Assessment and Management of Urban Microclimate for the Public Realm

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Urban Form alters the climate on various scales:

- Precipitation
- Heat
- Wind

Intentional Design can mitigate and possibly enhance the micro-climates of cities.
CityComfort+: Modeling Comfort for the Public Realm

Presenting a New Approach to Predicting Human Comfort in Urban Settings

WHY?
• Human Comfort is an Attribute of outdoor places
• Currently there is no systematic or acceptable method for quantifying comfort in outdoor places—Noise and Shading Studies are used as proxies
• Important to anticipate future conditions with sophisticated and reliable models
What is Human Comfort?

- Physiology, thermal equilibrium, social context, aesthetic appeal, inspiration, location

- Tapestry of physical, psychological and social factors
Assessment and Management of Urban Micro-climate for the Public Realm

OUTLINE

- THERMAL COMFORT – elusive
- NEED FOR A MODEL OF THERMAL COMFORT – for today and future
- CITYCOMFORT+ -- Theory, physics and modules
- VALIDATION -- Instruments and people
- APPLICATION – Copley Plaza, Boston, MA USA
- APPLICATION – Hong Kong, China
Eat Food, Burn Calories, Do Work, Produce Heat

$\text{CO}_2$

$\text{H}_2\text{O}$
100 Watts
Adapt To Conditions To Maintain Comfort
We know a great deal about thermal regulation and modeling comfort

- Metabolic Activity
- Environmental conditions
- Age
- Gender
- Clothing
- Activities
- Preference
- Locations

www.thermoanalytics.com
Balance between Internal Heat and Environment

http://www.thermoanalytics.com/human_thermal_comfort
Nakuru National Park, Kenya

rainbow-over-the-savannah-lake-nakuru-national-park-kenya/
Average Temperature in the 70s and 80s
Making occupants “comfortable” is fundamental to HVAC Design for the Built Environment

Center for the Built Environment at UC-Berkeley
Modifying Indoor Comfort Models for Outdoors
Urban Environments are complex
Conditions Change!

HARVARD SQUARE

JANUARY 2015
Boston Common: the Public Realm
Modeling Public Places: Now and for the Future
2014: One for the Record Books NASA and NOAA confirm that last year was the hottest in recorded history.
Climate Change and Heat Stress by 2050

70% - 90%+ Change Summer Temperatures will exceed Median Summer T from 1900-2006

Battisti and Naylor 1999
Human Responses to Heat Stress

Heat Index Chart

- MILD STRESS
- DISTRESSED
- SEVERE STRESS
- FATAL

Temperature (°F) vs. Relative Humidity (%)
Mortality and Temperature: Multi-City Analysis

City-specific and pooled realtionship

(Gasparrini and Armstrong 2011b, Gasparrini et al. 2012)
HEAT STRESS IS SERIOUS FOR CROPS, ANIMALS AND HUMANS
Motivation for CityComfort+

• To quantify links between climate and its benefits/risks --- environmental, social and economic.

• For a design tool that quickly assess microclimates --- for proposed/existing urban development.

• For support tools to management urban microclimates --- through building codes, standards, and guidelines.
## Existing Tools Are Limited

<table>
<thead>
<tr>
<th>Tools</th>
<th>Author Institutions</th>
<th>Radiation</th>
<th>Wind Speed</th>
<th>Air Temp.</th>
<th>Human Responses</th>
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</table>
CityComfort+: A Model For Urban Thermal Environment

INPUT
- Weather Station Solar Radiation
- Weather Station Air Temperature
- Weather Station Wind Speed
- Weather Station Relative Humidity
- Urban Geometries Surface Properties
- Metabolism Clothing

MICROCLIMATE
- \(T_{mrt}\)
- Air Temperature
- Wind
- Humidity
- Noise/Air Pollution (upcoming)

HUMAN PERCEPTION
- Comfort
- Stress
- Thermal Strain

ACTIONS
- Alternative Design
- Renovation
- Safety Codes
- Thermal Comfort Guidelines
CityComfort+ Key Components

1) a physics-based model to assess heat transfer and diffusion with the urban canopy layer,
2) a statistically-adjusted human biometeorology model to predict thermoregulation and responses of local inhabitants.
3) inputs are weather data, 3D urban geometries, anthropogenic heat source profiles, and personal parameters (metabolic rate, bodily posture, clothing, etc.);
4) the outputs are urban thermal parameters and indices for human thermal sensation, comfort, and stress in high spatial-temporal resolution.

District Scale (>1000m) →

Canyon Scale (10-100m) →

Pedestrian Scale (1m)

\[ Q_{bi} + q_{a}^{gen} + Q_{gi} + Q_{ji} = 0 \]
Assessment of Human Thermal Regulation

**PMV-PPD**
The Predicted Mean Vote (fanger, 1972) is derived from the physics of heat transfer combined with an empirical fit to sensation.

**COMFA**
The COMFA model (Brown & Gillespie, 1995) provides a swift comfort index in landscape areas based on a person thermal balance.

**SET* & ET* & PET**
Standard Effective Temperature (SET) (Gagge, 1971, 1986) is the equivalent air temperature of an isothermal environment at 50% RH in which a subject, while wearing clothing standardized for the activity concerned, has the same heat stress and thermoregulatory strain as in the actual environment.

**UTCI**
The Universal Thermal Climate Index is the air temperature of the reference condition with the same physiological response as the actual condition. The index is based on the UTCI-Fiala human biometeorological model that is the most complex compared with previous ones.
Validation with Instruments

USGS Color Ortho Imagery 2008, Source: MassGIS
Predicted & Measured $T_{mrt}$

Harvard Countway Library, 30 minute time-step

**Rayman 1.2**

$Y = 0.84 X + 10.28$

$R^2 = 0.86$

$RMSE = 11.57 \degree C$

**ENVI-met 3.1**

$Y = 0.92 X + 1.93$

$R^2 = 0.70$

$RMSE = 7.99 \degree C$

**SOLWEIG 2.2**

$Y = 1.01 X + 0.42$

$R^2 = 0.92$

$RMSE = 7.01 \degree C$

**CityComfort+**

$Y = 1.06 X - 1.88$

$R^2 = 0.95$

$RMSE = 5.11 \degree C$
Validation with People

Experiment Campaign Sept. 15 & Oct. 27, 2012

Harvard University Campus
Field Studies in Hong Kong

Pilot Studies at Sai Ying Pun in Hong Kong. Images taken 12:00pm 16/07/2014, Source: Yali Wang
Rapid assessment of a proposed urban development at early stages; design professionals can compare the performance of alternative urban layouts based on quantifiable evidences.

Supports design and urban planning policies by providing examples of safety codes and thermal comfort guidelines for the study sites, which can reduce safety risks for vulnerable population and extend comfortable seasons.
Before the Copley Place Residential Tower
Annual – hourly thermal comfort at Dartmouth & Stuart

UTC Index.

0  5  10  15  20  25  30  35  40
mod. cold str. slight cold stress no thermal str. mod. heat str. strong heat str. very strong heat str.
After the Copley Place Residential Tower

Annual – hourly thermal comfort at Dartmouth & Stuart

0 5 10 15 20 25 30 35 40 UTCI Index.

mod. cold str. slight cold stress no thermal str. mod. heat str. strong heat str. very strong heat str.

January
February
March
April
May
June
July
August
September
October
November
December
Pre-1984 Design

Annual – hourly thermal comfort at Copley Square

- 0 UTCI Index.
- 5 mod. cold str.
- 10 slight cold stress
- 15 no thermal str.
- 20 mod. heat str.
- 25 strong heat str.
- 30 very strong heat str.
- 35
- 40

- Jan
- Feb
- Mar
- Apr
- May
- Jun
- Jul
- Aug
- Sept
- Oct
- Nov
- Dec

- mod. cold str.
- slight cold stress
- no thermal str.
- mod. heat str.
- strong heat str.
- very strong heat str.
Present Condition

Annual – hourly thermal comfort at Copley Square

mod. cold str. | slight cold stress | no thermal str. | mod. heat str. | strong heat str. | very strong heat str.

UTC Index: 0 5 10 15 20 25 30 35 40
2020 A2 Scenario

Annual – hourly thermal comfort at Copley Square

UTC Index.

- 0 UTCI: very strong heat str.
- 30 UTCI: strong heat str.
- 35 UTCI: mod. heat str.
- 40 UTCI: no thermal str.
- 0 UTCI: mod. cold str.
- 10 UTCI: slight cold stress
- 15 UTCI: no thermal stress
- 20 UTCI: no thermal stress
- 25 UTCI: no thermal stress
- 30 UTCI: no thermal stress
- 35 UTCI: no thermal stress
- 40 UTCI: no thermal stress

Temperature Increase

- 0°C: very strong heat str.
- 1.5°C: strong heat str.
- 2°C: mod. heat str.
- 2.5°C: no thermal str.
- 3°C: no thermal str.
- 3.5°C: no thermal str.
- 4°C: no thermal str.
- 4.5°C: no thermal str.
- 5°C: no thermal str.
- 5.5°C: no thermal str.
- 6°C: no thermal str.
- 6.5°C: no thermal str.
- 7°C: no thermal str.
- 7.5°C: no thermal str.
2050 A2 Scenario

Annual – hourly thermal comfort at Copley Square

0 5 10 15 20 25 30 35 40 UTCI Index.

mod. cold str. slight cold stress no thermal str. mod. heat str. strong heat str. very strong heat str.

Temperature Increase

(C)
2080 A2 Scenario

Annual – hourly thermal comfort at Copley Square

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Temperature Increase

- 0°C
- 0.5°C
- 1°C
- 1.5°C
- 2°C
- 2.5°C
- 3°C
- 3.5°C
- 4°C
- 4.5°C
- 5°C
- 5.5°C
- 6°C
- 6.5°C
- 7°C
- 7.5°C
Thermal Comfort Autonomy: Percentage of Comfortable Hours on Annual Basis

TCA (%)

30
More Comfortable

27

24

21

18

15
Less Comfortable

Pre-1984

Current Condition

Copley Place Tower

2080
Informed Design

Annual – hourly thermal comfort at Copley Square

UTC Index.
Application: Design & Urban Planning Practices

**Codes & Guidelines**
- Performance-based code

**Surface Material**
- Material Emissivity / Albedo / Thermal Massing

**Passive Design**
- Shading Devices
- Vegetation

**Active Design**
- Evaporative Cooling
- Radiant Cooling/Heating

**CFD simulation of Harvard Campus**
Source: Jianxiang Huang

**Solar Fan for Toronto**
Source: Bosselman, 1991

**Thermal Properties of Material**

**Shading devices**
Source: Lutz Katzschner

**Windbreaks in the Netherlands**
Source: Christoph Reinhart

**Radiant Heater in GreenAcre Park**
Manhattan, New York

**Evaporative Cooling System**
Shanghai World Expo
Application: Safety Codes & Thermal Comfort Guidelines

CityComfort+ can inform urban planning and design practices to enhance the safety and comfort of inhabitants by taking full advantage of the sun, wind, and the modifying effects of cities.

Thermal Stress

- **APPROVAL**: Compliance with prescribed envelope
- **REJECTION**: Infringement on comfort at key area

Thermal Comfort

- **APPROVAL**: Mitigation measures installed at key area
Other Application: Local – Specific Weather Services
**Design Recommendation**

Informed Building Layouts Can Reduce Extreme Heat Stress

**Scenario 1**
(Status Quo)

**Scenario 2**
(Podium Removal)

**Scenario 3**
(Ground Elevation)

Sai Ying Pun, Hong Kong. 14:00 pm, August 14, 2014  Air Temp. 28.8 C, Relative Humidity 81% (average daily high temp. in August)
Design Recommendation

Informed Building Layouts Can Enhance Air Ventilation

Scenario 1
(Status Quo)
Stagnant Airflow at human-level

Scenario 2
(Podium Removal)
Enhanced Airflow

Scenario 3
(Ground Elevation)
Accelerated Airflow

Informed Building Layouts Can Enhance Air Ventilation
HAPI
Health And Places Initiative

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