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tapias@arch.ethz.ch

Building as a System
- Climate -

Information Architecture & Future Cities

Chair of
Information
Architecture

Content

Learning Objectives

- **Understand** what is urban climate and why it is important for urban planning and design.
- **Identify** the urban microclimate scale of intervention.
- **Recognize** the effects of different heat sources on microclimatic conditions.
- **Understand** the different urban strategies for climate responsive design in the urban scale.
- **Identify** tools for measuring urban climate and microclimate

Urban Climate

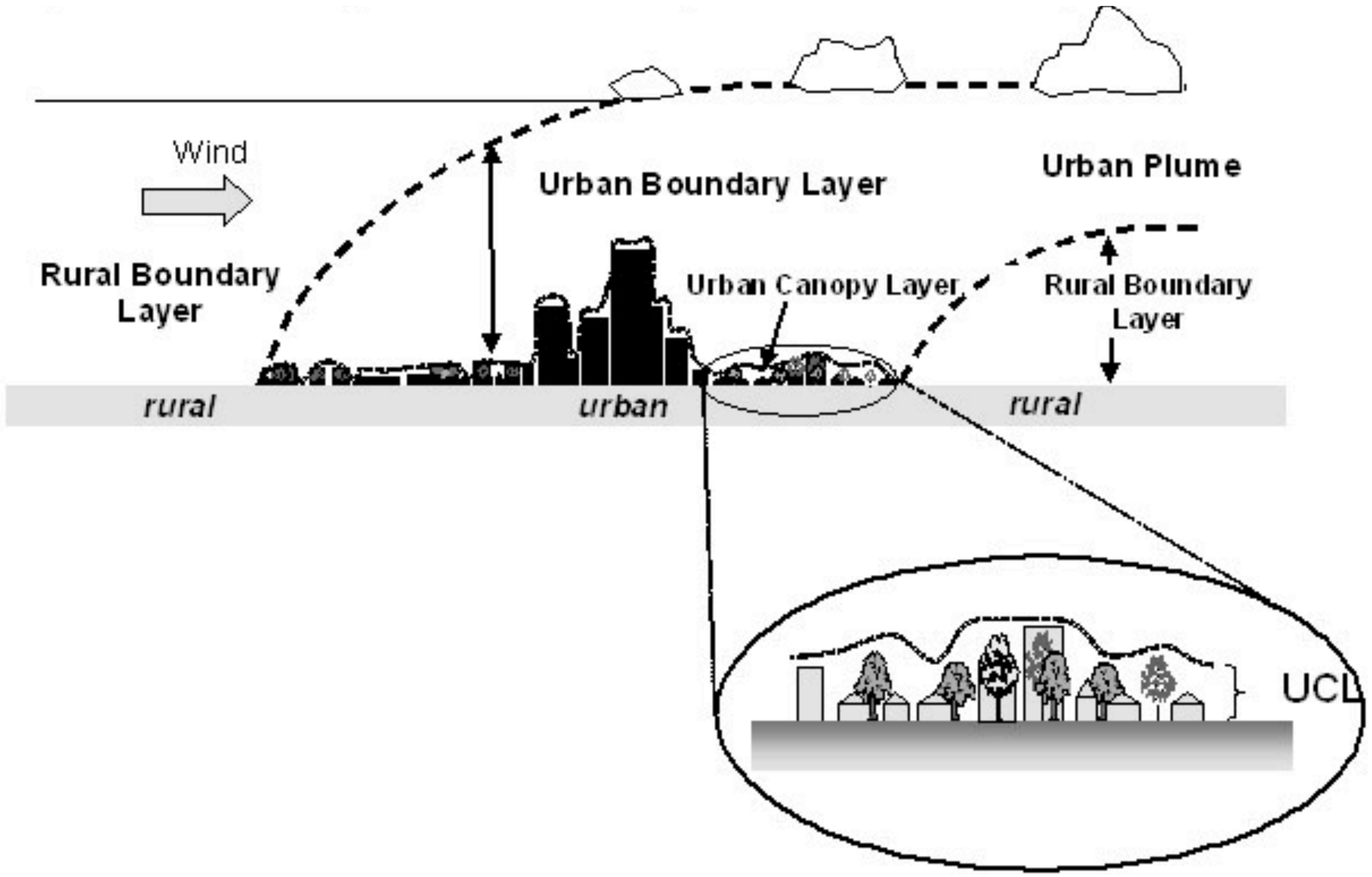
What is Urban Climate?

- <u>Climate</u> is the pattern of variation in precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather that occur in a given region over long periods. (*http://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html*)

- <u>Urban climate</u> refers to climatic conditions in an urban area that differs from the climate of its rural surroundings. This is attributable to urban development.

Urban Climate

Components of Urban Atmosphere



Main components of urban atmosphere (Voogt, 2004). Two-layer classification of thermal modification based on Oke, 1976.

- Urban Boundary Layer (UBL): Refers to that portion of the planetary boundary layer whose characteristics are affected by the presence of an urban area at its lower boundary.
- Urban Canopy Layer (UCL): Consists of the air contained between the urban roughness elements (mainly buildings). Its climate is dominated by the nature of the immediate surroundings (especially site materials and geometry).

(Oke, 1976)

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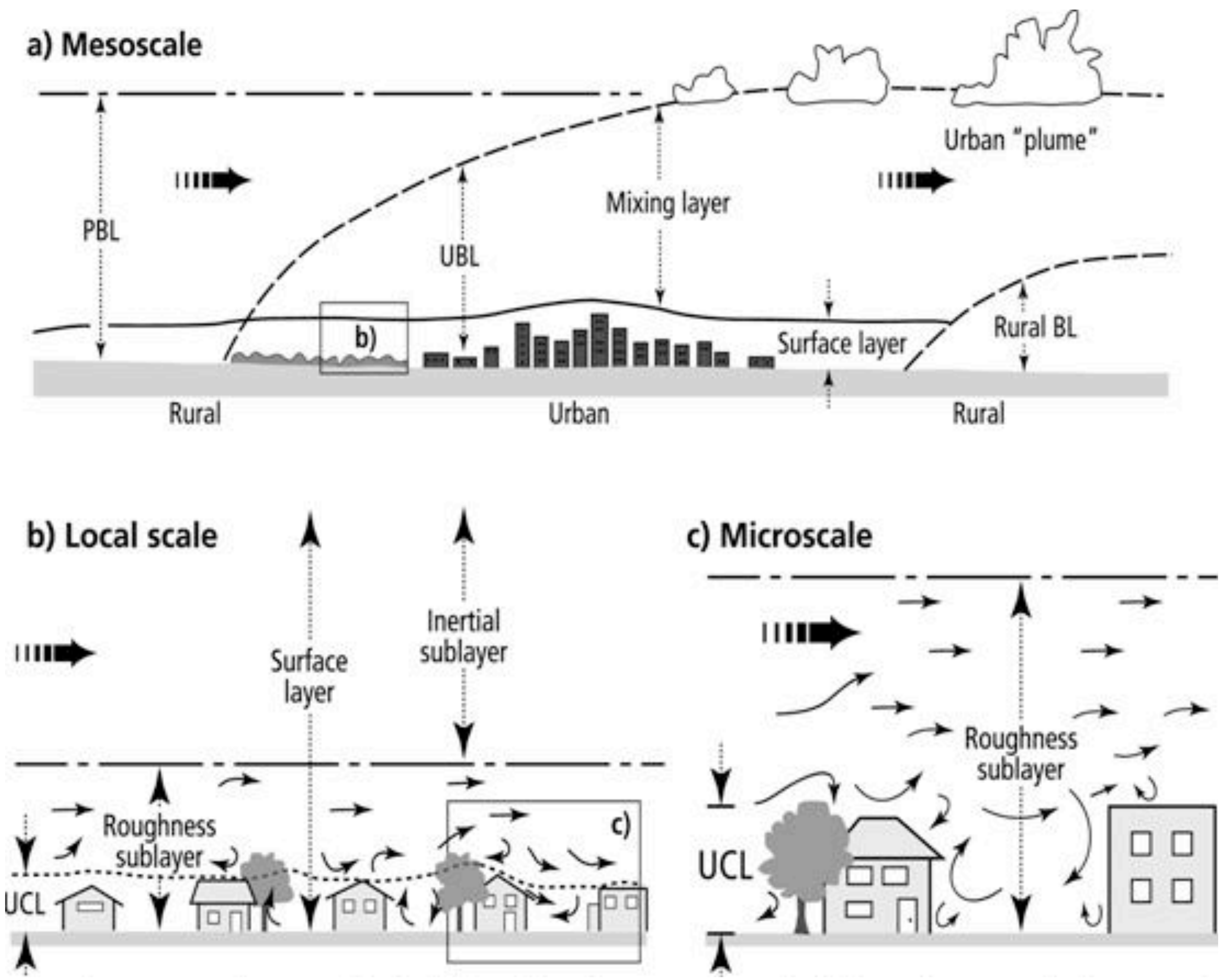
Urban Climate

Scales



Vertical structure of the urban atmosphere (Oke, 1997)

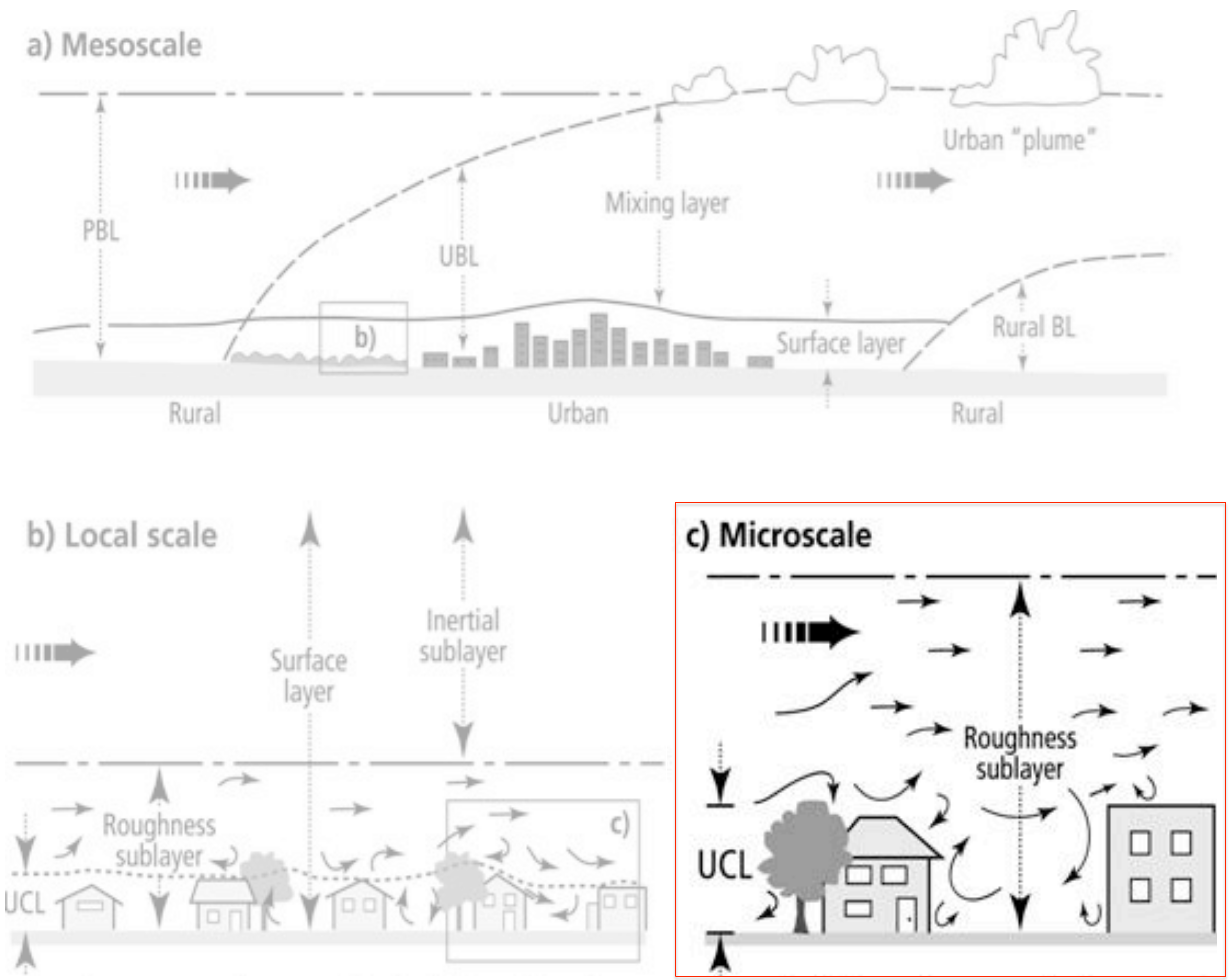
a) Mesoscale: Urban region at the scale of a whole city.

b) Local scale: single urban terrain zone or land use zone.

c) Microscale: Street canyon.

Urban Climate

Scales



Vertical structure of the urban atmosphere (Oke, 1997)

a) Mesoscale: Urban region at the scale of a whole city.

b) Local scale: single urban terrain zone or land use zone.

c) Microscale: Street canyon.

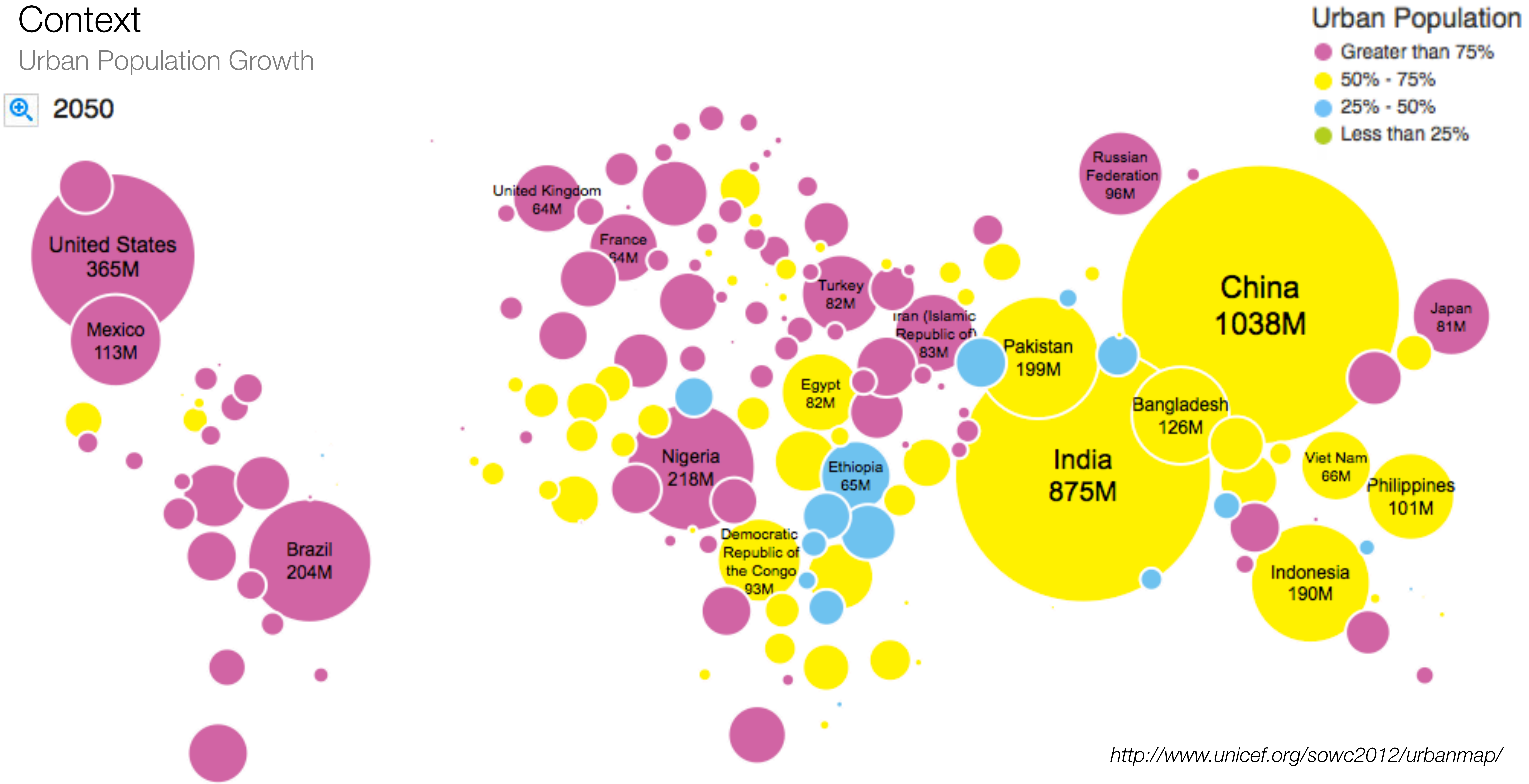
Microclimate is defined as the climate that prevails at the micro-scale level and that differs from the surrounding area.

(Erell; Pearlmutter; Williamson, 2011)

Why is this important?

Context

Urban Population Growth



http://www.unicef.org/sowc2012/urbanmap/

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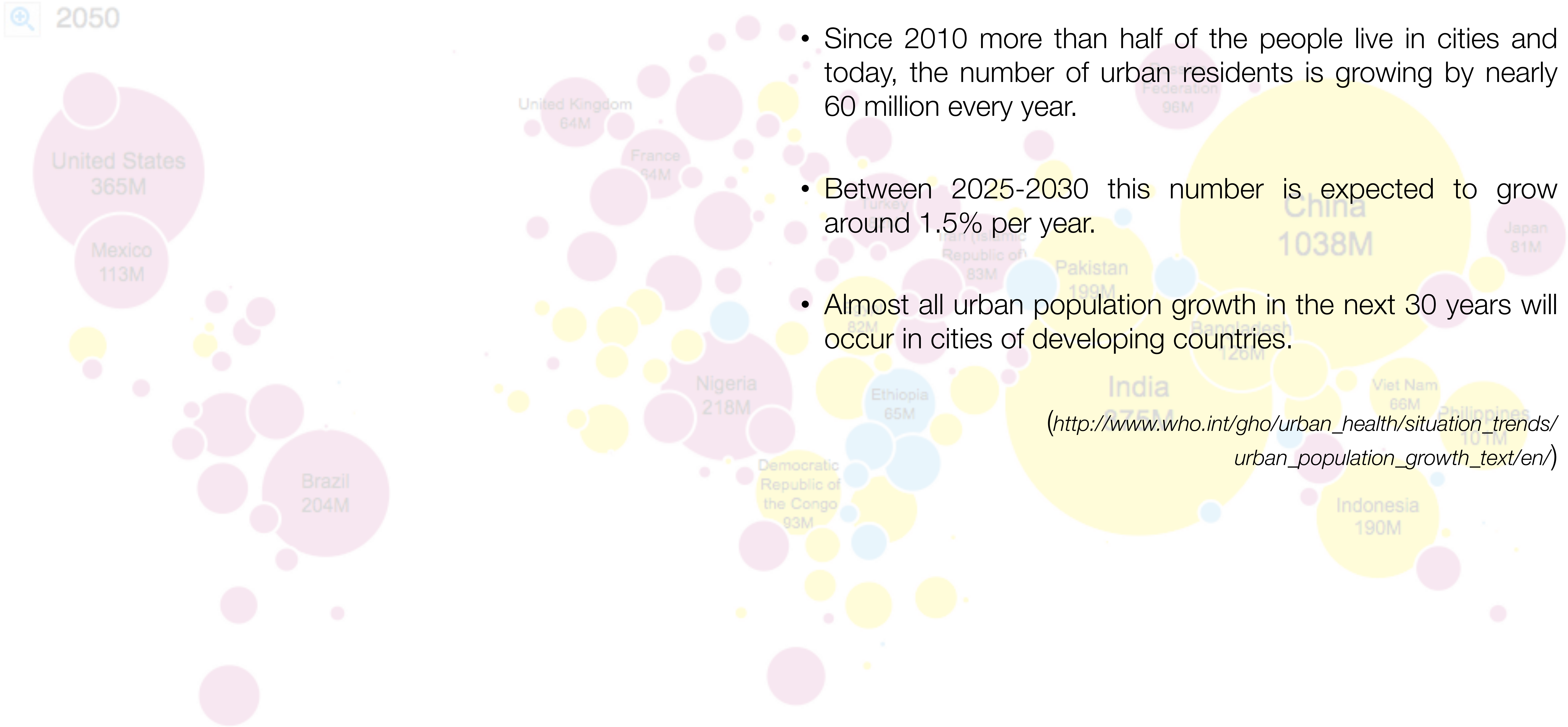
Context

Urban Population Growth



- Since 2010 more than half of the people live in cities and today, the number of urban residents is growing by nearly 60 million every year.
- Between 2025-2030 this number is expected to grow around 1.5% per year.
- Almost all urban population growth in the next 30 years will occur in cities of developing countries.

(*http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/*)

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Context

Climate-change and the city

- The world is facing the rapid process of climate-change and cities are seen not only **as the main contributor** but also as potential sites of climate vulnerability.

(Bulkeley, 2013)

www.scientificamerican.com

Context

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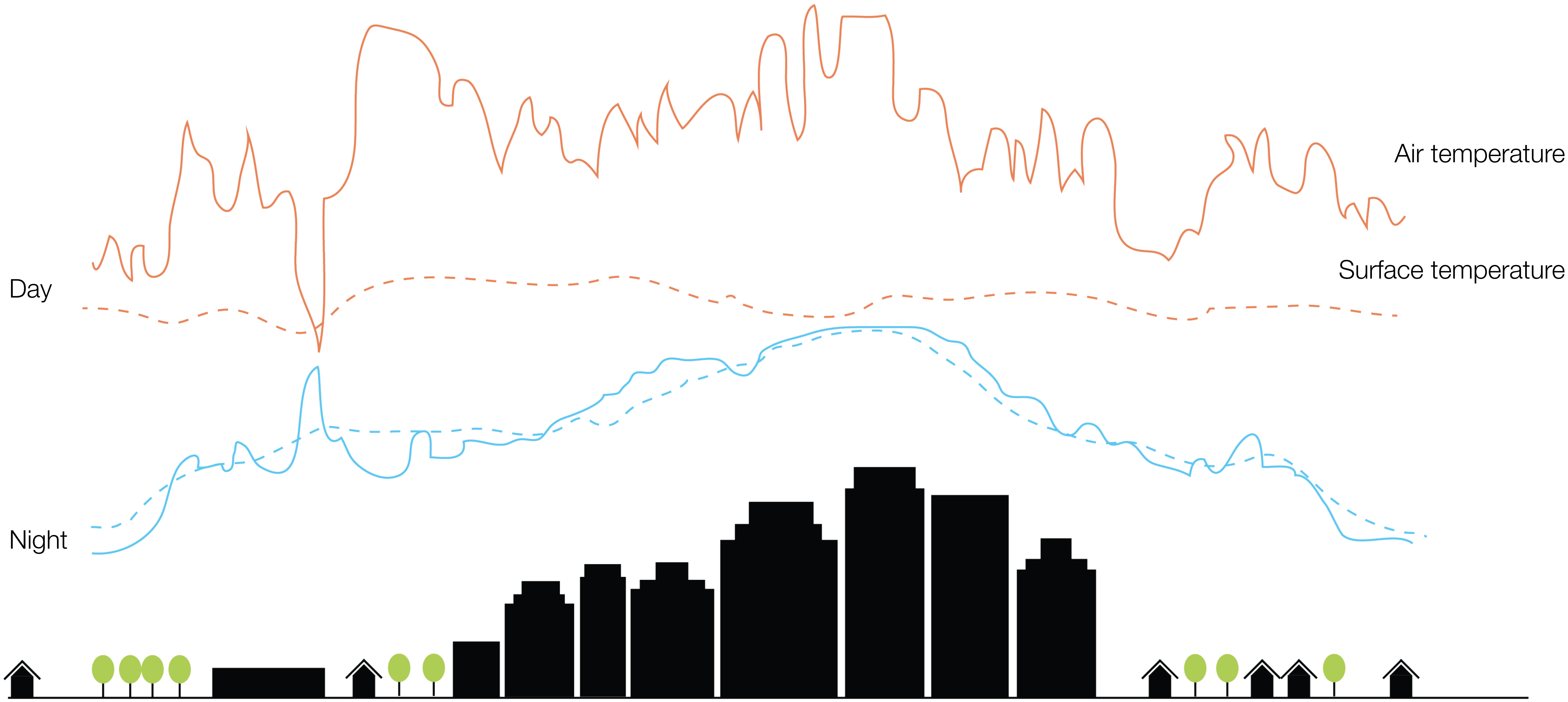
www.sustainablecitiescollective.com/

Context

Urban Heat Island



Modified from Voogt, 2000

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Context

Urban Heat Islands

Bruelisauer, M., 2013

- Anthropogenic heat.

Context

Urban Heat Islands

Schmitt, G., 2013

- Anthropogenic heat.
- Configuration of building

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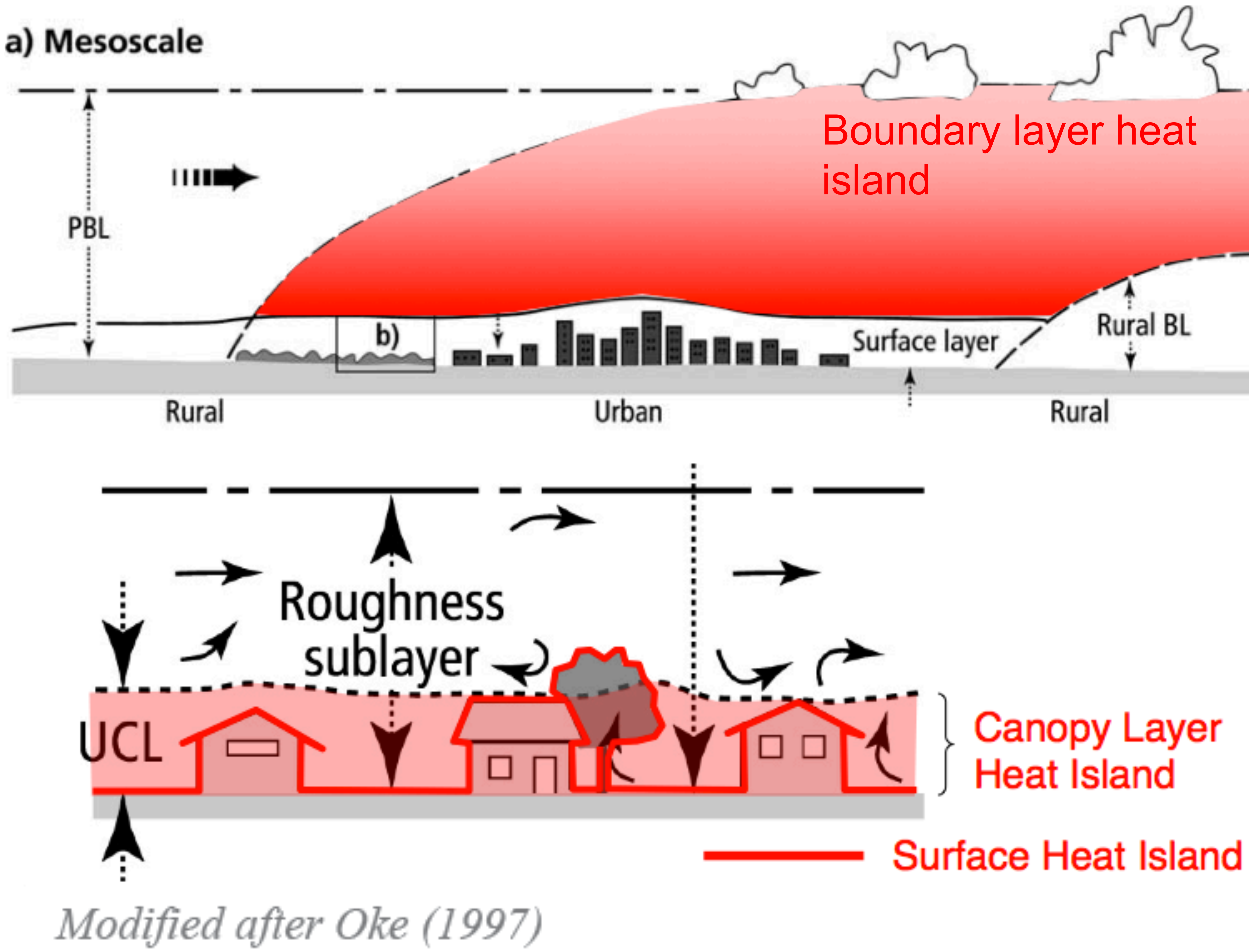
Context

Urban Heat Islands



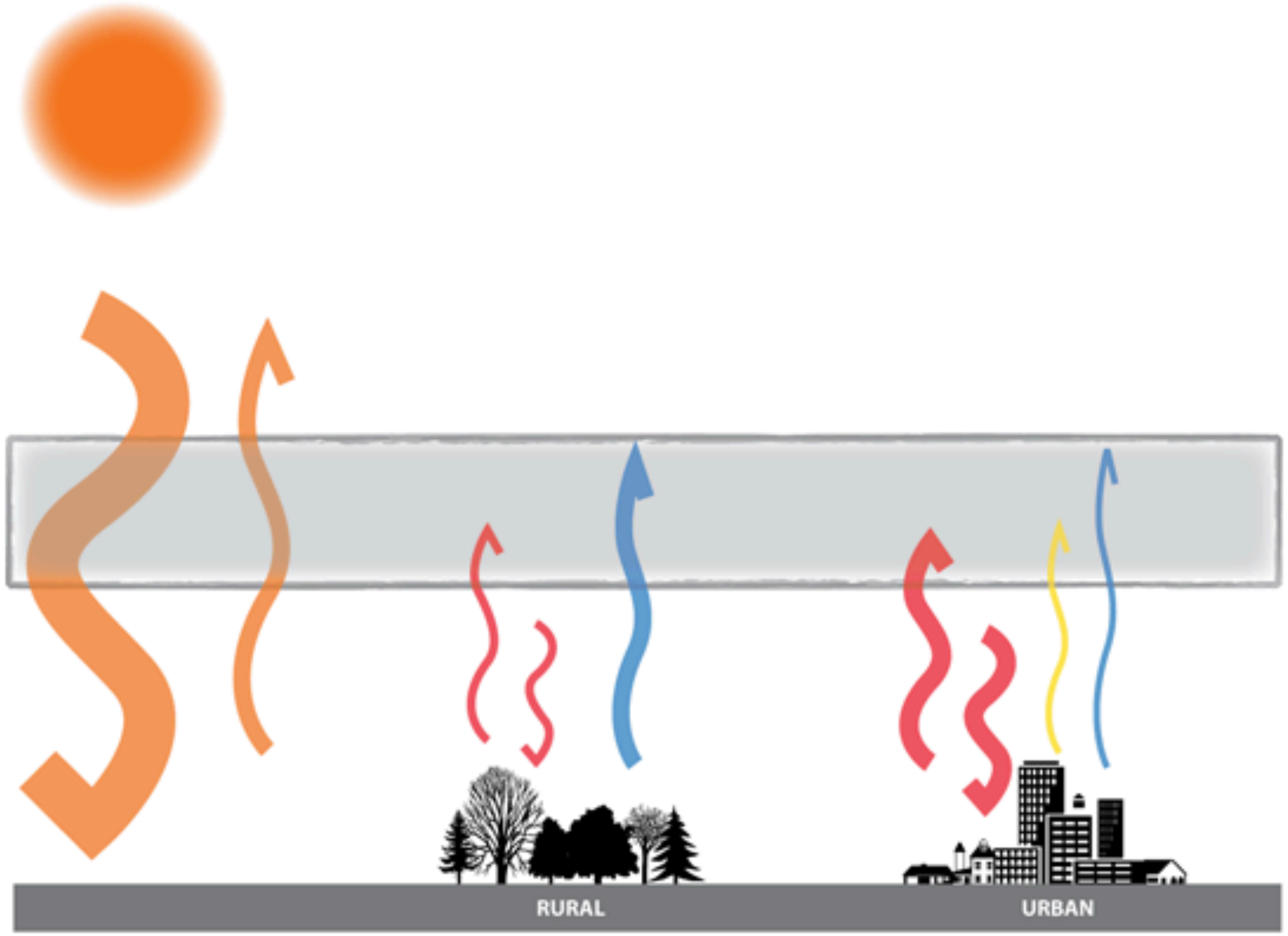
(http://www.epa.gov/heatisld/resources/pdf/EPA_How_to_measure_a_UHI.pdf)

- Types of UHI:
  - Boundary layer heat island (BLHI) –Air
  - Canopy layer heat island (CLHI) – Air
  - Surface heat island (SHI) - Surface

(Oke, 1976), (Oke, 1995), (Voogt, 2004)

The Urban Energy Balance

Definition



Urban Climate Lab (http://www.urbanclimate.gatech.edu/)

'Surface energy balance' (SEB):

Energy balance:

$$\Delta U = Q - W$$

Change in internal energy = heat added to the system – work done by the system

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The Urban Energy Balance

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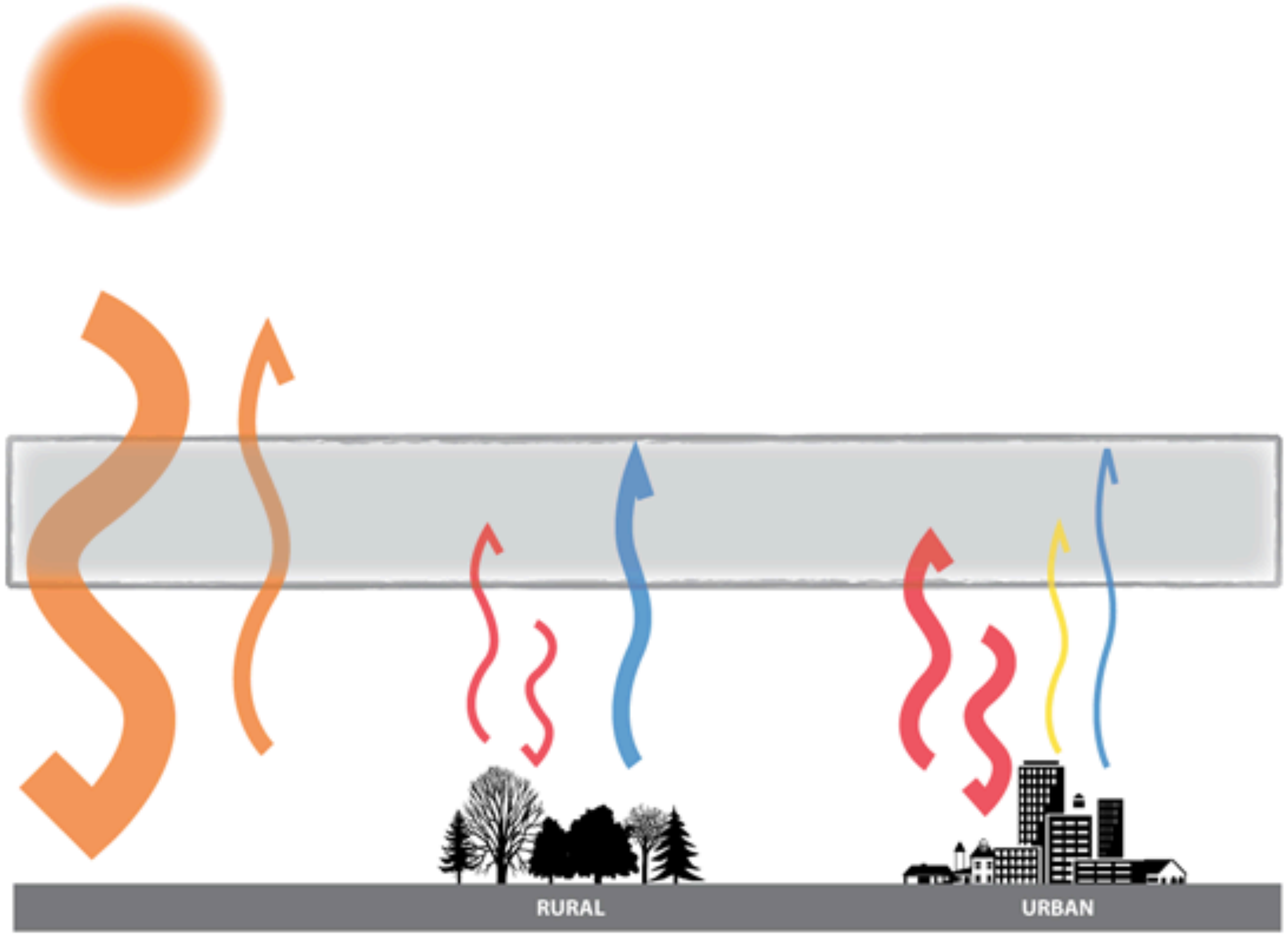

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Simple words…

The difference between the total incoming and the total outgoing energy of a physical system. If the balance is positive, warming occurs; if it is negative, cooling occurs.

(Erell; Pearlmutter; Williamson, 2011)

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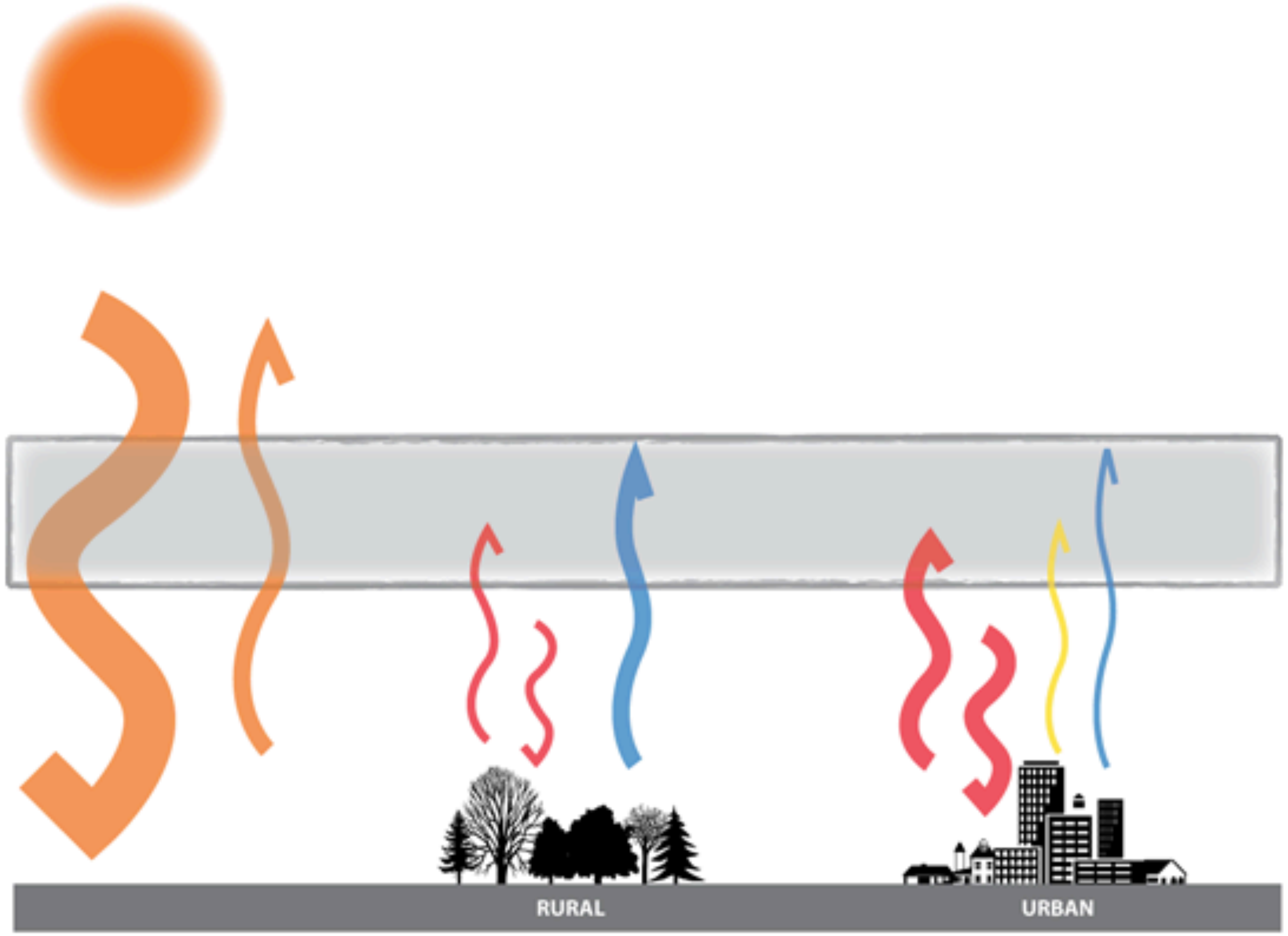

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Energy input = Energy output + change in stored energy

(Erell; Pearlmutter; Williamson, 2011)

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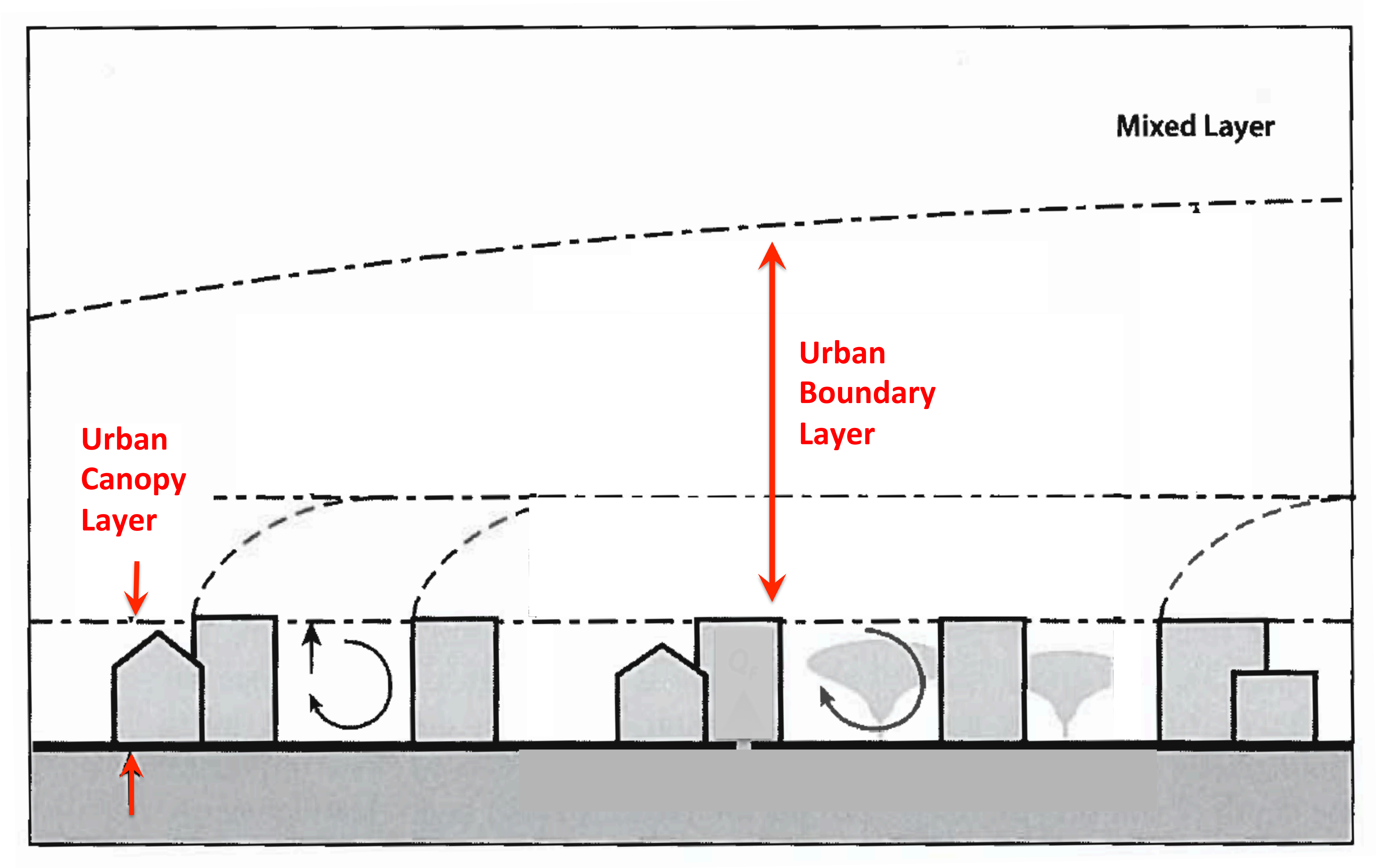
The Urban Energy Balance

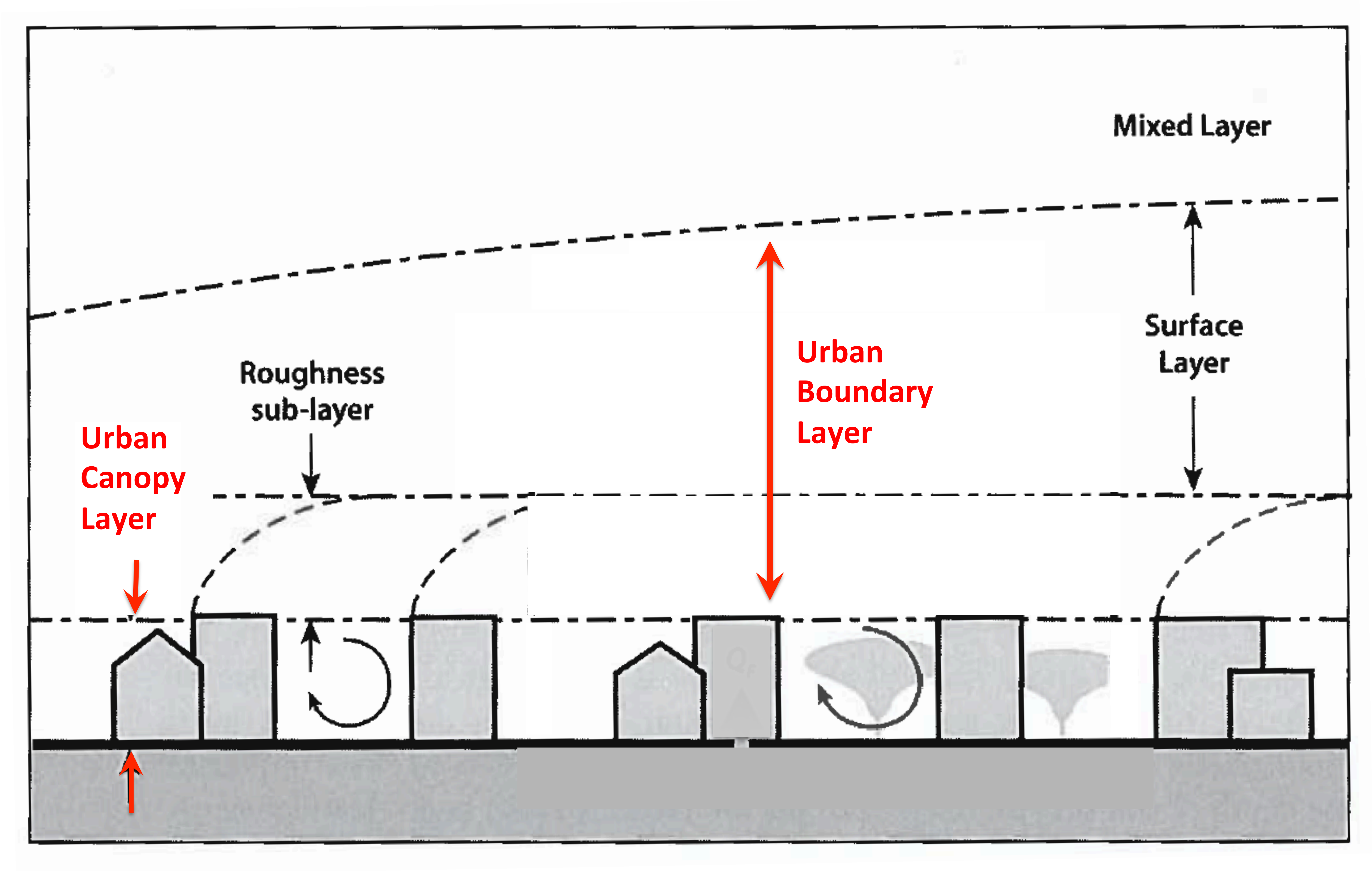
Components of urban surface energy balance



Urban atmospheric layers
Modified from (Erell; Pearlmutter; Williamson, 2011)

The Urban Energy Balance

Components of urban surface energy balance



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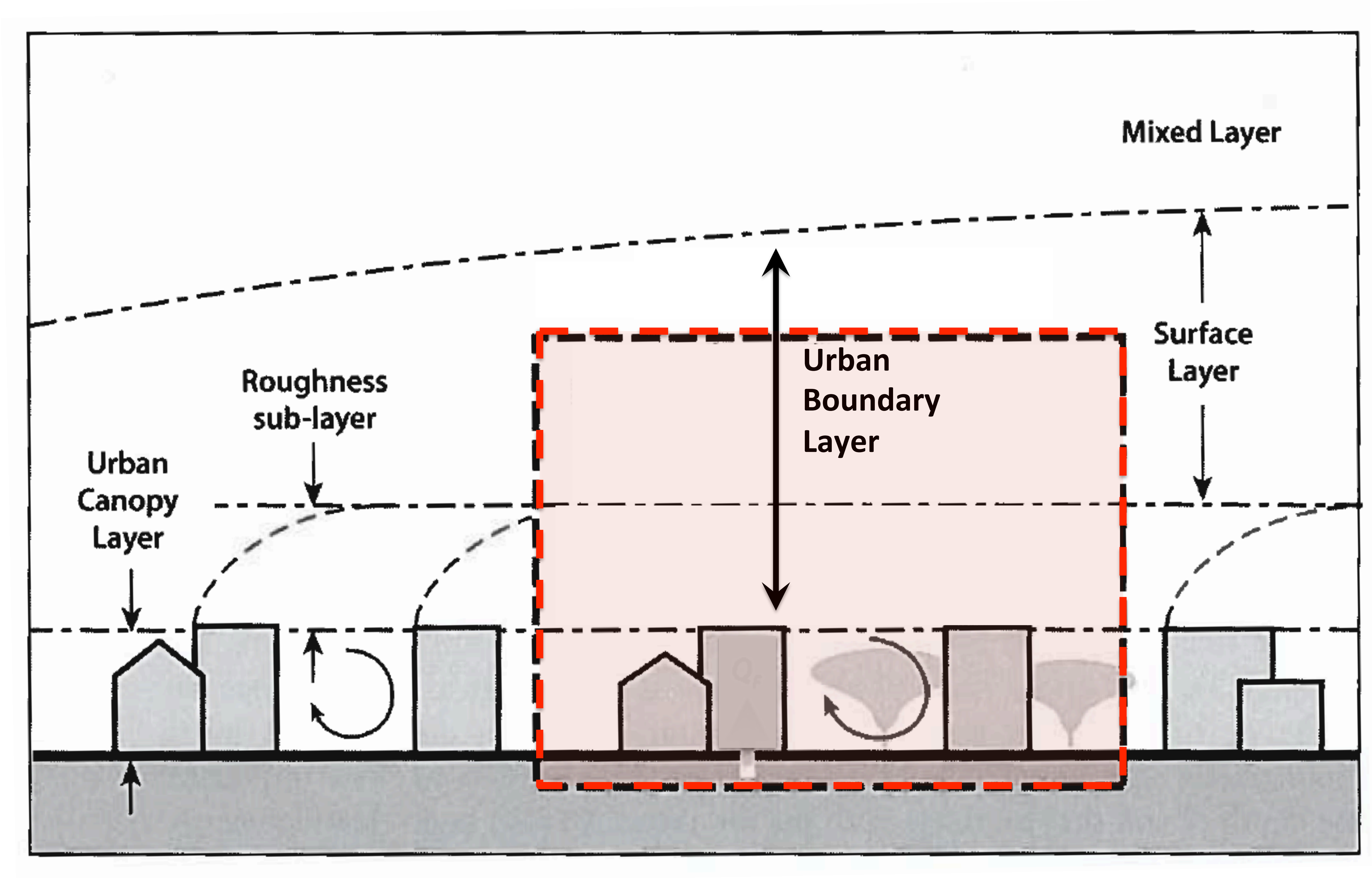
The Urban Energy Balance

Components of urban surface energy balance



Boundary of the urban surface energy balance (SEB)
Modified from (Erell; Pearlmutter; Williamson, 2011)

Surface energy balance:

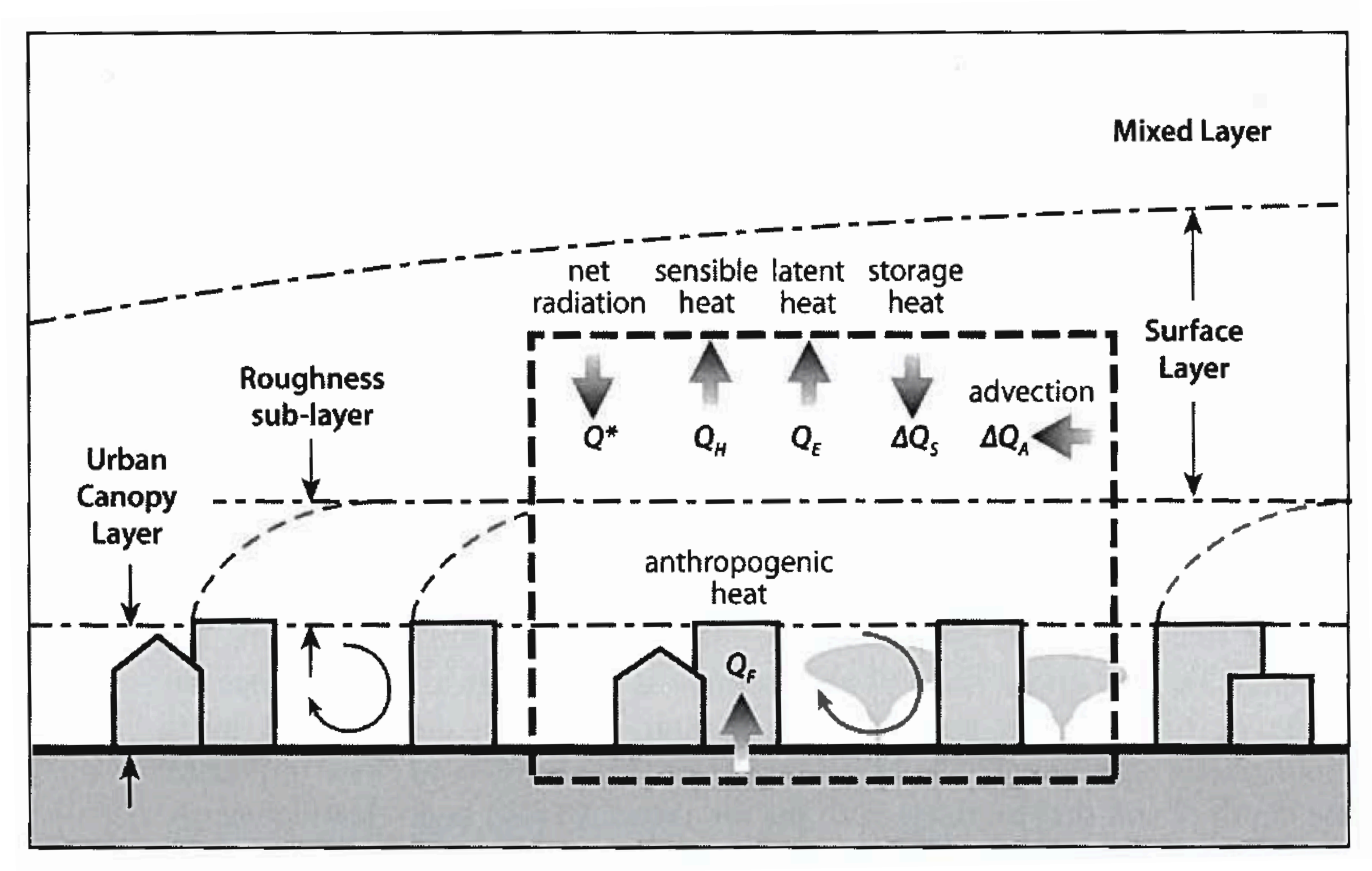
Local or mesoscale phenomenon.

The energy transfer between this surface and the atmosphere is quantified by measuring or modeling fluxes above the urban canopy, at a height which is sufficient to ensure that these fluxes are representative of the overall urban terrain.

(Erell; Pearlmutter; Williamson, 2011)

The Urban Energy Balance

Components of urban surface energy balance



Components of the urban surface energy balance (SEB)
(Erell; Pearlmutter; Williamson, 2011)

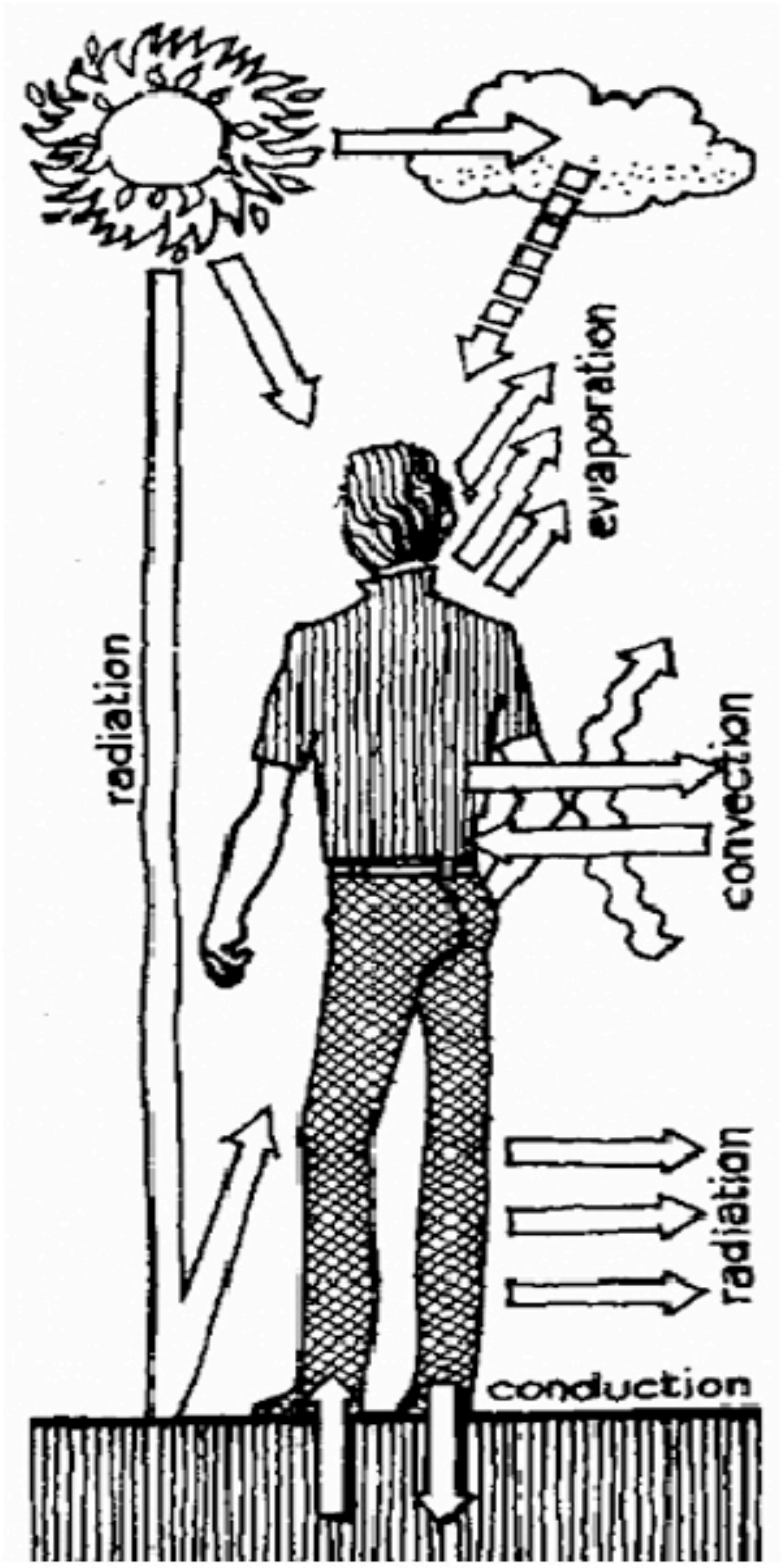
Surface energy balance:

$$Q^{*} + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A$$

(Erell; Pearlmutter; Williamson, 2011)

Outdoor Thermal Comfort

Definition



Thermal exchange between the human body and its environment (http://www.archinology.com/thermal-comfort/)

Outdoor Thermal Comfort

Definition

Parque de los pies descalzos,
Medellin, Colombia

Thermal preferences

Outdoor Thermal Comfort

Definition

Parque de los pies descalzos,
Medellin, Colombia

Comfort:

Universal definable state of affairs

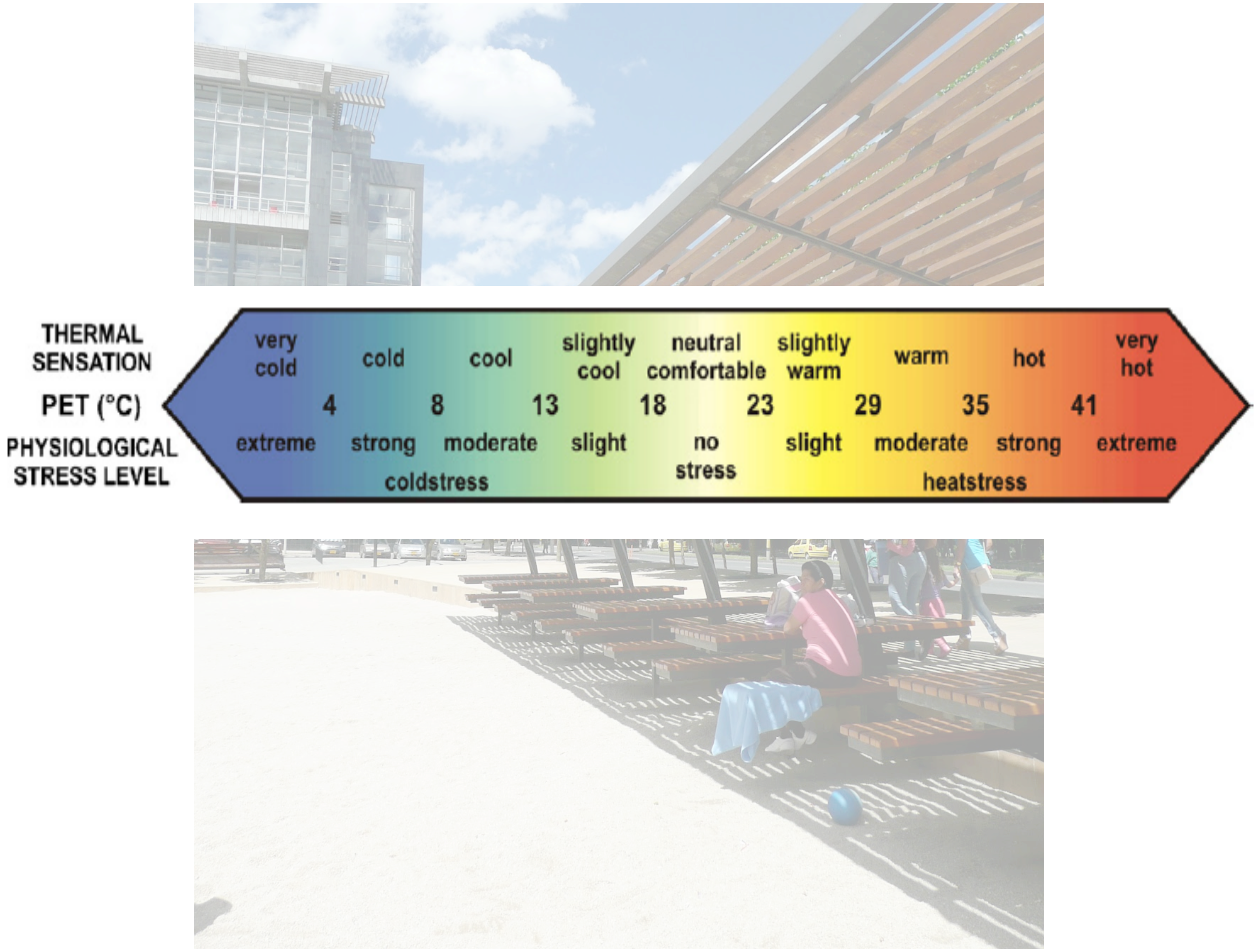
Socio-cultural achievement.

Outdoor spaces are important for cities as these provide daily pedestrian traffic and different outdoor activities contributing to urban livability and vitality *(Chen; Ng, 2011)*.

Promoting the use of streets and outdoor spaces by pedestrians will benefit cities from physical, environmental, economical, and social aspects *(Hakim et al., 1998)*.

Outdoor Thermal Comfort

Environmental comfort indices



PET ranges for various thermal sensation and stress levels (Matzarakis et al., 1999).

The degree of impact of outdoor thermal environment on thermal comfort varies with the thermal requirements of people in different climatic regions.

A number of bio-meteorological indices have been developed to describe human thermal comfort level by linking local microclimatic condition and human thermal sensation *(Chen & Ng, 2011)*.

Thermal indices: such as PMV, ITS, fuzzy-PMV, OUT-SET,COMFA, PET

PET is particularly suitable for outdoor thermal comfort analysis *(Chen; Ng, 2011; Lin et al., 2009)*

Outdoor Thermal Comfort

Thermal preference

Parque de los pies descalzos,
Medellin, Colombia

Requirements

Composite description of a desired outcome.

Design means

The way by which the design requirements are realized in the material world.

Outdoor Thermal Comfort

Thermal preference

Parque de los pies descalzos,
Medellin, Colombia

Requirements

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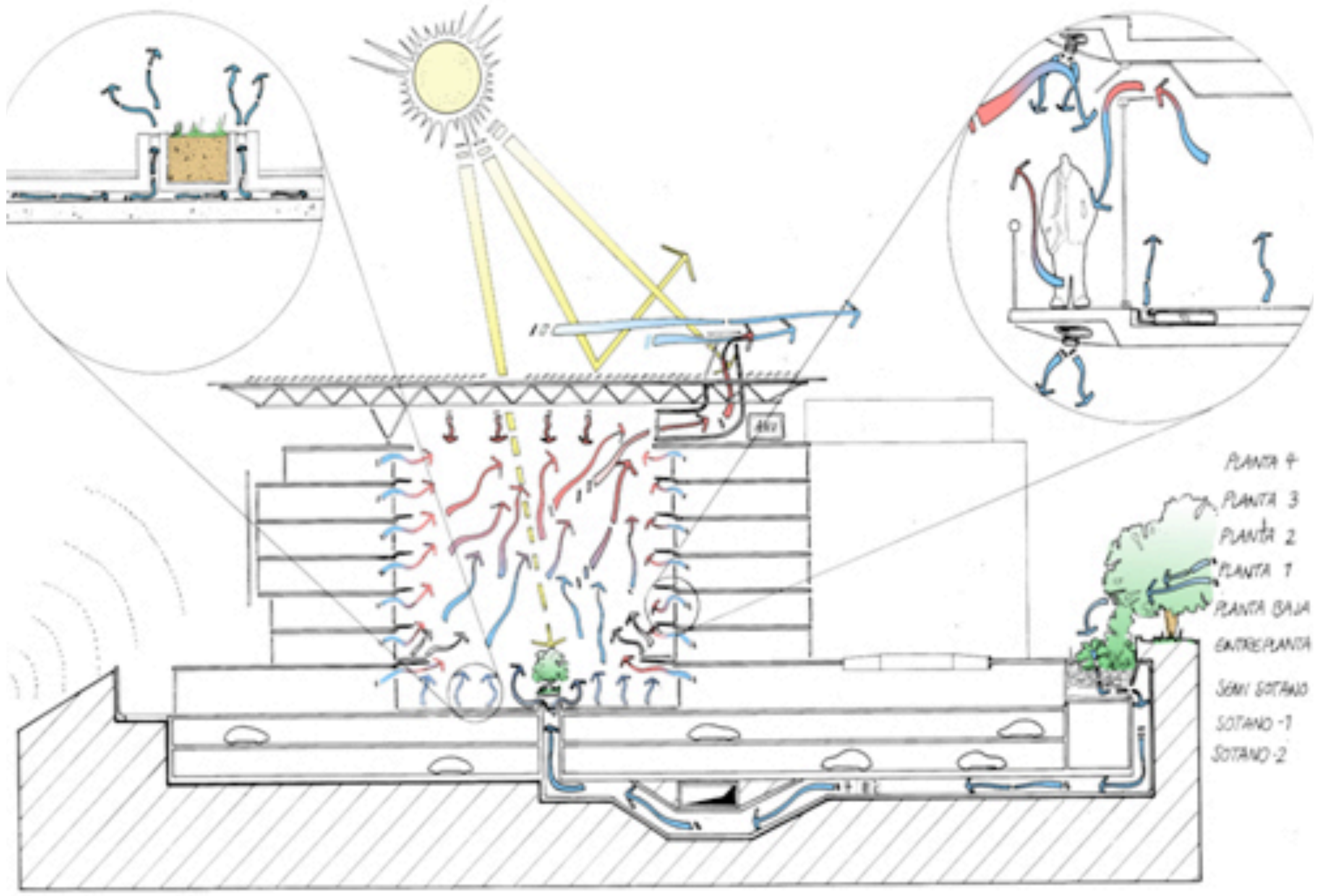
Thermal preference

Combination of physical factors influencing thermal sensation, which a person in a particular environment would choose when constrain by climate and other influences regarding urban context.

Preference of climatic attributes: air temperature, air movement, radiation and humidity.

Bioclimatic Design

Definition



A building designed to save energy (Sede Endesa, Rafael de la Hoz)

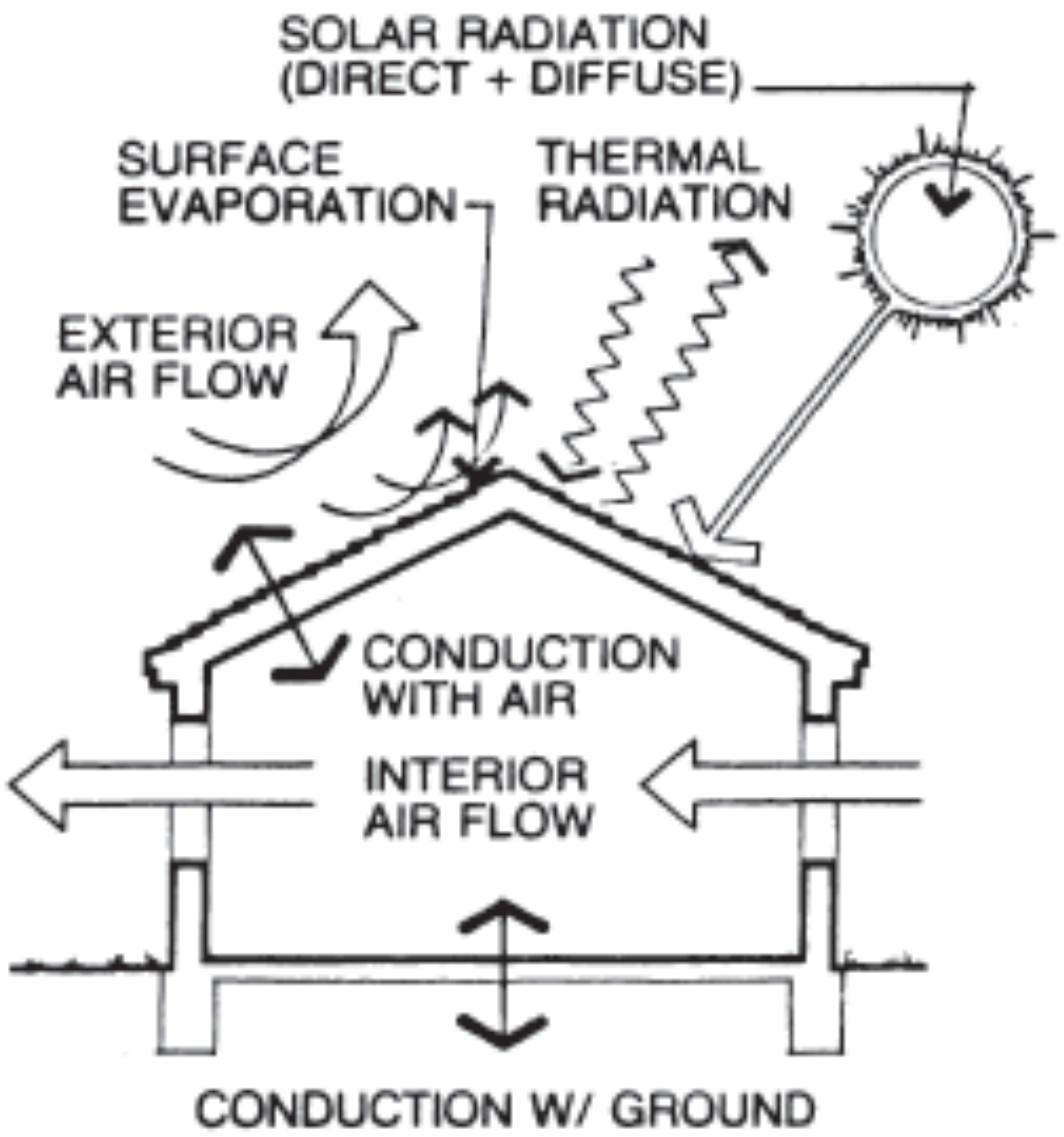
- Boclimatic design: create urban areas and buildings that are designed according to the microclimate conditions aiming to ensure internal thermal comfort, minimize energy consumption by using renewable energy sources, “passive heating and cooling”.

- Design based upon climate (environmental architecture/ climate design)

Approach from Architecture

Bioclimatic Design

Definition



Paths of Heating Energy Exchange at the Building Scale (Watson, 1989)

- Bioclimatic design addresses:
  - Site and climatic analysis.
  - Heat energy exchange. Internal versus external building loads.
  - Design strategies to reduce energy consumption in buildings and enhance thermal comfort according climate conditions.

(www.aiafla.org/upload_documents/COTEQuickReference081204.doc)

Bioclimatic Design

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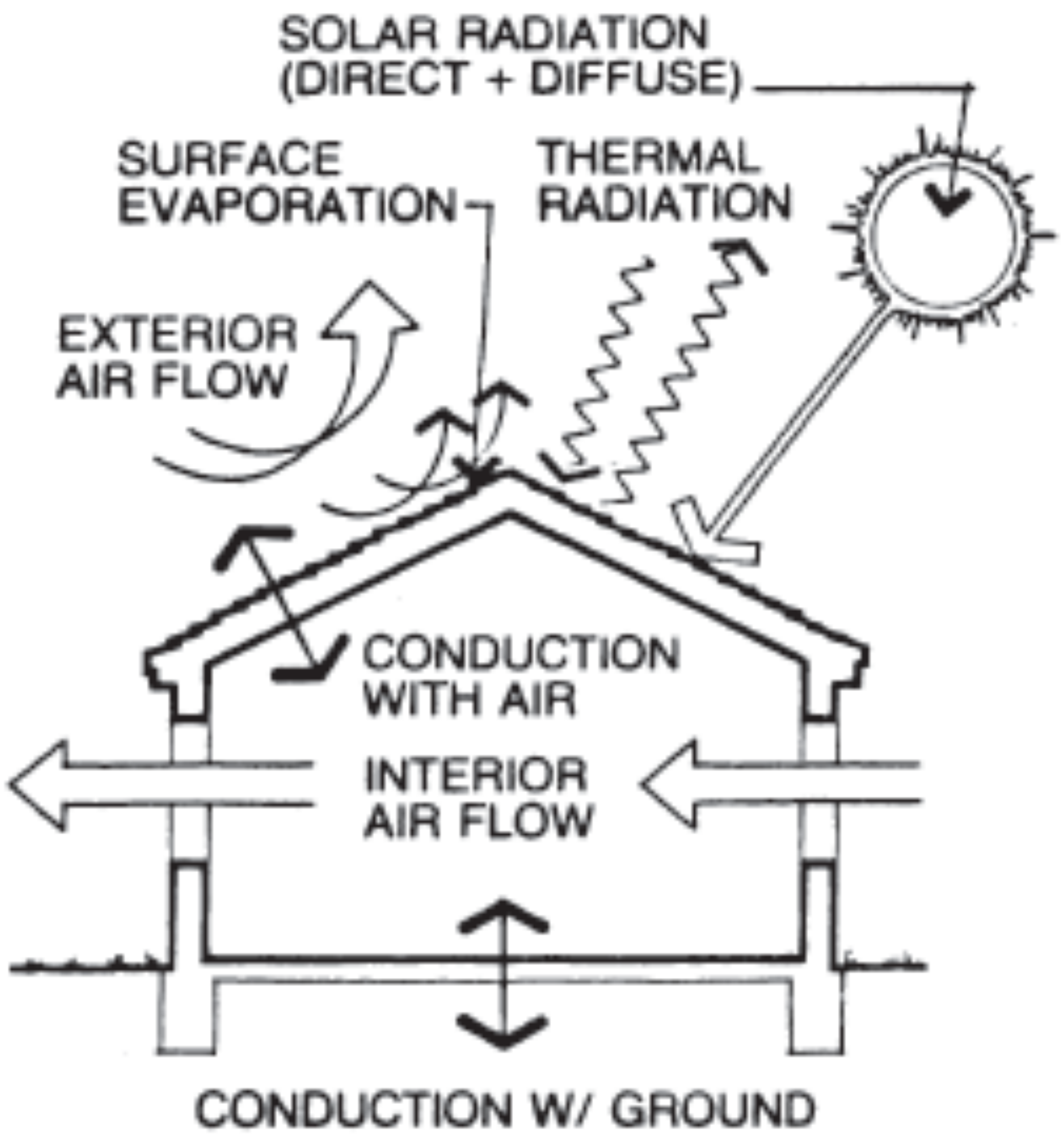

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- Principle Criteria:
  - Sunlight (Isolation, shading, orientation)
  - Wind (Air flow)

  Thermal conditions / Temperature

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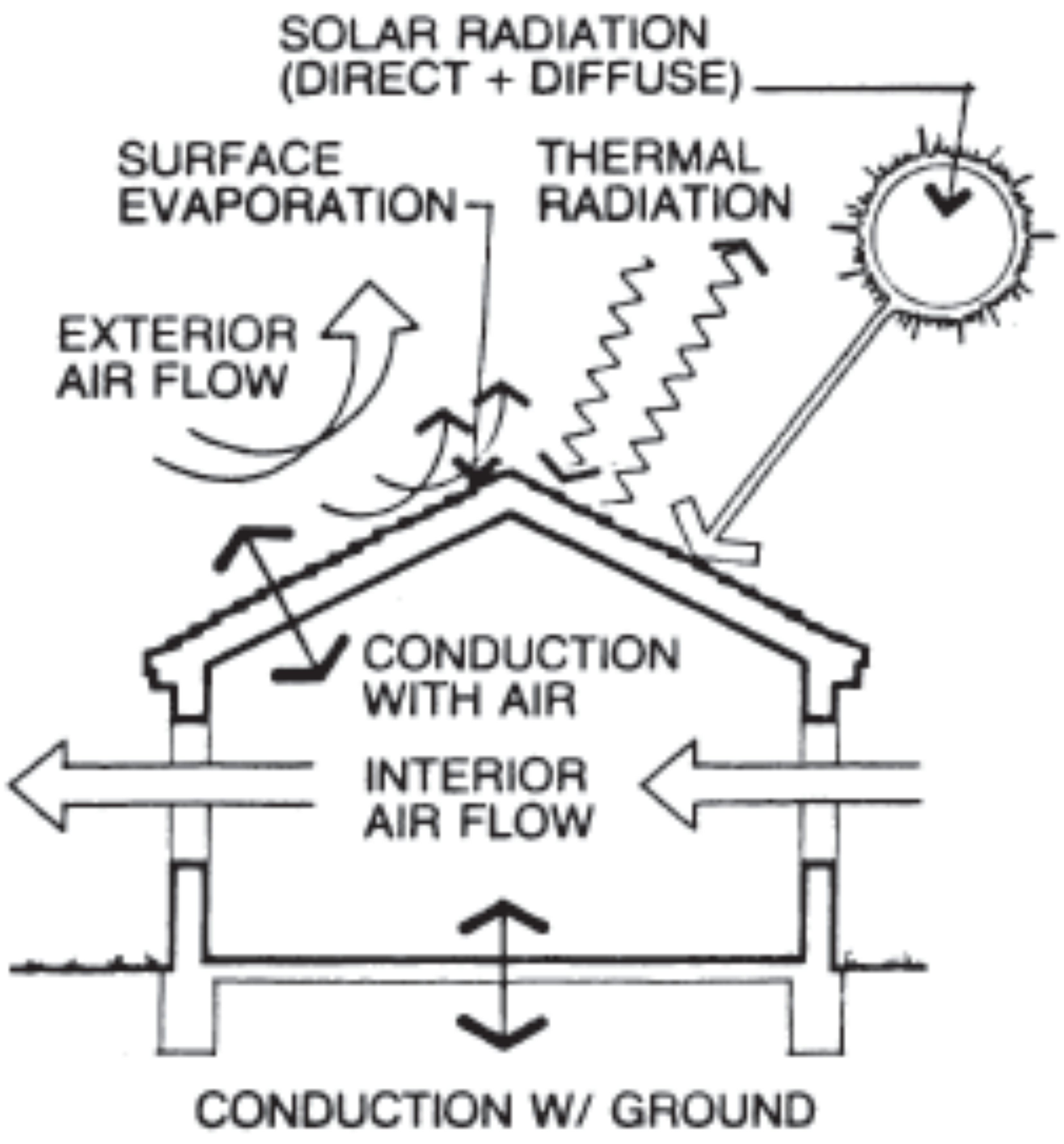
Bioclimatic Design

Definition



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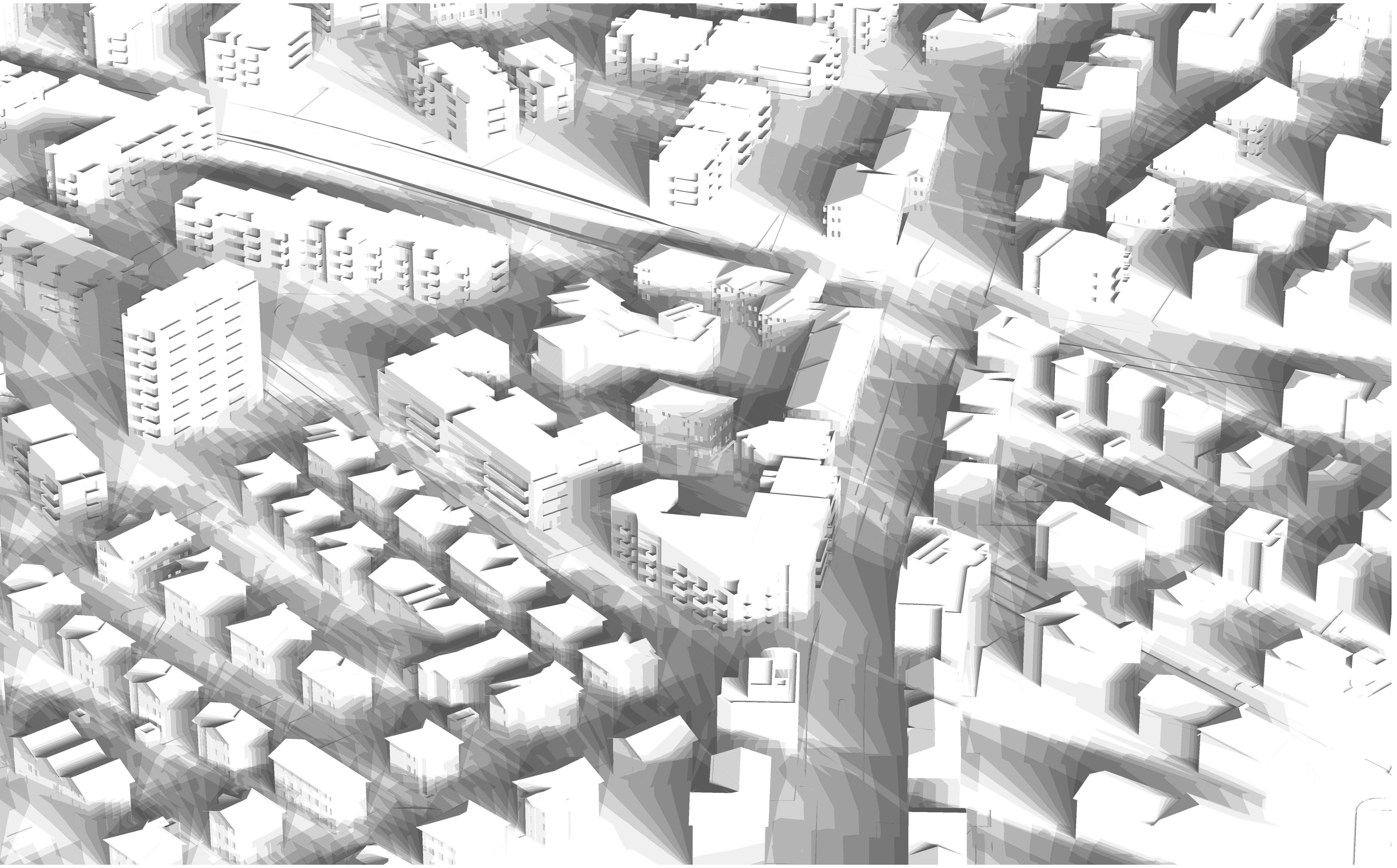
Heat Energy exchange

Approach from Urban Design

Bioclimatic Design

Urban planning



- Urban designers can create favorable microclimatic conditions in and around buildings and outdoor spaces to dramatically increase comfort and reduce building energy requirements.

- Examples:
  - Wind breaks (winter): Use neighboring land forms, structures, or vegetation for winter wind protection.
  - Sun shading (summer): Because sun angles are different in summer than in winter, it is possible to shade spaces and building openings from the sun during the overheated summer period while allowing the sun s heat to reach.

Urban Design Approach

Goals

Ralph L. Knowles, 1999

1. Configuration of buildings for reducing energy consumption.

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Urban Design Approach

Goals

Masdar city

1. Configuration of buildings for reducing energy consumption.

2. Configuration of urban spaces to enhance outdoor thermal comfort.

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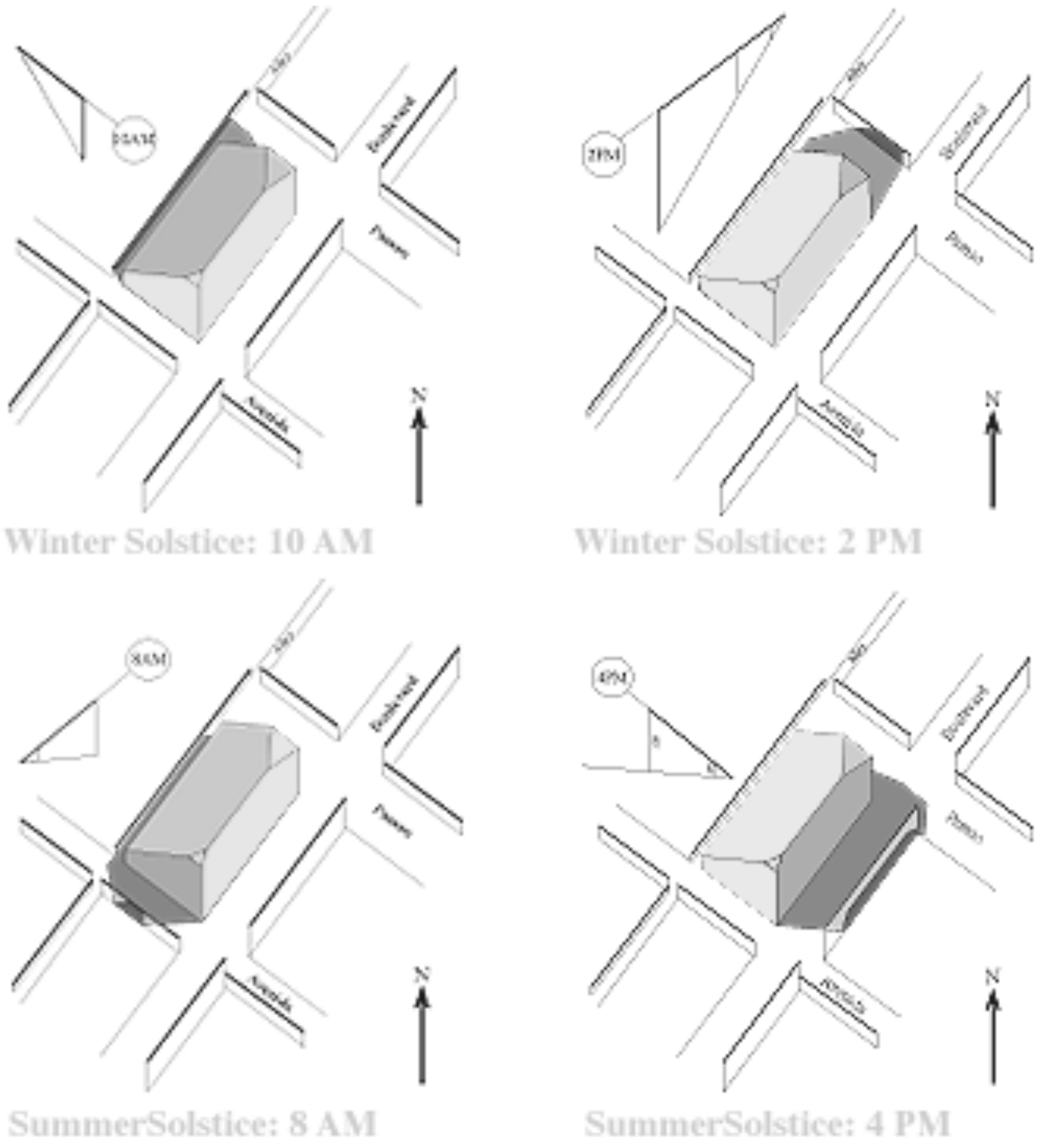
Bioclimatic Design

Urban planning strategies – Sun



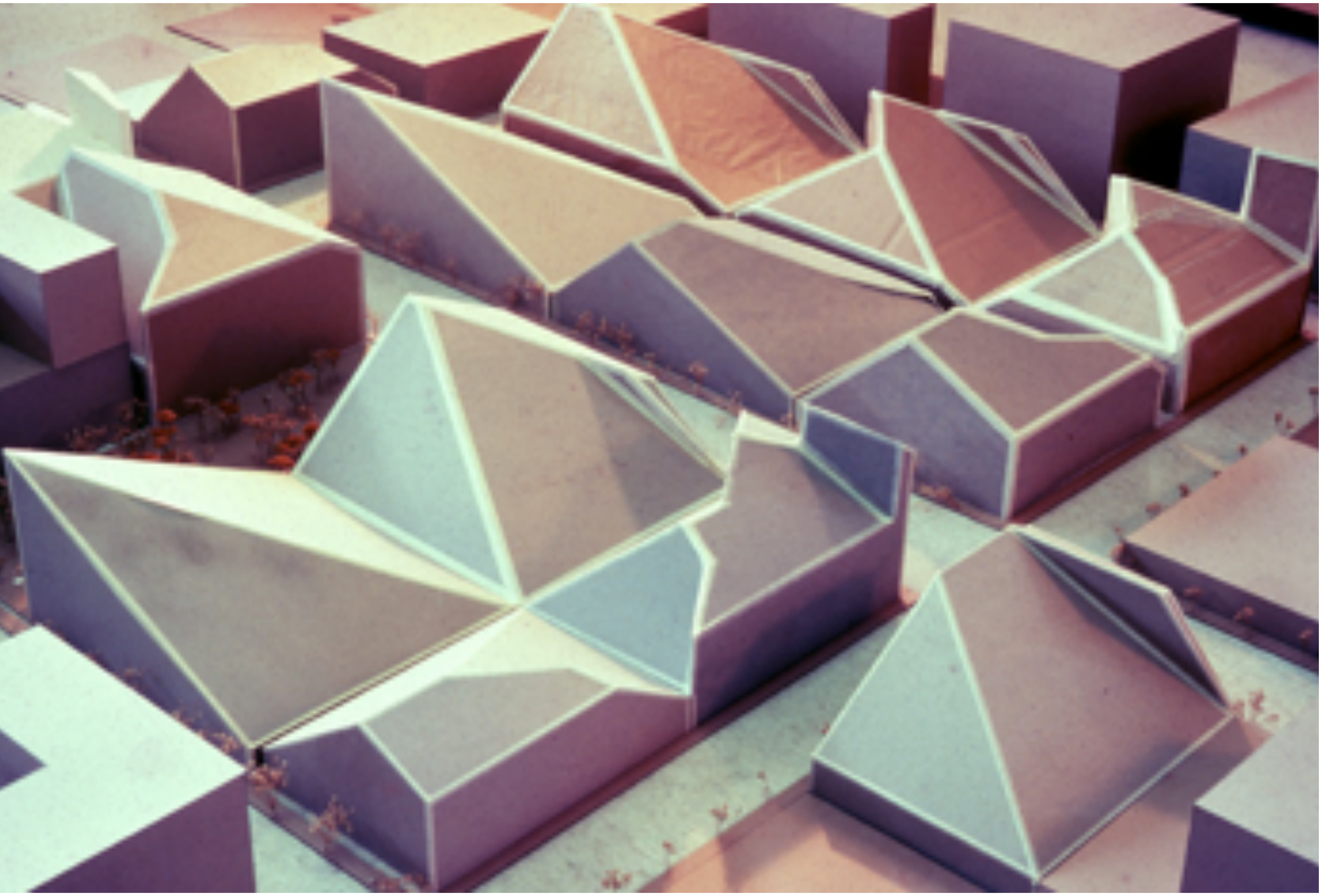
Ralph L. Knowles, 1999

- The **Solar Envelope Concept** was introduced by Ralph L. Knowles (1974) as a framework for architecture and urban design to:
  - provide solar access needs according to building geometry,
  - and support solar energy for future developments.

- Solar zoning envelope: largest possible building area on a land parcel preventing shadowing neighboring properties during specific times.

Bioclimatic Design

Urban planning – Sun



Ralph L. Knowles, 1999

Bioclimatic Design

Urban planning – Sun

Ralph L. Knowles, 1999

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Bioclimatic Design

Urban planning strategies – Wind

- Patterns of airflow in build-up areas.
- At each level of scale, physical man-made and natural features have distinct modifying effects on wind speed, direction and intensity of turbulence.
  - Wind near the ground
  - Wind in the urban canopy-layer
  - Wind in the urban boundary-layer

Bioclimatic Design

Urban planning strategies – Wind

- At each level of scale, physical man-made and natural features have distinct modifying effects on wind speed, direction and intensity of turbulence.
  - Wind near the ground
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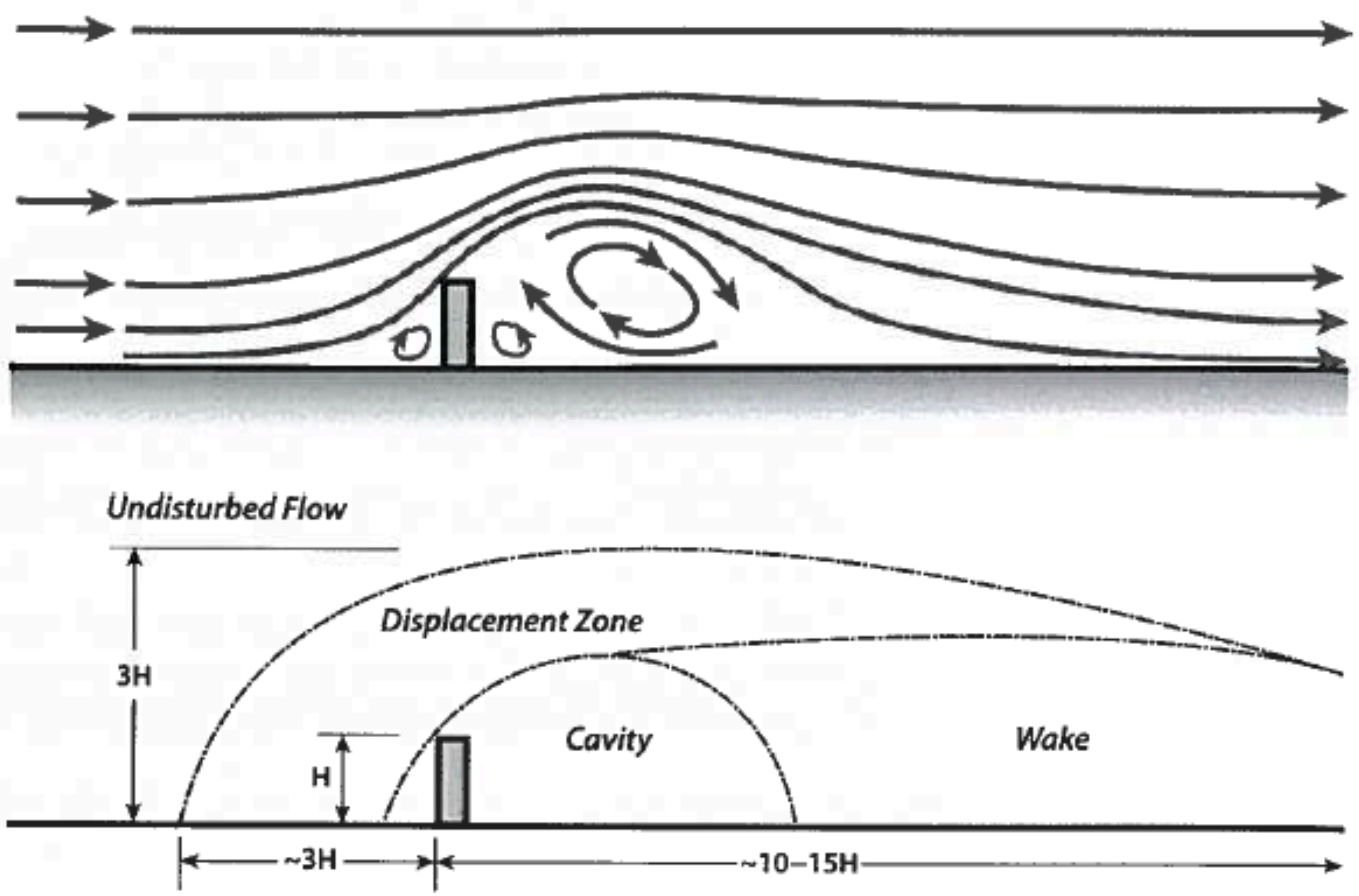

Figure 4.1 Schematic section showing typical pattern of air-flow over an isolated building, depicted as streamlines (top) and general flow zones (bottom)

(Erell; Pearlmutter; Williamson, 2011)

- At each level of scale, physical man-made and natural features have distinct modifying effects on wind speed, direction and intensity of turbulence.
  - **Wind near the ground**
    - On average, wind flows horizontal, which maybe mainly regional wind. Any changes from level ground (urban elements) will obstruct the flow and modify the pattern.
    - Obstruction by an isolated obstacle (Bluff-body).
  - Wind in the urban canopy-layer

Bioclimatic Design

Urban planning strategies – Wind

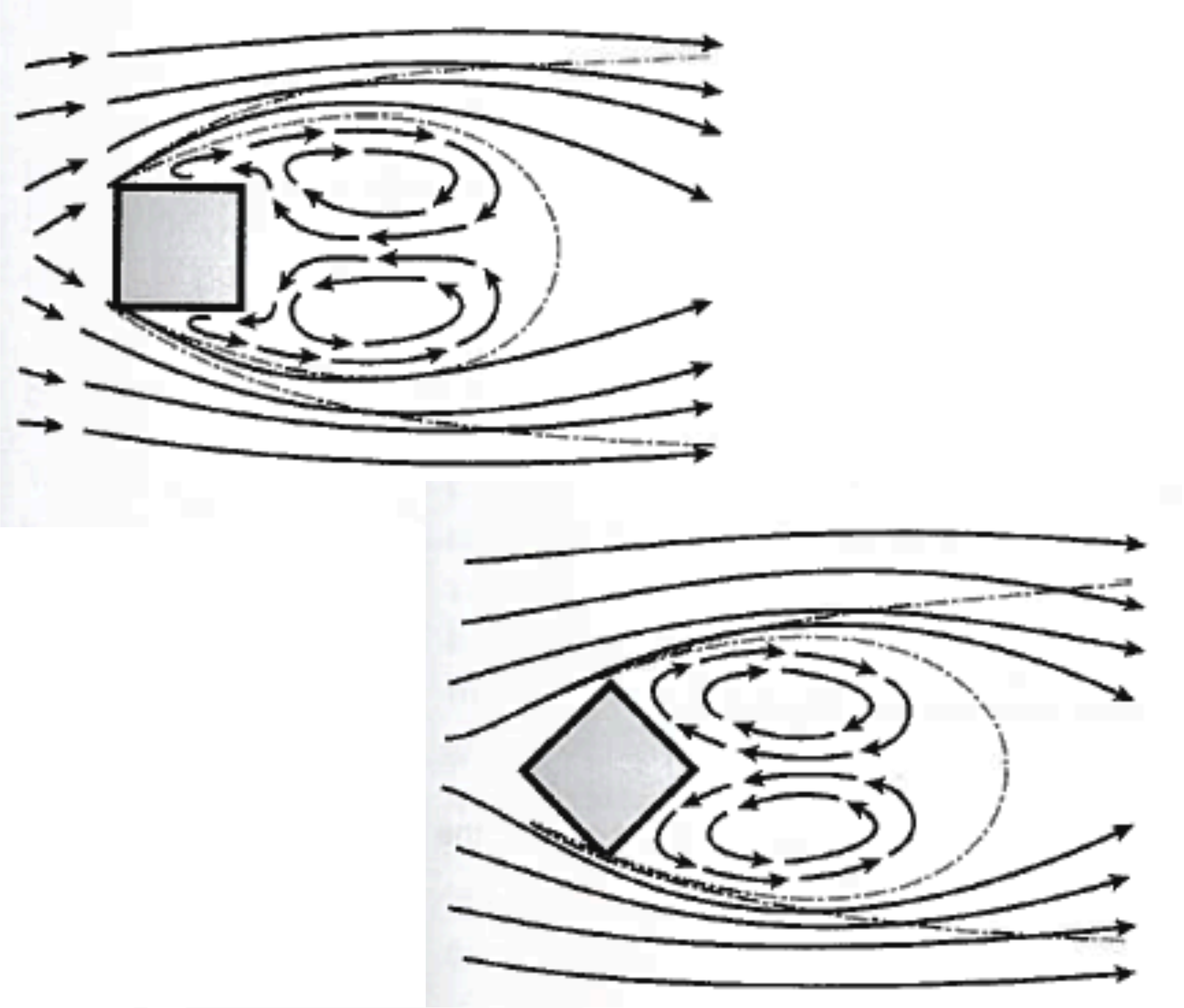

Figure 4.3 Flow pattern around a sharp-edged building

Source: Based on Oke (1987).

(Erell; Pearlmutter; Williamson, 2011)

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  - **Wind near the ground**
    - On average, wind flows horizontal, which maybe mainly regional wind. Any changes from level ground (urban elements) will obstruct the flow and modify the pattern.
    - Obstruction by an isolated obstacle (Bluff-body).
    - Other types of flow correspond to those affected by building geometries (the windward face of a building or the pressure difference of the face regions of a building- windward and leeward).
  - Wind in the urban canopy-layer

Bioclimatic Design

Urban planning strategies – Wind

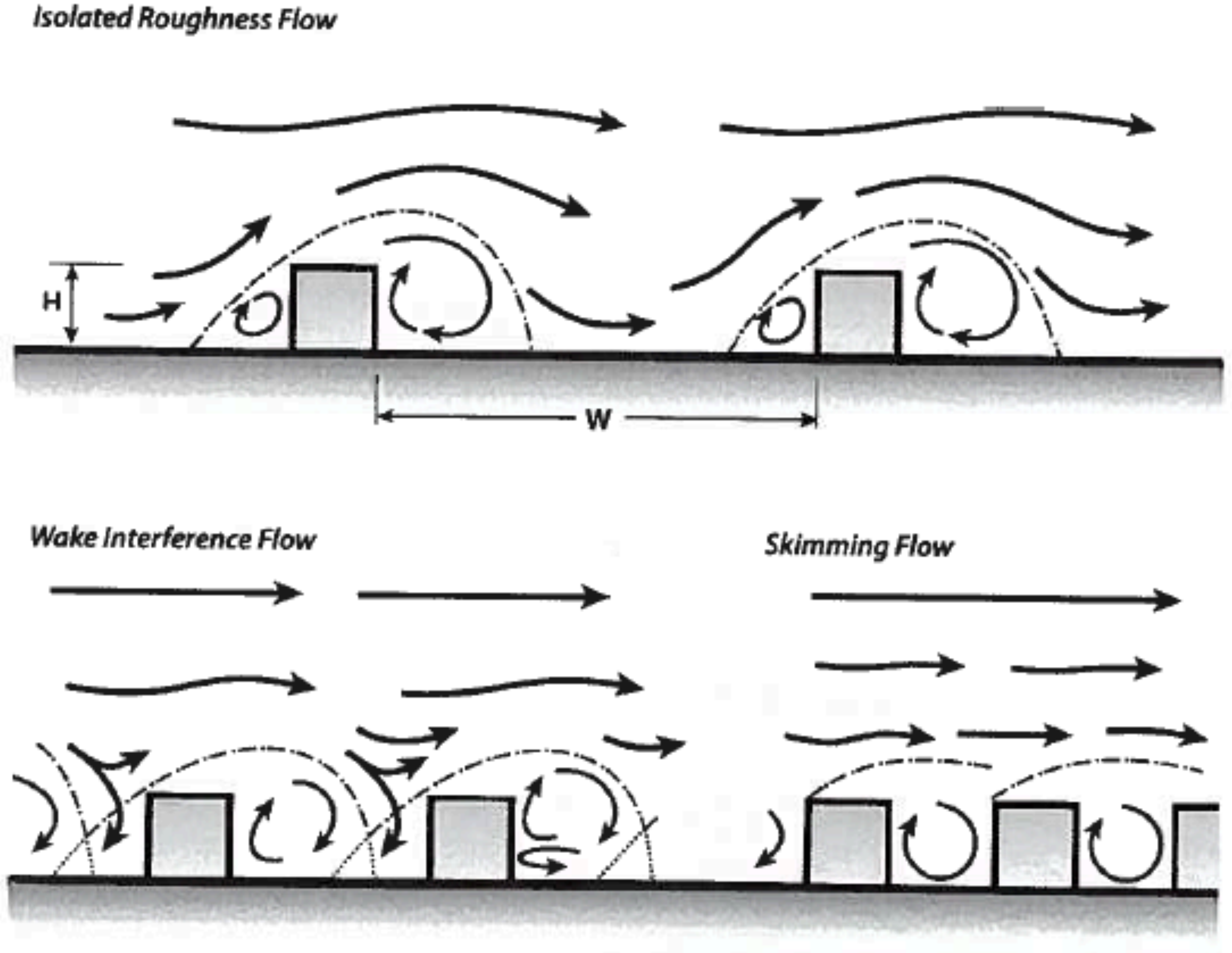


Figure 4.4 Flow regimes associated with different urban geometries, drawn by Oke (1987) on the basis of wind tunnel experiments carried out by Hussain and Lee, 1980.

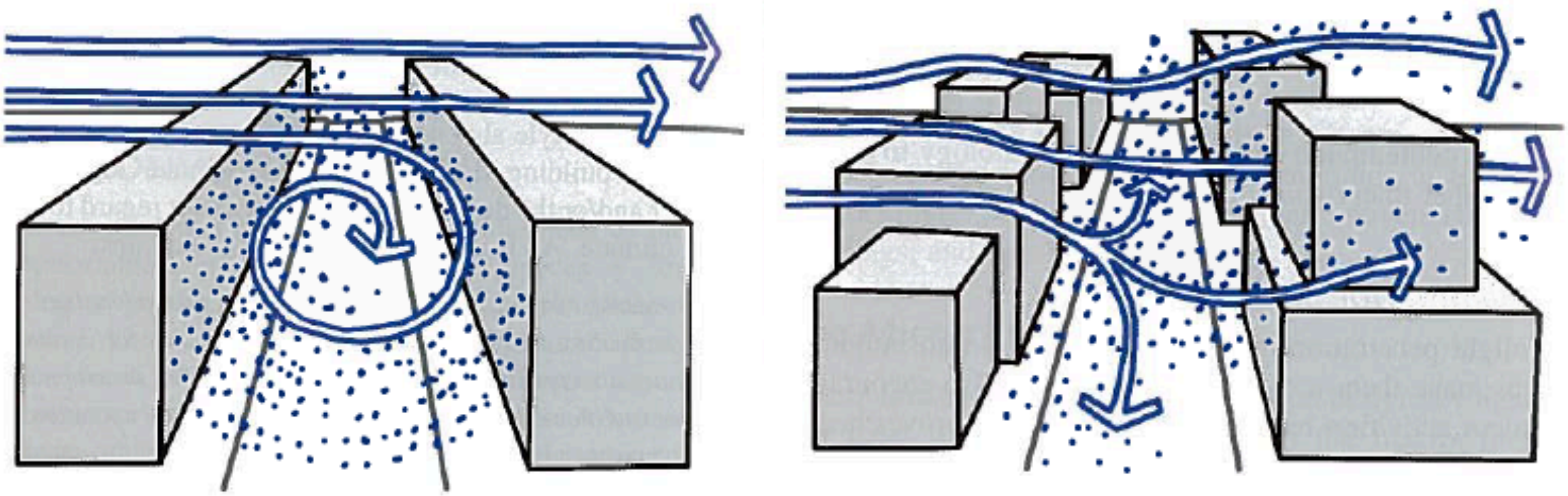
Source: Based on Oke (1987).

(Erell; Pearlmutter; Williamson, 2011)

- At each level of scale, physical man-made and natural features have distinct modifying effects on wind speed, direction and intensity of turbulence.
  - Wind near the ground
  - **Wind in the urban canopy-layer**
    - Wind speed and directions are extremely variable.
    - Observations show a sharp drop on the average wind speed below roof level, but microscale changes in geometry may result in localized areas with high wind speed.
    - In canyon wind flow, we find three distinct wind regimes according to the spaces between buildings.

Bioclimatic Design

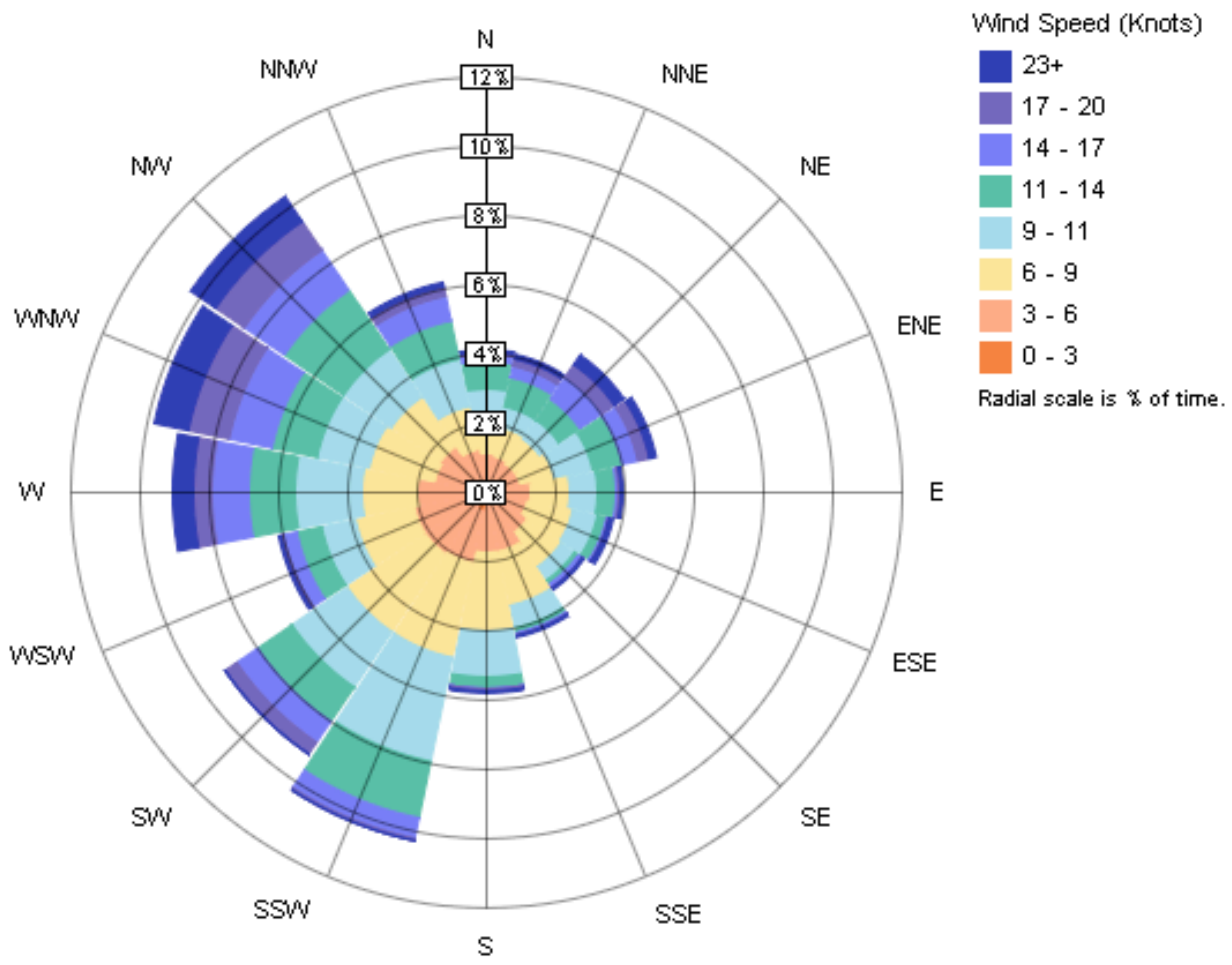
Urban planning strategies – Wind



(Carmona; Tiesdell; Heath; Oc, 2010)

Measuring Urban Microclimate

Wind

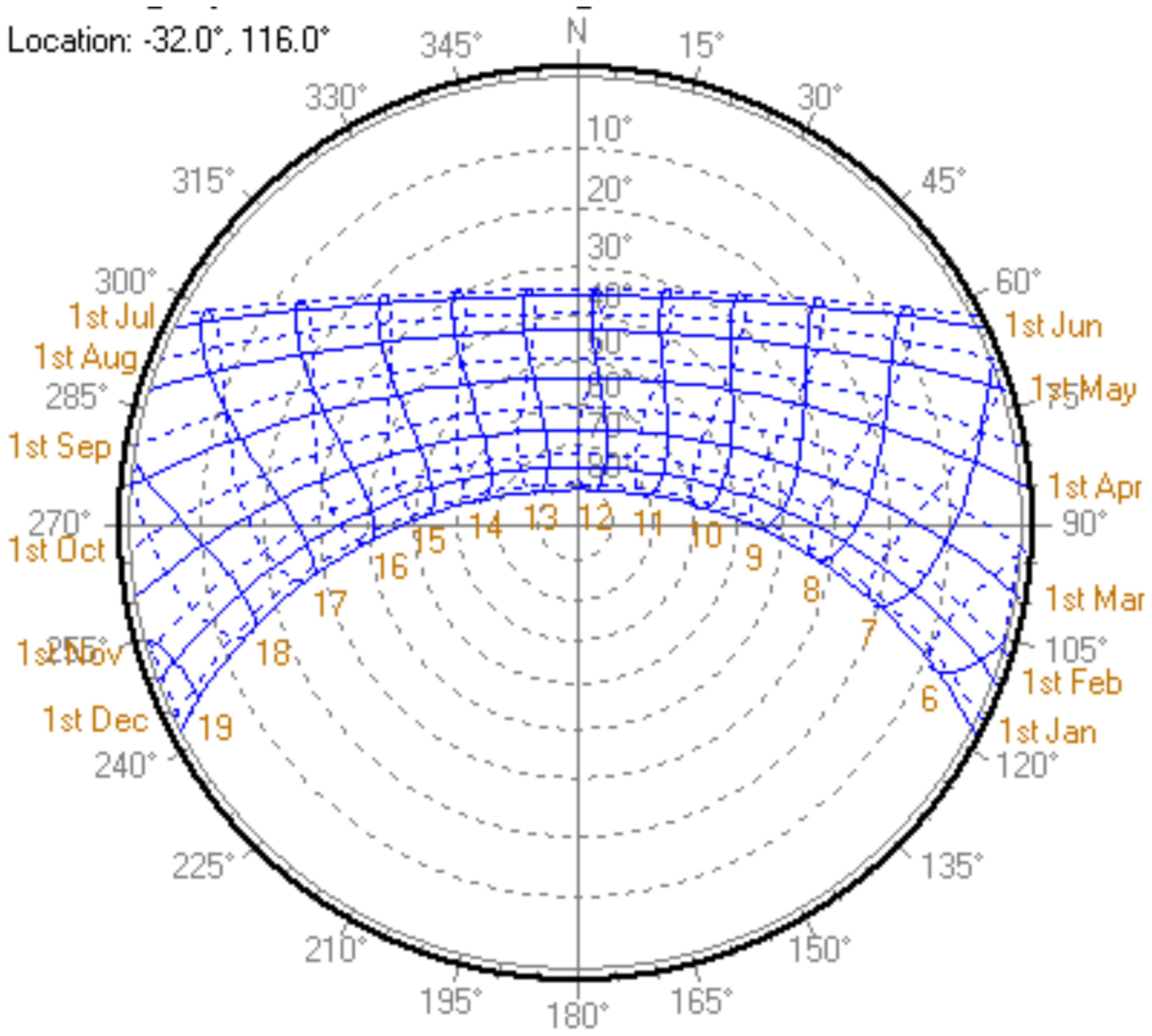


Wind rose

- Graphic tool to give a brief but precise view of **how wind speed and direction** (prevailing wind) are typically distributed at a particular location.

Measuring Urban Microclimate

Sun path

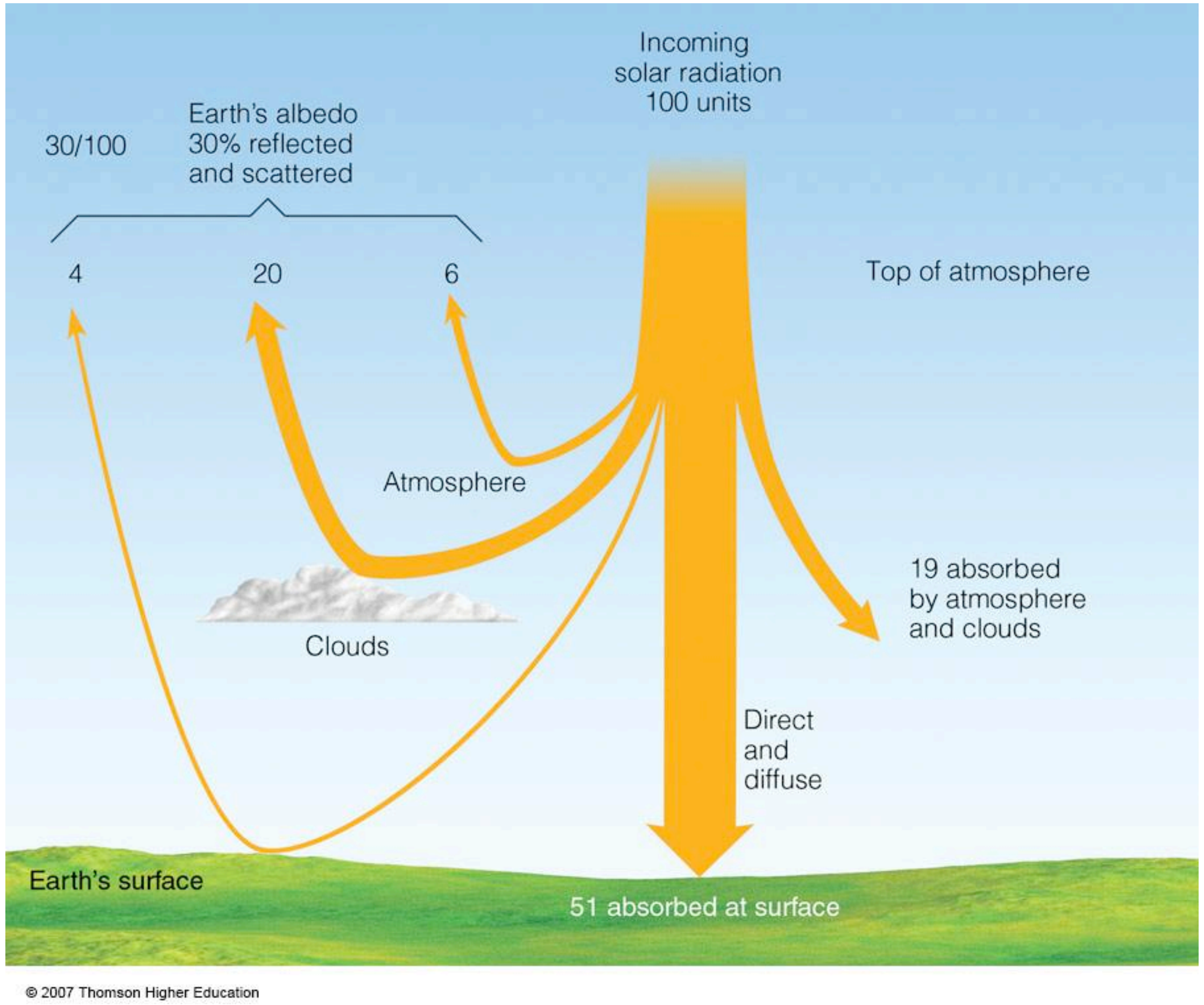


Stereographic sun-path diagram

- Representing annual changes in the path of the Sun through the sky in a single 2D diagram. They provide a summary of solar position that the designer can refer to when considering **shading requirements** and design options.

Measuring Urban Microclimate

Solar insolation



Solar radiation. (http://apollo.lsc.vsc.edu/classes/met130/notes/chapter2/sw_atm.html)

- Insolation: the amount of **solar radiation** reaching/received a surface per unit of time and area.
- Solar exposure

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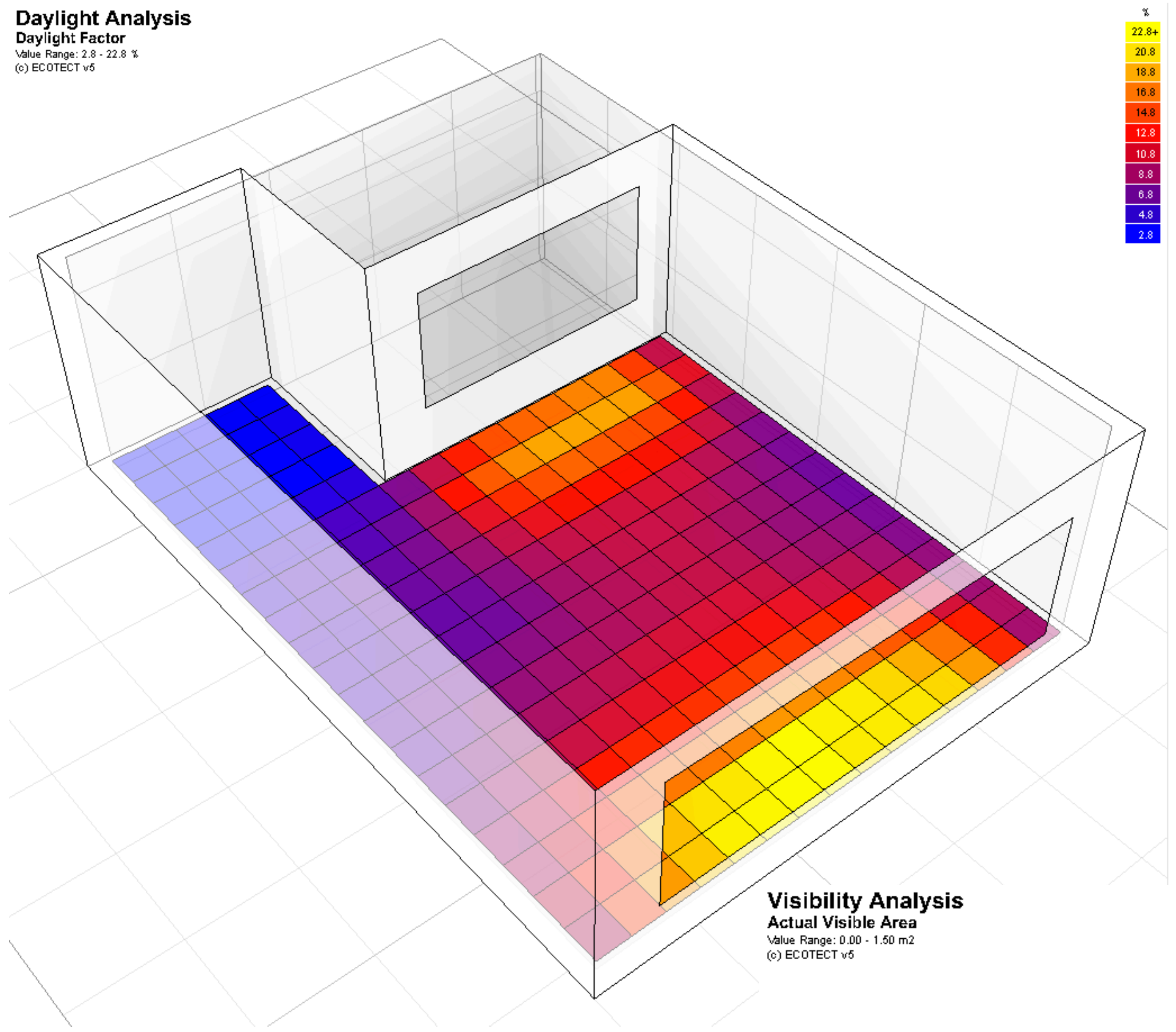
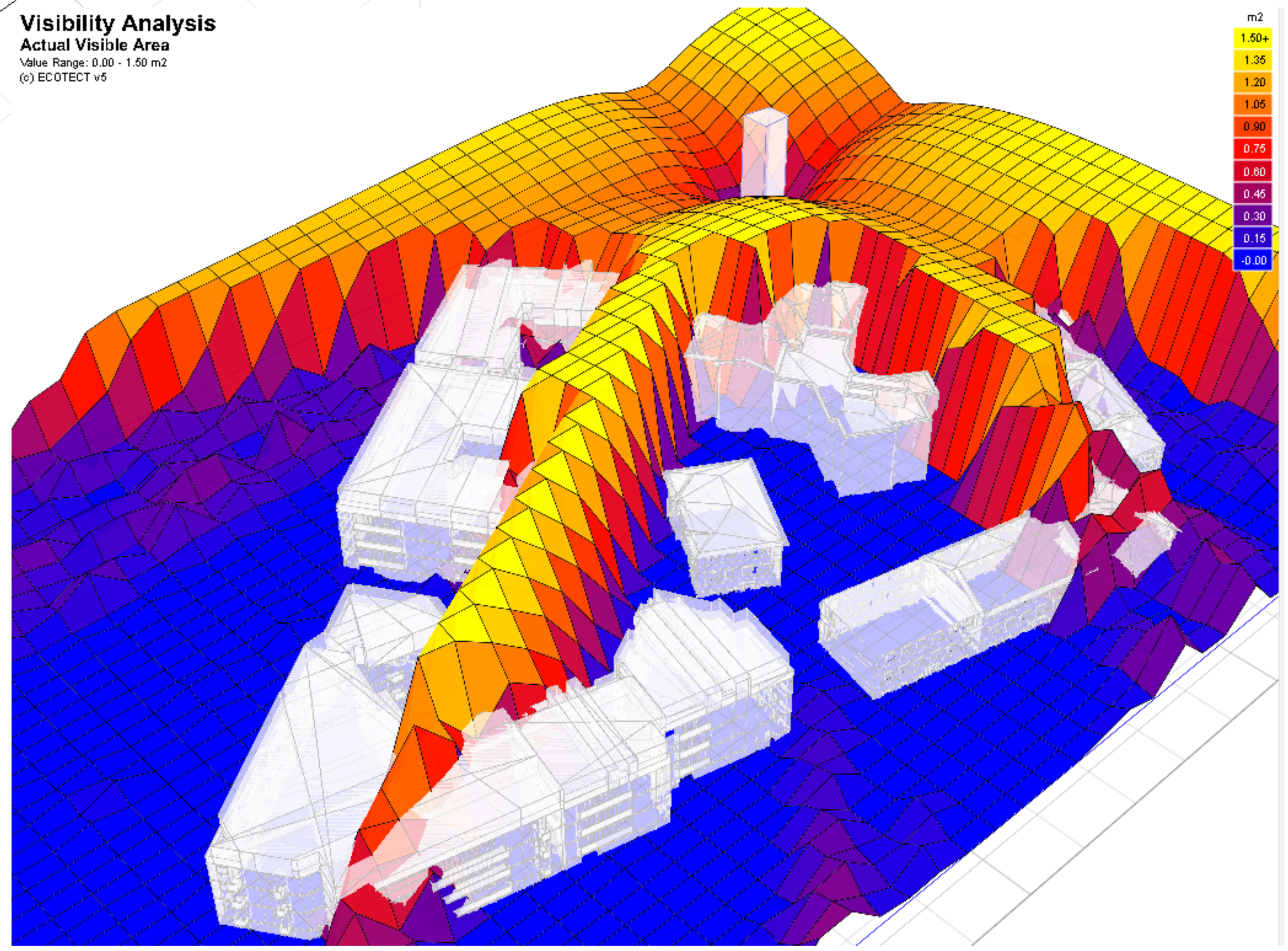
Tools

Tools – Environmental Analysis

General measurements

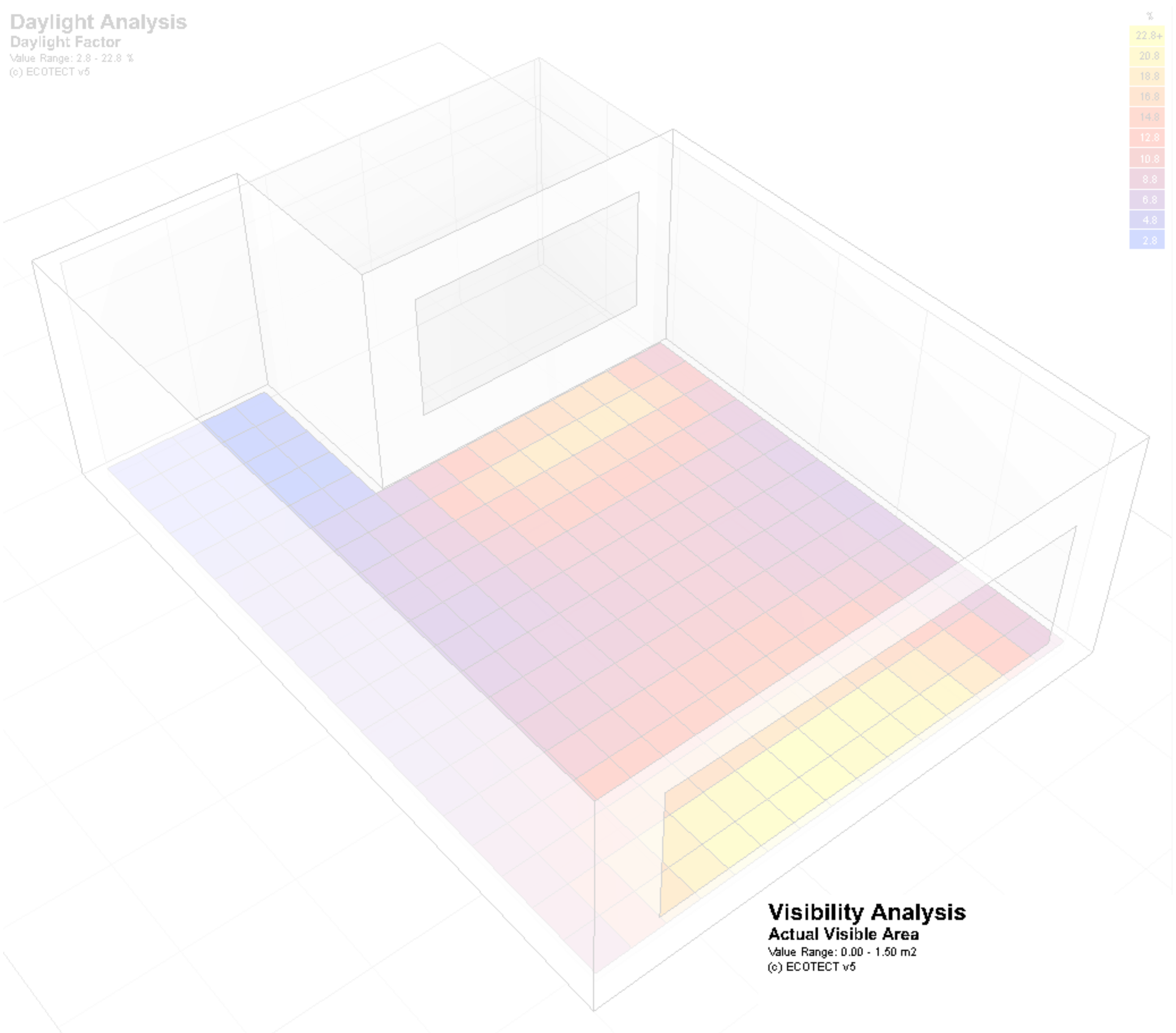


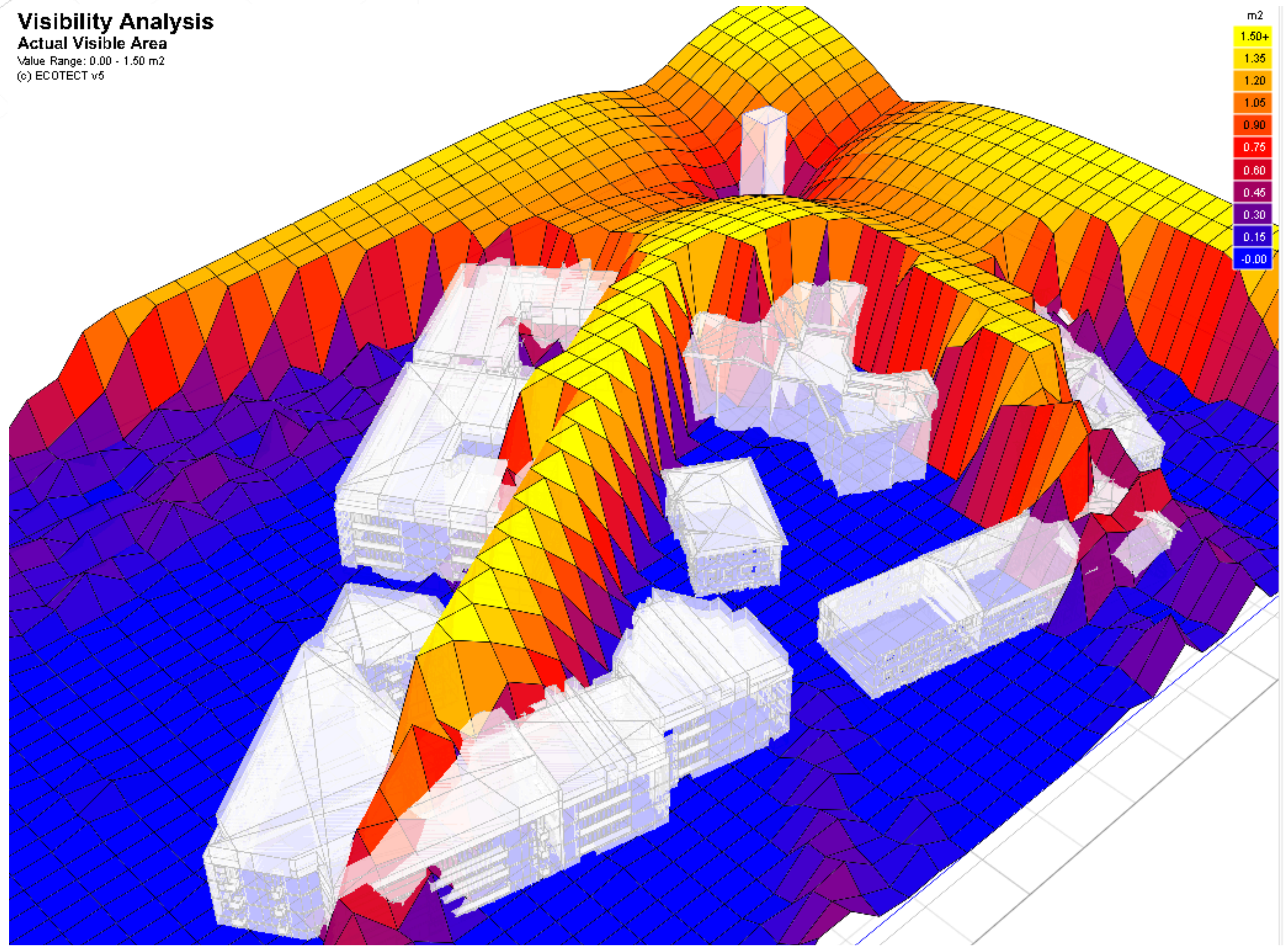


- Whole-building energy analysis
- Thermal performance
- Water usage and cost evaluation
- Daylighting
- Wind analysis
- Solar radiation
- Shadows range

Tools – Environmental Analysis

General measurements





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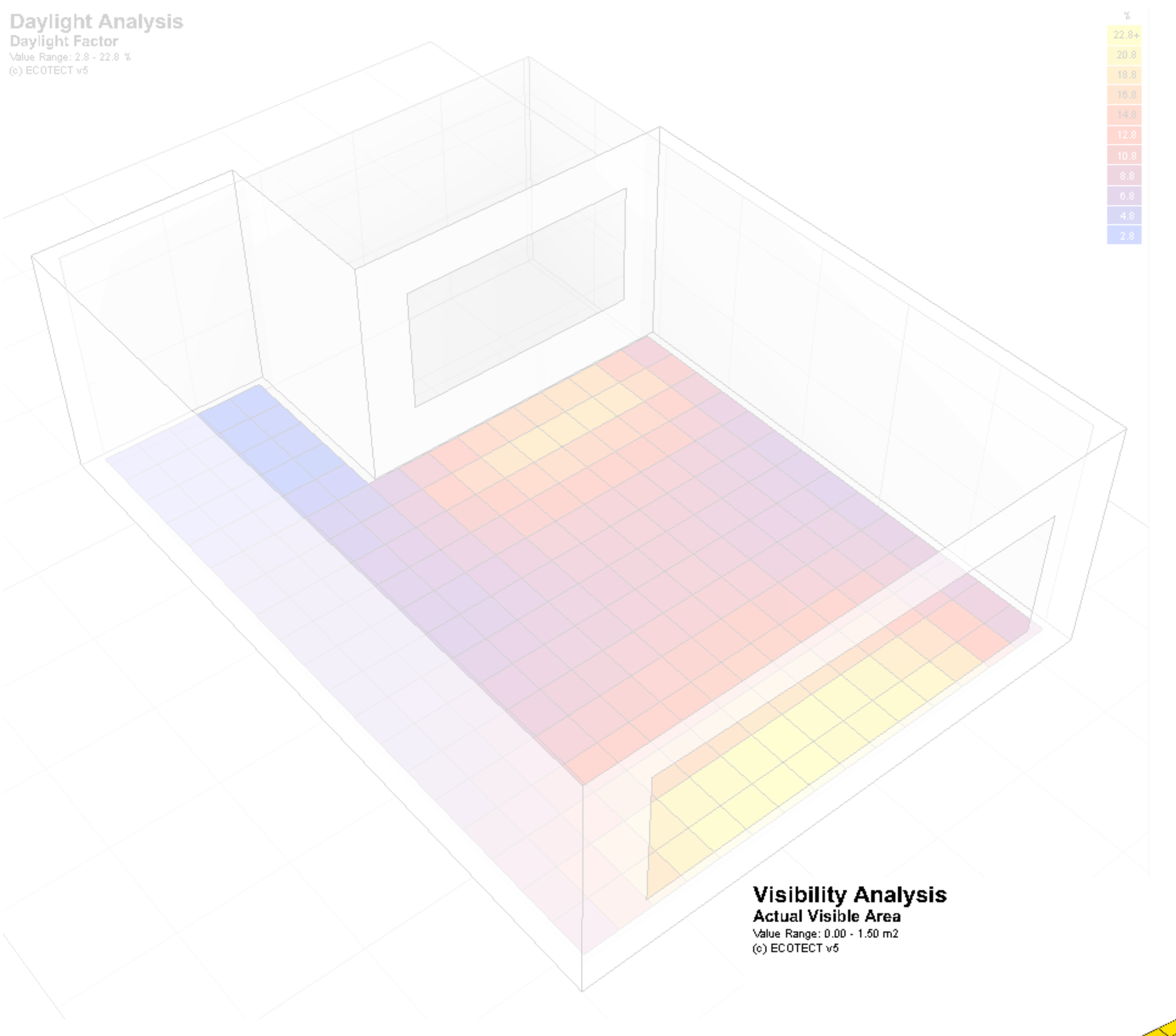
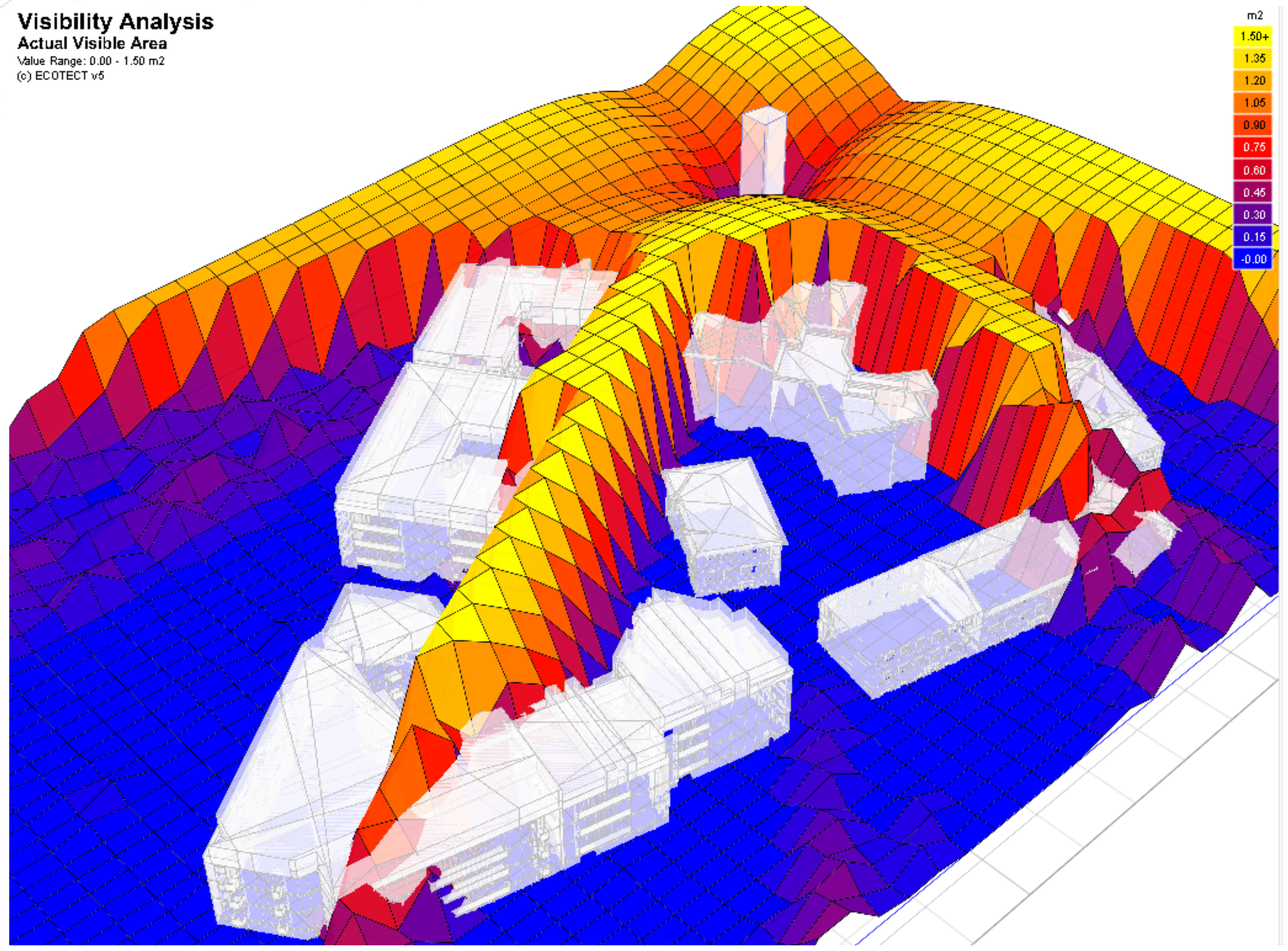
Urban scale

Tools – Environmental Analysis

General measurements





- Whole-building energy analysis
- Thermal performance
- Water usage and cost evaluation
- Daylighting
- Wind analysis
- Solar radiation
- Shadows range
- Visual Impact
- Acoustics

Urban scale

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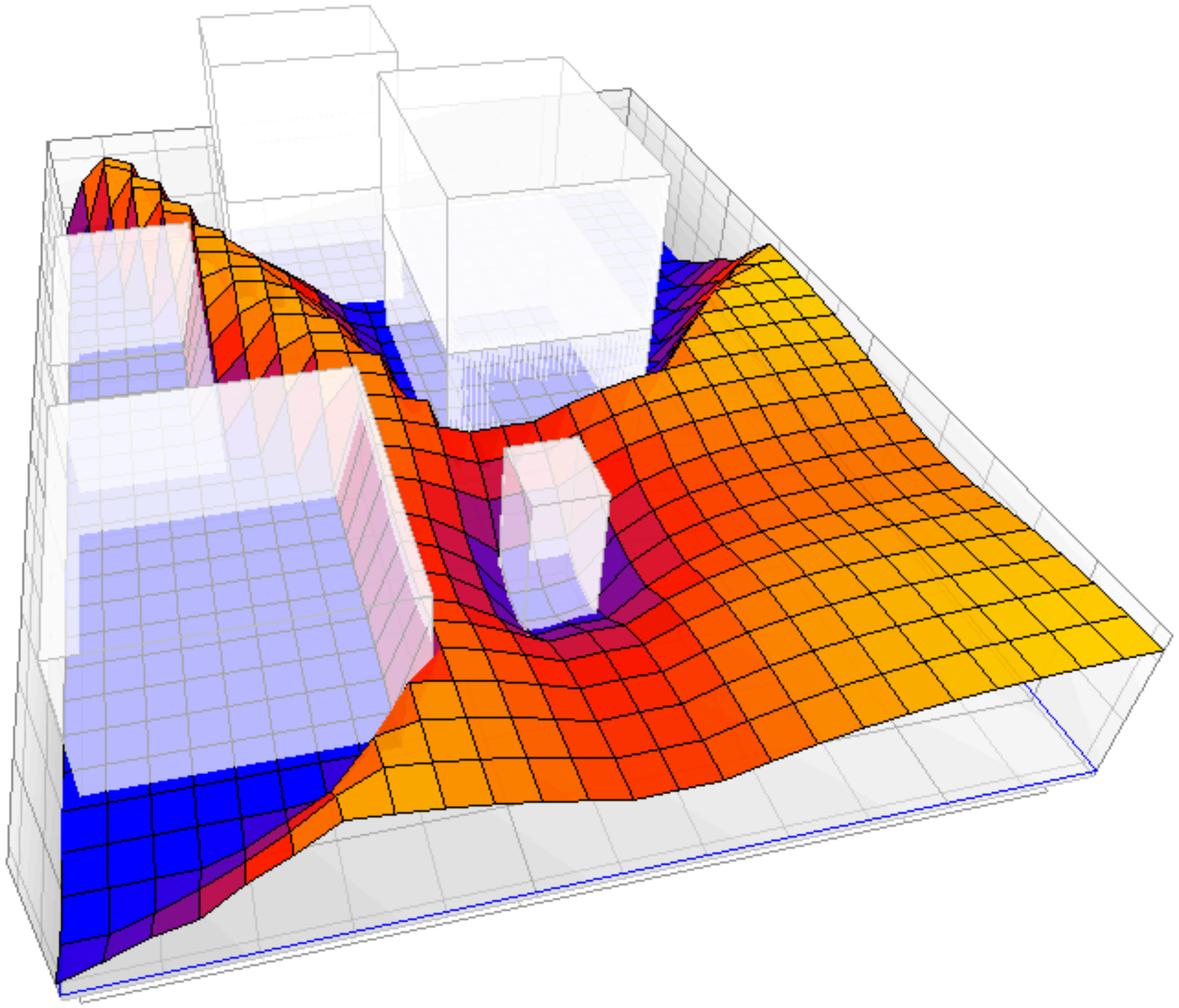
Tools – Environmental Analysis

Autodesk Ecotect



- Highly visual software for the analysis and simulation of environmental performance in buildings and urban areas. It is designed for **early stages of conceptual design** towards the understanding of environmental factors and interactions in order to support the design procedures in architecture.

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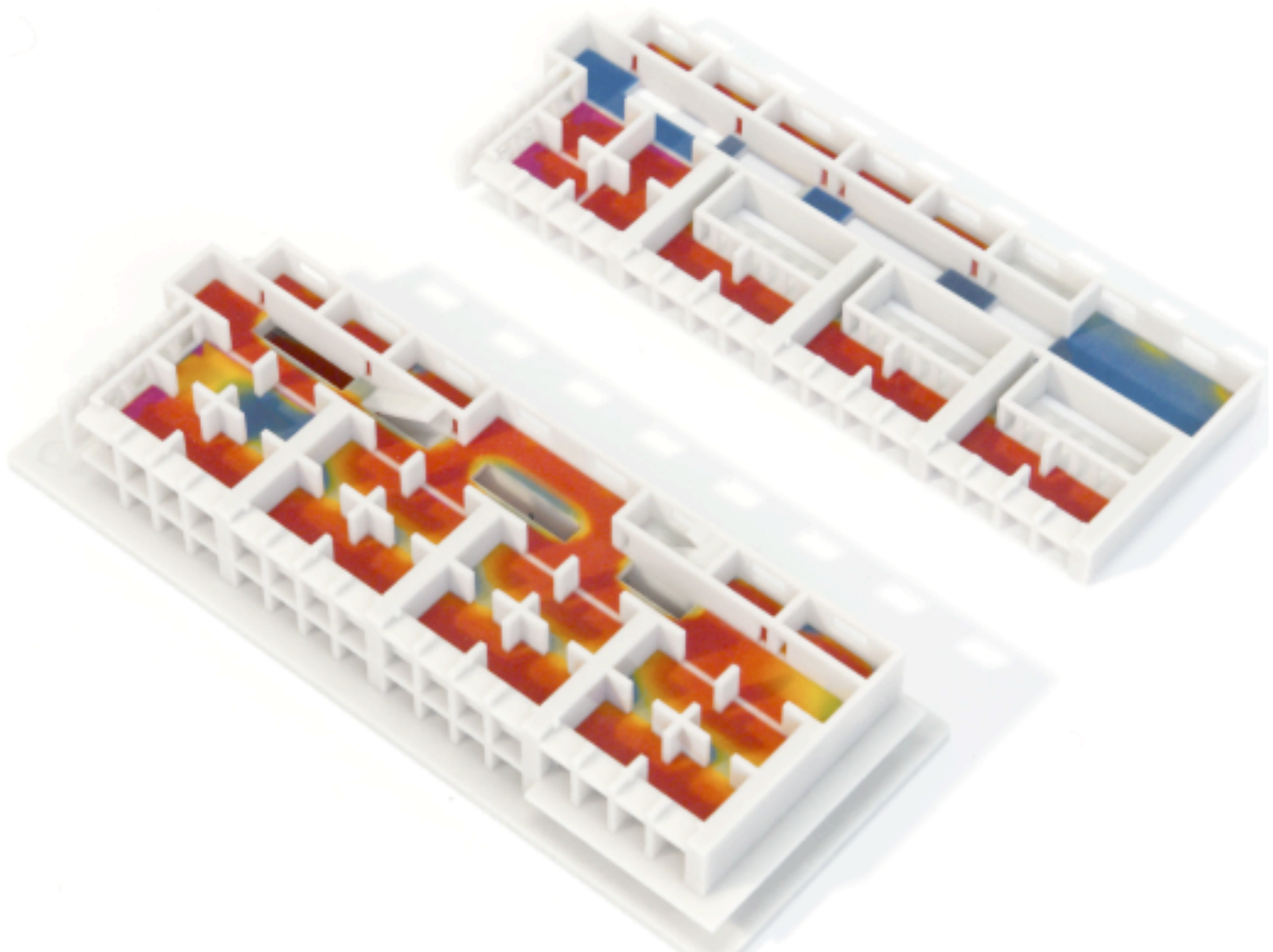
Tools – Environmental Analysis & Parametric Modeling

Rhinoceros/DIVA



(http://diva4rhino.com/photo/hashtgerd-iran-design-11-summer-12?context=latest#!/photo/hashtgerd-iran-design-11-summer-12/next?context=lates)

- Tool for environmental performance evaluations of individual buildings and urban areas. Highly optimized daylighting and energy modeling plug-in or the Rhinoceros (NURBS modeling).

Tools

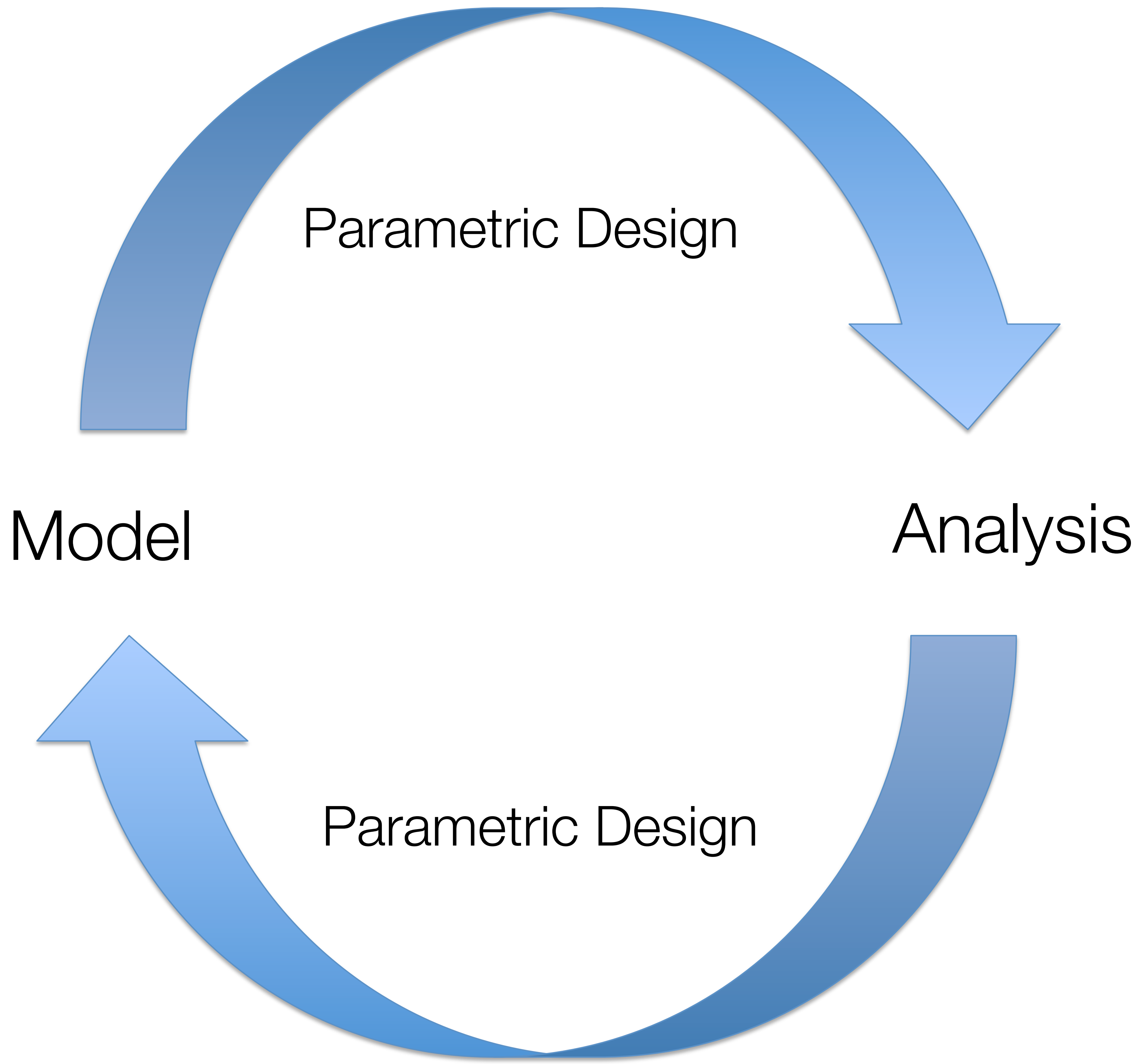
Analysis tools

Model → Analysis → Data → Model → Analysis

Tools

Parametric Design

Model → Analysis → Data → Model → Analysis



Minimizing the effort needed to create and test design variants.

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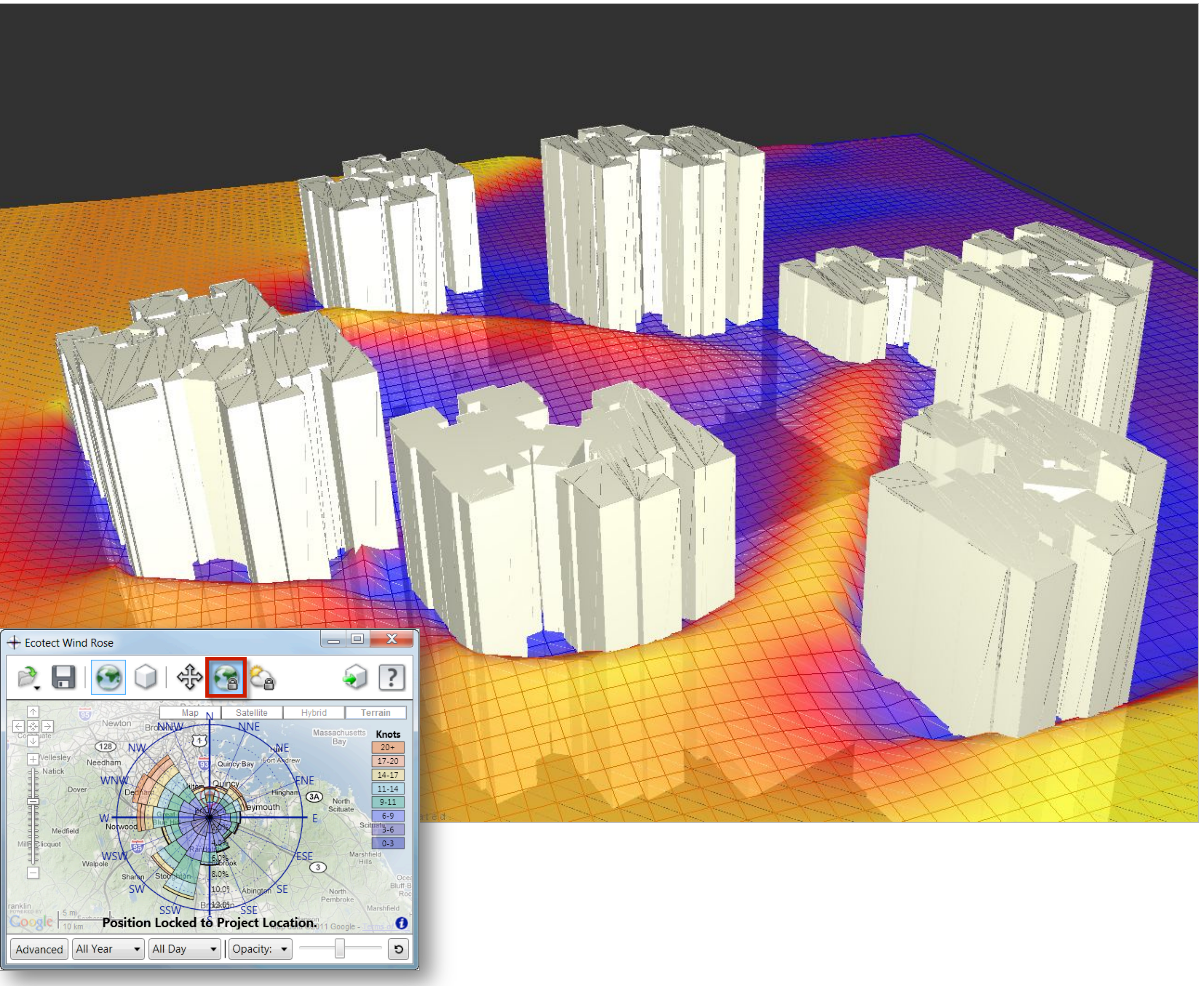
Tools – Environmental Analysis & Parametric Modeling

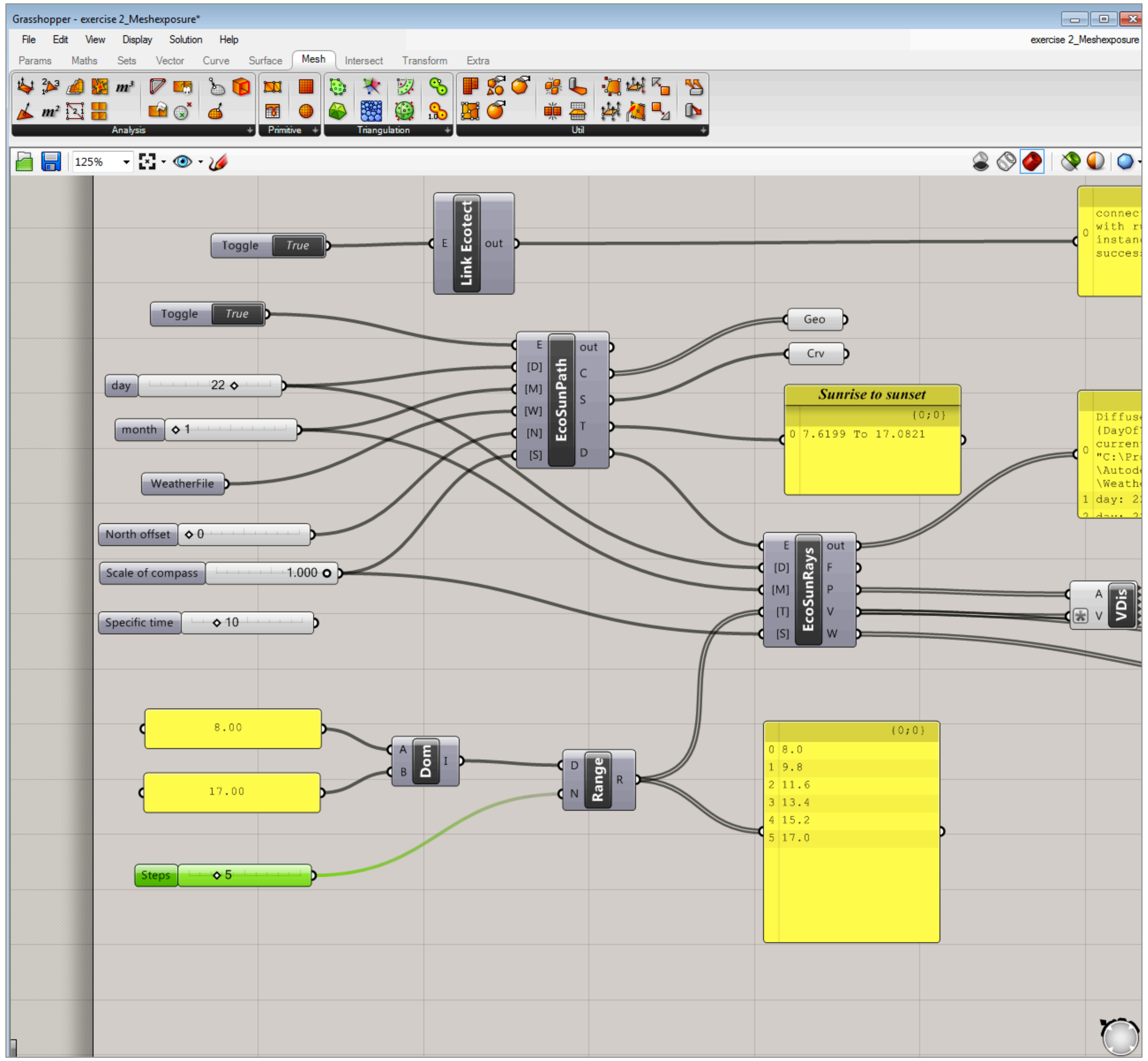
Autodesk Revit/Vasari



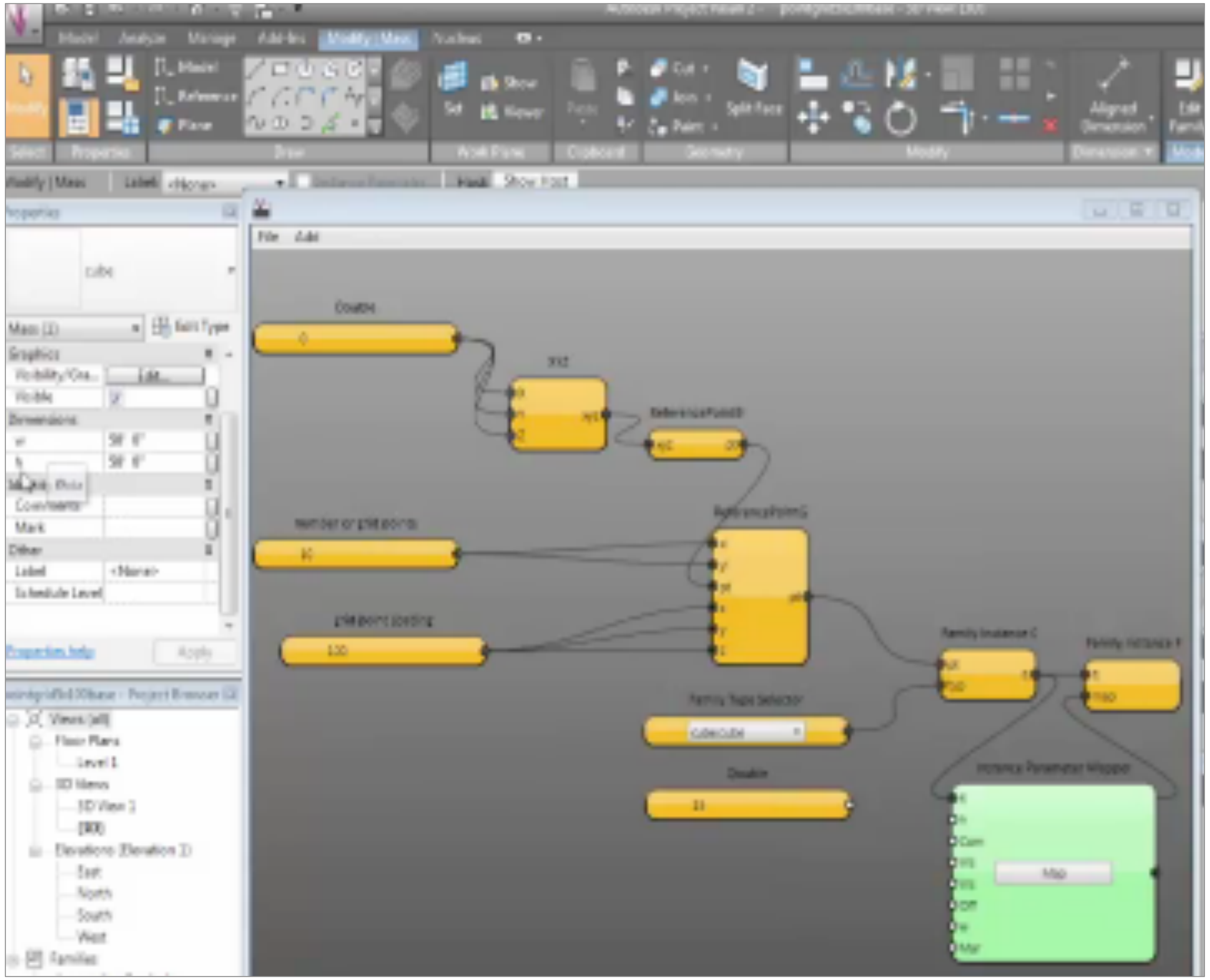
- Tool for creating building concepts. Link energy modeling with the Autodesk Revit platform for BIM.
- Vasari's wind tunnel tool is an easy to use **computational fluid dynamics (CFD)** tool that is useful for early-stage conceptual analysis of airflow around building site and building form.

Tools – Parametric Modeling & Visual Programing

Rhinoceros/Grasshopper



Vasari/Dynamo



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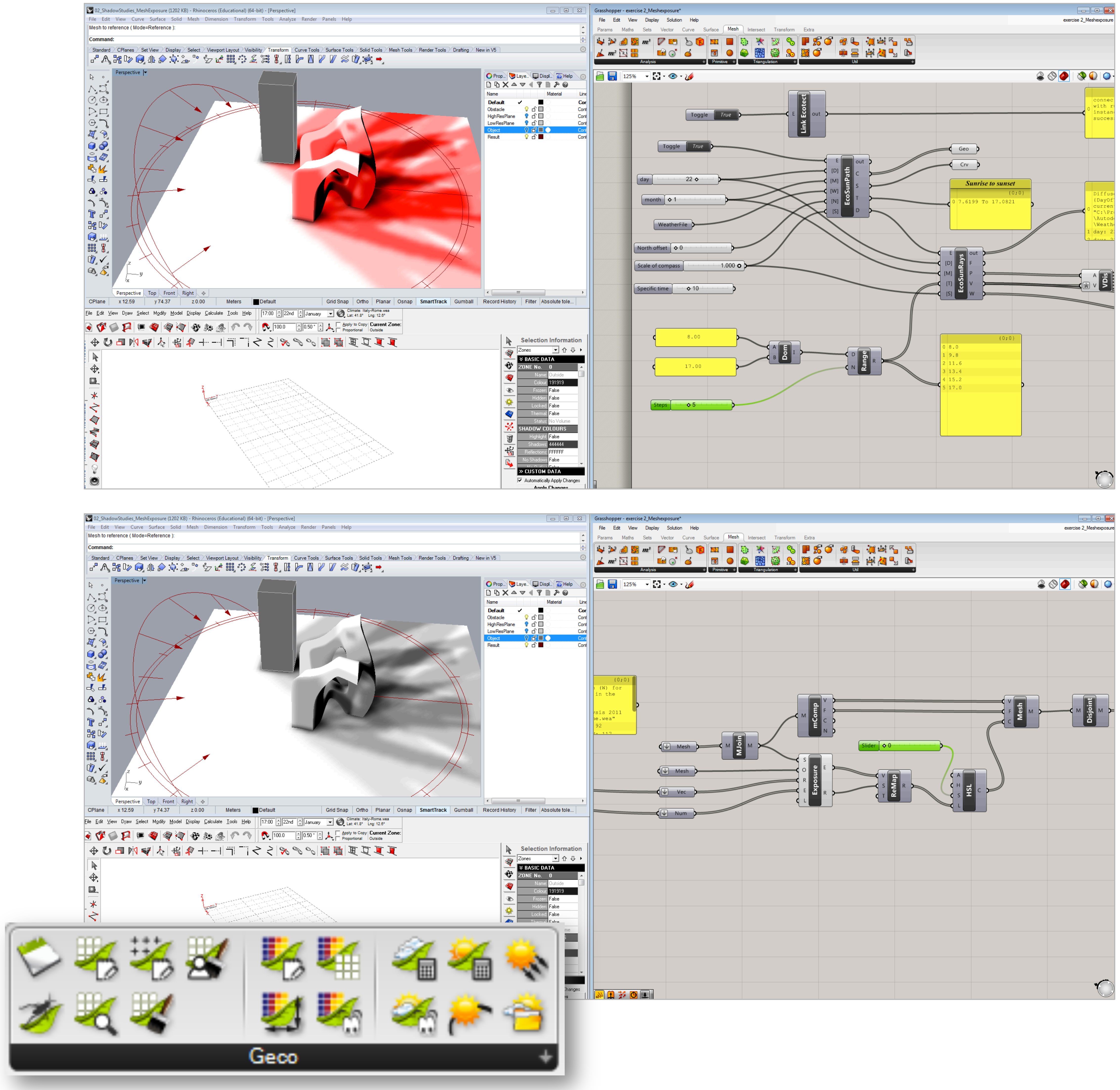
Tools – Environmental Analysis & Parametric Design/ Visual Programing

Rhinoceros/Grasshopper/GECO

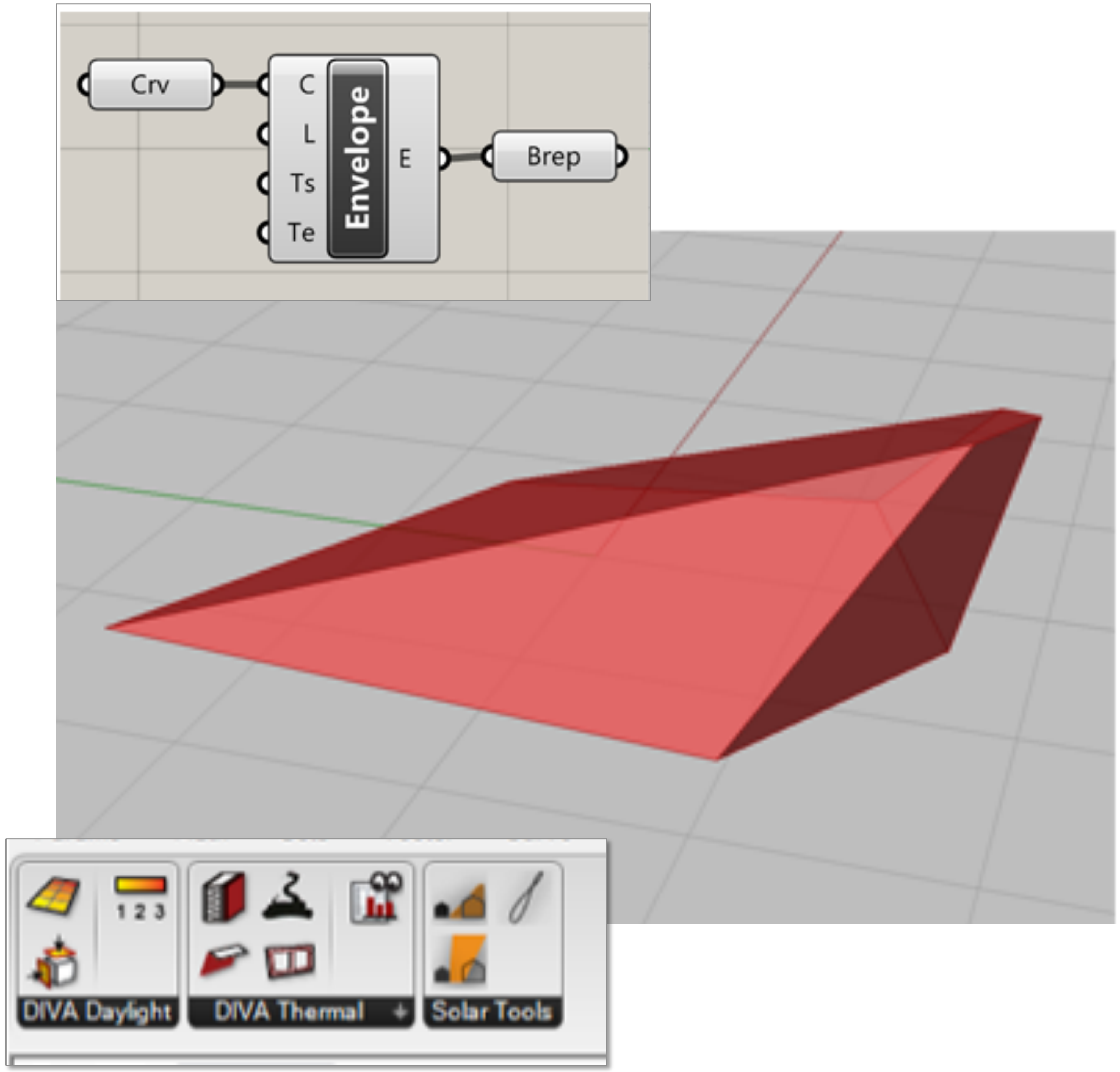


- **GECO** offers a direct link between Rhino/Grasshopper models and Ecotect.

- The plug-in allows to export complex geometries very quickly, evaluate your design in Ecotect and access the performances data, to import the results as feedback to Grasshopper.

Tools – Environmental Analysis & Parametric modeling \ Visual Programing

Rhinoceros/Grasshopper/DIVA

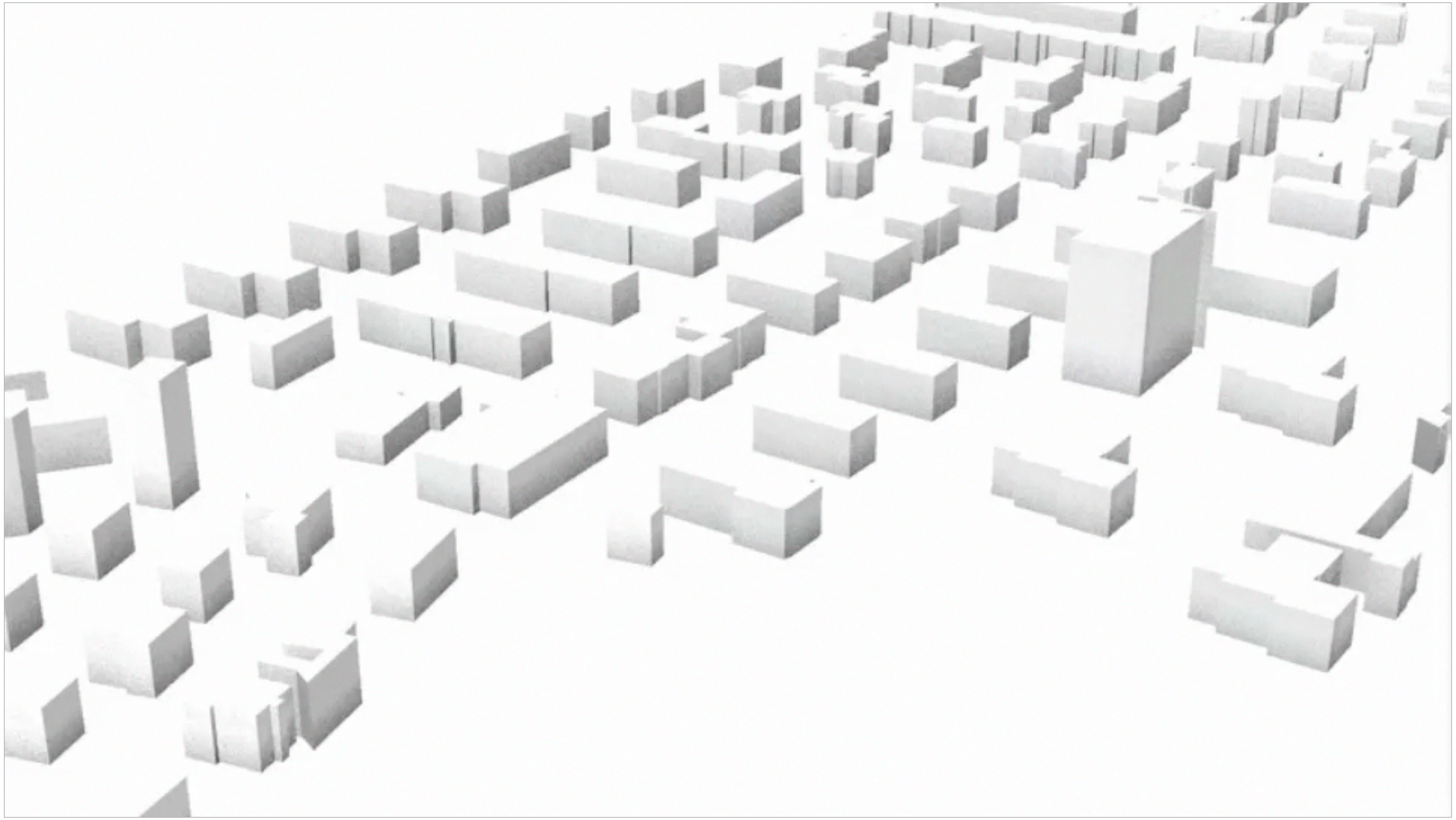


- The DIVA-for-Grasshopper assembly extends the DIVA-for-Rhino tools to the generative modeling program Grasshopper.

http://diva4rhino.com/user-guide/grasshopper/install

Tools – Environmental Analysis & Parametric Design/ Visual Programing

Rhinoceros/Grasshopper/GECO



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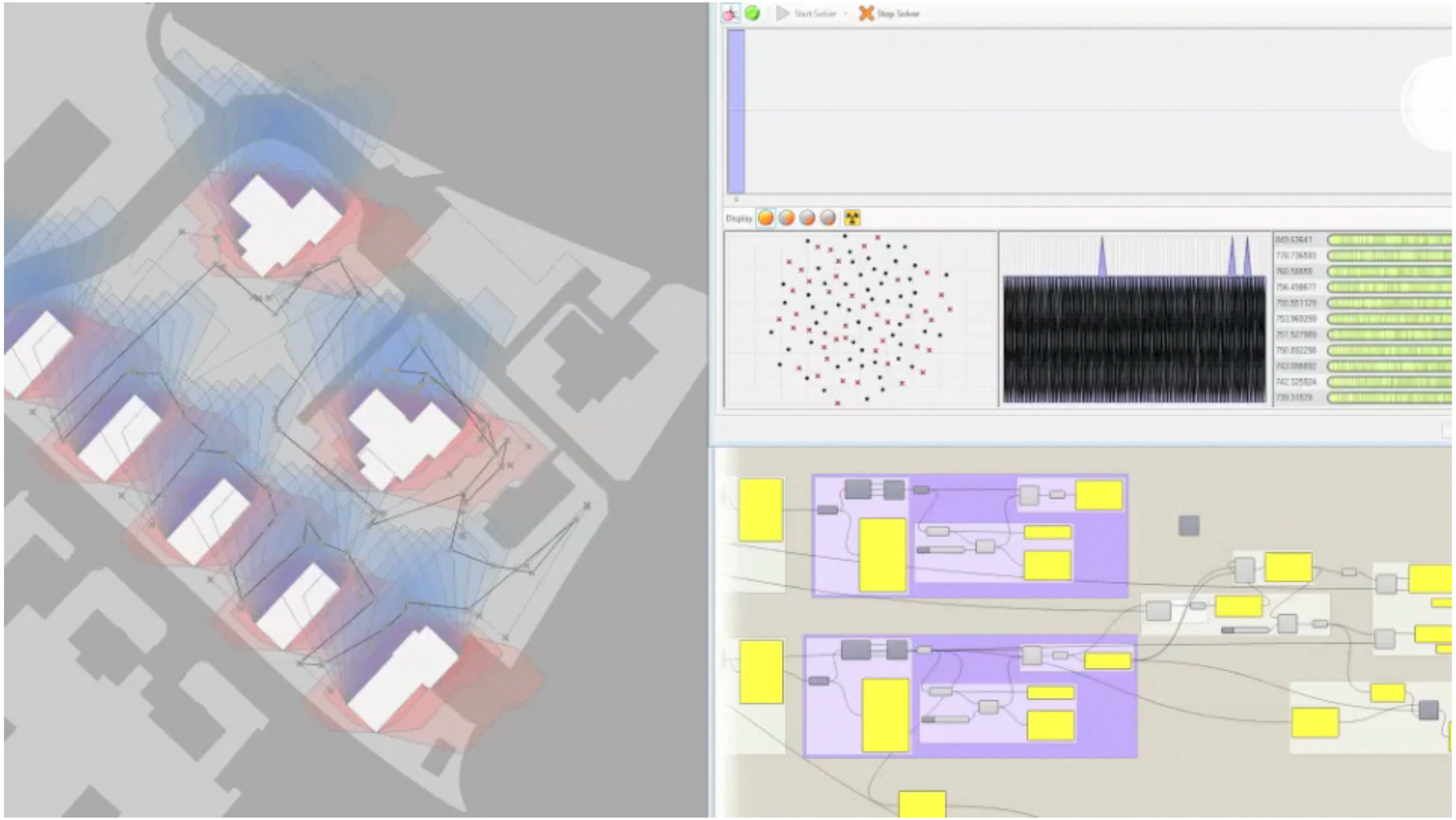
iA Chair of Information Architecture

Tools – Environmental Analysis & Parametric Design/ Visual Programing

Rhinoceros/Grasshopper/GECO



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Conclusion

- Urban climate refers to climatic conditions in an urban area that differs from the climate of its rural surroundings. Urban Heat Islands.
- Urban Microclimate is defined as the climate that prevails at the micro-scale level and that differs from the surrounding area.
- Anthropogenic heat is one of the main causes affecting microclimatic conditions in cities.
- Studying the effect of urban climate is important in order to overcome the Contemporary issues cities are and will face (e.g. urban population growth and climate change). **Creation of urban strategies according to urban climate.**
- Indicators like the outdoor thermal comfort are useful to understand the urban context and support design decisions.
- Parametric Design Tools help on minimizing the effort needed to create and test design variants.

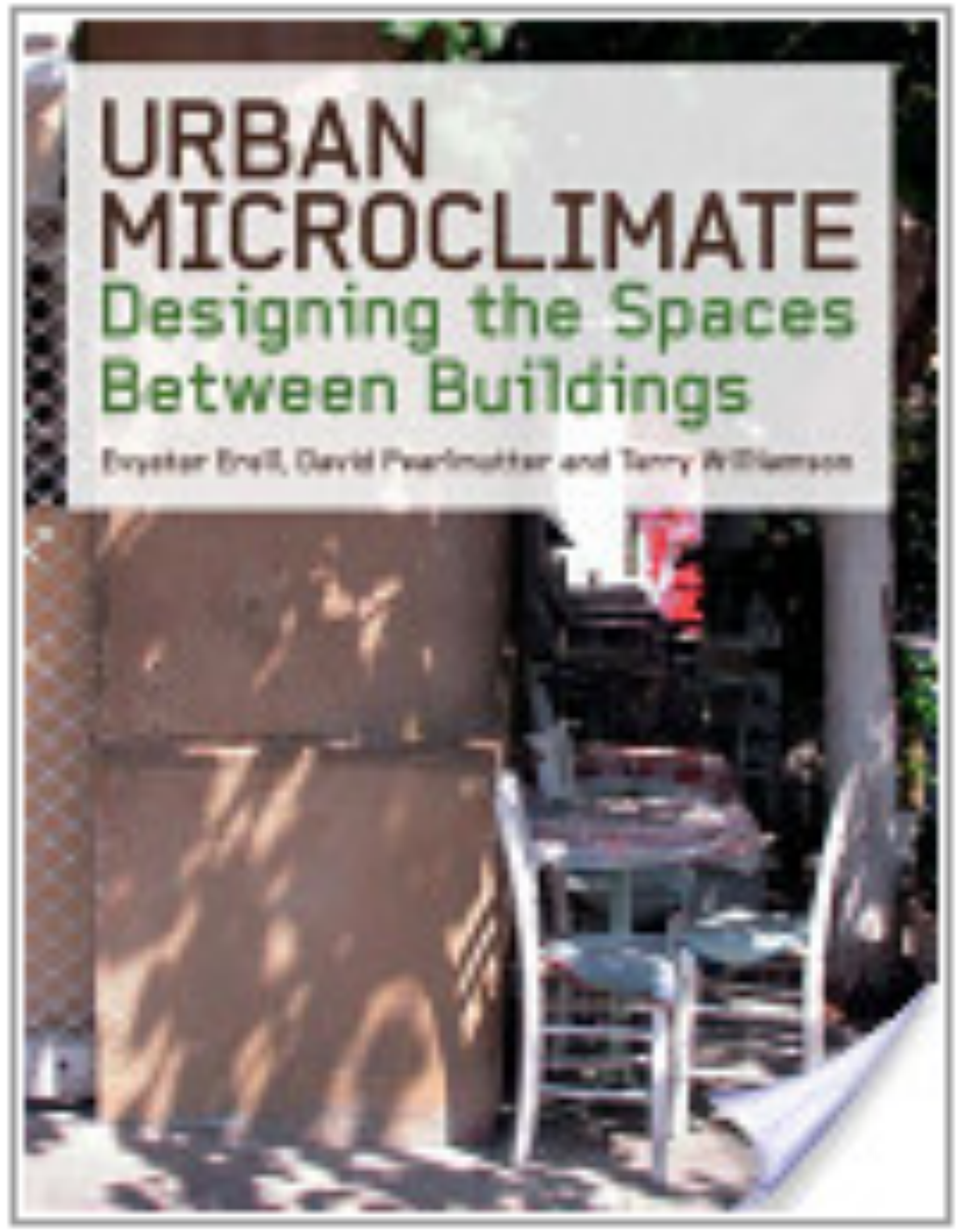
Literature

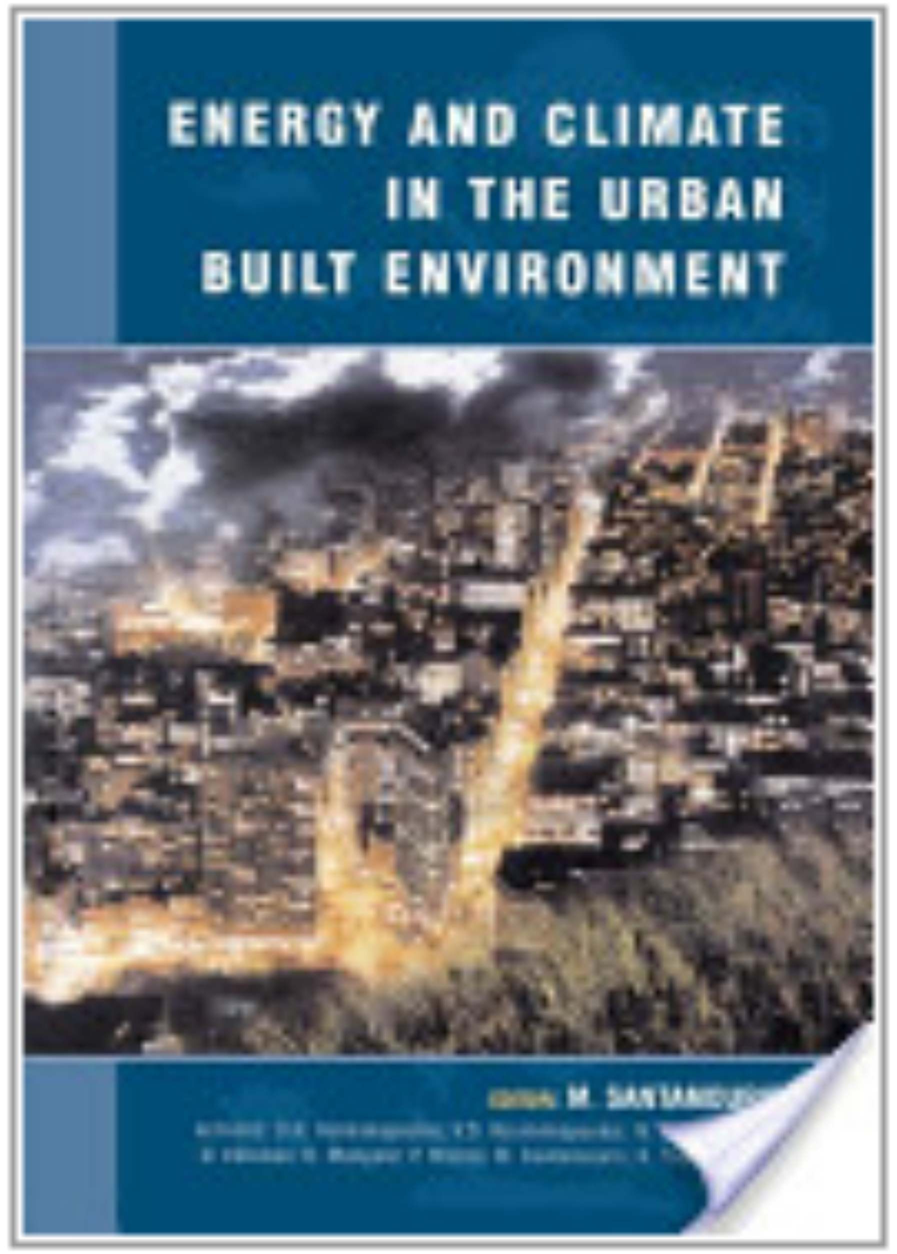
- Erell, E.; Pearlmutter, D.; Williamson, T. 2011. Urban Microclimate: Designing the Spaces Between Buildings. Earthscan.

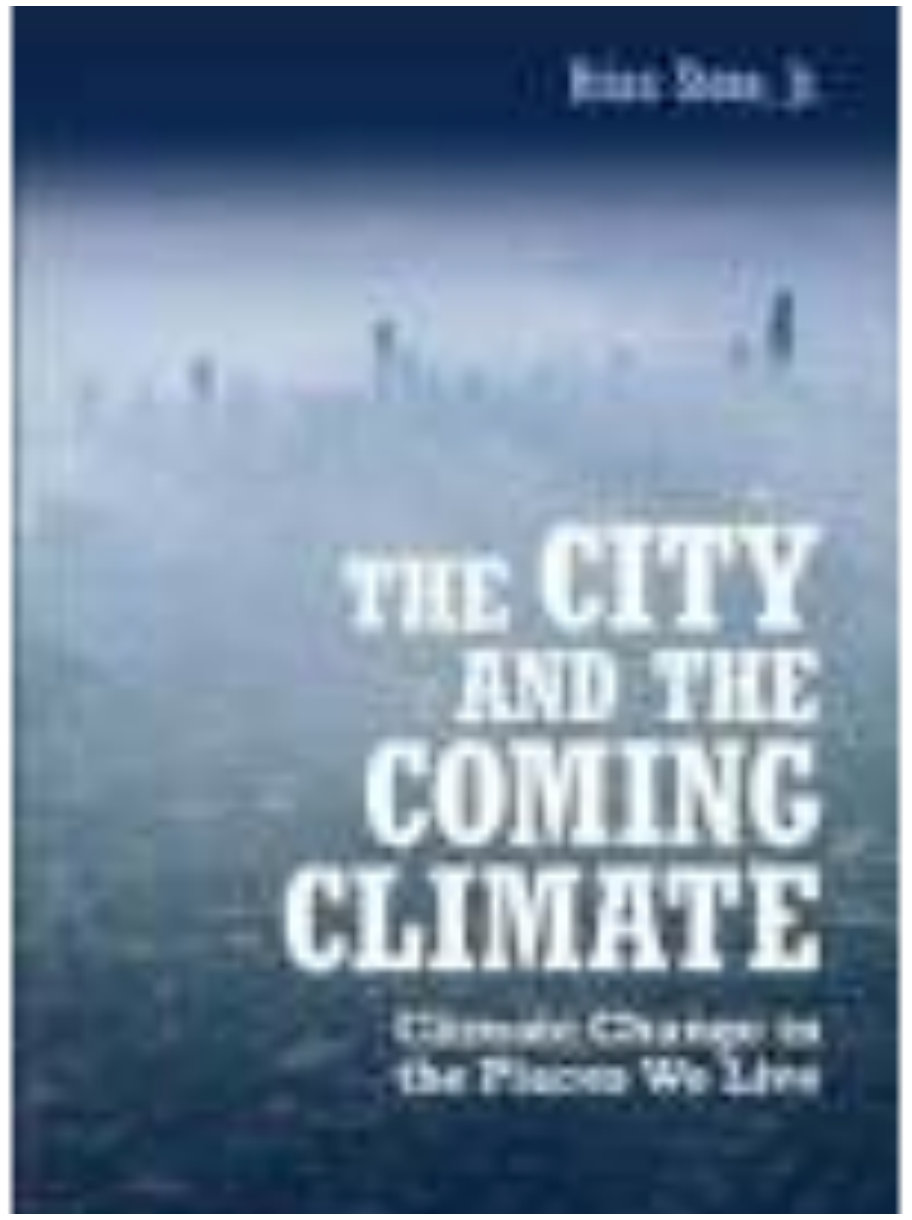
- Asimakopoulos, D.N. ; Asimakopoulos, V.D. ; Chrisomallidou, N. ;. Klitsikas, N; Mangold, D. ; Michel, P. ; Santamouris, M. ; Tsangrassoulis, A. . 2001. Energy and Climate in the Urban Built Environment. Edited by M. Santamouris.

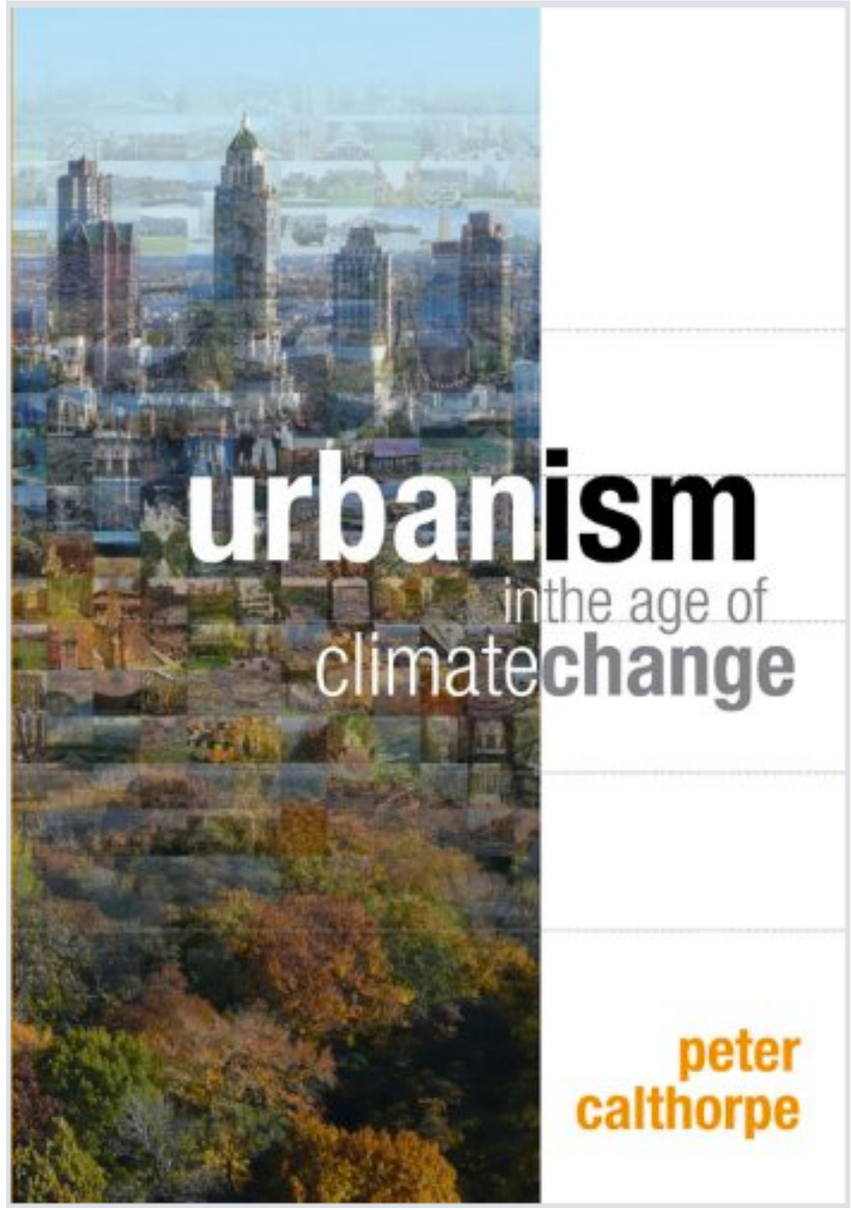
- Stone, B Jr. 2012. The City and the Coming Climate: Climate Change in the Places We Live. Cambridge University Press.

- Calthorpe, P. 2011. Urbanism in the Age of Climate Change. Island press.









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References

- Oke, T.R. 1997. Urban environments. The Surface Climates of Canada, Bailey, W.G., T.R. Oke, and W.R. Rouse (eds.), McGill-Queen's University Press, Montreal, 303-327.
- Oke, T.R. 1976. The distinction between canopy and boundary-layer urban heat islands, Atmosphere, 14:4, 268-277
- Erell, E.; Pearlmutter, D.; Williamson, T. 2011. Urban Microclimate: Designing the Spaces Between Buildings. Earthscan.
- Voogt, JA. 2004. America Institute of Biological Sciences. actionbioscience.org.
- Emmanuel, R. 2005. An Urban Approach To Climate Sensitive Design: Strategies for the Tropics.
- Knowles, R. 1974. Energy and Form. Cambridge, Massachusetts and London, England, MIT Press.
- Knowles, R; Berry, R. 1980. Solar Envelope Concepts: Moderate Density Building Applications : Final Report , Solar Energy Information Data Bank (U.S.), Solar Energy Research Institute.
- Knowles, R. 1981. Sun Rhythm Form. Cambridge, Massachusetts and London, England, MIT Press.
- Carmona, M; Tiesdell, S; Heath, T; Oc, T. 2010. Public Places, Urban Spaces: The dimensions of urban design. Second edition. Routledge.

- http://www.epa.gov/heatisland/
- http://www.unicef.org/sowc2012/urbanmap/
- http://www.actionbioscience.org/environment/voogt.html
- http://diva4rhino.com/user-guide/grasshopper/solar
- http://www-bcf.usc.edu/~rknowles/sol_env/sol_env.html#anchor361801