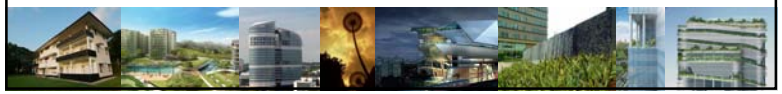
DEVELOPMENT OF EMPIRICAL MODELS FOR AN ESTATE LEVEL AIR TEMPERATURE PREDICTION IN SINGAPORE

Screening Tool for Estate Environment Evaluation (STEVE)

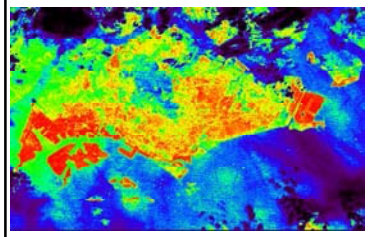
Steve Kardinal Jusuf
PhD Candidate, M.Sc. (Bdg.Sc.), B.Arch (Hons)
&
Assoc. Prof. Dr Wong Nyuk Hien



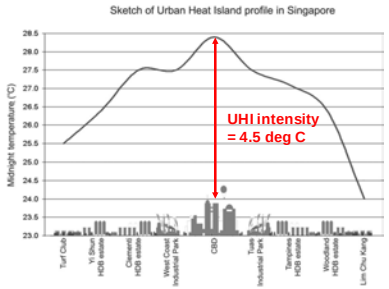
CONTENT

INTRODUCTION

- Singapore UHI study in 2004 showed the UHI intensity between CBD and "rural" area was up to 4.5 deg C.



Thermal Satellite Image



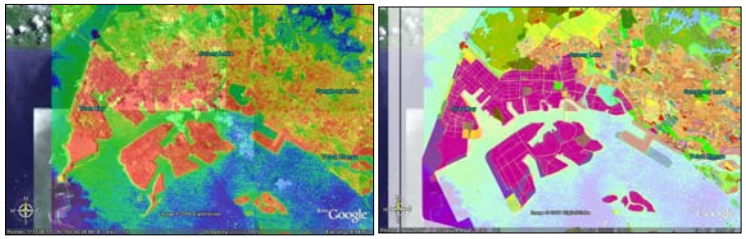
Source: Wong, N. H. and Chen, Y. (2009). *Tropical urban heat islands: Climate, building and greenery*. Taylor and Francis, UK.

INTRODUCTION

MACRO SCALE STUDY
Day Time Analysis Result

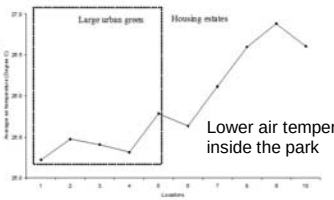
JURONG INDUSTRIAL AREA

- The hot surface area spreads ***exactly*** in the industrial land use zone



INTRODUCTION

Impact of parks



Lower air temperature inside the park

	cooling load (kWh)	Energy savings (compared with 400m)
In the park	9077	10%
100m from the park	9219	9%
200m from the park	9383	7%
300m from the park	9672	4%
400m from the park	10123	0%

Outdoor air temperature determines the energy savings of buildings. **Every 1 deg C** of outdoor air temperature reduction **saves 5%** of building energy consumption.

Proper urban planning will help to keep the urban air temperature cool

Source: Chen Yu and Wong Nyuk Hien. (2006). Thermal benefits of city parks. *Energy and Buildings*, 38, 105-120.

CONTENT

RESEARCH OBJECTIVES

This project bridges the gap between Scientist and Professionals who are non-scientists, as the following:

- The basic principle of GIS-based climatic maps is that they provide color images of the study area from red (hot) to blue (cool). Planners, as compared to read graphs and numbers can easily understand these images.
- The most important deliverable is the air temperature prediction models (Tmin, Tavg and Tmax), which has been developed based on the few years field measurements data, geographical and urban morphology database. The ***STEVE*** tool was then developed for the planners to use the models easily in predicting the air temperature condition due to the master planning process.

CONTENT

METHODOLOGY

AIR TEMPERATURE MODELS DEVELOPMENT

The field measurements for the models development were between ***September 2005*** and ***March 2008*** with total of ***110 points*** of measurement in NUS and one-north.

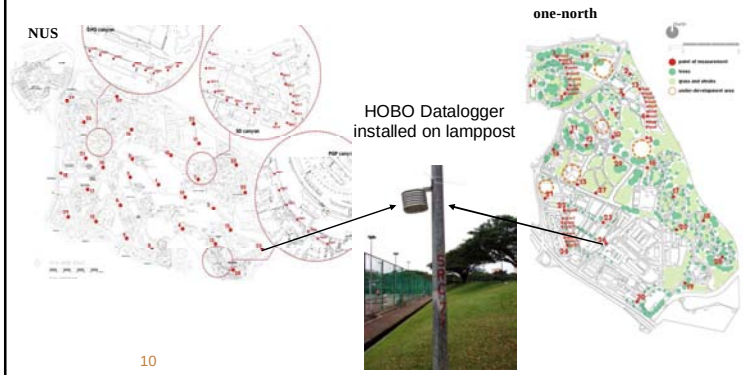
Model validation were using the field measurement result between ***April and June 2008***

ESTATE	TYPE OF MEASUREMENT	PERIOD OF MEASUREMENT
NUS	Estate-wide	10-24 September 2005
NUS	Estate-wide	26 August-25 September 2006
NUS	Canyon (ENG & PGP)*	17 July-20 October 2007
NUS	Canyon (PGP, SD2 & SD4)*	23 October 2007-31 March 2008
One-North	Estate-wide	23 October 2007-31 March 2008
One-North	Canyon (AYER, BIO, ROCH)*	23 October 2007-31 March 2008
One-North	Canyon (AYER, BIO, ROCH)* for model validation	1 April - 30 June 2008

* Engineering (ENG), Price George's Park (PGP), Science Drive 2 (SD2), Science Drive 4 (SD4), Ayer Rajah Industrial Estate (AYER), Biopolis (BIO) and Rochester Park (ROCH)

METHODOLOGY

- Points of measurement in ***NUS Kent Ridge Campus*** and ***one-north***

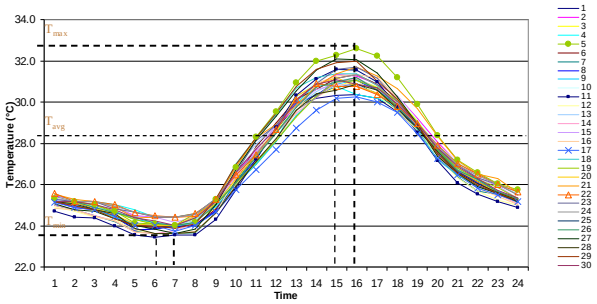


CONTENT

- Introduction
- Research Objectives
- Methodology
- **Temperature Map**
- Hypothesis
- Air Temperature Models
- Sensitivity Analysis
- Application
- STEVE Tool
- Limitations

TEMPERATURE MAP

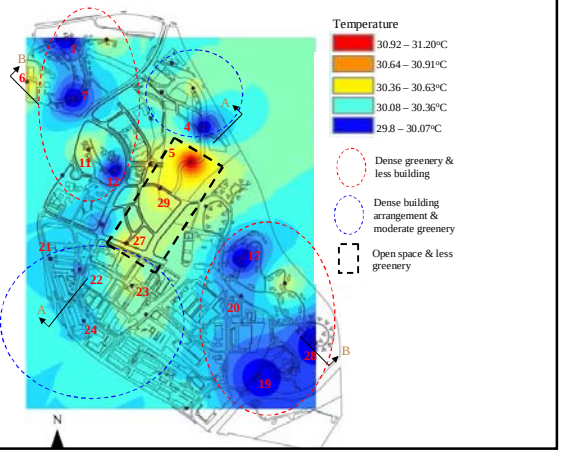
Typical hot day temperature profile



- Maximum temperature occurs at 1500-1600hrs, while minimum temperature occurs at 0600-0700hrs

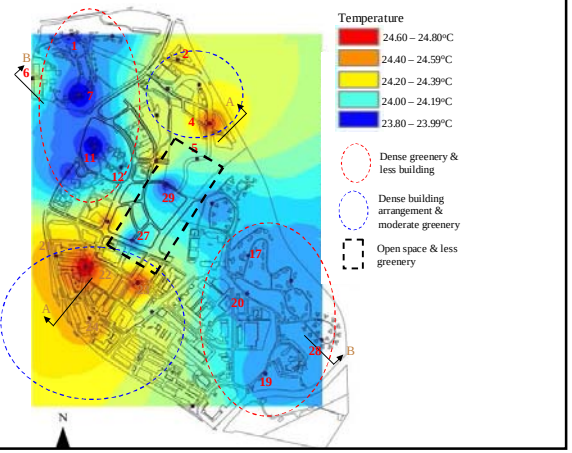
TEMPERATURE MAP

Temperature Map of average temperature on selected hot days at 1600



TEMPERATURE MAP

Temperature Map of average temperature on selected hot days at 0600

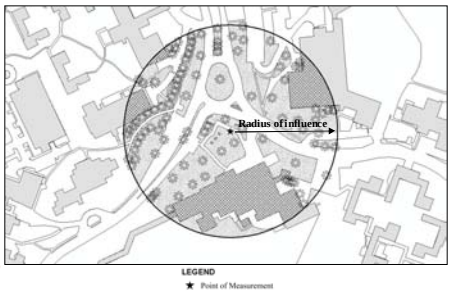


CONTENT

HYPOTHESIS

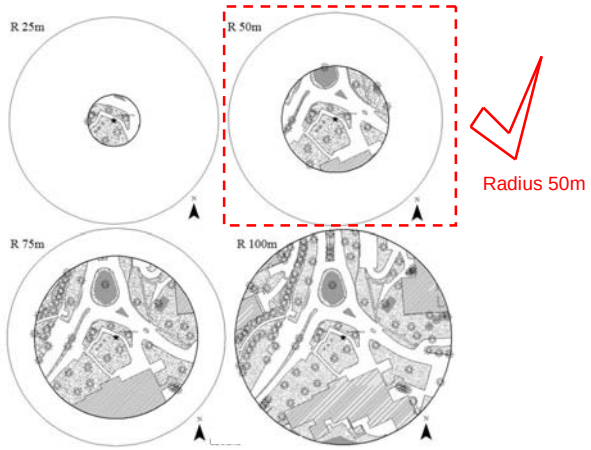
Air temperature prediction model

"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"***



HYPOTHESIS

Selection of Radius of Influence



CONTENT

AIR TEMPERATURE MODELS

Daily Minimum, Average and Maximum Temperatures

Climatic Predictors Urban Morphology Predictors

Minimum Temperature

$$T_{min}\,(°C) = 4.061 + 0.839\,\text{Ref}\,T_{min}\,(°C) + 0.004\,\text{PAVE}\,(\%) - 0.193\,\text{GnPR} - 0.029\,\text{HBDG} + 1.339\text{E-}06\,\text{WALL}\,(m^2)$$

$R^2 = 0.86$, $F = 1707.45$ and Std. Error = 0.47 (Sig. 0.00) (8.1)

Average Temperature

$$T_{avg}\,(°C) = 2.347 + 0.904\,\text{Ref}\,T_{avg}\,(°C) + 5.786\text{E-}05\,\text{SOLAR}_{total}\,(W/m^2) + 0.007\,\text{PAVE}\,(\%) - 0.06\,\text{GnPR} - 0.015\,\text{HBDG} + 1.311\text{E-}05\,\text{WALL}\,(m^2) + 0.633\,\text{SVF}$$

$R^2 = 0.91$, $F = 2170.49$ and Std. Error = 0.27 (Sig. 0.00) (8.2)

Maximum Temperature

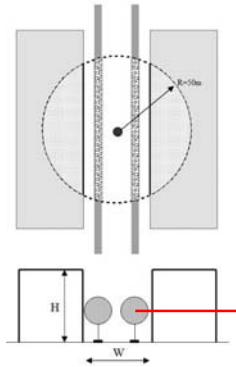
$$T_{max}\,(°C) = 7.542 + 0.684\,\text{Ref}\,T_{max}\,(°C) + 0.003\,\text{SOLAR}_{max}\,(W/m^2) + 0.005\,\text{PAVE}\,(\%) - 0.016\,\text{HBDG} + 6.777\text{E-}06\,\text{WALL}\,(m^2) + 1.467\,\text{SVF} + 1.466\,\text{ALB}$$

$R^2 = 0.54$, $F = 241.92$ and Std. Error = 0.59 (Sig. 0.00) (8.3)

CONTENT

SENSITIVITY ANALYSIS

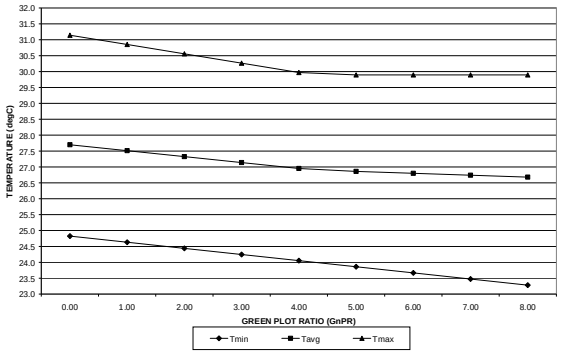
MODEL 1 – Change of GnPR



Change amount of greenery

SENSITIVITY ANALYSIS

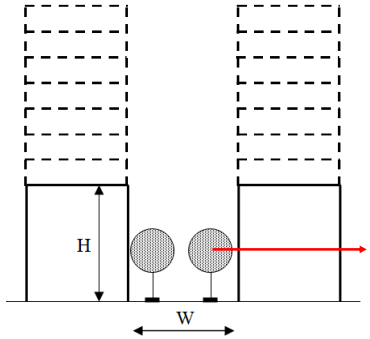
MODEL 1 – Change of GnPR



Predicted T_{min}, T_{avg} and T_{max} for various values of GnPR value

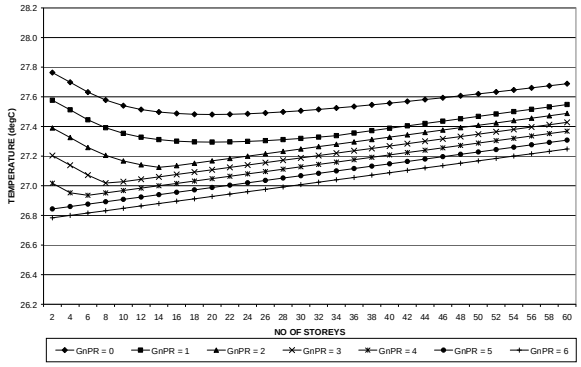
SENSITIVITY ANALYSIS

MODEL 2 – Change of building height & GnPR



SENSITIVITY ANALYSIS

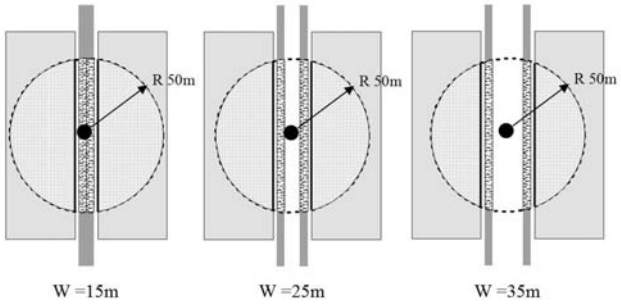
MODEL 2 – Change of building height & GnPR



Predicted T_{avg} for various values of No of storeys and GnPR value

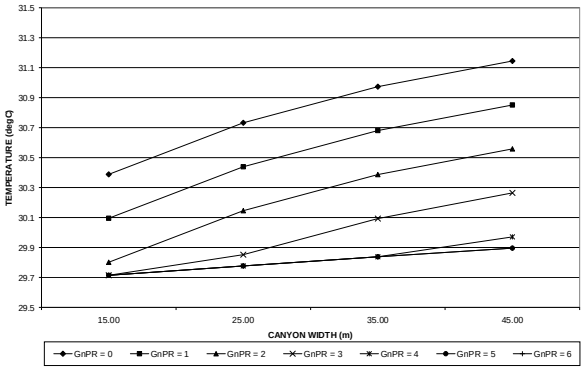
SENSITIVITY ANALYSIS

MODEL 3 – Change of canyon width & GnPR



SENSITIVITY ANALYSIS

MODEL 3 – Change of canyon width & GnPR



Predicted T_{max} for various values of canyon width and GnPR value

CONTENT

- Introduction
- Research Objectives
- Methodology
- Temperature Map
- Hypothesis
- Air Temperature Models
- Sensitivity Analysis
- **Application**
- STEVE Tool
- Limitations

APPLICATION

 One-North current condition (left) and master plan (right)

APPLICATION

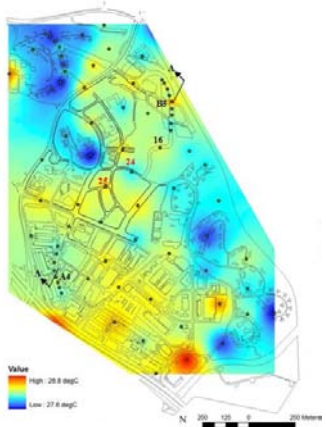
Zoning of One-North master plan

Simulation scenario:

1. To study the importance of green belt to the environment.
   - ***Master plan model 1***: The green belt is covered with grass only (GnPR of green belt = 1).
   - ***Master plan model 2***: The green belt was planted with only trees that have green plot ratio value of 3 (GnPR= 3). The reduction of SVF values due to trees were also considered

APPLICATION

SCENARIO 1 : The calculated average air temperature

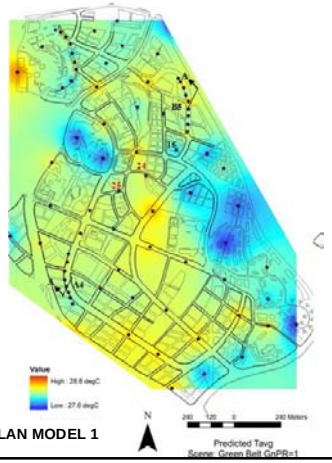


CURRENT CONDITION

APPLICATION

SCENARIO 1 : The calculated average air temperature

Master plan model 1: The green belt is covered with grass only (GnPR of green belt = 1).

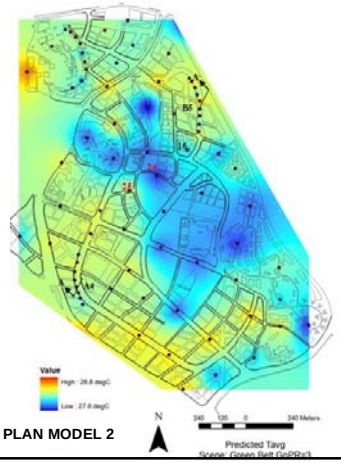


MASTER PLAN MODEL 1

APPLICATION

SCENARIO 1 : The calculated average air temperature

Master plan model 2: The green belt was planted with only trees that have green plot ratio value of 3 (GnPR= 3). The reduction of SVF values due to trees were also considered

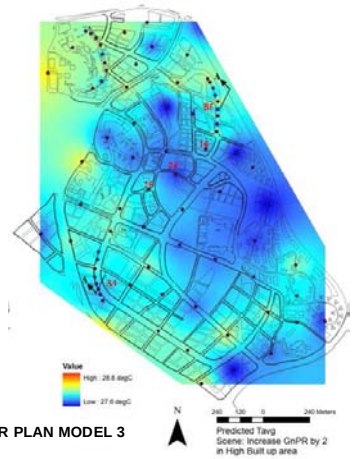


MASTER PLAN MODEL 2

APPLICATION

SCENARIO 2 : The calculated average air temperature

Master plan model 3: The GnPR values at high built up areas were increased by 2.

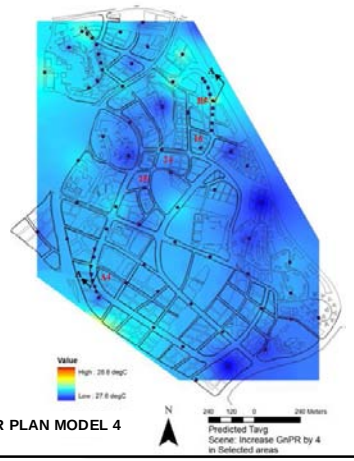


MASTER PLAN MODEL 3

APPLICATION

SCENARIO 2 : The calculated average air temperature

Master plan model 4: The GnPR values at selected areas were further increased by 2, which mainly due to trees (i.e. SVF reduction by 0.4).



MASTER PLAN MODEL 4

CONTENT

STEVE Tool

- Facts:
  - Various climatology research with various prediction models
  - The models are far ***too complicated*** for educated non-scientists, such as urban planners.
  - At the building design level, CAD software has been developed and integrated with some simulation software, called as building information modeling (BIM).
- Gap between ***scientists*** and ***planners***.
- ***No software*** or ***tool*** that can equip planners to design and do assessment at the same time.

STEVE Tool

Demo

SCREENING TOOL FOR ESTATE ENVIRONMENT EVALUATION (STEVE)

CONTENT

LIMITATIONS

- The existing condition and proposed master plan maps serve only as a guide map for the users or planners. Planners will not be able to change the master plan design inside STEVE platform. Design changes are done in different software, such as CAD software, calculate the new value of each urban morphology parameters and then, input them to STEVE calculator.
- The locations of points were predetermined during STEVE development, working together with planners to select the representative points across the estate. For this reason, when planners would like to predict the air temperatures at other predetermined points, they need to get the value urban morphology parameters from CAD software and then input them to STEVE calculator.
- The predicted temperature, calculated in STEVE tool, need to be inputted to GIS in order to generate predicted temperature map.

ACKNOWLEDGEMENTS

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THANK YOU