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

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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.”
“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.”

The hypothesis

Problems

Explanatory variables

Identified constraint

Key conclusions

Climate knowledge have low impact on the planning process

Lack of methods and techniques for collecting and analysis climate data

Lack of consensus of the role and importance of climate knowledge for the planning process

Communication problems between climate experts and urban planners

Lack of communication between technical, administrative and political spheres

Lack of incentives among investors

Problems centered around the decision-making process

Policy questions for example the need for economic priorities between different activities

Technical

Lack of easily accessible information and tools

Lack of knowledge

Climatic aspects are embedded in other aspects

Planners fell uncertain about their own knowledge

Other priorities

Time and costs

Fear of formal complaints

Changed or unclear policy

Status of the planning

The housing market

Develop tool and courses suitable for urban planners

Improve awareness for urban climate

Improve communication and argumentation

Improve institutional capacity

[Modified after Eliasson, 2000]
(1.3) Of course it’s hot!! This is Thailand.

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

"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

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)

- **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.”

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

3.3 A general framework for outdoor thermal comfort assessment

**Step I. Outdoor Environmental Control**

1. Classifying Chiang Mai by Local Climate Zones
   - Surface Configuration
   - Surface Composition
   - GIS&RS-multivariate analysis approach
   - Cluster analysis (CA)
   - Selected zone to carry out a deep summer field study

**Step II. Input Conditions & Field Survey**

- (a) Micro-Climate Measurements
  - Air temperature
  - Air velocity
  - Humidity
  - Radiant temperature

- (b) Questionnaires or Structured Interviews
  - Human physiology
  - Activity and clothing insulation
  - Thermal perception
  - Psychological mechanisms
  - Age, gender, .., etc.

**Step III. Evaluation & Prediction Results**

- Physiologically equivalent temperature (PET)
- Transversal Method (or True-experiments)
- Calculation of thermal comfort index

- Determination of neutral and thermal acceptable range
- Effects of Health Status on Human Thermal Comfort
- Recommendations

- Time periods of field survey
- Health status assessment
  - Body mass index (BMI)
  - Height
  - Weight
  - ASHRAE Standard 55-2004
  - Experience
  - Expectation
  - Preferences
  - Thermal history
  - Socio-cultural
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.
To define an urban area of thermally homogenous surface properties by using a GIS&RS-multivariate analysis approach to delineate thermal climate units.

Quantifying the stability of summer temperatures for different thermal climate zones (Pearson’s correlation to examine the relationship)

Test of homogeneity of variances (Dunnett’s T3)

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

<table>
<thead>
<tr>
<th>Cluster Number</th>
<th>Stability of Surface Temperature (Celsius) *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Class 1</td>
<td>30.50</td>
</tr>
<tr>
<td>Class 2</td>
<td>31.53</td>
</tr>
<tr>
<td><strong>Class 3</strong></td>
<td><strong>34.28</strong></td>
</tr>
<tr>
<td>Class 4</td>
<td>32.52</td>
</tr>
<tr>
<td>Class 5</td>
<td>30.14</td>
</tr>
<tr>
<td><strong>Class 6</strong></td>
<td><strong>34.49</strong></td>
</tr>
<tr>
<td>Class 7</td>
<td>32.23</td>
</tr>
<tr>
<td>Class 8</td>
<td>33.30</td>
</tr>
</tbody>
</table>

Note: *Surface temperature acquired on March 20th, 2014, the Landsat 8 Thermal Infrared Sensor (TIRS)
The Spatial Pattern of Thermal Climate Zone Classes

Class 1 (n=1,254) 26.16%
Class 2 (n=784) 16.35%
Class 3 (n=170) 3.55%
Class 4 (n=405) 8.45%
Class 5 (n=513) 10.70%
Class 6 (n=232) 4.84%
Class 7 (n=832) 17.36%
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

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.

(3.5) 16

Testo 435-2 Data Logger
Lutron WBGT-2010SD Eko MS-602 Pyranometer
UNI-T UT30A Digital Multimeter
Hot-wire Anemometer

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

Sampling Distribution (410)
1 (77 Zones)
2 (109 Zones)
3 (27 Zones)
4 (6 Zones)
5 (2 Zones)

(3.5) (b) Instrumental setup

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.

(Photo: Author, 2014)
(3.6) Summertime thermal sensation survey in Chiang Mai

(a) Training programs and requirements

(b) Interviewers conducting the survey

(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 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

<table>
<thead>
<tr>
<th>Personal data</th>
<th>Outdoor</th>
<th>Semi-outdoor</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respondent’s number</td>
<td>214</td>
<td>82</td>
<td>296</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>136</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>78</td>
<td>128</td>
</tr>
<tr>
<td>Age (year)</td>
<td>Average</td>
<td>35.4</td>
<td>34.9</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>80</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>14.7</td>
<td>14.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>Average</td>
<td>57.9</td>
<td>57.1</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>108</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>34</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>10.0</td>
<td>11.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Average</td>
<td>163.0</td>
<td>161.6</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>179</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>150</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>7.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Clothing (clo)</td>
<td>Average</td>
<td>0.56</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Max.</td>
<td>1.68</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>Min.</td>
<td>0.24</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>0.21</td>
<td>0.18</td>
</tr>
</tbody>
</table>
(4.2) Comparing linear regressions of thermal sensation and PET and, percentage of thermal acceptable ranges for the respondents voted in different environments.

### Table: Thermal Sensation and PET Comparison

<table>
<thead>
<tr>
<th>Environments</th>
<th>Thermal neutrality (°C PET) or MTSV=0</th>
<th>Thermal acceptable ranges (°C PET)</th>
<th>Thermal uncomfortable ranges (°C PET)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simple linear regression</strong></td>
<td><strong>Quadratic polynomial</strong></td>
<td><strong>Simple linear regression</strong></td>
<td><strong>Quadratic polynomial</strong></td>
</tr>
<tr>
<td><strong>1. Outdoor</strong></td>
<td>27.1</td>
<td>27.0</td>
<td>23.1-31.0 (range=7.9)</td>
</tr>
<tr>
<td><strong>2. Semi-outdoor</strong></td>
<td>28.5</td>
<td>27.2</td>
<td>22.4-32.0 (range=9.7)</td>
</tr>
</tbody>
</table>
(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:

<table>
<thead>
<tr>
<th>Environments</th>
<th>Stepwise multiple regression equation</th>
<th>R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Outdoor</td>
<td>$PET = 0.518(Tmrt) + 0.603(Ta) - 4.071(WS) - 2.909$</td>
<td>0.958**</td>
</tr>
<tr>
<td>2. Semi-outdoor</td>
<td>$PET = 1.201(Ta) - 6.552$</td>
<td>0.979**</td>
</tr>
</tbody>
</table>

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 0.01 level**
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 0.01 level**
### Environments

**Body mass index (BMI)**

- **Thermal neutrality (°C PET)**
- **Thermal acceptable ranges (°C PET)**
- **Thermal uncomfortable ranges (°C PET)**

<table>
<thead>
<tr>
<th>Environments</th>
<th>Body mass index (BMI)</th>
<th>Thermal neutrality (°C PET)</th>
<th>Thermal acceptable ranges (°C PET)</th>
<th>Thermal uncomfortable ranges (°C PET)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Outdoor</strong></td>
<td>Underweight (&lt;=18.49)</td>
<td>5.0</td>
<td>7.2-17.1</td>
<td>&lt;7.2 and &gt;17.1</td>
</tr>
<tr>
<td></td>
<td>Normal (22.99-18.50)**</td>
<td>29.0</td>
<td>25.9-32.2</td>
<td>&lt;25.9 and &gt;32.2</td>
</tr>
<tr>
<td></td>
<td>Overweight (&gt;=23.00)**</td>
<td>25.4</td>
<td>21.8-29.1</td>
<td>&lt;21.8 and &gt;29.1</td>
</tr>
<tr>
<td><strong>2. Semi-outdoor</strong></td>
<td>Underweight (&lt;=18.49)</td>
<td>18.8</td>
<td>29.3-8.4</td>
<td>&lt;8.4 and &gt;29.3</td>
</tr>
<tr>
<td></td>
<td>Normal (22.99-18.50)**</td>
<td>28.6</td>
<td>24.3-32.9</td>
<td>&lt;24.3 and &gt;32.9</td>
</tr>
<tr>
<td></td>
<td>Overweight (&gt;=23.00)**</td>
<td>24.3</td>
<td>18.2-30.4</td>
<td>&lt;18.2 and &gt;30.4</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level**
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

THE OPTIMUM DESIGN SYSTEM

City Planner

Step 1: Setting of Problem
- Design Objective
- Design Parameter
- Method of Optimum Design
- Evaluation Method and Standard Value for Optimum Design

Step 2: Numerical Analysis
Input Data
Numerical Analysis of Outdoor Thermal Environment
The Spatial Distribution of Air Temperature, Wind Velocity, Humidity and Mean Radiant Temperature (MRT) are Obtained.

Step 3: Evaluation and Control
Feedback on Design Parameter
- Change of Design Parameter
  - The design target is not filled
- Outdoor Thermal Environment Evaluation
  - The design target is filled
Optimum Evaluation Value
Optimum Design

[Source: Author]
Adoption of Environmental Design Strategies to Improve Outdoor Human Thermal Comfort Using Microclimate Simulation Model

- **Case 1**: Base case

- **Case 2**: Add trees, grass roofs and cool pavements

(Source: Author, 2014)
Simulation Model for Existing Case

Selected Input Folder

\(\text{(home)\|sys.basedata}\)

\(\text{(output folder)\|\(\text{(subfolders)}\)}\)

1. Parameters Settings
   - Main Configuration File (.CF)

2. Model Geometry Settings
   - Area Input File (.IN)

**Simulation Files**

- Defines - Buildings
- Plants
- Soils
- Sources
- Receptors

Simulation specific databases
- Plants
- Sources
Adding to global databases

Global Databases and Settings

- Plant Database (PLANT.DAT)
- Soil Profiles (PROFILS.DAT)
- Soils Database (SOILS.DAT)
- Sources Database (SOURCE.DAT)

Main 3D Output Files

- 1D-Inflow Profile
- Receptor 1D-Output
  - Time Series Files
  - Snapshot Files
- Data link to BOTworld
- BioMet

Calculates thermal comfort indices
- PMV/PPD
- PET
- UTCI

Source: http://www.envi-met.com
Inquiry-Based Planning for Improving a Comfortable Outdoor Thermal Environment

- **Case 1:** Base case

- **Case 2:** Add trees, grass roofs and cool pavements

Different PET for different scenarios

Note: April 27, 2014 as a simulation day at the peak of the summer (at 2pm.) (Source: Author)
“If a man can control his mind he can find the way to Enlightenment, and all wisdom and virtue will naturally ...”

-- Buddha quotes --
Thank you for your attention.

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