Thermal Comfort Conditions of Urban Spaces in a Hot-Humid Climate of Chiang Mai City, Thailand

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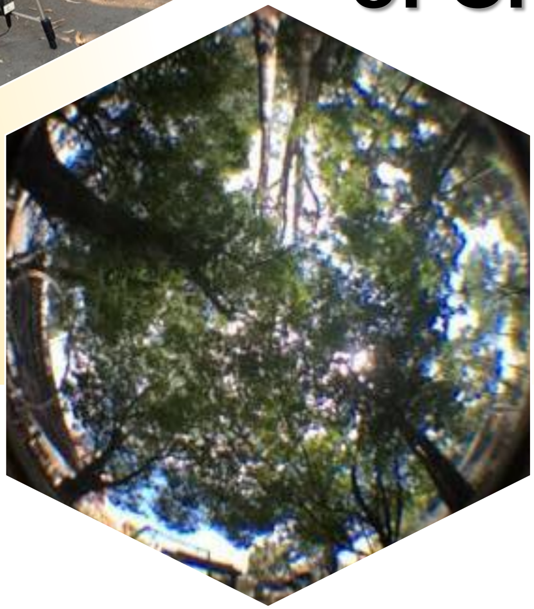

9TH INTERNATIONAL CONFERENCE ON URBAN CLIMATE

The Centre de Congrès Pierre Baudis in Toulouse (22-24 July 2015)

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CONTENTS

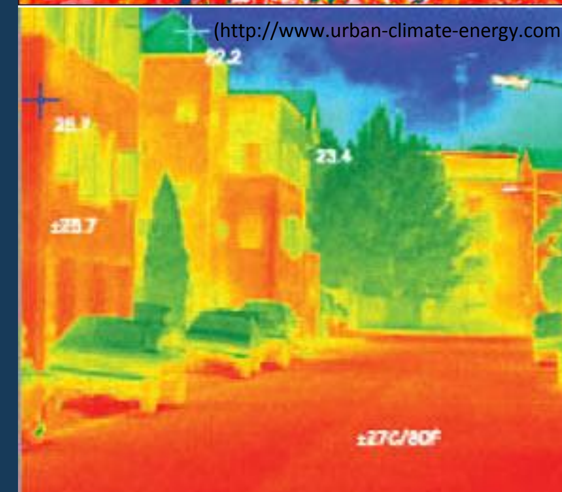
1. Background and Key Issues

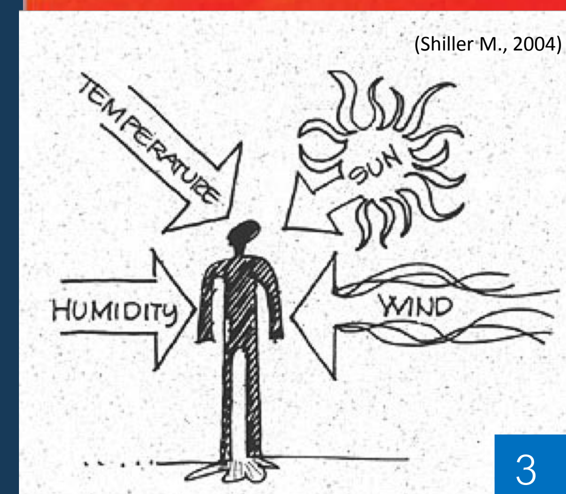
(1.1) The need for urban climatic design

- **Urbanization causes microclimate changes.**
- **Urban areas consume enormous amounts of energy.**
- **The goal of urban climatic design is to achieve human comfort for a majority of urban dwellers.**

"improve the comfort of the inhabitants outdoors and indoors, as well as improving the possibilities for the house and surrounding outdoor environment to create a comfortable climate with a minimal energy use … and to reduce the energy demand of the buildings for heating in winter and for cooling in summer."


(NASA, 1997)


(http://www.urban-climate-energy.com)

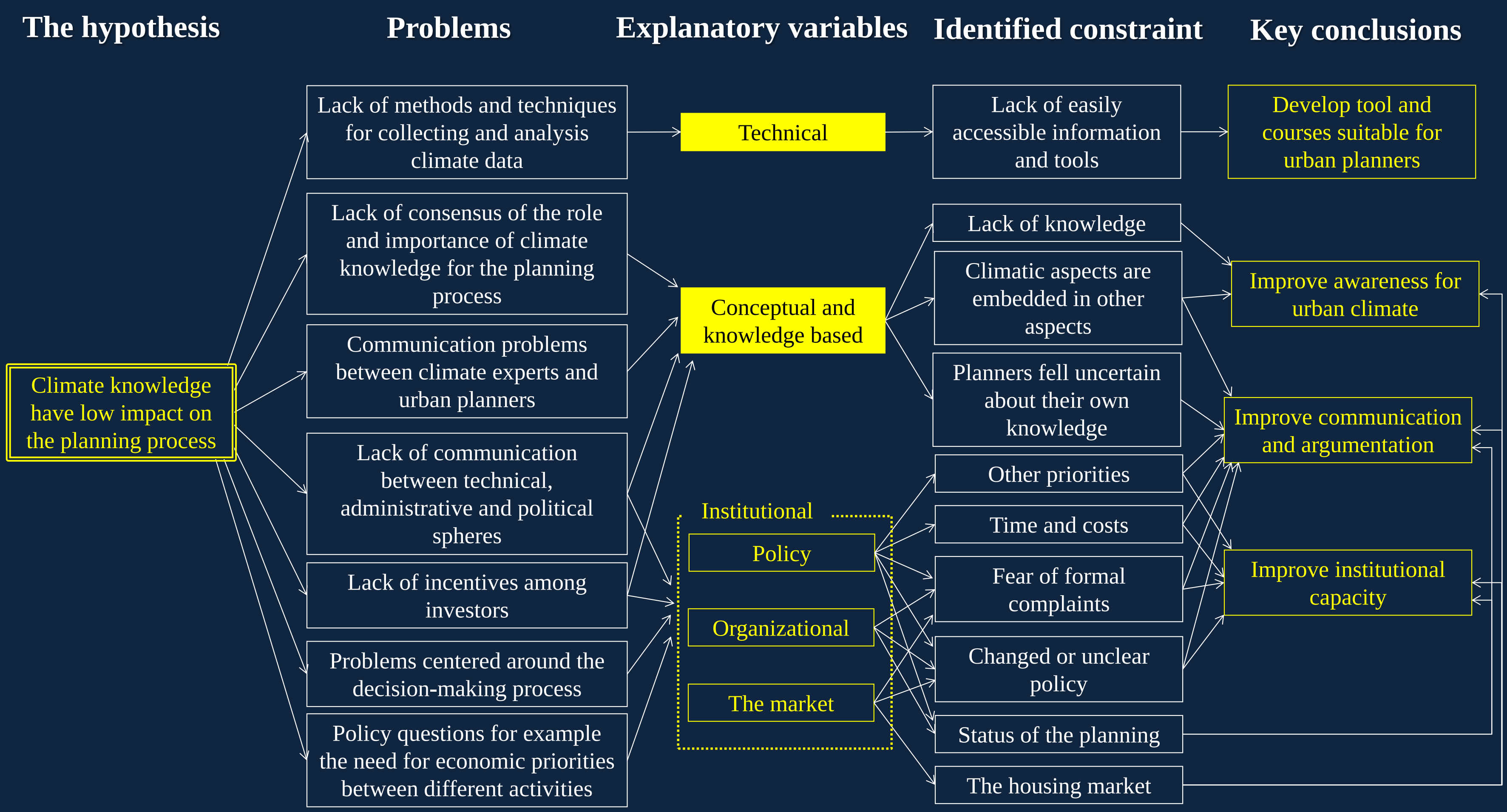


(Shiller M., 2004)

“The climate of urban areas can be modified by urban planners and designers, through *knowledge* of the features that affect the urban climate.”

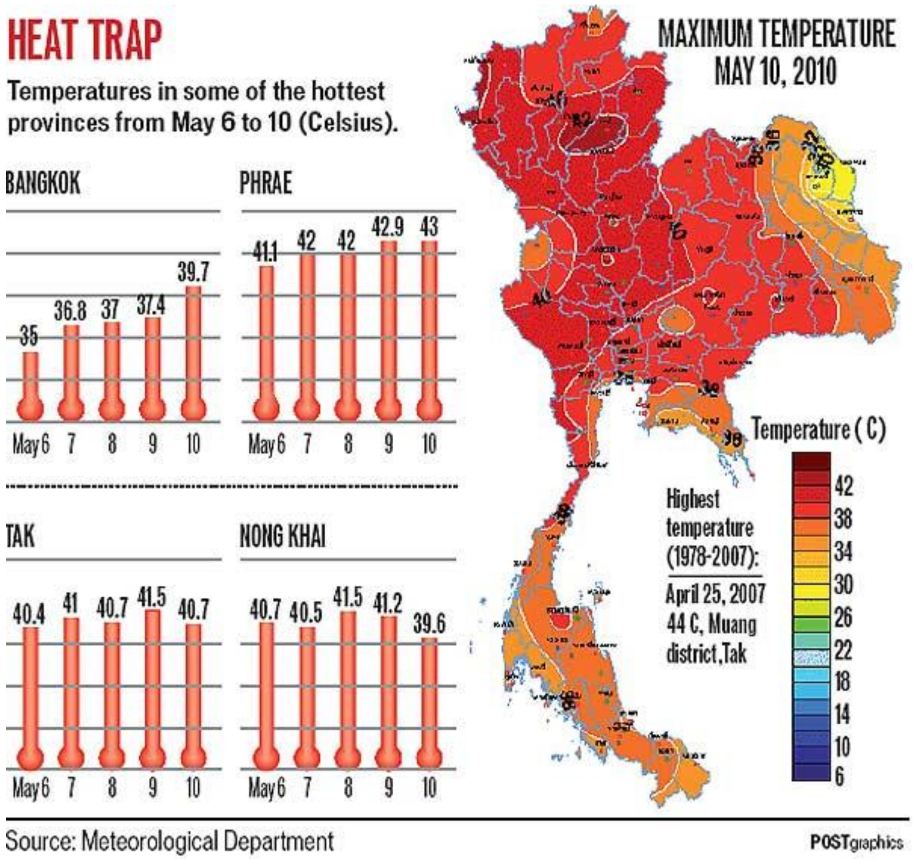
(1.2) The use of climate knowledge in urban planning

"Urban planners must be *assisted by and work with urban climatologists* when interpreting and applying urban climatic considerations."



[Modified after Eliasson, 2000]

(1.3) Of course it's hot!! This is Thailand.



"April will be this year's hottest month, with maximum temperatures of about 42-43 Celsius. The average temperature in Thailand so far this month is 35 Celsius, it added."
(Thai Meteorological Department, April 2014)

Source: http://www.bangkokpost.com

Source: APICHART JINAKUL

- Motorcyclists were using any **shade** they could find yesterday to get through one of the hottest days of the year.

Source: http://englishnews.thaipbs.or.th/

- The hottest day on April 27, 2014 when the sun closest to the capital and directly above it.

2. OBJECTIVES

- To investigate thermal sensation for local occupants of outdoor and semi-outdoor urban environments in a highest thermal load problem zone of Chiang Mai urban area,

- To estimate the impact of climate conditions on human thermal comfort in different urban environments, and

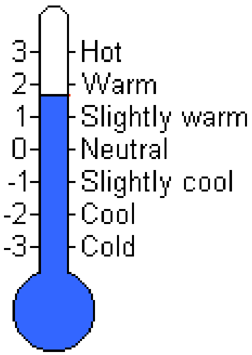
- To investigate the effects of health status on human thermal comfort in outdoor and semi-outdoor urban spaces of Chiang Mai city.

(3.1) What is Comfort or Discomfort for Human?

❑ What is human thermal comfort?

“Human thermal comfort as the state of mind that expresses satisfaction with the surrounding environment.”

Defined by *ASHRAE* (The American Society of Heating, Refrigerating and Air Conditioning Engineers)



(Source: INNOVA, 2004)

❑ Why is thermal comfort important?

“It can affect human health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality.”

Source: U.S. Center for Disease Control and Prevention, 2006.
Extreme Heat: A Prevention Guide to Promote Your Personal Health and Safety.

(3.2) Interrelationships between the various parameters of psychological adaptation in outdoor thermal comfort study

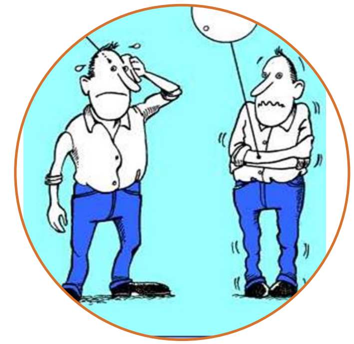
Environmental factors

- Air temperature
- Air movement
- Humidity
- Radiation

Personal factors

- Metabolic rate (light activity-sitting and standing)
- Clothing

(ASHRAE Standard 55, 2010*)



Contributing factors

- Food and drink
- Acclimatization
- Body shape
- Age and gender
- State of health

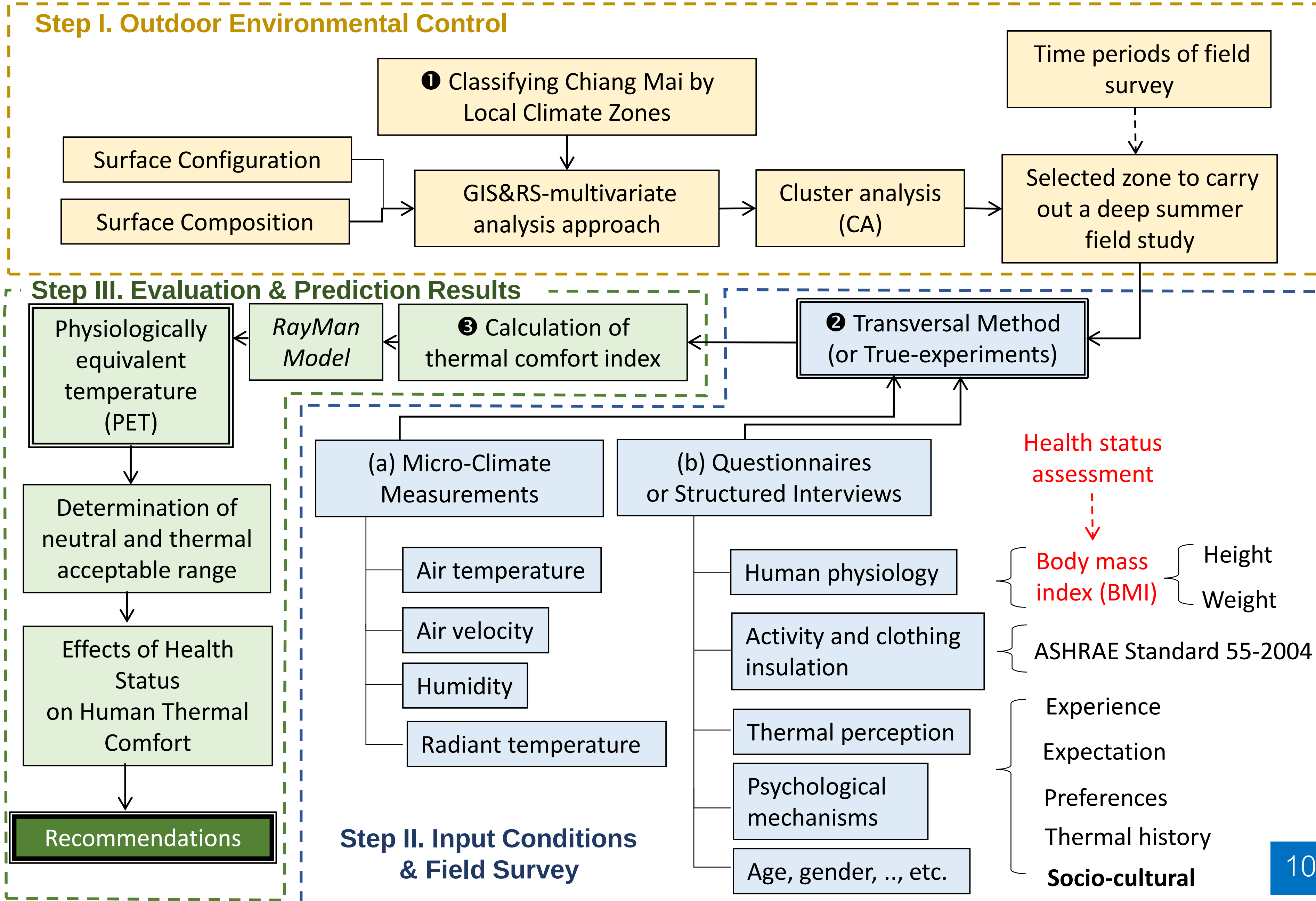
Micro-meteorological measurement

Questionnaire survey addressing "the subjects"

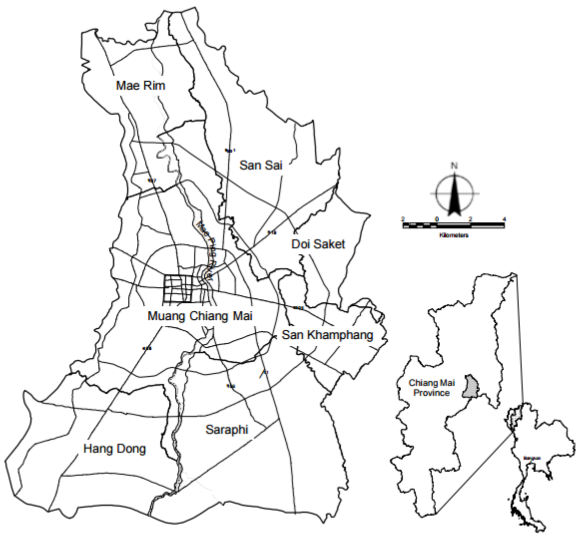
Thermal comfort variables

** ASHRAE 55, 2010. Thermal Environmental Conditions for Human Occupancy*

3.3 A general framework for outdoor thermal comfort assessment

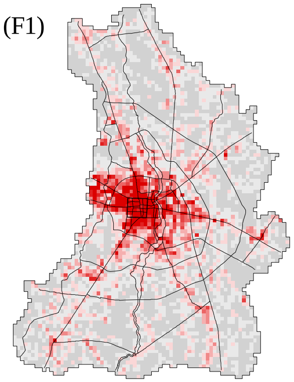


The 9 Surface Properties that Affects Air Flow and Radiational Heating/Cooling at the Ground



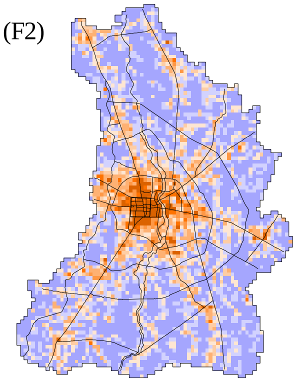
The study area of Chiang Mai Metropolitan Area (CMMA), an area of approximately 409 sq.km.

(F1)



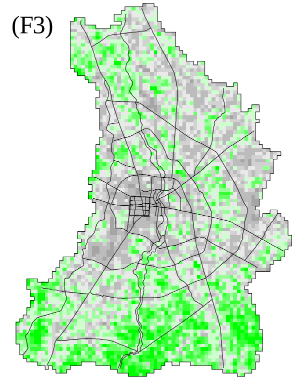
Floor Area Ratio (FAR)

(F2)



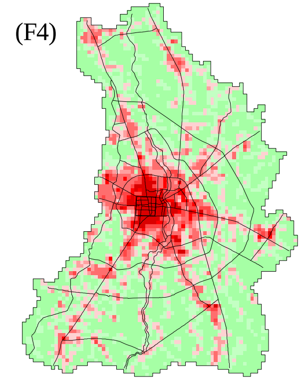
Building Coverage Ratio (BCR)

(F3)



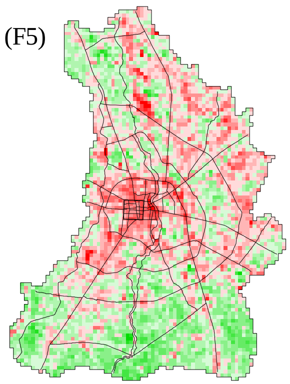
Green Coverage Ratio (GCR)

(F4)



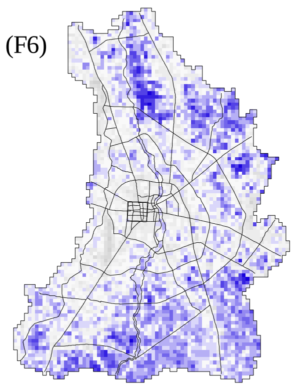
Building Density (Bldg.Den.)

(F5)



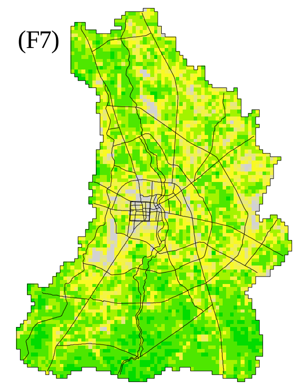
Vegetation Index (NDVI)

(F6)



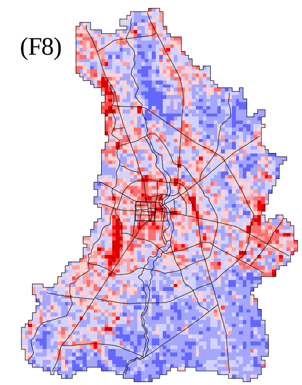
Water Index (NDWI)

(F7)



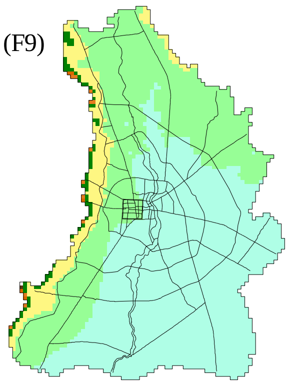
Distance from Large Green Areas (Dist.LGA)

(F8)



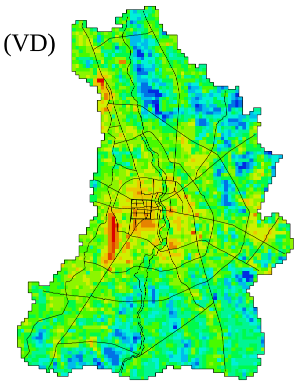
Distance from Large Wetland Areas (Dist.LWA)

(F9)



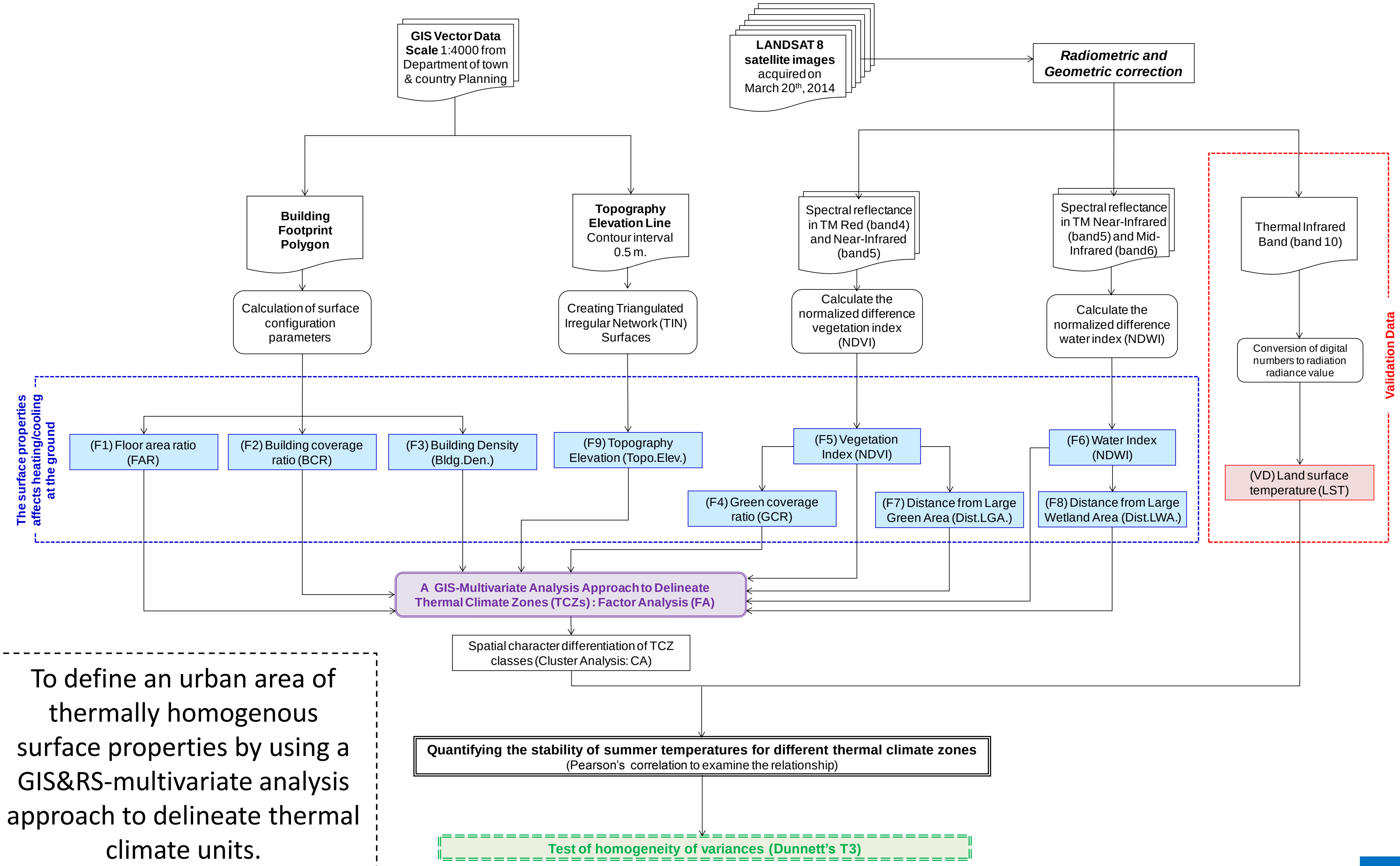
Topography Elevation (Topo.Elev.)

(VD)



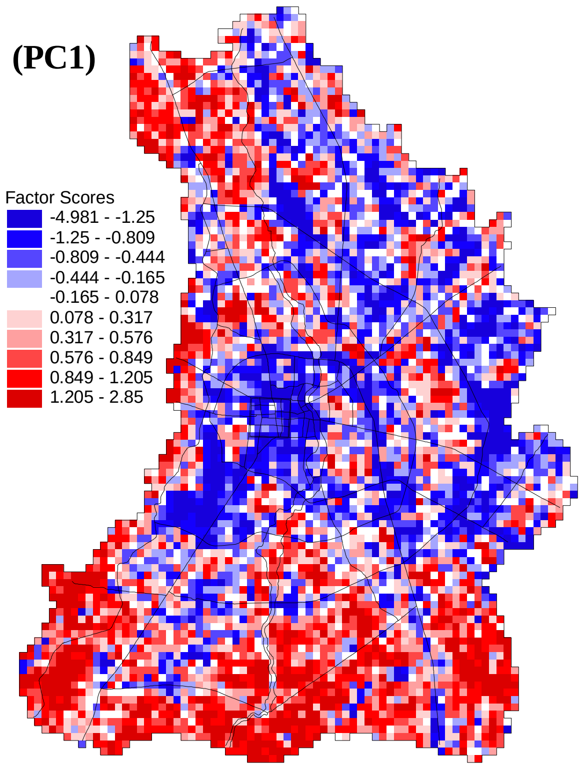
Land Surface Temperature (Avg.LST)
[Acquired on 20-Mar-2014 LANDSAT8 TIRS]

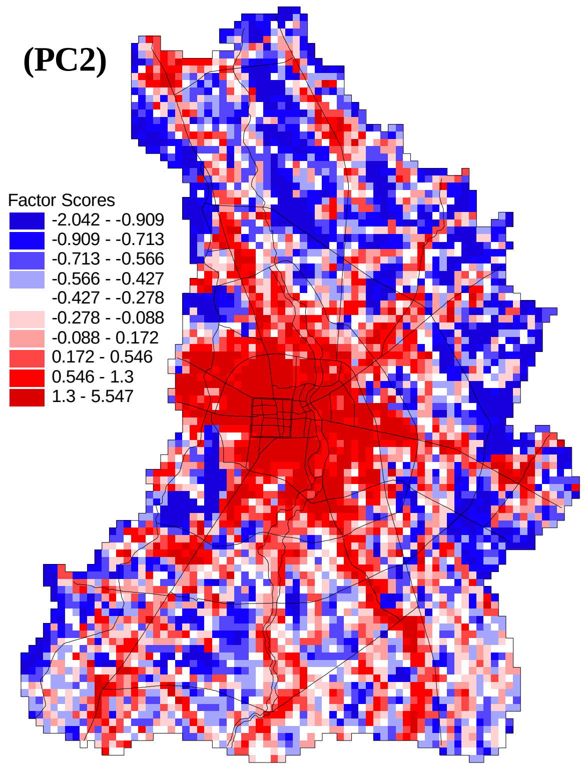
(3.4) Technical flowchart of TCZs classification and temperature stability evaluation

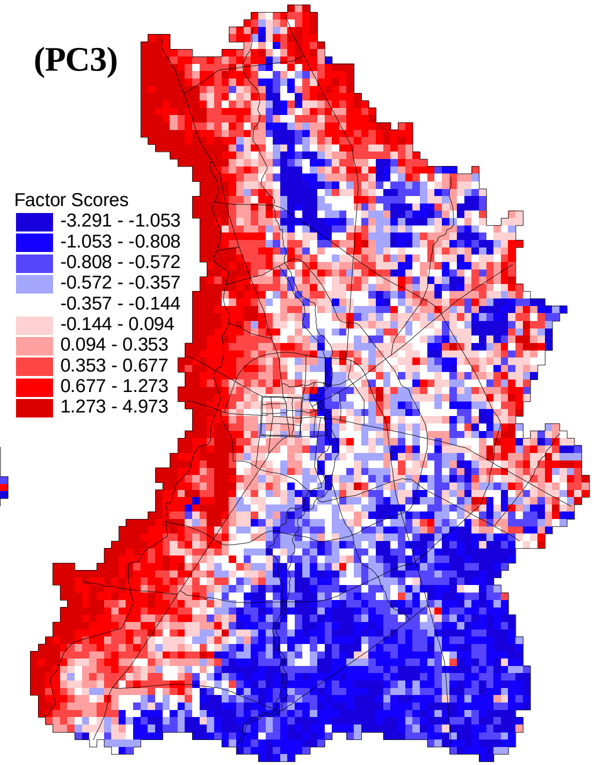


To define an urban area of thermally homogenous surface properties by using a GIS&RS-multivariate analysis approach to delineate thermal climate units.

The Number of Components Extracted in a Principal Component Analysis Results







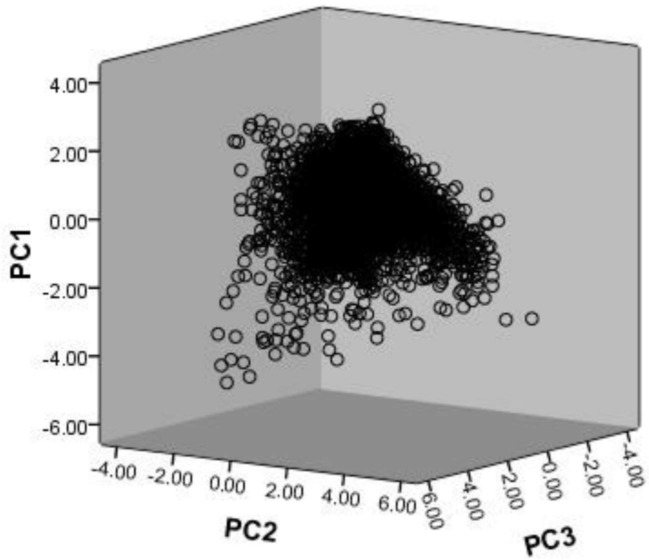
Principal Component 1
1. Green coverage ratio (GCR)
2. Vegetation index
3. Distance to large green areas

Principal Component 2
1. Floor area ratio (FAR)
2. Building coverage ratio (BCR)
3. Building density

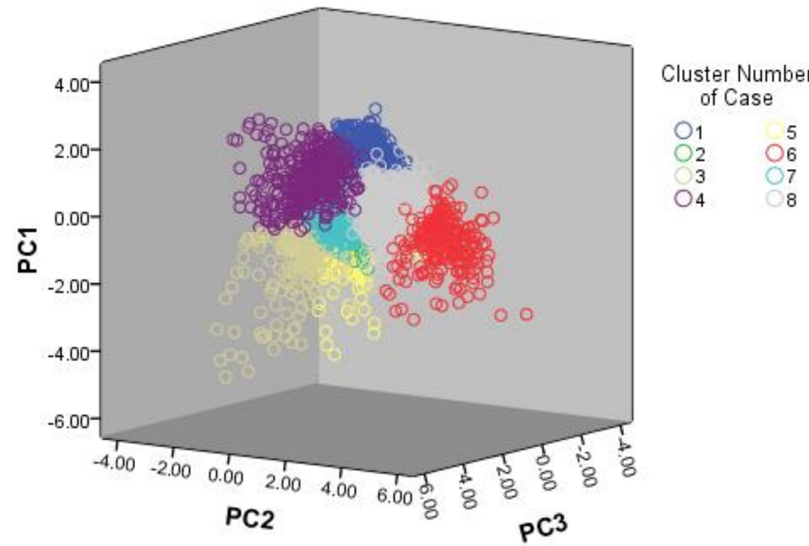
Principal Component 3
1. Water index
2. Distance to large water areas
3. Topographic elevation

Cluster Analysis (CA) Approach to Delineate Thermal Climate Zones

(a) Scatterplot of different components combination

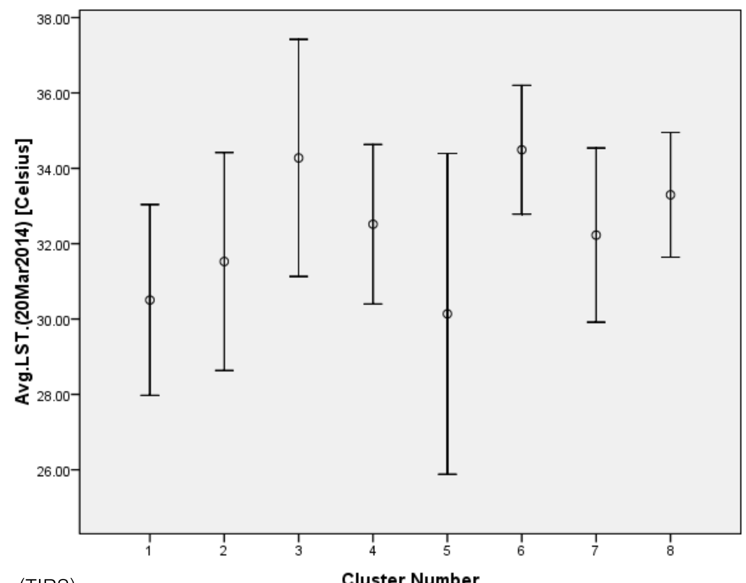


(b) Cluster analysis to generate the classes



(c) The Stability of Surface Temperature for Different Thermal Climate Zones

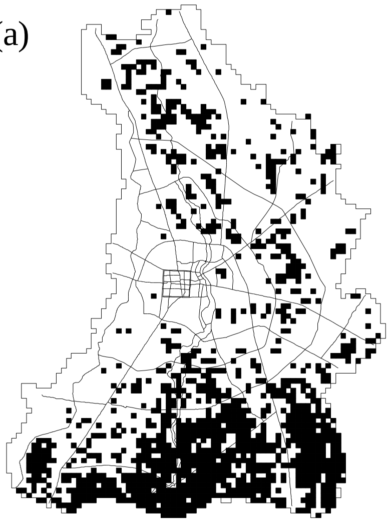
Cluster Number	Stability of Surface Temperature (Celsius) *	
	Mean	Std. Deviation
Class 1	30.50	1.27
Class 2	31.53	1.45
Class 3	34.28	1.57
Class 4	32.52	1.06
Class 5	30.14	2.13
Class 6	34.49	0.85
Class 7	32.23	1.16
Class 8	33.30	0.83



Note: *Surface temperature acquired on March 20th 2014 the Landsat 8 Thermal Infrared Sensor (TIRS)

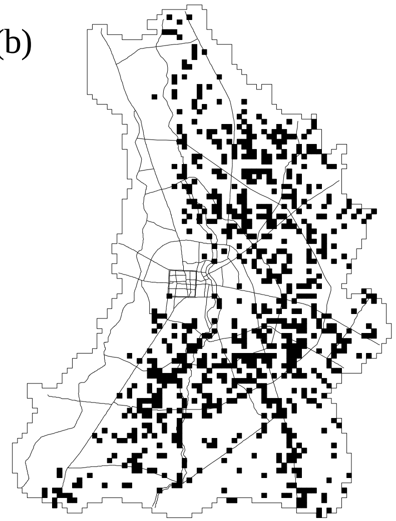
The Spatial Pattern of Thermal Climate Zone Classes

(a)



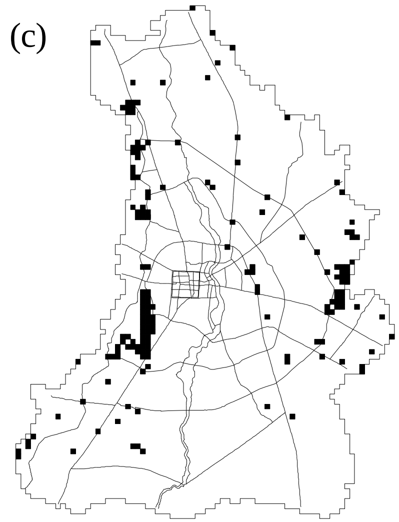
Class 1 (n=1,254) 26.16%

(b)



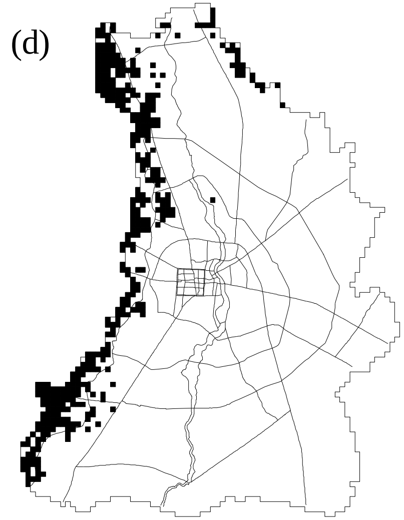
Class 2 (n=784) 16.35%

(c)



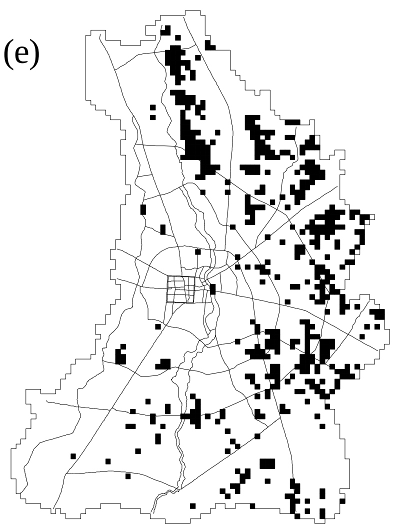
Class 3 (n=170) 3.55%

(d)



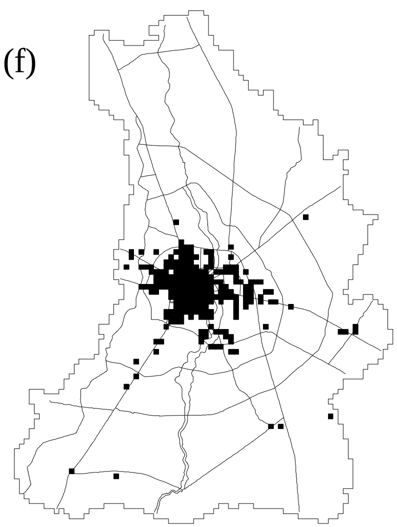
Class 4 (n=405) 8.45%

(e)



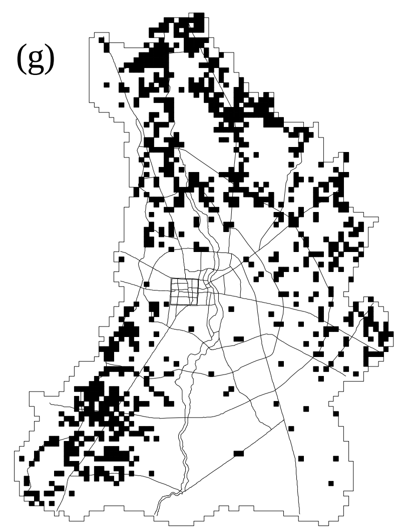
Class 5 (n=513) 10.70%

(f)



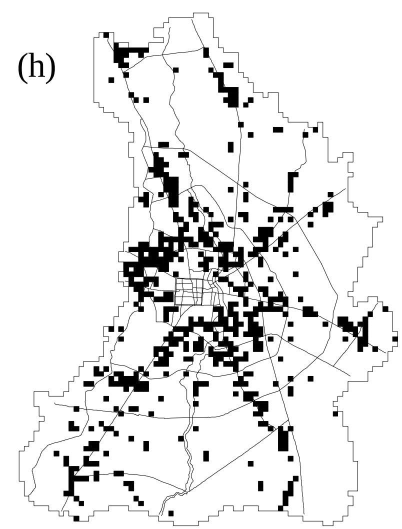
Class 6 (n=232) 4.84%

(g)



Class 7 (n=832) 17.36%

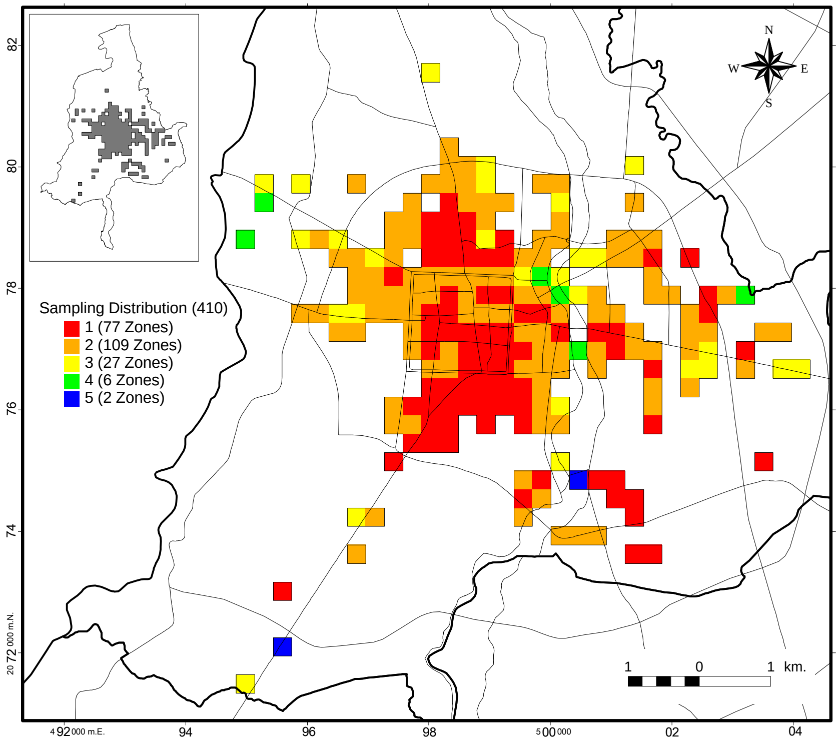
(h)



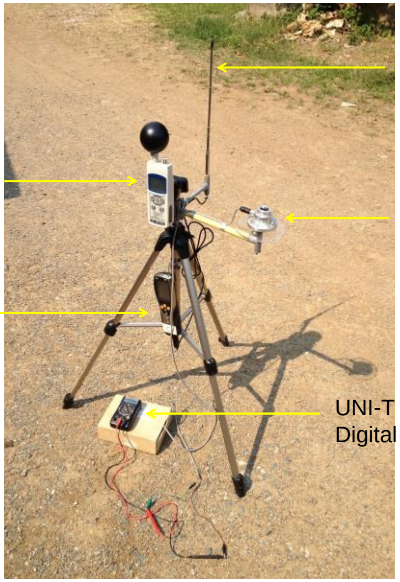
Class 8 (n=604) 12.60%

(3.5) Microclimatic measurements and thermal comfort calculation

(a) Selected climate zone to carry out a field study



(b) Instrumental setup



(Photo: Author, 2014)

Experimental design:

❖ This study presents a field study on outdoor thermal comfort conducted in the highest temperature variation of Class 6 zone.

❖ A 410 sampling distribution for outdoor thermal sensation survey are expected to be observed.

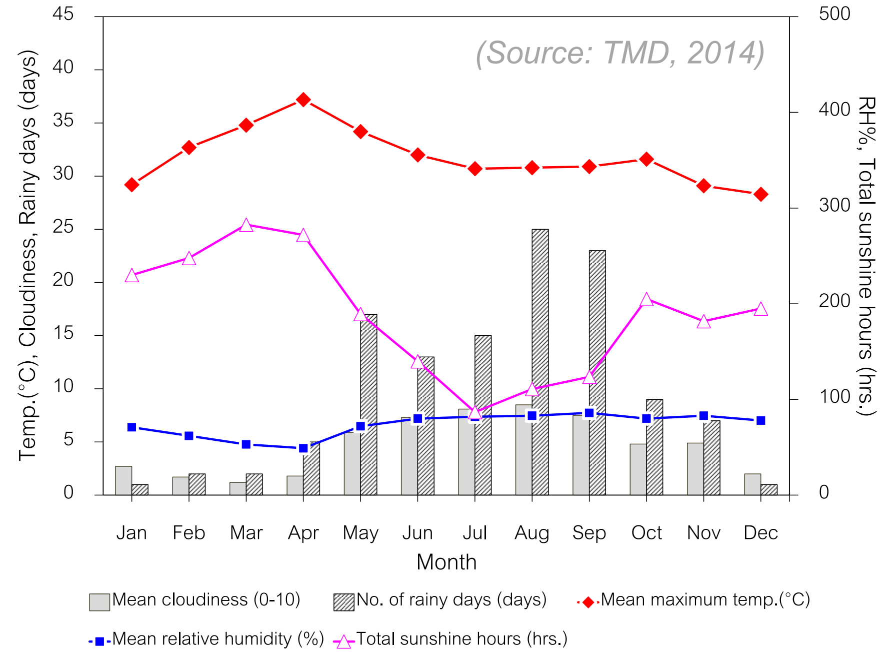
(3.6) Summertime thermal sensation survey in Chiang Mai

(a) Training programs and requirements

(b) Interviewers conducting the survey

(Photo: Author, 2014)

(c) Monthly mean climatic conditions of Chiang Mai City



Field survey conditions:

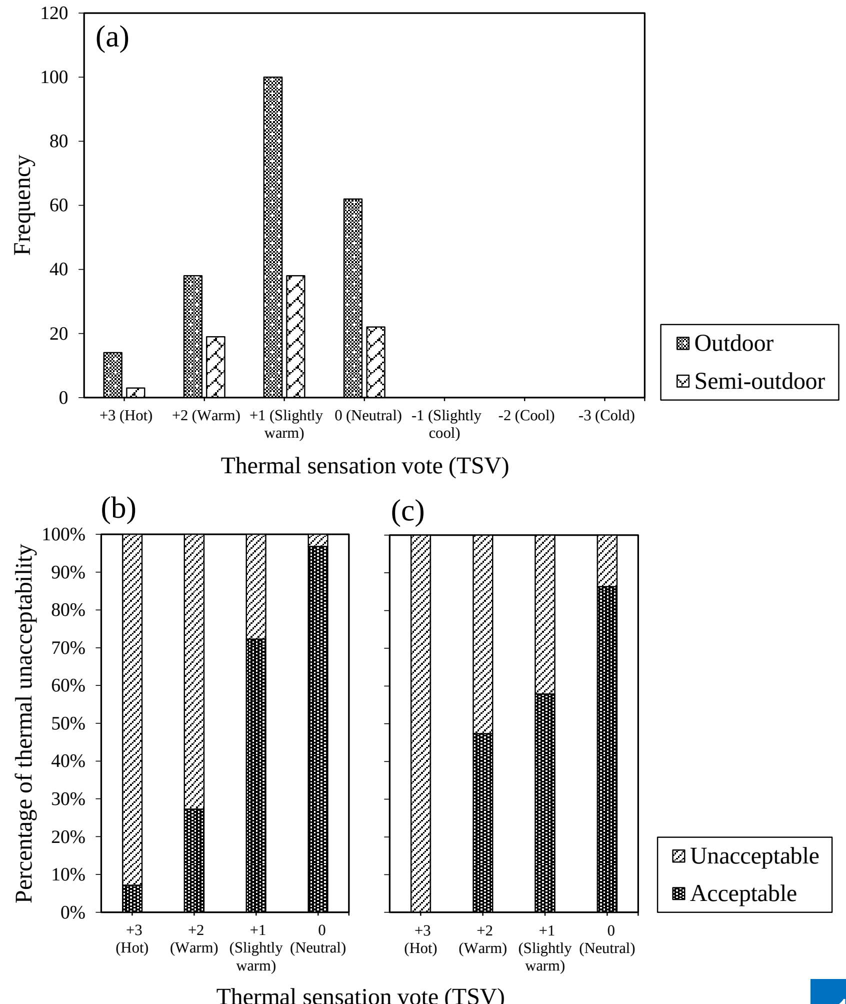
- The measurement period was conducted during the daytime from 8 am to 4 pm on April within the year 2014, which is the most representative a hottest month of summer in Chiang Mai city,
- A total of 296 questionnaires were collected in the outdoor (72.3%) and semi-outdoor (27.7%) urban spaces during the survey.
- The majority of *the respondents (99.8%) stayed under trees or buildings shaded conditions*.

4. RESULTS

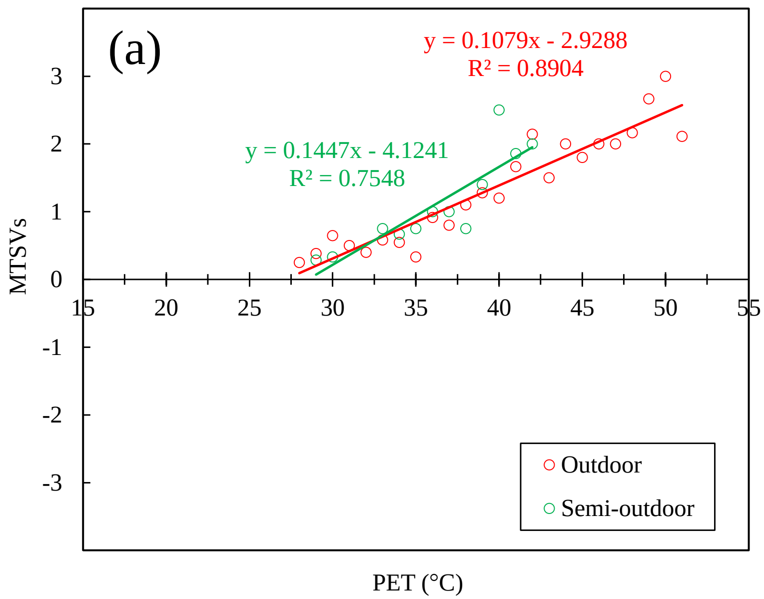
(4.1) Frequency distribution of thermal sensation votes in the both outdoor and semi-outdoor spaces

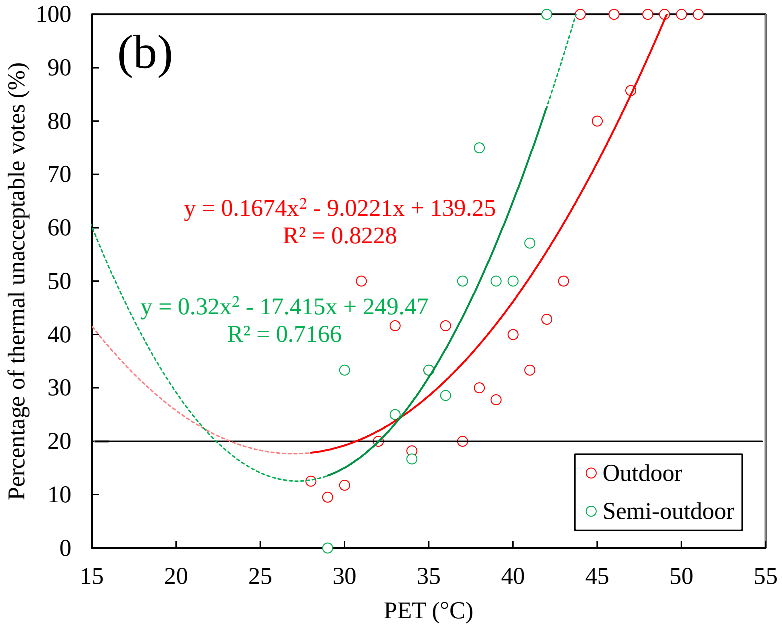
Table: Summary of the respondents and their distribution in each urban space

Personal data		Outdoor	Semi-outdoor	All
Respondent's number		214	82	296
Gender	Male	136	32	168
	Female	78	50	128
Age (year)	Average	35.4	34.9	35.3
	Max.	80	71	80
	Min.	15	15	15
	S.D.	14.7	14.0	14.5
Weight (kg)	Average	57.9	57.1	57.7
	Max	108	95	108
	Min	34	35	34
	S.D.	10.0	11.7	10.5
Height (cm)	Average	163.0	161.6	162.6
	Max.	179	182	182
	Min.	150	149	149
	S.D.	7.0	6.1	6.8
Clothing (clo)	Average	0.56	0.53	0.55
	Max.	1.68	1.05	1.68
	Min.	0.24	0.14	0.14
	S.D.	0.21	0.18	0.20



(4.2) Comparing linear regressions of thermal sensation and PET and, percentage of thermal acceptable ranges for the respondents voted in different environments.





Environments	Thermal neutrality (°C PET) or MTSV=0		Thermal acceptable ranges (°C PET)	Thermal uncomfortable rages (°C PET)
	Simple linear regression	Quadratic polynomial		
1. Outdoor	27.1	27.0	23.1-31.0 (range=7.9)	<23.1 and >31.0
2. Semi-outdoor	28.5	27.2	22.4-32.0 (range=9.7)	<22.4 and >32.0

(4.3) Estimate the Impact of climate conditions and thermal comfort index

The multiple regression analysis was conducted to determine the impact of climate conditions and thermal comfort index given as:

Environments	Stepwise multiple regression equation	R Square
1.Outdoor	*PET*=0.518*(Tmrt)*+0.603*(Ta)*-4.071*(WS)*-2.909	0.958**
2.Semi-outdoor	*PET*=1.201*(Ta)*-6.552	0.979**

Where:

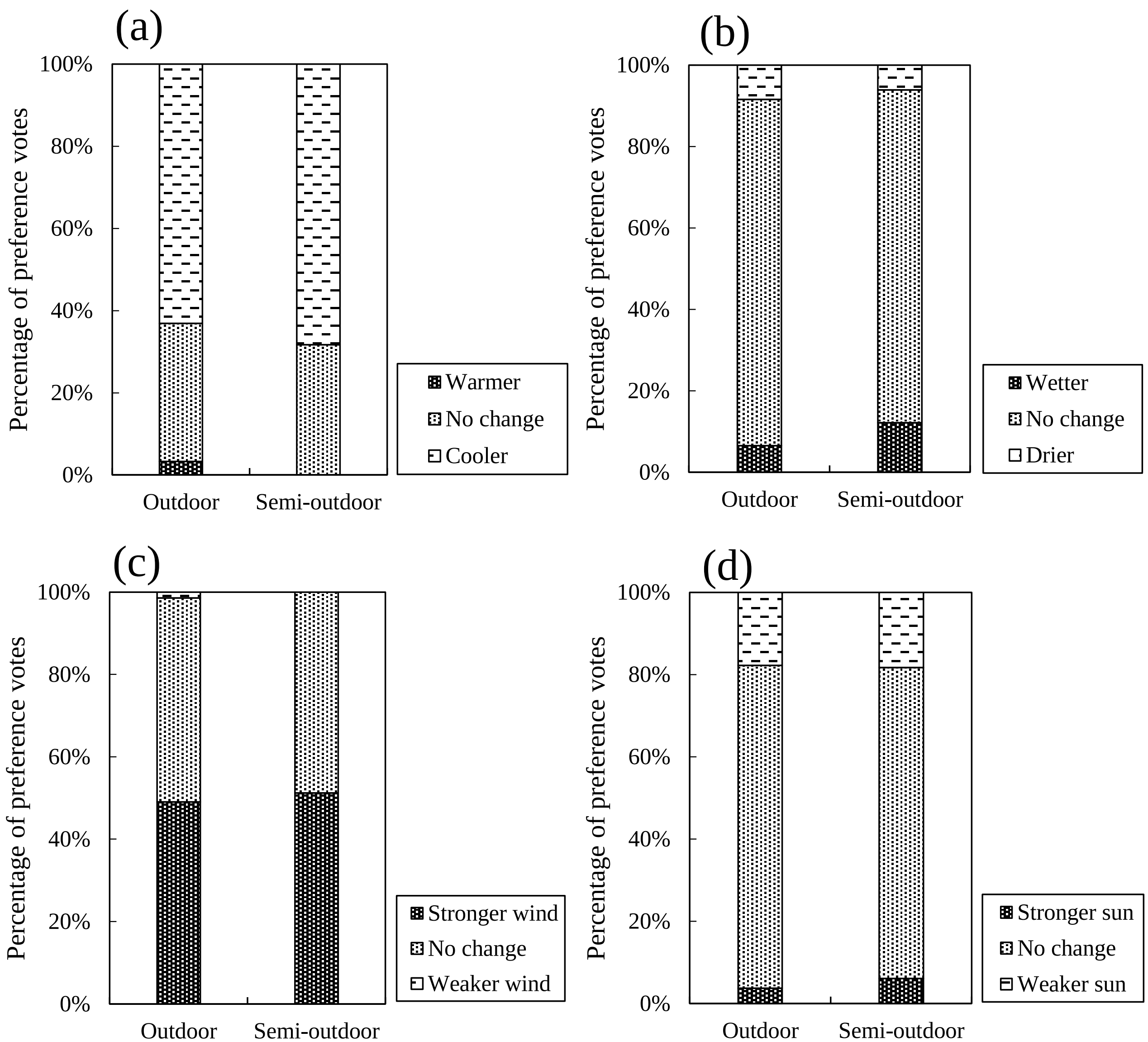
PET = Physiological Equivalent Temperature (°C)

Tmrt = Mean Radiant Temperature (°C)

Ta = Air Temperature (°C)

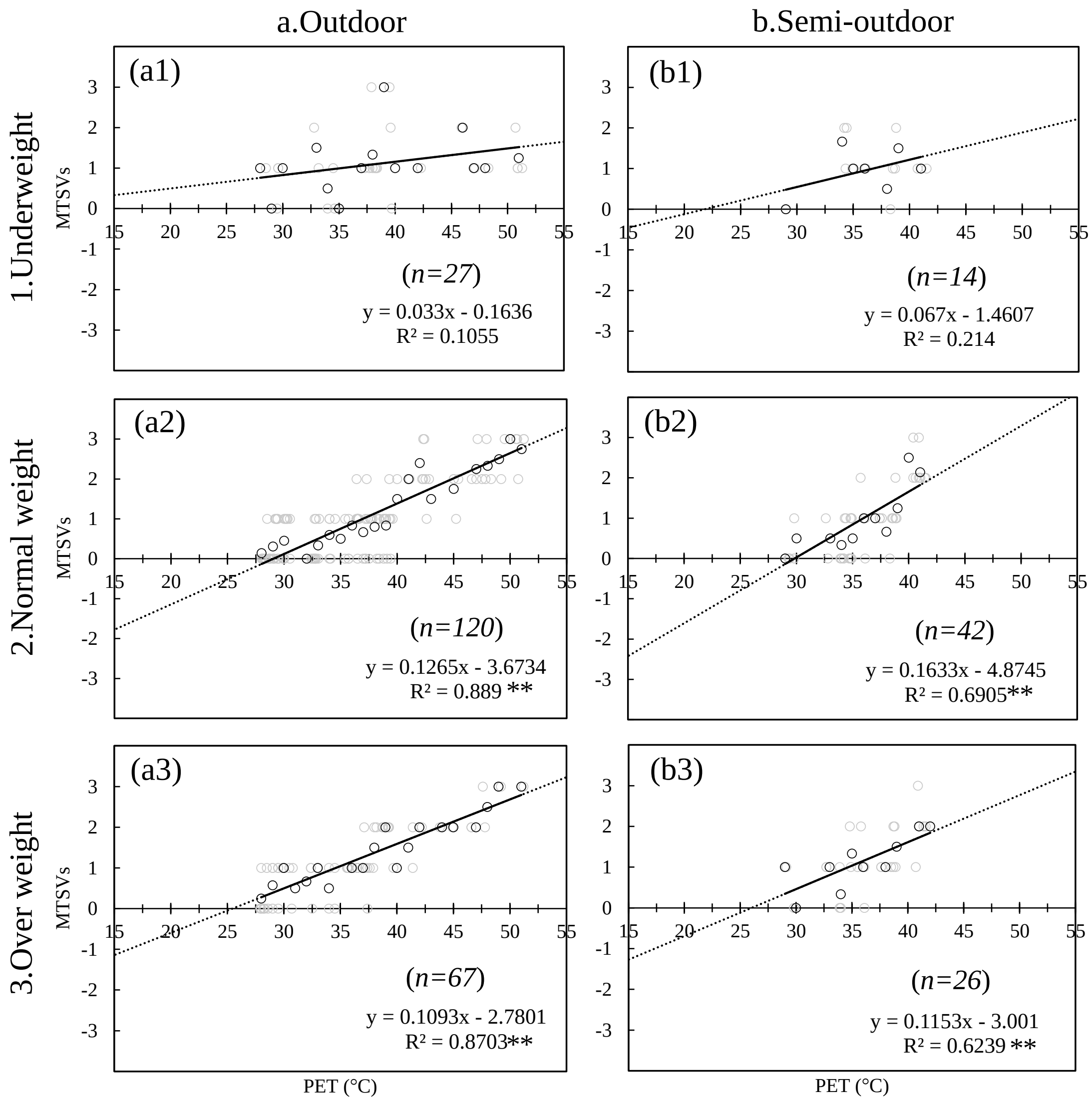
WS = Wind Speed (m/s)

***Correlation is significant at the 0.01level*



Thermal Sensations and Preferences Regarding: (a) Air temperature, (b) Humidity, (c) Wind and (d) Sun

(4.4) Effects of respondents' thermal sensation votes in different body mass index (BMI) classes for (a) outdoor and (b) semi-outdoor environments.



***Correlation is significant at the 0.01level*

(4.5) Effects of respondents' thermal sensation votes in different body mass index (BMI) classes for outdoor and semi-outdoor environments

Environments	Body mass index (BMI)	Thermal neutrality (°C PET)	Thermal acceptable ranges (°C PET)	Thermal uncomfortable rages (°C PET)
1.Outdoor	Underweight (<=18.49)	5.0	7.2-17.1	<7.2 and >17.1
	Normal (22.99-18.50)**	29.0	25.9-32.2	<25.9 and >32.2
	Overweight (>=23.00)**	25.4	21.8-29.1	<21.8 and >29.1
2.Semi-outdoor	Underweight (<=18.49)	18.8	29.3-8.4	<8.4 and >29.3
	Normal (22.99-18.50)**	28.6	24.3-32.9	<24.3 and >32.9
	Overweight (>=23.00)**	24.3	18.2-30.4	<18.2 and >30.4

****Correlation is significant at the 0.01level*

5. CONCLUSIONS

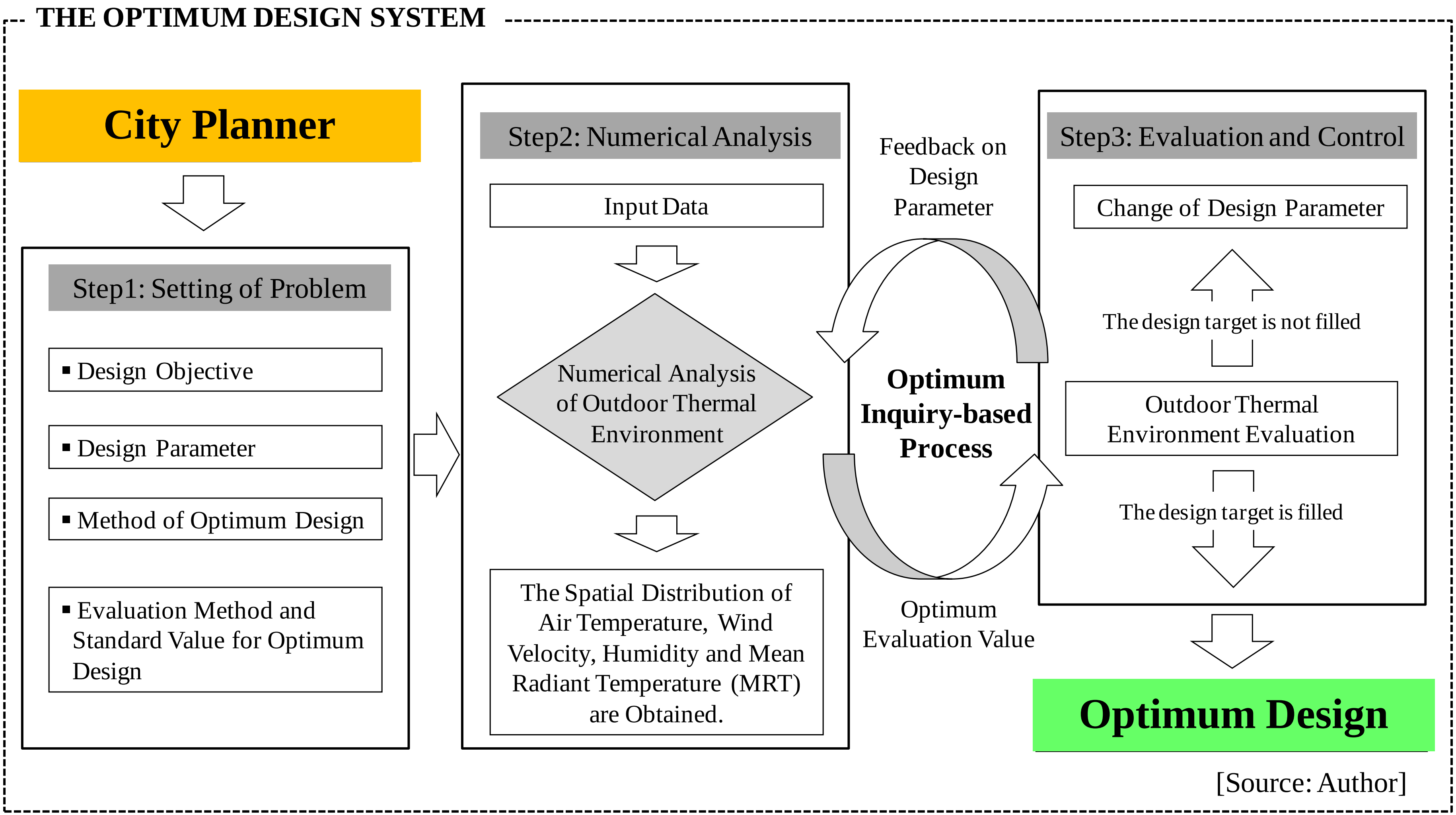
- The neutral sensation PET temperatures (MTSV=0) of outdoor and semi-outdoor spaces were 27.1 ◦C and 28.5 ◦C, respectively. And the acceptable thermal conditions (by ASHRAE Standard 55 corresponded with minimum standard of 80% acceptability) ranges were 31.0-23.1◦C and 32.0-22.4◦C, respectively.

- Compared with the thermal acceptable range between both spaces was found that the thermal acceptable range in the semi-outdoor environment is much higher than the outdoor environment, indicating that occupants in different spaces have different thermal requirements.

- In a hot-humid region such as Chiang Mai, applied with air movement increasing and sunshine eliminating design strategies, can effectively increase occupant thermal comfort and further increase their utilization rate of these spaces.

6. RECOMMENDATIONS

Exploring the characteristics of an optimum design for inquiry-based pleasant outdoor environment with the numerical climate model analysis



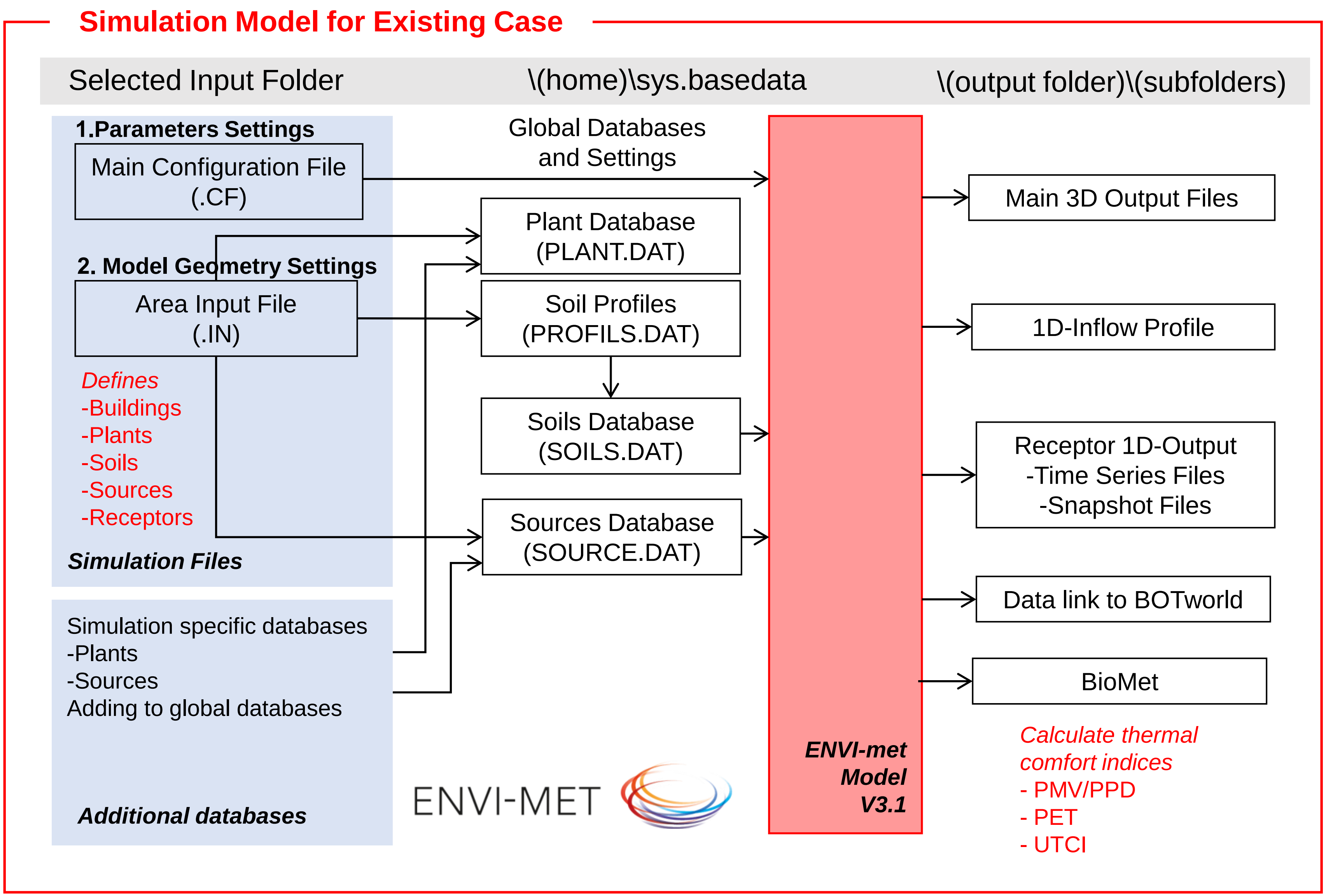
Adoption of Environmental Design Strategies to Improve Outdoor Human Thermal Comfort Using Microclimate Simulation Model

- ❑ Case1: Base case

- ❑ Case2: Add trees, grass roofs and cool pavements

(Source: Author, 2014)

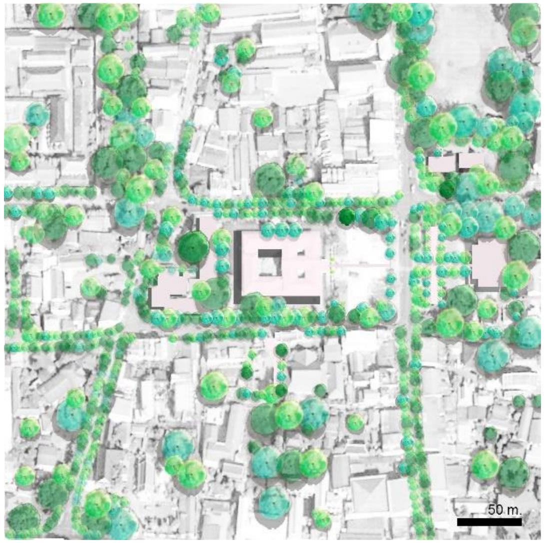
Micro-Climate Simulation Tools to Support Urban Planning and Outdoor Environmental Design



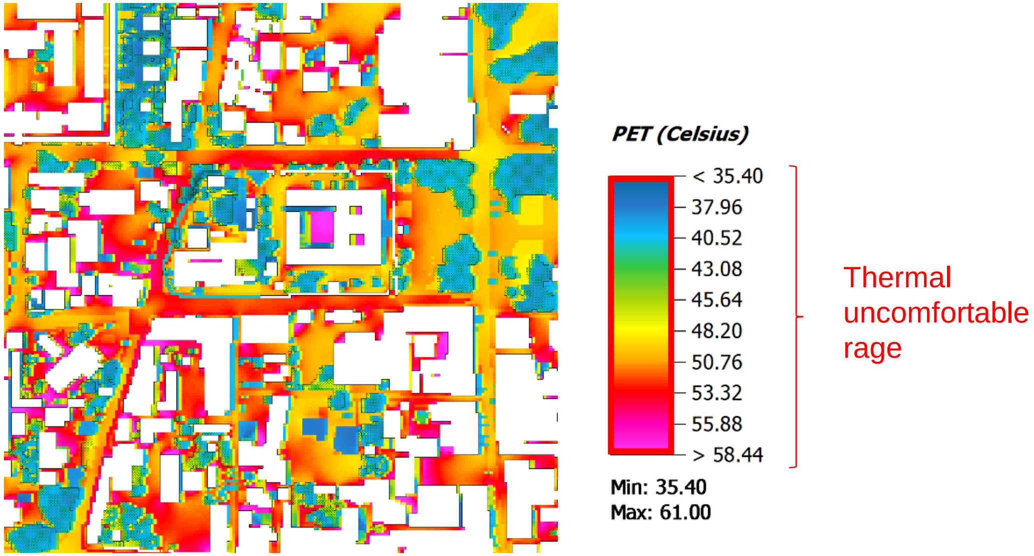
Source: http://www.envi-met.com

Inquiry-Based Planning for Improving a Comfortable Outdoor Thermal Environment

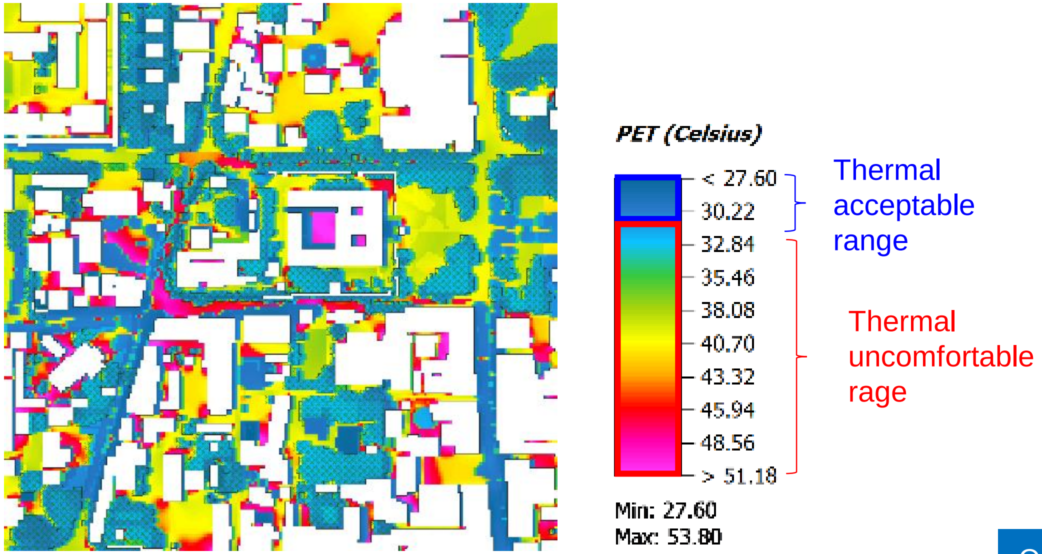
- Case1: Base case



- Different PET for different scenarios



- Case2: Add trees, grass roofs and cool pavements



Note: April 27, 2014 as a simulation day at the peak of the summer (at 2pm.) (Source: Author)

(Photo: Author, 2014)

END

Thank you for your attention.

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