Improved operational flexibility.
   - ➢ Improved productivity
   - ➢ Reduced maintenance cost and downtime

Retro-commissioning- Stages

Planning Stage

5. Obtaining Management Support
   - Create a Business case with benefits to the organization
   - Provide the financial analysis, life-cycle cost analysis.
   - Educate all the management team responsible for operations.
   - Update them regularly.
   - Don't oversell and give unrealistic achievements, if over delivered on the first projects it boosts confidence level which makes easy to get approval for next projects.

BCA ACADEMY

Retro-commissioning- Stages

Planning Stage

6. Setting up right team and choosing right contractor

   Project success depends on getting the right people involved. Choose the commissioning contractor who knows not only to measure the system performance but also have total system knowledge at component level. Typically commissioning company shall have the following prerequisites.

   - ✓ Operation and Maintenance
   - ✓ Testing and Commissioning
   - ✓ Addition and Alteration Works
   - ✓ Design of ACMV system, Controls and Automation
   - ✓ Simulation, Selection and in-depth knowledge of Motors, Drives Chiller, Pumps, CT, AHU/FCU at component level.
   - ✓ Enough track records on successful implementations of retro-commissioning projects and achievements

Retro-commissioning- Stages

Planning Stage

6. Setting up right team and choosing right contractor (Cont'd)
   - Team can comprises of the following

     Commissioning/Optimizing Company
     - Building Owner or Representative
     - Facility Manager
     - Mechanical, Electrical, and Controls Engineers
     - Equipment Supplier / Vendor representative / Maintenance Contractors
   - Every team member should know the objective of the project and work towards common objective.

BCA ACADEMY

Retro-commissioning- Stages

Checklist on required all data.

Investigation Stage

1. Investigation and detailed study
   - Collect the data from calibrated instruments (Not from BMS)
   - Analyze the data, compare with design specifications.
   - Simulate the chiller and pump performance based on operating conditions and identify the operating design efficiency.
   - Compare the operating design efficiency with actual measured efficiency, if any deviations identify the root causes.
   - Identify the ways and conditions to reduce the flow and pressure for the same cooling load.
   - Identify way to reduce the cooling load and demand without compromising comfort level.
   - Identify the operational flexibilities and additional features
   - List the improvement works, Conduct cost and benefit analysis

Retro-commissioning- Stages

BCA ACADEMY

Investigation Stage

2. Baseline methodology
   - Establish instruments required, it is strongly recommended to follow BCA M&V requirements for sensor accuracy and installation.
   - Permanent meters to be proposed to compare before and after energy consumption and efficiency.
   - Establish proper baseline and verification methodology, to verify the savings and benefits.

Retro-commissioning- Stages

BCA ACADEMY

Investigation Stage

2. Baseline methodology (Cont'd)
   - It is very important to have proper measurement and verification system.
   - Power meters to be installed at all equipment.
   - Cooling load meters to be installed.
   - All the meters to be linked to computer for establishing the reference value (KW/RT)
   - After installation measure the cooling load and kWh from same meters and establish efficiency.
   - Difference in the efficiency is savings in kW/RT.
   - Comparing the kWH not a good practice, as kWH also depends on cooling which depend on various factors such as weather, occupancy etc. Use only KW/RT or efficiency as benchmark
   - Always reconcile the savings with buildings energy bills
   - Engage independent third party to verify the Savings if required

Retro-commissioning- Stages

BCA ACADEMY

Investigation Stage

2. Baseline methodology (Cont'd)
   - Example of measuring kwh Vs Kw/RT

	Before	After	
		Scenario-1 (Same Cooling load)	Scenario-2 (Cooling load reduced due to low occupancy)
Cooling Load (TH) (A)	360,000	360,000	288,000
Plant KWH (B)	324,000	252,000	201,600
Plant Efficiency (C)	0.9	0.7	0.7
Reference Value KW/RT (D)	0.9	0.9	0.9
Savings in KW/RT (E= C-D)		0.2	0.2
KWH Savings due to efficiency improvements = E*A		72,000	57,600
Based on KWH (Absolute Value)		72,000	122,400

Retro-commissioning- Stages

BCA ACADEMY

Implementation Stage

1. Baseline establishment
   - Install permanent meters
   - Collect the data for baseline
   - Establish baseline
   - **Don't do any implementation or adjustments without establishing baseline**
   - Baseline to be signed off by relevant parties

Retro-commissioning- Stages

BCA ACADEMY

Implementation Stage

2. Implementation
   - Prioritize implementation areas.
   - ONE STEP AT ONE TIME
   - Strongly recommended to divide the various works in to stages like
     - Pump Optimization
     - CT Optimization
     - AHU Optimization
     - Kitchen/Car Park Ventilation Optimization etc
   - Commission each system, monitor, resolve the issues if any, once smooth go to the next system.
   - Establish benchmarks of system performance

BCA ACADEMY

Retro-commissioning- Stages

Implementation Stage

2. Implementation (Cont'd)
   - Example of benchmarks/KPI - Chiller

Chiller KW/RT	Condenser Water flow
Chiller Evaporator Pressure Drop at given flow	Evaporator approach temperature
Chiller Condenser Pressure Drop at given flow	Condenser approach temperature
Chilled Water flow	Water Temp

Retro-commissioning- Stages

Implementation Stage

2. Implementation (Cont'd)
   - Example of benchmarks/KPI - Pump

Pump KW/RT	Pump Head
Strainer pressure drop at given flow	Pump and motor efficiency and given flow and head

   - Example of benchmarks/KPI - CT

Approach temperature	Pressure drop across the CT at given flow
Cooling Tower treatment	Fan and motor efficiency and given flow

BCA ACADEMY

Retro-commissioning- Stages

Implementation Stage

2. Implementation (Cond't)
   - Example of benchmarks/KPI - AHU

AHU KW/RT	Coil Pressure Drop
Strainer pressure drop at given flow	Filter Pressure drop
CO2 level	Coil approach temperature

   - Example of benchmarks/KPI – Kitchen Ventilation System

Supply Pressure /Flow	Supply fan KW/Hz
Exhaust Pressure / Flow	Exhaust fan KW/HZ
Fan Pressure at given flow	

Retro-commissioning- Stages

BCA ACADEMY

Handing over stage

Handing over must have the following.

- Training to various operators and maintenance team/contractors
- Proper documentation complete OMM comes also
  - Troubleshooting guide.
  - T&C reports
  - KPI and Benchmark.
  - Step by Step method of corrective action if any KPI deviates etc Commission over all system
- Handover the system to respective maintenance contractors or facilities

Retro-commissioning- Stages

BCA ACADEMY

Continues Monitoring and Commissioning

In order to sustain savings, system performance to be monitored, measured and improved continuously

- Remote monitoring, alarm and KPIs.
- Generate Monthly reports and review.
- Take immediate corrective actions.
- Include performance measures and KPIs into the maintenance contracts.
- Appreciate and reward teams who are initiating on energy conservation

Conclusion

BCA ACADEMY

- Building Sector globally accounts for 40% of Energy
- 33% of Greenhouse Gas Emissions (Price et al, 2006)
- Over 80% of Greenhouse Gas emissions and energy consumption happens in the operational stage of building life cycle
- **FM is Key in managing the operational stage of buildings and reducing energy consumption in buildings**
- Energy Conservation plays important role and key in sustainability agenda.
- Existing buildings are possible to achieve Green Mark even platinum rating through retro-commissioning without changing equipment

Conclusion (Cont'd)

BCA ACADEMY

➢Savings through Optimization/Retro-commissioning can range up to 40% and $12.5/m^2$ with average payback of around 1.5 years

➢Based on past trend, electricity tariff increasing around 8% year on year, meaning amount of savings in $ also increase by 8% per year.

➢Energy Savings performance model available in the market, possible to have 30% to 70% of total savings for first 4 to 5 years and 100% after contract period **without any outlay and no audit costs**

➢Energy efficiency program also comes with various benefits such as Remote monitoring, Predicted failures, Reduced downtime, auto reporting and increased productivity

Q&A

Thank You

Certification Course for Green Mark Facilities Professional (GMFP)

(Core Module)

Retro Commissioning and Performance Contracting

E2green Pte Ltd

Course Overview

Part II : Performance Contracting

Day 2 (pm) & Day 3 (am/pm)

- Introduction to Performance Contracting
- Economic Analysis Tools of the Energy Efficient Projects (EEP)
- Measurement & Verification in EEP
- Legal Documentation of Performance Contract
- Development of an Performance Contracting Plan, Process & Implementation
- Case Study

BCA ACADEMY

Trainer Contacts

Er. Patrick Foong
PE
Managing Director , E2green Pte Ltd
(A Member of Crescendas Group)

9017-6992

patrick@e2-green.com

BCA ACADEMY

Introduction to Performance Contracting

Introduction

- Energy Performance Contract (EPC) is a performance-based procurement method and the business model revolves around getting the actual savings realized to pay for the energy-efficient project (EEP).
- EPC is usually implemented as turnkey (design & build) project providing building owners with a set of comprehensive energy conservation measures (ECM) with guarantees that the stream of income from the cost savings, or the renewable energy will be sufficient to repay the cost of the EEP, including funding cost.
- In short, it is a form of creative financing for capital project improvement which allows funding of energy upgrades from cost reductions.
- Means to deliver infrastructure improvements & energy efficient projects (EEP) to buildings & facilities that lack technical & manpower resources, funding and understanding of risk.

E2green Pte Ltd
BCA ACADEMY

Introduction

- Cash-tight , yet credit-worthy owners like the Management Corporation Strata Titles (MCST) in Singapore are good prospects for EPC.
- Cost of capital may be higher for ESCO than customers but the latter may be reluctant to borrow (eg. SR required for fixed levy in MCST)
- Characterized by transfer of technical risks from Client to ESCO.
- Biggest challenge is the measurement & performance verification as the protocols used (eg. IPMVP) may not be comfortable to the Customer
- Hence, critical to define baselines, setting the system boundary and conditions as changes in energy consumption affects targeted savings.
- Under off-balance sheet financing (non-appropriation financing), funder holds title to equipment during term of contract.
- ESCO usually provides performance guarantee with buffer.

Introduction

Energy Performance Contracting (EPC) Models

(A) Guaranteed Savings

(B) Shared Savings

(C) Variation of the above

(D) BREEF Scheme

E2green Pte Ltd
BCA ACADEMY

(A) Guaranteed Savings (GESP)

- ESCO assumes entire performance & design risk
- Customer (Owner) finances the project
- Performance related to level of energy saved

- **Pros**
  - P1: FI better equipped to assess and handle customers' credit risk
  - P2: Supports growth of ESCOs, esp. newly-established ones

- **Cons**
  - C1: Difficult to introduce EPC in developing markets as customers required to assume investment repayment risk
  - C2: If customer borrows, debt appears on balance sheet

(B) Shared Savings (SESP)

- ESCO assumes both performance & credit risk
- ESCO finances project (partially/fully)
- Takes lion share of savings for defined period

- **Pros**

P1: Good model in developing markets - customers assume no financial risk

P2: Usually off balance sheet of customers.

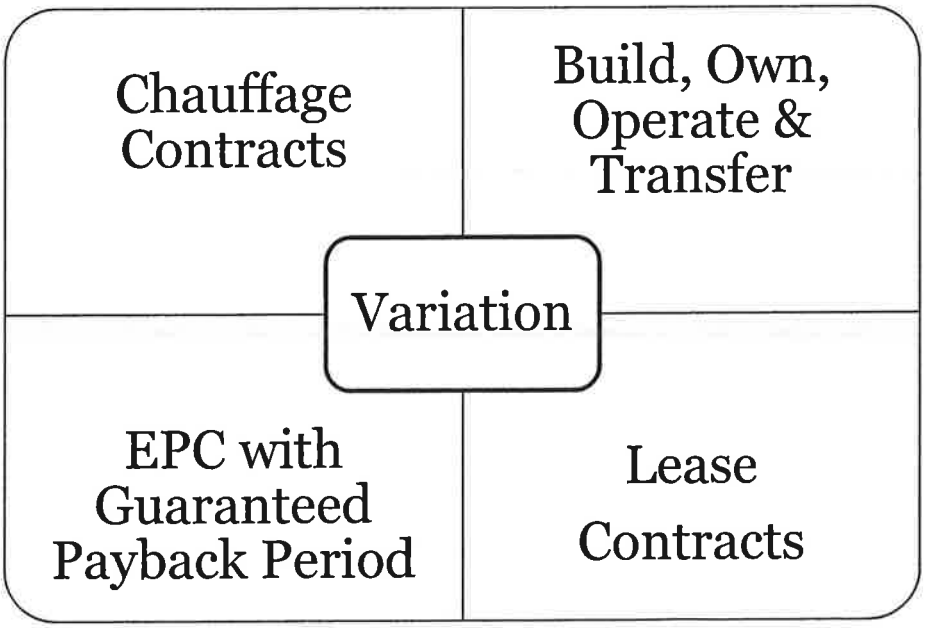
- **Cons**

C1: If the customer is "under-water", revenue stream from project stops and puts ESCO at risk.

C2: Over-gearing/leveraging puts smaller ESCO into indebtedness and limits the number of projects it can undertake.

E2green Pte Ltd
BCA ACADEMY

(C) Variation of Above



(C) Variation of Above

- C1: Chauffage Contracts
- C2: Build, Own, Operate & Transfer (BOOT)
- C3: EPC with Guaranteed Payback Period
- C4: Lease Contracts

E2green Pte Ltd
BCA ACADEMY

(C1) Chauffage Contracts

- Extreme form of energy management out-sourcing.

  Eg. ESCO takes over the retrofitting of the entire chilled water plant and sells the owner chilled water at $0.40 per ton-hr
- ESCO provides agreed level of energy service for lower than the current bill
- Element of shared savings in addition to the guaranteed savings element
- Contract typically beyond 15 years and ESCO responsible for entire O&M over the span of the contract
- Useful when customer wants to outsource facility and investment

(C2) Build, Own, Operate & Transfer (BOOT)

- ESCO designs, builds, finances, owns and operates the plant for a defined period and transfers ownership across to the Client
- May require a Special Purpose Vehicle (SPV) for the project
- Customer enters into a long-term contract with the SPV and are charged for the service delivered
- Service charge includes capital & operating costs recovery and project profit

E2green Pte Ltd
BCA ACADEMY

(C3) EPC with Guaranteed Payback Period (GPP)

- ESCO designs, builds, finances and maintains retrofitted plant up till the date when the "Principal Sum" and "Interest Costs" are fully repaid and will be time bound up till a prescribed Guaranteed Payback Period (GPP)
- ESCO collects all or a percentage of the future cash flows (savings) which are used for the repayment of the "Principal Sum" and "Interests Cost"
- The "Principal Sum" is usually the project cost plus the profit and when this sum plus the "Interest Cost" have been fully repaid, the plant is transferred in its entirety to the Client
- If the "Principal Sum" and "Interest Costs" could not be recovered by the GPP, the collection stops and the plant is still transferred to the Customer at a nominal sum, say $1. This is off-balance sheet financing.

(C4) LEASE CONTRACTS

- Attractive alternative to borrowing
- Commonly used for industrial equipment
- Capital Lease - Customer owns the equipment and benefits from associate tax benefits
- Operating Lease - ESCO owns the equipment and rents it to Client for a fixed monthly fee. This is off-balance sheet financing for the Client

E2green Pte Ltd
BCA ACADEMY

(B) BREEF Scheme

- Help owners overcome high upfront cost of energy efficient retrofits
- Designed for building owners and energy services companies (ESCO)
- Permanent accurate instrumentation for each of the plant sub-systems

Max quantum per loan	:	S$5M and up to 80% of Project Cost
Loan Tenure	:	18 months -– 8 years
Chiller Plant Performance	:	Better than 0.75 kW/ton

Economic Analysis Tools of the Energy Efficient Projects (EEP)

E2green Pte Ltd
BCA ACADEMY

Financial Analysis Tools for EEP

- Time Value of Money - Future & Present Value
- Use of FVIF and PVIF Table
- Ordinary Annuity vs Annuity Due
- Use of FVIFA and PVIFA Tables
- Payback Period & Return on Investment (ROI)
- Capital Budgeting Techniques
  Net Present Value (NPV) and Internal Rate of Return (IRR)

Time Value of Money - Future & Present Value

- A dollar received today is worth more than it's worth in the future
- Time value of money is one of the most important financial concepts
- Future value of a single cashflow

$FV_n = PV*(1+k)^n$

Where
FV_n is the future value at end of period n
PV is the present value
K is the interest rate per time period and
n is the number of time periods (yearly, quarterly, monthly, etc)

- Use FVIF table for single cashflows

- Example

  $10K @4% p.a. for 2 years compounded semi-annually

  Ans: PV = $10K k=4%/2,
  n=4 (periods) and from $FVIF_{2\%,4}$, FV_2 = $10K x 1.0824 = $10,824

E2green Pte Ltd
BCA ACADEMY

Time Value of Money – Future & Present Value

- Present Value is the current value of future cashflows and the process of finding the present value is referred to as discounting (discount rate) and is the reverse of compounding
- Hence $PV = FV_n/(1+k)^n$ or $PV = FV_n \times PVIF_{k,n}$
- Use PVIF table for single cashflows

- Example

  An investment pays $100K at the end of 5 years. What is the maximum amount you should pay for this investment if your required rate of return is 5% p.a.?

  Ans: $PV = FV_5 \times PVIF_{5\%,5}$ = $100K x 0.7835 = $78,350

Ordinary Annuity & Annuity Due

- Ordinary Annuity are payments (PMT) at end of each period

- $\therefore$ (Future) FVA ordinary = PMT x $FVIFA_{k,n}$

Eg : What is the future value of a 3-year ordinary annuity of $10K@10% p.a?
Ans: FVA ordinary = \$10K x $FVIFA_{10\%,3}$ = \$10K x 3.31 =\$33,100

- $\therefore$ (Present) PVA ordinary = PMT x $PVIFA_{k,n}$

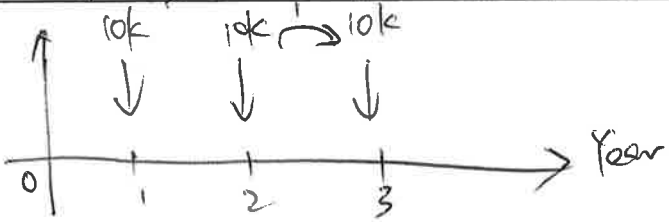
Eg : What is the present value of a 5-year ordinary annuity of $1K@4% p.a?
Ans: PVA ordinary = \$1K x $PFVIFA_{4\%,5}$ = \$1K x 4.4518 =\$4,452

BCA ACADEMY

Financial Analysis Tools for EEP

Table Illustrating Computation of FVA Ordinary

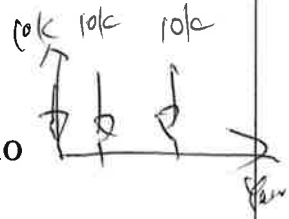
End of Year	Amount ($)	Years Compounded	FVIF	FV at Year End ($)
1	10000	2	1.21	12,100
2	10000	1	1.10	11,000
3	10000	0	1.00	10,000
				33,100



Ordinary Annuity & Annuity Due

- Annuity Due are payments (PMT) at beginning of each period

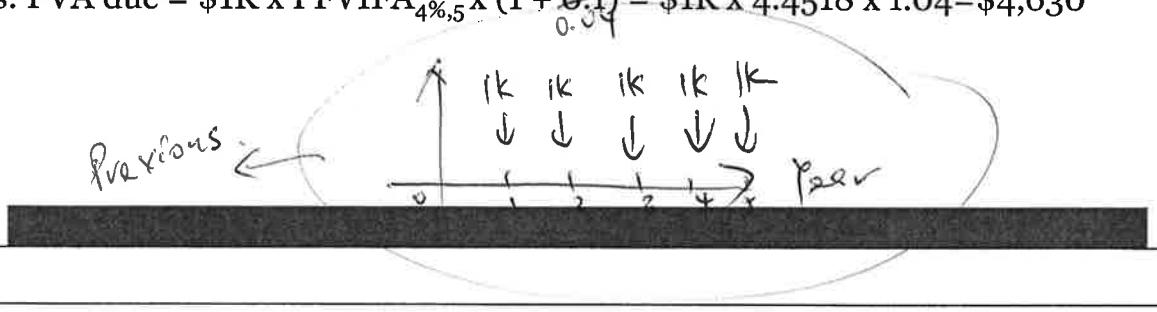
- ∴ (Future) FVA due = PMT x $FVIFA_{k,n}$ x (1+k)



Eg : What is the future value of a 3-year annuity due of $10K@10% p.a?
Ans: FVA due = \$10K x $FVIFA_{10\%,3}$ x (1 + 0.1) = \$10K x 3.31 x 1.1 =\$36,410

- ∴ (Present) PVA due = PMT x $PVIFA_{k,n}$ x (1+k)

Eg : What is the present value of a 5-year annuity due of \$1K@4% p.a?
Ans: PVA due = \$1K x $PFVIFA_{4\%,5}$ x (1 + 0.1) = \$1K x 4.4518 x 1.04=\$4,630



BCA ACADEMY

Financial Analysis Tools for EEP

Table Illustrating Computation of FVA Due

End of Year	Amount ($)	Years Compounded	FVIF	FV at Year End ($)
1	10000	3	1.331	13,310
2	10000	2	1.210	12,100
3	10000	1	1.100	11,000
				36,410

Simple Payback & Return on Investment

- Payback Period refers to the exact amount of time required for the owner to recover its initial investment and if we do not take into consideration the time value of money, then it is known as Simple Payback Period.
- Return on Investment (ROI) is the ratio of money gained or lost on an investment relative to the amount invested.
- Capital budgeting techniques utilizes ROI, which is a family of financial measurements known as Net Present Value (NPV), Internal Rate of Return (IRR) and Payback
- NPV, IRR and Payback are 3 key measures commonly used to appraise investment decisions

BCA ACADEMY

Net Present Value (NPV)

- Represents the amount of value added as a result of implementing a proposed project (eg. EEP)
- Considers time value of money by discounting all future cashflows to the present and compare it against the initial investment.
- A positive NPV → investment would add value and a negative NPV → investment would subtract value.
- Hence **NPV = ∑ PV of a project's cash inflows – Initial Investment**
- Eg: Initial Investment (Yr 0): $18,000; Discount Rate@10%

	Yr 1	Yr 2	Yr 3	Yr 4
Cashflow	$3,900	$4,700	$5,500	$6,300
PVIF@10%	0.9091	0.8264	0.7513	0.6830
PV of cashflow	$3,627	$3,884	$4,132	$4,303

∴ NPV = $(3,627+3,884+4,132+4,303) – $18,000 = –$2,054 (negative)

Simple Payback

- Using the example for NPV, simple payback would be 3+ years as the cashflow (without taking into time value of money) is $(3,900 + 4,700 + 5,500) = $ 14,100 in 3 years and $20,400 in 4 years.
- If the maximum acceptable payback period is 3 years, then the project would be rejected.

E2green Pte Ltd
BCA ACADEMY

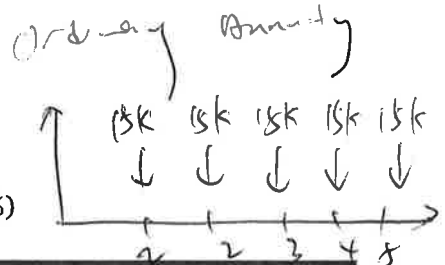
Internal Rate of Return (IRR)

- It is the discount rate that equates the present value of cash inflows with the initial investment. It uses a trial and error approach to find the IRR (or Excel)
- It is the implied minimum rate of return (k%) of the project where, PV (inflows) = Initial Investment. That is, NPV = 0
- Decision criteria : If IRR > cost of capital, accept project; If IRR< cost of capital, reject project
- The higher the IRR, the more attractive is the project
- In a given stream of equal cash flows, PVA = PMT x $PVIFA_{k\%,n}$, find unknown k
- Example

  Building owner is evaluating an EEP which requires an initial investment of $55,500 and is expected to generate savings of $15,000 for 5 years. Owner requires a minimum rate of return of 6%. Calculate IRR and advise if EEP is OK.

Ans:
PV (inflows) – Initial Investment = 0
$15,000 x $PVIFA_{k\%,5}$ - $55,000 = 0
$\therefore PVIFA_{IRR,5} = 55,000/15,000 = 3.7$

From PVIFA table, IRR=11% and EEP should be accepted (>6%)



Verification of Savings for EEP

- **Efficiency Valuation Organisation (EVO) publishes the International Performance Measurement and Verification Protocol (IPMVP®)**

- Documents common terms and methods to evaluate performance of EEP
- Provides methods for determining savings based either on whole facility or ECM
- Specifies the contents of a Measurement & Verification Plan (M&V)
- Applies to a wide variety of facilities – both existing and new buildings and systems

- **Benefits of using IPMVP**

- Substantiation of payments for performance
- Lower transaction costs in EPC
- International credibility for energy savings reports
- Supports resource efficiency and environmental objectives and enhance credibility of
- Reported results, especially when submitting to authorities like BCA and NEA

BCA ACADEMY

Measurement & Verification in Energy Efficient Projects (EEP)

Measurement & Verification (M&V) for EEP (Chilled Water Plant)

- M&V is the process of using accurate instrumentation to reliably determine "actual" savings for an EEP. Simply put, savings are determined by comparing consumption and or performance before and after implementation of the EEP, with appropriate adjustments for changes in conditions

- M&V activities consists of some or all of the following:

- Sensor and metering installation, calibration and maintenance
- Data gathering (raw data) & converted (Excel format) for calculation & presentation
- Development of an acceptable computation method and acceptable estimates
- Operational System efficiency (OSE) computation based on the as-measured data
- Generation of reports (eg. OSE), QA and third party verification of reports

- M&V activities consists of some or all of the following:

- Accurate, Complete, Conservative, Consistent , Relevant & Transparent

E2green Pte Ltd
BCA ACADEMY

Measurement & Verification (M&V) for EEP (Chilled Water Plant)

- With regards to M&V, Green Mark for New Non-Residential Buildings V4 (effective 1 Dec 2010) and for existing Non-Residential Buildings V3 (effective 26 Jul 2012) calls for :

- Provision of permanent instrumentation for measuring thermal load and energy use

- Purpose is to evaluate the operating system efficiency (OSE) of the plant, water-cooled or air-cooled

- Installed instrumentation must be able to calculate the resultant plant efficiency (kW/RT) to within 5% of its true value

- Heat Balance substantiating test in accordance with ASHRAE Guide 22 and AHRI 550/590

- In formulating the EPC, it is important to understand the requirements, appreciate the common pitfalls, measurement uncertainties and calibration requirements, and recognize what I takes before it can be accepted by the Authorities (BCA) for Green Mark certification

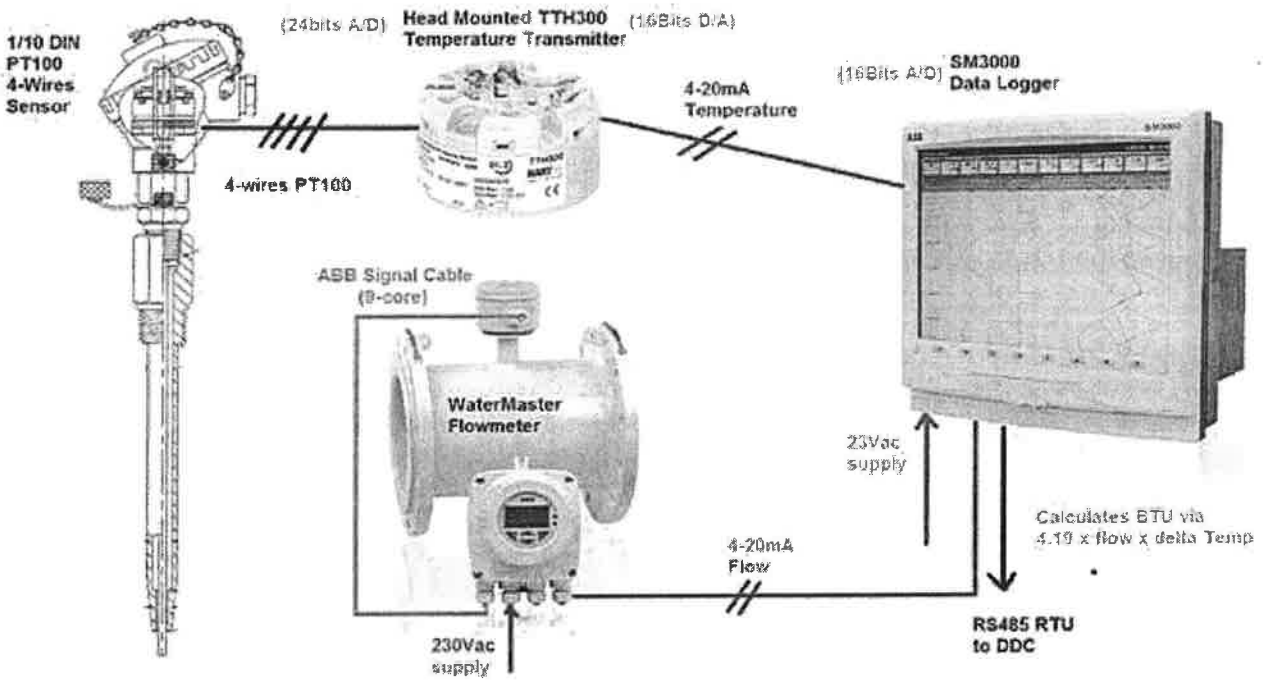
Measurement & Verification (M&V) for EEP (Chilled Water Plant)

- With regards to M&V, Green Mark for New Non-Residential Buildings V4 (effective 1 Dec 2010) and for existing Non-Residential Buildings V3 (effective 26 Jul 2012) calls for :

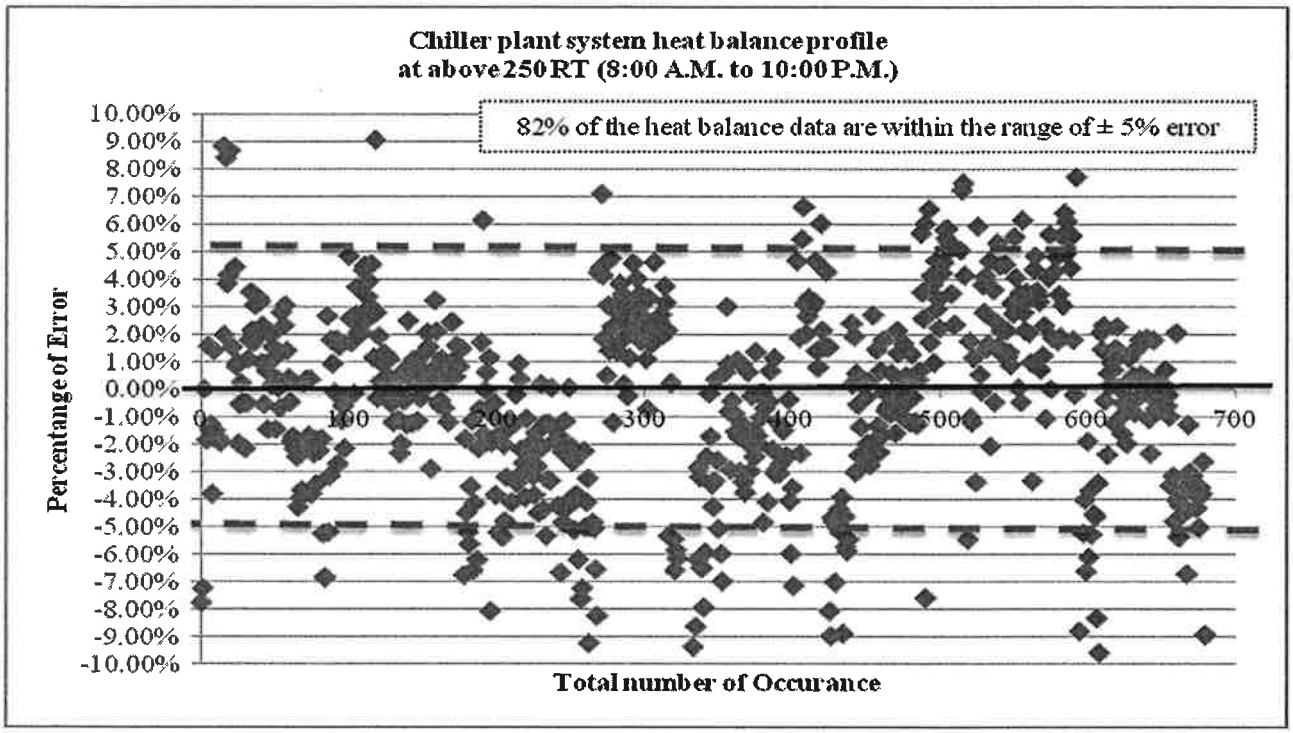
- Dedicated meters for Chiller, CHWP, CWP and CLT Sub-System
- Data Acquisition : A/D converter minimum resolution of 16-bit
- Data Logging interval : 1-minute sampling
- Flow meters : Ultrasonic or full bore magnetic type (± 1% over measurement range)
- Power Meter : ANSI C12.1 - 2008 Class 1 (± 1% over measurement range)
- Temperature sensors (Thermistors, RTDs) to be located and installed per manufacturer's recommendation (±0.05^{0}C over operating range)
- Two spare thermo-wells at both sides of the sensor

BCA ACADEMY

Permanent Instrumentation (M&V)



Heat Balance Substantiating Test



BCA ACADEMY

Verification of Savings for EEP

- **International** Performance Measurement and Verification Protocol (IPMVP®) provides 4 options to determine actual savings

Option A : Retrofit Isolation (Key Parameter Measurement)
Option B : Retrofit Isolation (All Parameter Measurement – kWh used)
Option C : Whole Facility Savings
Option D : Calibrated Simulation Savings (Predicts Energy Pattern)

- **Basis for Adjustments**

- Routine
- Non-Routine

Verification of Savings for EEP

Routine Adjustments

- Expected to change routinely such as weather or production volume
- Adjustment methodology can be simple such as a constant value or complex, based on a linear or non-linear function correlating the adjustment to several independent variables

Non-Routine Adjustments

- Refers to energy-governing factors which do not usually change (known as static factors), such as facility size, design and operation of installed equipment, number of production shifts, type of occupancy, etc.

- Examples include:
  - Changes in the space to be heated or air-conditioned
  - Changes in occupancy type such as change of use from office to a Food & Beverage outlet
  - Change in IEQ requirements: illumination, operative temperature, ventilation rate
  - Change in operating schedule, such as changes in Mall operating hours
  - Change in RETV/ETTV due to change in façade materials, insulation, air tightness

E2green Pte Ltd
BCA ACADEMY

Verification of Savings for EEP

Option A : Retrofit Isolation (Key Parameter Measurement)

- Savings are determined by field measurement of the key performance parameter(s)
- Frequency of measurement from short-term to continual monitoring
- Parameters not selected for field measurement are estimated; based on historical data, manufacturer's specifications or engineering judgment
- Savings are calculated from difference between calculation of baseline and reporting period energy consumption
- Routine and non-routine adjustments may be required

Example of application:

A lighting retrofit where the power drawn is the key performance parameter that is measured periodically. The operating hours of the lighting in question is based on the operating schedules

Verification of Savings for EEP

Option B : Retrofit Isolation (All Parameter Measurement)

- Savings are determined by field measurement of the key performance parameter(s)
- Frequency of measurement from short-term to continual monitoring
- Savings are calculated from difference between calculation of baseline and reporting period energy consumption
- Routine and non-routine adjustments may be required

Example of application:

Variable frequency drives and controls to an induction motor to vary flowrate of a pump. Power consumption is monitored say, for a week and is then taken as the baseline. The power consumption is then measured over the reporting period to track the savings realised.

E2green Pte Ltd
BCA ACADEMY

Verification of Savings for EEP

Option C : Whole Facility

- Savings are determined by measuring energy use at the whole facility or common area consumption in the case of strata-titled divided buildings (MCST)
- Continuous measurements of the entire facility's energy consumption over reporting period
- Savings are calculated from difference between the baseline and the actual (usually month to month comparison) reporting period energy consumption
- Routine and non-routine adjustments are usually required
- Common area consumption from the monthly utility bill usually computed from : <Master sub-meter minus $\sum$ (consumption of all tenants in the facility)>

Example of application:

The common area consumption of a strata-divided commercial building where the baseline has been mutually agreed based on the last 12 months average consumption

Example

In the case of an EEP involving the central chilled water plant of a commercial retail cum office building, a substantial part of the common area consumption may be from the air-conditioning system and changes in the consumption for others (lighting, power, etc may be assumed to be relatively constant unless adjustments are required)

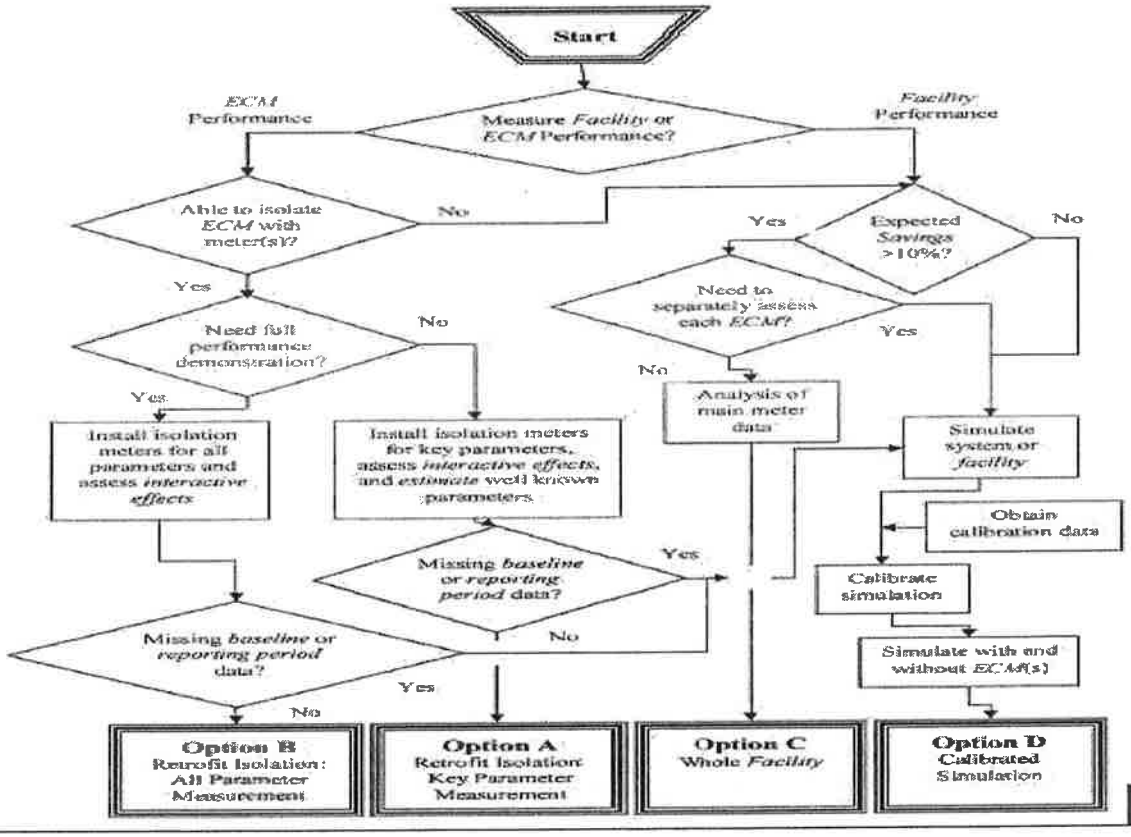
Verification of Savings for EEP

Option D : Calibrated Simulation

- Savings are determined through simulation of the energy use of the whole or sub-facility
- Simulation routines required to model actual performance within facility
- Savings are calculated from energy use simulation, calibrated with hourly or monthly utility billing data
- Multifaceted EEP affecting many systems in a building/facility but where no meter existed in the baseline period
- Energy use measurements after installation of the meters are then used to calibrate the simulations
- Baseline energy use, using the calibrated simulation, is compared to a simulation of reporting period energy use

BCA ACADEMY

Option Selection Process (Extract from IPMPV)



Option Selection Table (Extract from IPMPV)

ECM Project Characteristic	Suggested Option			
	A	B	C	D
Need to assess *ECMs* individually	X	X		X
Need to assess only total facility performance			X	X
Expected *savings* less than 10% of utility meter	X	X		X
Significance of some *energy* driving variables is unclear		X	X	X
Interactive effects of ECM are significant or unmeasurable			X	X
Many future changes expected within *measurement boundary*	X			X
Long term performance assessment needed	X		X	
Baseline data not available				X
Non-technical persons must understand reports	X	X	X	
Metering skill available	X	X		
Computer simulation skill available				X
Experience reading utility bills and performing regression analysis available			X	

E2green Pte Ltd
BCA ACADEMY

Legal Documentation of Performance Contract

Legal Aspects of EPC (Key Areas To Be Covered)

- Definitions & Interpretation
- Conditions Precedent
- Term
- Energy Savings & Project Cost Recovery
- Post-Retrofit Maintenance
- Calculation & Payment to Charges
- Client's Obligations
- Failure or Temporary Discontinuance of EEP
- Metering Equipment
- Client's Installation
- Assignment
- Termination
- Indemnities
- Ownership of EEP's Equipment
- Insurance, Waiver, Entire Agreement
- Notices
- Severability
- Access to Site
- Baseline & Reference Points
- Confidentiality
- Contracts (Rights of Third Parties) (Cap53B)
- Governing Law & Jurisdiction
- Appendices

E2green Pte Ltd
BCA ACADEMY

Legal Aspects of EPC (Key Areas To Be Covered)

Definitions & Interpretation

Objectives is to ensure that the words and expressions used have the same meaning throughout the Agreement

For Example:

"Business Cost" may be defined as "The reimbursement of the business cost to the ESCO payable on the Total Project Cost outstanding and which will be based on the Business Times Prime Rate + x % on the outstanding Total Project Costs at any one time calculated on a monthly basis on the 1st of every calendar month until full repayment of the Total Project Cost.

This Business Cost shall be paid monthly to the ESCO by the Client and shall be over and above the monthly savings that is to be used towards the repayment of the outstanding Total Project Cost owing to the ESCO"

Legal Aspects of EPC (Key Areas To Be Covered)

Conditions Precedent

The obligations of both the ESCO and the Client from the date of the Agreement are usually conditional upon a number of conditions precedent, such as:

- The Client is to provide the ESCO with all necessary access to the site and access to all documents and information as required by the ESCO to implement the EEP
- ESCO to ensure that the EEP will not affect, within reasonable means, the operation of the facility and that the implementation will be in accordance with the scope and specification of the works spelt out in the Agreement
- Compliance by each party, as far as practicable and within reason, to the Project Timeline as spelt out in the Agreement
- Provided that the Client is not in breach of any terms in the Agreement, the ESCO warrants and undertakes that it shall not, on or before the Testing &Commissioning Date, terminate the Agreement
- At all times from the date of commencement of the Agreement and up to the end of the Guaranteed Payback Period, and so long as the Client dutifully makes payments in accordance with Clause XXX herein, the Client shall have physical possession and an unqualified right and lien over the ESCO's equipment.

E2green Pte Ltd
BCA ACADEMY

Legal Aspects of EPC (Key Areas To Be Covered)

Term

Objective is to spell out the duration and to document under what circumstances that the term could be effected, such as:

- The Agreement shall come into effect on the date of the Agreement and shall continue in full force and effect until upon recovery of the Total Project Cost and business costs outstanding by the ESCO or upon expiry of the Guaranteed Payback Period, whichever is earlier.
- The Guaranteed Payback Period shall be extended by the aggregate of any periods during which Force Majeure circumstances exist, provided such aggregate period does not exceed three (3) months.

Legal Aspects of EPC (Key Areas To Be Covered)

Energy Savings & Project Cost Recovery

Objective is to spell out the considerations such as ESCO agreeing to funding the project cost, Client agreeing to compensate the ESCO on the business cost, each party agreeing to compute the monthly savings based on a fixed tariff rate, etc. such as :

- The ESCO shall recover the Total Project Cost based on the actual savings derived and the collection shall cease once the Total Project Cost has been fully recovered or up t the Guaranteed Payback Period, whichever is earlier.
- For the first 12 months following the commencement of the Guaranteed Payback Period, the ESCO shall be entitled to claim a fixed amount of $XXX per month irrespective of the savings based on the agreed tariff of $XXX/kWh. The ESCO will thereafter submit a yearly re-conciliation Savings report based on the actual computed savings using the derivation described in Appendix X, from which an adjustment shall be made. The fixed amount to be claimed by the ESCO for the next 12 months shall be based on the actual average monthly savings over the preceding 12 months.
- In the event there is a dispute on the actual computed savings for any one year, the Parties shall refer the dispute to the Singapore Institute of Surveyors and Valuers to appoint an independent Quantity Surveyor to calculate the actual computed savings for that year. The decision of the said independent Quantity Surveyor shall be final and binding on the Parties save for any manifest error or fraud.

E2green Pte Ltd
BCA ACADEMY
Legal Aspects of EPC (Key Areas To Be Covered)

Post-Retrofit Maintenance

As the EEP is implemented as an EPC, it is only logical that the maintenance be undertaken by the ESCO (EPC Contractor) over the period of the Agreement. Examples of clauses to be included:

- Maintenance of the "EEP Equipment" shall be undertaken by the ESCO from the commencement of the Guaranteed Payback Period up till the date of transfer, care and custody to the Client in such manner and frequency as the ESCO deems fit at its absolute discretion. The amount payable for such maintenance by the Client to the ESCO shall be based on shall be based on that quoted by the successful suppliers/service providers for such maintenance for the respective sub-systems making up the "EEP Equipment"
- Any additional costs and expenses to the ESCO, including the costs related to investigation of the cause of any defect or malfunction, where the need for repair, maintenance or the provision of spares or replacement components is caused by any of the following circumstances shall be the responsibility of and be borne by the Client:
  - works external to the EEP
  - relocation of EEP Equipment not made by or on behalf of the ESCO
  - any error and/or omission and/or negligence and/or wilful default of the Client, its employees, agents or contractors
  - any modification, adjustment or repair to the EEP equipment made by the Client without the written consent of the ESC)

Legal Aspects of EPC (Key Areas To Be Covered)

Calculation & Payment to Charges

Objective is to spell out how the ESCO will be paid, treatment with regards to delayed payment, whether partial lump sum repayments are allowed, etc. The following are examples of clauses to be included:

- ESCO shall be entitled to invoice the Client monthly in arrears, 100% of the calculated Savings each month in accordance with Appendix XYZ.
- The Client shall pay each invoice in full within thirty (30) days of the date of the invoice. If any invoice remains unpaid thereafter, the ESCO shall (in addition to other remedies) be entitled to charge delayed payment costs on the amount unpaid on and from that date at the annual rate of x%.
- The Client shall be entitled to make partial repayments on top of the monthly repayments on the outstanding amount due to the ESCO without incurring any penalty payment

E2green Pte Ltd
BCA ACADEMY

Legal Aspects of EPC (Key Areas To Be Covered)

Client's Obligations

Objective is to spell out what the Client is expected to do, especially over the Guaranteed Payback Period otherwise, it may jeopardize the ESCO in its quest to recover the Total Project Cost from the actual savings realized. Examples of relevant clauses include:

- The Client must act and take appropriate and necessary steps to protect the EEP Equipment from damage or loss but shall endeavor in all emergencies where reasonable, to contact the ESCO before taking any pre-emptive actions on their own to protect the said Equipment.
- The Client must not allow any person other than the ESCO or its authorized representatives to adjust, maintain, repair, replace, move, remove, alter or interfere with the EEP Equipment save in an emergency and upon so doing shall forthwith notify the ESCO in writing.
- The Client shall ensure that the ESCO and its employees and others authorized by the ESCO have uninterrupted, clear, easy free and quick access to the Site and access to supply of electricity, water and gas free of charge, for the purpose of inspecting, repairing, examining and maintaining the EEP Equipment.

Legal Aspects of EPC (Key Areas To Be Covered)

Failure or Temporary Discontinuance of EEP

Objective is to put in a proviso to allow the ESCO to temporarily discontinue the implementation of the EEP. The rationale for such clauses include:

- Prevent danger or damage
- Enable the ESCO at mutually agreed times to inspect, test, alter, maintain, repair, renew, replace or add to all or any part of the equipment and system under the EEP

E2green Pte Ltd
BCA ACADEMY

Legal Aspects of EPC (Key Areas To Be Covered)

Metering Equipment

Objective is to put in a proviso to allow the ESCO to access to the Site to verify readings by the utility companies as well as to verify the accuracy of the permanent instrumentation at site. Over time, the sensors and meters that were installed may have drifted and the savings achieved may not correlate with what is deduced form the bills.

- The ESCO may take a reading of the supply of electricity at any time.
- The ESCO shall be entitled at its own expense at any time to install its own metering equipment (temporarily) which are calibrated by a laboratory approved or accredited by the Singapore Accreditation Council.

Legal Aspects of EPC (Key Areas To Be Covered)

Client's Installation

Objective is to spell out in the Agreement in no uncertain terms the obligations of the Client with regards to the EEP system and equipment during and after completion of the EEP.

For example,

- The ESCO shall be liable for the EEP system and equipment and its interface with the existing plant facilities during the installation phase. The ESCO shall not be responsible to insure the operations, adequacy, safety or other characteristics after the completion of the EEP.
- The Client shall at all times keep their apparatus and controls forming part of their Facilities adequately and properly serviced, and set or adjusted to the satisfaction of the ESCO in such a manner that it will not affect or endanger the systems and equipment of the EEP.
- If the ESCO discovers or have pointed out any defect in any part of the existing Facilities that would likely to adversely affect or endanger the EEP systems and equipment or the ESCO's employees, agents, contractors or others acting on its authority, the Client shall forthwith disconnect such part of the Facilities from the EEP systems and equipment until such defect shall have been remedied to the reasonable satisfaction of the ESCO.

E2green Pte Ltd
BCA ACADEMY
Legal Aspects of EPC (Key Areas To Be Covered)

Assignment

It is very important to differentiate between an assignment as opposed to a novation of a contract. In the case of an assignment, of rights under a contract, it is normally restricted to the benefit of the contract. For example, if the ESCO irrevocably assigns to a third party all their rights, title and interests in respect of any and all monies payable ant to become payable to the ESCO by the Client, it has still not transfer the "burden" of the contract to the sub-contractor. Wishes to transfer BOTH the benefits and the burden of the contract to a third party, this would require that it be done by way of a novation.

A typical clause would be:

- The ESCO may with the consent of the Client, assign or otherwise transfer the Contract in whole or in part or any benefit or interest in the Contract to any other person by written notice to the Client PROVIDED THAT such consent by the Client shall not be unreasonably withheld and subject to the Client's satisfaction of the competence and/or capabilities and/or credit standing of the assignee and subject always that such assignment shall only take place at least 1 year after the Defects Liability.

Legal Aspects of EPC (Key Areas To Be Covered)

Termination

This is one of the most important contract clauses as termination provisos can be lifesavers for parties that find themselves in a raw deal. They can easily be the bane of a contractual relationship if not carefully drafted.

In particular for EPC, it is critical to put in clauses that will protect the recovery of the investment as the payback period may be many years down the road.

One such proviso would be:

- Without prejudice to any antecedent rights or remedies, either Party may terminate the contract forthwith on written notice if the Client goes into liquidation (save for the purposes of re-construction or amalgamation) including but not limited to as a result of:
  - An enbloc sale
  - Force Majeure for an aggregate period exceeding 3 months
  - Compulsory Land Acquisition
  - Full Redemption of the un-recovered part of the Total Project Cost, including all outstanding business costs

E2green Pte Ltd
BCA ACADEMY
Legal Aspects of EPC (Key Areas To Be Covered)

Indemnities

The purpose is to indemnify each party against losses, costs, damages and expenses arising from the loss of or damage to any physical property caused by the negligent, malicious or reckless acts and/or omissions of the other party (ESCO or Client), its servants, agents or independent contractors.

Ownership of EEP Equipment

If the EPC is structured such that the funding is to be off balance sheet, then the Client must acknowledge that the EEP equipment belongs to the ESCO who shall have the legal and beneficial interest and right to such equipment whether or not attached to the Site and shall not form part of the Site and shall be free of any lien, charge or encumbrance created or to be created over the Site or part of it. Upon completion of the Guaranteed Payback Period or upon repayment of the Total Project Cost and all outstanding business costs, whichever is earlier, the EEP Equipment shall thereafter be transferred to and belong to the Client.

Legal Aspects of EPC (Key Areas To Be Covered)

Insurance

Each party shall for its respective interests effect and maintain various insurance policies during the construction period and throughout the term of the contractors.

Waiver

Proviso put in to ensure that any delay on the part of either contracting party (ESCO or Client) in enforcing any term or condition, right or remedy in respect of the Contract would not be deemed as a waiver of any right or remedy.

Entire Agreement

Purpose is to specify clearly that the Contract (Agreement) to be signed constitutes the entire agreement between the parties and supersedes all previous agreements and understandings between the parties in that respect, and each of the Parties acknowledges and confirms that it does not enter into the Agreement in reliance on any representation or warranty or other undertaking not fully reflected in the terms of the Agreement. Of course, both parties may enter into a Supplemental Agreement subsequently and may supersede some of the terms and conditions but must be executed jointly in writing.

E2green Pte Ltd
BCA ACADEMY

Legal Aspects of EPC (Key Areas To Be Covered)

Notices

The form of notices required, such as to be in writing and shall be given or sent by hand, telex, facsimile transmission or first class post or recorded delivery to the address of the party concerned.

Severability

Clause included to the effect that if there is any provision(s) in the Agreement that is held by any Court or other competent Authority to be void or unenforceable in full or in part, then all other provisions of the Agreement [and the remainder of that said provision(s) shall remain in full force and effect.

Access to Site

Clause put in to ensure that ESCO is always granted access to the Site to perform and discharge its obligations under the Agreement during regular business hours or such other reasonable hours as may be requested by the ESCO from time to time.

Legal Aspects of EPC (Key Areas To Be Covered)

Baseline and Reference Point

If the the IPMVP option chosen is based on the whole facility approach, then an agreed baseline kWh (common area only in the case of MCST) could be documented in the Agreement based on the actual monthly utility bills over a 12-month period based on a particular reference year on an average, say over 3 years on a month to month basis.

The baseline report will give the baseline consumption measurements for both the reference year monthly electrical energy and water consumption, a summary of the measured indoor conditions for both the tenanted and common areas prior to implementation of the EEP (assuming chiller plant replacement) together with appendices on the graphical plots for:

a. Histogram of cooling load
b. Chiller system performance
c. Building cooling load
d. Chiller system power performance
e. Chilled water supply temperature
f. Chilled water return temperature
g. Chilled water flow rate
h. Condenser water supply temperature
i. Condenser water return temperature

E2green Pte Ltd
BCA ACADEMY

Legal Aspects of EPC (Key Areas To Be Covered)

Confidentiality

This clause ensures that both parties shall at all times during the continuance of the Agreement and after its termination, keep all information supplied to it by the other party (or any of its representative or employees) and all information it may otherwise become possessed or aware or with respect to the other Party's equipment or the business or financial affairs of the other Party strictly confidential. he form of notices required, such as to be in writing and shall be given or sent by hand, telex, facsimile transmission or first class post or recorded delivery to the address of the Party concerned.

Contracts (Rights of Third Parties) (Cap 53B)

This is to spell out clearly that a person who is not a party to the Agreement will not have ant rights under the Contracts (Right of Third Party)(Cap53B), to enforce any provision in the Agreement.

Legal Aspects of EPC (Key Areas To Be Covered)

Governing Law & Jurisdiction

If the Agreement is to be executed in Singapore, it may be prudent to include a clause to stipulate that it is to be governed by and interpreted in accordance with the laws of the Republic of Singapore and the Parties agree to the exclusive jurisdiction of the Singapore Courts.

Appendices

The Agreement may have many appendices, which together, for part of the Agreement that would be binding on the contracting parties, for example :

- Detailed scope of work making up the EEP
- Project Schedule
- Baseline Measurements
- Measurement & Verification Plan giving the basis for computation of energy savings, adopted baseline operating schedule, basis for adjustments to energy savings, the reference baseline to be used for all monthly savings, sample of savings calculations.

E2green Pte Ltd
BCA ACADEMY

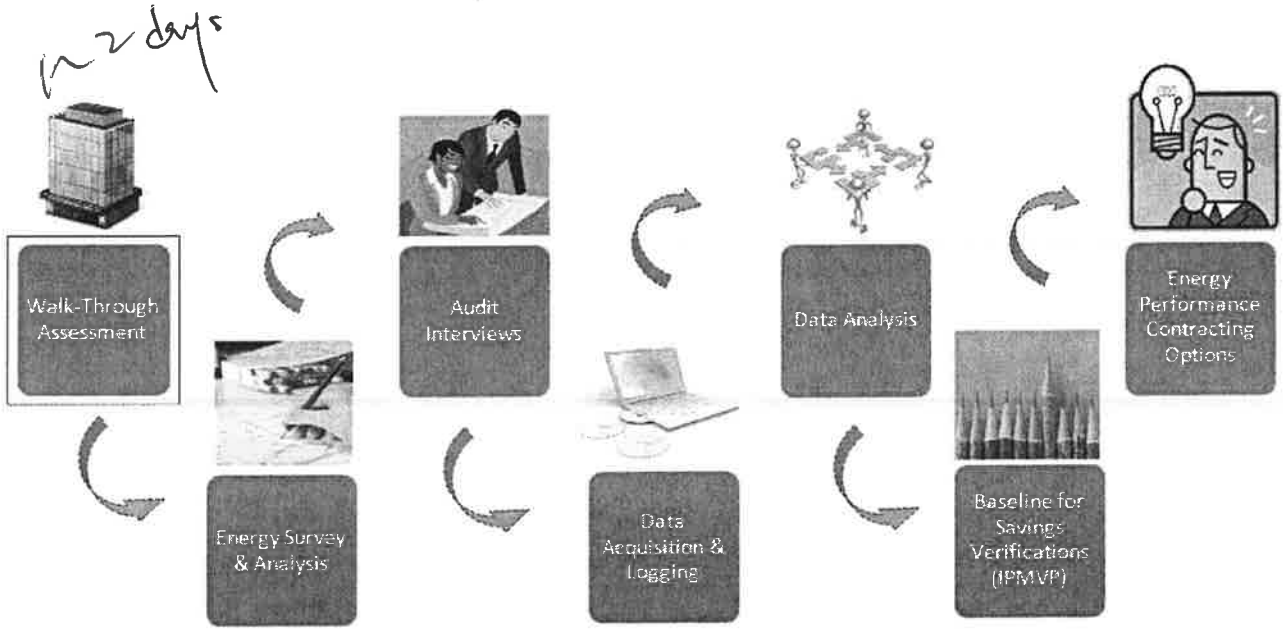
Development of an Performance Contracting Plan, Process & Implementation

Plan, Process & Implementation

- Detailed Energy Audit (to establish the baseline)
- Gap Analysis (for Green Mark) – Optional
- Design (Engineering & Energy Consultancy)
- Arrangement of financing (for funded solutions)
- Construction Management (Contracts & Project Management)
- Performance Verification (usually with BCA or NEA)
- M&V Plan for computation of savings – Penalties/Incentives
- Post-Retrofit O&M regime for sustainability of savings

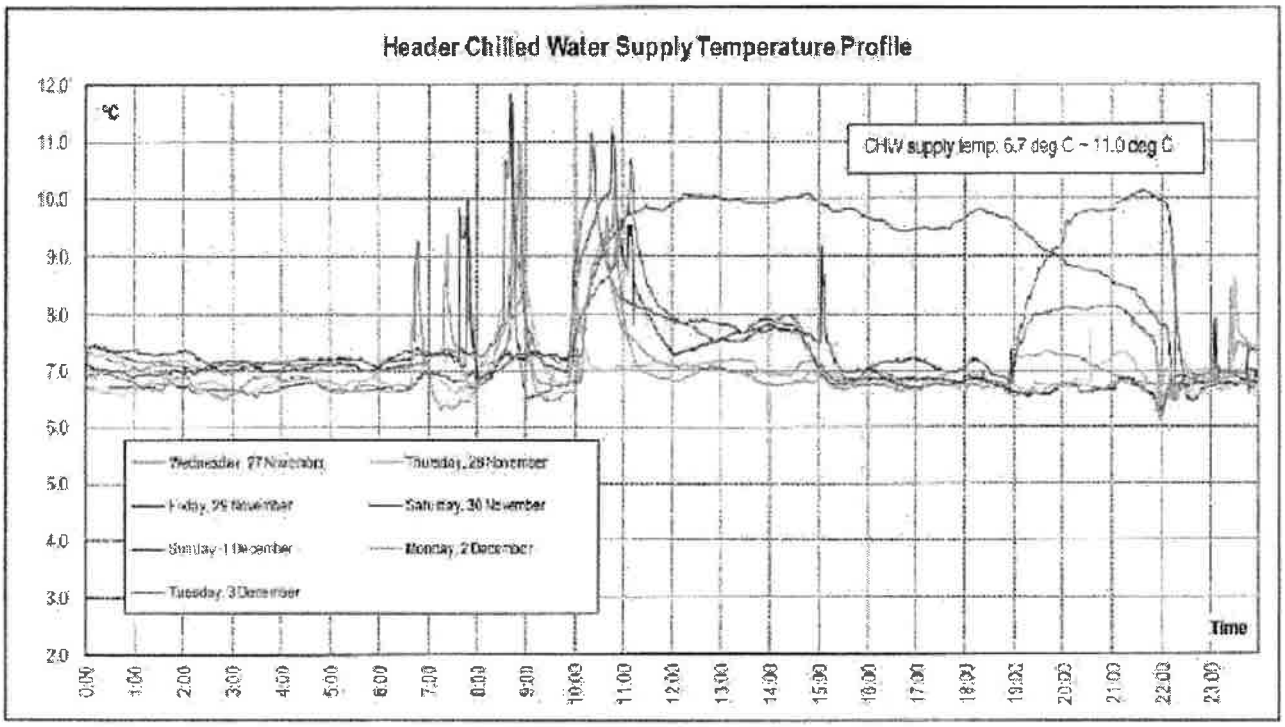
BCA ACADEMY

Plan, Process & Implementation



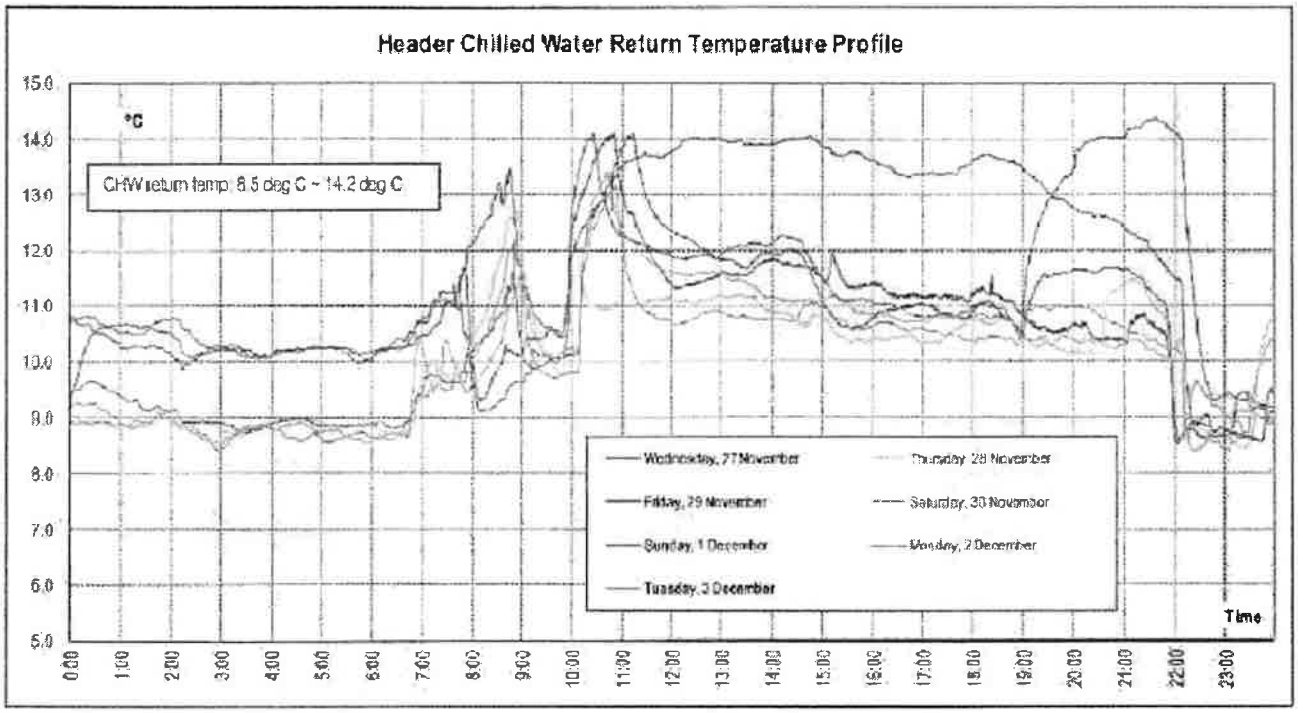
- *collection of building info*
- *utility bill analysis*
- *load factors, EEI*
- *comparison with benchmarks*
- *identification of potential ECMs*

Measurement & Performance Verification

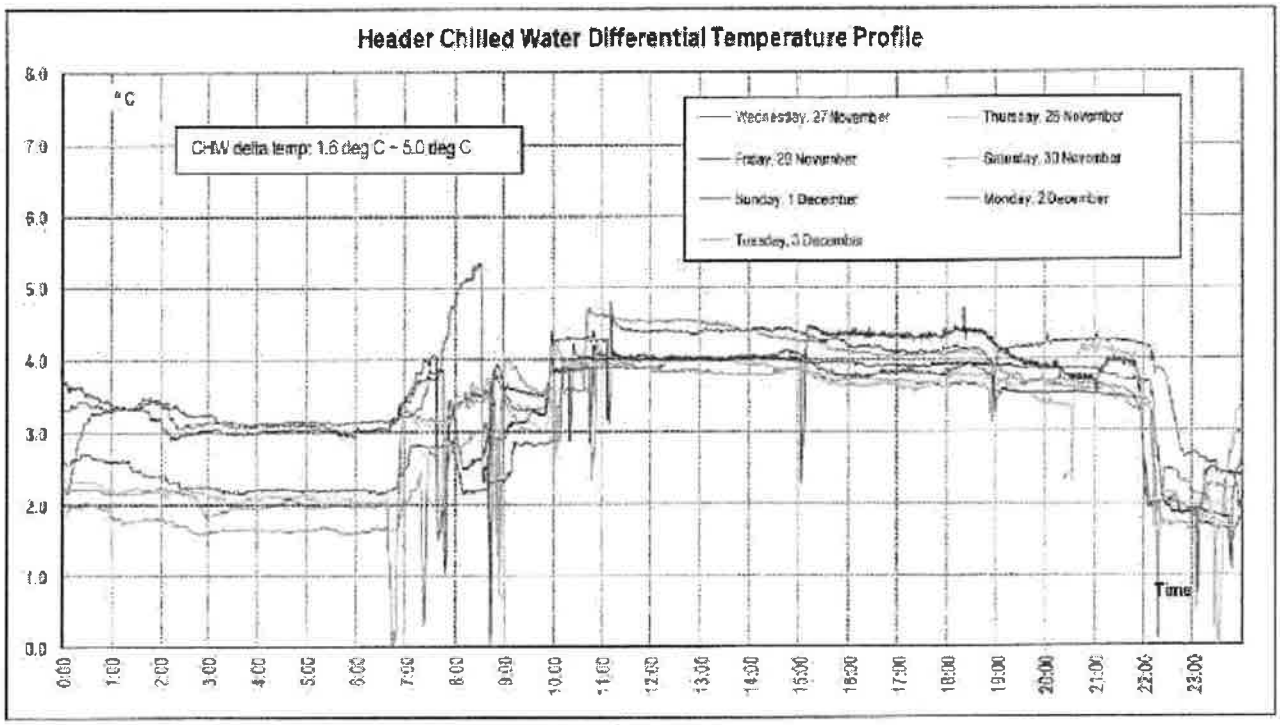


BCA ACADEMY

Measurement & Performance Verification



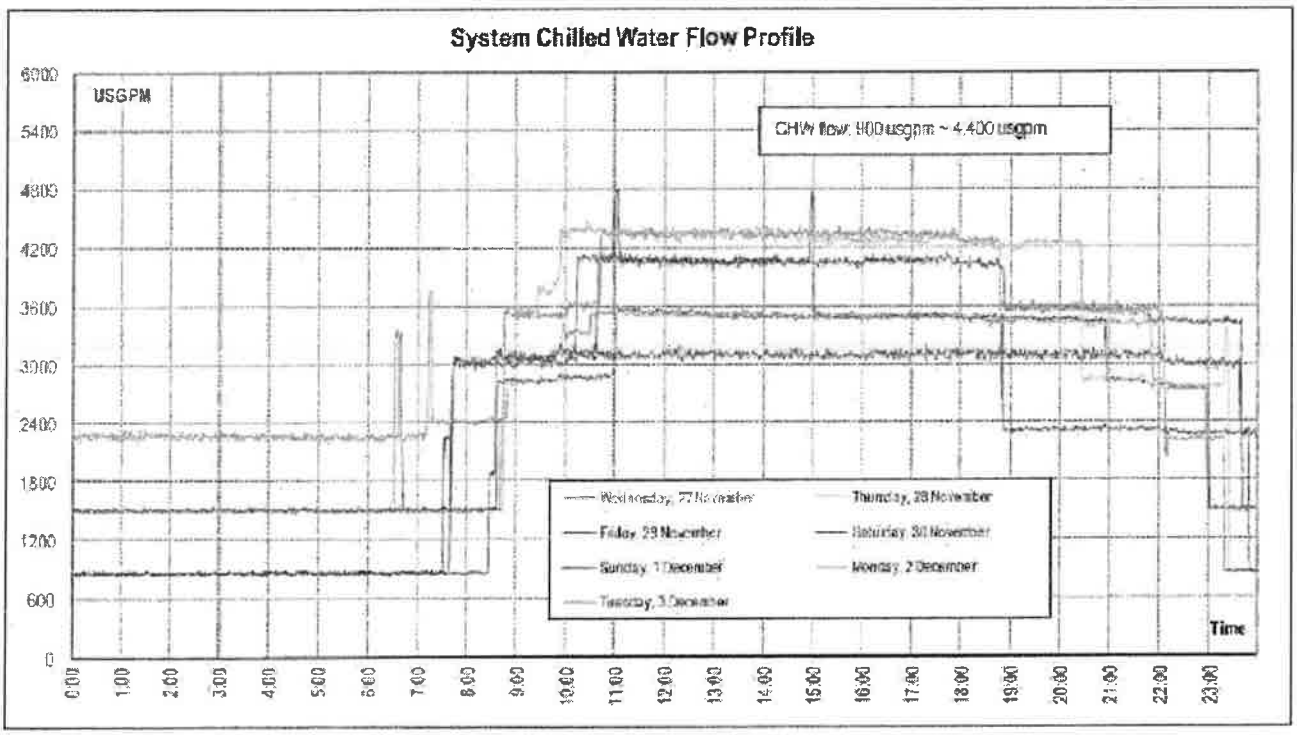
Measurement & Performance Verification



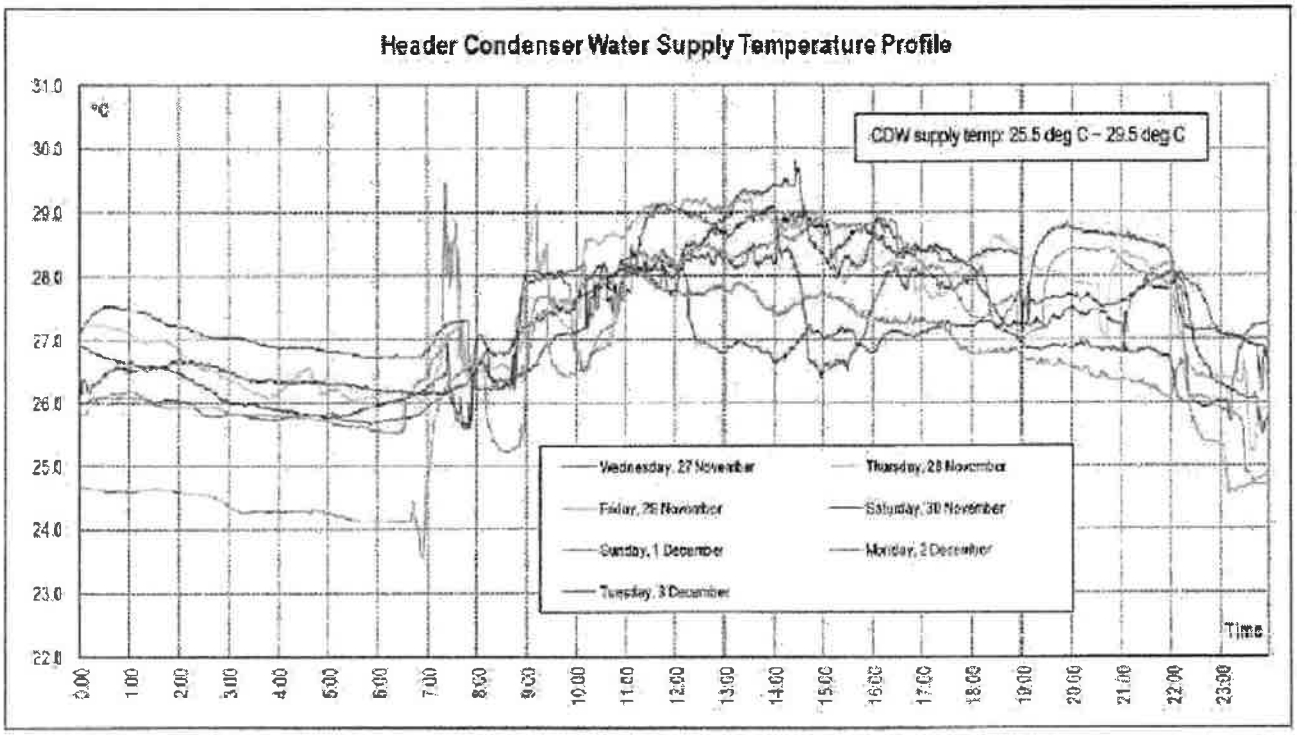
E2green Pte Ltd

BCA ACADEMY

Measurement & Performance Verification

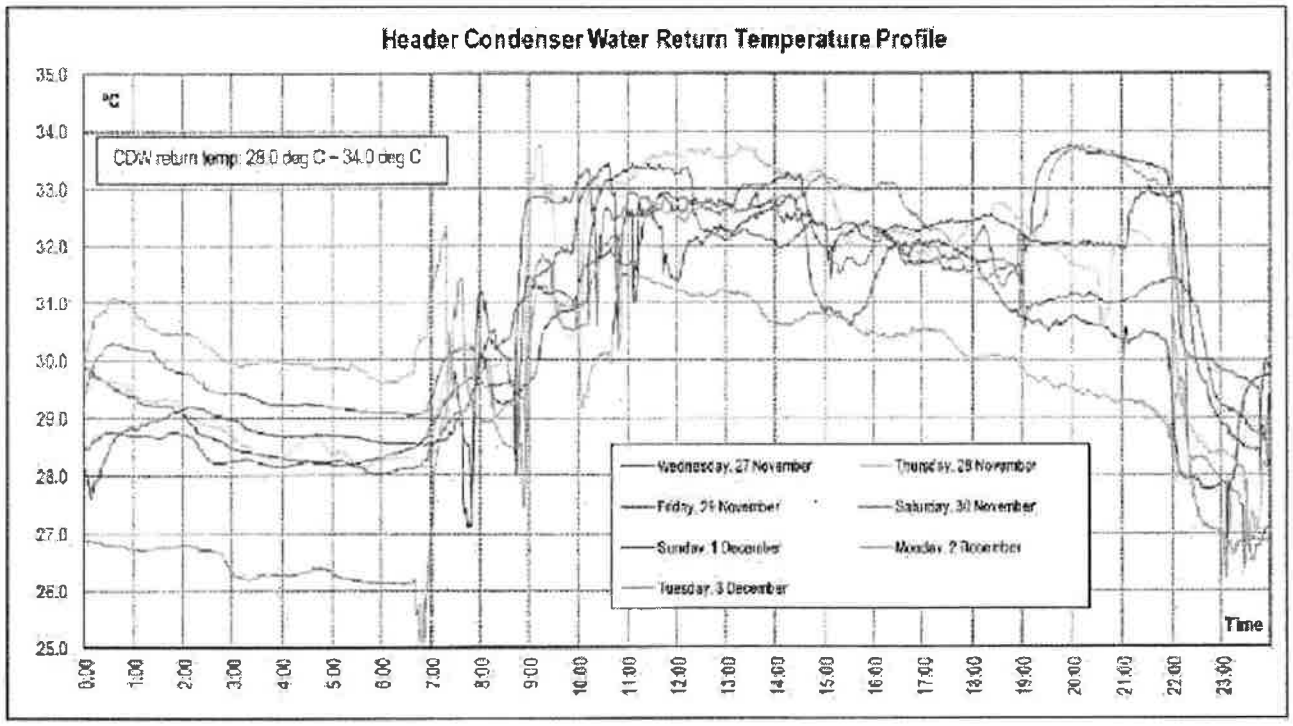


Measurement & Performance Verification

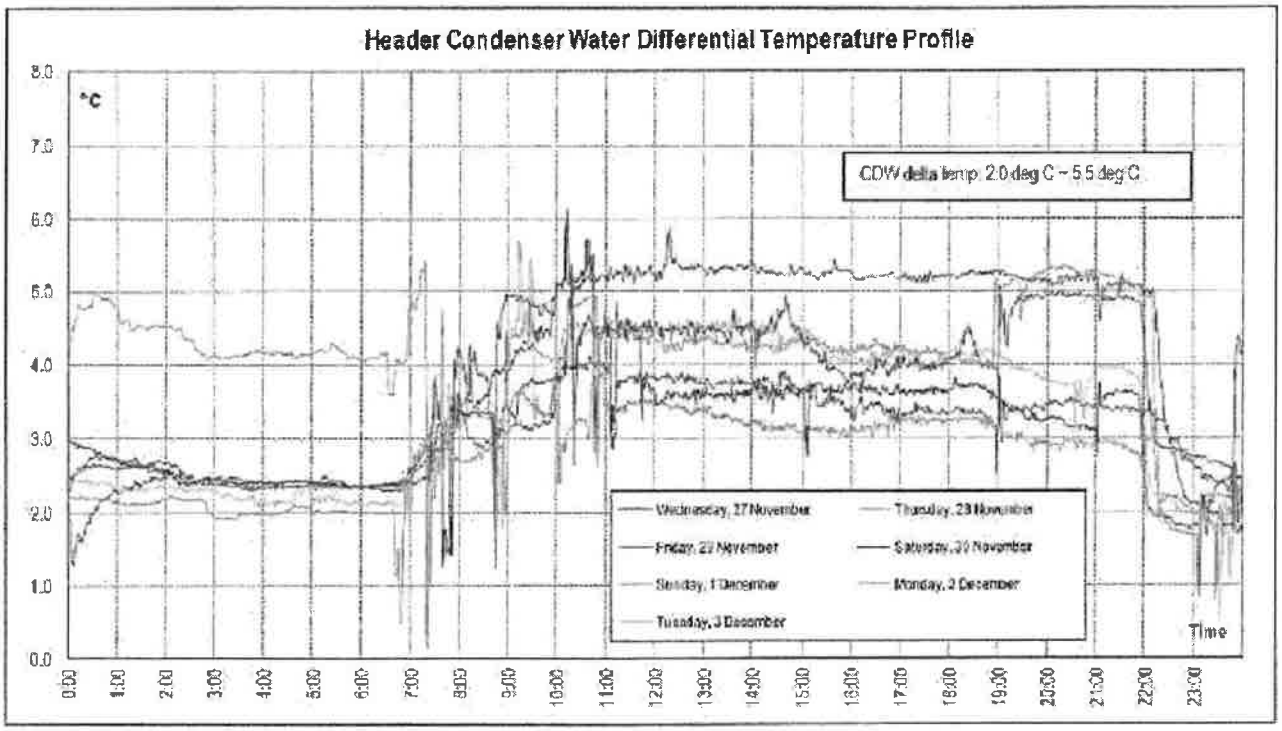


BCA ACADEMY

Measurement & Performance Verification

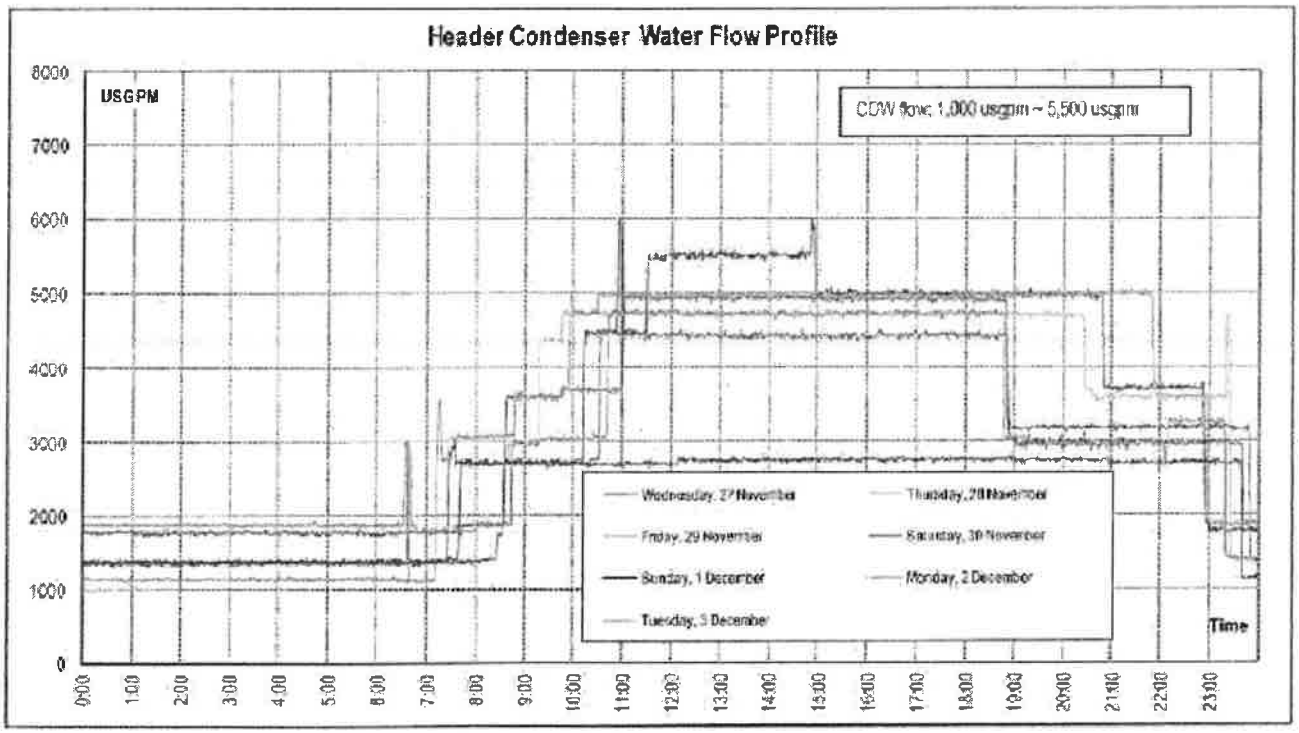


Measurement & Performance Verification

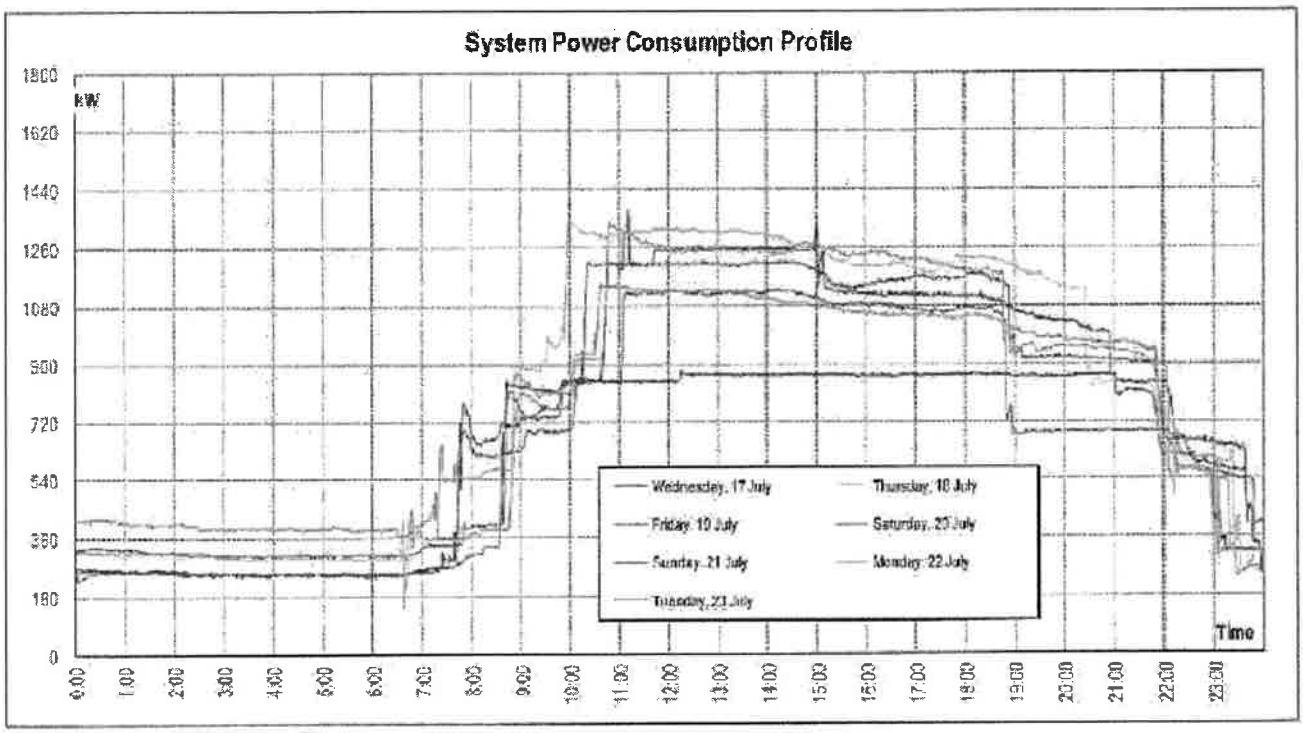


BCA ACADEMY

Measurement & Performance Verification

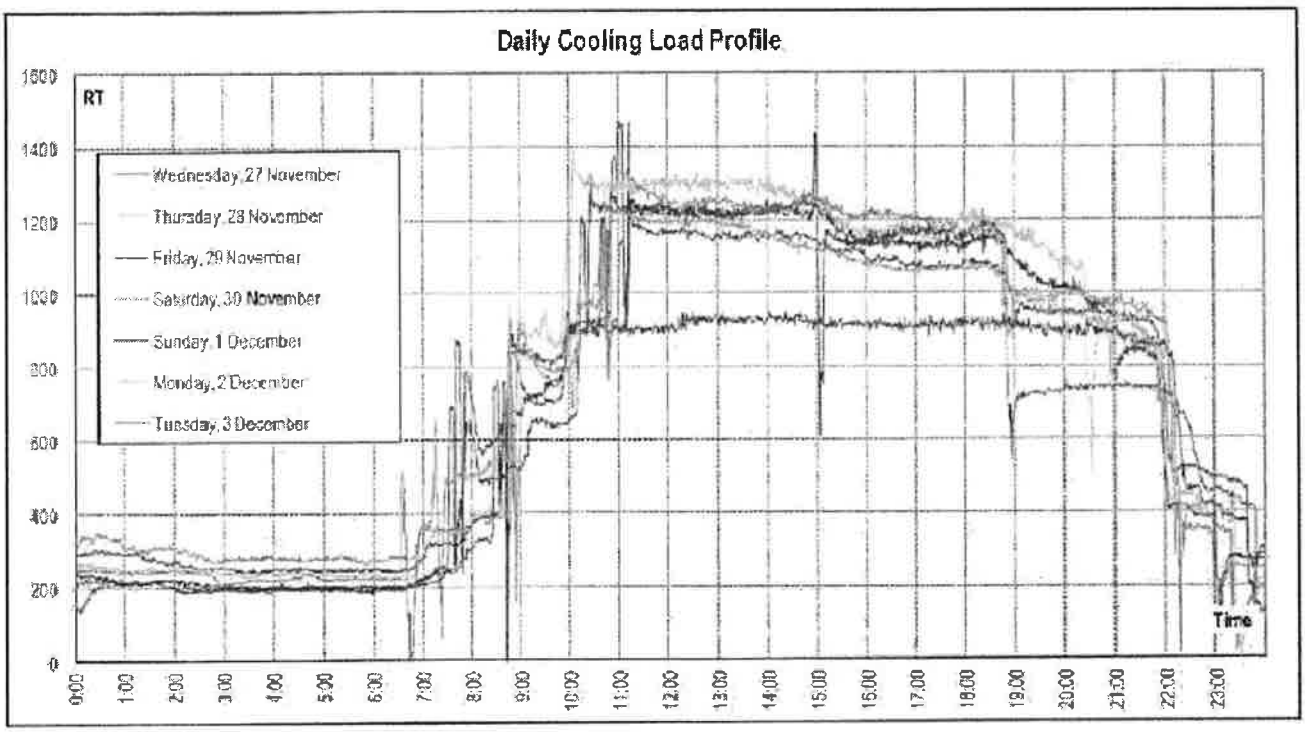


Measurement & Performance Verification

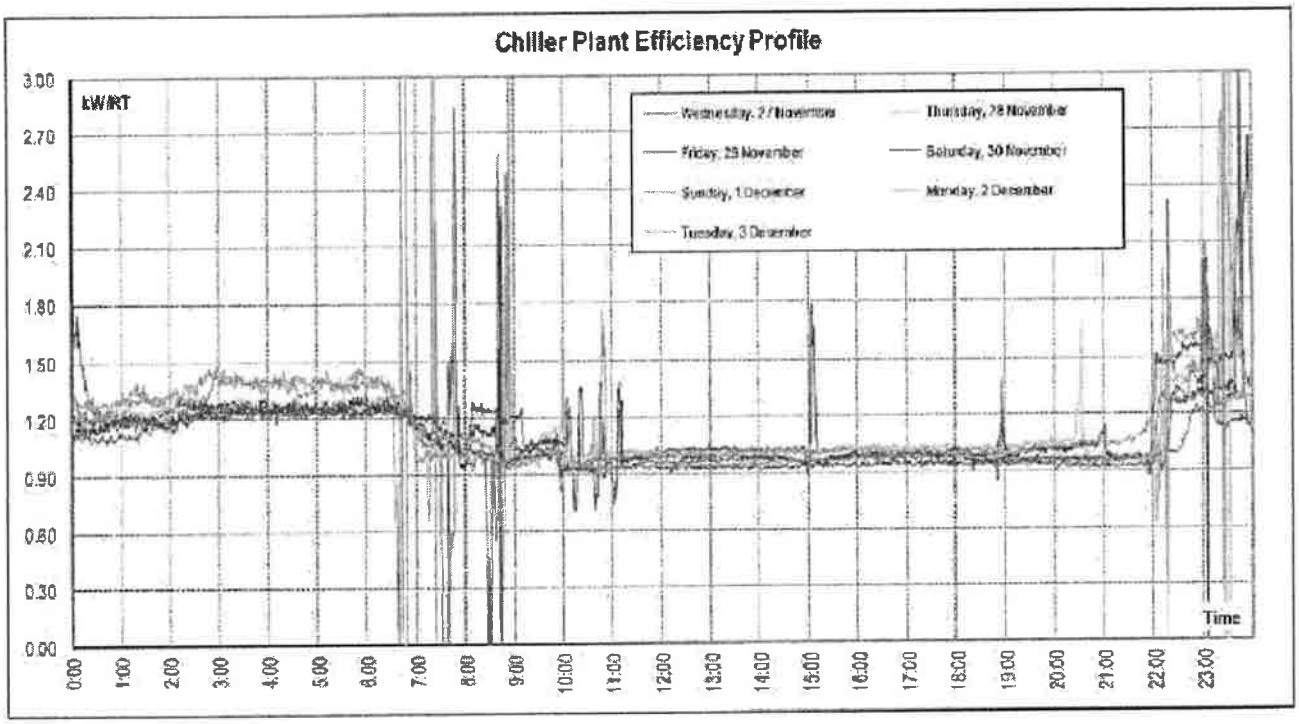


BCA ACADEMY

Measurement & Performance Verification



Measurement & Performance Verification



E2green Pte Ltd
BCA ACADEMY

Sustainability Audit & Green Mark Certification

Energy Efficiency	Water Efficiency	Green Features & Innovations	Environmental Protection	Indoor Environment Quality
• Building Envelope (ETTV) • Air-Conditioning & Ventilation System • Artificial Lighting • Lifts & Escalators • Energy Efficiency Features • Renewable Energy	• Water Efficient Fittings • Use of sub-metering & Leak Detection • Irrigation – Rainwater / Recycled Water • Cooling Towers – Newater & Min 6 COC	• Pneumatic Waste Collection System • Light shelves, cool paints, heat recovery devices • Auto Condenser Tube Cleaning • Non-Chemical Water Treatment • Thermal Energy Storage Cooling • Co & Tri-Generation Plants (sun pipes etc) • Renewable Energy (PV & BIPV)	• Sustainable Construction • Use of Greenery • Environmental Management Practice/Refrigerants • Public Transport Accessibility	• Thermal Comfort • Noise Level • Indoor Air Pollutants • High Frequency Ballasts

Plan, Process & Implementation

LIFE CYCLE COST COMPARISON BETWEEN OPERATING EXISITING .V. RETROFITTING WITH A NEW PLANT FOR BUILDING XYZ

Existing Plant						New Plant						Projected Savings to Client
Year#	First cost	Plant Operating Cost	Plant Repair Cost	Salvage Value	Total cost	Year #	First cost	Plant Operating Cost	Plant Repair Cost	Salvage Value	Total cost	
14		$1,109,156				1	$1,500,000	$859,156				
15		$1,109,156				2		$859,156				
16		$1,109,156				3		$859,156				
17		$1,109,156				4		$859,156				
18		$1,109,156				5		$859,156				
19		$1,109,156				6		$859,156				
20		$1,109,156				7		$859,156				
1	$2,200,000	$859,156				8		$859,156				
2		$859,156				9		$859,156				
3		$859,156				10		$859,156				
4		$859,156				11		$859,156				
5		$859,156				12		$859,156				
6		$859,156				13		$859,156				
7		$859,156				14		$859,156				
8		$859,156				15		$859,156				
9		$859,156				16		$859,156				
10		$859,156				17		$859,156				
11		$859,156				18		$859,156				
12		$859,156				19		$859,156				
13		$859,156				20		$859,156				
14		$859,156				**1	$770,000	$859,156				
15		$859,156				2		$859,156				
16		$859,156				3		$859,156				
17		$859,156				4		$859,156				
18		$859,156				5		$859,156				
19		$859,156				6		$859,156				
20		$859,156				7		$859,156				
	$2,200,000	$24,947,213			$27,147,213		$2,270,000	$23,197,212			$25,467,212	**$1,680,001**

E2green Pte Ltd

BCA ACADEMY

Plan, Process & Implementation

Assumptions made on previous table

- Operating cost under "existing plant" is the minimum as it would be higher in practice when it ages and with no energy management system (EMS).
- Operating cost under "new plant" is the maximum as minimum guaranteed savings under EPC is assumed to be $250,000 with EMS in place.
- Cost of replacement to be $2.2M and existing plant is 13 years in service.
- For "new plant", first cost is 2.2M less $700K (cash incentive from enhanced GMIS-EB based on 35% of Qualifying Cost)
- Economical lifespan of chiller plant taken to be 20 years
- A pro-rated additional cost of $770K ($2.2M/20 x 7) was added to year #21st of the "new plant" to illustrate the savings over a 27-year period.

Plan, Process & Implementation

Key findings based on 36 retrofitted buildings in Singapore

- On average, the Energy Usage Index improved by 16% annually or about 58 kWh/m²/year
- Chiller Plant Performance improved by at least 40%, down from above 1.1 kW/RT to 0.65 kW/RT
- The bulk of the savings is from the replacement or upgrading of the central chilled water plant
- Simple payback period for hotels - 4.1 years, retail building - 4.6 years and office buildings – 6.3 years
- In a joint research by NUS and 6 property advisories, its was found that retrofitted buildings costs 10% less to operate and translates into 2% increase in the valuation of the buildings

E2green Pte Ltd
BCA ACADEMY

Case Study

E2green Pte Ltd

BCA ACADEMY

Golden Mile Tower (EPC for Chiller Plants)

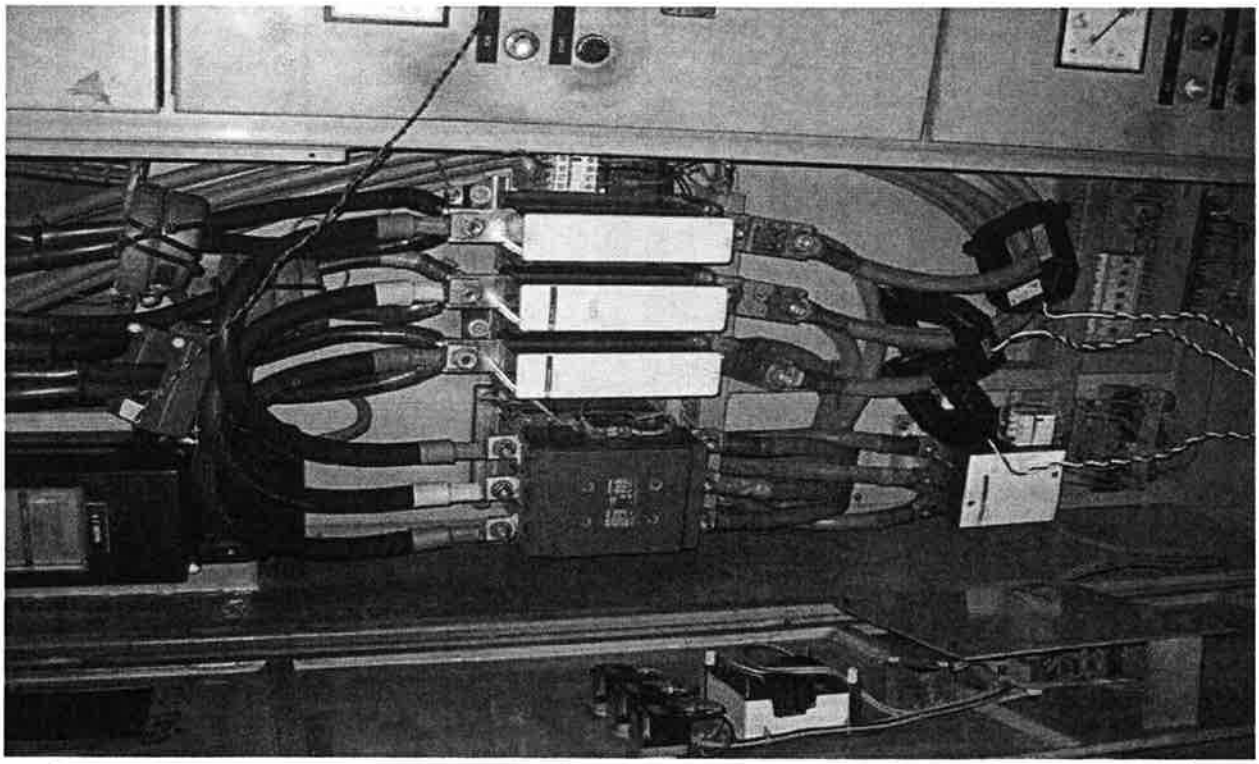
ECMs (from Detailed Energy Audit)

- General Lighting control & strategy
- Air-Conditioning
- Mechanical Ventilation
- Electrical Distribution
- Green Initiatives - recycling of AHU condensate, etc)
- Water Consumption Level
- Vertical Transportation System - Lifts & Escalators
- Indoor Environmental Quality**

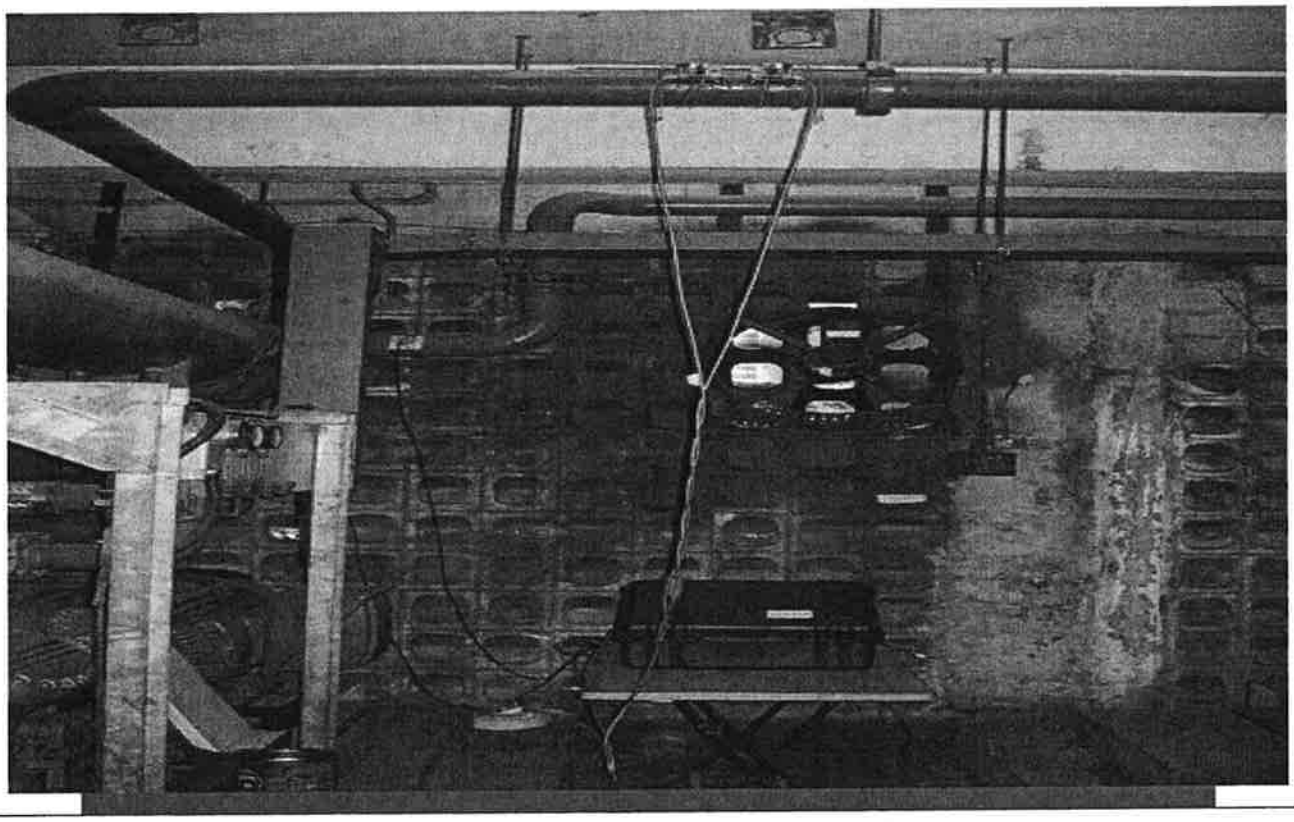
E2green Pte Ltd

BCA ACADEMY

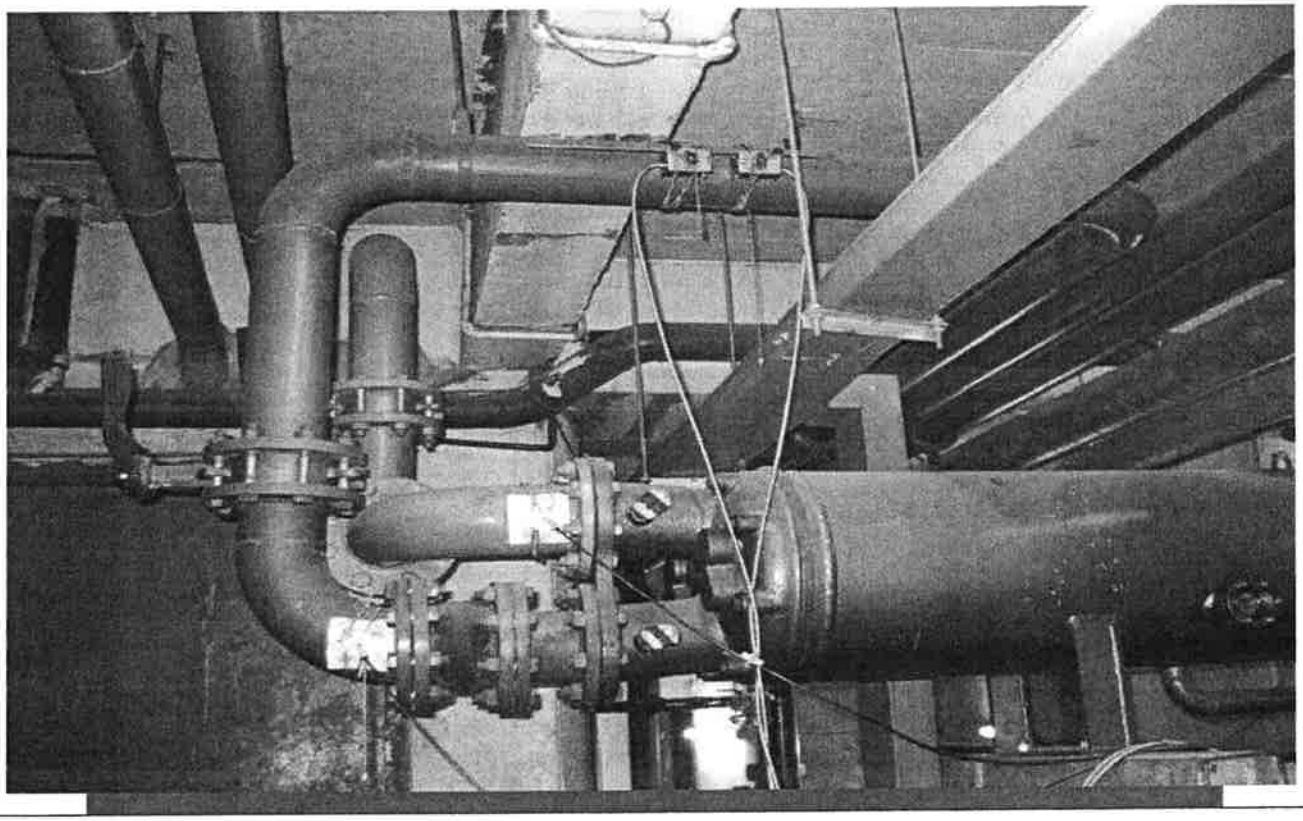
Golden Mile Tower (EPC for Chiller Plants)



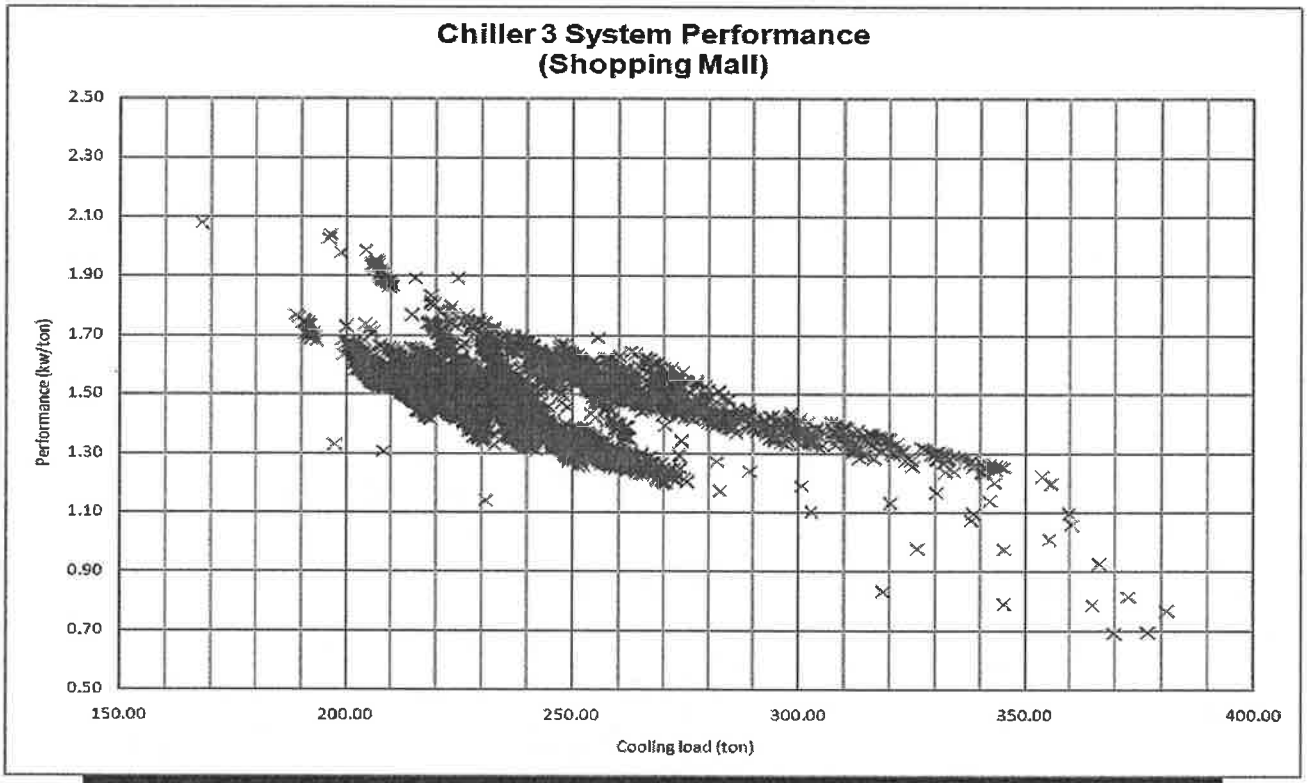
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd
BCA ACADEMY
Golden Mile Tower (EPC for Chiller Plants)

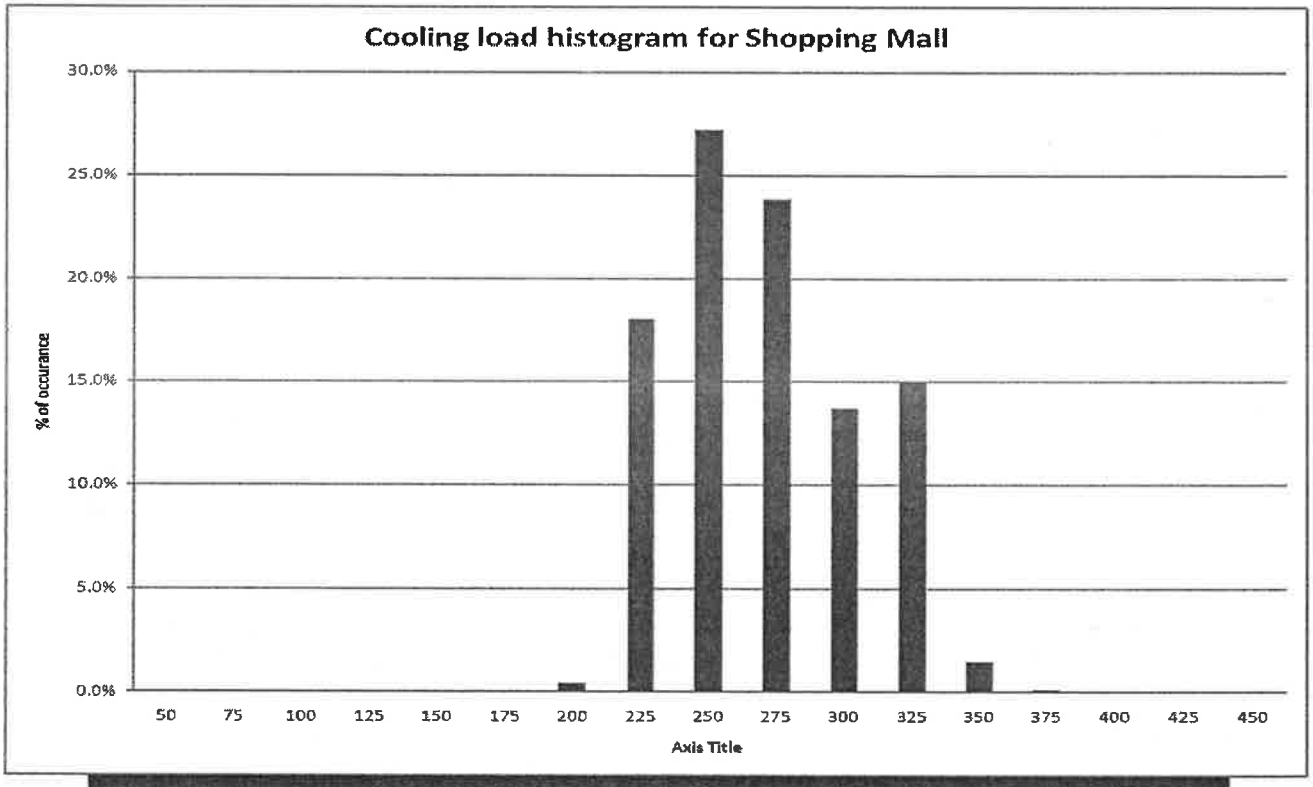


Golden Mile Tower (EPC for Chiller Plants)

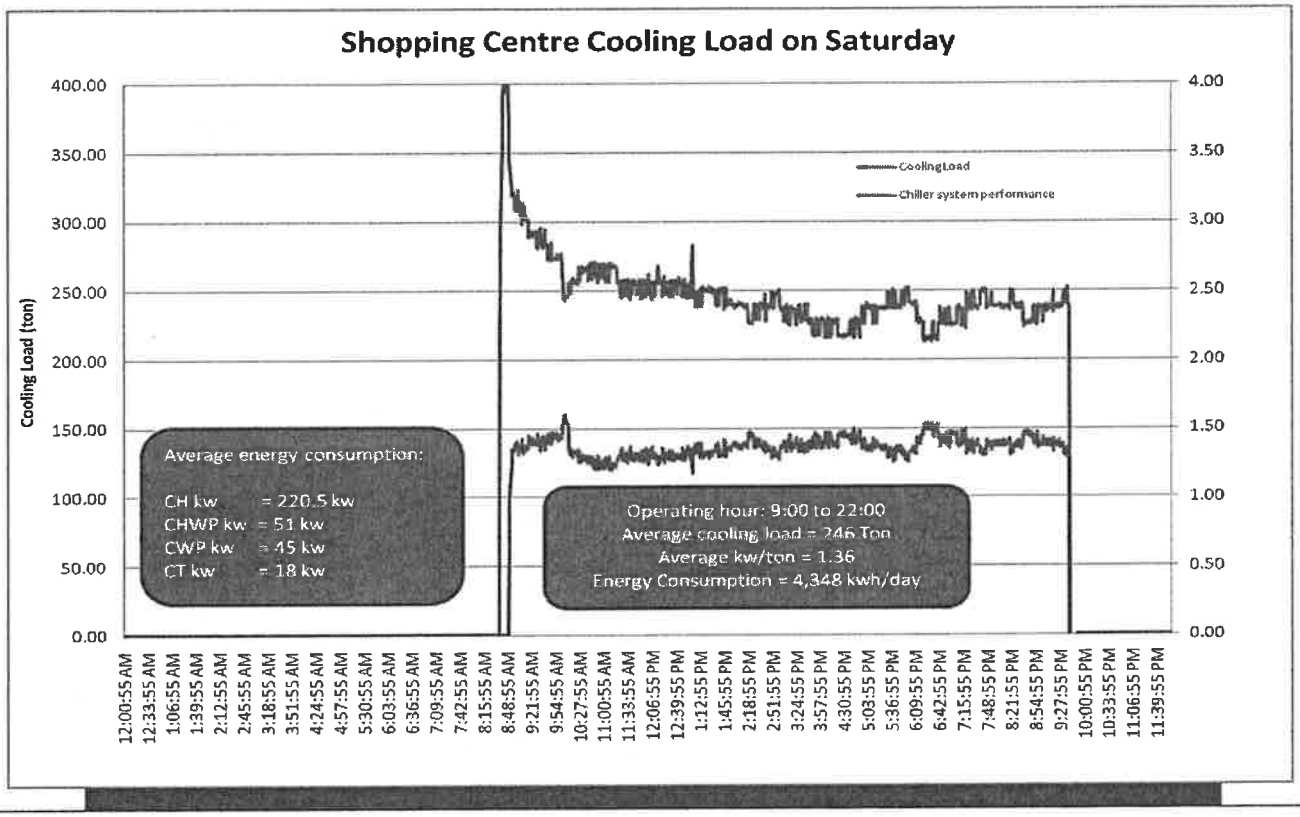


E2green Pte Ltd
BCA ACADEMY

Golden Mile Tower (EPC for Chiller Plants)

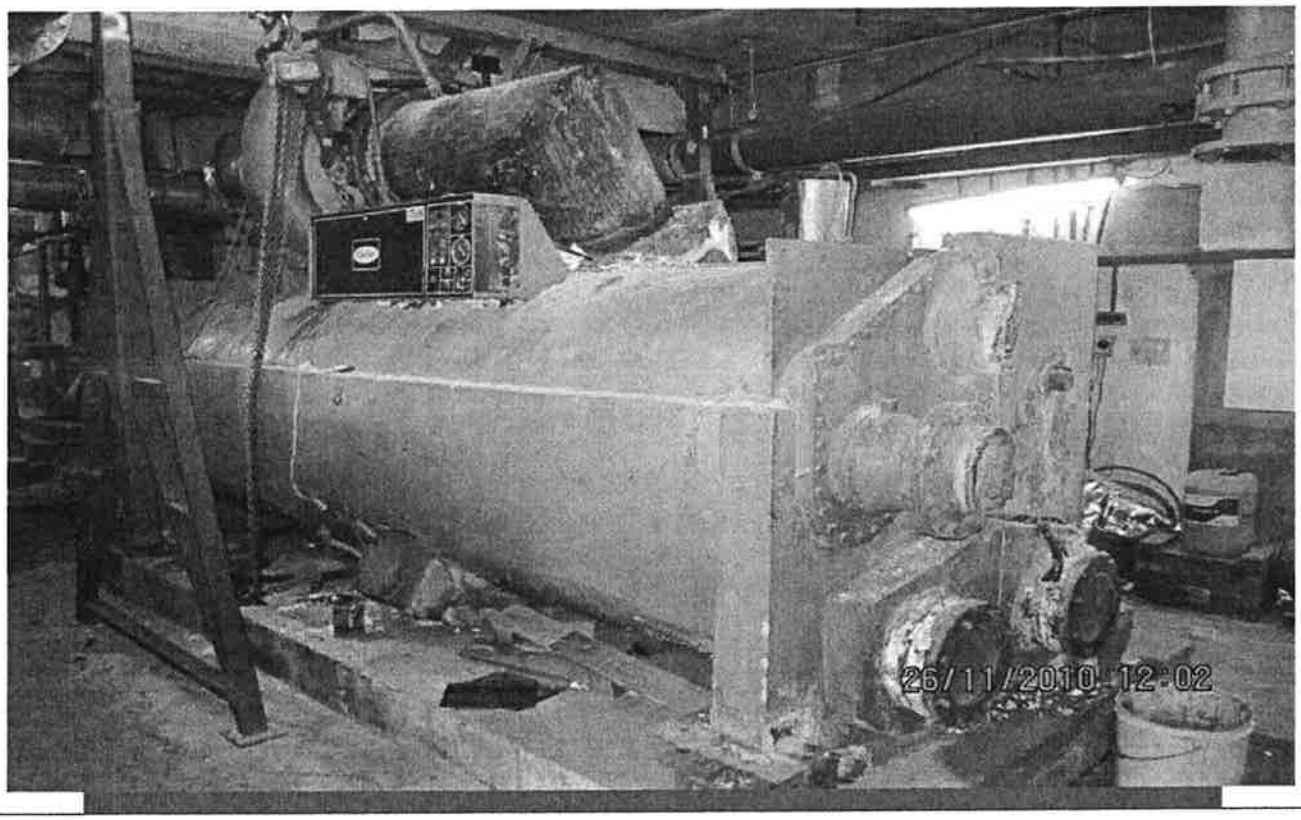


Golden Mile Tower (EPC for Chiller Plants)



BCA ACADEMY

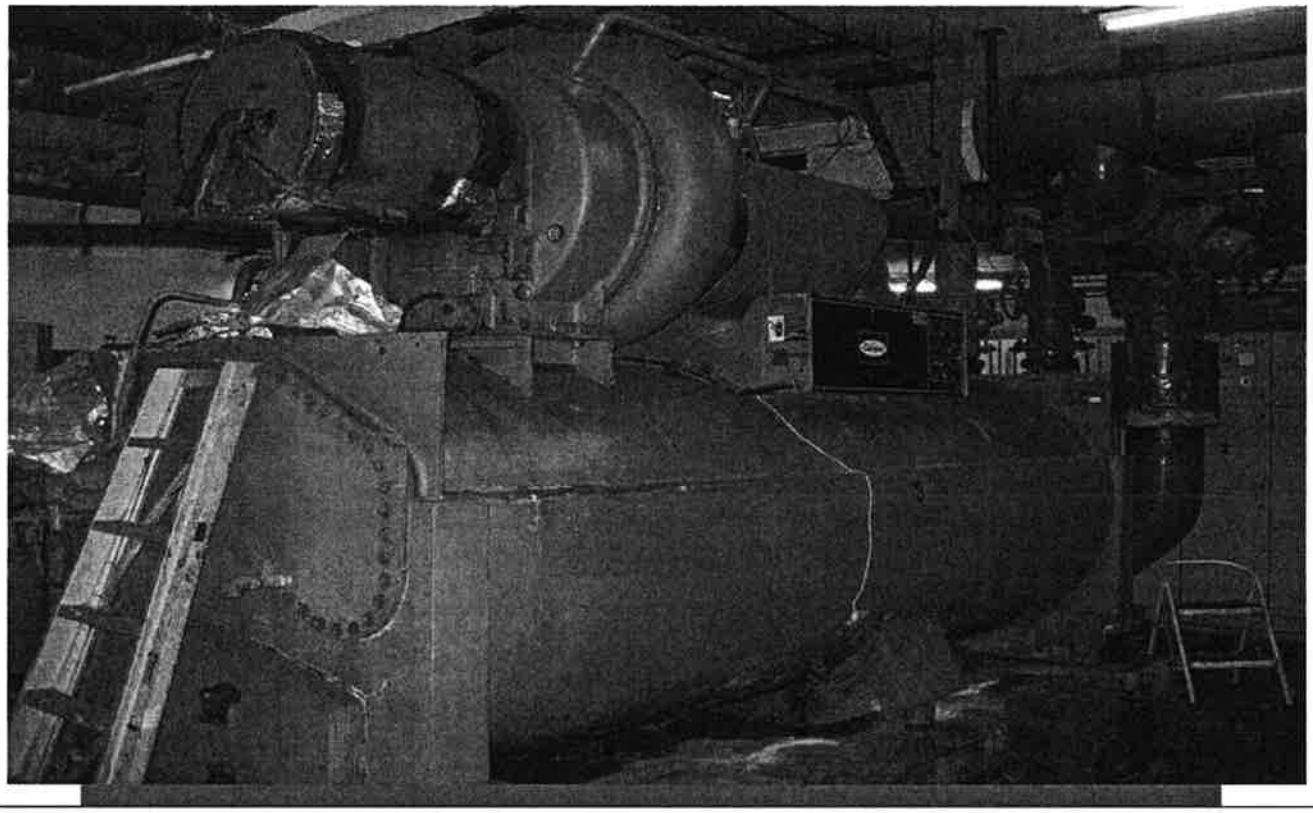
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

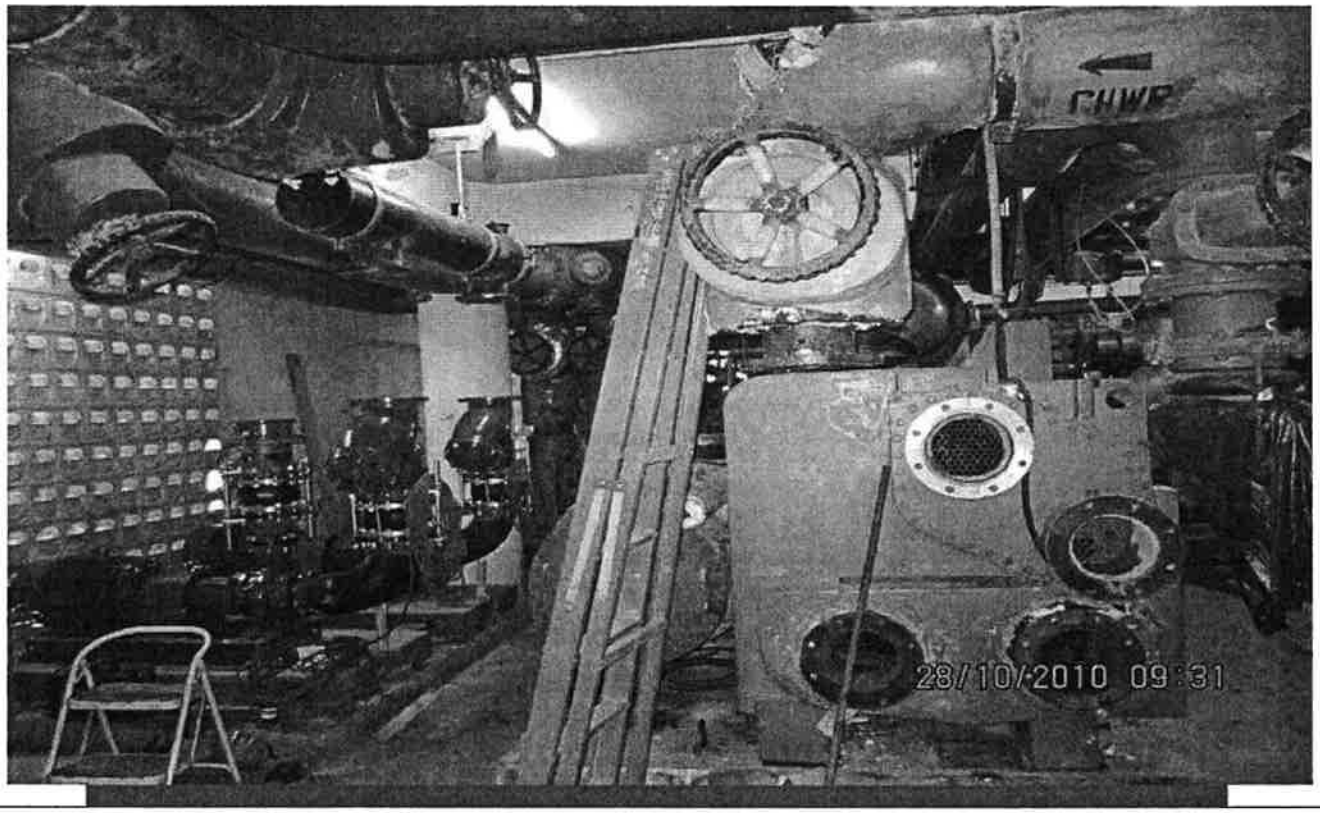
Golden Mile Tower (EPC for Chiller Plants)



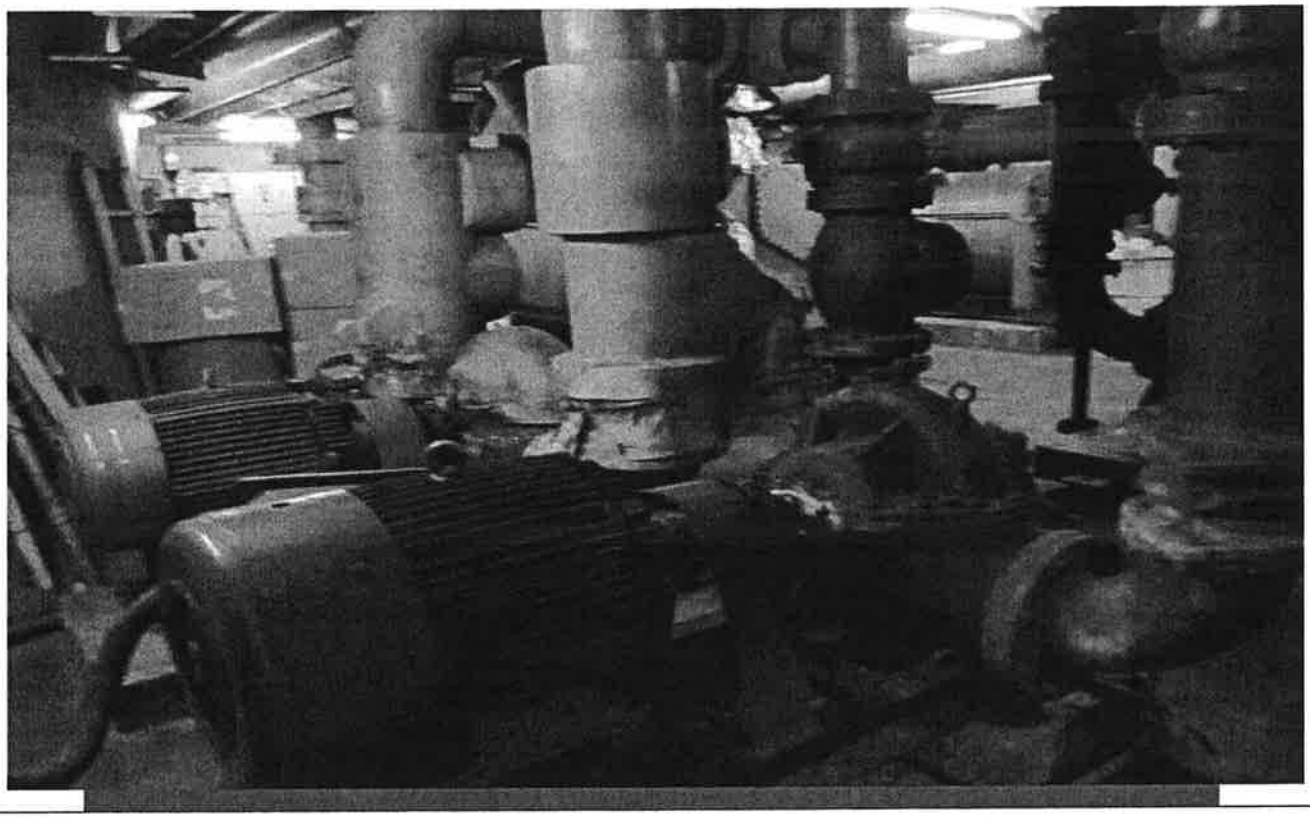
E2green Pte Ltd

BCA ACADEMY

Golden Mile Tower (EPC for Chiller Plants)



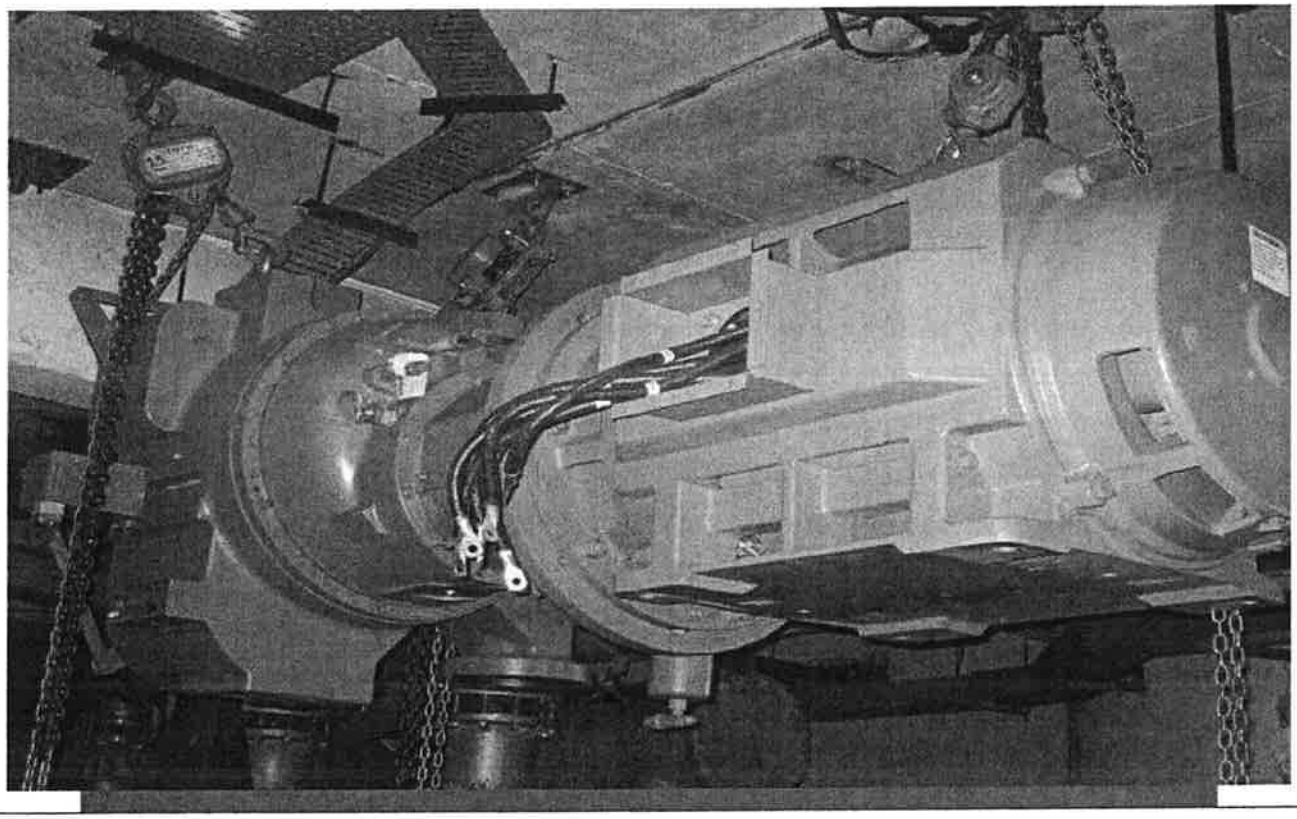
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

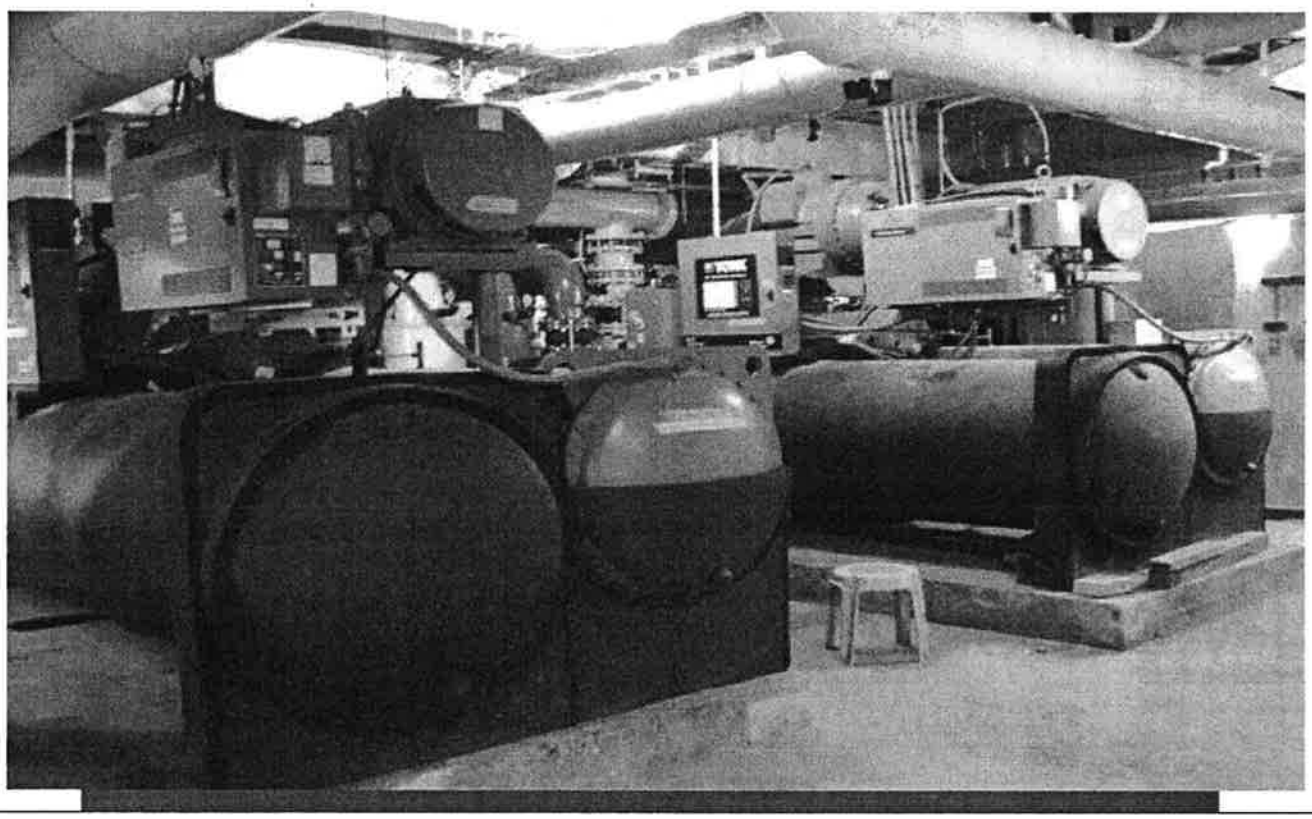
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

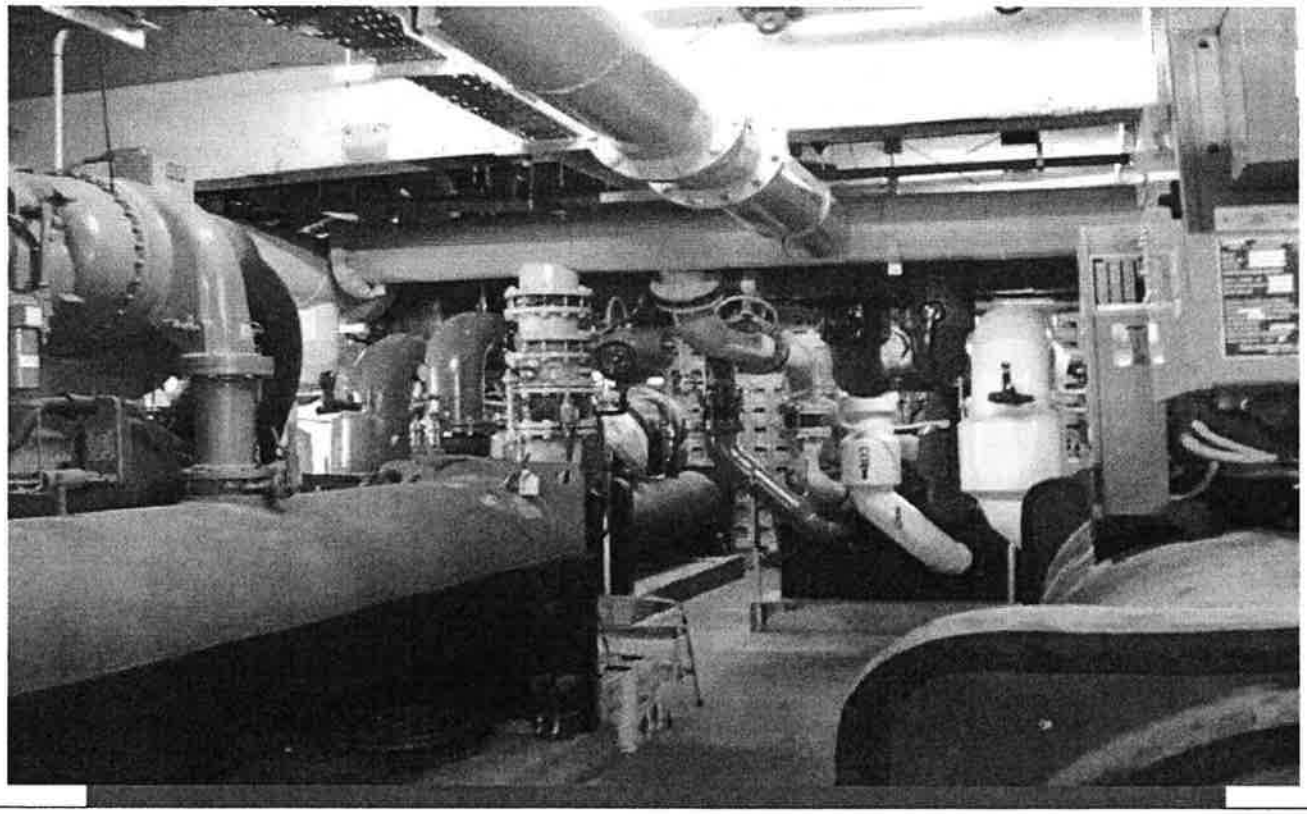
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

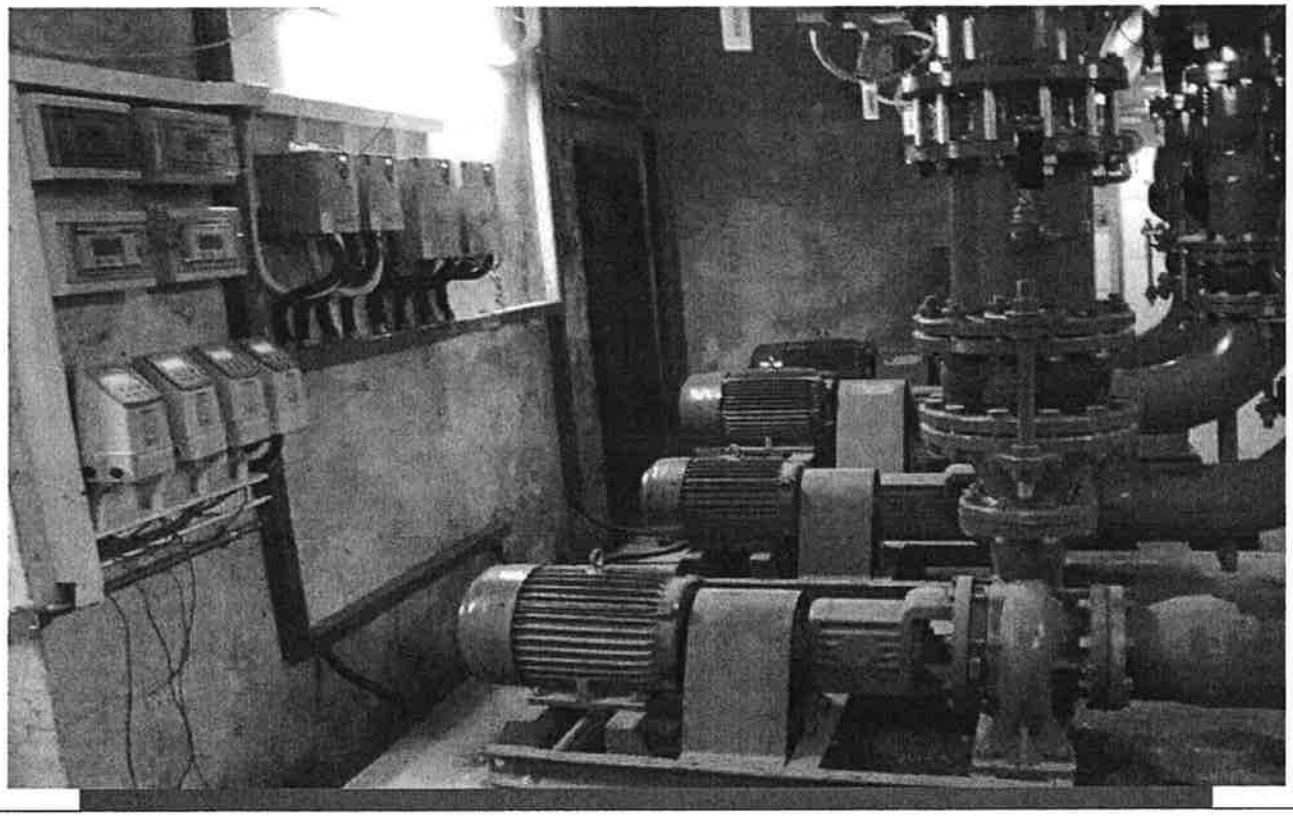
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

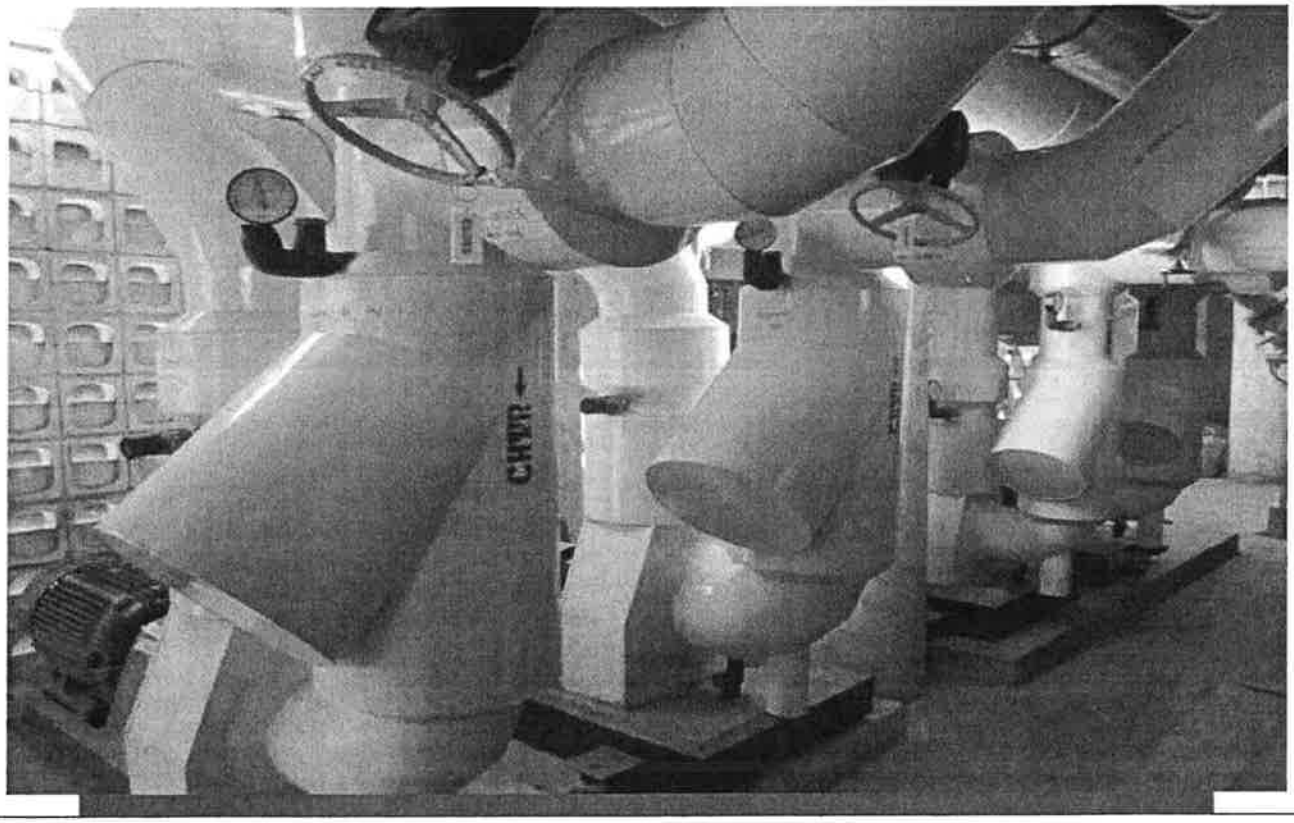
Golden Mile Tower (EPC for Chiller Plants)



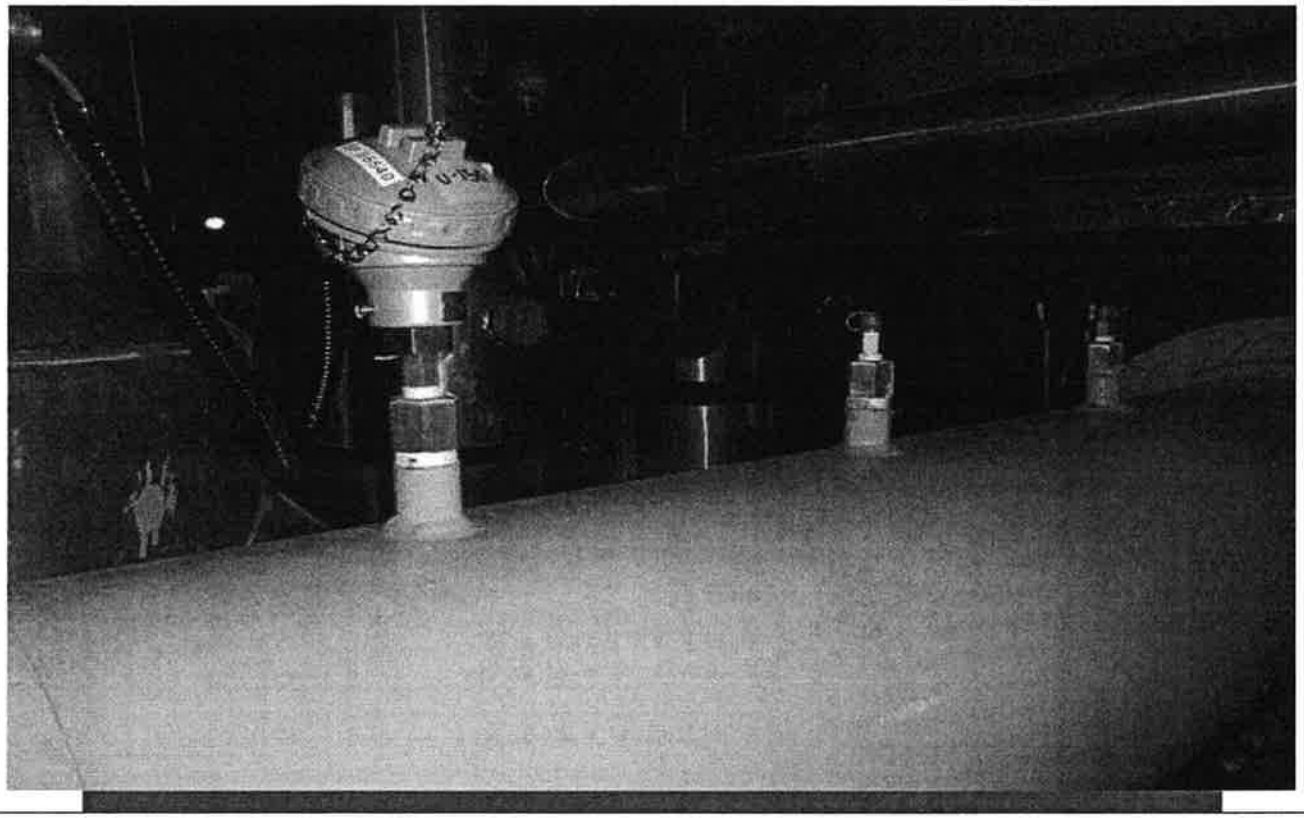
E2green Pte Ltd

BCA ACADEMY

Golden Mile Tower (EPC for Chiller Plants)



Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

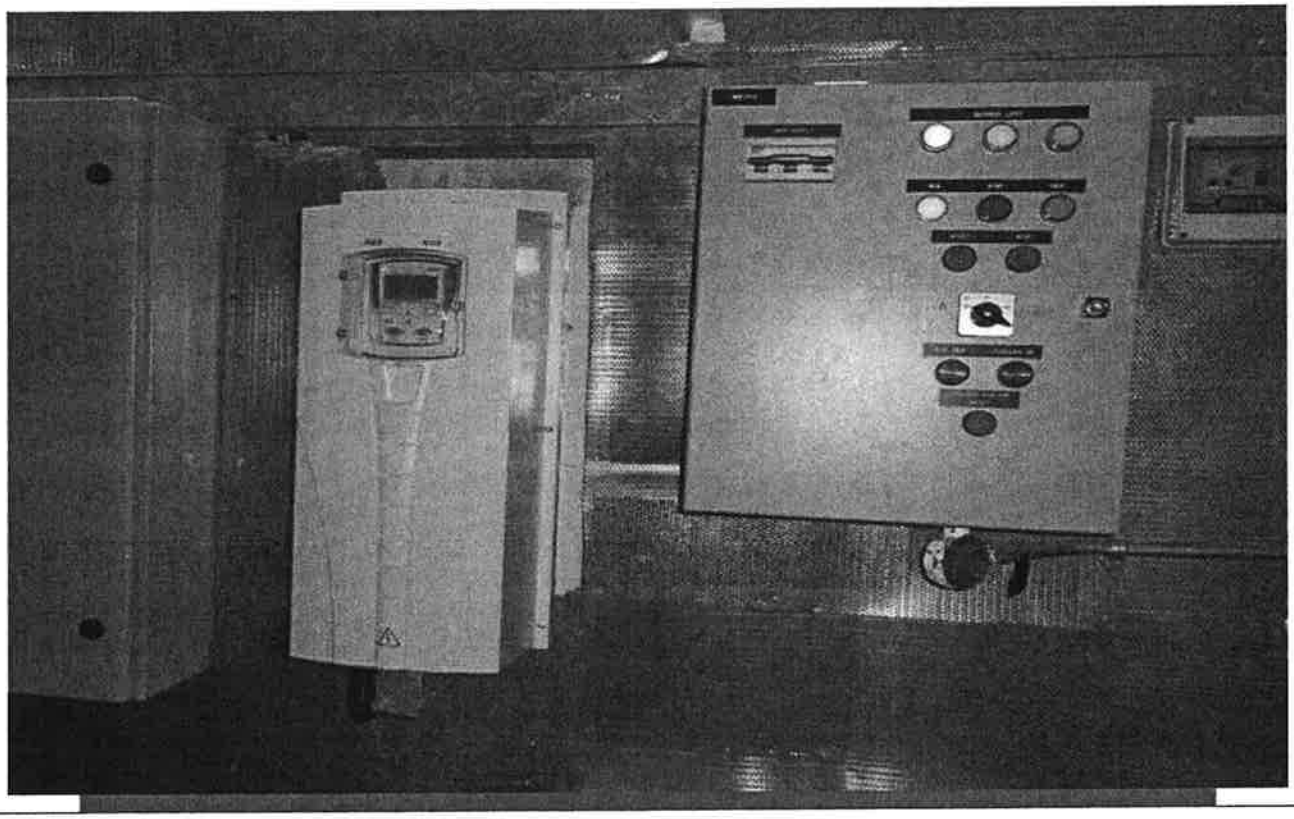
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

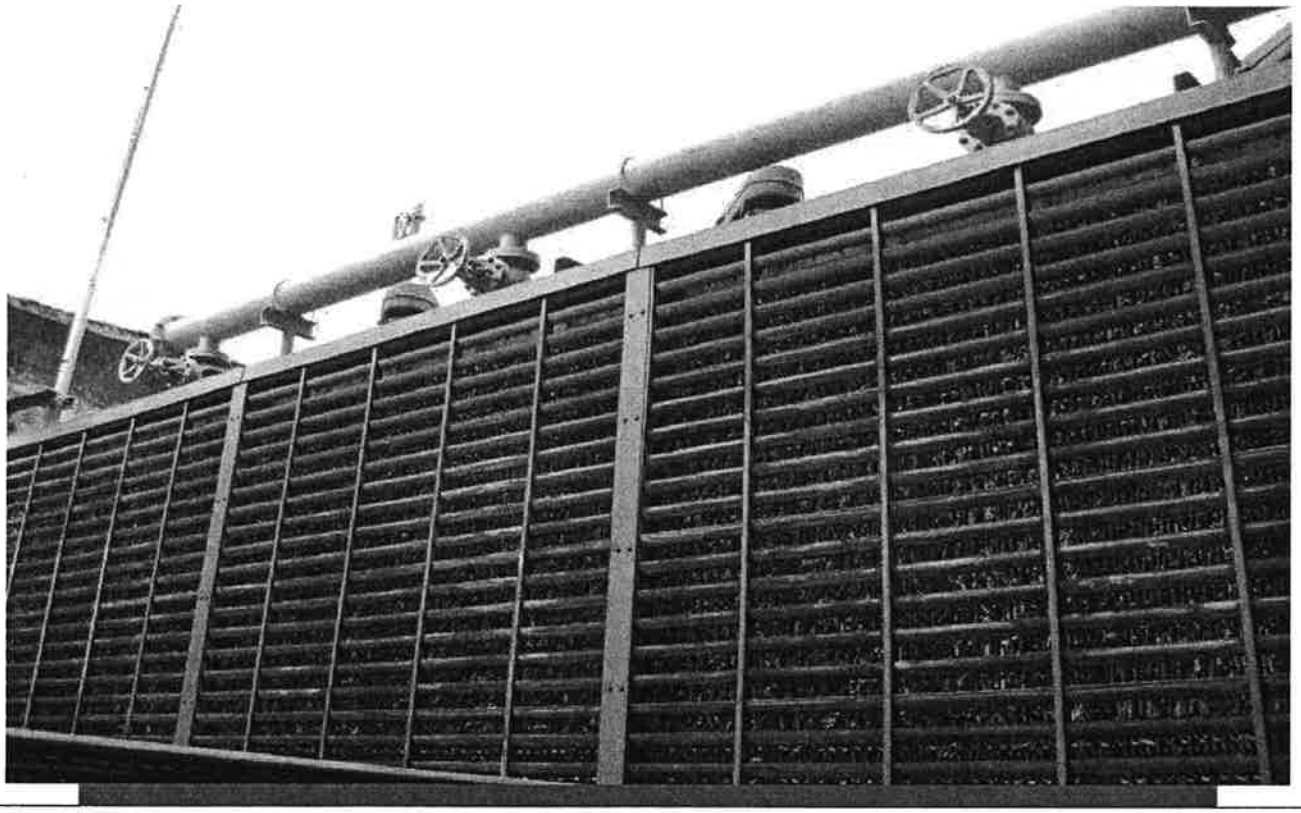
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

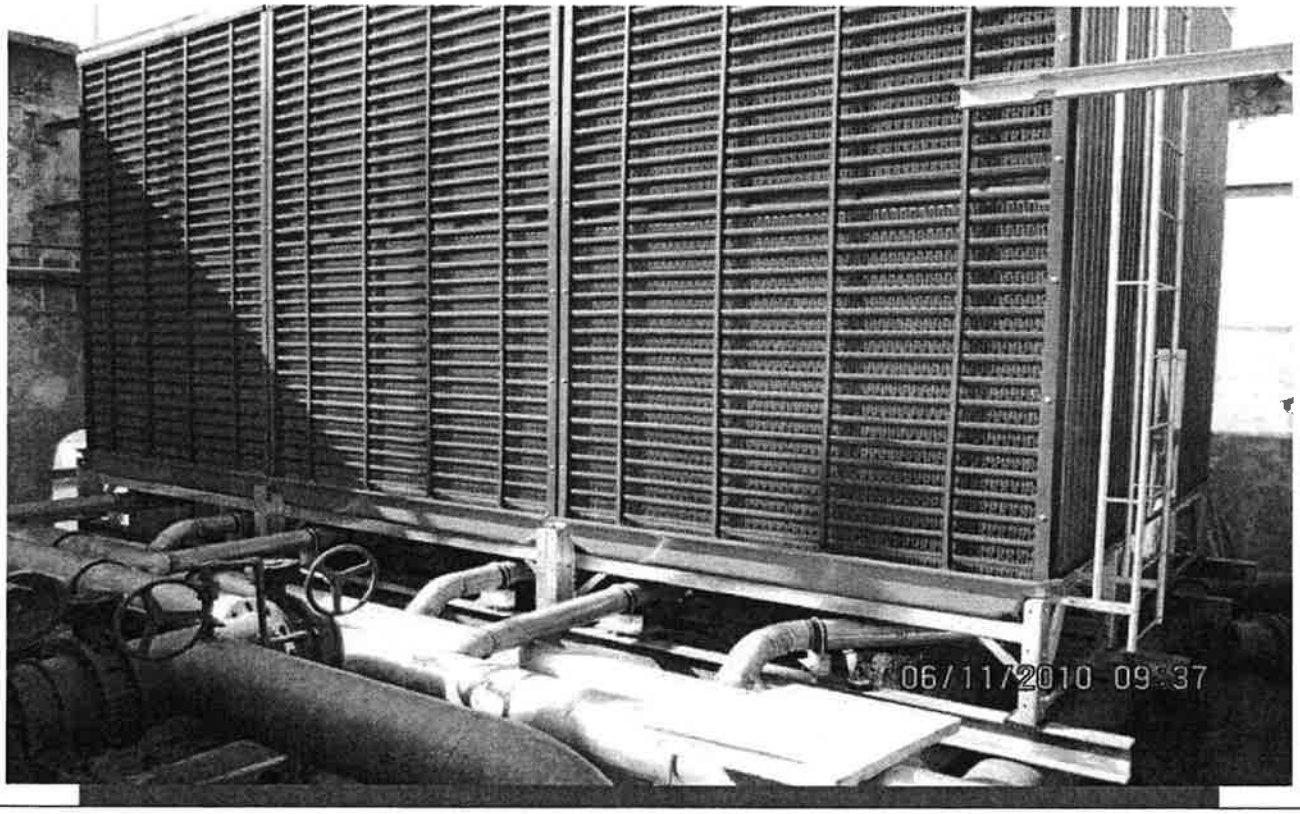
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

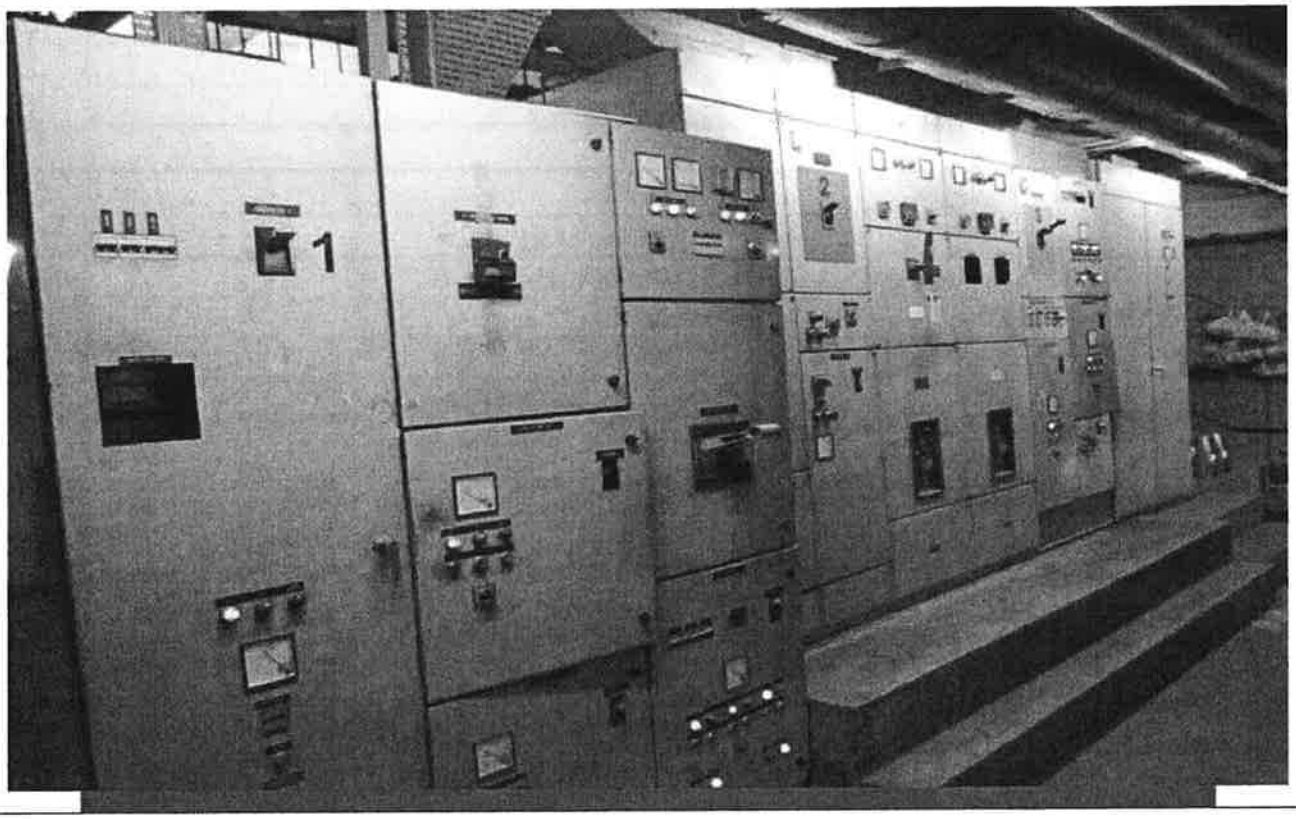
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

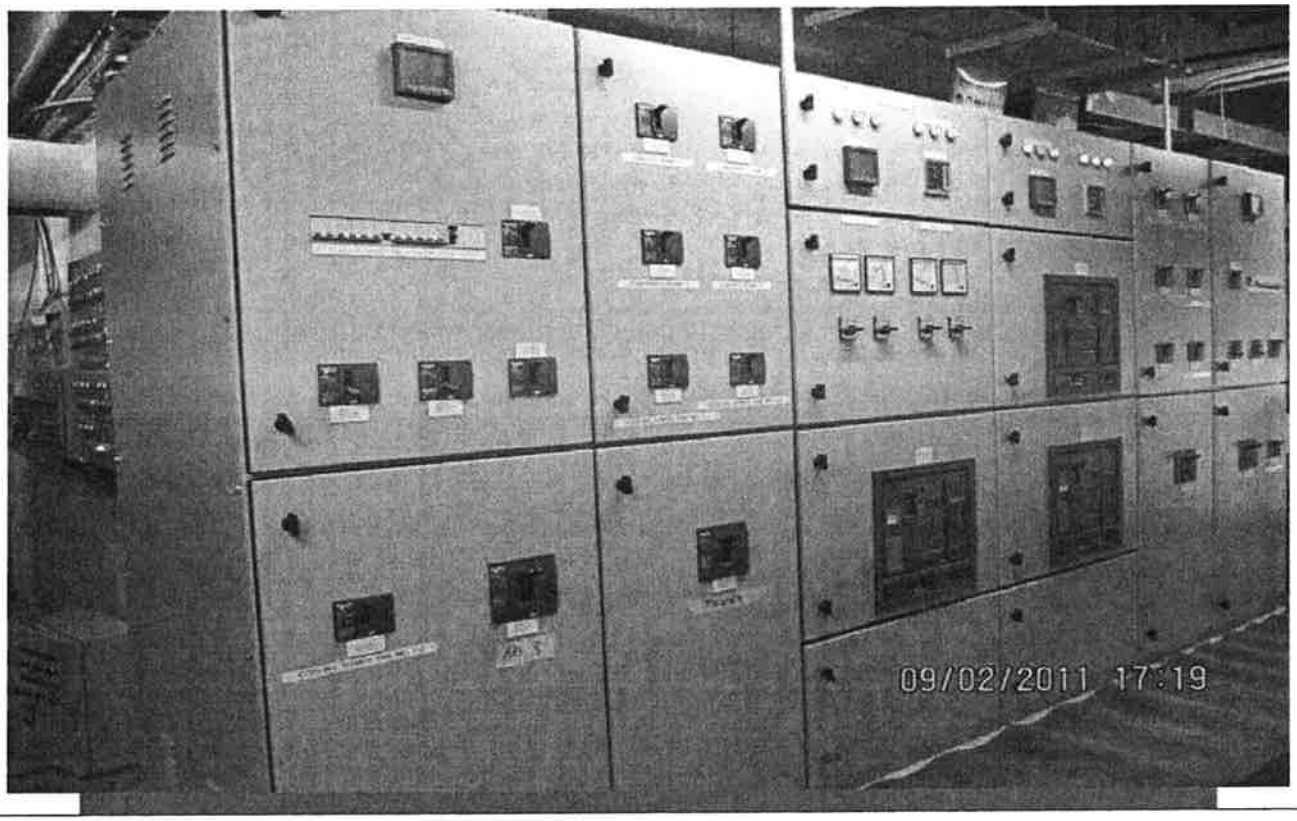
Golden Mile Tower (EPC for Chiller Plants)



E2green Pte Ltd

BCA ACADEMY

Golden Mile Tower (EPC for Chiller Plants)



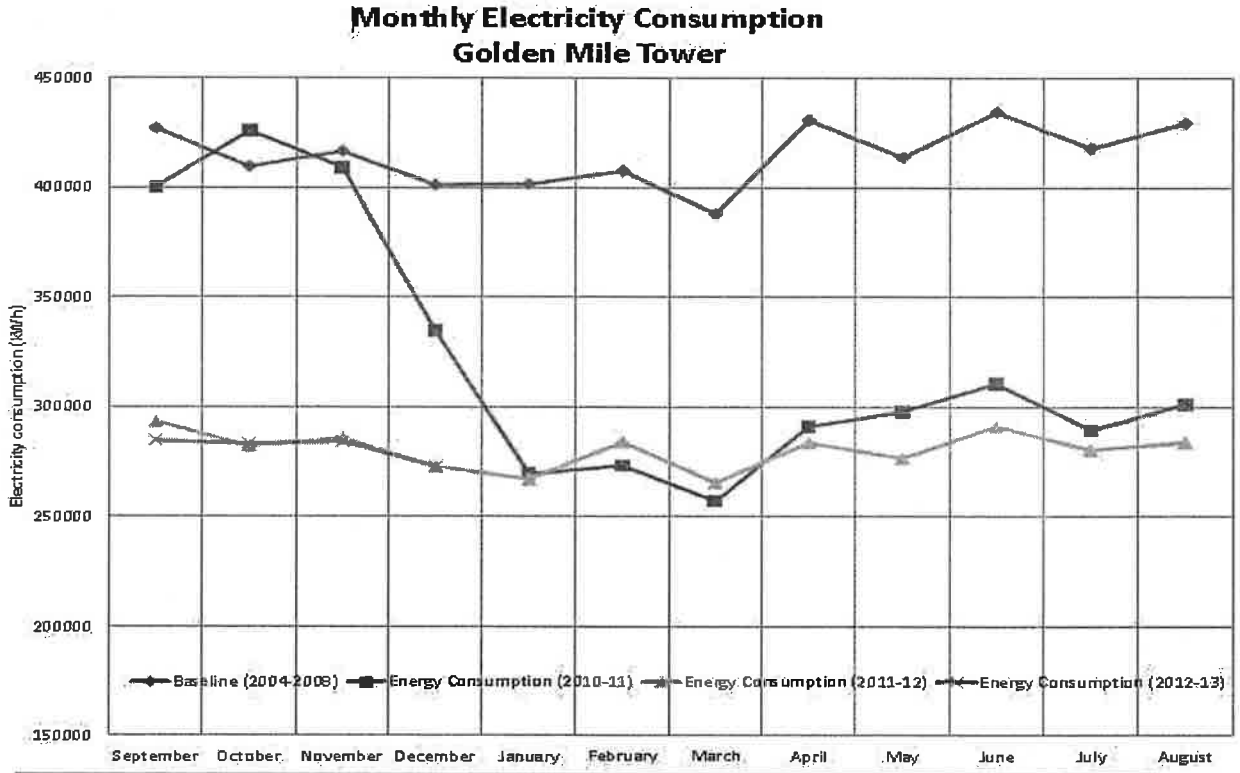
Golden Mile Tower (EPC for Chiller Plants)

Project Overview & Savings Achieved

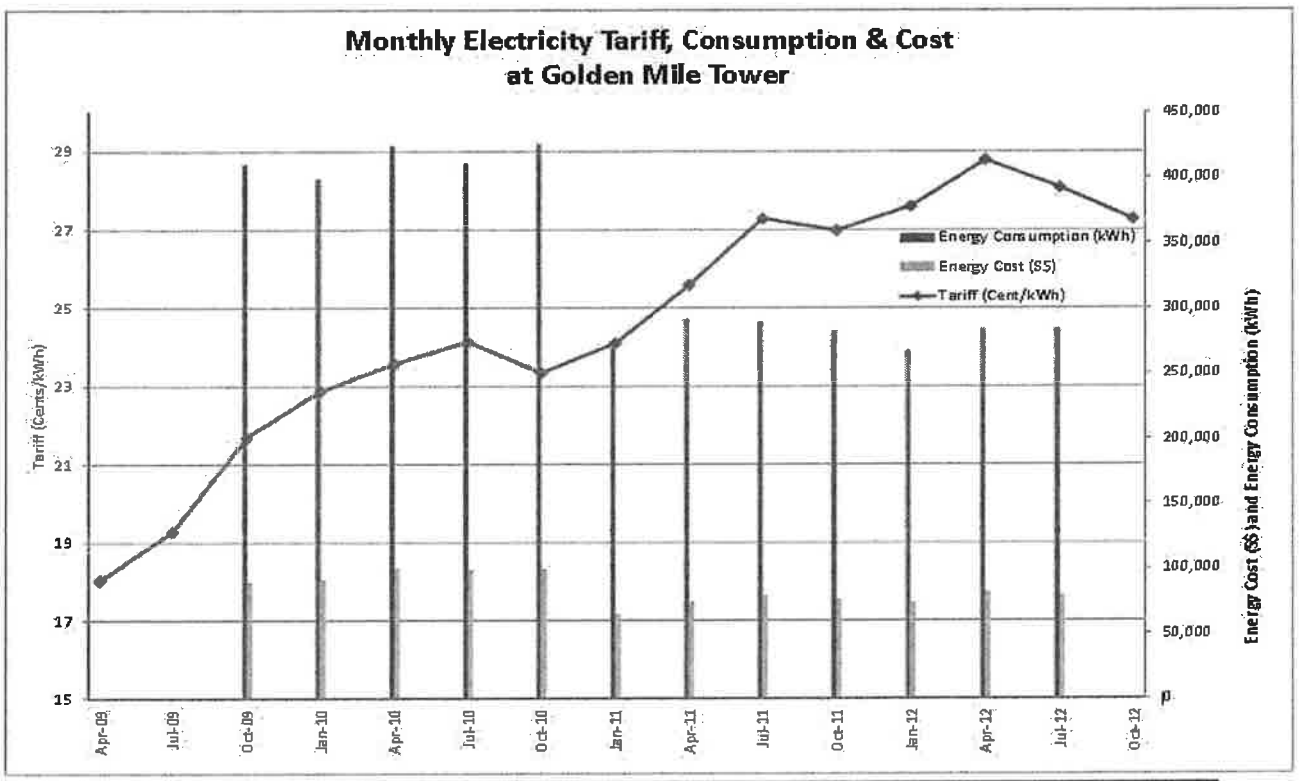
Subject Building	Golden Mile Towers
Age	40 years
GFA (m^2)	38,743
A/C area (m^2)	32,000
Average consumption/month	414000 kW/h
Projected Savings/month	165,900 kWh (40%)
Projected ROI	22%
Pre Retrofit Performance	Office : 1.22 kW/ton
	Retail : 1.51 kW/ton
	Cinema : 2.10 kW/ton
Post Retrofit Performance	<0.7 kW/ton
Pre-Retrofit configuration	2x500 RT(R11) + 1x600RT(R12)
	+ 3x100RT DX (for cinema)
Post-Retrofit configuration	2x425RT(R134a) + 2x200RT(R134a)
Peak/Average Load	Office : 400RT / 356RT
	Retail : 350RT / 236RT
	Cinema : 80RT / 64RT

BCA ACADEMY

Golden Mile Tower (EPC for Chiller Plants)



Golden Mile Tower (EPC for Chiller Plants)



BCA ACADEMY

Observations

- Optimizing components in isolation, such as replacing one of the older chillers alone will not result in significant savings
- Many existing buildings have old equipment which are inefficient, typically oversized and not optimally configured
- EPC is a viable way to address the above which cannot be addressed adequately through their capital budget process
- Decision for selection of equipment should be based on Life Cycle Costing – first cost, O&M over its working life and residual cost
- Many MCSTs lack capital maintenance budgets and need immediate action to limit greenhouse gas emissions and improve efficiency

Observations

- In the course of "greening" the buildings, one can take stock and address issues affecting the Indoor Environmental Quality of the building, especially IAQ aspects – untreated fresh air, poor kitchen exhaust, high bacterial count, etc.
- Retrofitting for higher energy efficiency should not be viewed as a one-off project but rather as a continual process in order that long term goals (energy savings) can be realized.
- Retrofitting/Optimizing the existing chiller plant presents an excellent opportunity for cost savings, both in terms of energy and maintenance.
- Facilities Management team must have the passion and understand the need for energy conservation in order that the whole exercise can remain sustainable.
- ESCO & EPC projects – important contributors to development of clean energy, sustainability & climate change mitigation strategies

E2green Pte Ltd
BCA ACADEMY

Thank You

PVIFA

PVIFA Table

Present Value Interest Factors for an Annuity, Compounded at k Percent for n periods : $PVIFA_{k,n} =$

$$\frac{1 - \frac{1}{(1+k)^n}}{k \text{ (for non-zero k)}}$$

Number of Periods, (n)	Interest Rate , k																					
	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%
1	1.00	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929	0.8772	0.8621	0.8475	0.8333	0.8197	0.8065	0.7937	0.7813	0.7692
2	2.00	1.9704	1.9416	1.9135	1.8861	1.8594	1.8334	1.8080	1.7833	1.7591	1.7355	1.7125	1.6901	1.6467	1.6052	1.5656	1.5278	1.4915	1.4568	1.4235	1.3916	1.3609
3	3.00	2.9410	2.8839	2.8286	2.7751	2.7232	2.6730	2.6243	2.5771	2.5313	2.4869	2.4437	2.4018	2.3216	2.2459	2.1743	2.1065	2.0422	1.9813	1.9234	1.8684	1.8161
4	4.00	3.9020	3.8077	3.7171	3.6299	3.5460	3.4651	3.3872	3.3121	3.2397	3.1699	3.1024	3.0373	2.9137	2.7982	2.6901	2.5887	2.4936	2.4043	2.3202	2.2410	2.1662
5	5.00	4.8534	4.7135	4.5797	4.4518	4.3295	4.2124	4.1002	3.9927	3.8897	3.7908	3.6959	3.6048	3.4331	3.2743	3.1272	2.9906	2.8636	2.7454	2.6351	2.5320	2.4356
6	6.00	5.7955	5.6014	5.4172	5.2421	5.0757	4.9173	4.7665	4.6229	4.4859	4.3553	4.2305	4.1114	3.8887	3.6847	3.4976	3.3255	3.1669	3.0205	2.8850	2.7594	2.6427
7	7.00	6.7282	6.4720	6.2303	6.0021	5.7864	5.5824	5.3893	5.2064	5.0330	4.8684	4.7122	4.5638	4.2883	4.0386	3.8115	3.6046	3.4155	3.2423	3.0833	2.9370	2.8021
8	8.00	7.6517	7.3255	7.0197	6.7327	6.4632	6.2098	5.9713	5.7466	5.5348	5.3349	5.1461	4.9676	4.6389	4.3436	4.0776	3.8372	3.6193	3.4212	3.2407	3.0758	2.9247
9	9.00	8.5660	8.1622	7.7861	7.4353	7.1078	6.8017	6.5152	6.2469	5.9952	5.7590	5.5370	5.3282	4.9464	4.6065	4.3030	4.0310	3.7863	3.5655	3.3657	3.1842	3.0190
10	10.00	9.4713	8.9826	8.5302	8.1109	7.7217	7.3601	7.0236	6.7101	6.4177	6.1446	5.8892	5.6502	5.2161	4.8332	4.4941	4.1925	3.9232	3.6819	3.4648	3.2689	3.0915
11	11.00	10.368	9.787	9.253	8.760	8.306	7.887	7.499	7.1390	6.8052	6.4951	6.2065	5.9377	5.4527	5.0286	4.6560	4.3271	4.0354	3.7757	3.5435	3.3351	3.1473
12	12.00	11.255	10.575	9.954	9.385	8.863	8.384	7.943	7.5361	7.1607	6.8137	6.4924	6.1944	5.6603	5.1971	4.7932	4.4392	4.1274	3.8514	3.6059	3.3868	3.1903
13	13.00	12.134	11.348	10.635	9.986	9.394	8.853	8.358	7.9038	7.4869	7.1034	6.7499	6.4235	5.8424	5.3423	4.9095	4.5327	4.2028	3.9124	3.6555	3.4272	3.2233
14	14.00	13.004	12.106	11.296	10.563	9.899	9.295	8.745	8.2442	7.7862	7.3667	6.9819	6.6282	6.0021	5.4675	5.0081	4.6106	4.2646	3.9616	3.6949	3.4587	3.2487
15	15.00	13.865	12.849	11.938	11.118	10.380	9.712	9.108	8.5595	8.0607	7.6061	7.1909	6.8109	6.1422	5.5755	5.0916	4.6755	4.3152	4.0013	3.7261	3.4834	3.2682
16	16.00	14.718	13.578	12.561	11.652	10.838	10.106	9.447	8.8514	8.3126	7.8237	7.3792	6.9740	6.2651	5.6685	5.1624	4.7296	4.3567	4.0333	3.7509	3.5026	3.2832
17	17.00	15.562	14.292	13.166	12.166	11.274	10.477	9.763	9.1216	8.5436	8.0216	7.5488	7.1196	6.3729	5.7487	5.2223	4.7746	4.3908	4.0591	3.7705	3.5177	3.2948
18	18.00	16.398	14.992	13.754	12.659	11.690	10.828	10.059	9.3719	8.7556	8.2014	7.7016	7.2497	6.4674	5.8178	5.2732	4.8122	4.4187	4.0799	3.7861	3.5294	3.3037
19	19.00	17.226	15.678	14.324	13.134	12.085	11.158	10.336	9.6036	8.9501	8.3649	7.8393	7.3658	6.5504	5.8775	5.3162	4.8435	4.4415	4.0967	3.7985	3.5386	3.3105
20	20.00	18.046	16.351	14.877	13.590	12.462	11.470	10.594	9.8181	9.1285	8.5136	7.9633	7.4694	6.6231	5.9288	5.3527	4.8696	4.4603	4.1103	3.8083	3.5458	3.3158
21	21.00	18.857	17.011	15.415	14.029	12.821	11.764	10.836	10.0168	9.2922	8.6487	8.0751	7.5620	6.6870	5.9731	5.3837	4.8913	4.4756	4.1212	3.8161	3.5514	3.3198
22	22.00	19.660	17.658	15.937	14.451	13.163	12.042	11.061	10.2007	9.4424	8.7715	8.1757	7.6446	6.7429	6.0113	5.4099	4.9094	4.4882	4.1300	3.8223	3.5558	3.3230
23	23.00	20.456	18.292	16.444	14.857	13.489	12.303	11.272	10.3711	9.5802	8.8832	8.2664	7.7184	6.7921	6.0442	5.4321	4.9245	4.4985	4.1371	3.8273	3.5592	3.3254
24	24.00	21.243	18.914	16.936	15.247	13.799	12.550	11.469	10.5288	9.7066	8.9847	8.3481	7.7843	6.8351	6.0726	5.4509	4.9371	4.5070	4.1428	3.8312	3.5619	3.3272
25	25.00	22.023	19.523	17.413	15.622	14.094	12.783	11.654	10.6748	9.8226	9.0770	8.4217	7.8431	6.8729	6.0971	5.4669	4.9476	4.5139	4.1474	3.8342	3.5640	3.3286
26	26.00	22.795	20.121	17.877	15.983	14.375	13.003	11.826	10.8100	9.9290	9.1609	8.4881	7.8957	6.9061	6.1182	5.4804	4.9563	4.5196	4.1511	3.8367	3.5656	3.3297
27	27.00	23.560	20.707	18.327	16.330	14.643	13.211	11.987	10.9352	10.0266	9.2372	8.5478	7.9426	6.9352	6.1364	5.4919	4.9636	4.5243	4.1542	3.8387	3.5669	3.3305
28	28.00	24.316	21.281	18.764	16.663	14.898	13.406	12.137	11.0511	10.1161	9.3066	8.6016	7.9844	6.9607	6.1520	5.5016	4.9697	4.5281	4.1566	3.8402	3.5679	3.3312
29	29.00	25.066	21.844	19.188	16.984	15.141	13.591	12.278	11.1584	10.1983	9.3696	8.6501	8.0218	6.9830	6.1656	5.5098	4.9747	4.5312	4.1585	3.8414	3.5687	3.3317
30	30.00	25.808	22.396	19.600	17.292	15.372	13.765	12.409	11.2578	10.2737	9.4269	8.6938	8.0552	7.0027	6.1772	5.5168	4.9789	4.5338	4.1601	3.8424	3.5693	3.3321
31	31.00	26.542	22.938	20.000	17.588	15.593	13.929	12.532	11.3498	10.3428	9.4790	8.7331	8.0850	7.0199	6.1872	5.5227	4.9824	4.5359	4.1614	3.8432	3.5697	3.3324
32	32.00	27.270	23.468	20.389	17.874	15.803	14.084	12.647	11.4350	10.4062	9.5264	8.7686	8.1116	7.0350	6.1959	5.5277	4.9854	4.5376	4.1624	3.8438	3.5701	3.3326
33	33.00	27.990	23.989	20.766	18.148	16.003	14.230	12.754	11.5139	10.4644	9.5694	8.8005	8.1354	7.0482	6.2034	5.5320	4.9878	4.5390	4.1632	3.8443	3.5704	3.3328
34	34.00	28.703	24.499	21.132	18.411	16.193	14.368	12.854	11.5869	10.5178	9.6086	8.8293	8.1566	7.0599	6.2098	5.5356	4.9898	4.5402	4.1639	3.8447	3.5706	3.3329
35	35.00	29.409	24.999	21.487	18.665	16.374	14.498	12.948	11.6546	10.5668	9.6442	8.8552	8.1755	7.0700	6.2153	5.5386	4.9915	4.5411	4.1644	3.8450	3.5708	3.3330

PVIF

PVIF Table

Present Value Interest Factors, Compounded at k Percent for n periods : $PVIF_{k,n} = \frac{1}{(1+k)^n}$

Number of Periods, (n)	Interest Rate , k																				
	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%
1	1.00	0.9901	0.9804	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091	0.9009	0.8929	0.8772	0.8621	0.8475	0.8333	0.8197	0.8065	0.7937	0.7813	0.7692
2	1.00	0.9803	0.9612	0.9426	0.9246	0.9070	0.8900	0.8734	0.8573	0.8417	0.8264	0.8116	0.7972	0.7695	0.7432	0.7182	0.6944	0.6719	0.6504	0.6299	0.6104	0.5917
3	1.00	0.9706	0.9423	0.9151	0.8890	0.8638	0.8396	0.8163	0.7938	0.7722	0.7513	0.7312	0.7118	0.6750	0.6407	0.6086	0.5787	0.5507	0.5245	0.4999	0.4768	0.4552
4	1.00	0.9610	0.9238	0.8885	0.8548	0.8227	0.7921	0.7629	0.7350	0.7084	0.6830	0.6587	0.6355	0.5921	0.5523	0.5158	0.4823	0.4514	0.4230	0.3968	0.3725	0.3501
5	1.00	0.9515	0.9057	0.8626	0.8219	0.7835	0.7473	0.7130	0.6806	0.6499	0.6209	0.5935	0.5674	0.5194	0.4761	0.4371	0.4019	0.3700	0.3411	0.3149	0.2910	0.2693
6	1.00	0.9420	0.8880	0.8375	0.7903	0.7462	0.7050	0.6663	0.6302	0.5963	0.5645	0.5346	0.5066	0.4556	0.4104	0.3704	0.3349	0.3033	0.2751	0.2499	0.2274	0.2072
7	1.00	0.9327	0.8706	0.8131	0.7599	0.7107	0.6651	0.6227	0.5835	0.5470	0.5132	0.4817	0.4523	0.3996	0.3538	0.3139	0.2791	0.2486	0.2218	0.1983	0.1776	0.1594
8	1.00	0.9235	0.8535	0.7894	0.7307	0.6768	0.6274	0.5820	0.5403	0.5019	0.4665	0.4339	0.4039	0.3506	0.3050	0.2660	0.2326	0.2038	0.1789	0.1574	0.1388	0.1226
9	1.00	0.9143	0.8368	0.7664	0.7026	0.6446	0.5919	0.5439	0.5002	0.4604	0.4241	0.3909	0.3606	0.3075	0.2630	0.2255	0.1938	0.1670	0.1443	0.1249	0.1084	0.0943
10	1.00	0.9053	0.8203	0.7441	0.6756	0.6139	0.5584	0.5083	0.4632	0.4224	0.3855	0.3522	0.3220	0.2697	0.2267	0.1911	0.1615	0.1369	0.1164	0.0992	0.0847	0.0725
11	1.00	0.8963	0.8043	0.7224	0.6496	0.5847	0.5268	0.4751	0.4289	0.3875	0.3505	0.3173	0.2875	0.2366	0.1954	0.1619	0.1346	0.1122	0.0938	0.0787	0.0662	0.0558
12	1.00	0.8874	0.7885	0.7014	0.6246	0.5568	0.4970	0.4440	0.3971	0.3555	0.3186	0.2858	0.2567	0.2076	0.1685	0.1372	0.1122	0.0920	0.0757	0.0625	0.0517	0.0429
13	1.00	0.8787	0.7730	0.6810	0.6006	0.5303	0.4688	0.4150	0.3677	0.3262	0.2897	0.2575	0.2292	0.1821	0.1452	0.1163	0.0935	0.0754	0.0610	0.0496	0.0404	0.0330
14	1.00	0.8700	0.7579	0.6611	0.5775	0.5051	0.4423	0.3878	0.3405	0.2992	0.2633	0.2320	0.2046	0.1597	0.1252	0.0985	0.0779	0.0618	0.0492	0.0393	0.0316	0.0254
15	1.00	0.8613	0.7430	0.6419	0.5553	0.4810	0.4173	0.3624	0.3152	0.2745	0.2394	0.2090	0.1827	0.1401	0.1079	0.0835	0.0649	0.0507	0.0397	0.0312	0.0247	0.0195
16	1.00	0.8528	0.7284	0.6232	0.5339	0.4581	0.3936	0.3387	0.2919	0.2519	0.2176	0.1883	0.1631	0.1229	0.0930	0.0708	0.0541	0.0415	0.0320	0.0248	0.0193	0.0150
17	1.00	0.8444	0.7142	0.6050	0.5134	0.4363	0.3714	0.3166	0.2703	0.2311	0.1978	0.1696	0.1456	0.1078	0.0802	0.0600	0.0451	0.0340	0.0258	0.0197	0.0150	0.0116
18	1.00	0.8360	0.7002	0.5874	0.4936	0.4155	0.3503	0.2959	0.2502	0.2120	0.1799	0.1528	0.1300	0.0946	0.0691	0.0508	0.0376	0.0279	0.0208	0.0156	0.0118	0.0089
19	1.00	0.8277	0.6864	0.5703	0.4746	0.3957	0.3305	0.2765	0.2317	0.1945	0.1635	0.1377	0.1161	0.0829	0.0596	0.0431	0.0313	0.0229	0.0168	0.0124	0.0092	0.0068
20	1.00	0.8195	0.6730	0.5537	0.4564	0.3769	0.3118	0.2584	0.2145	0.1784	0.1486	0.1240	0.1037	0.0728	0.0514	0.0365	0.0261	0.0187	0.0135	0.0098	0.0072	0.0053
21	1.00	0.8114	0.6598	0.5375	0.4388	0.3589	0.2942	0.2415	0.1987	0.1637	0.1351	0.1117	0.0926	0.0638	0.0443	0.0309	0.0217	0.0154	0.0109	0.0078	0.0056	0.0040
22	1.00	0.8034	0.6468	0.5219	0.4220	0.3418	0.2775	0.2257	0.1839	0.1502	0.1228	0.1007	0.0826	0.0560	0.0382	0.0262	0.0181	0.0126	0.0088	0.0062	0.0044	0.0031
23	1.00	0.7954	0.6342	0.5067	0.4057	0.3256	0.2618	0.2109	0.1703	0.1378	0.1117	0.0907	0.0738	0.0491	0.0329	0.0222	0.0151	0.0103	0.0071	0.0049	0.0034	0.0024
24	1.00	0.7876	0.6217	0.4919	0.3901	0.3101	0.2470	0.1971	0.1577	0.1264	0.1015	0.0817	0.0659	0.0431	0.0284	0.0188	0.0126	0.0085	0.0057	0.0039	0.0027	0.0018
25	1.00	0.7798	0.6095	0.4776	0.3751	0.2953	0.2330	0.1842	0.1460	0.1160	0.0923	0.0736	0.0588	0.0378	0.0245	0.0160	0.0105	0.0069	0.0046	0.0031	0.0021	0.0014
26	1.00	0.7720	0.5976	0.4637	0.3607	0.2812	0.2198	0.1722	0.1352	0.1064	0.0839	0.0663	0.0525	0.0331	0.0211	0.0135	0.0087	0.0057	0.0037	0.0025	0.0016	0.0011
27	1.00	0.7644	0.5859	0.4502	0.3468	0.2678	0.2074	0.1609	0.1252	0.0976	0.0763	0.0597	0.0469	0.0291	0.0182	0.0115	0.0073	0.0047	0.0030	0.0019	0.0013	0.0008
28	1.00	0.7568	0.5744	0.4371	0.3335	0.2551	0.1956	0.1504	0.1159	0.0895	0.0693	0.0538	0.0419	0.0255	0.0157	0.0097	0.0061	0.0038	0.0024	0.0015	0.0010	0.0006
29	1.00	0.7493	0.5631	0.4243	0.3207	0.2429	0.1846	0.1406	0.1073	0.0822	0.0630	0.0485	0.0374	0.0224	0.0135	0.0082	0.0051	0.0031	0.0020	0.0012	0.0008	0.0005
30	1.00	0.7419	0.5521	0.4120	0.3083	0.2314	0.1741	0.1314	0.0994	0.0754	0.0573	0.0437	0.0334	0.0196	0.0116	0.0070	0.0042	0.0026	0.0016	0.0010	0.0006	0.0004
31	1.00	0.7346	0.5412	0.4000	0.2965	0.2204	0.1643	0.1228	0.0920	0.0691	0.0521	0.0394	0.0298	0.0172	0.0100	0.0059	0.0035	0.0021	0.0013	0.0008	0.0005	0.0003
32	1.00	0.7273	0.5306	0.3883	0.2851	0.2099	0.1550	0.1147	0.0852	0.0634	0.0474	0.0355	0.0266	0.0151	0.0087	0.0050	0.0029	0.0017	0.0010	0.0006	0.0004	0.0002
33	1.00	0.7201	0.5202	0.3770	0.2741	0.1999	0.1462	0.1072	0.0789	0.0582	0.0431	0.0319	0.0238	0.0132	0.0075	0.0042	0.0024	0.0014	0.0008	0.0005	0.0003	0.0002
34	1.00	0.7130	0.5100	0.3660	0.2636	0.1904	0.1379	0.1002	0.0730	0.0534	0.0391	0.0288	0.0212	0.0116	0.0064	0.0036	0.0020	0.0012	0.0007	0.0004	0.0002	0.0001
35	1.00	0.7059	0.5000	0.3554	0.2534	0.1813	0.1301	0.0937	0.0676	0.0490	0.0356	0.0259	0.0189	0.0102	0.0055	0.0030	0.0017	0.0009	0.0005	0.0003	0.0002	0.0001

FVIFA

FVIFA Table

Future Value Interest Factors for an Annuity, Compounded at k Percent for n periods : $FVIFA_{k,n} = \frac{(1+k)^n - 1}{k}$ (for non-zero k)

Number of Periods,(n)	Interest Rate , k																					
	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	2.000	2.010	2.020	2.030	2.040	2.050	2.060	2.070	2.080	2.090	2.100	2.110	2.120	2.140	2.160	2.180	2.200	2.220	2.240	2.260	2.280	2.300
3	3.000	3.030	3.060	3.091	3.122	3.153	3.184	3.215	3.246	3.278	3.310	3.342	3.374	3.440	3.506	3.572	3.640	3.708	3.778	3.848	3.918	3.990
4	4.000	4.060	4.122	4.184	4.246	4.310	4.375	4.440	4.506	4.573	4.641	4.710	4.779	4.921	5.066	5.215	5.368	5.524	5.684	5.848	6.016	6.187
5	5.000	5.101	5.204	5.309	5.416	5.526	5.637	5.751	5.867	5.985	6.105	6.228	6.353	6.610	6.877	7.154	7.442	7.740	8.048	8.368	8.700	9.043
6	6.000	6.152	6.308	6.468	6.633	6.802	6.975	7.153	7.336	7.523	7.716	7.913	8.115	8.536	8.977	9.442	9.930	10.442	10.980	11.544	12.136	12.756
7	7.000	7.214	7.434	7.662	7.898	8.142	8.394	8.654	8.923	9.200	9.487	9.783	10.089	10.730	11.414	12.142	12.916	13.740	14.615	15.546	16.534	17.583
8	8.000	8.286	8.583	8.892	9.214	9.549	9.897	10.260	10.637	11.028	11.436	11.859	12.300	13.233	14.240	15.327	16.499	17.762	19.123	20.588	22.163	23.858
9	9.000	9.369	9.755	10.159	10.583	11.027	11.491	11.978	12.488	13.021	13.579	14.164	14.776	16.085	17.519	19.086	20.799	22.670	24.712	26.940	29.369	32.015
10	10.000	10.462	10.950	11.464	12.006	12.578	13.181	13.816	14.487	15.193	15.937	16.722	17.549	19.337	21.321	23.521	25.959	28.657	31.643	34.945	38.593	42.619
11	11.000	11.567	12.169	12.808	13.486	14.207	14.972	15.784	16.645	17.560	18.531	19.561	20.655	23.045	25.733	28.755	32.150	35.962	40.238	45.031	50.398	56.405
12	12.000	12.683	13.412	14.192	15.026	15.917	16.870	17.888	18.977	20.141	21.384	22.713	24.133	27.271	30.850	34.931	39.581	44.874	50.895	57.739	65.510	74.327
13	13.000	13.809	14.680	15.618	16.627	17.713	18.882	20.141	21.495	22.953	24.523	26.212	28.029	32.089	36.786	42.219	48.497	55.746	64.110	73.751	84.853	97.625
14	14.000	14.947	15.974	17.086	18.292	19.599	21.015	22.550	24.215	26.019	27.975	30.095	32.393	37.581	43.672	50.818	59.196	69.010	80.496	93.926	109.612	127.913
15	15.000	16.097	17.293	18.599	20.024	21.579	23.276	25.129	27.152	29.361	31.772	34.405	37.280	43.842	51.660	60.965	72.035	85.192	100.815	119.347	141.303	167.286
16	16.000	17.258	18.639	20.157	21.825	23.657	25.673	27.888	30.324	33.003	35.950	39.190	42.753	50.980	60.925	72.939	87.442	104.935	126.011	151.377	181.868	218.472
17	17.000	18.430	20.012	21.762	23.698	25.840	28.213	30.840	33.750	36.974	40.545	44.501	48.884	59.118	71.673	87.068	105.931	129.020	157.253	191.735	233.791	285.014
18	18.000	19.615	21.412	23.414	25.645	28.132	30.906	33.999	37.450	41.301	45.599	50.396	55.750	68.394	84.141	103.740	128.117	158.405	195.994	242.585	300.252	371.518
19	19.000	20.811	22.841	25.117	27.671	30.539	33.760	37.379	41.446	46.018	51.159	56.939	63.440	78.969	98.603	123.414	154.740	194.254	244.033	306.658	385.323	483.973
20	20.000	22.019	24.297	26.870	29.778	33.066	36.786	40.995	45.762	51.160	57.275	64.203	72.052	91.025	115.380	146.628	186.688	237.989	303.601	387.389	494.213	630.165
21	21.000	23.239	25.783	28.676	31.969	35.719	39.993	44.865	50.423	56.765	64.002	72.265	81.699	104.768	134.841	174.021	225.026	291.347	377.465	489.110	633.593	820.215
22	22.000	24.472	27.299	30.537	34.248	38.505	43.392	49.006	55.457	62.873	71.403	81.214	92.503	120.436	157.415	206.345	271.031	356.443	469.056	617.278	811.999	1,067.280
23	23.000	25.716	28.845	32.453	36.618	41.430	46.996	53.436	60.893	69.532	79.543	91.148	104.603	138.297	183.601	244.487	326.237	435.861	582.630	778.771	1,040.358	1,388.464
24	24.000	26.973	30.422	34.426	39.083	44.502	50.816	58.177	66.765	76.790	88.497	102.174	118.155	158.659	213.978	289.494	392.484	532.750	723.461	982.251	1,332.659	1,806.003
25	25.000	28.243	32.030	36.459	41.646	47.727	54.865	63.249	73.106	84.701	98.347	114.413	133.334	181.871	249.214	342.603	471.981	650.955	898.092	1,238.636	1,706.803	2,348.803
26	26.000	29.526	33.671	38.553	44.312	51.113	59.156	68.676	79.954	93.324	109.182	127.999	150.334	208.333	290.088	405.272	567.377	795.165	1,114.634	1,561.682	2,185.708	3,054.444
27	27.000	30.821	35.344	40.710	47.084	54.669	63.706	74.484	87.351	102.723	121.100	143.079	169.374	238.499	337.502	479.221	681.853	971.102	1,383.146	1,968.719	2,798.706	3,971.778
28	28.000	32.129	37.051	42.931	49.968	58.403	68.528	80.698	95.339	112.968	134.210	159.817	190.699	272.889	392.503	566.481	819.223	1,185.744	1,716.101	2,481.586	3,583.344	5,164.311
29	29.000	33.450	38.792	45.219	52.966	62.323	73.640	87.347	103.966	124.135	148.631	178.397	214.583	312.094	456.303	669.447	984.068	1,447.608	2,128.965	3,127.798	4,587.680	6,714.604
30	30.000	34.785	40.568	47.575	56.085	66.439	79.058	94.461	113.283	136.308	164.494	199.021	241.333	356.787	530.312	790.948	1,181.882	1,767.081	2,640.916	3,942.026	5,873.231	8,729.985
31	31.000	36.133	42.379	50.003	59.328	70.761	84.802	102.073	123.346	149.575	181.9	221.9	271.3	407.7	616.2	934.3	1,419.3	2,156.8	3,275.7	4,968.0	7,516.7	11,350.0
32	32.000	37.494	44.227	52.503	62.701	75.299	90.890	110.218	134.214	164.037	201.1	247.3	304.8	465.8	715.7	1,103.5	1,704.1	2,632.3	4,062.9	6,260.6	9,625.0	14,756.0
33	33.000	38.869	46.112	55.078	66.210	80.064	97.343	118.933	145.951	179.800	222.3	275.5	342.4	532.0	831.3	1,303.1	2,045.9	3,212.5	5,039.0	7,889.4	12,321.0	19,183.8
34	34.000	40.258	48.034	57.73	69.86	85.07	104.18	128.259	158.627	196.982	245.5	306.8	384.5	607.5	965.3	1,538.7	2,456.1	3,920.2	6,249.4	9,941.6	15,771.8	24,939.9
35	35.000	41.660	49.994	60.46	73.65	90.32	111.43	138.237	172.317	215.711	271.0	341.6	431.7	693.6	1,120.7	1,816.7	2,948.3	4,783.6	7,750.2	12,527.4	20,189.0	32,422.9
36	36.000	43.077	51.994	63.28	77.60	95.84	119.12	148.913	187.102	236.125	299.1	380.2	484.5	791.7	1,301.0	2,144.6	3,539.0	5,837.0	9,611.3	15,785.6	25,842.9	42,150.7
37	37.000	44.508	54.034	66.17	81.70	101.63	127.27	160.337	203.070	258.376	330.0	423.0	543.6	903.5	1,510.2	2,531.7	4,247.8	7,122.2	11,919.0	19,890.8	33,079.9	54,796.9
38	38.000	45.953	56.115	69.16	85.97	107.71	135.90	172.561	220.316	282.630	364.0	470.5	609.8	1,031.0	1,752.8	2,988.4	5,098.4	8,690.1	14,780.5	25,063.4	42,343.2	71,237.0
39	39.000	47.412	58.237	72.23	90.41	114.10	145.06	185.640	238.941	309.066	401.4	523.3	684.0	1,176.3	2,034.3	3,527.3	6,119.0	10,602.9	18,328.9	31,580.9	54,200.4	92,609.1
40	40.000	48.886	60.402	75.40	95.03	120.80	154.76	199.635	259.057	337.882	442.6	581.8	767.1	1,342.0	2,360.8	4,163.2	7,343.9	12,936.5	22,728.8	39,793.0	69,377.5	120,392.9

FVIF

FVIF Table

Future Value Interest Factors, Compounded at k Percent for n periods : $FVIF_{k,n} = (1+k)^n$

Number of Periods, (n)	Interest Rate , k																				
	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	14%	16%	18%	20%	22%	24%	26%	28%	30%
1	1.000	1.0100	1.0200	1.0300	1.0400	1.0500	1.0600	1.0700	1.0800	1.0900	1.1000	1.1100	1.1200	1.1400	1.1600	1.1800	1.2000	1.2200	1.2400	1.2600	1.2800	1.3000
2	1.000	1.0201	1.0404	1.0609	1.0816	1.1025	1.1236	1.1449	1.1664	1.1881	1.2100	1.2321	1.2544	1.2996	1.3456	1.3924	1.4400	1.4884	1.5376	1.5876	1.6384	1.6900
3	1.000	1.0303	1.0612	1.0927	1.1249	1.1576	1.1910	1.2250	1.2597	1.2950	1.3310	1.3676	1.4049	1.4815	1.5609	1.6430	1.7280	1.8158	1.9066	2.0004	2.0972	2.1970
4	1.000	1.0406	1.0824	1.1255	1.1699	1.2155	1.2625	1.3108	1.3605	1.4116	1.4641	1.5181	1.5735	1.6890	1.8106	1.9388	2.0736	2.2153	2.3642	2.5205	2.6844	2.8561
5	1.000	1.0510	1.1041	1.1593	1.2167	1.2763	1.3382	1.4026	1.4693	1.5386	1.6105	1.6851	1.7623	1.9254	2.1003	2.2878	2.4883	2.7027	2.9316	3.1758	3.4360	3.7129
6	1.000	1.0615	1.1262	1.1941	1.2653	1.3401	1.4185	1.5007	1.5869	1.6771	1.7716	1.8704	1.9738	2.1950	2.4364	2.6996	2.9860	3.2973	3.6352	4.0015	4.3980	4.8268
7	1.000	1.0721	1.1487	1.2299	1.3159	1.4071	1.5036	1.6058	1.7138	1.8280	1.9487	2.0762	2.2107	2.5023	2.8262	3.1855	3.5832	4.0227	4.5077	5.0419	5.6295	6.2749
8	1.000	1.0829	1.1717	1.2668	1.3686	1.4775	1.5938	1.7182	1.8509	1.9926	2.1436	2.3045	2.4760	2.8526	3.2784	3.7589	4.2998	4.9077	5.5895	6.3528	7.2058	8.1573
9	1.000	1.0937	1.1951	1.3048	1.4233	1.5513	1.6895	1.8385	1.9990	2.1719	2.3579	2.5580	2.7731	3.2519	3.8030	4.4355	5.1598	5.9874	6.9310	8.0045	9.2234	10.6045
10	1.000	1.1046	1.2190	1.3439	1.4802	1.6289	1.7908	1.9672	2.1589	2.3674	2.5937	2.8394	3.1058	3.7072	4.4114	5.2338	6.1917	7.3046	8.5944	10.0857	11.8059	13.7858
11	1.000	1.1157	1.2434	1.3842	1.5395	1.7103	1.8983	2.1049	2.3316	2.5804	2.8531	3.1518	3.4785	4.2262	5.1173	6.1759	7.4301	8.9117	10.6571	12.7080	15.1116	17.9216
12	1.000	1.1268	1.2682	1.4258	1.6010	1.7959	2.0122	2.2522	2.5182	2.8127	3.1384	3.4985	3.8960	4.8179	5.9360	7.2876	8.9161	10.8722	13.2148	16.0120	19.3428	23.2981
13	1.000	1.1381	1.2936	1.4685	1.6651	1.8856	2.1329	2.4098	2.7196	3.0658	3.4523	3.8833	4.3635	5.4924	6.8858	8.5994	10.6993	13.2641	16.3863	20.1752	24.7588	30.2875
14	1.000	1.1495	1.3195	1.5126	1.7317	1.9799	2.2609	2.5785	2.9372	3.3417	3.7975	4.3104	4.8871	6.2613	7.9875	10.1472	12.8392	16.1822	20.3191	25.4207	31.6913	39.3738
15	1.000	1.1610	1.3459	1.5580	1.8009	2.0789	2.3966	2.7590	3.1722	3.6425	4.1772	4.7846	5.4736	7.1379	9.2655	11.9737	15.4070	19.7423	25.1956	32.0301	40.5648	51.1859
16	1.000	1.1726	1.3728	1.6047	1.8730	2.1829	2.5404	2.9522	3.4259	3.9703	4.5950	5.3109	6.1304	8.1372	10.7480	14.1290	18.4884	24.0856	31.2426	40.3579	51.9230	66.5417
17	1.000	1.1843	1.4002	1.6528	1.9479	2.2920	2.6928	3.1588	3.7000	4.3276	5.0545	5.8951	6.8660	9.2765	12.4677	16.6722	22.1861	29.3844	38.7408	50.8510	66.4614	86.5042
18	1.000	1.1961	1.4282	1.7024	2.0258	2.4066	2.8543	3.3799	3.9960	4.7171	5.5599	6.5436	7.6900	10.5752	14.4625	19.6733	26.6233	35.8490	48.0386	64.0722	85.0706	112.4554
19	1.000	1.2081	1.4568	1.7535	2.1068	2.5270	3.0256	3.6165	4.3157	5.1417	6.1159	7.2633	8.6128	12.0557	16.7765	23.2144	31.9480	43.7358	59.5679	80.7310	108.8904	146.1920
20	1.000	1.2202	1.4859	1.8061	2.1911	2.6533	3.2071	3.8697	4.6610	5.6044	6.7275	8.0623	9.6463	13.7435	19.4608	27.3930	38.3376	53.3576	73.8641	101.7211	139.3797	190.0496
21	1.000	1.2324	1.5157	1.8603	2.2788	2.7860	3.3996	4.1406	5.0338	6.1088	7.4002	8.9492	10.8038	15.6676	22.5745	32.3238	46.0051	65.0963	91.5915	128.1685	178.4060	247.0645
22	1.000	1.2447	1.5460	1.9161	2.3699	2.9253	3.6035	4.4304	5.4365	6.6586	8.1403	9.9336	12.1003	17.8610	26.1864	38.1421	55.2061	79.4175	113.5735	161.4924	228.3596	321.1839
23	1.000	1.2572	1.5769	1.9736	2.4647	3.0715	3.8197	4.7405	5.8715	7.2579	8.9543	11.0263	13.5523	20.3616	30.3762	45.0076	66.2474	96.8894	140.8312	203.4804	292.3003	417.5391
24	1.000	1.2697	1.6084	2.0328	2.5633	3.2251	4.0489	5.0724	6.3412	7.9111	9.8497	12.2392	15.1786	23.2122	35.2364	53.1090	79.4968	118.2050	174.6306	256.3853	374.1444	542.8008
25	1.000	1.2824	1.6406	2.0938	2.6658	3.3864	4.2919	5.4274	6.8485	8.6231	10.8347	13.5855	17.0001	26.4619	40.8742	62.6686	95.3962	144.2101	216.5420	323.0454	478.9049	705.6410
26	1.000	1.2953	1.6734	2.1566	2.7725	3.5557	4.5494	5.8074	7.3964	9.3992	11.9182	15.0799	19.0401	30.1666	47.4141	73.9490	114.4755	175.9364	268.5121	407.0373	612.9982	917.3333
27	1.000	1.3082	1.7069	2.2213	2.8834	3.7335	4.8223	6.2139	7.9881	10.2451	13.1100	16.7386	21.3249	34.3899	55.0004	87.2598	137.3706	214.6424	332.9550	512.8570	784.6377	1,192.5333
28	1.000	1.3213	1.7410	2.2879	2.9987	3.9201	5.1117	6.6488	8.6271	11.1671	14.4210	18.5799	23.8839	39.2045	63.8004	102.9666	164.8447	261.8637	412.8642	646.2124	1,004.3363	1,550.2933
29	1.000	1.3345	1.7758	2.3566	3.1187	4.1161	5.4184	7.1143	9.3173	12.1722	15.8631	20.6237	26.7499	44.6931	74.0085	121.5005	197.8136	319.4737	511.9516	814.2276	1,285.5504	2,015.3813
30	1.000	1.3478	1.8114	2.4273	3.2434	4.3219	5.7435	7.6123	10.0627	13.2677	17.4494	22.8923	29.9599	50.9502	85.8499	143.3706	237.3763	389.7579	634.8199	1,025.9267	1,645.5046	2,619.9956
31	1.000	1.3613	1.8476	2.5001	3.3731	4.5380	6.0881	8.1451	10.8677	14.4618	19.1943	25.4104	33.5551	58.0832	99.5859	169.1774	284.8516	475.5046	787.1767	1,292.6677	2,106.2458	3,405.9943
32	1.000	1.3749	1.8845	2.5751	3.5081	4.7649	6.4534	8.7153	11.7371	15.7633	21.1138	28.2056	37.5817	66.2148	115.5196	199.6293	341.8219	580.1156	976.0991	1,628.7613	2,695.9947	4,427.7926
33	1.000	1.3887	1.9222	2.6523	3.6484	5.0032	6.8406	9.3253	12.6760	17.1820	23.2252	31.3082	42.0915	75.4849	134.0027	235.5625	410.1863	707.7411	1,210.3629	2,052.2392	3,450.8732	5,756.1304
34	1.000	1.4026	1.9607	2.7319	3.7943	5.2533	7.2510	9.9781	13.6901	18.7284	25.5477	34.7521	47.1425	86.0528	155.4432	277.9638	492.2235	863.4441	1,500.8500	2,585.8215	4,417.1177	7,482.9696
35	1.000	1.4166	1.9999	2.8139	3.9461	5.5160	7.6861	10.6766	14.7853	20.4140	28.1024	38.5749	52.7996	98.1002	180.3141	327.9973	590.6682	1,053.4018	1,861.0540	3,258.1350	5,653.9106	9,727.8604
36	1.000	1.4308	2.0399	2.8983	4.1039	5.7918	8.1473	11.4239	15.9682	22.2512	30.9127	42.8181	59.1356	111.8342	209.1643	387.0368	708.8019	1,285.1502	2,307.7070	4,105.2501	7,237.0056	12,646.2186
37	1.000	1.4451	2.0807	2.9852	4.2681	6.0814	8.6361	12.2236	17.2456	24.2538	34.0039	47.5281	66.2318	127.4910	242.6306	456.7034	850.5622	1,567.8833	2,861.5567	5,172.6152	9,263.3671	16,440.0841
38	1.000	1.4595	2.1223	3.0748	4.4388	6.3855	9.154	13.079	18.625	26.437	37.404	52.756	74.180	145.340	281.452	538.910	1,020.675	1,912.818	3,548.330	6,517.495	11,857.110	21,372.109
39	1.000	1.4741	2.1647	3.1670	4.6164	6.7048	9.704	13.995	20.115	28.816	41.145	58.559	83.081	165.687	326.484	635.914	1,224.810	2,333.638	4,399.930	8,212.044	15,177.101	27,783.742
40	1.000	1.4889	2.2080	3.2620	4.8010	7.0400	10.286	14.974	21.725	31.409	45.259	65.001	93.051	188.884	378.721	750.378	1,469.772	2,847.038	5,455.913	10,347.175	19,426.689	36,118.865
41	1.000	1.5038	2.2522	3.3599	4.9931	7.3920	10.903	16.023	23.462	34.236	49.785	72.151	104.217	215.327	439.317	885.446	1,763.726	3,473.386	6,765.332	13,037.441	24,866.162	46,954.524
42	1.000	1.5188	2.2972	3.4607	5.1928	7.7616	11.557	17.144	25.339	37.318	54.764	80.088	116.723	245.473	509.607	1,044.827	2,116.471	4,237.531	8,389.011	16,427.175	31,828.687	61,040.882
43	1.000	1.5340	2.3432	3.5645	5.4005	8.1497	12.250	18.344	27.367	40.676	60.240	88.897	130.730	279.839	591.144	1,232.896	2,539.765	5,169.788	10,402.374	20,698.241	40,740.720	79,353.146
44	1.000	1.5493	2.3901	3.6715	5.6165	8.5572	12.985	19.628	29.556	44.337	66.264	98.676	146.418	319.017	685.727	1,454.817	3,047.718	6,307.141	12,898.944	26,079.784	52,148.121	103,159.090
45	1.000	1.5648	2.4379	3.7816	5.8412	8.9850	13.765	21.002	31.920	48.327	72.890	109.530	163.988	363.679	795.444	1,716.684	3,657.262	7,694.712	15,994.690	32,860.527	66,749.595	134,106.817
46	1.000	1.5805	2.4866	3.8950	6.0748	9.4343	14.590	22.473	34.474	52.677	80.180	121.579	183.666	414.594	922.715	2,025.687	4,388.714	9,387.549	19,833.416	41,404.265	85,439.481	174,338.862
47	1.000	1.5963	2.5363	4.0119	6.3178	9.9060	15.466	24.046	37.232	57.418	88.197	134.952	205.706	472.637	1,070.349	2,390.311	5,266.457	11,452.810	24,593.436	52,169.373	109,362.536	226,640.520
48	1.000	1.6122	2.5871	4.1323	6.5705	10.401	16.394	25.729	40.211	62.585	97.017	149.797	230.391	538.807	1,241.605	2,820.567	6,319.749	13,972.428	30,495.860	65,733.410	139,984.046	294,632.676
49	1.000	1.6283	2.6388	4.2562	6.8333	10.921	17.378	27.530	43.427	68.218	106.719	166.275	258.038	614.239	1,440.262	3,328.269	7,583.698	17,046.362	37,814.867	82,824.097	179,179.579	383,022.479
50	1.000	1.6446	2.6916	4.3839	7.1067	11.467	18.420	29.457	46.902	74.358	117.391	184.565	289.002	700.233	1,670.704	3,927.357	9,100.438	20,796.561	46,890.435	104,358.362	229,349.862	497,929.223