Urban Microclimate and Building Interactions

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Romanian Conference on Energy Performance of Buildings
National Library of Romania, Bucharest
June 5th & 6th 2014
Urban Heat Island phenomenon

Sketch of an Urban Heat-Island Profile

Late Afternoon Temperature

Rural  Commercial  Urban Residential  Suburban Residential
Suburban Residential  Downtown  Park  Rural Farmland
Evolution of urban temperatures

Maximum difference in urban and rural temperature for US and European cities.
From [Littlefair, 2000], data from (Oke 1982).
Distribution of cooling load [kWh/m$^3$] in Athens 2004, for a set point of 26 °C, (Santamouris et al, 2004)
Main causes of Urban Heat Island

- Low surface albedo
- Low evapotranspiration rate
- Geometry and orientation
- Anthropogenic heat
- Urban greenhouse effect

- Cool surfaces
- Greenery
Temperature rise of various materials in sunlight

Temperature Rise (°C)

Solar Absorptance

- Optical White
- White Paint
- White Cement Coat.
- Al Roof Coat.
- Lt. Green Paint
- Lt. Red Paint
- Red Clay Tile
- White Asphalt Shingle
- Green Asphalt Shingle
- Black Paint
- IR-Reflected Black
- Galvanized Steel
Cool colors reflect invisible near-infrared sunlight

**Solar Energy Distribution**

- 5% ultraviolet (300-400 nm)
- 43% visible (400-700 nm)
- 52% near-infrared (700-2500 nm)
Principle of cool materials

- **cool materials**
  - high solar reflectance
    - less solar radiation absorbed
    - lower surface T
    - less heat penetrates into the building
  - high infrared emittance
    - faster release of heat (IR radiation)
    - less heat transferred to ambient air
Cool roof technologies

cool concrete tile  
R ≥ 0.40

standard concrete tile  
(same color)

solar reflectance gain =  
+0.37  +0.26  +0.23  +0.15  +0.29  +0.29

Cool roof technologies

cool

standard

solar reflectance = 0.27  
thermal emittance = 0.85  
roof temp – air temp = 36°C (65°F)

solar reflectance = 0.08  
thermal emittance = 0.85  
roof temp – air temp = 45°C (81°F)
Effect of roof spectral reflectance SR on building energy consumption

CS: Cool Savings
HP: Heat Penalties
NS: Net Savings

(Zinzi, 2010)
Effect of roof spectral reflectance SR on building energy consumption

CS: Cool Savings
HP: Heat Penalties
NS: Net Savings

(Zinzi, 2010)
Energy and environmental benefits of « vegetalisation » strategies

- Solar protection of buildings
- Evaporative cooling
- Wind shield
- Increase of particles deposition
- Natural sequestration of carbon
- Noise reduction
- Stormwater runoff management
Green wall and roof technologies

Green wall

Extensive green roof

Intensive green roof

Planted facade

Extensive green roof
Reduction of roof surface temperature caused by green roofs

(Chen and Wong, 2009)
Reduction of air temperature caused by green roofs

(Chen and Wong, 2009)
Reduction of wall surface temperature caused by green walls

Wall surface temperature without greenery (°C)

Maximum reduction of temperature (°C)
Reduction of indoor air temperature caused by green walls

Maximum reduction of temperature ($^\circ$ C)

Maximum indoor temperature without greenery ($^\circ$ C)
First findings

• More than 70% of our buildings are located in urban sites,

• Improving their energy efficiency and IEQ as well as the quality of urban environments needs an **integrated** approach taking into account the **strong interactions** between buildings and the urban environment,

• New sustainable technologies are necessary for comfortable and healthy buildings in Urban Environment,

• **New tools and models are needed for these evaluations.**
Development of a new numerical tool

- Numerical study: modelling
  - Outdoor airflow
  - Radiative exchanges
  - Green surfaces
  - Buildings
  - Coupling

- Lanscaping strategies
  - Green surfaces benefits
  - Indoor thermal comfort
  - Energy consumption…
Case study

Studied building (99.2x9.6x15 m)

Top view

3D view

Pin Sec district in Nantes (France)
Outdoor airflow modelling

- CFD code FLUENT
- Numerical wind tunnel
- 3D unstructured grid of 1,725,000 tetraedral air cells
- k-ε turbulence model
Radiative exchanges

- SOLENE code
- Short-wave and long-wave radiation
- Sun and sky modelling: “all weather” Perez model
- Radiosity method
- View factor (contour-integration)
Green area modelling

- Tree
- Ground
# Green area modelling

<table>
<thead>
<tr>
<th>Atmosphere</th>
<th>Green surface</th>
<th>Wall or roof</th>
<th>Indoor air</th>
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</table>

- **Green roof**
- **Planted facade**
Building thermal model

- SOLENE sub-model
- Multizone building model
- Nodal network
Coupling method

CFD initialization computation

Time step \( t_n \)

Transfer of boundary layer Fluent output variables \( \rho_u, T_{bd}, q_{bd} \)

Update boundary conditions

Momentum X, Y, Z
Mass continuity
Turbulence (k-\epsilon model)
Energy
Species transport (0-D)
Update physical properties

Yes
No
Convergence

CFD (Fluent)

Thermoradative initialization computation

Time step \( t_n \)

Update boundary conditions

IR Balance (Radiosity)

Yes
No
Convergence

Update physical properties

T_g
T_g initialization
T_g trees
T_g soils
T_g build 1
T_g build 2

Thermoradative balance (Solena)

Transfer of Solena output surface variables \( T_{bd}, \Phi_{trees}, \Phi_{soils} \)

Yes
No
Convergence

T_{bd}

Transfer of boundary layer Fluent output variables \( \rho_u, T_{bd}, q_{bd} \)

Time step \( t_{n+1} \)

Volume data

Fuel Data
Hot period free running indoor temperature

(a) Urban block without green surfaces
(b) Urban block with green surfaces

(c) Indoor temperature in the second floor of the central building – Non insulated building
Hot season indoor thermal comfort

Standard EN15251: Indoor environmental input parameters for design and assessment of energy performance of building addressing indoor air quality, thermal environment, lighting and acoustics
Parametric study

- Indirect effects of green surfaces on indoor thermal comfort in the studied building
- Coupled indirect and direct effects on indoor thermal comfort in the studied building

Direct effect of planted facades

Indirect effect of planted facades
Parametric study: indirect effects

Reduction of categories II+III+IV compared to case 0
Parametric study: Indirect vs direct effects
Conclusion

- Development of models: outdoor airflow, radiative exchanges, thermal building, green surfaces
- Models coupling: urban climate assessment numerical tool
- Parametric study on a real district (Nantes, France)
- Direct and indirect effects of green surfaces on indoor thermal comfort
Thank you for your attention