ASHRAE Distinguished Lecturer Talk
ASHRAE India Chapter
New Delhi
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Ventilation, IAQ and Energy Issues in hot humid climates – Past, Present and Future

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Department of Building, School of Design and Environment

Learning Objectives

1. Describe an integrated IAQ-Energy audit methodology
2. Interpret the IAQ and Energy audit data from case studies in a hot and humid climate
3. Describe the key features of Thermal Comfort and Ventilation Standards (a) ASHRAE Standards 55 & 62.1 and (b) Singapore Standards
4. Describe the Singapore Green Mark Scheme for rating buildings for environmental sustainability
IAQ Scenario

...... improving building environments may result in health benefits for more than 15 million of the 89 million US indoor workers, with estimated economic benefits of $5 to $75 billion annually.


Benefits and costs of improved IEQ in U.S. offices

Scenarios
• Increasing vent rates when below 10 or 15 l/s per person
• Adding O/A economisers and controls when absent
• Eliminating winter indoor temps >23°C
• Reducing dampness and mold problems

Estimated Benefits
• Increased work performance
• Reduced SBS symptoms
• Reduced absenteeism
• Improved thermal comfort for millions of office workers

Combined potential annual economic benefit of a set of nonoverlapping scenarios ≈$20 billion

Quantitative estimates have a high uncertainty – BUT opportunity for substantial benefits is clear
IAQ - Source Control

“If there is a pile of manure in a space, do not try to remove the odor by ventilation. Remove the pile of manure.”

Max Joseph von Pettenkofer (1818-1901), German chemist

IAQ Audit - CASE STUDIES
OBJECTIVES OF AUDIT

- Establish status of Indoor Air Quality (IAQ)
- Identify strategies for improving IAQ
- Basis for developing an IAQ audit and management program
Figure 11: A comparison of MALE and FEMALE Building Related Symptoms (Mean of all five buildings) - Here and Now (%)

<table>
<thead>
<tr>
<th></th>
<th>Building Related Symptoms</th>
<th>Percentage of occupants experiencing symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Total</td>
</tr>
<tr>
<td>Dryeye</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>Sinusitis</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>Dizziness</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>Headache</td>
<td>34</td>
<td>37</td>
</tr>
<tr>
<td>Migraine</td>
<td>26</td>
<td>30</td>
</tr>
<tr>
<td>Runnose</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Wateryeye</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Cough</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Headache</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Flusymp</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Rash</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>


Acceptability of Indoor Air Quality (% Dissatisfied) - A Comparison of Singapore and EU studies

<table>
<thead>
<tr>
<th></th>
<th>% Dissatisfies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>25.0</td>
</tr>
<tr>
<td>Singapore</td>
<td>30.0</td>
</tr>
<tr>
<td>Switzerland</td>
<td>30.0</td>
</tr>
<tr>
<td>Finland</td>
<td>30.0</td>
</tr>
<tr>
<td>France</td>
<td>30.0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>30.0</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>30.0</td>
</tr>
<tr>
<td>Greece</td>
<td>30.0</td>
</tr>
<tr>
<td>Denmark</td>
<td>30.0</td>
</tr>
<tr>
<td>Norway</td>
<td>30.0</td>
</tr>
</tbody>
</table>
Figure 7: Indoor air acceptability versus thermal comfort

\[
y = 2.877x - 0.7754 \\
R^2 = 0.8529
\]

\[
y = 3.6399x - 2.0058 \\
R^2 = 0.8499
\]

Figure 9: Indoor air acceptability versus stuffiness

\[
y = 1.3945x - 1.5936 \\
R^2 = 0.9385
\]

\[
y = 1.1797x - 0.4819 \\
R^2 = 0.8136
\]
DIMENSIONS OF INDOOR AIR QUALITY

- Chemical
- Biological
- Physical

Objective Measurements – IAQ parameters

CHEMICAL

- Sources
  - Interior furnishings
  - Equipment
  - Stationery
  - Outside sources
- Particular chemicals
  - TVOCs
  - Formaldehyde
  - Carbon Monoxide
  - Carbon Dioxide
BIOLOGICAL

- Sources
  - Occupants
  - Visitors
  - Food
  - Outside sources

- Particular contaminants
  - Total Bacteria
  - Yeasts & Molds

**Guideline value = 500 CFU/m³**

VENTILATION STUDIES IN NINE AIR-CONDITIONED OFFICE BUILDINGS IN SINGAPORE

**Period of Study: 1993 - 1997**
Factors affecting ventilation performance
Ø space layout
Ø fresh air quantity
Ø supply diffusers and return grilles

Indoor air flow pattern
Ø Short circuiting
Ø Piston flow
Ø Perfect mixing

Flow pattern affects
• Indoor Air Quality (IAQ)
• Building energy consumption

VENTILATION CHARACTERISTICS

THE VENTILATION MODEL
Age-of-air
Laverage amount of time elapsed since molecules in a sample entered the building
• measured by tracer gas techniques

"youngest" air found where the outdoor air comes into the room –

"oldest" air found at any other point in the room
Tracer Gas Monitoring

- TRACER GAS MEASUREMENTS

- AGE OF AIR VALUES
  - LOCAL MEAN AGE OF AIR
  - ROOM AVERAGE AGE OF AIR

- AIR CHANGE RATE

- Air Exchange Effectiveness (also known as Ventilation Effectiveness)

Type of tracers used usually colourless, odourless, inert gases (e.g. SF6)

Important aspect of TG measurements can be made in occupied buildings
Concentration-decay method

Air Change per Hour (ACH)

slope of the tracer gas concentration decay curve

\[
ACH = \ln(C_0 - \ln(C_1)) \quad \frac{\Delta t}{\Delta t}
\]

Linear Plot

Semi Log Plot

Tracer Gas (ppm)

Tracer Gas (ppm)

Time

Time
Air Exchange Effectiveness

Perfectly mixed air - datum for all three AEE parameters
AEE = 1

\[ \text{AEE}_G = 2.0 \] "perfect" displacement flow

\[ \text{AEE}_G < 1.0 \] shortcircuiting
\[ \text{AEE}_G > 1.0 \] displacement flow

the greater the deviations from unity, more pronounced are the two flow patterns

Key building characteristics

- Floor by Floor AHUs CAV system: A, C
- Floor by Floor AHUs VAV system: B, D, E, BB, DD, EE
- 3 Central AHUs VAV system: CC
Figure 1: Summary of Air Change per Hour (ACH) values

Figure 2: Comparison of fresh air provision based on design occupancy
Conclusions – 9 Buildings Study

- Tracer gas analysis: In-situ ventilation measurements
- Significant variations in ACH values
- Minor short-circuiting profiles in some zones
- AEE values generally indicative of well-mixed flow patterns
Some other Observations
Air change rates (ACH) measured in the European and Singapore buildings studied

VENTILATION & IAQ ISSUES IN SPLIT SYSTEM AIR-CONDITIONING UNIT IN A RESIDENTIAL BUILDING IN SINGAPORE

Year of study: 2002/2003
Master Bed-room in a condominium apartment (8th Storey)

CO2 concentration during measurement and night-time sleeping period

2 Adults, 1 Child – Sleeping Period during night

4 Adults (Experiment Phase)

Exhaust fan switched on
Thermal Comfort
Ventilation
and
IAQ
Standards

Current version –
ASHRAE Standard
55-2013

SSPC 55 to maintain and revise Standard 55. Standard on continuous maintenance.
Standard 55 placed on continuous maintenance January 24, 2004 (Anaheim). SSPC 55
Thermal Comfort

ASHRAE Standard 55-2010

Draft

Radiant temperature discomfort
Vertical Air Temperature Difference
Floor surface temperature
Temperature variations with time
Cyclic variations (15 minutes interval)
Drifts or Ramps (non-cyclic changes - > 15 mins)

Local thermal discomfort
Elevated Air Speed
Humidity - No lower limit - 0.012 kg/kg upper limit
Operative temperature

Data based on ISO 7730 and ASHRAE STD55

Upper Recommended Humidity Limits: 0.012 Humidity ratio

Lower Humidity Limit

PMV Limits

Operative Temperature, °C

Dew Point Temperature, °C
Professor Chandra Sekhar, National
University of Singapore

9/6/14

Figure 5.2.1.2 Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV).

- Occupant controlled NV spaces
- Adaptive model – global database of 21,000 meas – primarily in office buildings
- No mechanical cooling system
- No humidity or air speed limits required
- Allows for local thermal discomfort in typical buildings
- Operable windows – open to outdoors
- Accounts for people’s clothing adaptation in NV spaces
- Mech Vent with unconditioned air possible

Figure 5.3 Acceptable operative temperature ranges for naturally conditioned spaces.
Professor Chandra Sekhar, National University of Singapore
Purpose

Specify minimum ventilation rates & other measures – to provide IAQ acceptable to occupants & minimise adverse health effects

Guidance for IAQ improvement in existing buildings

62.1-2013

Acceptable Indoor Air Quality

air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction
Green Building Standard

- Published in January 2010
- Serves as benchmark for sustainable green buildings – does not apply to all buildings
- Addresses energy, impact on the atmosphere, sustainable sites, water use, materials and resources and IEQ
- Jurisdictional compliance option for International Green Construction Code

www.ashrae.org/greenstandard

Standard 189.1

- Standard for Design of High-Performance Green Buildings
- An ANSI standard developed in model code language
- Provides minimum requirements for high-performance, green building
Standard 189.1 Topic Areas

SS Sustainable Sites
WE Water Use Efficiency
EE Energy Efficiency
IEQ Indoor Environmental Quality
MR Building’s Impact on the Atmosphere, Materials & Resources
CO Construction and Operations Plans

SINGAPORE

SS 553 : 2009 Code of Practice for Air-conditioning and Mechanical Ventilation in Buildings (formerly CP 13)

SS 554 : 2009 Code of Practice for Indoor Air Quality for Air-Conditioned Buildings

Published November 2009
### Table 1 – Outdoor air supply requirement for comfort air-conditioning

<table>
<thead>
<tr>
<th>Type of building/Occupancy</th>
<th>Minimum outdoor air supply</th>
<th>ASHRAE Std 62.1-2010 (l/s/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restaurants</td>
<td>3.4</td>
<td>5.1</td>
</tr>
<tr>
<td>i) Dance halls</td>
<td>7.0</td>
<td>10.3</td>
</tr>
<tr>
<td>Offices</td>
<td>0.6</td>
<td>8.5</td>
</tr>
<tr>
<td>ii) Shops, supermarkets and department stores</td>
<td>1.1</td>
<td>7.8/7.6/7.8</td>
</tr>
<tr>
<td>Theatres and cinemas seating area</td>
<td>2.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Lobbies and corridors</td>
<td>0.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Concourses</td>
<td>1.1</td>
<td>3.5</td>
</tr>
<tr>
<td>iii) Hotel guest rooms</td>
<td>15.0 L/s per room</td>
<td>5.5</td>
</tr>
<tr>
<td>iv) Classrooms</td>
<td>2.8</td>
<td>4 – 7.4</td>
</tr>
<tr>
<td>Primary school children and above</td>
<td>2.8</td>
<td>8.6</td>
</tr>
<tr>
<td>Childcare Centres</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>

SS 553 : 2009

Energy Scenario

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Professor Chandra Sekhar, National University of Singapore
World Marketed Energy Consumption by Region, 2004-2030

OECD and Non-OECD Commercial Sector Delivered Energy Consumption, 2004-2030

Commercial and Services sectors – includes different building types
- Office buildings, schools, stores, correctional institutions, restaurants, hotels, hospitals, museums, banks, stadium


BCA Green Mark Scheme
Singapore

New Buildings
- New Dev
- Redevelopment
- A&A to existing buildings
- Major retrofitting

Existing Buildings
- Under operation with no significant retrofitting works

Green Mark Assessment Criteria

BCA – Building and Construction Authority, Singapore
## Points for Green Mark Criteria

### BCA Green Mark for Non-Residential Building

**Version 4.1**

15 January 2013

[BCA Green Mark logo]


<table>
<thead>
<tr>
<th>BCA Green Mark Schemes</th>
<th>Description</th>
<th>Effective Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Residential New Buildings (Version 4.1)</td>
<td>Applicable for new buildings such as offices, commercial, industrial and institutional buildings with or without air-conditioning systems.</td>
<td>15 Jan 2013 onwards</td>
</tr>
<tr>
<td>Residential New buildings (Version 4.1)</td>
<td>For new private and public residential developments.</td>
<td>15 Jan 2013 onwards</td>
</tr>
<tr>
<td>Existing Buildings (Version 3)</td>
<td>Applicable to existing commercial, industrial and institutional buildings under operation.</td>
<td>26 Jul 2012 onwards</td>
</tr>
<tr>
<td>Existing Buildings (Version 2.1)</td>
<td>Applicable to existing commercial, industrial and institutional buildings under operation. Assessment by this criteria is necessary for application of GMIS (Existing Building).</td>
<td>1 Dec 2009 onwards</td>
</tr>
<tr>
<td>Existing Residential Buildings (Version 1)</td>
<td>For existing private and public residential developments.</td>
<td>19 May 2011 onwards</td>
</tr>
<tr>
<td>Existing Schools (Version 1)</td>
<td>Applicable to MOE main stream schools (excluding International schools, Universities and Institute of Higher Learning: Polytechnics and ITE).</td>
<td>4 Aug 2011 onwards</td>
</tr>
<tr>
<td>Office Interior (Version 1.1)</td>
<td>Applicable for tenant renovation and maintenance practices.</td>
<td>01 Nov 2012 onwards</td>
</tr>
<tr>
<td>Landed Houses (Version 1)</td>
<td>For landed housing projects.</td>
<td>27 May 2009 onwards</td>
</tr>
<tr>
<td>Infrastructure (Version 1)</td>
<td>For infrastructure projects e.g. as barrages, roads, bridges.</td>
<td>27 May 2009 onwards</td>
</tr>
<tr>
<td>District (Version 2)</td>
<td>For district projects.</td>
<td>01 Jan 2013 onwards</td>
</tr>
<tr>
<td>Restaurants (Version 1)</td>
<td>For Restaurants.</td>
<td>12 Sep 2011 onwards</td>
</tr>
<tr>
<td>Supermarket (Version 1)</td>
<td>For Supermarket.</td>
<td>11 Oct 2012 onwards</td>
</tr>
<tr>
<td>Existing Data Cetres (Version 1)</td>
<td>For Existing Data Cetres.</td>
<td>11 Oct 2012 onwards</td>
</tr>
<tr>
<td>Retail (Version 1)</td>
<td>For Retail Tenants.</td>
<td>11 Oct 2012 onwards</td>
</tr>
<tr>
<td>New Parks (Version 1)</td>
<td>For New Parks</td>
<td>26 May 2010 onwards</td>
</tr>
<tr>
<td>Existing Parks (Version 1)</td>
<td>For Existing Parks</td>
<td>22 May 2008 onwards</td>
</tr>
</tbody>
</table>
## Green Mark Award Rating

<table>
<thead>
<tr>
<th>Green Mark Points</th>
<th>Green Mark Rating</th>
</tr>
</thead>
</table>
| 90 and above      | Green Mark Platinum  
|                   | GMIS Req → Energy Modeling →  
|                   | At least 30% Energy Savings |
| 85 to < 90        | Green Mark GoldPLUS  
|                   | GMIS Req → Energy Modeling →  
|                   | At least 25% Energy Savings |
| 75 to < 85        | Green Mark Gold     |
| 50 to < 75        | Green Mark Certified |

### Green Mark Building Projects in Singapore (Cumulative)

- **GFA (million m²)**
- **Number of building projects**
- **FY05** to **FY13**

Professor Chandra Sekhar, National University of Singapore
PERCENTAGE OF GREEN BUILDINGS IN SINGAPORE

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>0%</td>
</tr>
<tr>
<td>2013</td>
<td>21%</td>
</tr>
<tr>
<td>2030</td>
<td>80%</td>
</tr>
</tbody>
</table>

**NATIONAL LIBRARY BUILDING**

- 16-storey state-of-the-art library with a 3-level basement
- Two blocks - library collections - space for other public activities
- A 618-seat theatre
- Owner’s commitment at conceptualisation stage - design considerations: impact on environment, energy and water efficiency.
- Computer simulation & modeling - to find the best bldg orientation & configure - buffer from direct solar heat & optimising natural vent & daylighting.
- Passive design solutions with env-friendly technologies

**KEY GREEN FEATURES**

- Building orientated away from the E-W sun - sun shading features west face of building
- Energy efficient features - daylight sensors with automatic blinds at the building facades, motion sensors & energy efficient lightings
- An open plaza area between the two blocks - allows natural ventilation and daylighting
- Extensive landscaping, sky terraces and roof gardens - to lower local ambient temp
- Rain sensor - part of the automatic irrigation system for rooftop gardens. Water efficient taps & cisterns used to conserve water
Zero Energy Building @ BCA Academy (Special Buildings)

Key Features:
• Sunshading devices and efficient glazing.
• ACMV System (high performance chillers, displacement ventilation, personalised ventilation, under-floor air distribution system).
• Photovoltaic Technology of 190kWp capacity.
• Solar assisted stack ventilation.
• Mirror ducts, light pipes and light shelves.
• Sensors and monitoring system for all rooms.

2010 Green Mark Platinum

Key Features:
• Estimated energy savings: 388,720 kWh/yr
• Estimated water savings: 3,620 m³/yr
• ETTV: 43.79 W/m²

2012 Green Mark Platinum

Carlton City Hotel Singapore

New Non-Residential Buildings

Key Features:
• Estimated energy savings: 3,653,112 kWh/yr; estimated water savings: 12,300 m³/yr; ETTV: 31.41 W/m².
• Odour plant system efficiency of ≤ 0.6%Whton.
• Extensive use of LED lighting.
• Regenerative Drive Lift.
• Electric vehicle charging station.
• Air Handling Units (AHUs) and Fan Coil Units (FCUs) condense water recycling system.
• Non-chemical anti-termite system.
• Air purification system to improve indoor air quality.

Client / Developer
Carlton Properties (Singapore) Pte. Ltd.

Project Manager
KPR Quantity Surveyors (Singapore) Pte Ltd

Architect
DP Architects Pte Ltd

M&E Engineer
Baca Carter Hollings & Ferner G&A Pte Ltd

Structural Engineer
T.Y.Lin International Pte Ltd

Quantity Surveyor
KPR Quantity Surveyors (Singapore) Pte Ltd

Main Contractor
Kajima Overseas Asia Pte Ltd

Landscape Consultant
Site Concepts International Pte Ltd

Lighting Consultant
The Lightbox Pte Ltd

Interior Designer
Hirsch Bedner Associates Pte Ltd

Facade Consultant
A waiveon Singapore (Pte.) Ltd.

ACMV Contractor
Shinta Corporation (Singapore Branch)

A/V Consultant
Acmeon Acoustics Consultants Pte Ltd

Sign & Way Finding
Strategy Consultant Design Datum Pte Ltd

ESD Consultant
Kam Pte Ltd

Professor Chandra Sekhar, National University of Singapore
2013

BCA GREEN MARK FOR BUILDINGS AWARD

EduSports Building

New Non-Residential Buildings

Client / Developer
National University of Singapore

Architect
CP Architects Pte Ltd

M&E Engineer
Baca Carter Hollings & Ferrier (S.E. Asia) Pte Ltd

Structural Engineer
Baca Carter Hollings & Ferrier (S.E. Asia) Pte Ltd

Quantity Surveyor
Rider Levett Bucknall Pte Ltd

Main Contractor
Ando Singapore Pte Ltd

Landscape Consultant
Sireetocks Pte Ltd

ESD Consultant
Arup Singapore Pte Ltd

Key Features
- Estimated energy savings: 1,819,308 kWh/yr; estimated water savings: 709 m³/yr; ETTV: 31.5 W/m².
- Naturally ventilated semi-outdoor atrium.
- Extensive green roof.
- Waste management including provision of recycling facilities, recycling of e-waste and organic wastes and implementation of biodegradable food packaging.
- High performance, self-cleaning façades with cool paint coating.
- UV emitters in AHU to improve indoor air quality.
- Drought tolerant plants to reduce water consumption.
- Educational features including LCD display of energy/water consumption.

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BCA GREEN MARK FOR BUILDINGS AWARD

Changi City

New Non-Residential Buildings

Client / Developer
Ascendas Frasers Pte Ltd.

Project Manager
Ascendas Frasers Pte Ltd.

Architect
Aedas Pte Ltd.

M&E Engineer
Baca Carter Hollings & Ferrier (S.E. Asia) Pte Ltd.

Structural Engineers
Retail and Hotel
DE Consultants (S) Pte Ltd.

Quantity Surveyor
KRF Quantity Surveyors (Singapore) Pte Ltd

Main Contractor
Nakano Singapore Pte Ltd.

Landscape Consultant
Belt Collins International (Singapore) Pte Ltd.

ESD Consultant
Arup Singapore Pte Ltd

Key Features
- Estimated energy savings: 15,056,223 kWh/yr; estimated water savings: 299,582 m³/yr; ETTV: 40.77 W/m².
- Designation control system for lifts in office building.
- AHU installed with UV emitter to improve indoor air quality.
- Skylight at retail atrium to provide natural daylight.
- Recycling of AMU condensate in office building and hotel.
2013

BCA GREEN MARK FOR BUILDINGS AWARD

Fusionopolis Phase ZA @ one-north
New Non-Residential Buildings

Clients / Developers

JTC Corporation
A*STAR

Project Manager
PM Link Pte Ltd

Architect

B&T Consultants Pte Ltd

M&E Engineer
Parsons Brinckerhoff Pte Ltd

Structural Engineer

Aero-Singapore Pte Ltd

Quantity Surveyor

KPK Quantity Surveyors
Singapore Pte Ltd

Main Contractor

GS Engineering & Construction Corp

Landscape Consultant
Martin Lee Designs

ESD Consultant
Parsons Brinckerhoff Pte Ltd

Key Features

- Estimated energy savings: 14,839,226 kWh/yr;
estimated water savings: 15,660 m3/yr; ETTV: 34.75 kWe2.
- Chiller plant system efficiency of 0.80 kWh/ton.
- Permanent measurement and verification instrumentation
  for the monitoring of IHAd water plant efficiency and heat
  balance.
- Low-e double glazing of vision panels.
- Integrated design of heat pipes for cooling coil at Modular
  Air Handling Units (MAHU) for efficient dehumidification and
  temperature control.
- Use of high performance fan filter units with low power
  consumption DC motors.
- Use of 50.5% certified carpets, laminates, waterproofing systems,
  exterior paint and dry wall partitions. Timber decking, raised
  floor, ceiling panel made up of more than 30% of recycled
  content.

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BCA GREEN MARK FOR BUILDINGS AWARD

Mount Elizabeth Novena Hospital
New Non-Residential Buildings

Clients / Developers

Parkway Novena Pte Ltd
Parkway Irawaddy Pte Ltd

Architect

Consultants Incorporated Architects & Planners

Interior Design

HRM International (Singapore) Pte Ltd

M&E Engineer
Parsons Brinckerhoff Pte Ltd

Lighting Consultant
The Lightbox Pte Ltd

Structural Engineer

TJLun International Pte Ltd

Quantity Surveyor
Langdon & Scall Singapore Pte Ltd

Main Contractor

Penta-Ocean Construction Co., Ltd

Landscape Consultant
![Image](image)

THP & ESD Consultant
![Image](image)

ZEB-Technology Pte Ltd

Key Features

- Estimated energy savings: 15,126,542 kWh/yr; estimated water
  savings: 6,374,42 m3/yr; ETTV: 31.78 kWm2.
- Efficient chiller plant room design with an efficiency of 0.625 kW/ton.
- Pre-cool AHU to improve indoor air quality, energy efficiency and
  Relative Humidity (RH) control.
- Demand control ventilation with carbon monoxide (CO) sensors for
  car park and carbon dioxide (CO2) sensors.
- Permanent instrumentation for measurement and verification of
  chiller plant.
- 114kWp onsite energy generation through photovoltaic panels.
- Energy efficient lighting design with LED and other efficient lighting
  systems.
- Lifts and escalators installed with Variable Voltage Variable Frequency
  (VVVF) motor and sensors.
- Extensive greenery at various levels.
### Final Words

1. **IAQ & Energy Issues**
2. Impact of ventilation and IAQ on occupant productivity and health
3. **IAQ Audit – IAQ parameters, Ventilation parameters, Human Response**
4. **Relevant Standards**
5. **Energy Scenario**
6. **Integrated IAQ Energy Assessment**
Thank You for your Attention