Holistic Method on Performing Microclimate Analyses of an Urban Area in The Tropics

Dr. MARCEL IGNATIUS

Prof WONG Nyuk Hien

Dr. Steve Kardinal JUSUF

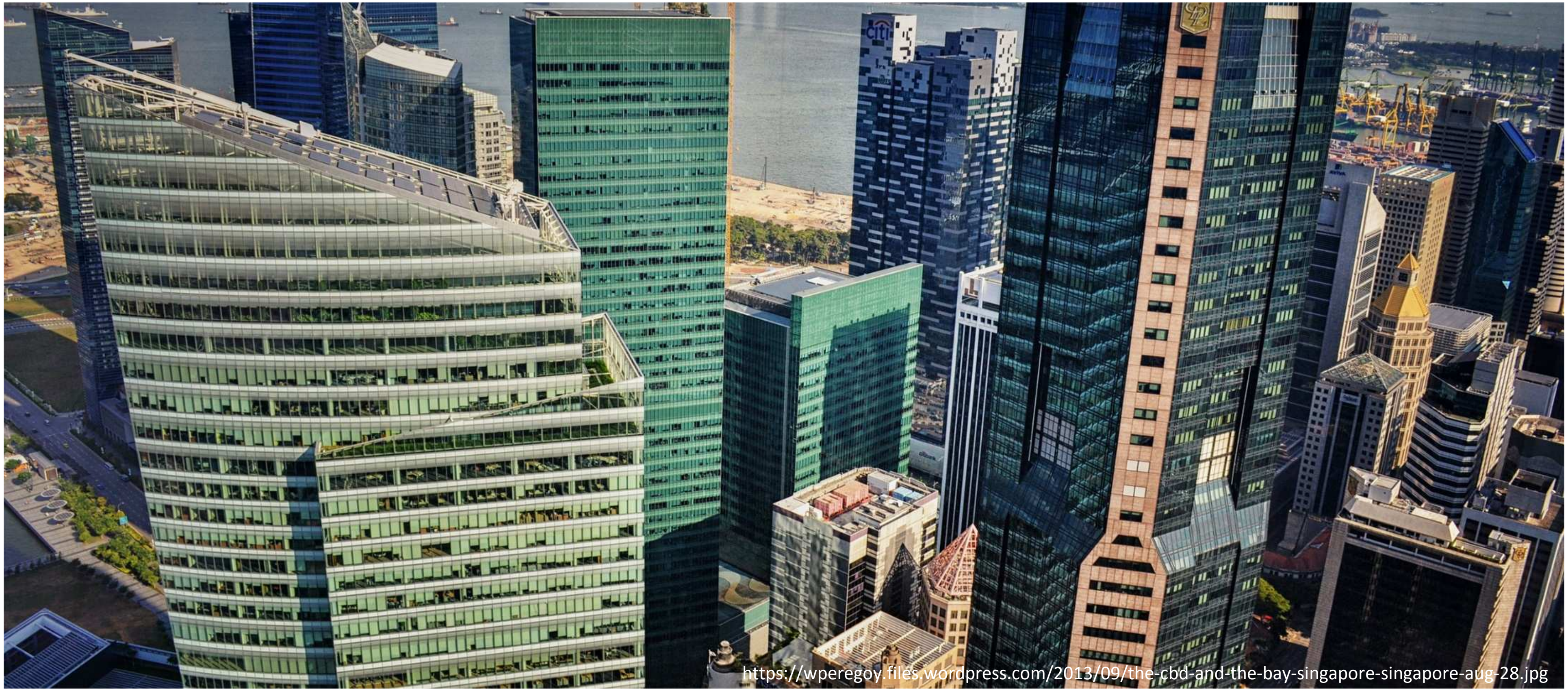
Daniel HII Jun Chung

NUS National University of Singapore

9th International Conference on Urban Climate (ICUC)

20 . 07 . 2015

introduction

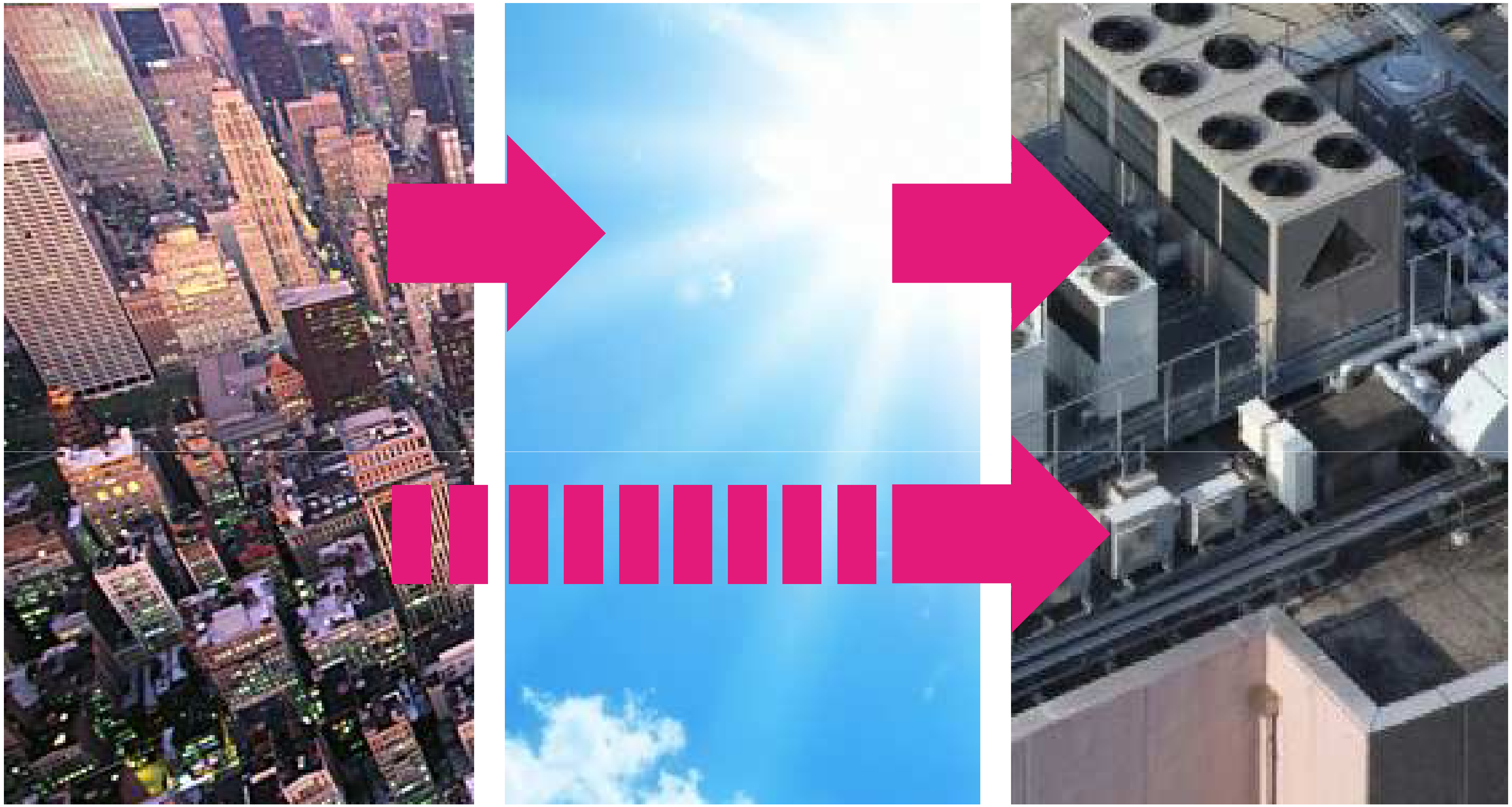


- The urban population in 2014 accounted for **54%** of the total global population, up from **34%** in 1960, and continues to grow (WHO).
- Cities are growing towards **megacities** with higher density urban planning, narrower urban corridors and more high-rise urban structures.

introduction

- **Increasing urbanization** causes the deterioration of the urban environment, as the size of **housing plots decreases**, thus **increasing densities** and **crowding out greeneries** (Santamouris, Asimakopoulos et al. 2001)
- Cities tend to record **higher temperatures** than their non-urbanized surroundings, a phenomenon known as **Urban Heat Island (UHI)** (Jusuf, Wong et al. 2007; Oke 1982).
- **Building sector** is accountable for more than **40% of global energy consumption** and **30% of global greenhouse emissions**, which comes from both **commercial and residential usage** (C2ES, 2009).
- In the ASEAN region, **commercial buildings** are accountable for **30% of all the electricity use** and will demand approximately another **40% of generation capacity** in years to come (MECM, 2001)
- Overcrowded and densely built urban areas also affect other microclimate aspects such as **urban ventilation and outdoor thermal comfort**.

methodology



URBAN TEXTURE

MICRO
CLIMATE

HEAT GAIN/
ENERGY

objectives

- The scope of this study focuses on **non-domestic/commercial office buildings** type within Singapore context, as an example of high density urban area typology.
- This study explores the effect of **urban texture**, characterized by its physical density and form, on the:

  1. **outdoor temperature**
  2. **heat gains**
  3. **Ventilation**
  4. **outdoor thermal comfort; in district/precinct level.**

- To transform the relationship how between urban texture and micro-climatic condition into a **practical analysis approach** for urban performance evaluation.

models application

This exercise tries to demonstrate a more comprehensive micro climate analysis on a precinct by looking at several components:

1. **Thermal Load Models** are used to predict the energy performance and external heat gains.
2. **Screening Tool for Estate Environment Evaluation (STEVE)** tool was used to analyze outdoor temperature and greenery implementation.
3. Urban ventilation analysis will be conducted by using **the Ventilation Ratio (VR)** method, observing the urban geometric condition to determine the wind speed condition at the pedestrian level.
4. For outdoor thermal comfort, the **Thermal Sensation Vote (TSV)** was used to categorizes the human perception of thermal comfort in the outdoor area.

methodology – case study

- Using a 9 ha of office precinct site at CBD.
- The precinct comprises 6 planning blocks of 6.3 ha, with 2 large, elongated blocks (1.95 ha each) and 4 rectangular blocks (0.6 ha each).
- A parametric design approach was implemented on configuring the whole precinct layout.

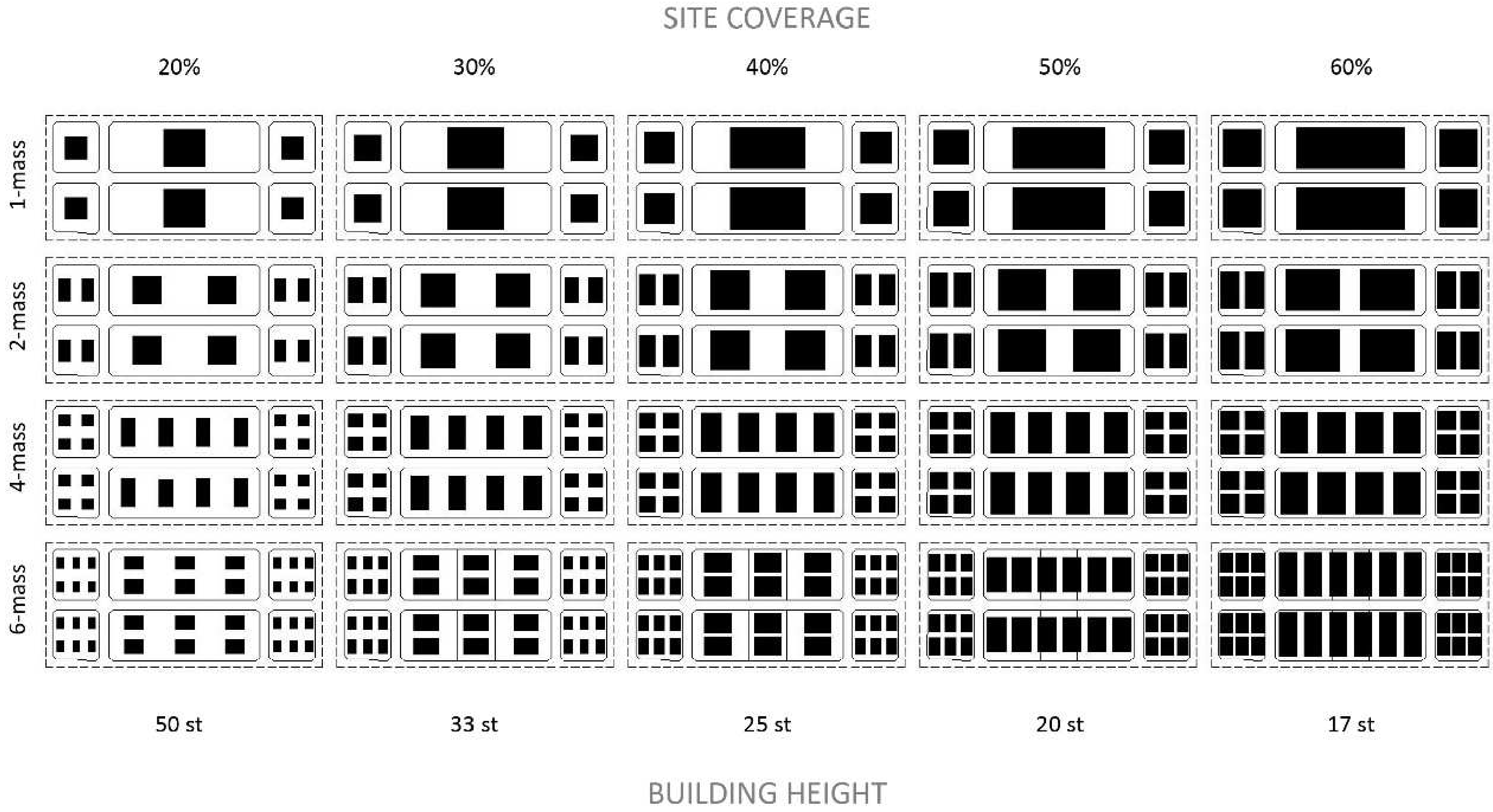
BLOCK INFO

FAR/Plot Ratio : 10

Block Area (buildable) : 63,000 m^2

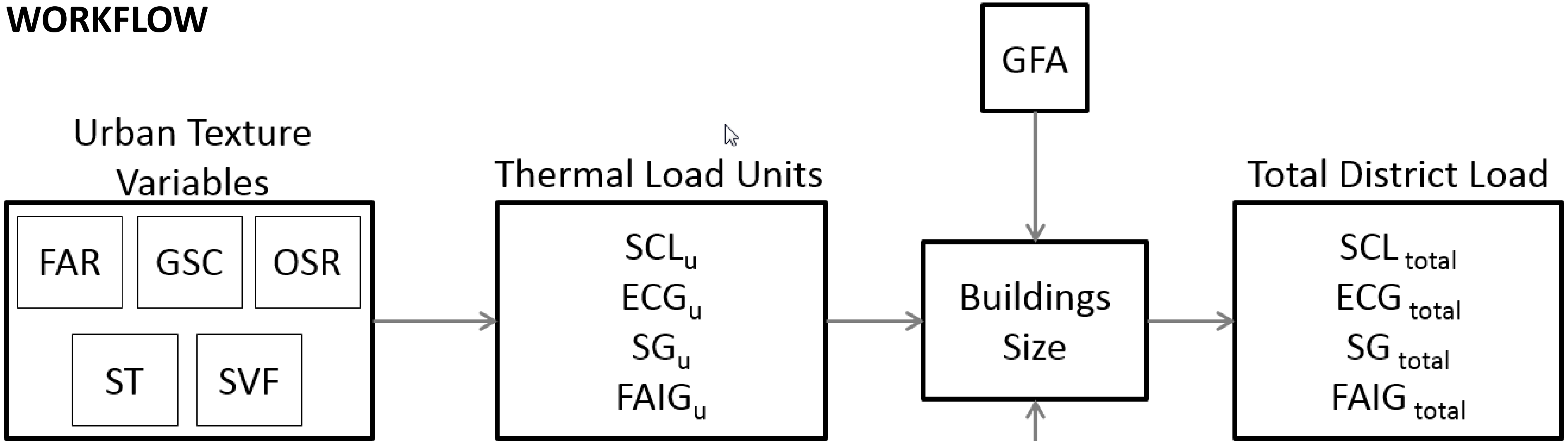
Max Gross Floor Area : 630,000 m^2

methodology – parametric design



analysis #1 – thermal load models

WORKFLOW



FAR = Floor Area Ratio
GSC = Gross Site Coverage ratio
OSR = Open Space Ratio
ST = average no of Stories
SVF = Sky View Factor

SCL = Sensible Cooling Load
ECG = Envelope Conduction Gain
SG = Solar Gain
FAIG = Fresh Air Intake Gain

$$ECG_U(\mathrm{Wh\,m^{-4}}) = 0.7078(\mathrm{Wh\,m^{-4}})(SVF)^{0.3398}(OSR)^{0.6491}(ST)^{-0.3149}$$

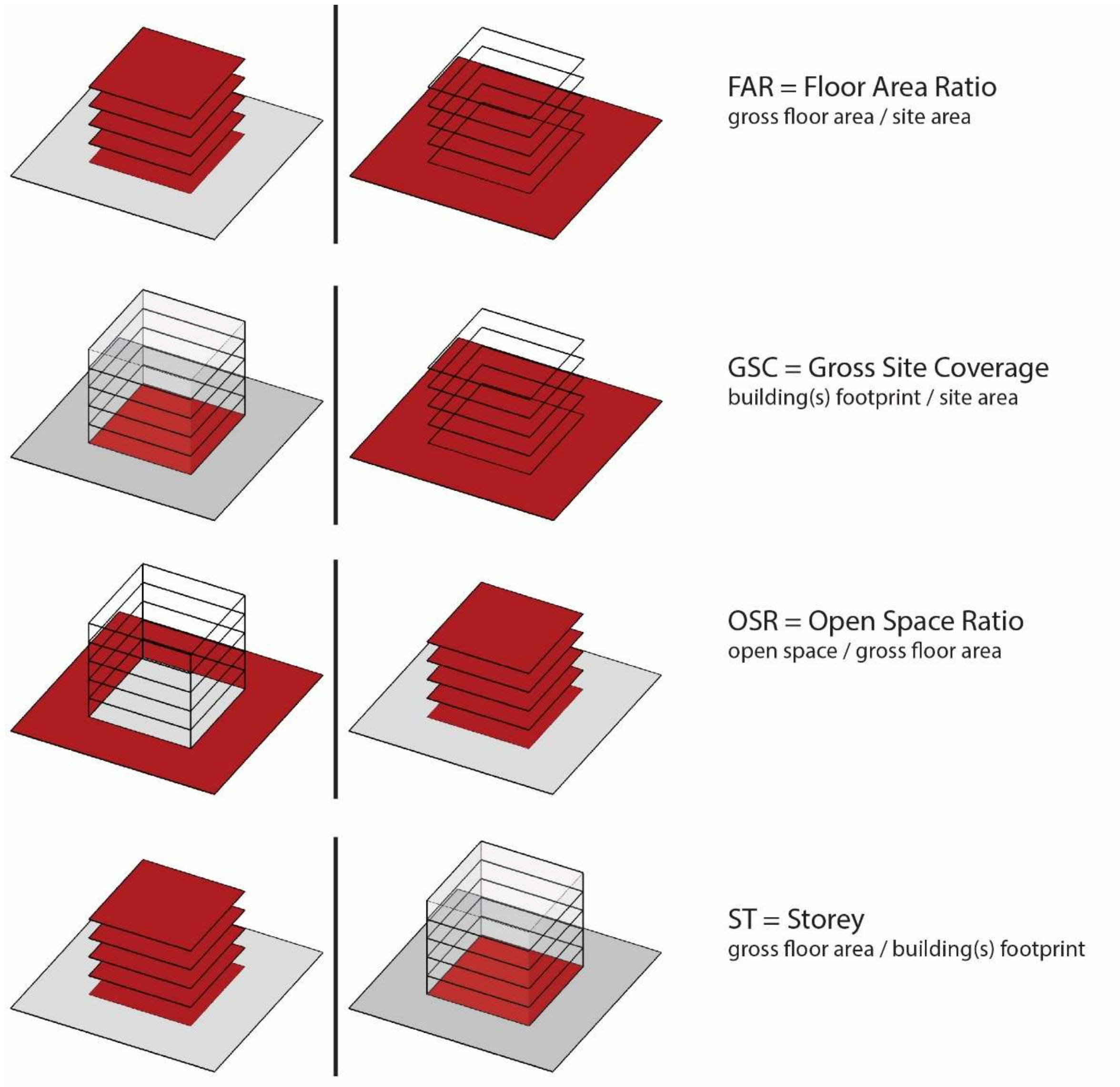
$$SG_U(\mathrm{Wh\,m^{-4}}) = 0.19(\mathrm{Wh\,m^{-4}})(SVF)^{0.4994}(FAR)^{-0.6417}(GSC)^{-0.556}$$

$$FAIG_U(\mathrm{Wh\,m^{-4}}) = 0.5441(\mathrm{Wh\,m^{-4}})(SVF)^{2.2811}$$

$$SCL_U(\mathrm{Wh\,m^{-4}}) = 5.637(\mathrm{Wh\,m^{-4}})(SVF)^{1.7662}(OSR)^{0.1689}$$

analysis #1 – thermal load models

VARIABLES

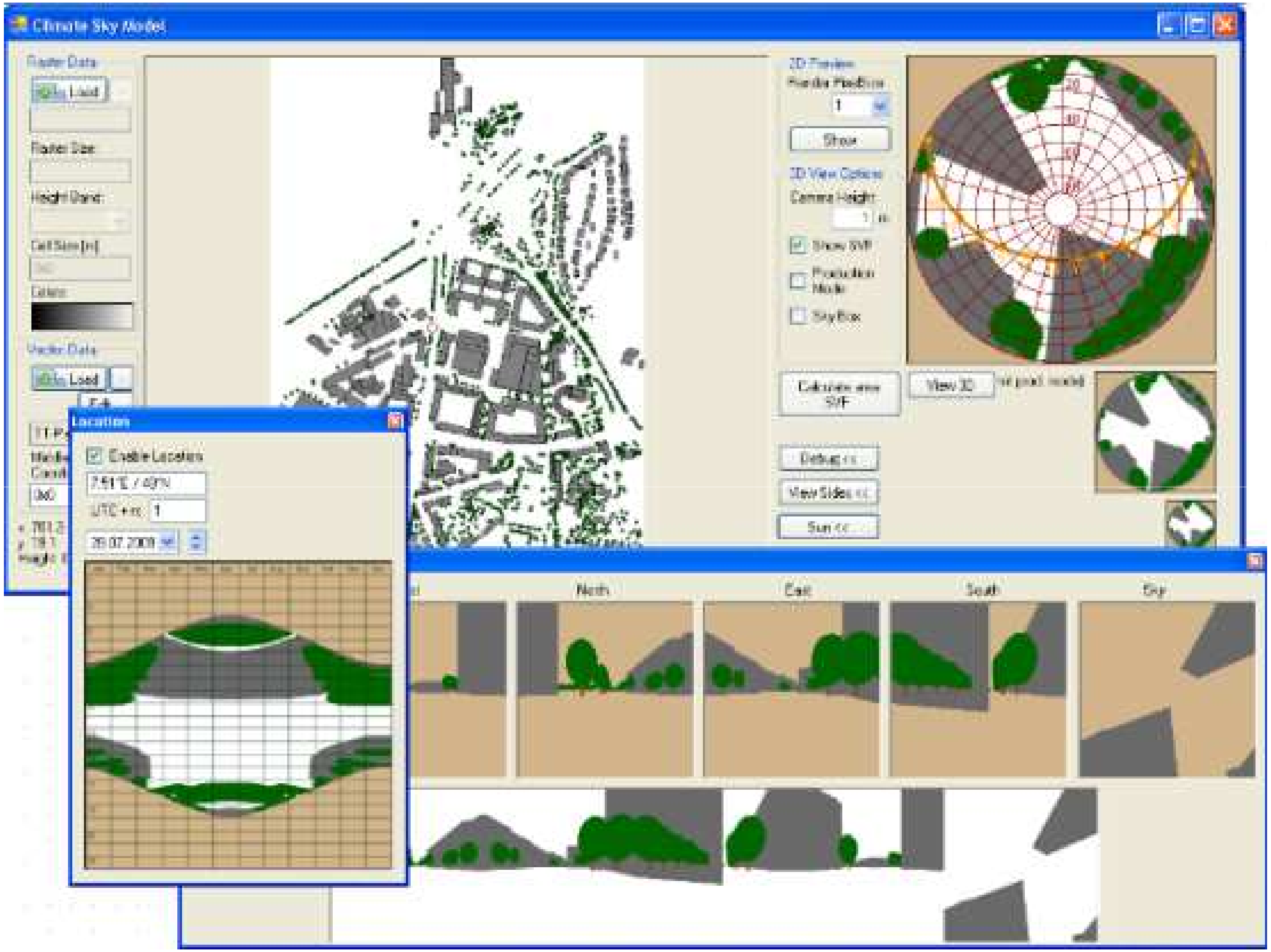


Spacematrix variables (Pont and Haupt, 2010)

analysis #1 – thermal load models

VARIABLES

SKY VIEW FACTOR



(Matuschek and Matzarakis 2010, Matzarakis and Fröhlich 2010)

methodology – parametric design

Site Coverage	20%	30%	40%	50%	60%
FAR	7	7	7	7	7
ST	50	33	25	20	17
OSR	0.123	0.113	0.103	0.093	0.083
GSC	0.140	0.210	0.280	0.350	0.420

SKY VIEW FACTORS

Site Coverage	20%	30%	40%	50%	60%
1-mass	0.562	0.533	0.514	0.489	0.468
2-mass	0.474	0.447	0.434	0.422	0.413
4-mass	0.389	0.366	0.360	0.348	0.352
6-mass	0.358	0.346	0.345	0.343	0.327

LOW HIGH

BUILDING SURFACE AREA (total)

Site Coverage	20%	30%	40%	50%	60%
1-mass	197,162.90	169,744.20	158,248.80	152,686.20	150,761.90
2-mass	281,736.10	237,748.00	215,509.10	201,837.40	193,886.40
4-mass	392,056.10	327,376.00	293,517.20	269,467.20	253,626.70
6-mass	471,577.00	394,599.50	350,668.30	326,246.80	317,528.50

(Unit: m^2)

LOW HIGH

analysis #2 – ventilation ratio

Precinct-scale wind flow is quantified by the area-averaged wind velocity ratio (V_R) which is defined as:

$$V_R = V_p / V_\infty$$

V_p wind velocity at **pedestrian level (2m above ground)** after taking into account the effects of buildings.

V_∞ area-averaged wind velocity magnitude extracted at a study level over the wind velocity at the **top of the urban boundary layer that is not affected** by ground roughness and other site features

The V_R model for the pedestrian level within the overall precinct or estate-level was regressed from the urban morphological predictors within a given precinct area of 500 m x 500 m (or 25 ha) at 2 meter high, based on the general wind profile conditions of Singapore:

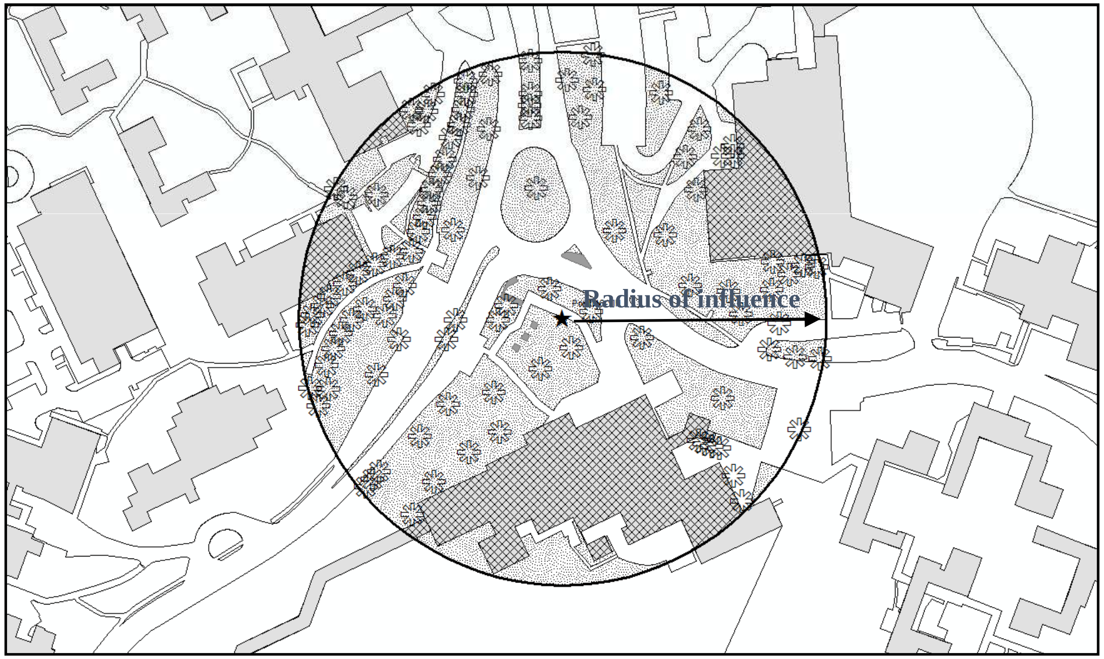
$$\text{[illegible]} = 0.132 + 0.178(\text{[illegible]}) - 0.006(\text{[illegible]})(\text{[illegible]} - 1) + 0.001(\text{[illegible]})(\text{[illegible]}) - 0.043(\text{[illegible]}) + 0.693(\text{[illegible]}) - 0.002(\text{[illegible]})(\text{[illegible]}) + 0.261(\text{[illegible]})$$

(Lee 2013, Lee, Jusuf et al. 2013, Lee and Wong 2014)

analysis #3 – ambient temperature

The Screening Tool for Estate Environment Evaluation (STEVE)

"The air temperature of a point at a certain height level is the function of the local climate characteristics, which deviates according to the surrounding urban morphology characteristics (building, pavement and greenery) at a *certain radius*". STEVE takes into account of climate and urban morphology predictors.



(Wong, Jusuf et al. 2007, Wong and Jusuf 2008, Wong and Jusuf 2008, Jusuf and Wong 2009)

CLIMATE PREDICTORS

Ref T_{min}	=	daily minimum temperature at reference point
Ref T_{avg}	=	daily average temperature at reference point
Ref T_{max}	=	daily maximum temperature at reference point
$SOLAR_{total}$	=	average of daily solar radiation
$SOLAR_{max}$	=	maximum of daily solar radiation

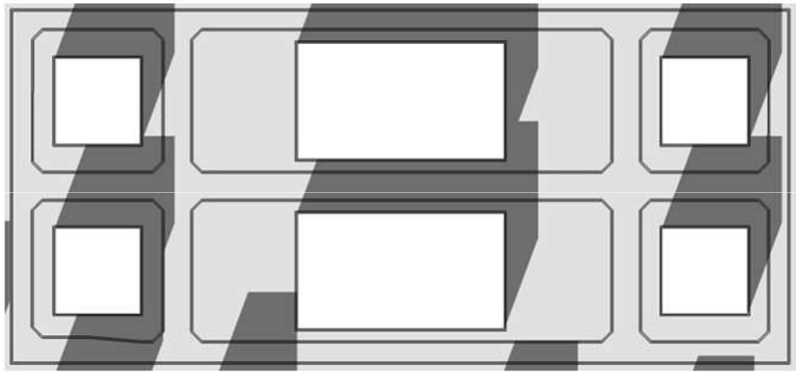
URBAN MORPHOLOGY PREDICTORS

PAVE	=	percentage of pavement area over R 50m surface area
HBDG	=	average height to building area ratio
WALL	=	total wall surface area
GnPR	=	Green Plot Ratio
SVF	=	sky view factor
ALB	=	average surface albedo

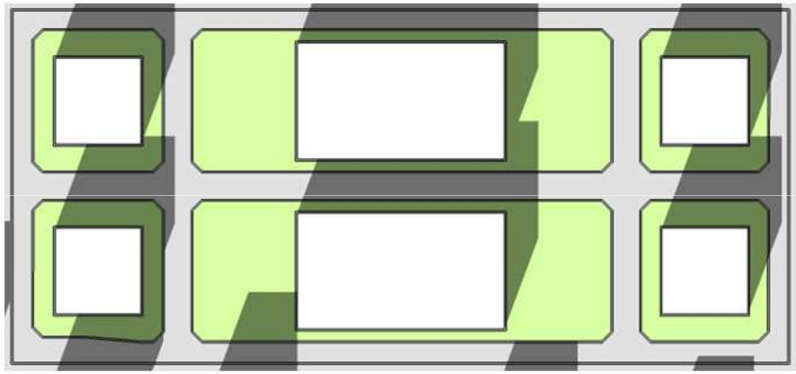
analysis #3 – ambient temperature

1. No wind
Paved open space
(BASELINE)
2. Wind Considered
Paved open space
3. Wind Considered
Turf open space
4. Wind Considered
Trees planted
Turf open space
5. Wind Considered
Trees planted
Turf open space

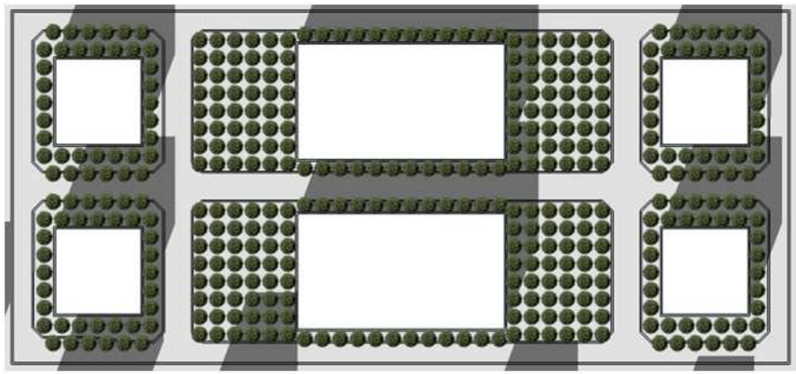
[2] PAVEMENT



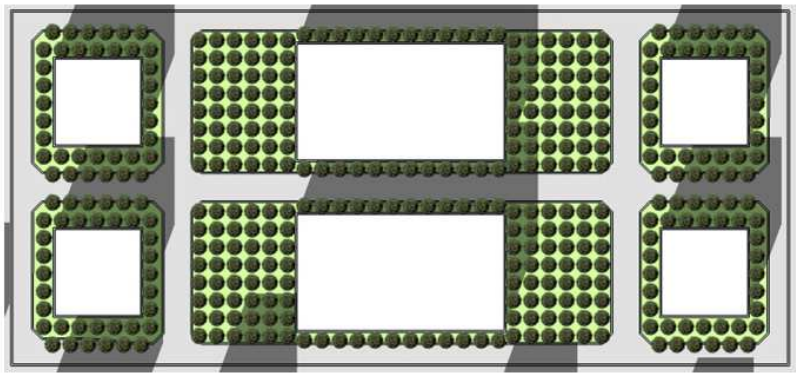
[3] TURFING



[4] PAVEMENT + TREES

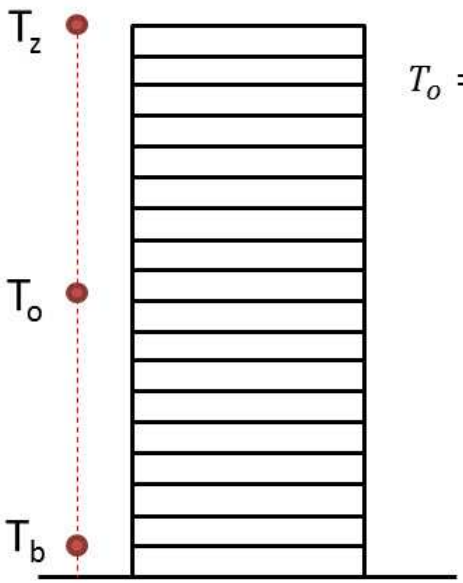


[5] TURFING + TREES

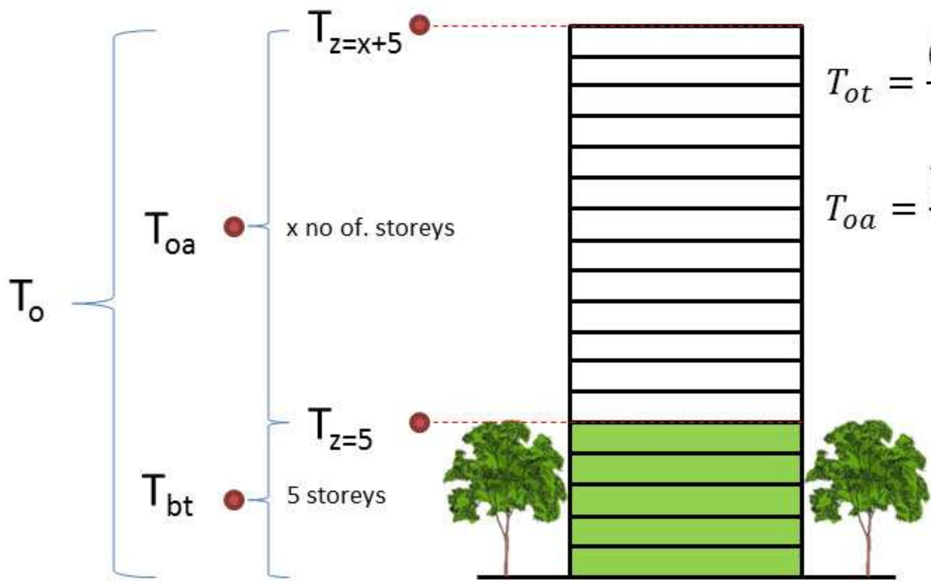


analysis #3 – ambient temperature

1. No wind, Paved open space (BASELINE)
2. Wind Considered, Paved open space
3. Wind Considered, Turf open space
4. Wind Considered, Trees planted, Turf open space
5. Wind Considered, Trees planted, Turf open space



$$T_o = \frac{T_z + T_b}{2}$$



$$T_{ot} = \frac{(T_{oa} \times x) + (T_{bt} \times 5)}{x + 5}$$

$$T_{oa} = \frac{T_{z(5)} + T_{z(x+5)}}{2}$$

Notes:

T_b =air temperature at base (ground), °C
T_z =air temperature at altitude *z*, °C
T_o =outdoor air temperature, °C

Notes:

T_{bt} =air temperature at bottom which influenced by trees, °C
T_{z1} =air temperature at altitude *z1*, above the tree layer, °C
T_z =air temperature at altitude *z*, °C
T_{oa} =outdoor air temperature above the tree layer, °C
T_o =outdoor air temperature, °C

analysis #4 – outdoor thermal comfort

- Thermal Sensation Vote (TSV) is used for predicting and evaluating people's thermal sensation; it was proposed for Singapore under certain outdoor thermal conditions.
- The model is a function of four independent variables: air temperature (Ta), relative humidity (RH), wind speed (V) and mean radiant temperature (Tmrt).

$$TSV = 0.398T_a + 0.023RH - 0.329V + 0.038T_{mrt} - 14.061$$

or

$$TSV = 0.315T_a - 0.078V - 8.825$$

TSV range	Perception
-3 ～ -2	cold to cool
-2 ～ -1	cool to slightly cool
-1 ～ 0	slightly cool to neutral
0 ～ 1	neutral to slightly warm
1 ～ 2	slightly warm to warm
2 ～ 3	warm to hot

(Yang, Wong et al. 2013, Yang, Wong et al. 2013)

results – thermal load calculation

NUS National University of Singapore

ANNUAL ENVELOPE CONDUCTIONG GAIN (ECG)

Site Coverage	20%	30%	40%	50%	60%
1-mass	5,411.63	4,936.25	4,671.24	4,448.96	4,230.87
2-mass	7,298.24	6,512.62	6,006.13	5,593.94	5,214.80
4-mass	9,496.49	8,378.88	7,676.78	6,994.77	6,461.07
6-mass	11,104.88	9,908.42	9,039.87	8,427.10	7,888.99

ANNUAL SOLAR GAIN UNIT (SG)

Site Coverage	20%	30%	40%	50%	60%
1-mass	12,427.33	8,316.74	6,488.77	5,394.20	4,708.42
2-mass	16,310.24	10,668.68	8,120.72	6,624.74	5,688.73
4-mass	20,563.77	13,294.72	10,074.35	8,032.60	6,870.69
6-mass	23,729.86	15,581.20	11,782.82	9,655.12	8,291.06

ANNUAL FRESH AIR INTAKE GAIN UNIT (FAIG)

Site Coverage	20%	30%	40%	50%	60%
1-mass	18,154.06	13,850.26	11,886.23	10,235.49	9,143.58
2-mass	17,590.86	12,985.56	11,004.52	9,667.85	8,841.36
4-mass	15,595.92	11,332.68	9,784.63	8,314.42	8,032.36
6-mass	15,521.89	12,016.36	10,608.29	9,739.47	8,500.57

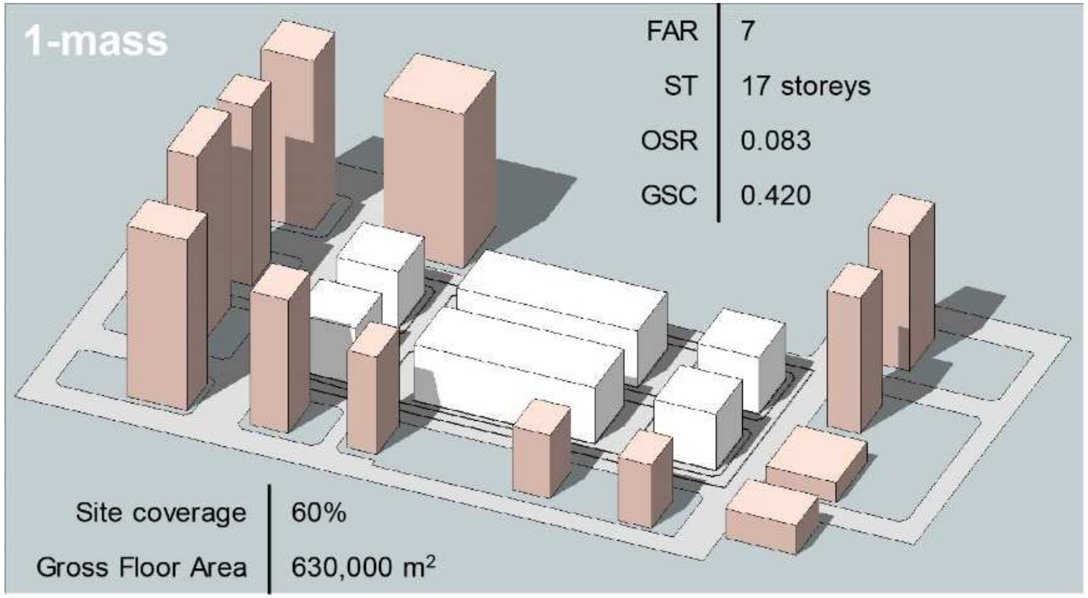
ANNUAL SENSIBLE COOLING LOAD UNIT (SCL)

Site Coverage	20%	30%	40%	50%	60%
1-mass	177,612.40	137,272.74	118,165.36	102,615.31	91,979.28
2-mass	187,874.70	140,908.16	119,357.29	104,564.81	94,852.81
4-mass	184,410.64	136,306.31	116,849.42	99,312.25	93,564.84
6-mass	191,553.77	148,772.39	129,492.52	117,204.04	102,847.08

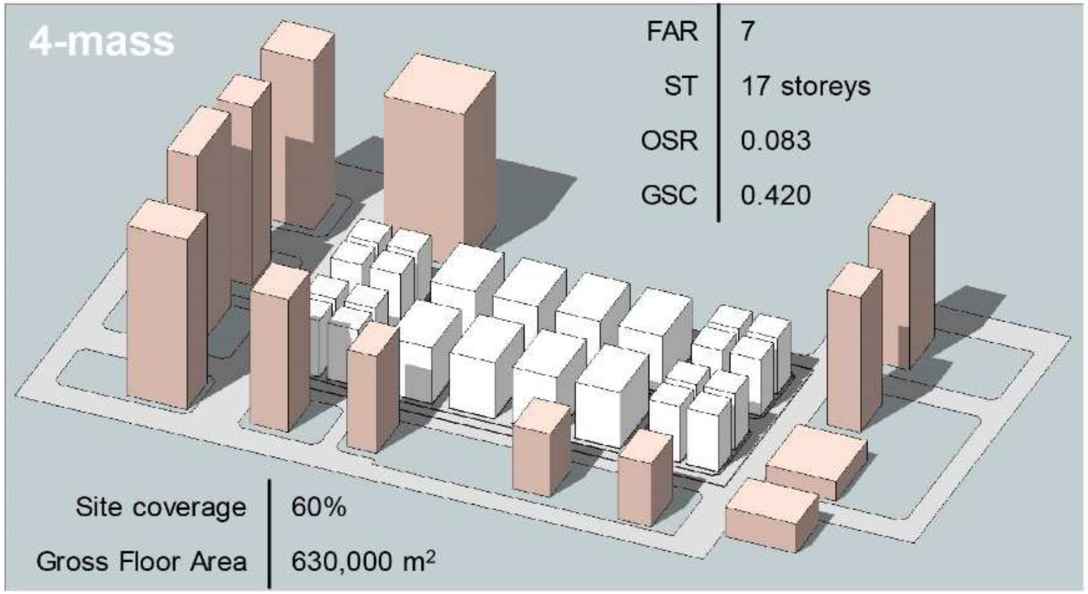
(Unit: MWh)

LOW HIGH

results – thermal load calculation

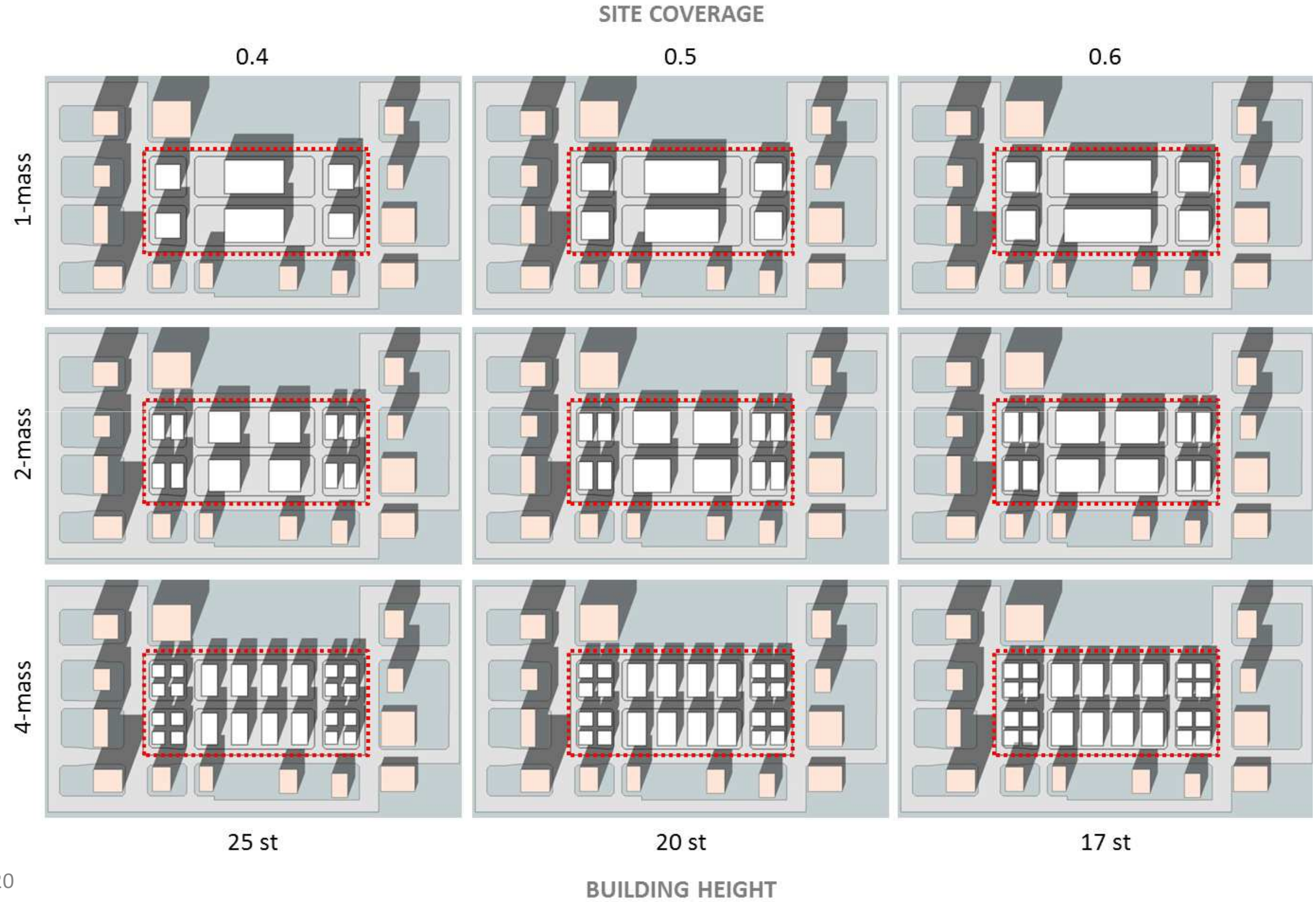


Surface Area	150,762 m^2
SVF	0.468
ECG_U	0.044545 Wh/m^{-4}
SG_U	0.049573 Wh/m^{-4}
SCL_U	0.968407 Wh/m^{-4}
Annual ECG	4,230.87 MWh
Annual SG	4,708.42 MWh
Annual SCL	91,979.28 MWh



Surface Area	253,627 m^2
SVF	0.352
$FAIG_U$	0.050270 Wh/m^{-4}
Annual FAIG	8,032.36 MWh

results – thermal load calculation



results – urban ventilation

$V_\infty = 6m/s$

	SITE COVERAGE 40%	50%	60%		SITE COVERAGE 40%	50%	60%
VR				**Wind Speed (m/s)**			
1-mass	0.328	0.325	0.319	1-mass	1.971	1.952	1.915
2-mass	0.310	0.308	0.306	2-mass	1.863	1.850	1.837
4-mass	0.288	0.294	0.292	4-mass	1.728	1.761	1.752

results – ambient temperature

Ambient Temperature Prediction Comparison

(with wind impact and open space surface modification)

T_{avg} (daytime)

SC	BASELINE 40%	BASELINE 50%	BASELINE 60%	PAVED WIND 40%	PAVED WIND 50%	PAVED WIND 60%	TURFING WIND 40%	TURFING WIND 50%	TURFING WIND 60%	PAVED + TREES WIND 40%	PAVED + TREES WIND 50%	PAVED + TREES WIND 60%	TURFING + TREES WIND 40%	TURFING + TREES WIND 50%	TURFING + TREES WIND 60%
1-mass	30.04	30.02	29.99	29.72	29.70	29.69	29.43	29.46	29.51	29.44	29.48	29.49	29.25	29.32	29.35
2-mass	30.03	30.01	30.00	29.72	29.71	29.69	29.46	29.50	29.53	29.46	29.50	29.50	29.29	29.38	29.40
4-mass	30.03	30.01	29.99	29.75	29.72	29.70	29.51	29.53	29.56	29.50	29.49	29.56	29.39	29.40	29.49

Reduction

SC	PAVED WIND 40%	PAVED WIND 50%	PAVED WIND 60%	TURFING WIND 40%	TURFING WIND 50%	TURFING WIND 60%	PAVED + TREES WIND 40%	PAVED + TREES WIND 50%	PAVED + TREES WIND 60%	TURFING + TREES WIND 40%	TURFING + TREES WIND 50%	TURFING + TREES WIND 60%
1-mass	0.32	0.32	0.30	0.61	0.56	0.48	0.60	0.54	0.51	0.79	0.70	0.64
2-mass	0.30	0.30	0.30	0.56	0.51	0.47	0.56	0.51	0.50	0.74	0.63	0.60
4-mass	0.28	0.29	0.29	0.52	0.47	0.43	0.52	0.51	0.43	0.64	0.60	0.50

T_{max}

SC	BASELINE 40%	BASELINE 50%	BASELINE 60%	PAVED WIND 40%	PAVED WIND 50%	PAVED WIND 60%	TURFING WIND 40%	TURFING WIND 50%	TURFING WIND 60%	PAVED + TREES WIND 40%	PAVED + TREES WIND 50%	PAVED + TREES WIND 60%	TURFING + TREES WIND 40%	TURFING + TREES WIND 50%	TURFING + TREES WIND 60%
1-mass	32.35	32.29	32.21	31.58	31.52	31.49	31.29	31.29	31.31	31.32	31.32	31.32	31.05	31.10	31.11
2-mass	32.21	32.18	32.15	31.49	31.46	31.43	31.23	31.25	31.27	31.21	31.25	31.22	31.00	31.09	31.10
4-mass	32.10	32.08	32.07	31.43	31.39	31.37	31.19	31.21	31.24	31.15	31.15	31.23	31.03	31.05	31.13

Reduction

SC	PAVED WIND 40%	PAVED WIND 50%	PAVED WIND 60%	TURFING WIND 40%	TURFING WIND 50%	TURFING WIND 60%	PAVED + TREES WIND 40%	PAVED + TREES WIND 50%	PAVED + TREES WIND 60%	TURFING + TREES WIND 40%	TURFING + TREES WIND 50%	TURFING + TREES WIND 60%
1-mass	0.77	0.77	0.72	1.06	1.00	0.90	1.03	0.97	0.89	1.30	1.19	1.09
2-mass	0.72	0.72	0.72	0.98	0.93	0.88	1.00	0.93	0.93	1.21	1.09	1.04
4-mass	0.67	0.69	0.70	0.91	0.87	0.83	0.95	0.93	0.84	1.07	1.03	0.93

*in degree Celsius (°C)

**Baseline → no wind, paved open space

TEMPERATURE: HIGH – LOW

REDUCTION: LEAST – MOST

results – energy performance + benchmarking

Energy Consumption Reduction

(with wind impact and open space surface modification)

°C Reduction in $T_{avg\ (daytime)}$

SC	Type	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass	30.04	0.32	0.61	0.60	0.79
	2-mass	30.03	0.30	0.56	0.56	0.74
	4-mass	30.03	0.28	0.52	0.52	0.64
50%	1-mass	30.02	0.32	0.56	0.54	0.70
	2-mass	30.01	0.30	0.51	0.51	0.63
	4-mass	30.01	0.29	0.47	0.51	0.63
60%	1-mass	29.99	0.30	0.48	0.51	0.64
	2-mass	30.00	0.30	0.47	0.50	0.60
	4-mass	29.99	0.29	0.43	0.43	0.50

*Baseline → no wind, paved open space

LEAST MOST

*values in °C

% Reduction (in energy consumption)

SC	Type	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass		1.61	3.05	2.98	3.95
	2-mass		1.51	2.82	2.82	3.70
	4-mass		1.41	2.60	2.62	3.19
50%	1-mass		1.61	2.78	2.71	3.49
	2-mass		1.51	2.57	2.56	3.16
	4-mass		1.45	2.37	2.57	3.16
60%	1-mass		1.51	2.40	2.54	3.21
	2-mass		1.51	2.33	2.50	2.99
	4-mass		1.47	2.16	2.14	2.52

1°C ↓ - 5% ↓

LEAST MOST

*values in %

Reduction (in energy consumption)

SC	Type	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass	145.25	142.91	140.82	140.92	139.51
	2-mass	145.62	143.42	141.52	141.52	140.23
	4-mass	144.83	142.79	141.06	141.03	140.21
50%	1-mass	140.33	138.07	136.43	136.53	135.43
	2-mass	140.95	138.82	137.33	137.34	136.49
	4-mass	139.29	137.27	135.99	135.71	134.89
60%	1-mass	136.97	134.90	133.68	133.49	132.58
	2-mass	137.88	135.80	134.67	134.43	133.76
	4-mass	137.47	135.45	134.50	134.53	134.01

HIGH LOW

*values in kWh/m²/yr

Reduction (in electricity tariff)

SC	Type	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass		0.63	1.20	1.17	1.55
	2-mass		0.59	1.11	1.11	1.45
	4-mass		0.55	1.02	1.02	1.25
50%	1-mass		0.61	1.05	1.03	1.32
	2-mass		0.57	0.98	0.97	1.20
	4-mass		0.55	0.89	0.97	1.19
60%	1-mass		0.56	0.89	0.94	1.19
	2-mass		0.56	0.87	0.93	1.11
	4-mass		0.55	0.80	0.79	0.94

HIGH LOW

*values in Million Singapore Dollars
**tariff: 0.27$/Watt

This illustrates the impact of the temperature reduction on energy consumption, with every 1° C reduction bringing down the 5% overall building energy usage (Chen and Wong, 2006; Wong and Chen, 2009; Wong et al., 2011b). The energy consumption values are refers on the sensible cooling load from the thermal load calculation (which has been converted into the energy usage) and added with standard lighting and equipment energy consumption.

results – outdoor thermal comfort

Thermal Sensation Vote (TSV) Comparison

T_{avg} (daytime)

Wind + Dry bulb Temperature Prediction

SC	Type	Wind Speed	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass	1.971	30.04	29.72	29.43	29.44	29.25
	2-mass	1.863	30.03	29.72	29.46	29.46	29.29
	4-mass	1.728	30.03	29.75	29.51	29.50	29.39
50%	1-mass	1.952	30.02	29.70	29.46	29.48	29.32
	2-mass	1.850	30.01	29.70	29.50	29.50	29.38
	4-mass	1.761	30.01	29.71	29.53	29.49	29.40
60%	1-mass	1.915	29.99	29.69	29.51	29.49	29.35
	2-mass	1.837	30.00	29.69	29.53	29.50	29.40
	4-mass	1.752	29.99	29.70	29.56	29.56	29.49

TSV Comparison

SC	Type	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass	0.48	0.38	0.29	0.30	0.24
	2-mass	0.49	0.39	0.31	0.31	0.25
	4-mass	0.50	0.41	0.34	0.33	0.30
50%	1-mass	0.48	0.38	0.30	0.31	0.26
	2-mass	0.48	0.39	0.32	0.32	0.29
	4-mass	0.49	0.40	0.34	0.33	0.30
60%	1-mass	0.47	0.38	0.32	0.31	0.27
	2-mass	0.48	0.39	0.33	0.32	0.29
	4-mass	0.49	0.39	0.35	0.35	0.33

T_{max}

Wind + Dry bulb Temperature Prediction

SC	Type	Wind Speed	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass	1.971	32.35	31.58	31.29	31.32	31.05
	2-mass	1.863	32.29	31.52	31.29	31.32	31.10
	4-mass	1.728	32.21	31.49	31.31	31.32	31.11
50%	1-mass	1.952	32.21	31.49	31.23	31.21	31.00
	2-mass	1.850	32.18	31.46	31.25	31.25	31.09
	4-mass	1.761	32.15	31.43	31.27	31.22	31.10
60%	1-mass	1.915	32.10	31.43	31.19	31.15	31.03
	2-mass	1.837	32.08	31.39	31.21	31.15	31.05
	4-mass	1.752	32.07	31.37	31.24	31.23	31.13

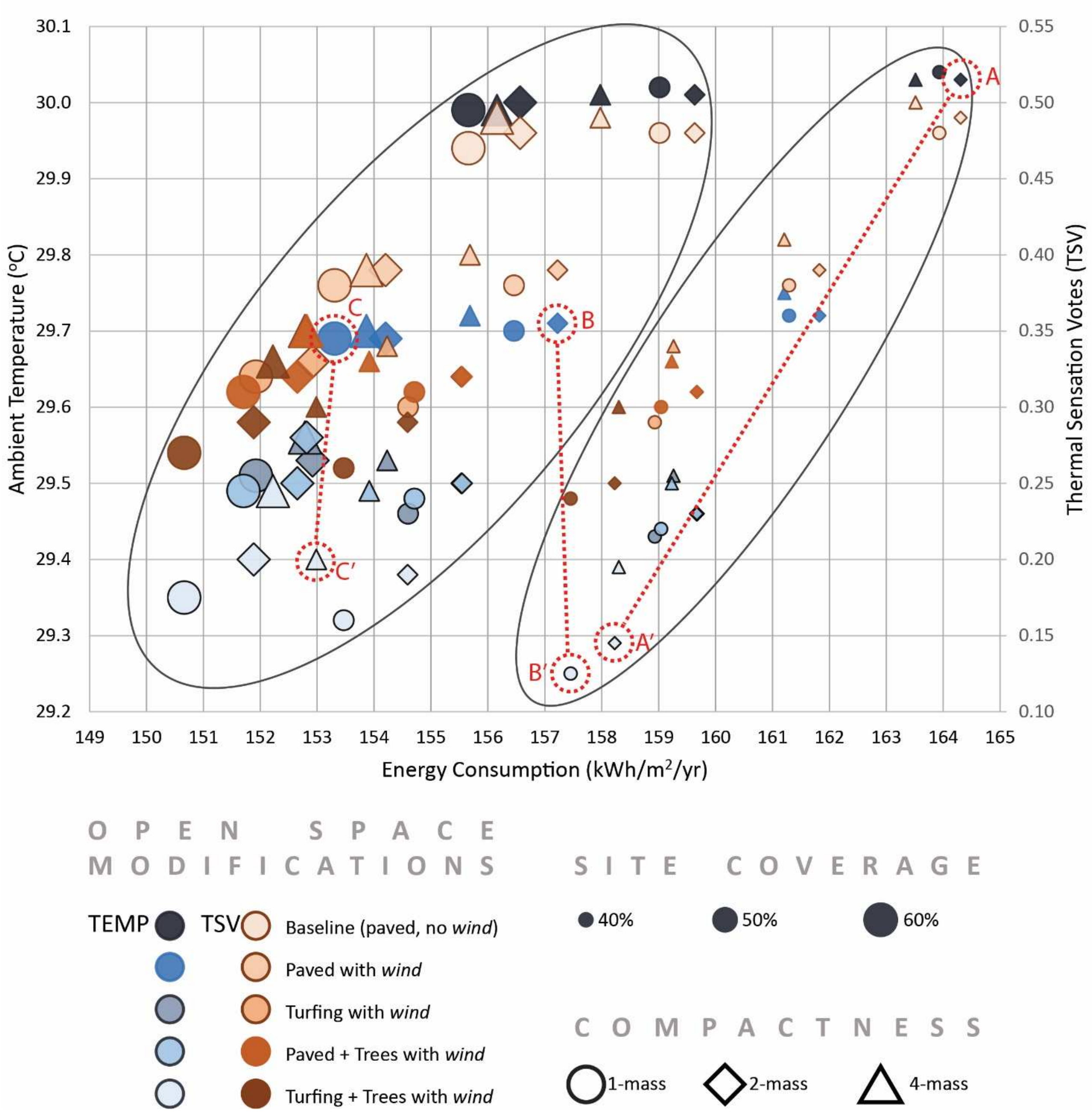
TSV Comparison

SC	Type	Baseline	Paved	Turfing	Paved + Trees	Turfing + Trees
40%	1-mass	1.21	0.97	0.88	0.89	0.80
	2-mass	1.20	0.96	0.89	0.90	0.83
	4-mass	1.19	0.96	0.90	0.91	0.84
50%	1-mass	1.17	0.94	0.86	0.85	0.79
	2-mass	1.17	0.94	0.87	0.88	0.82
	4-mass	1.16	0.94	0.89	0.87	0.84
60%	1-mass	1.14	0.93	0.85	0.84	0.80
	2-mass	1.14	0.92	0.86	0.84	0.81
	4-mass	1.14	0.92	0.88	0.88	0.85

HIGH LOW

TSV range	Perception
-3 ～ -2	cold to cool
-2 ～ -1	cool to slightly cool
-1 ～ 0	slightly cool to neutral
0 ～ 1	neutral to slightly warm
1 ～ 2	slightly warm to warm
2 ～ 3	warm to hot

benchmarking microclimatic components



conclusions

- The study has shown that the possibility of energy saving can be **compounded** when an observation is made at the macro level all of the buildings having an energy saving potential of 5% for every 1^{o}C reduction, due to a proper master plan design.
- Hence, when aspects other than urban form and density are addressed as well, one can expect **greater energy saving potential**.
- Shading in the tropics are beneficial during day time to reduce the external heat gain, especially from solar radiation.

contributions

- Microclimate analyses can be performed at **the early stages of the planning process**, when planners/designers could be well informed of the **environmental impact** of their design.
- It does not provide an **exact overview of energy consumption figures** at the district level, but rather **comparative figures** that will be useful for **benchmarking different design options** at the same time.

future works

NUS National University of Singapore

MICROCLIMATE ANALYSES

- AMBIENT TEMPERATURE
- EXTERNAL HEAT GAINS
- URBAN VENTILATION
- COOLING LOAD
- OUTDOOR THERMAL COMFORT
- ROOFTOP + VERTICAL GREENERY

→ single platform?

- ANTHROPOGENIC HEAT
- WATER COOLING EFFECT
- GLARE
- CITYGML PLATFORM
- RETRO-REFLECTIVE GLASS


Viktor Ramos, Richie Gelles


Aprilli Design Studio


Office of Metropolitan Architecture


Office of Metropolitan Architecture

…maybe?

references

Santamouris, M., et al. (2001). Energy and Climate in the Urban Built Environment. London, UK, James & James.

Jusuf, S. K., et al. (2007). "The influence of land use on the urban heat island in Singapore." Habitat International **31**.

Oke, T. R. (1982). "The energetic basis of the Urban Heat Island." Quarterly Journal of the Royal Meteorological Society **108**: 1-24.

Jusuf, S. K. and N. H. Wong (2009). Development of empirical models for an estate level air temperature prediction in Singapore. Second International Conference on Countermeasures to Urban Heat Islands. Berkeley, United States.

Jusuf, S. K., et al. (2007). "The influence of land use on the urban heat island in Singapore." Habitat International **31**.

Wong, N. H. and S. K. Jusuf (2008). "An Assessment Method for Existing Greenery Conditions in a University Campus." Architectural Science Review **51**(3): 116-126.

Wong, N. H. and S. K. Jusuf (2008). "GIS-based greenery evaluation on campus master plan." Landscape and Urban Planning **84**: 166–182.

Yang, W., et al. (2013). "Thermal comfort in outdoor urban spaces in Singapore." Building and Environment **59**: 426-435.

Yang, W., et al. (2013). "A comparative analysis of human thermal conditions in outdoor urban spaces in the summer season in Singapore and Changsha, China." International Journal of Biometeorology **57**: 895-907.

Lee, R. X. (2013). Development of estate level outdoor ventilation prediciton model for HDB estates in Singapore. Department of Building. Singapore, National University of Singapore. **Doctor of Philosophy**.

Lee, R. X., et al. (2013). "The study of height variation on outdoor ventilation for Singapore's high-rise residential housing estates." International Journal of Low-Carbon Technologies **0**: 1-19.

Lee, R. X. and N. H. Wong (2014). "A Parametric Study of Gross Building Coverage Ratio (GBCR) Variation on Outdoor Ventilation in Singapore's High-rise Residential Estates." Journal of Civil Engineering and Science **3**(2): 92-116.

THANK YOU

bdgmarc@nus.edu.sg
marcel.Ignatius@gmail.com

FOURTH INTERNATIONAL CONFERENCE ON COUNTERMEASURES TO URBAN HEAT ISLAND

4TH IC2UHI 2016

Fighting Urban Heat Island (UHI) and Climate Change through Mitigation and Adaptation

www.ic2uhi2016.org

---

30 – 31 MAY AND 1 JUNE 2016

NATIONAL UNIVERSITY OF SINGAPORE