



## High Performance Buildings for Singapore for Better Energy Management

Assoc Prof Dr Runa T HELLWIG  
Cluster Director Solar and Energy Efficient Buildings

Solar Energy Research Institute of Singapore (SERIS)

Capacity Building Programme for Officers of Electricity Regulatory  
Commissions  
19 February 2015, Singapore



SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



1

## SERIS

Solar Energy Research Institute of Singapore



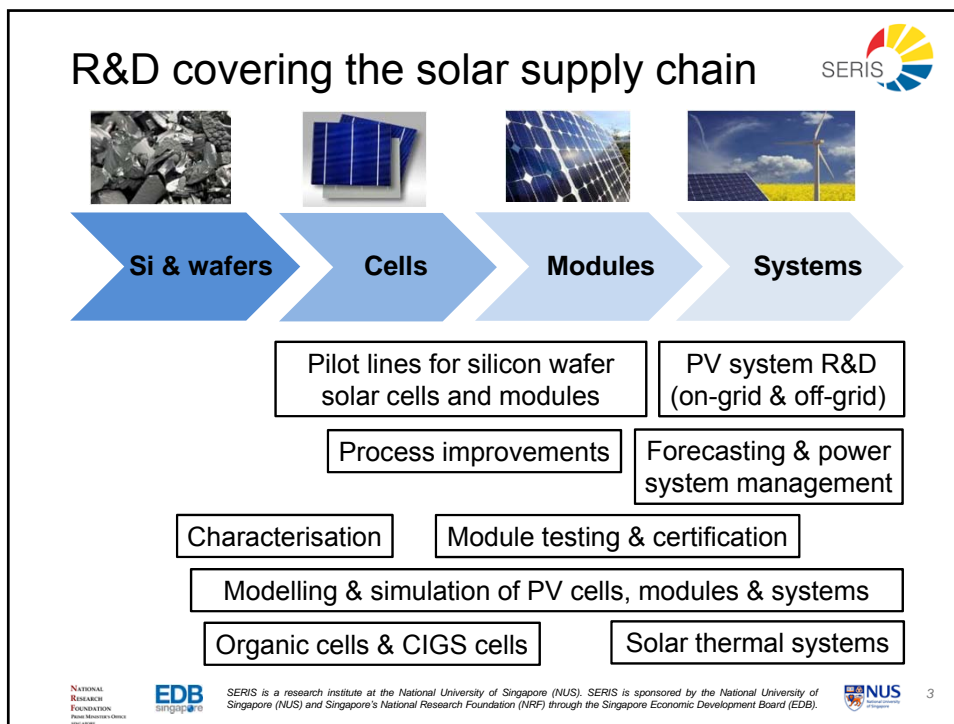
- ❑ Founded in 2008; focuses on applied solar energy research
- ❑ Part of the National University of Singapore (NUS)
- ❑ Rapid growth (now ~160 people and > 6000 m<sup>2</sup> of space)
- ❑ > USD 30 million investments for labs
- ❑ R&D focus is on PV (cells, modules, systems) and energy efficient buildings
- ❑ Specialised in professional services for the PV industry
- ❑ ISO 9001 & ISO 17025\* certified (\* PV Module Testing Lab)




SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).

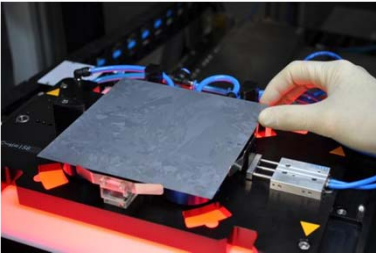



2



## Main R&D areas of SERIS









**Photovoltaic electricity generation:**

- Silicon wafer solar cells
- Thin-film solar cells (OPV, CIGS)
- PV modules (development & testing & certification)
- PV systems (on-grid & off-grid)
- Characterisation & simulation of PV materials, cells, modules, systems


**Solar and energy efficient buildings:**

- High-performance facades (incl. BIPV)
- Solar thermal systems


OPV = Organic photovoltaics  
 CIGS = Copper indium gallium selenide  
 BIPV = Building-integrated photovoltaics

SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


4

# Outline



- High Performance Buildings

Background

- Energy demand
- Singapore's climate

Buildings



- Demand side analysis
- Technologies

Regulations, Roadmaps


- Measures
- Green Mark Scheme
- Roadmaps

Proven Quality

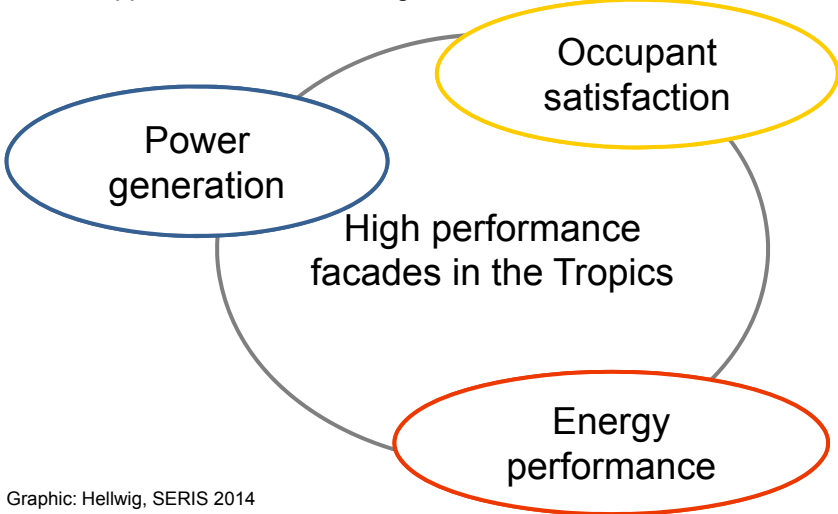
- Labelling - Applied Research - Test-bedding and Monitoring

NATIONAL RESEARCH FOUNDATION FROM MINISTRY OF EDUCATION  EDB Singapore SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  NUS 5

# Why High Performance Buildings?



Holistic approach towards buildings at SEEB





Power generation

Occupant satisfaction


High performance facades in the Tropics

Energy performance

Graphic: Hellwig, SERIS 2014


NATIONAL RESEARCH FOUNDATION FROM MINISTRY OF EDUCATION  EDB Singapore SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  NUS 6

# Background



NATIONAL RESEARCH FOUNDATION  
EDB singapore  
SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  
NUS

# Energy consumption in Singapore



**Primary Energy supply from fossil**  
109 TWh

- others 3.9%
- petroleum 0.9%
- natural gas 95.3%

**Final Energy consumed**  
45 TWh

- industry 19 TWh
- commerce and service 17 TWh
- household 6.8 TWh

electricity generated 48 TWh

generating losses 61 TWh, power plant efficiency 44%

own use & distribution losses 1.5 TWh

Increasing energy efficiency  
 Increasing share of renewables

port 2.3 TWh  
 : 0.4 TWh

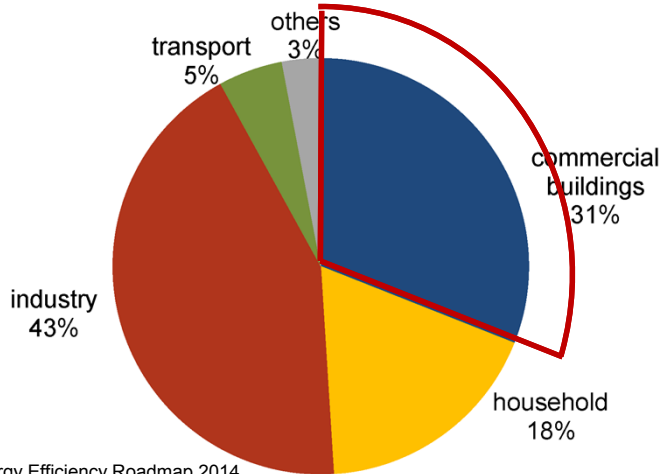
Graphic: Hellwig, SERIS 2014, Data Source: EMA: Singapore Energy Statistics 2014

NATIONAL RESEARCH FOUNDATION  
EDB singapore  
SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  
NUS

## Electricity consumption in Singapore (I)

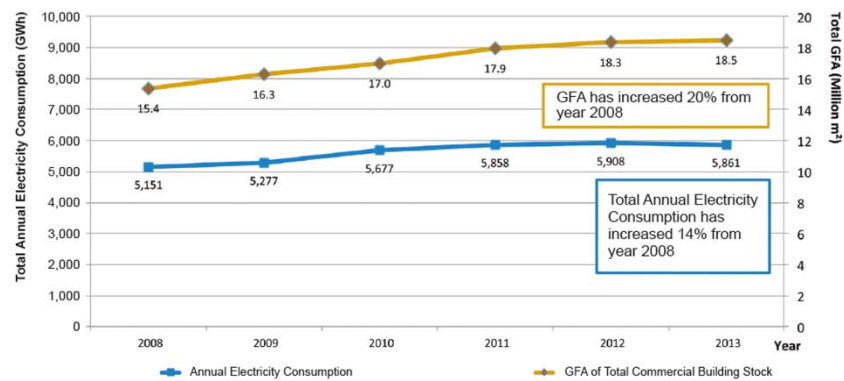


Break-down of the total electricity consumption in Singapore

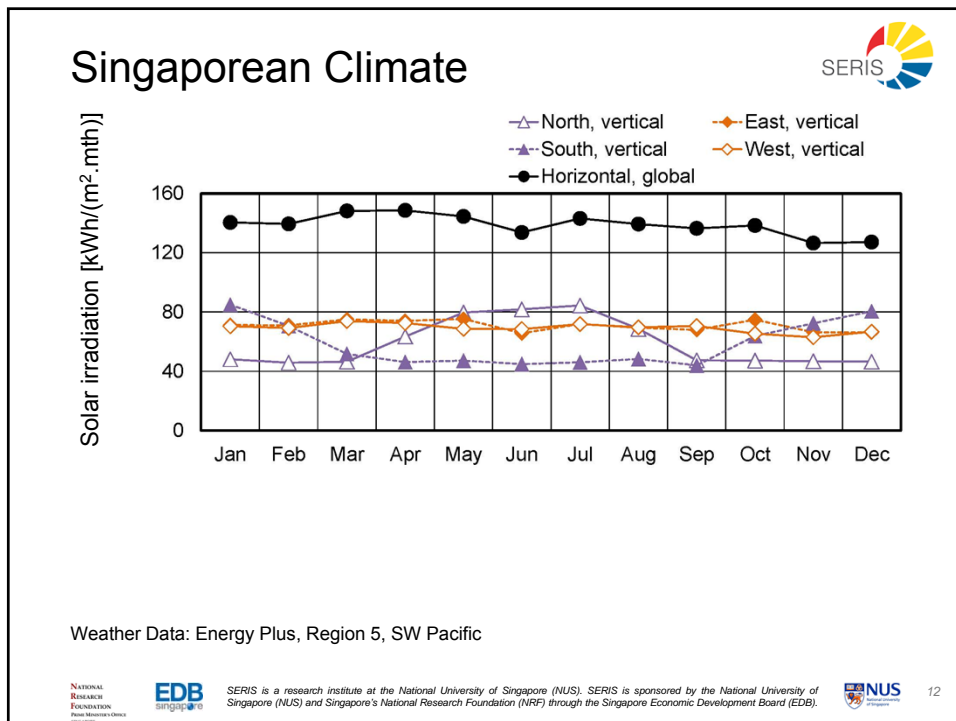
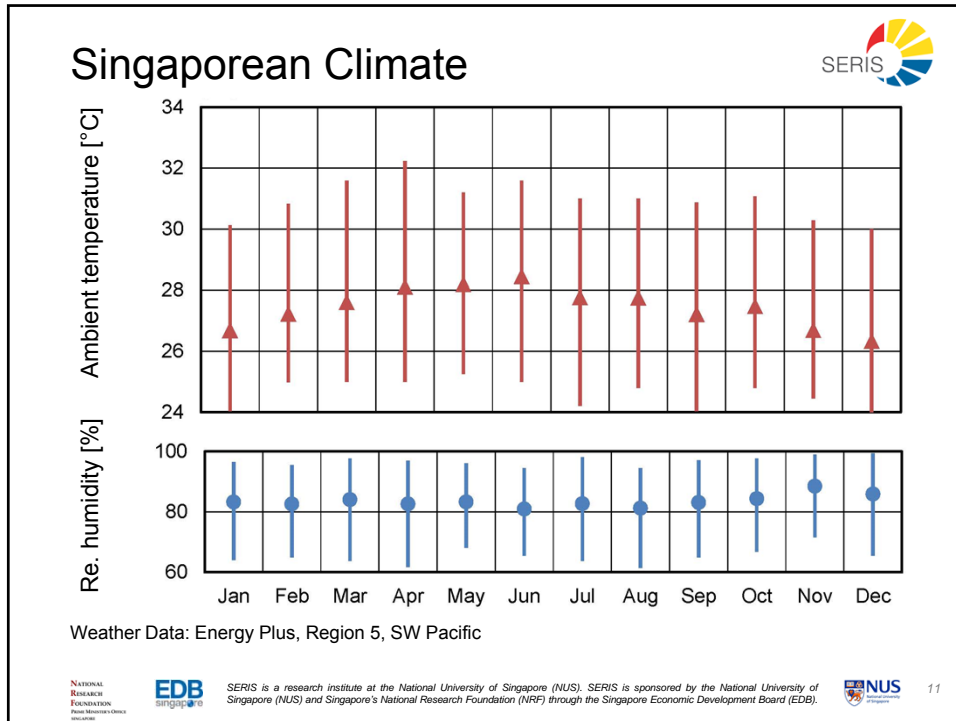


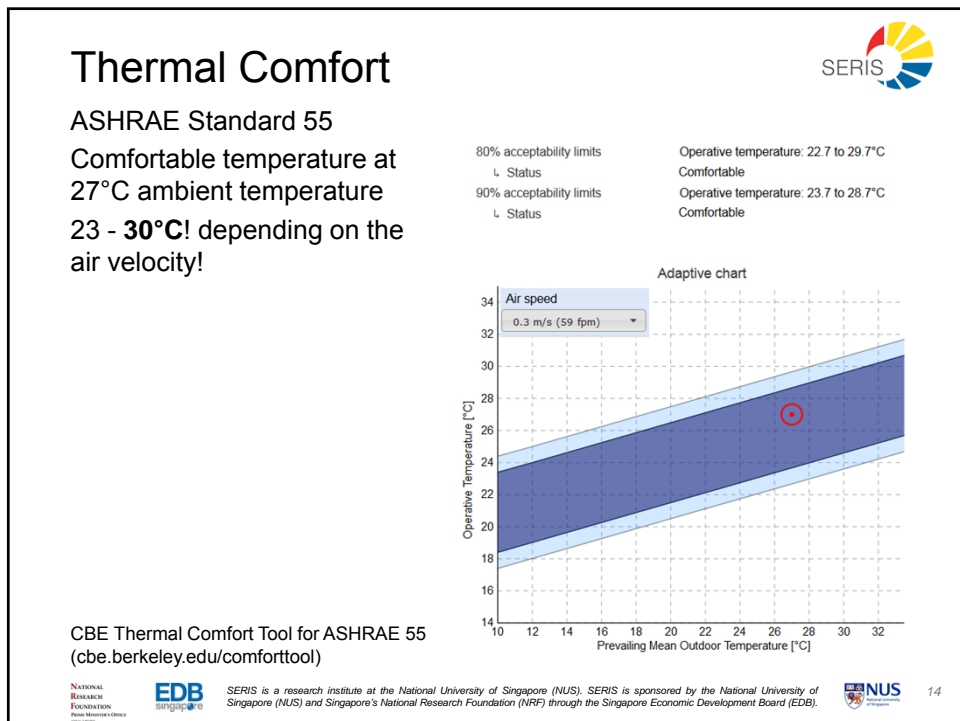
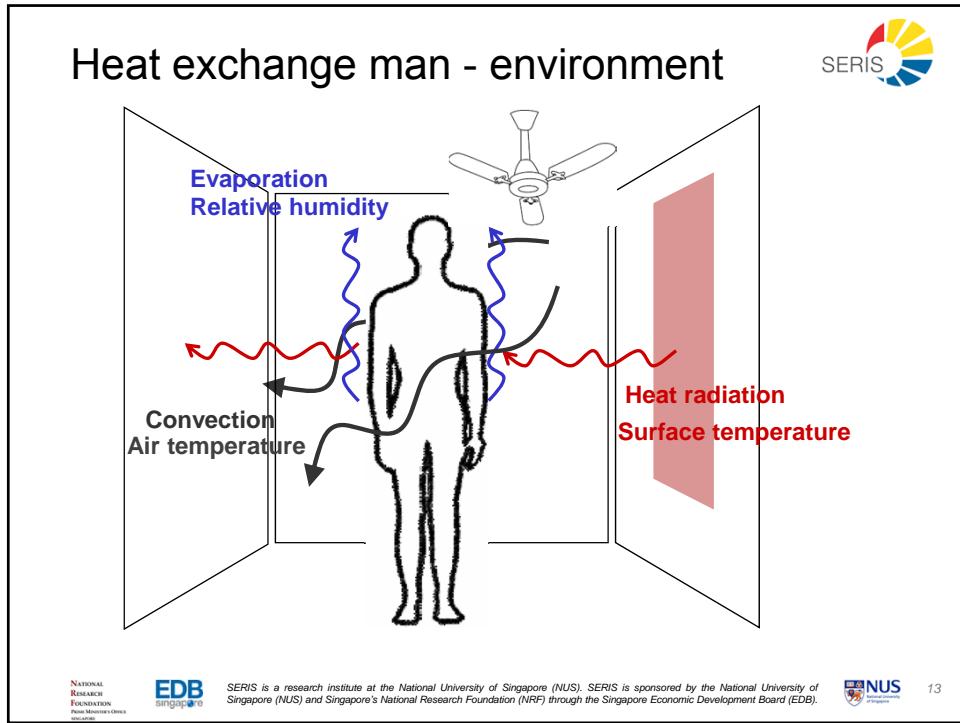
Source: Building Energy Efficiency Roadmap 2014

## Trend GFA and electricity consumption



BCA Building Energy Benchmarking Report 2014





## Thermal Comfort

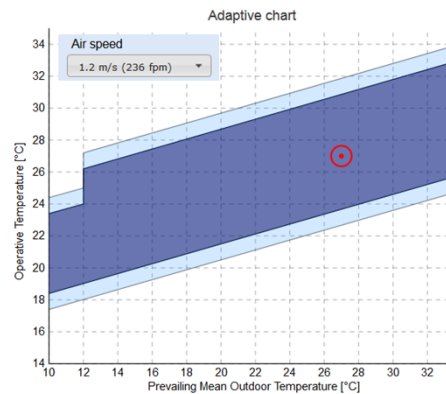
ASHRAE Standard 55

Comfortable temperature at  
27°C ambient temperature  
23 - 32°C! depending on the  
air velocity!



80% acceptability limits  
↳ Status  
90% acceptability limits  
↳ Status

Operative temperature: 22.7 to 31.9°C  
Comfortable  
Operative temperature: 23.7 to 30.9°C  
Comfortable



CBE Thermal Comfort Tool for ASHRAE 55  
(cbe.berkeley.edu/comforttool)



SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



15

## Singaporean Climate: Benefits and Challenges



Benefits:

- Sunlight / daylight/ solar radiation in abundance
- Ambient temperatures between 24 - 33°C
- Year long relatively constant climate (one solution!)
- Rain is available (greenery!)

Challenges:

- Very high relative humidity
- Reducing heat radiation from surfaces – comfort!
- Minimising heat gains from solar in buildings
- Providing suitable daylight at the same time
- Maximising energy harvesting (on limited space)



SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



16



# Buildings






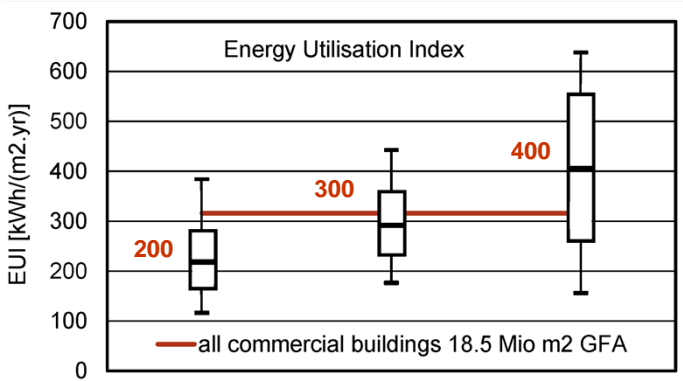
Photo: Hellwig 2015



NATIONAL RESEARCH FOUNDATION  
EDB singapore  
SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  
NUS 17

# Electricity in commercial buildings

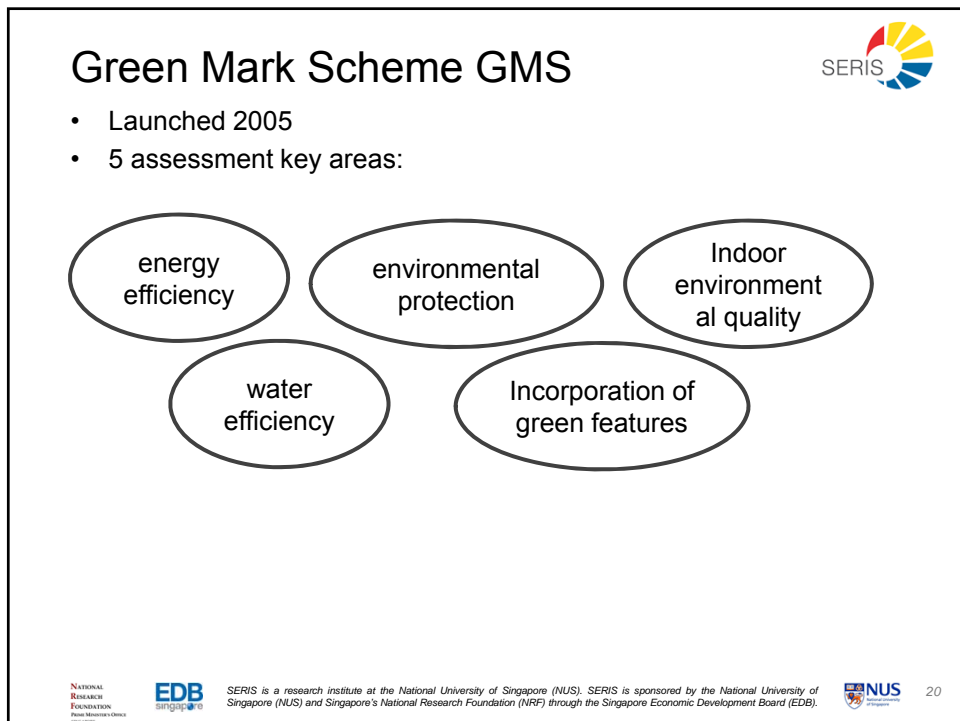
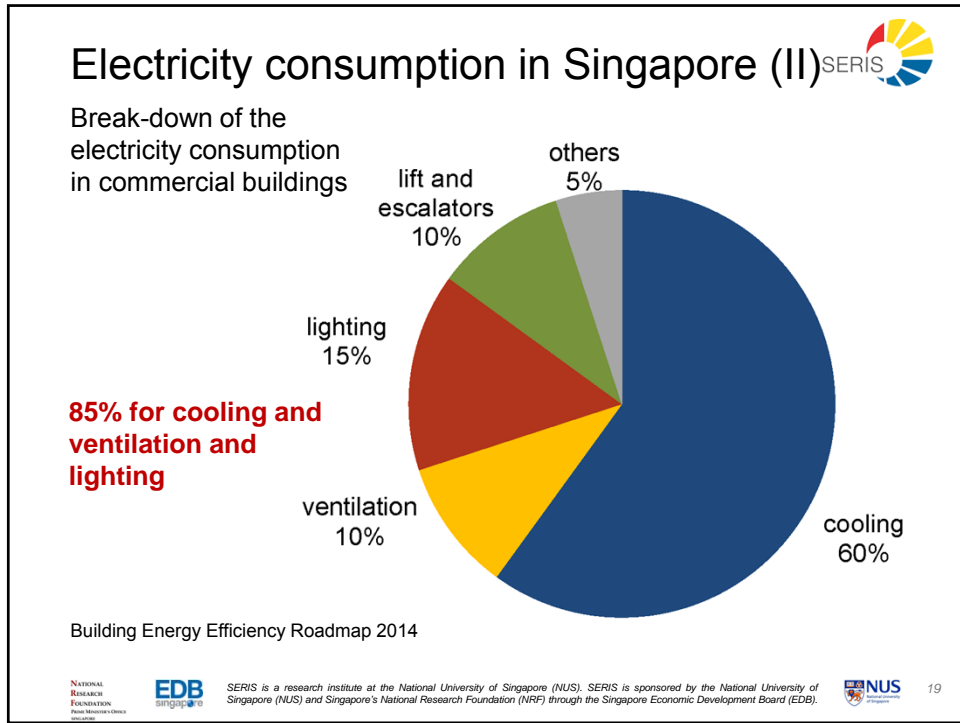
Electricity consumption (Final Energy consumption)  
Commercial buildings: 316 kWh/ (m<sup>2</sup>.yr), N = 729

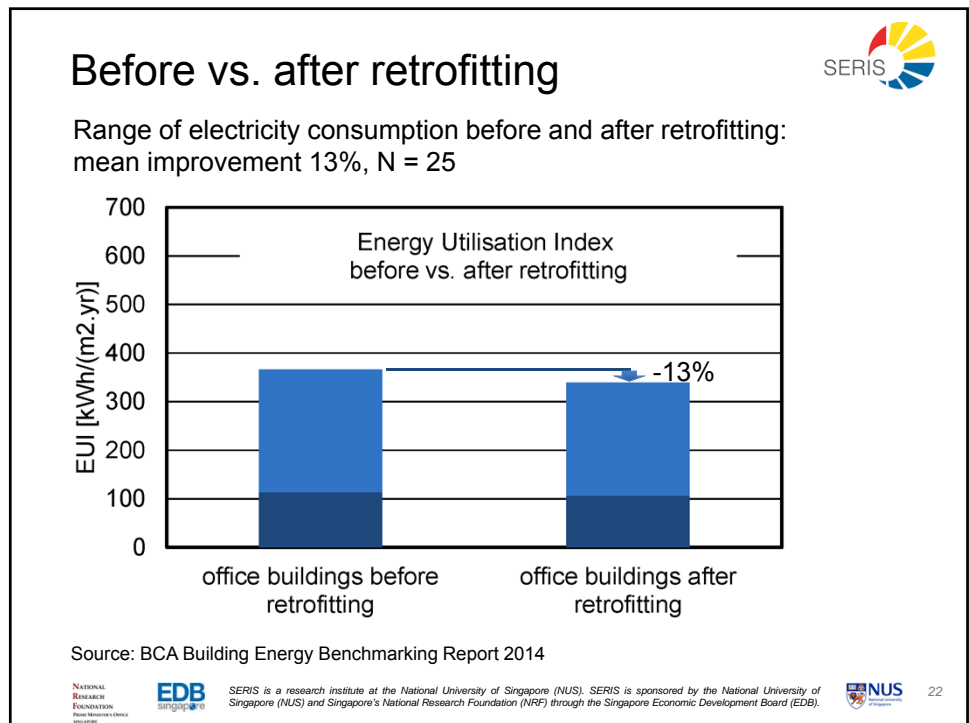
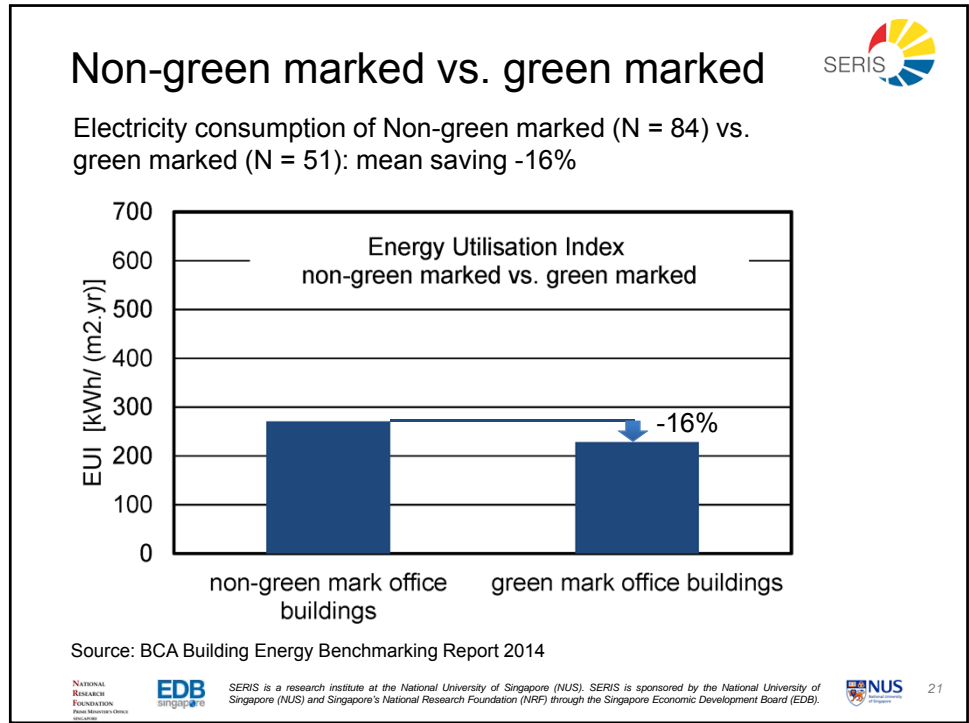



Building Type	Count	Median EUI [kWh/(m <sup>2</sup> .yr)]
office buildings	352	200
hotels	231	300
retails buildings	146	400
<b>all commercial buildings</b>	<b>729</b>	<b>316</b>


BCA Building Energy Benchmarking Report 2014

NATIONAL RESEARCH FOUNDATION  
EDB singapore  
SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  
NUS 18

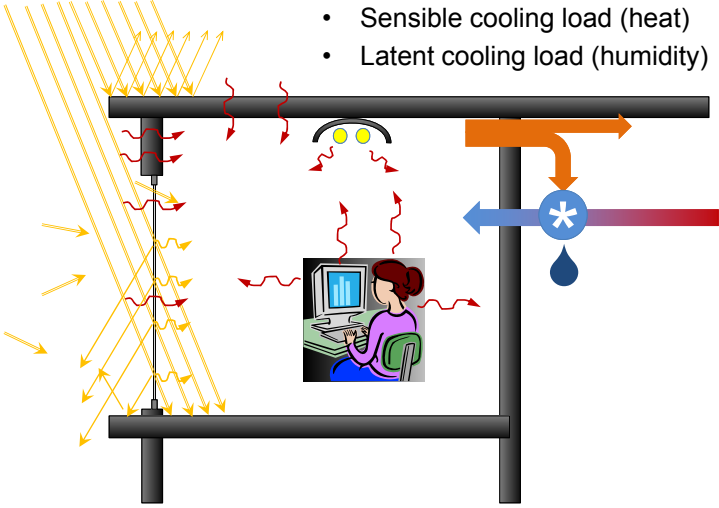






## Cooling loads in buildings




- Sensible cooling load (heat)
- Latent cooling load (humidity)




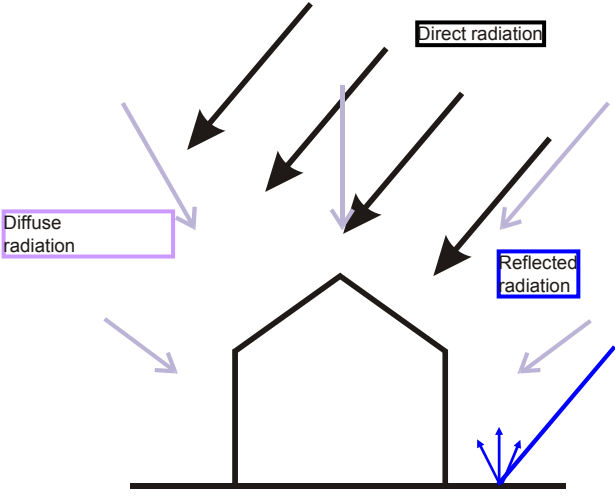





SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


23


## Shortwave radiation





SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


24

## Technologies



- Focus in this talk on buildings envelope (walls, windows, facades)

## Glazings



### Permanent properties

- Solar heat gain coefficient (SHGC) single glass pane: 85%
- SHGC double low-e (sun-protective) glazing: 40%

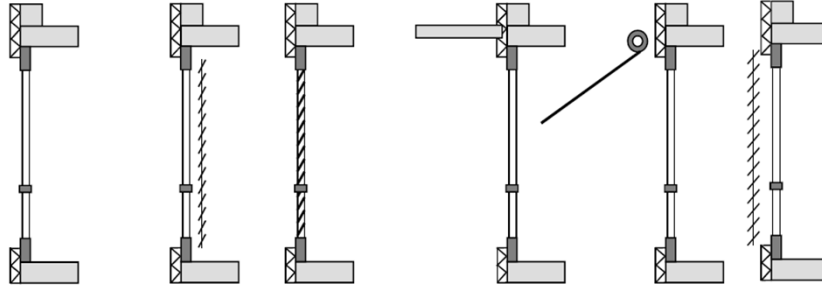
### Altering properties

- Thermochromic / electrochromic / photochromic
- Change of transmittance in response to
  - temperature change
  - voltage change
  - light change



Electrochromic glazing in ZEB@BCAA

# Solar shading devices



NATIONAL RESEARCH FOUNDATION



SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



27

# Shading



All photos: Hellwig 2015

NATIONAL RESEARCH FOUNDATION



SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



28

# Shading



All photos: Hellwig 2015



NATIONAL RESEARCH FOUNDATION **EDB** SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB). **NUS** 29

# Internal shading device



A high reflective screen cuts of 50 to 70% of the solar radiation!

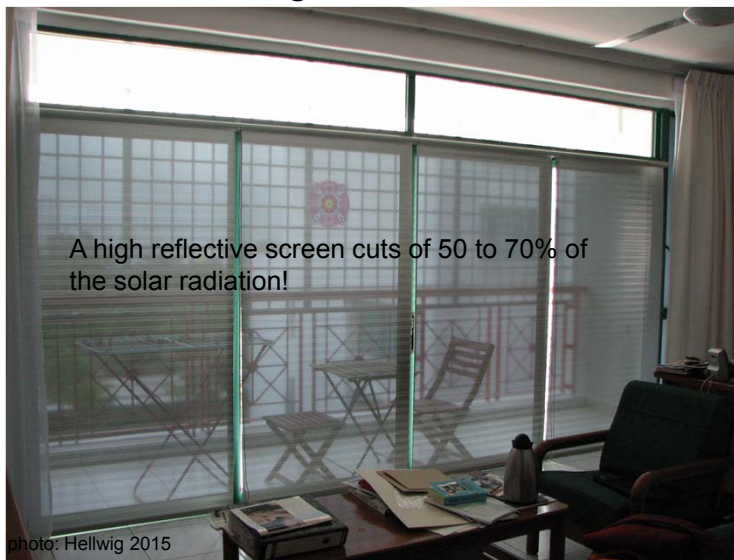
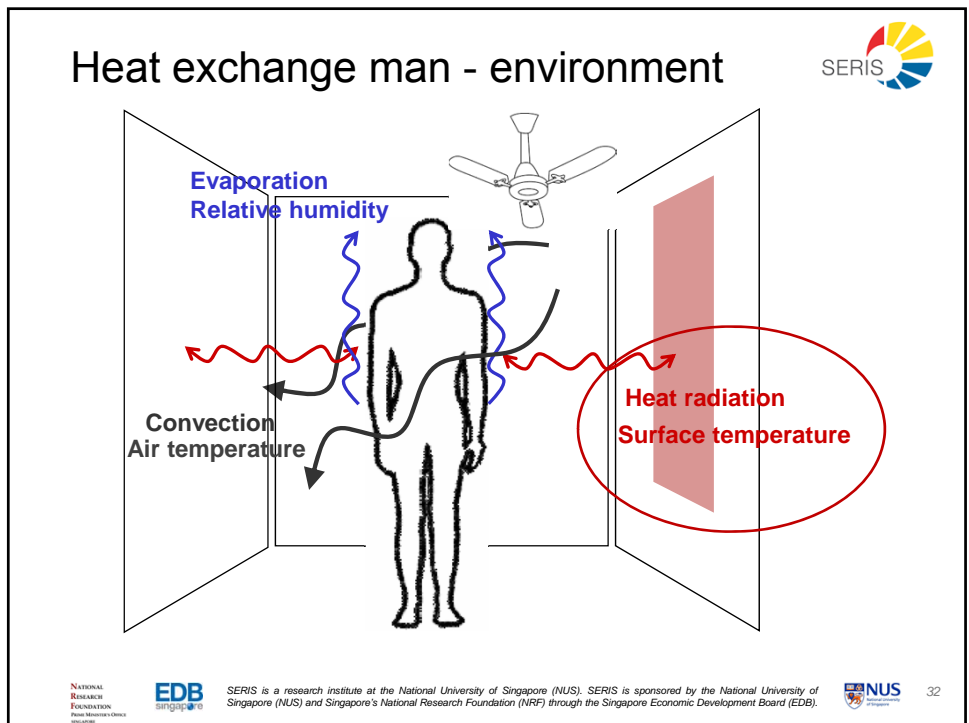
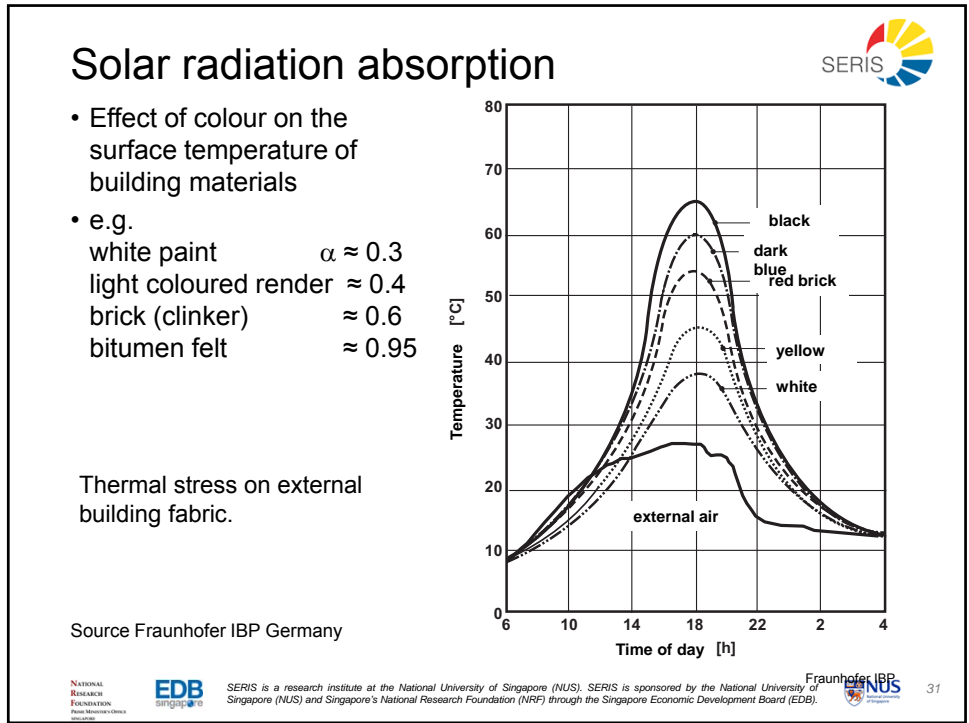


photo: Hellwig 2015

NATIONAL RESEARCH FOUNDATION **EDB** SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB). **NUS** 30







## Insulation



- Heat transmission through the building envelope (U-value  $W/(m^2.K)$  or R thermal resistance ( $m^2.K/W$ ))
- Single glazing:  $5.8 W/(m^2.K)$
- Double low-e glazing:  $1.5 W/(m^2.K)$
- Reducing the heat gain through transmission by factor 3-4
- Concrete roof, 0.20 m:  $1.4 W/(m^2.K)$
- Slightly insulated concrete roof, 4 cm:  $0.6 W/(m^2.K)$
- Reducing the heat gain through transmission by factor 2
- Compared to new windows factor 2.5

## Airtightness



Photo Hellwig 2015

## Air-leakage rate measurement



Reasons for establishing a proper building tightness:

- Avoiding unwanted heat gains through gaps in the building's envelope
- Avoiding additional energy consumption for cooling
- Avoiding moisture condensation problems

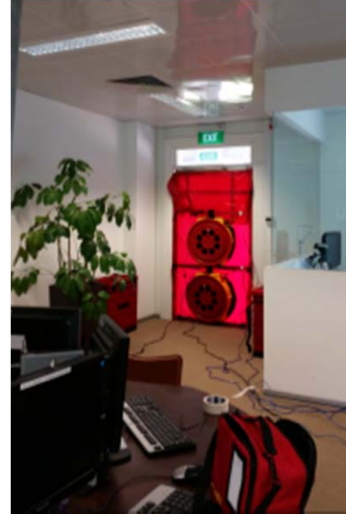


Photo: SERIS

## Focus area of SEEB



### High Performance Facades

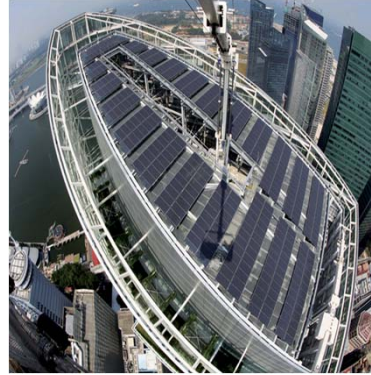
- Energy demand control through well-performing buildings
- Glazings – permanent, altering properties
- Shading – permanent, movable
- Insulation – reducing heat gains, moderating thermal inertia
- Air sealing – reducing uncontrolled heat gains through infiltration
- Synergy effects – on-site energy generation and shading



## Solar Energy has the best potential

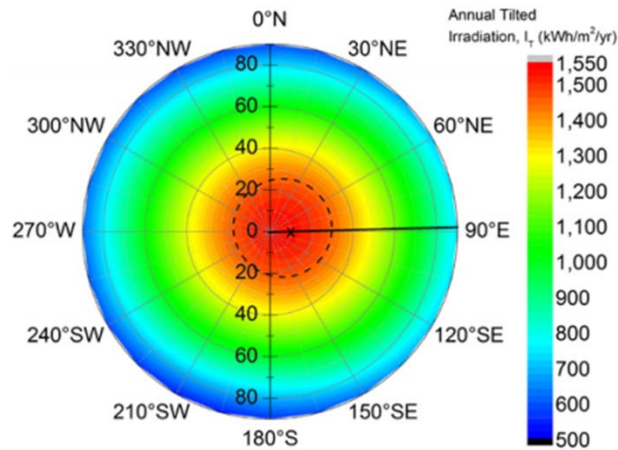


- Singapore receives lots of solar energy throughout the year (1630 kWh per m<sup>2</sup> per year)
- yield do I get from a PV system:
  - > 1,300 kWh / kWp (= 80% PR)
  - > 150 kWh / m<sup>2</sup> (unshaded roof area)



Ocean Financial Centre - SE Asia's highest solar installation (2011)

## Optimal orientation in Singapore



Source: YS KHOO et al., Optimal orientation and tilt angle for maximizing in-plane solar irradiation for PV applications in Singapore, IEEE Journal of Photovoltaics, Vol. 4, No. 2, March 2014

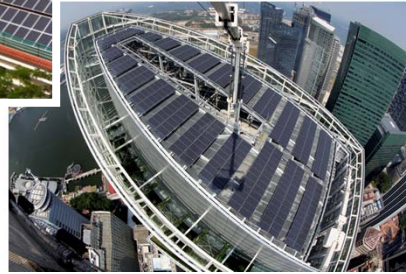
## Types of rooftops suitable for PV



### Pitched roofs



Module structures are fixed to the main beams of the underlying roof (rather than the tiles or building surface)



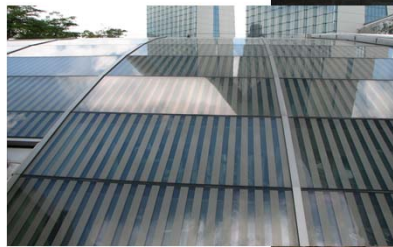
SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



## BIPV




All photos: Hellwig 2015




SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).





Launch of White PV in Singapore, 28/10/2014



*Press release*

**World premiere**

**White solar modules: a revolution for building integration**

Neuchâtel/Switzerland, 28 October 2014 — CSEM has developed a new generation of white solar modules. This innovative technology is particularly suited for building integration as the elements can blend into a building's skin and be used in a wide range of applications. Applications in the consumer goods sector are also expected.







Photo: Hellwig 2014


SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).

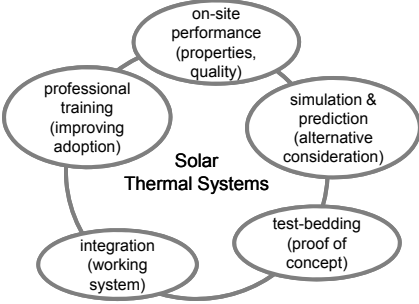

41



## Focus areas of SEEB

### Solar Thermal Systems


- Increasing the share of renewables
- Providing the energy on-site close to consumers
- Decreasing use of fossil fuels in the industry



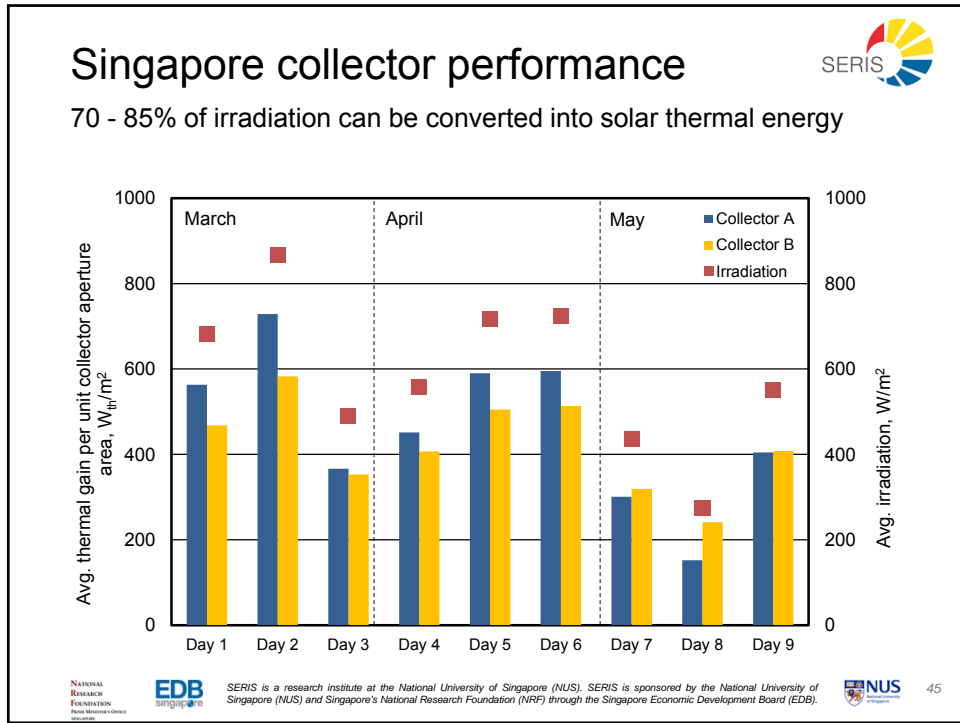


SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


44





## Technologies




- Glazings – permanent, altering properties
- Shading – permanent, movable
- Absorbtion – light colours
- Insulation – reducing heat gains
- Air sealing – reducing uncontrolled heat gains through infiltration
- BIPV and PV
- Solar thermal collectors

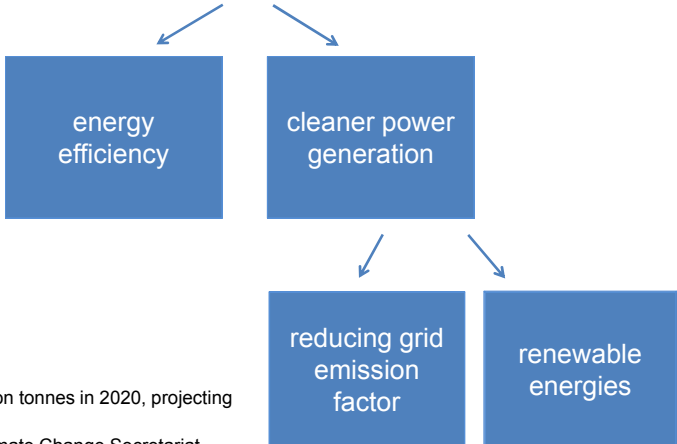
## Regulations, Roadmaps



## 7-11% CO<sub>2</sub> reduction commitment below the 2020 business-as-usual (BAU) emissions\*





Two major areas




```

graph TD
    A[Two major areas] --> B[energy efficiency]
    A --> C[cleaner power generation]
    C --> D[reducing grid emission factor]
    C --> E[renewable energies]
    
```

\* 77.2 million tonnes in 2020, projecting from 2005  
National Climate Change Secretariat

SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


49

## BCA Green Building Masterplan



**Vision**  
of making Singapore “A global leader in green buildings, with special expertise in the tropics and sub-tropics – enabling sustainable development and quality living”

Key strategic goals focusing on

- Continued Leadership;
- Proven Sustainability Performance; and
- Collaboration and Engagement with Stakeholders



Source: BCA 2014, 3<sup>rd</sup> Green Building Masterplan




SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


50



## Legislation for Existing Buildings

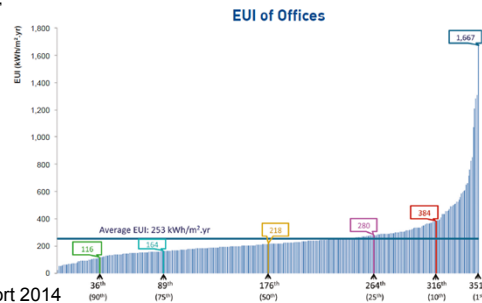


### Annual Mandatory Submission of Building Information and Energy Consumption Data

- Enacting 2012
- End of 2013 first data set

#### Containing:

- Occupancy type, activity type
- GFA, air-conditioned area, last renovation/ retrofitting
- Information on service: lighting, ACMV, lifts, hot water
- Energy Consumption: electricity, diesel, gas

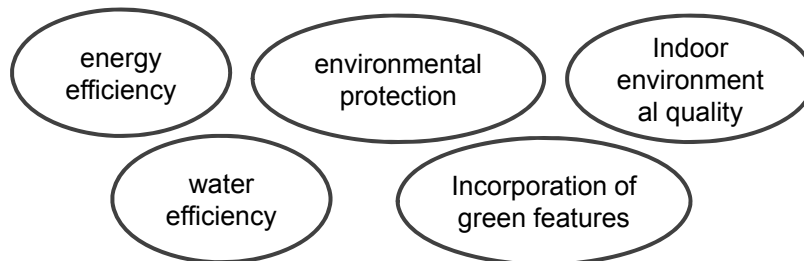


BCA Building Energy Benchmarking Report 2014

## Green Mark Scheme GMS



- Launched 2005
- 5 assessment key areas:



- Mandatory (Buildings Control Regulations): for all new buildings with GFA more than 2000 sqm to obtain a minimum score of 50 points (passed GMS)

## Incentives



- Singapore Green Mark Incentive Scheme
- Since 2009
- Available for new and private developments, redevelopments or major retrofiting
- Available for GM Platinum or Gold
- Increase of GFA by 1% (Gold) or 2% (Platinum)
- Subject to a cap of 2,500 sqm (Gold) and 5,000 sqm (Platinum)

## Singapore PV roadmap 2014

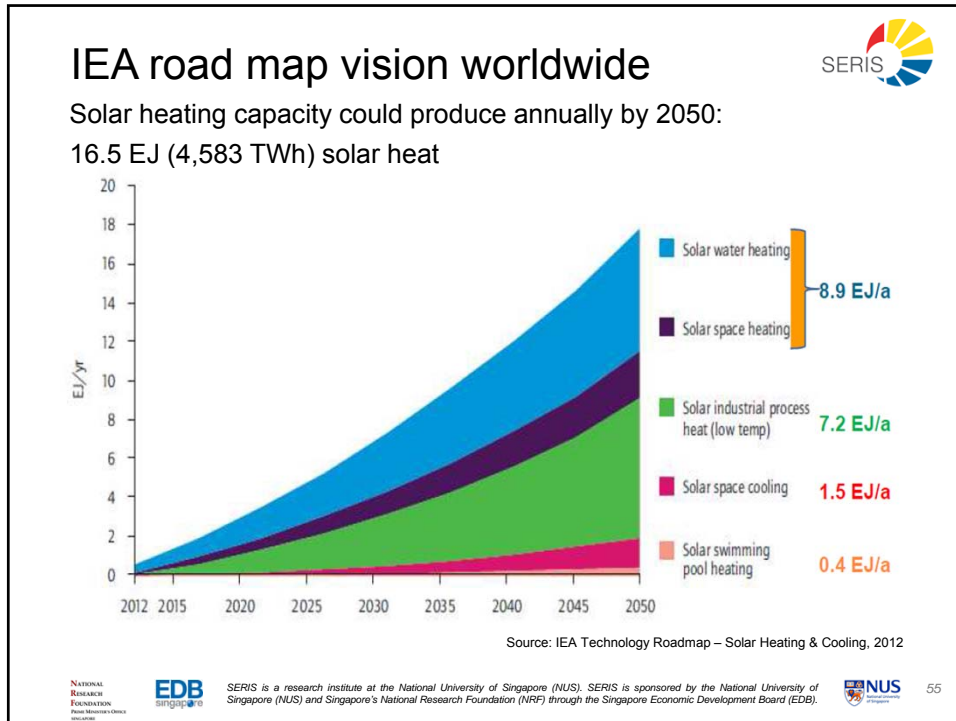





Facilitating the deployment of PV in Singapore

Short term (before 2020)


- Conjointly with architects, government agencies and industry address the issue of space utilisation and increasing space for PV use, whilst preserving the necessary urban green space.
- Create and test innovative solutions for system deployment (e.g. inland floating PV, building-integrated PV (BIPV), PV canopies, and extremely light weight movable PV canopy construction).
- Potential: 7 – 15 TWh by 2050
- Roof top area: 34 km<sup>2</sup>
- Facades (top 5 stories) 4 km<sup>2</sup>

Source: Solar Photovoltaic Roadmap for Singapore 2014




- ## Energy Efficiency Roadmap Singapore
- 
- 4 key areas
- Integrated Design (ID)
  - Building envelope and Façade system
  - Air-con mechanical ventilation
  - Building management Info system
- Source: Building Energy Efficiency Roadmap 2014
- 


SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


56

## Technical & non-technical challenges



EE roadmap	Technical Challenges	Non- Technical Challenges
	Lack of <u>test-bedding opportunities</u> <sup>1</sup>	Lack of <u>policies and incentives</u> for developing technologies from R&D to market adoption
	<u>Inefficient Operation, Maintenance and Management (OM&amp;M)</u>	OM&M with <u>short term contracts</u>
	Lack of <u>specific technologies</u> that can holistically address the issues around <u>retrofitting of existing buildings</u>	Lack of <u>right knowledge, awareness and training</u> of facility personnel in OM&M domain
	Lack of in-depth, up-to-date <u>knowledge of actual performance</u>	<u>Risk aversion</u> on taking up of new technologies due to lack of information, awareness, validated data, and incentives
	<u>Over sizing of systems and equipment</u> due to uncertainty of end-user energy profile and over provision to meet regulatory standards	Lack of in-depth knowledge on <u>costs</u> of technologies
	Lack of <u>easy to use software</u> for integrated design, modelling, simulation, and analysis	Lack of <u>accountability</u> of consultants and design team on actual performance of the building
	Lack of <u>data availability and measurement verification</u>	
	Lack of <u>accurate integrated design process and execution</u> (building design based on whole life cycle, cost benefit, risk analysis and social impact)	


Source: Building Energy Efficiency Roadmap 2014

NATIONAL RESEARCH FOUNDATION  
EDB singapore

SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).

NUS

57

- ## Building envelope and facades systems (BEFS)
- 
- Lacks identified in the EE Roadmap for key area BEFS
- Lack of effective passive and active design strategies for building envelopes
  - Lack of technology adaptation for the tropics
  - Ineffective usage of Envelope Thermal Transfer Value (ETTV) for design
- Source: Building Energy Efficiency Roadmap 2014
- NATIONAL RESEARCH FOUNDATION  
EDB singapore

SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



NUS
- 58

## EE Roadmap: identified technologies


Near Term T0	T0+2	Medium Term T0+5	Long Term T0+10	Outcome
<b>National components database</b>				<i>Need to establish a database of building components used in Singapore, including details such as material properties</i>
<b>Modeling outputs</b>				<i>Define standards for performance metrics reported as outputs</i>
<b>Integrated Design tools for multi-criteria optimisation</b>				<i>Optimise for whole building approach to minimize negative impacts and maximize efficiency</i>
<b>Tools for on-site façade performance</b>				<i>Establish performance targets based on live / realistic measurements</i>
<b>Multi functional façade</b>				<i>Use for energy storage/power/food generating devices</i>
<b>Development of dynamic shading systems</b>				<i>Optimized design and application of accurate façade systems for the building based on orientation</i>

1 out of 5 identified technology strategies is:  
**Integrated test-bedding of BEFS**

Source: Building Energy Efficiency Roadmap 2014

SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


59

## Proven Quality




SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).


60

# Labelling



National Environmental Agency provides Energy Efficiency Labels for:

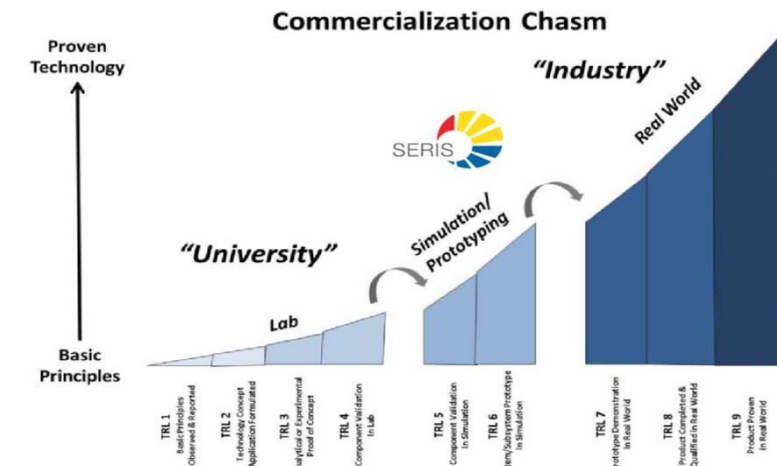
- 1 to 5 (highest performance) ticks
- e.g. air-conditioners, refrigerators

## How To Read The Energy Label



Source National Environmental Agency

# Technological Readiness Level



## Solar Energy Systems Cluster



### Research areas

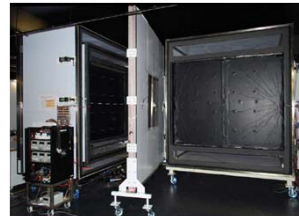


- ❑ On-grid and off-grid PV system technologies
  - Optimising performance and developing devices
- ❑ PV potential analysis
  - Evaluation of available roof-top areas using aerial views
- ❑ Solar resource forecasting
  - Spatial and time resolution of solar irradiation data using satellite data and meteorological stations
- ❑ PV-grid interactions
  - Influences of PV on network parameters and smart grids

## SEEB Cluster – Lab facilities



- Calorimeter Lab, Integrating sphere, UV/VIS/NIR spectrophotometer
- Material properties
  - U-value
  - Thermal conductivity (windows, walls, glazings, materials)
  - SHGC
  - Solar/ VIS reflectance and transmittance
  - Solar emittance
  - Shading coefficient (glazings, shadings, paints, coatings, roofs, façade elements)
  - visible light reflectance/ transmittance of patterned PV modules, of patterned glazing systems or translucent materials



## SEEB Cluster – On-site Testing



- Thermal imaging
- Heat flux, solar radiation, temperatures, volume flow
- On-site U-value measurement
- Holistic building energy audits
- Blower Door test: air tightness of buildings and air ducts, leakage detection
- Holistic energy audits



NATIONAL RESEARCH FOUNDATION  
PIONEER IN RESEARCH & INNOVATION



SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



66

## ZEB@BCAA

Zero Energy Building



NATIONAL RESEARCH FOUNDATION  
PIONEER IN RESEARCH & INNOVATION



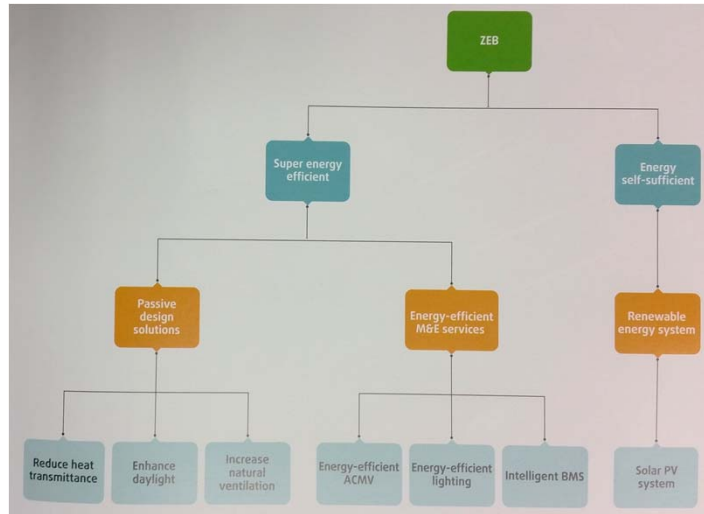
SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).



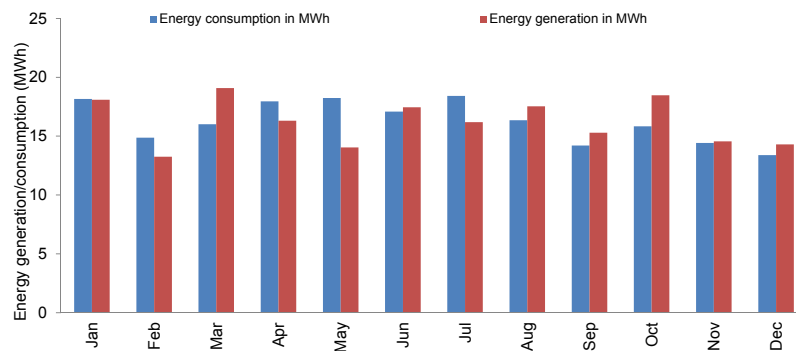
67



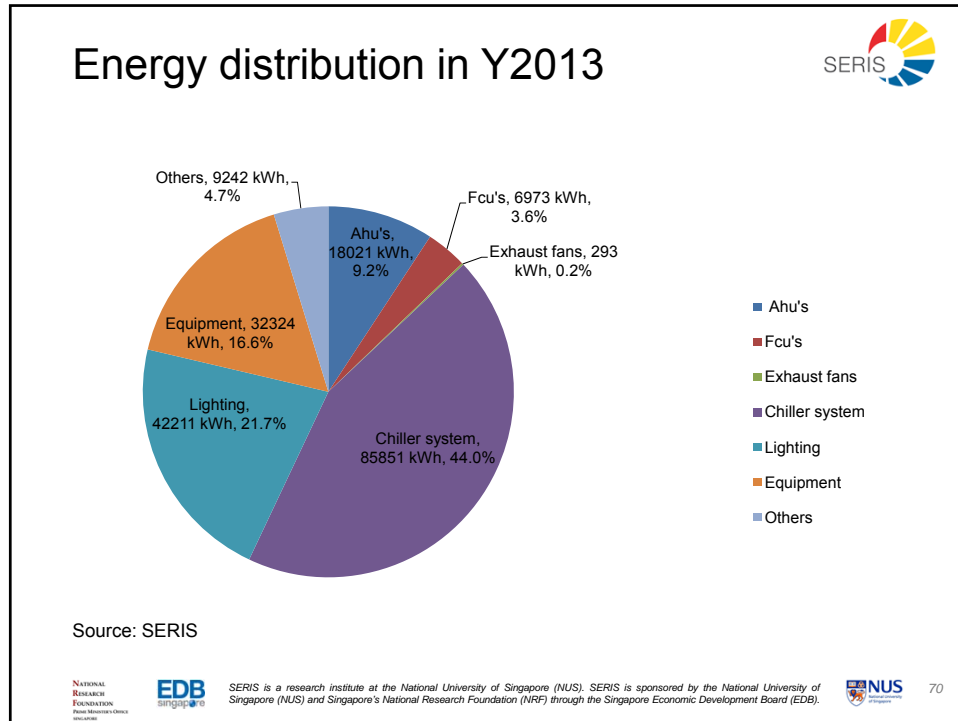
# ZEB@BCAA Guiding Principles



# ZEB@BCAA Monitoring



Source SERIS



## Summary

For high performance buildings



- Demand side analysis
- Climate adjusted strategies
- Different technologies available
- Identify strategies for priorities: Roadmaps
- Mandatory and voluntary measures
- Green Mark Scheme, Labelling
- Proven quality is necessary for reliability
- Applied Research - Test-bedding and Monitoring

NATIONAL RESEARCH FOUNDATION  
EDB singapore  
SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  
NUS  
71



Thank you for your attention!

[runa.hellwig@nus.edu.sg](mailto:runa.hellwig@nus.edu.sg)

More information at  
[www.seris.sg](http://www.seris.sg)



Annual Report  
2014

NATIONAL RESEARCH FOUNDATION  EDB SERIS is a research institute at the National University of Singapore (NUS). SERIS is sponsored by the National University of Singapore (NUS) and Singapore's National Research Foundation (NRF) through the Singapore Economic Development Board (EDB).  NUS 72