Creating Comfortable Outdoor Spaces
In Tropical Climates

3rd Annual Tropical Subtropical Green Building Alliance Conference, July 2012
Russell Cole
Director | Buildings Leader
Arup Singapore
Creating Outdoor Comfort in the Tropics:

1. The Challenge
2. Traditional Design Solutions
3. The 20th Century Response: Unsustainable Solutions
4. Modern Design Solutions

Agenda
Creating Outdoor Comfort in the Tropics:

The Challenge
Equatorial Tropical Climate

- Ambient Temperature 24°-32°
- Sun overhead +/- 23 degrees
- Two seasonal wind directions
- Low Wind Speeds
- Heavy Rainfall
- Intense Rainfall
- High and Constant Humidity
Factors Impacting Outdoor Comfort

• Heat, Temperature and Humidity
• Insects and Bugs
• Diseases and Infections
• Protection from the rain
• Sound carries on breezes
• Dust and Pollution
Thermal Comfort Factors

- Wind velocity
- Solar radiation
- Long wave radiation
- Air temperature
- Humidity
Thermal Comfort Factors

Environment:
- Wind velocity
- Solar radiation
- Long wave radiation
- Air temperature
- Humidity

Perception:
- Freedom of choice
- Usage of space
- Regional/seasonal
Thermal Comfort Factors

Environment
- Wind velocity
- Solar radiation
- Long wave radiation
- Air temperature
- Humidity

People
- Metabolism
- Clothing
- Activity

Perception
- Freedom of choice
- Usage of space
- Regional/seasonal
Outdoor Thermal Comfort Indices

- ASHRAE criteria established in North America
  - Standard Effective Temperature (SET) or “Thermal sensation”
  - Suited to temperate climates
  - Suited to lighter clothing
  - Suited to different climatic adaptation
Thermal Comfort in Singapore

Each dot represents one hour of the year

ASHRAE Standard Effective Temperature
Thermal Comfort in Singapore

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ASHRAE Standard Effective Temperature

Shading Line

Comfort Zone
Thermal Comfort in Singapore

Each dot represents one hour of the year

ASHRAE Standard Effective Temperature

Shading Line

Ventilation

Comfort Zone
Thermal Comfort in Singapore

Each dot represents one hour of the year.

ASHRAE Standard Effective Temperature

- **Shading Line**
- **Comfort Zone**
- **Ventilation**

Air Speed:
- 6 m/s
- 4 m/s
- 2 m/s
- 1 m/s

- **Air Temperature (ºC)**
- **Relative Humidity (%RH)**
Thermal Comfort in Singapore

Each dot represents one hour of the year.

ASHRAE Standard Effective Temperature

Evaporative Cooling
Ventilation
Comfort Zone
Shading Line

Effective Temperature

Human Thermal Comfort

Air Temperature (ºC)
Relative Humidity (%RH)
Thermal Comfort in Singapore

Each dot represents one hour of the year.

ASHRAE Standard Effective Temperature

Thermal Mass
Evaporative Cooling
Ventilation
Comfort Zone
Shading Line
Outdoor Thermal Comfort Indices

• ASHRAE criteria established in North America
  • Standard Effective Temperature (SET) or “Thermal sensation”
  • Suited to temperate climates
  • Suited to lighter clothing
  • Suited to different climatic adaptation

• Alternative criteria for the Tropics
  • Equatorial Comfort Index (ECI)
  • Developed in Malaysia & Singapore
  • Suited to climates beyond the 24°C wet bulb temperature isotherm
Thermal Comfort in Singapore

Equatorial Comfort Index

Reference:

Comfort Band:

\((V=0.2\text{ m/s}, \text{ constant } P_v=22.5\text{ mmHg})\)

<table>
<thead>
<tr>
<th>C</th>
<th>Comfort Assessment</th>
<th>Effective Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>very cold</td>
<td>&lt; 18.1</td>
</tr>
<tr>
<td>1</td>
<td>cold</td>
<td>&lt; 20.3</td>
</tr>
<tr>
<td>2</td>
<td>cool</td>
<td>&lt; 22.5</td>
</tr>
<tr>
<td>3</td>
<td>comfortably cool</td>
<td>&lt; 24.7</td>
</tr>
<tr>
<td>4</td>
<td>neither cool nor warm</td>
<td>&lt; 26.8</td>
</tr>
<tr>
<td>5</td>
<td>comfortably warm</td>
<td>&lt; 29.0</td>
</tr>
<tr>
<td>6</td>
<td>warm</td>
<td>&lt; 31.2</td>
</tr>
<tr>
<td>7</td>
<td>hot</td>
<td>&lt; 33.3</td>
</tr>
<tr>
<td>8</td>
<td>very hot</td>
<td>&lt; 35.5</td>
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\((V=1.5\text{ m/s}, \text{ constant } P_v=22.5\text{ mmHg})\)

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Thermal Comfort in Singapore

Equatorial Comfort Index

![Annual Comfort Levels Breakdown (6am-8pm)](chart)

- Comfortable
- Warm
- HOT!!
Creating Outdoor Comfort in the Tropics:

Traditional Design Solutions

Source: app.www.sg (uploaded by MICA)
Historical Design Solutions

• Malaysian Long House
• Kelongs
• Kampongs
• Shophouses
• Colonial Bungalows
• Colonial Institutions – Hospitals, Barracks, Government Buildings
Traditional Architecture

• Elevated platforms
• Lightweight construction
• Overhanging roofs

Philippine Nipa Hut
Source: abletesk.wordpress.com

Rungus Longhouses
Source: mount-kinabalu-borneo.com
Kampong Bungalows

• Large Overhangs
• High Level openings and vents
• Voids under the house
• Verandas
Singapore Shop Houses
Lau Pa Sat

• Shaded Throughout
• Screens and openings for ventilation
• Tall spaces – with vents at the top
• Fans for comfort

Source: app.www.sg (uploaded by MICA)
Colonial Buildings

• Shaded Corridors
• Shading Corridors
• Screens and openings for ventilation
• Tall spaces
• Fans for comfort
Colonial Buildings

• Large overhangs to shade walls
• Vents at high level
• Steps up to entrance
• Shutters
• High ceilings
• Shaded balconies
Pre-Air-conditioned Buildings
Creating Outdoor Comfort in the Tropics:
The 20th Century Response - Unsustainable Solutions
Comfort in the Tropics

• Current Solution is Lee Kuan Yew’s invention of the 20th Century

➢ Air Conditioning

Source: aroundtheregion.com
Comfort in the Tropics

• Current Solution is Lee Kuan Yew’s invention of the 20th Century

➢ Air Conditioning
  ➢ Sealed Buildings
  ➢ Humidity removed by over-cooling of intake air
  ➢ Limited air changes to reduce energy spent on dehumidification
  ➢ No occupant control
Rapidly growing energy consumption in the 20th century has caused an alarming increase in global CO₂ Emissions
Global CO₂ Emissions Reduction Targets

Current Emissions

2030 Targets

2050 Targets

Relative % Compared to 1990 Levels

+20%

0%

-20%

-40%

-60%

-80%

-100%

(Zero Carbon)

Europe

Japan

Europe

Japan

Australia

Australia

USA

Papua New Guinea

Papua New Guinea

80% Reduction required to avoid a 2°C temp rise and catastrophic climate disaster (Copenhagen Accord)
Every building we design today will be impacted by taxes, legislation and other mechanisms put in place to achieve global CO₂ emissions reduction targets.
Every building we design today will be impacted by taxes, legislation and other mechanisms put in place to achieve global CO$_2$ emissions reduction targets.

Energy-hungry buildings with poor amenity are likely to be outperformed by efficient, sustainable property assets.
Creating Outdoor Comfort in the Tropics:

Modern Design Solutions
Creating Outdoor Comfort Efficiently

Operative Temperature

Fully exposed

Provide shade
Creating Outdoor Comfort Efficiently

- Fully exposed
- Provide shade
- Provide shade + Capture or create air movement
Creating Outdoor Comfort Efficiently

- Fully exposed
- Provide shade
- Provide shade + Capture or create air movement
- Provide shade + Capture or create air movement + Reduce radiant temperature and air temperature
Creating Outdoor Comfort Efficiently

Provide shade whilst harvesting daylight & avoiding glare

Case Studies
• Clarke Quay
• South Beach
• NUS OED
• CCRC
• SNL
• NUS Edusport
Creating Outdoor Comfort Efficiently

Provide **shade** whilst harvesting daylight & avoiding glare

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THE CANOPIES PROVIDE SHADE WHILST MAINTAINING THE FEELING OF BEING OUTSIDE & ENJOYING VIEWS TO THE SKY, AND FREE FLOWING AIR MOVEMENT.
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<thead>
<tr>
<th></th>
<th>Analysis</th>
<th>Measurement</th>
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<tr>
<td>Clear Sky Average</td>
<td>36,000 lux</td>
<td>18,000 lux @ 80Kl</td>
</tr>
<tr>
<td>Overcast Sky Average</td>
<td>3,600 lux @ 9Kl</td>
<td>4,600 lux @ 16Kl</td>
</tr>
<tr>
<td>Daylight factor</td>
<td>39%</td>
<td>29% +/- 5</td>
</tr>
<tr>
<td>Annual lux hour</td>
<td>Min 12 Million for tree growth</td>
<td>Est 40 Million</td>
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Thermal Comfort with Two Layer ETFE Roof: 65% Printed Frit, SC = 0.51

Annual Comfort Levels Breakdown (6am-8pm) - No Effects being Counted

- Comfortable
- Warm
- HOT!!

Equatorial Comfort Index (band)
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Thermal sensation index: average 5.1
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Yearly average daylight level (lux)

<table>
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<tr>
<th>Lux</th>
<th>0</th>
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<tbody>
<tr>
<td>1500</td>
<td></td>
</tr>
<tr>
<td>1250</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>250</td>
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Majority of Area is over 1500 lux
(400 lux is acceptable for an office space)
Creating Outdoor Comfort Efficiently

Provide **shade** whilst harvesting daylight & avoiding glare

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Microclimate analysis & design
Creating Outdoor Comfort Efficiently
Case Studies
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Provide shade whilst harvesting daylight & avoiding glare

Source: Fosters & Partners
Microclimate analysis & design

Creating Outdoor Comfort Efficiently

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Provide shade whilst harvesting daylight & avoiding glare
Microclimate analysis & design

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Provide shade whilst harvesting daylight & avoiding glare
## Canopy BEM Comparison

A comparison of the performance of different canopies in Singapore

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<th>Roof temperature</th>
<th>Operative temperature Rise</th>
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<tr>
<td>Good</td>
<td>Louvers with no overlap</td>
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<td>ETFE</td>
<td>ETFE</td>
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</tr>
<tr>
<td>Fair</td>
<td>Louvers with overlap</td>
<td>ETFE</td>
<td>ETFE</td>
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<tr>
<td>Poor</td>
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<td>38 with GRC insulated 48 Aluminium uninsulated</td>
<td></td>
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Creating Outdoor Comfort Efficiently

Capture or create **air movement** with low energy consumption

Case Studies

- Clarke Quay
- South Beach
- NUS OED
- CCRC
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Creating Outdoor Comfort Efficiently

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Open Plaza

High Shading

Best Balance

High Air Velocity
Zone of influence

Original Design

Measured Performance
Creating Outdoor Comfort Efficiently

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<60% GFA Air-Conditioned

- Naturally ventilated service spaces
- Air-conditioned Office Space
- Naturally ventilated meeting rooms, and breakout and event spaces
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Creating Outdoor Comfort Efficiently

Capture or create **air movement** with low energy consumption

Case Studies
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Source: Aedas
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![Diagram showing air movement](image)

*Poor air movement in civic plaza*
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Poor air movement in civic plaza
Microclimate analysis & design

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Source: DPA
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Source: DPA
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Reduce **radiant** temperature and **air** temperature

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Reduce **radiant** temperature and **air** temperature

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Source: Foster & Partners
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Reduce **radiant** temperature and **air** temperature

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Source: Foster & Partners
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Reduce radiant temperature and air temperature

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Source: Foster & Partners
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Reduce radiant temperature and air temperature

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Source: Foster & Partners
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- Fully exposed
- Provide shade
- Provide shade + Capture or create air movement
- Provide shade + Capture or create air movement + Reduce radiant temperature and air temperature
Creating Outdoor Comfort Efficiently

- Fully exposed
- Provide shade
- Provide shade + Capture or create air movement
- Provide shade + Capture or create air movement + Reduce radiant temperature and air temperature
- Provide protection from wind driven rain
Creating Outdoor Comfort Efficiently

Provide protection from wind driven rain

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Provide protection from wind driven rain

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![Wind Velocity and Frequency Graph](image)
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Louver Type 2 - Inclined louvers without glass infill

Inclined louvers without glass infills provide a degree of rain protection combined with ventilation.
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Louvre Type 3 - Horizontal louvres with glass infill
louvres with glass infill provide rain shelter and allow flexibility in louvre spacing to achieve better transparency and lighter canopy appearance.
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70-75% of pedestrian path will have ≥95% rain protection during rainy days with Southerly wind