ASSESSMENT OF URBAN HEAT ISLAND MITIGATION STRATEGIES
-
LOCAL AND STREET SCALES

Advances in Urban Mitigation Technologies

12 JULY 2018 – POLYTECHNIC UNIVERSITY OF BARI, ITALY

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Assessment of Urban Heat Island mitigation strategies

1 UHI observations and building models

(A) Dense urban context and building environmental quality

(B) Local UHI physical models

2 UHI mitigation strategies

(A) Radiative properties

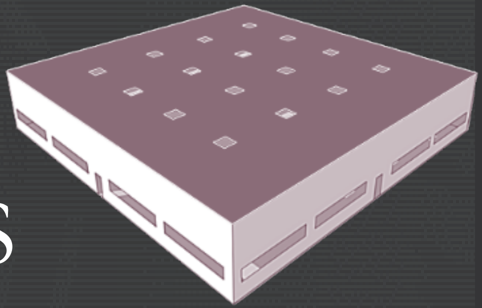
(B) Green roofs and façades

3

New challenges

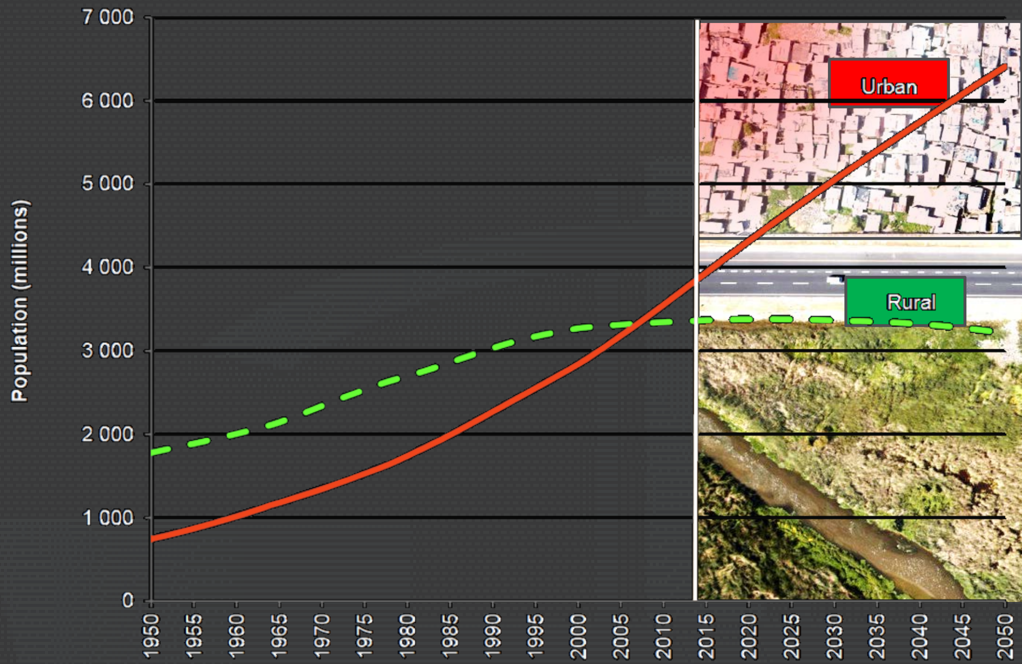
1.A

UHI OBSERVATIONS AND BUILDING MODELS



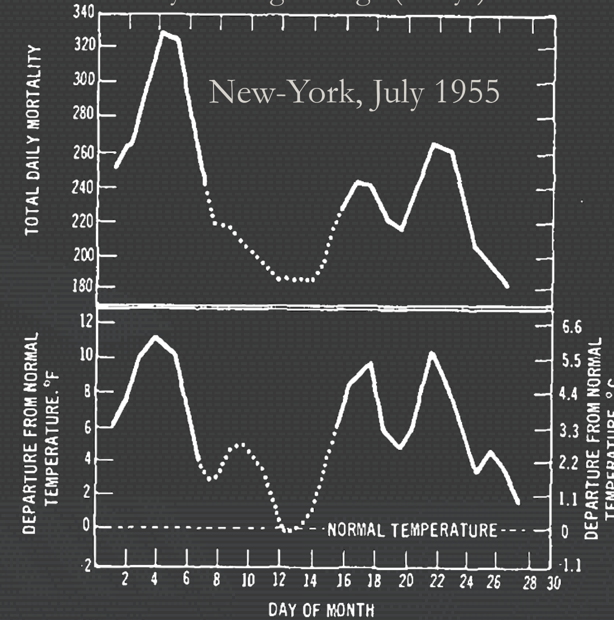
Dense urban context and building environmental quality

DENSE URBAN CONTEXT AND BUILDING ENVIRONMENTAL QUALITY

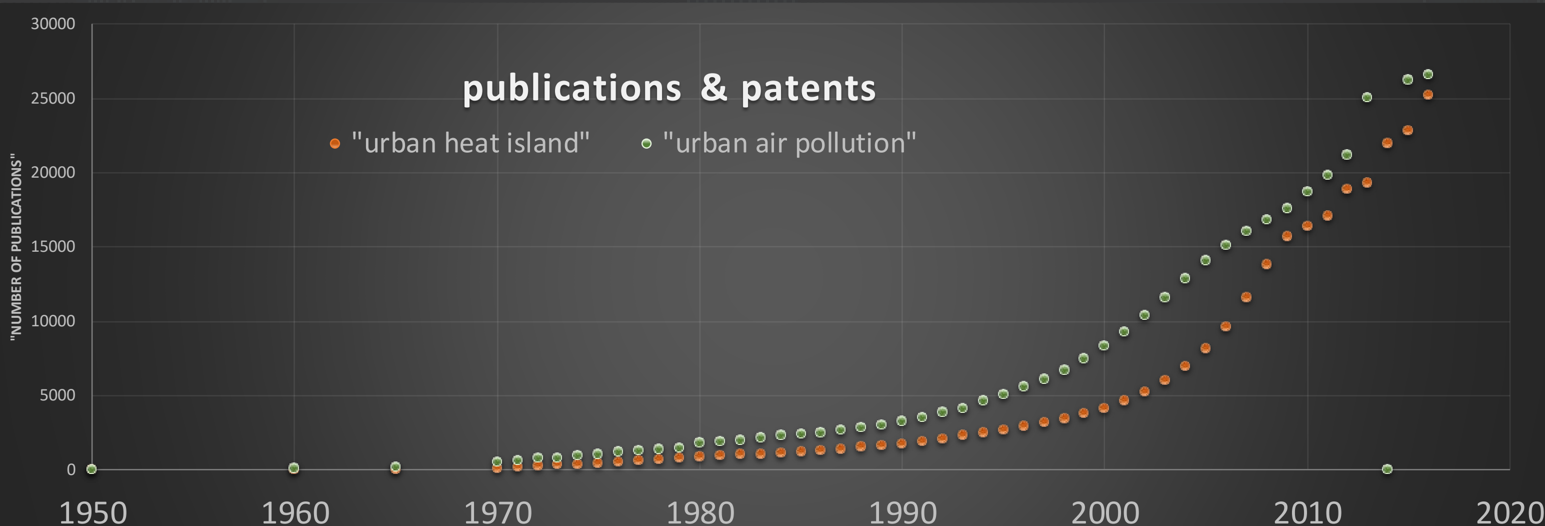


United Nations, 2015

Mortality moving average (3 days)



Temperature increase – moving average (3 days)
Clarke (1972)

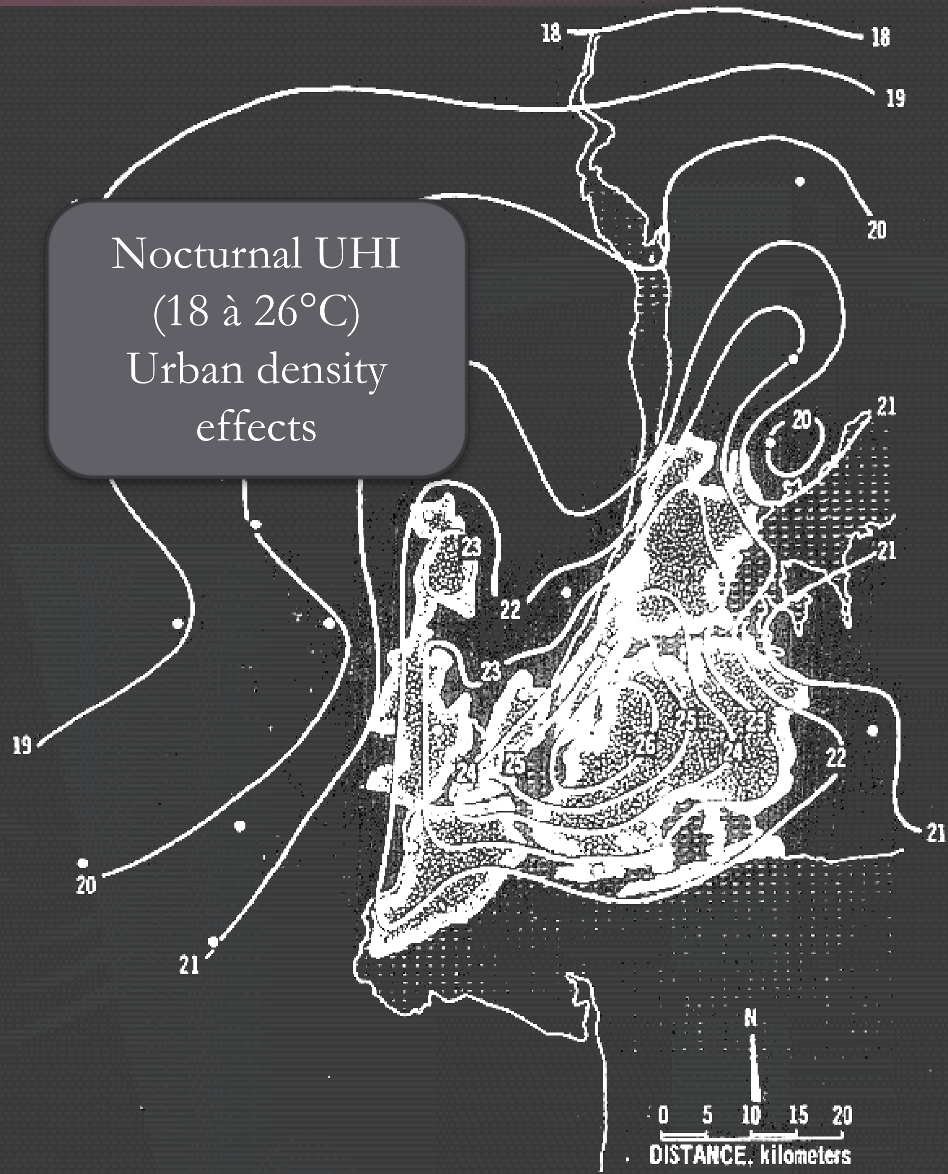


Climate change adaptation + city resilience

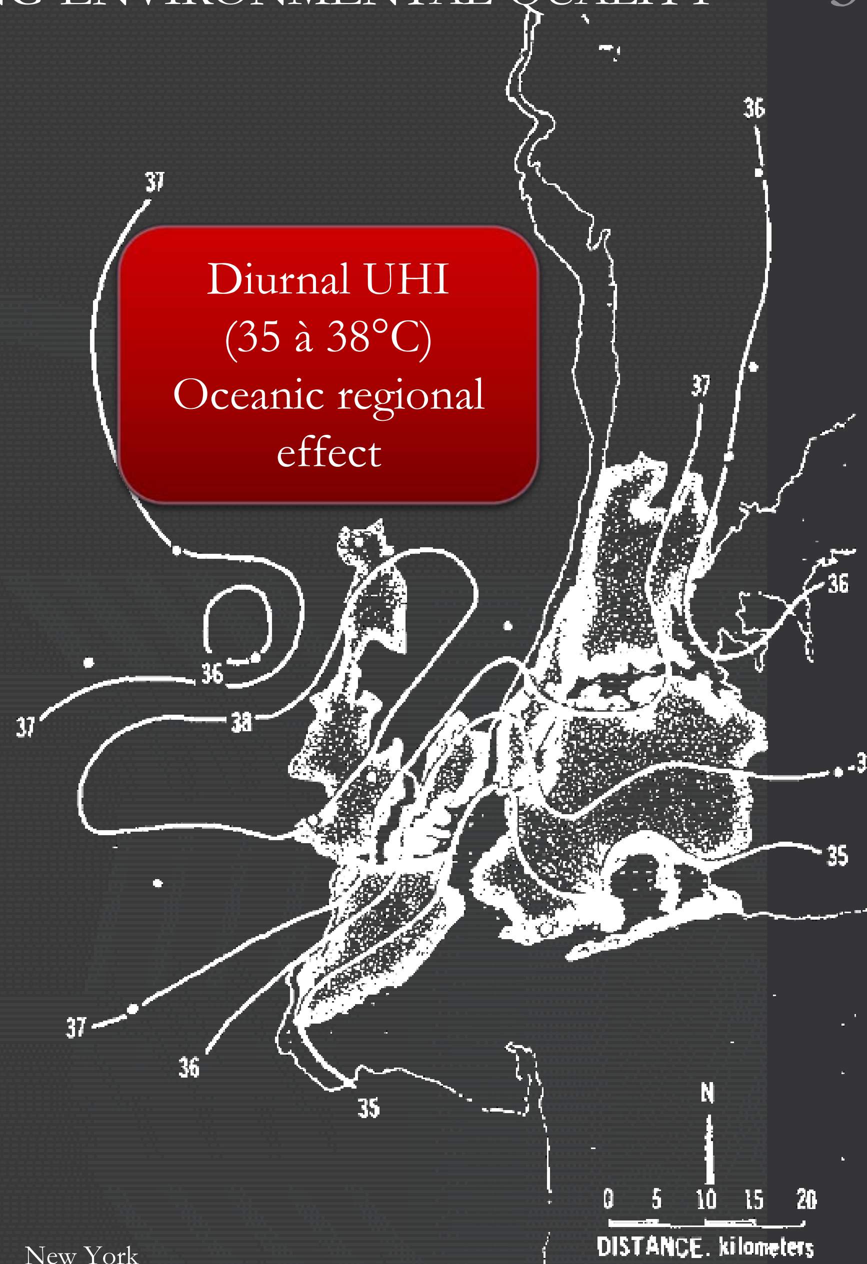
-

An increasing concern

DENSE URBAN CONTEXT AND BUILDING ENVIRONMENTAL QUALITY



Nocturnal UHI
(18 à 26°C)
Urban density effects

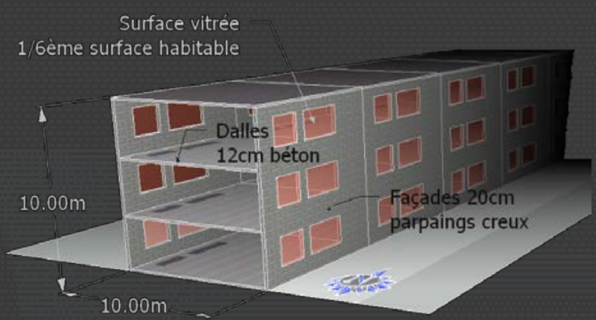


Diurnal UHI
(35 à 38°C)
Oceanic regional effect

Clarke (1972)

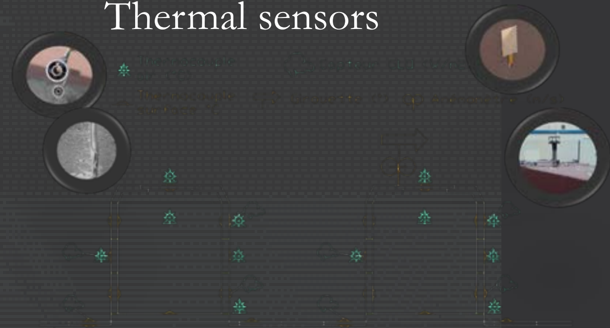
New York
June 1955 (6 days)

Thermal confinement at street scale – an experimental model (ClimaBat)

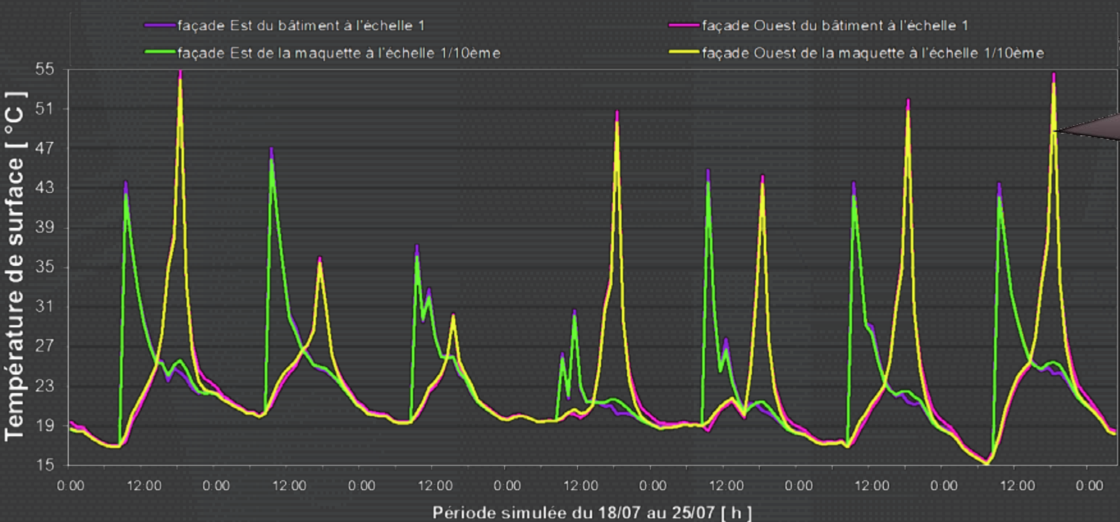


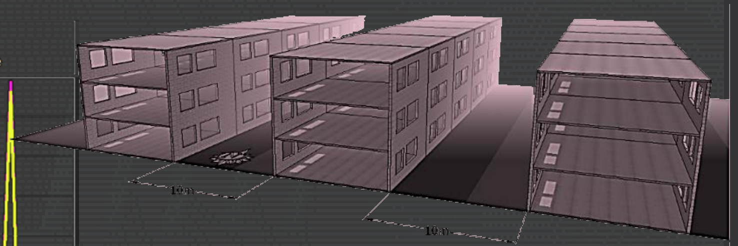
M. Doya, E. Bozonnet, F. Allard, Experimental measurement of cool facades' performance in a dense urban environment, Energy and Buildings. 55 (2012) 42–50. doi:10.1016/j.enbuild.2011.11.001.

Thermal sensors

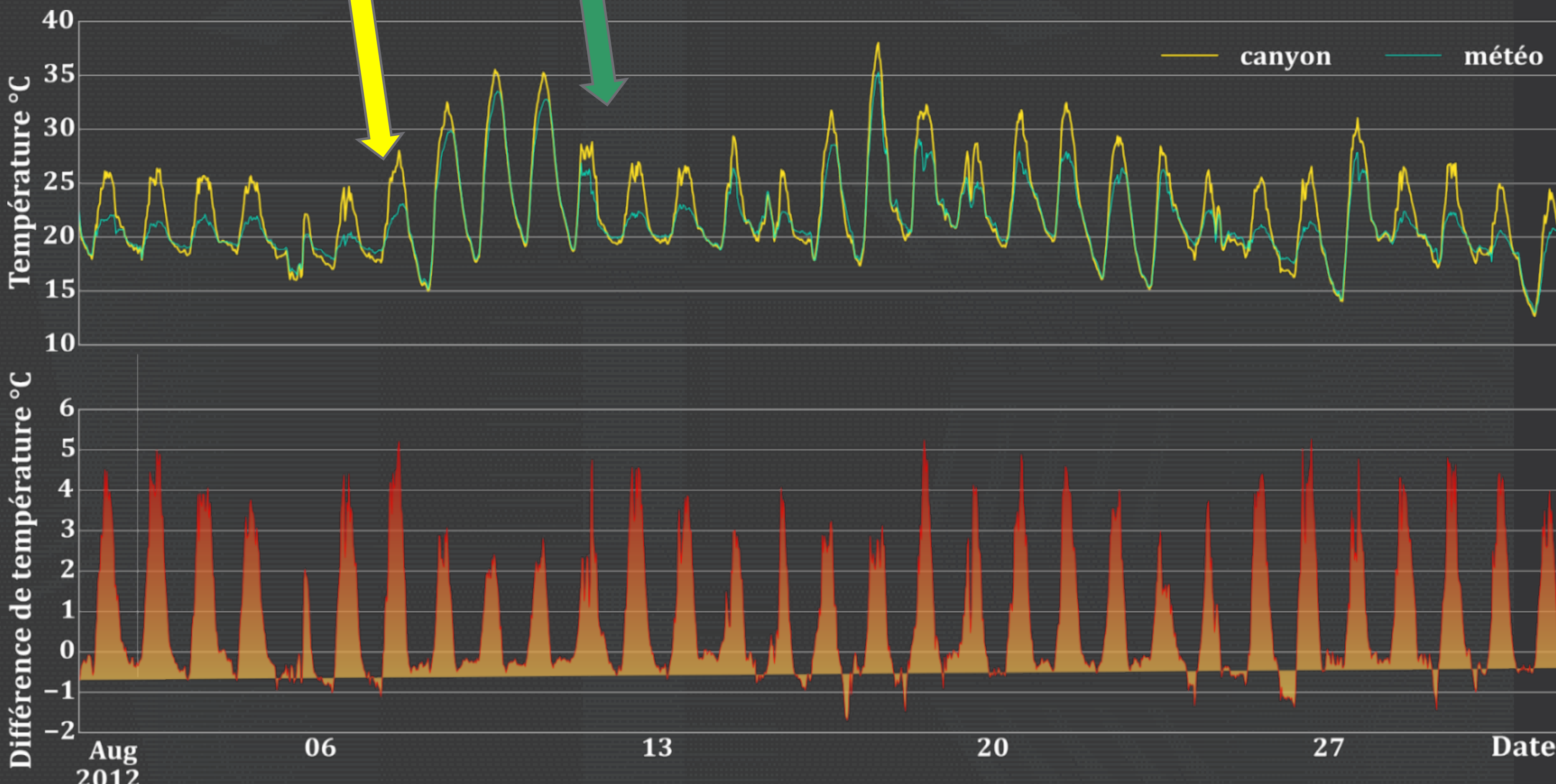


Reduced scale 1/10
Representative of building and street canyon



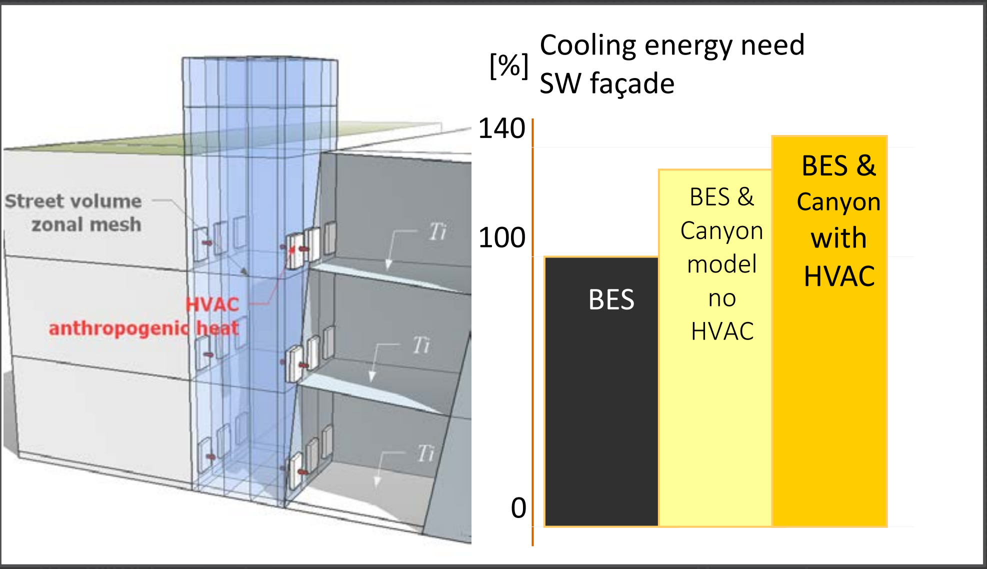


Thermal confinement at street scale – an experimental model (ClimaBat)

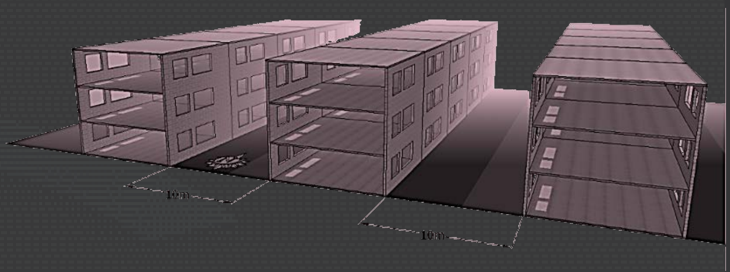


R. Djedjig, E. Bozonnet, R. Belarbi, Experimental study of the urban microclimate mitigation potential of green roofs and green walls in street canyons, Int. J. Low-Carbon Tech. 10 (2015) 34–44. doi:10.1093/ijlct/ctt019.

BUILDING/ANTHROPOGENIC CONTRIBUTION



STREET SCALE



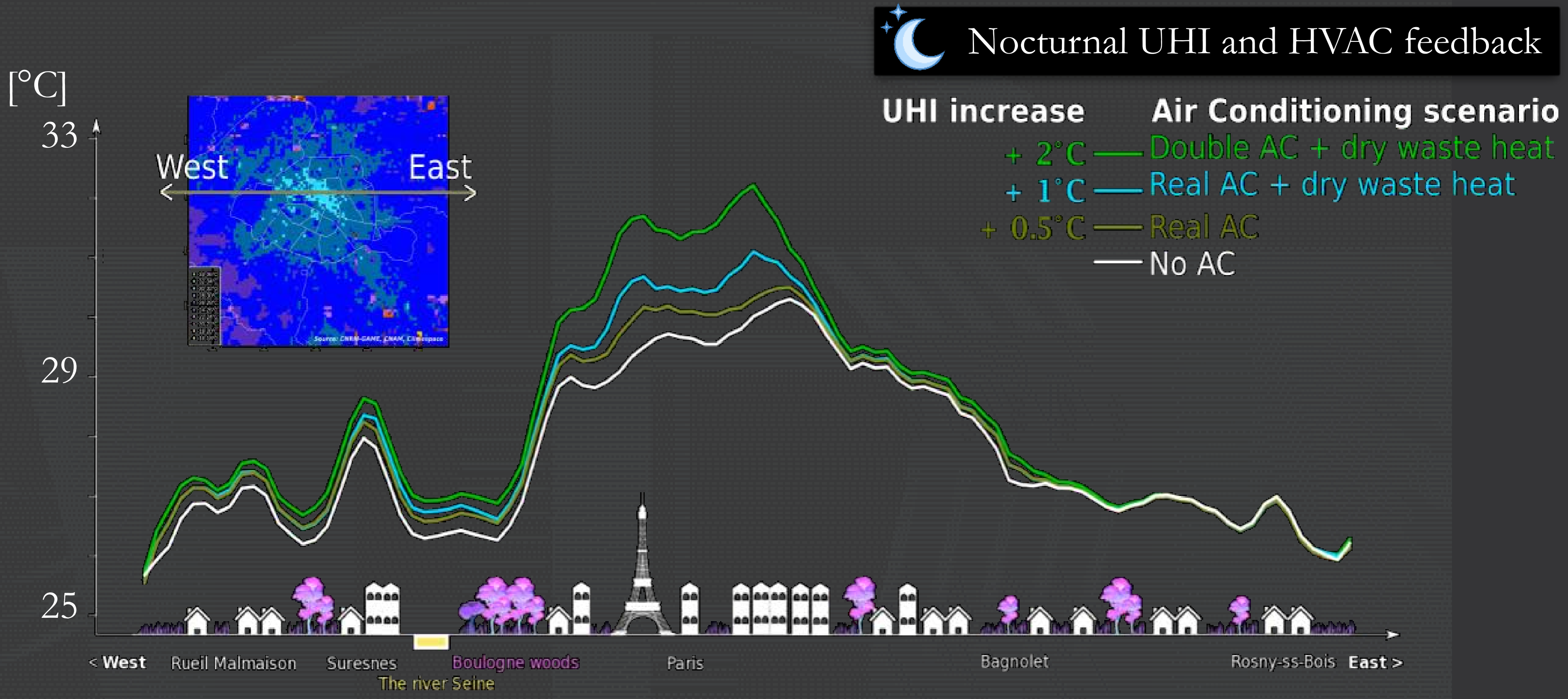
E. Bozonnet, R. Belarbi, F. Allard, Thermal Behaviour of buildings: modelling the impact of urban heat island, Journal of Harbin Institute of Technology (New Series). 14 (2007) 19–22.

« The urban thermal anomaly can be expected to increase if man continues to expand his cities into giant metropolitan regions. Because of the increasing use of air conditioning, the portion of the population of cities necessarily exposed to thermal stresses will decrease. **The heat and moisture removed from the buildings, however, will be dumped into the urban atmosphere and further increase the thermal anomaly of the city.** This will also increase thermal stresses on the inhabitants of the central city not fortunate enough to have air conditioning. »

J.F. Clarke - 1972

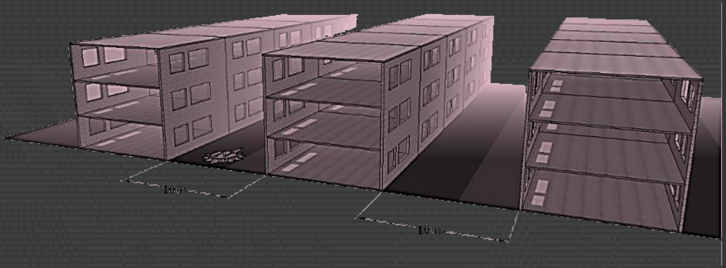
BUILDING/ANTHROPOGENIC CONTRIBUTION

MESO SCALE



de Munck et al., 2013

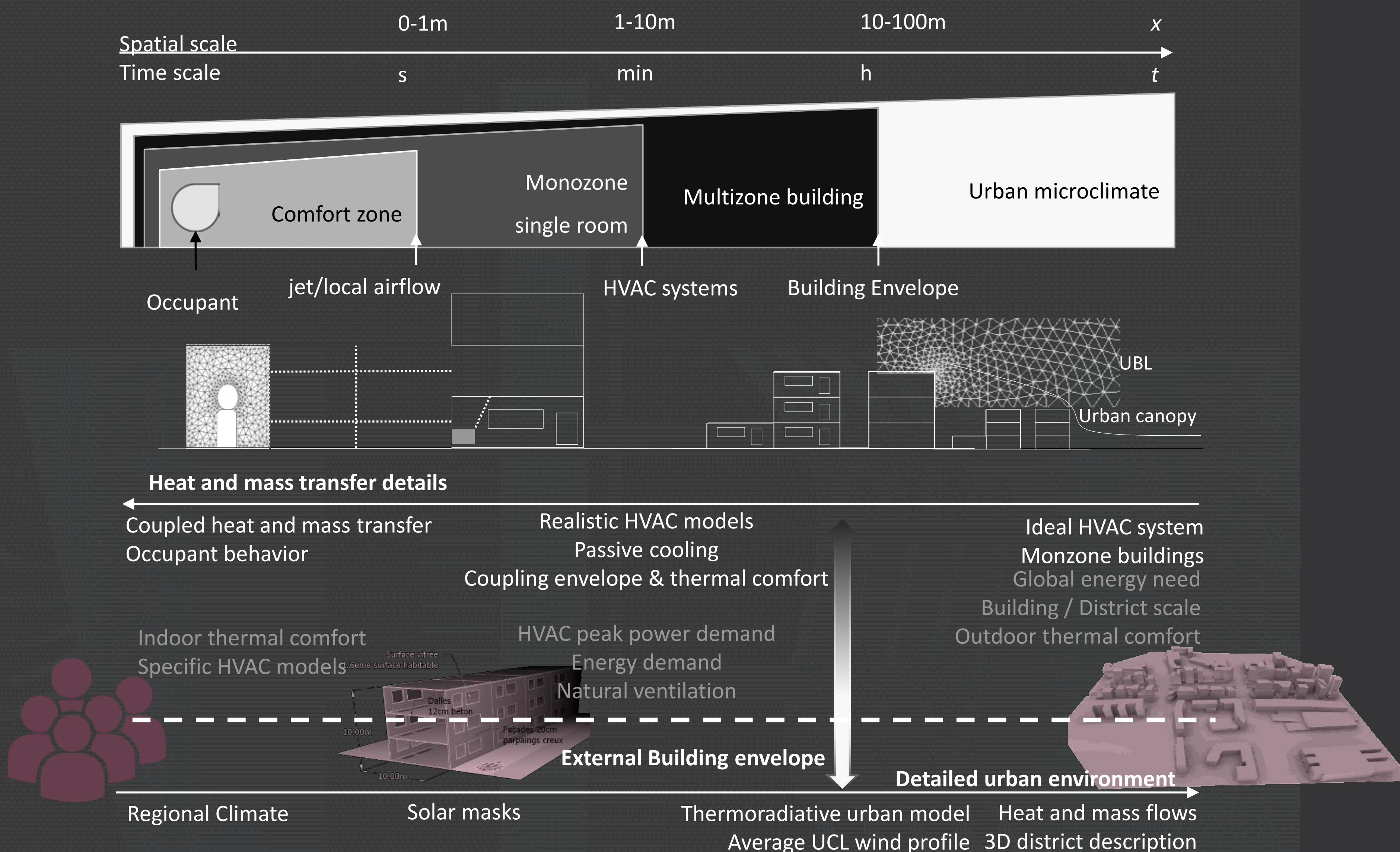
1.B



LOCAL UHI PHYSICAL MODELS

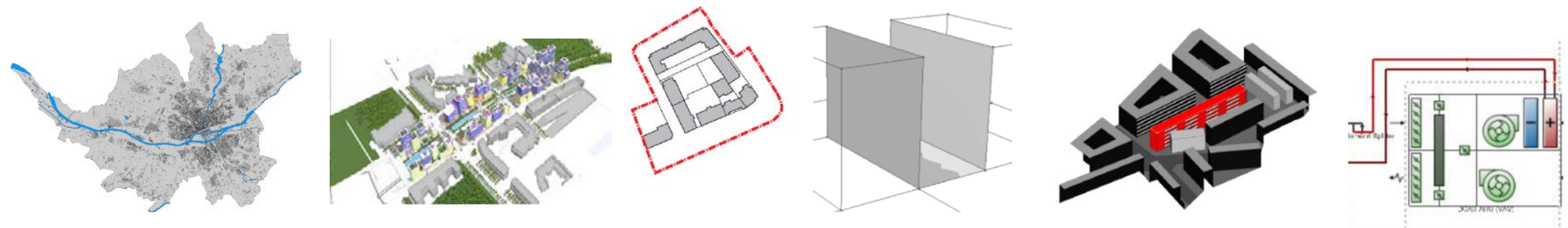
- Building Energy Simulation (BES)
- Street scale
- District scale

LOCAL UHI PHYSICAL MODELS – VARIOUS SCALES



LOCAL UHI PHYSICAL MODELS – VARIOUS SCALES

BES AND ENERGY PERFORMANCE



Impact of built areas on urban climate

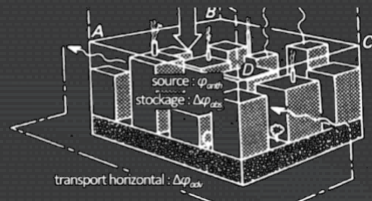
Eco-district

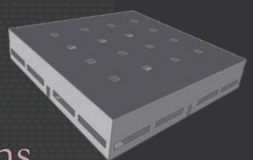
Impact urban climate on built spaces

City	District	Block	Street	Building	Systems	Spatial scales
Impact of climate change UHI assessment	Assessment of urban form Energy consumption at district scale	Assessment of urban form Solar access	Thermal comfort	Energy consumption - Indoor comfort	Energy Performance Assessments	Aims
ARPS LUMPS TEB SM2U	BEM CITY SIM	ENVI-MET	SOLENE Microclimate EnviBatE HIP	ENERGY PLUS TRNSYS		Models

LOCAL UHI PHYSICAL MODELS - BES AND ENERGY PERFORMANCE

Models to assess the impact of urban context on energy consumption





- Artefacts in BES

Generation of urban climate data → Boundary conditions → BES

- Coupled BES and urban microclimate simulation

Microclimate model → Boundary conditions → BES

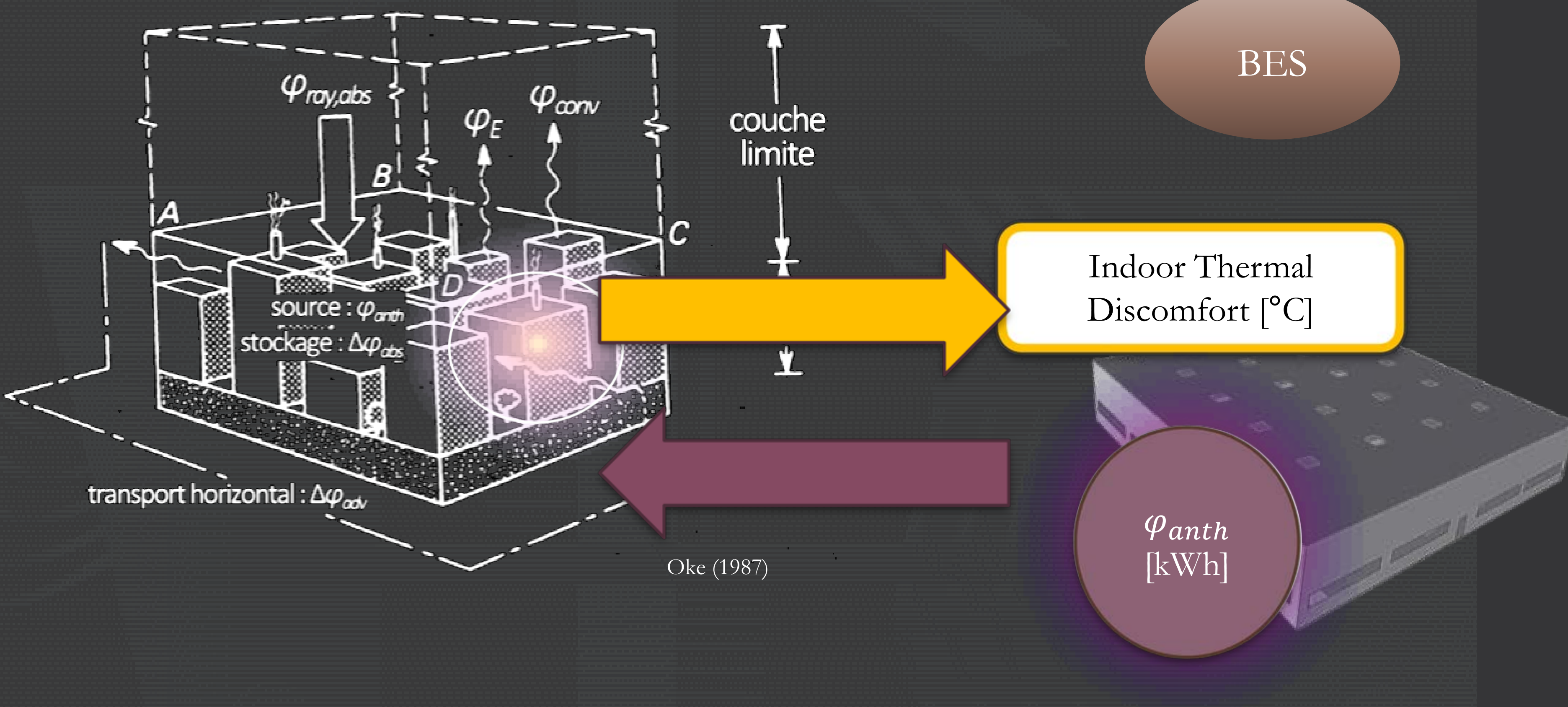
BES → Anthropogenic loads → Microclimate model

- Integrated models BES integrated in microclimate simulation

Microclimate model [BES]

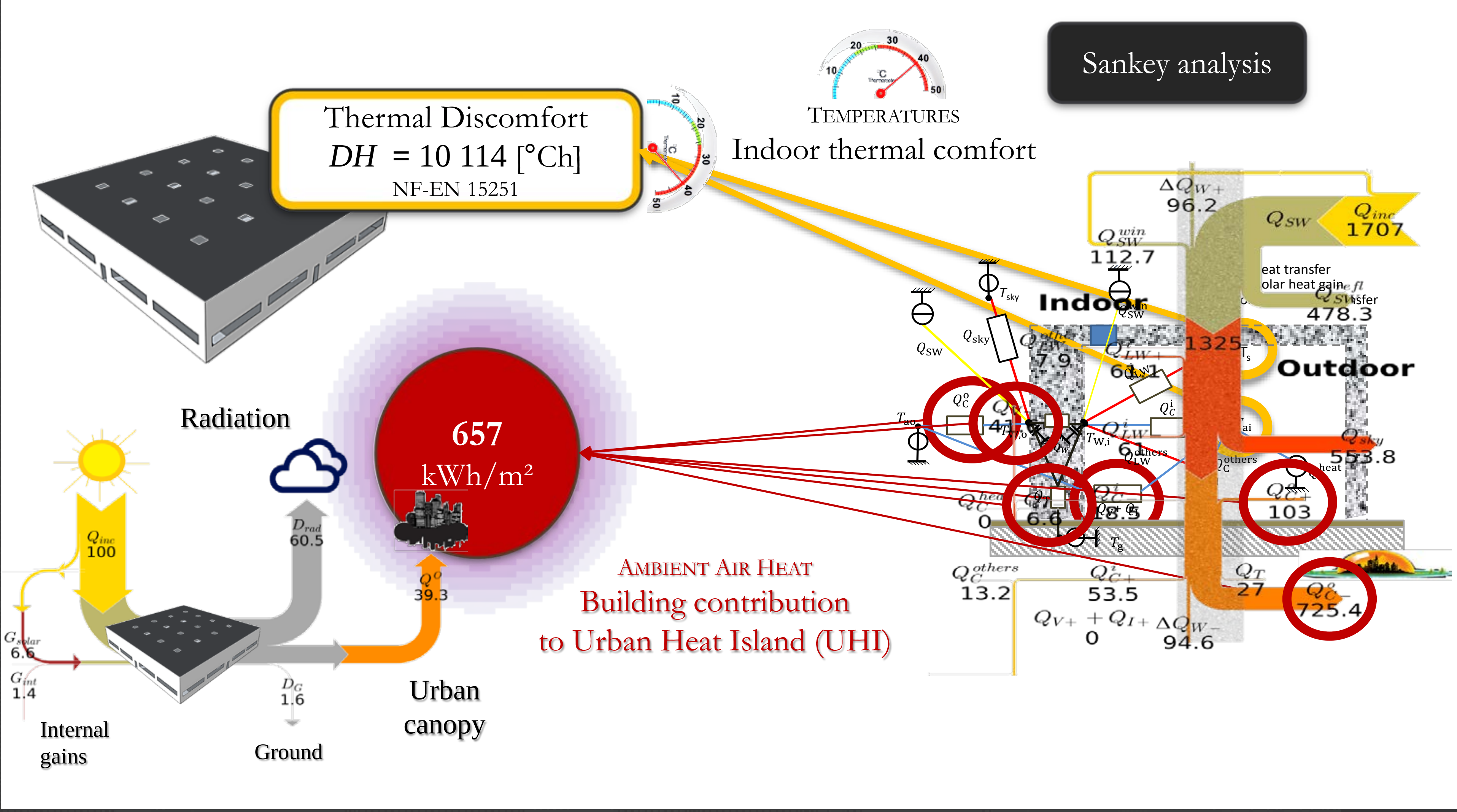
Mesoscale modeling approach – Town energy budget

$$\varphi_{ray,abs} + \varphi_{anth} = \varphi_{conv} + \varphi_E + \Delta\varphi_{abs} + \Delta\varphi_{adv}$$



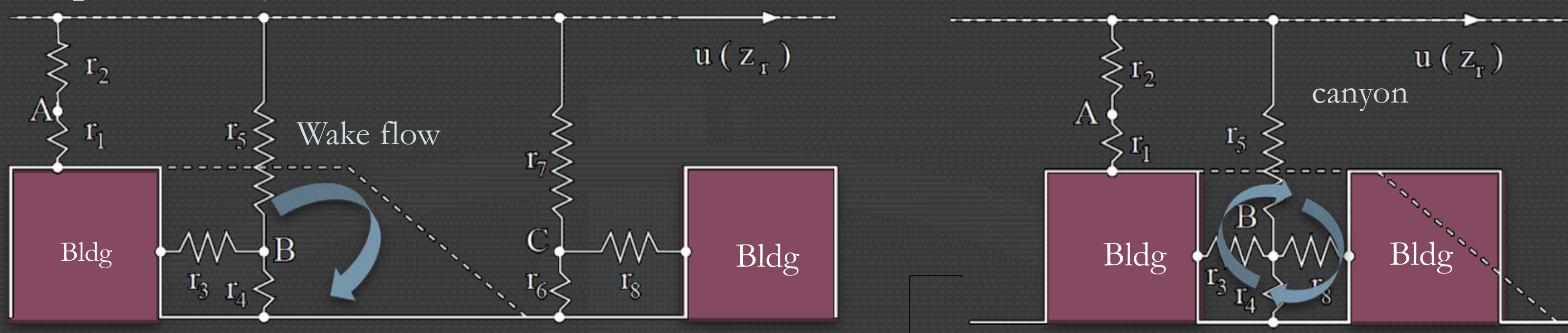
Oke (1987)

Local UHI physical models - BES and anthropogenic contribution

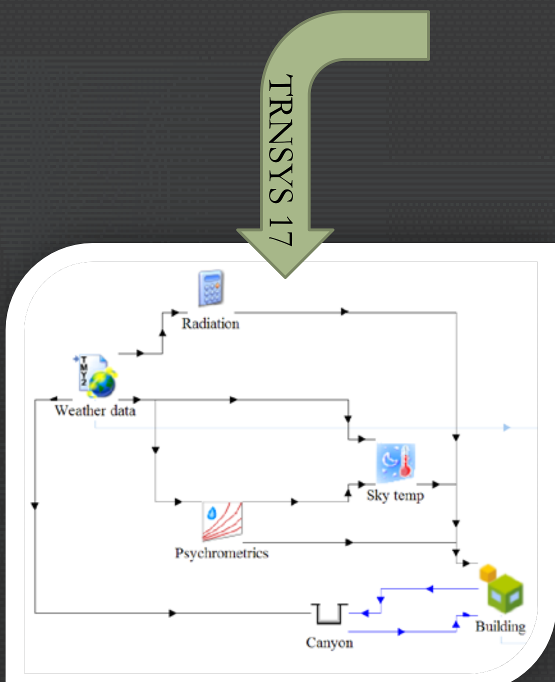


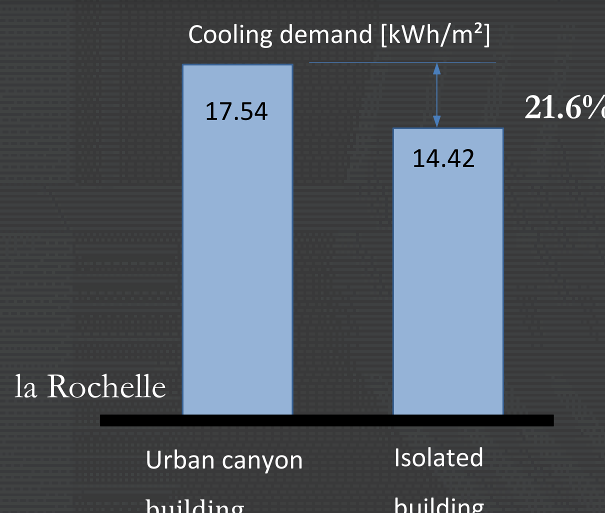
Coupled BES and local climate simulation

Simplified canyon model



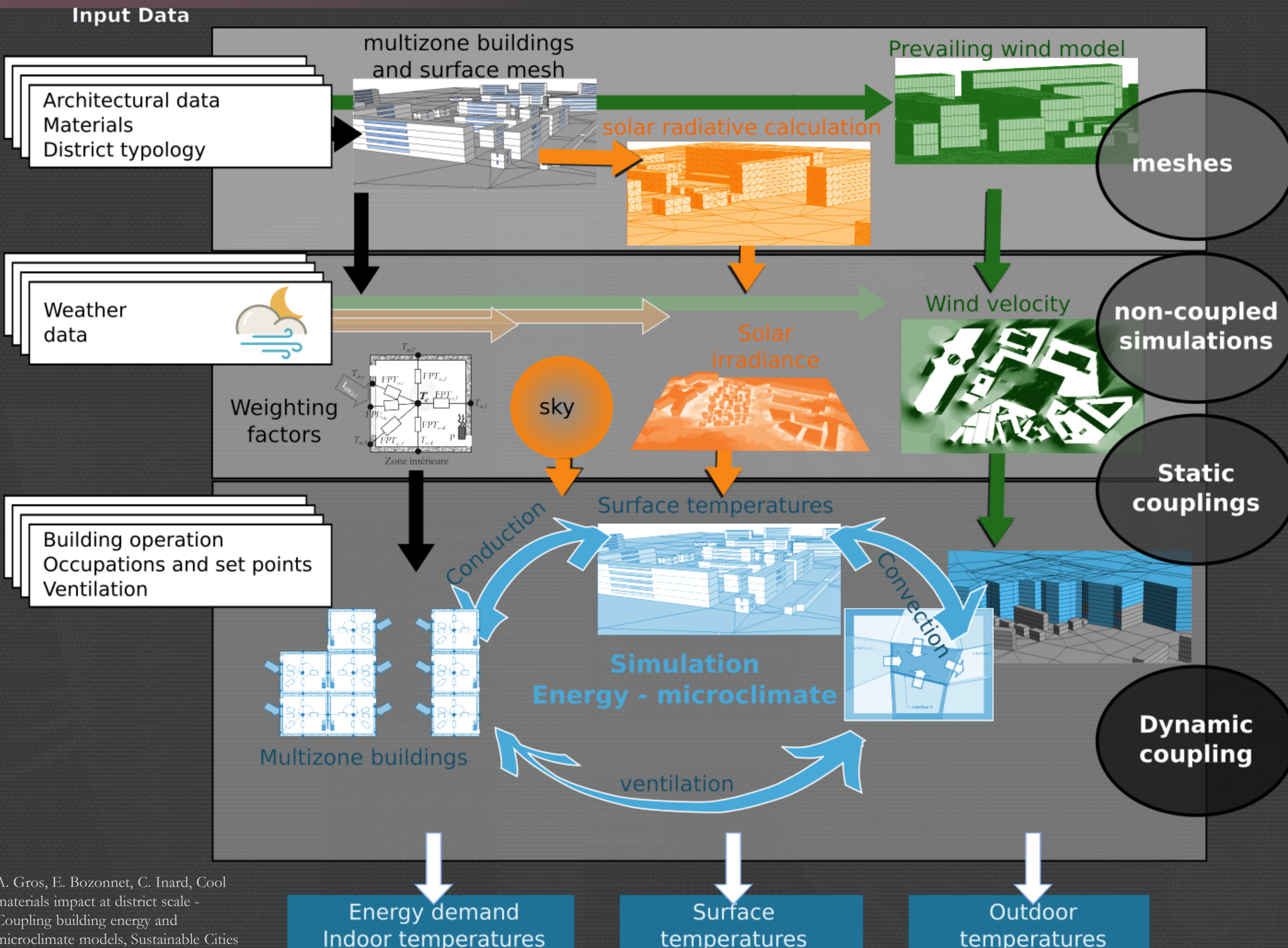
Harman et al., 2004





R. Djedjig, E. Bozonnet, R. Belarbi, Modeling green wall interactions with street canyons for building energy simulation in urban context, Urban Climate. 16 (2016) 75–85. doi:10.1016/j.uclim.2015.12.003.

Coupled model at district scale (EnviBatE)



A. Gros, E. Bozonnet, C. Inard, Cool materials impact at district scale - Coupling building energy and microclimate models, Sustainable Cities and Society. 13 (2014) 254–266. doi:10.1016/j.scs.2014.02.002.

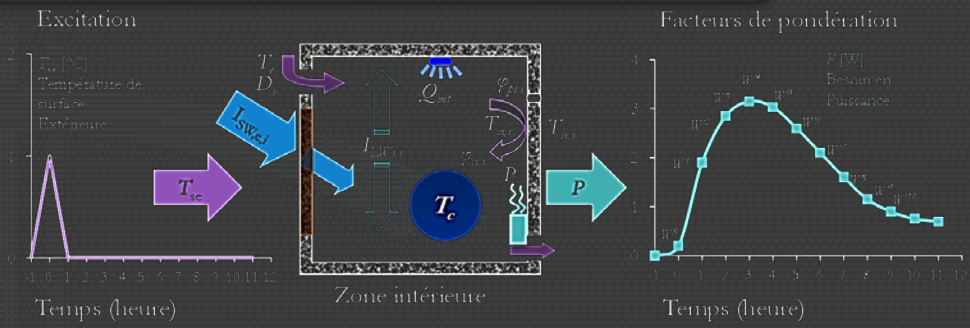
COUPLED BUILDING MODEL

Weighting factors – building response to UHI and indoor sollicitations

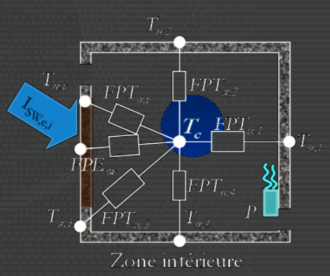
Based on response factors $Q_E{}^t$ [W] from each solicitation E at time step t

So for N_p solicitations :

$$Q_E^t = \sum_{n=0}^{N_p} W_E^n E^{t-n}$$



$$P^t = \rho c_p V \frac{\mathrm{d}T_c^t}{\mathrm{d}t} + \rho c_p D_v \left(T_c^t - T_{e,k}^t\right) - Q_{int}^t - Q_{I_{SW}}^t - Q_{T_c}^t - \sum_{j=1}^{N_p} Q_{T_{se,j}}^t$$

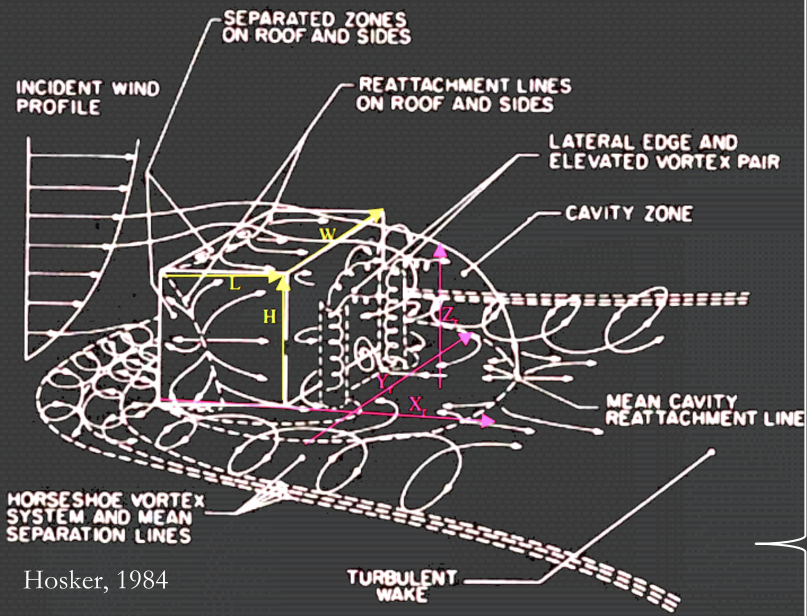


$$\begin{bmatrix} 1 & a_{01} & \cdots & a_{0Np} \\ 0 & a_{11} & \cdots & a_{1Np} \\ \vdots & \vdots & \ddots & \vdots \\ 0 & a_{Np1} & \cdots & a_{NpNp} \end{bmatrix} \begin{bmatrix} P \\ T_{se,1} \\ \vdots \\ T_{se,Np} \end{bmatrix} = \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_{Np} \end{bmatrix}$$

Coupled model

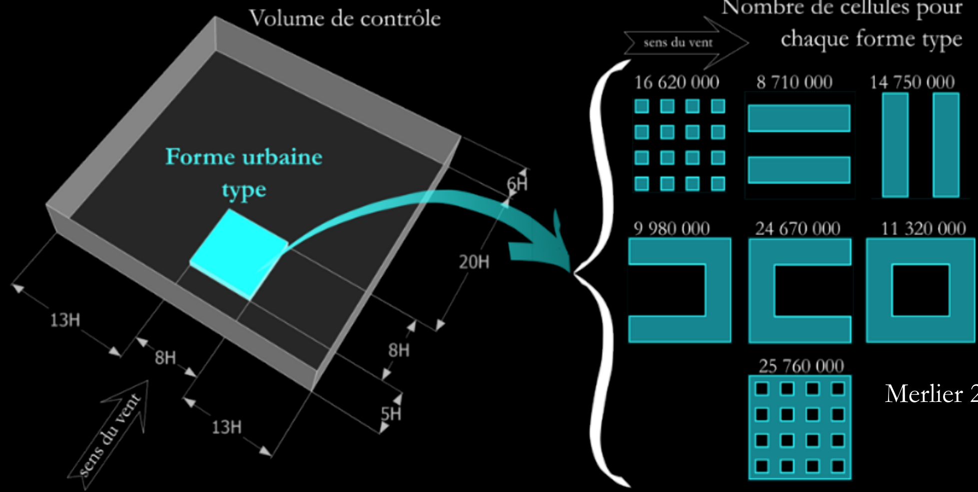
Matrix system for each zone and all district

URBAN WIND MODELS



Hosker, 1984

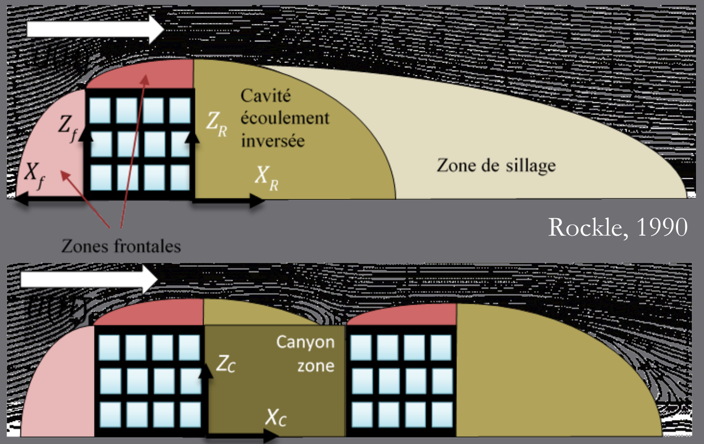
CFD
Numerical wind tunnel experiment



Merlier 2015

Large grids (13 × H on sides) to modify for each wind direction

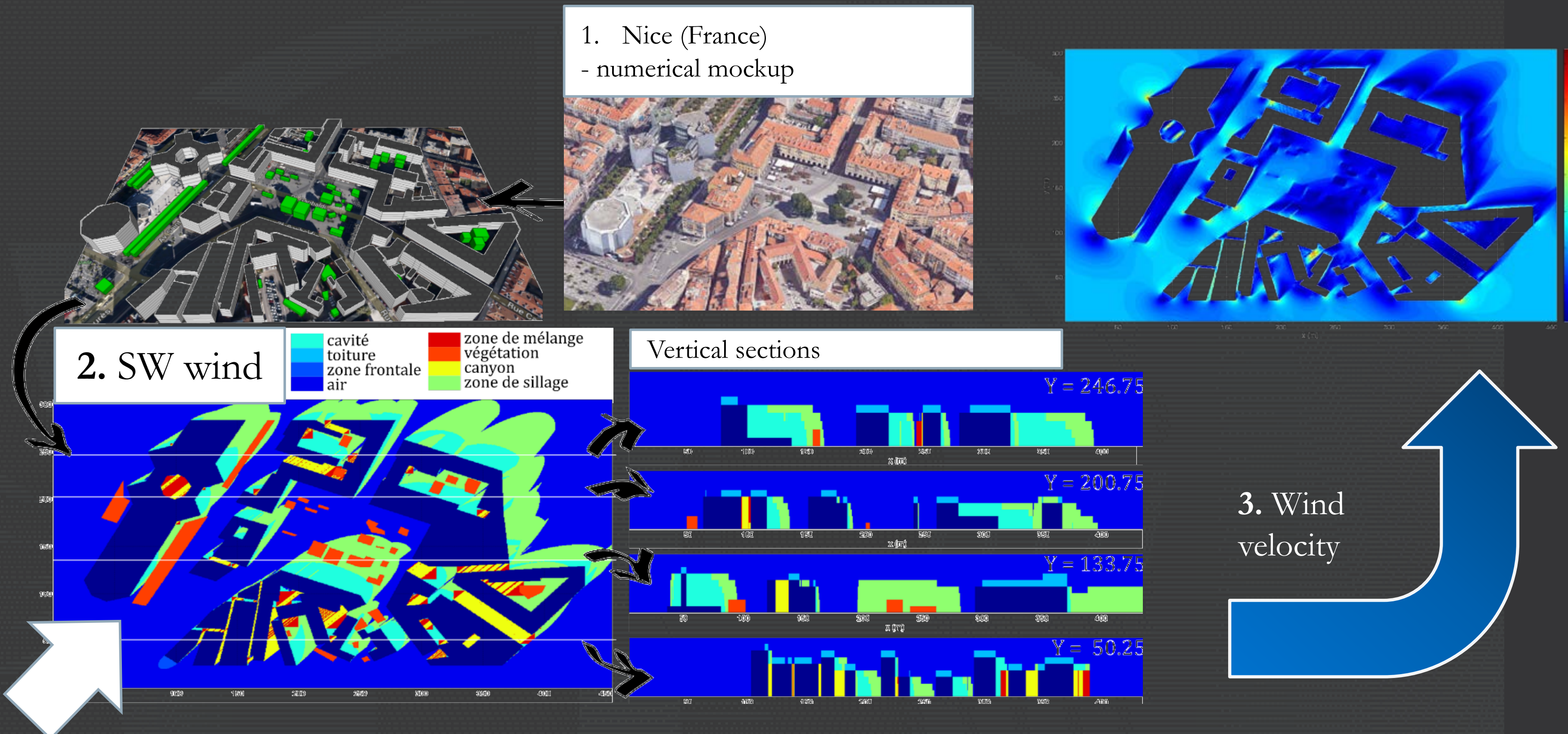
Zonal approach



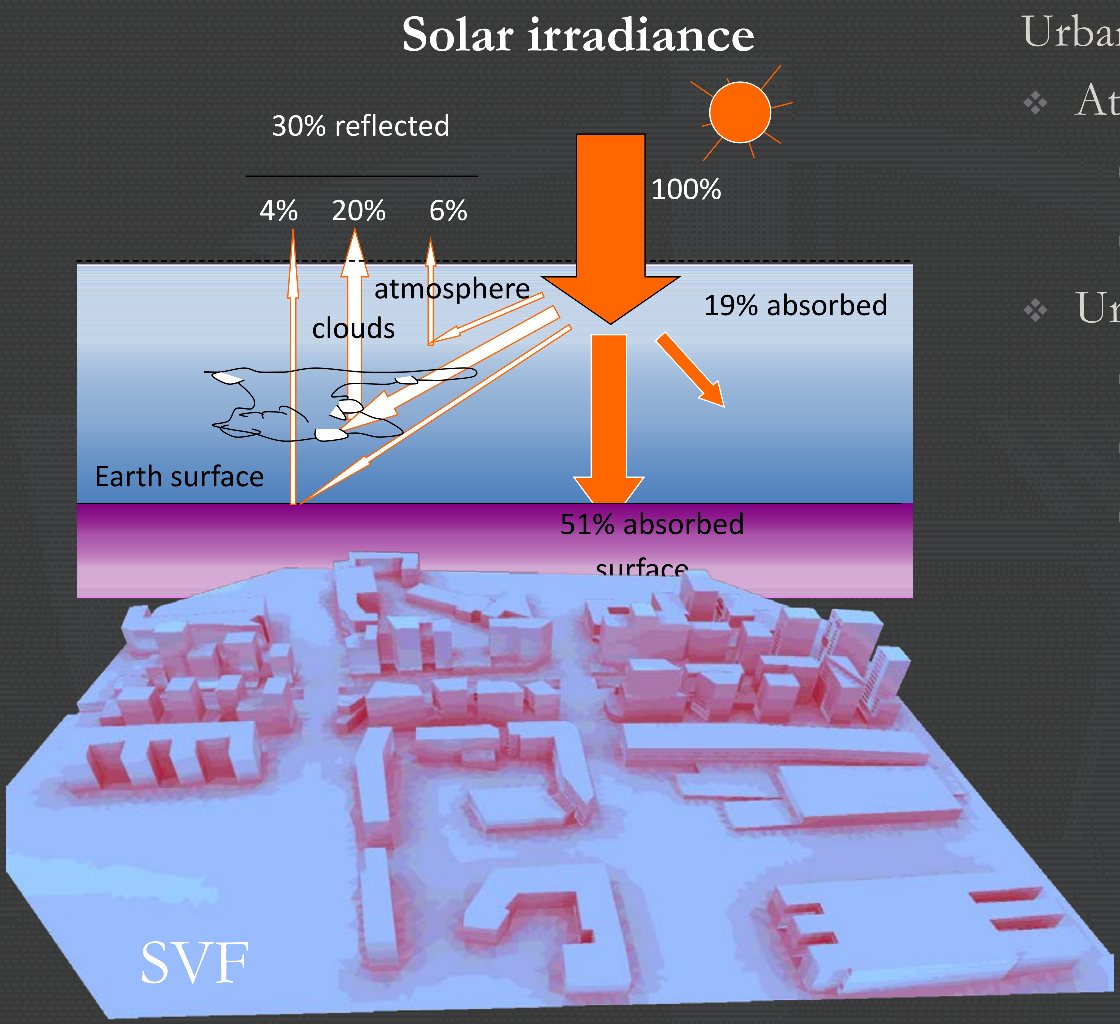
Rockle, 1990

Urban wind models

- Zonal approach depending on wind direction
- Confined zone identified at district scale



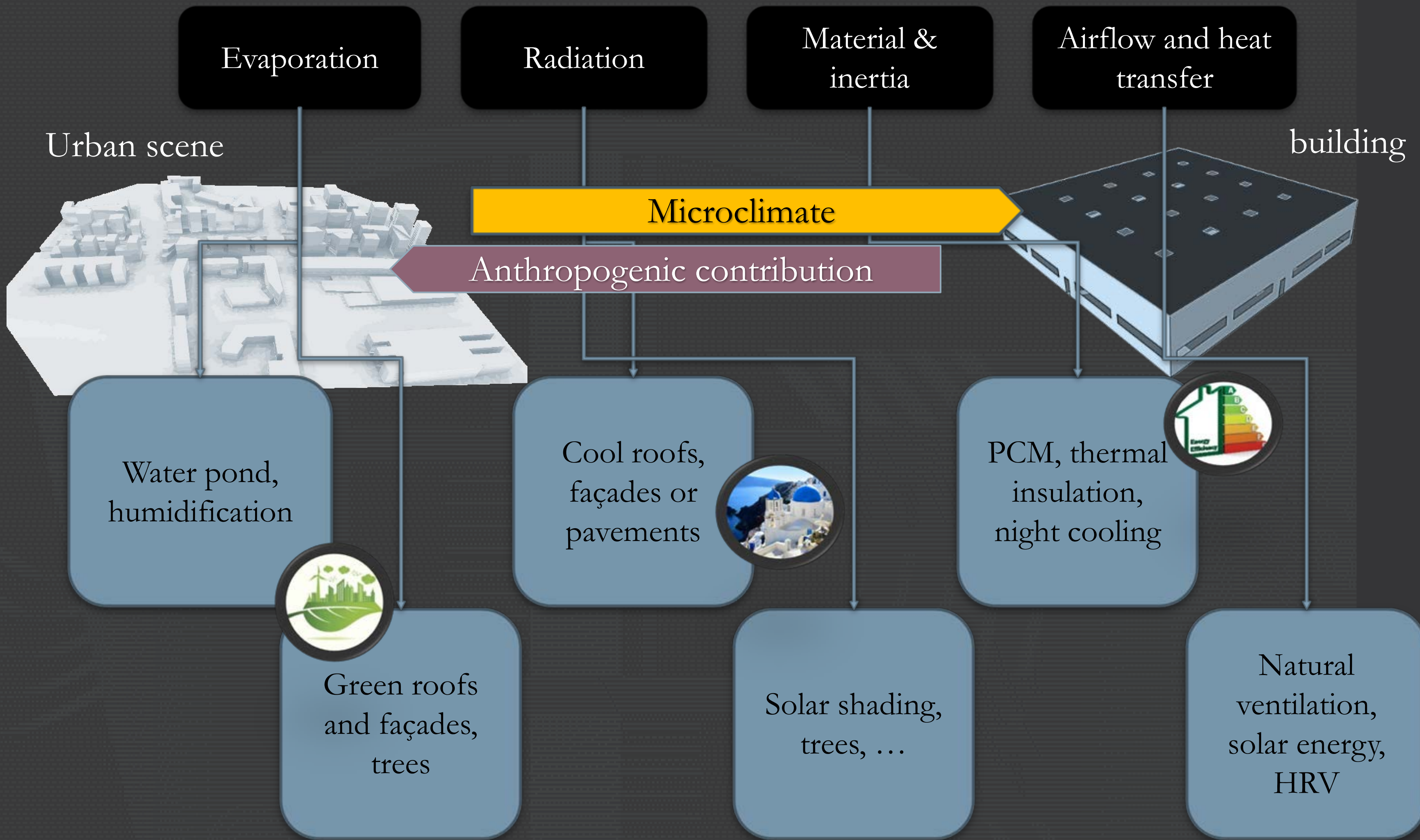
SOLAR IRRADIANCE



Urban context

- Atmospheric pollution
  - Decrease solar irradiance (SW)
  - Increased sky irradiance (LW)
- Urban morphology (density)
  - Increase mask effects (SW)
  - Decrease SVF (night cooling)
  - Radiative trapping (SW+LW)

CLIMATE ADAPTATION STRATEGIES AT DISTRICT AND BUILDING SCALE



2

UHI MITIGATION STRATEGIES

(A) Radiative cooling

(B) Green roofs and façades

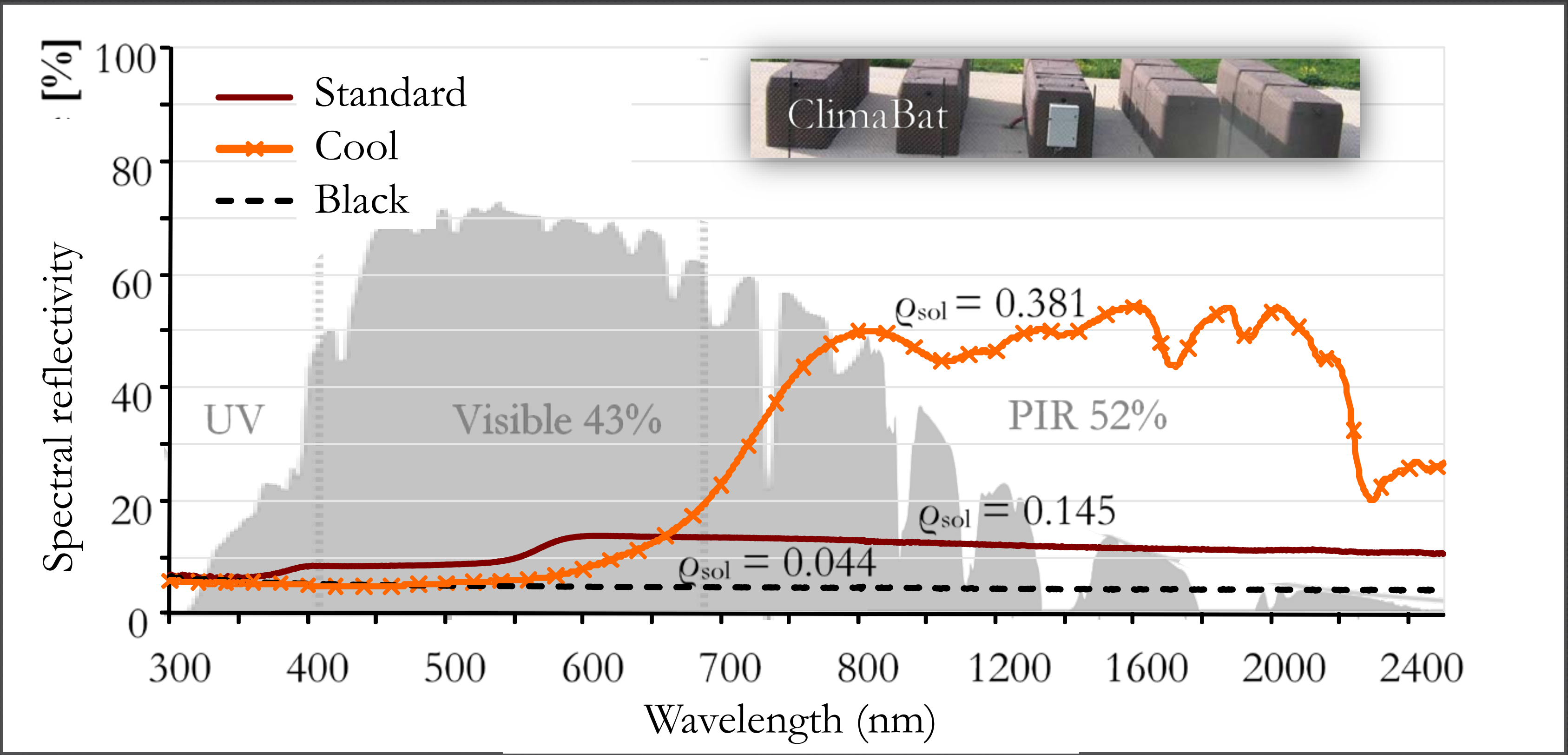
2.A

Radiative cooling strategy

Cool roofs and façades

Salt Lake City, Utah (NASA)

SPECTRAL SELECTIVITY FOR COOL COLORED PAINTS

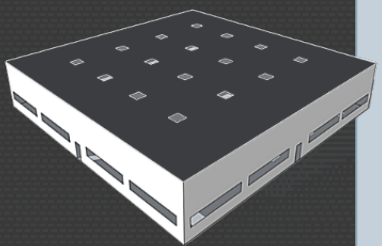


ClimaBat experiment (façades): simultaneous 3 different street configurations (standard, 2 cool façades, 1 cool + 1 standard façade)

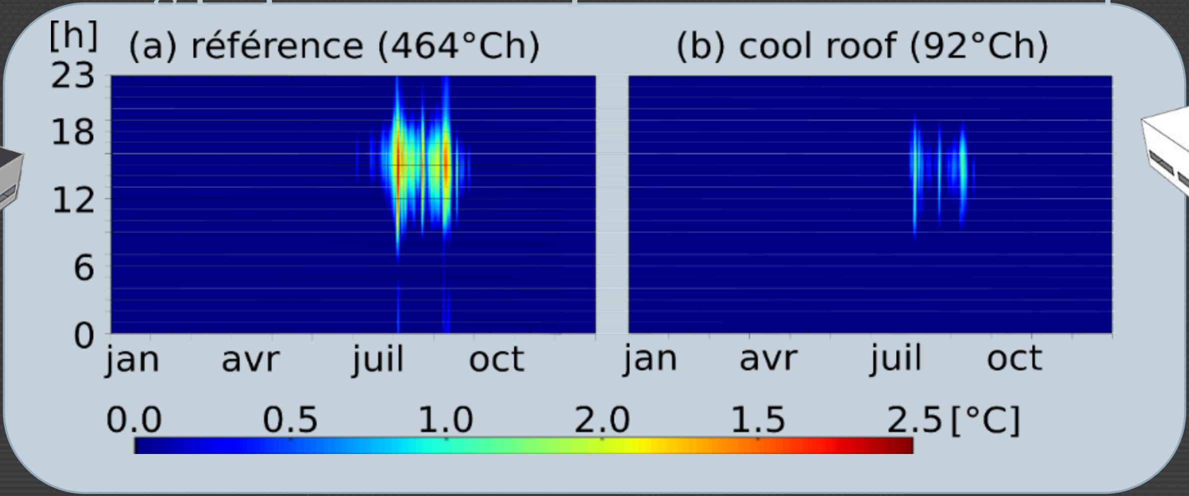
- « Building » overheating period decreases (7%)
- Indirect effect of radiative trapping into the street canyon increases with the single cool façade

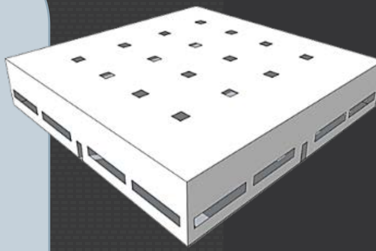
Cool roof effect on building

Overheating [°C] above the adaptive thermal comfort temperature

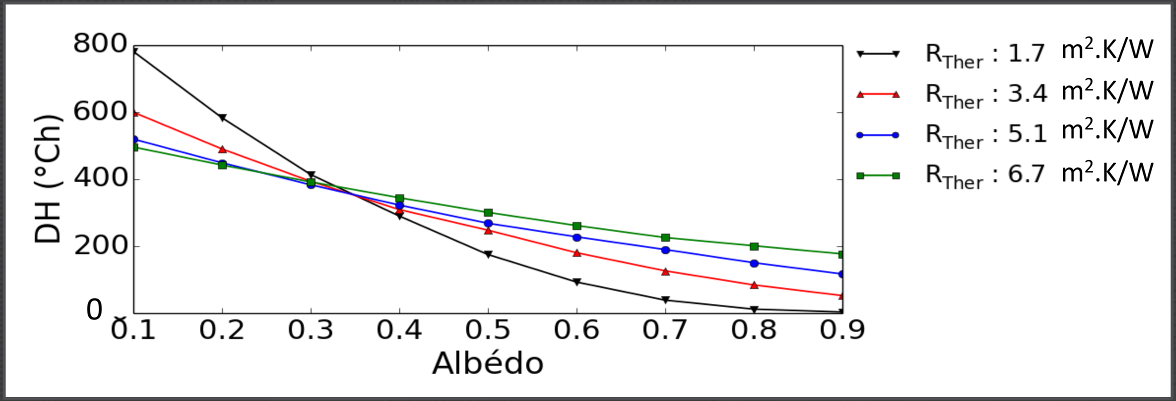


Commercial building
(Marseille)

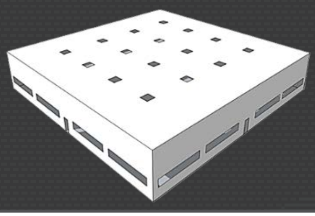




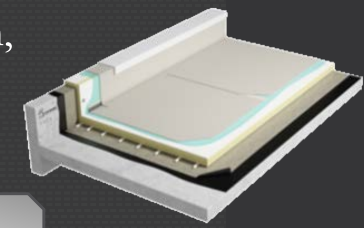
Thermal discomfort depending on building insulation and albedo

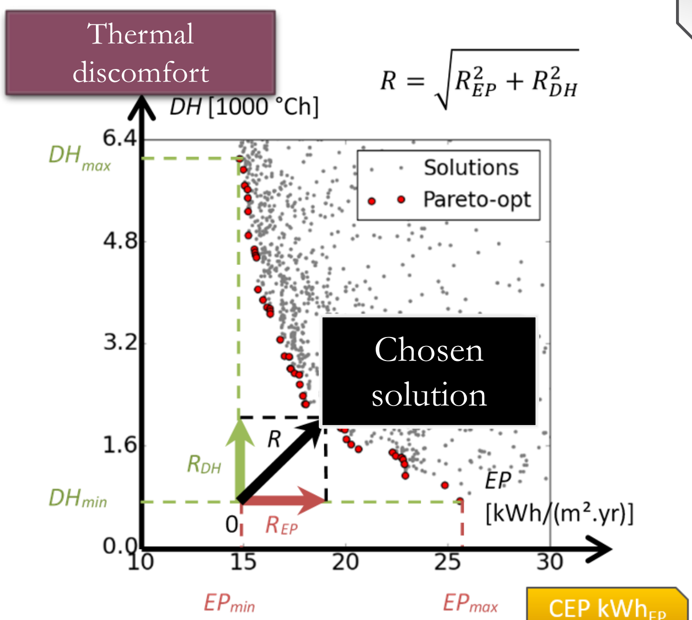


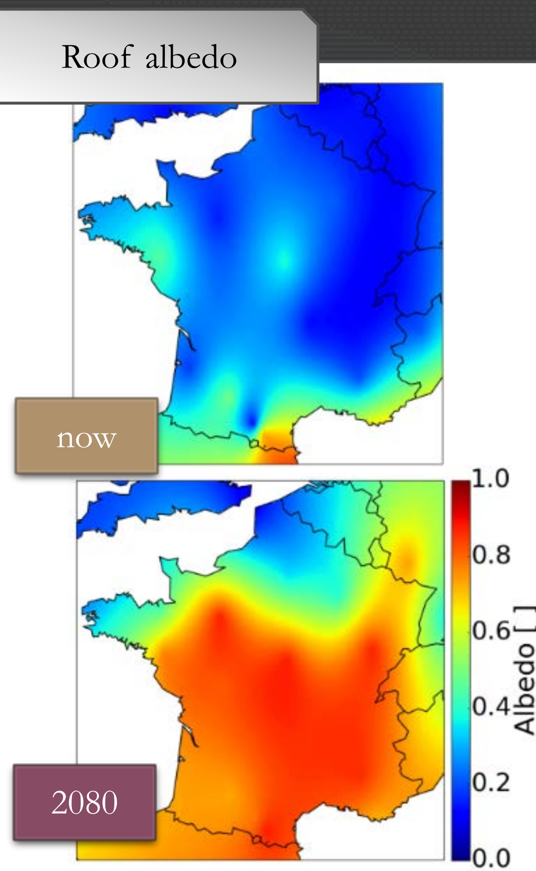
OPTIMAL BUILDING DESIGN – CLIMATE ADAPTATION

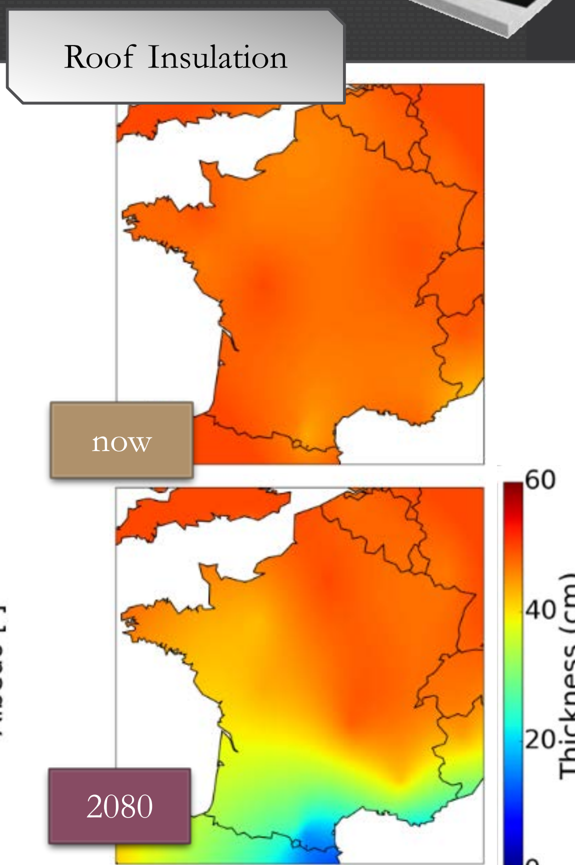


Optimal set of parameters: roof design (albedo, insulation, opening area), set points for nighttime natural ventilation, ground inertia



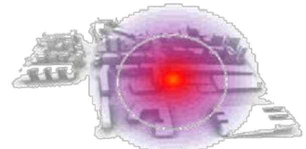




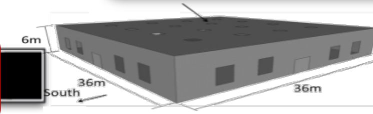


R. Lapisa, E. Bozonnet, P. Salagnac, M.O. Abadie, Optimized design of low-rise commercial buildings under various climates – Energy performance and passive cooling strategies, Building and Environment. 132 (2018) 83–95. doi:10.1016/j.buildenv.2018.01.029.

Building anthropogenic contribution

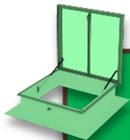


Reference

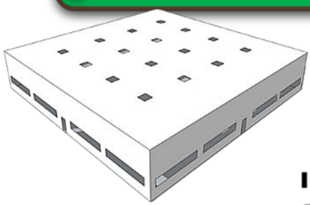


Ambient Cooling Indicator

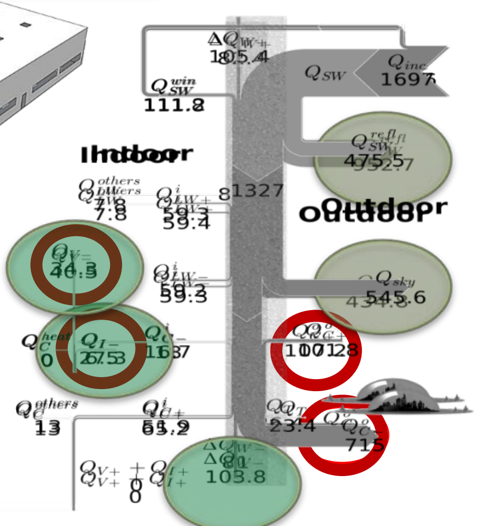
$$\eta_{\text{FRout}} = 100\,\frac{Q^{\text{ref}} - Q^{\text{o}}}{Q^{\text{o,ref}}}$$

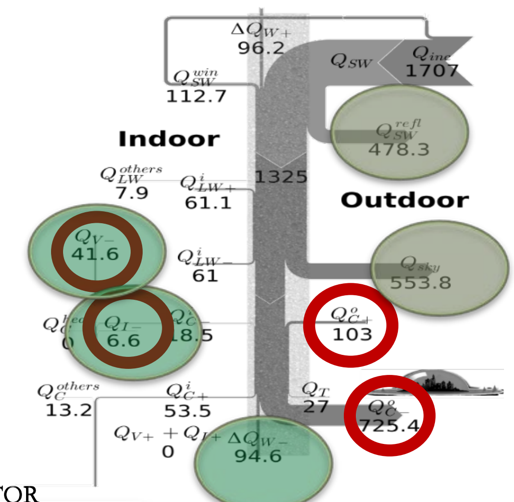


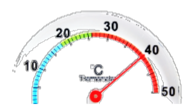
Natural Ventilation



Thermal mass & heat dissipation







Indoor Cooling Indicator

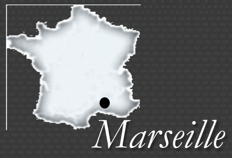
$$\eta_{\text{FRin}} = 100\,\frac{DH_{\text{ref}} - DH}{DH_{\text{ref}}}$$

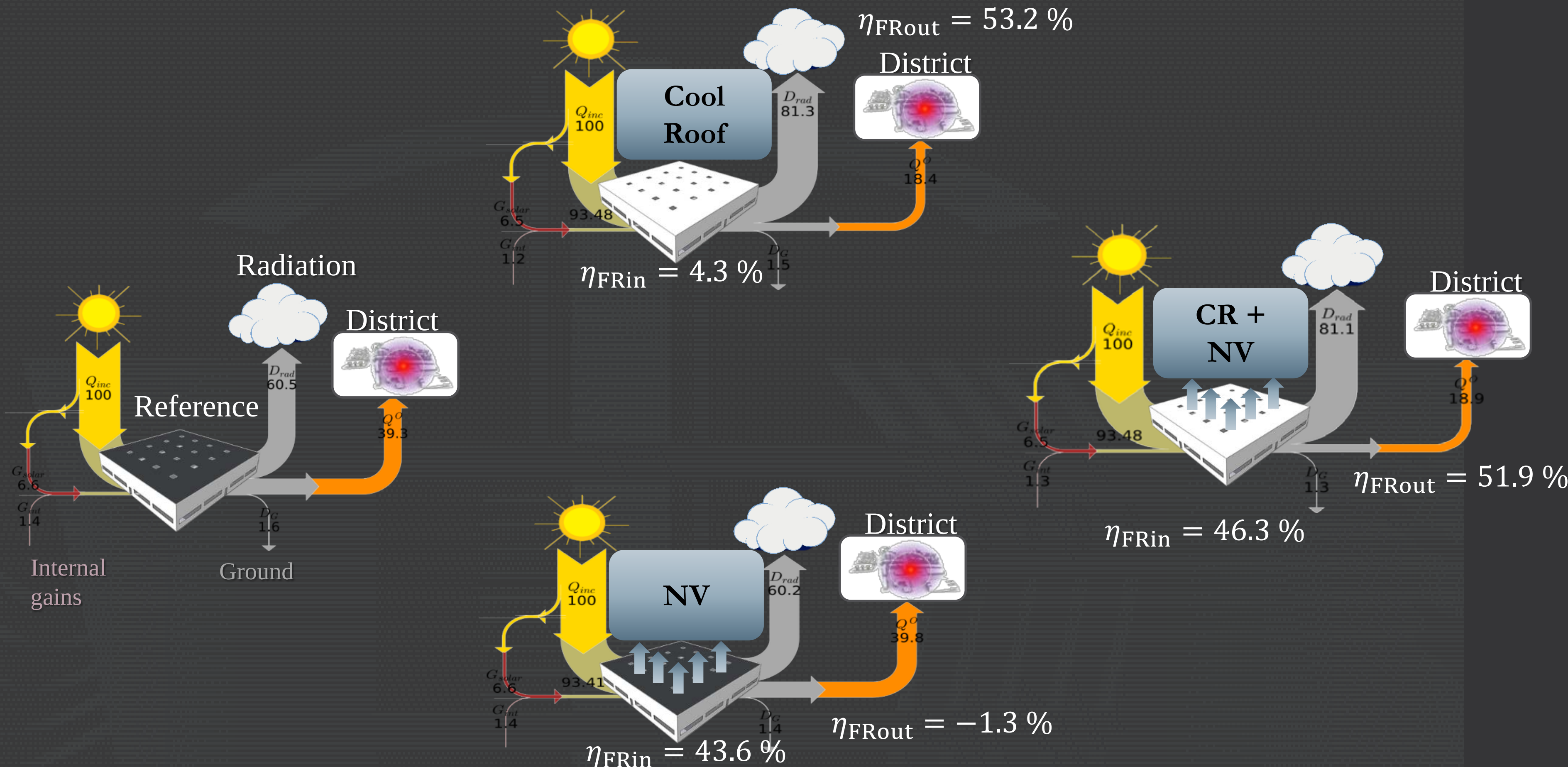
5709°Ch

10114°Ch

M. Kaboré, E. Bozonnet, P. Salagnac, M. Abadie, Indexes for passive building design in urban context – indoor and outdoor cooling potentials, Energy and Buildings. 173 (2018) 315–325. doi:10.1016/j.enbuild.2018.05.043.

BUILDING ANTHROPOGENIC CONTRIBUTION



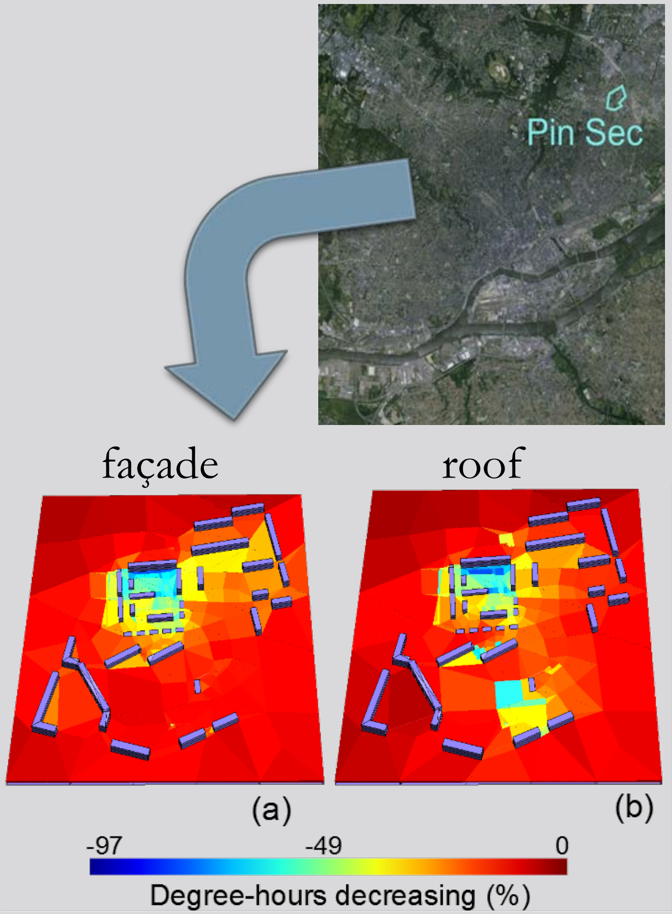


Cool roof and NV are a good combination for both UHI mitigation and direct indoor cooling

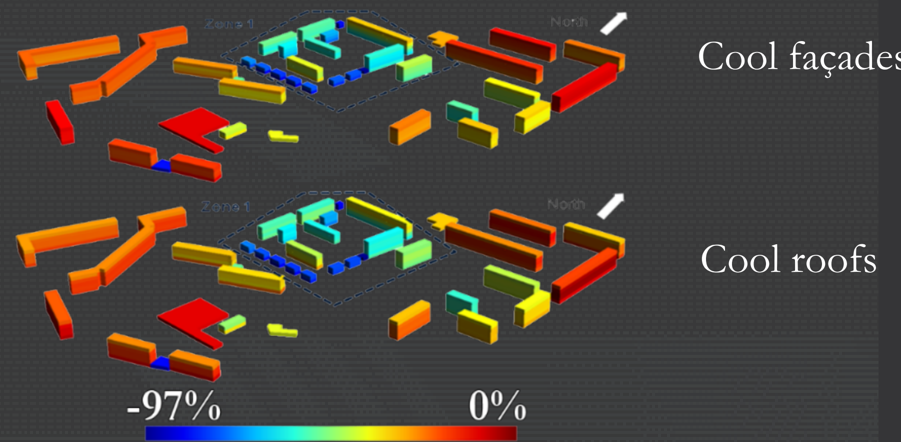
M. Kaboré, E. Bozonnet, P. Salagnac, M. Abadie, Indexes for passive building design in urban context – indoor and outdoor cooling potentials, Energy and Buildings. 173 (2018) 315–325. doi:10.1016/j.enbuild.2018.05.043.

ASSESSING DISTRICT HEAT ISLAND IMPACTS

Radiative cooling



Feedback effect on cooling energy demand



Cooling need relative decrease

A. Gros, E. Bozonnet, C. Inard, Cool materials impact at district scale - Coupling building energy and microclimate models, Sustainable Cities and Society. 13 (2014) 254–266. doi:10.1016/j.scs.2014.02.002.

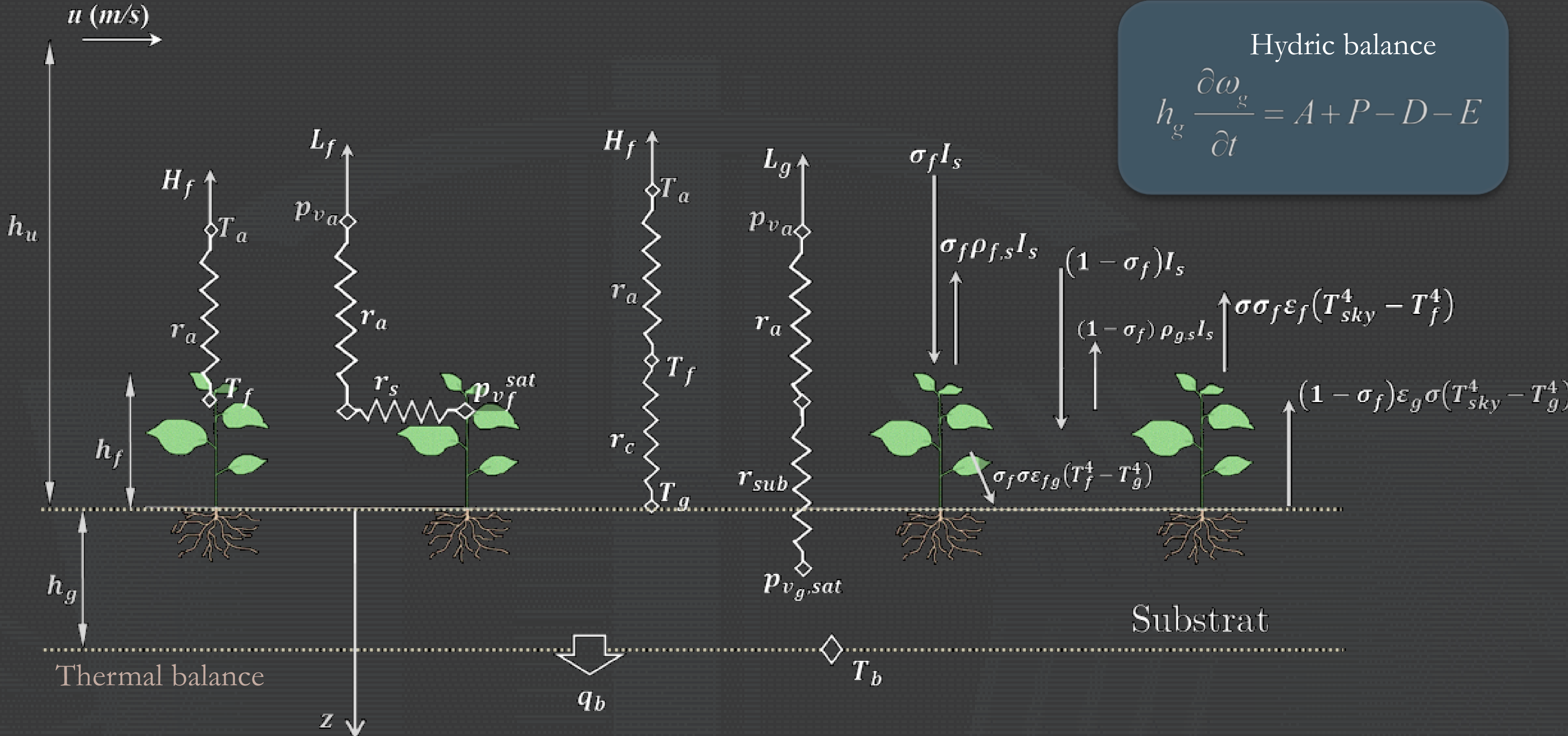
2.B

Green roofs and façades

Green envelope model – Vegetal canopy model

Hydric balance

$$h_g \frac{\partial \omega_g}{\partial t} = A + P - D - E$$



Vegetal canopy

$$(\rho c_p)_f \, d_f \, F \frac{dT_f}{dt} = Rn_f - H_f - L_f$$

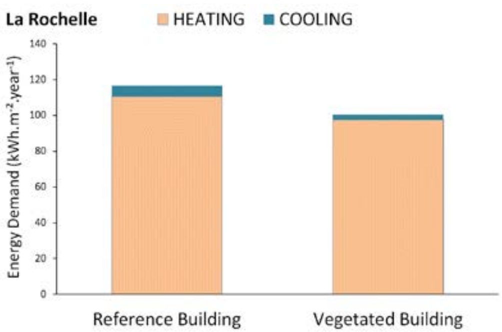
Ground

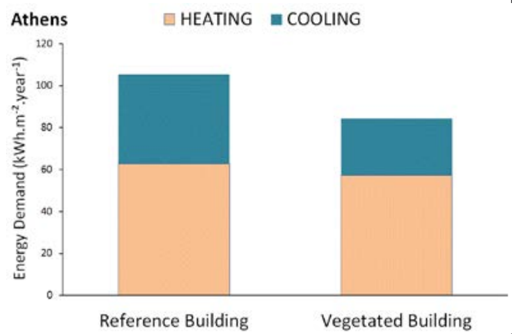
$$-k_{\omega_g} \left.\frac{\partial T}{\partial z}\right|_{z=0} = Rn_g - H_g - L_g$$

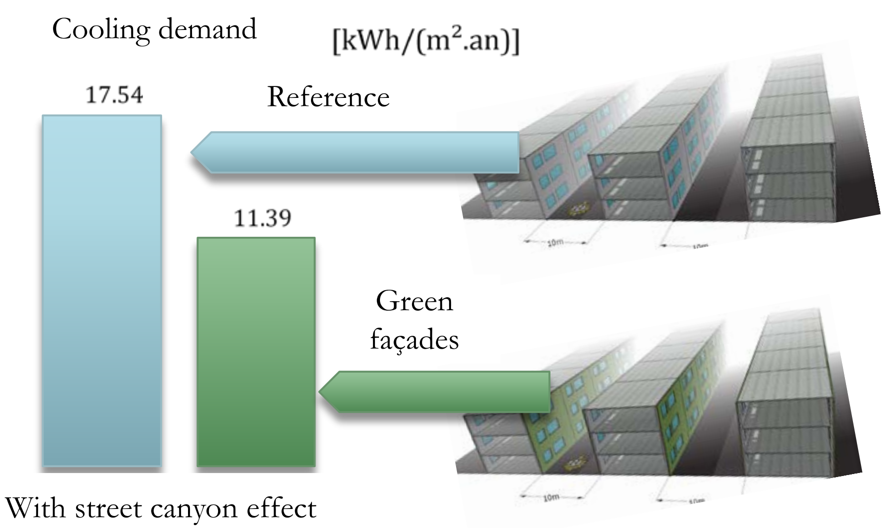
Substrate

$$\frac{\partial}{\partial t}\left[(\rho c_p)_{g,\omega_g} T \right] = \frac{\partial}{\partial z}\left(k_{\omega_g} \frac{\partial T}{\partial z} \right)$$

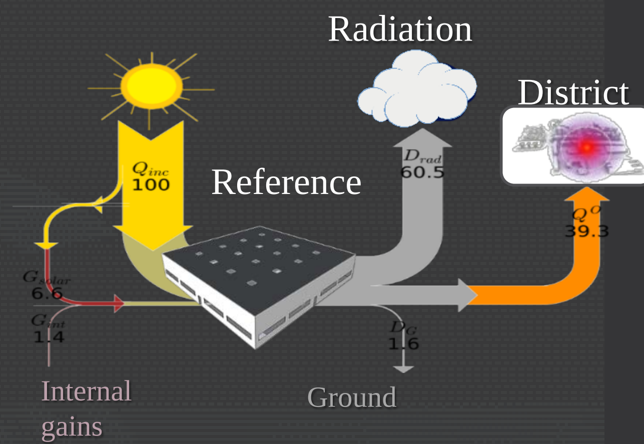
Direct effect on the building and local street canyon effect

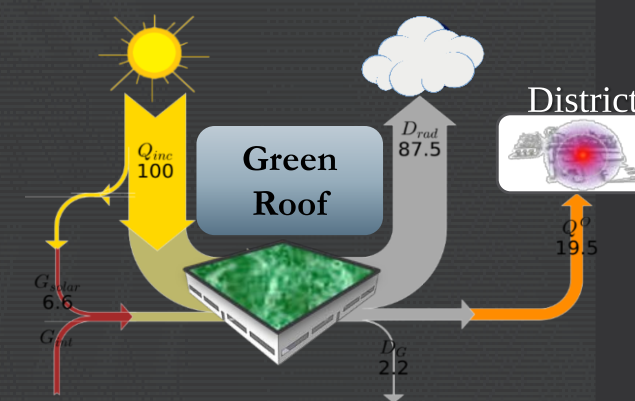






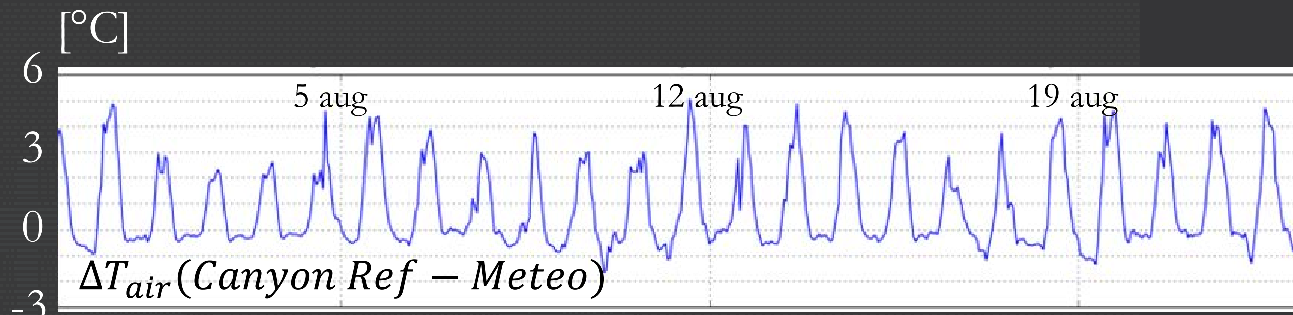
Direct effect on the UHI mitigation





Depending on the period the green roof can be a heat sink for the local environment

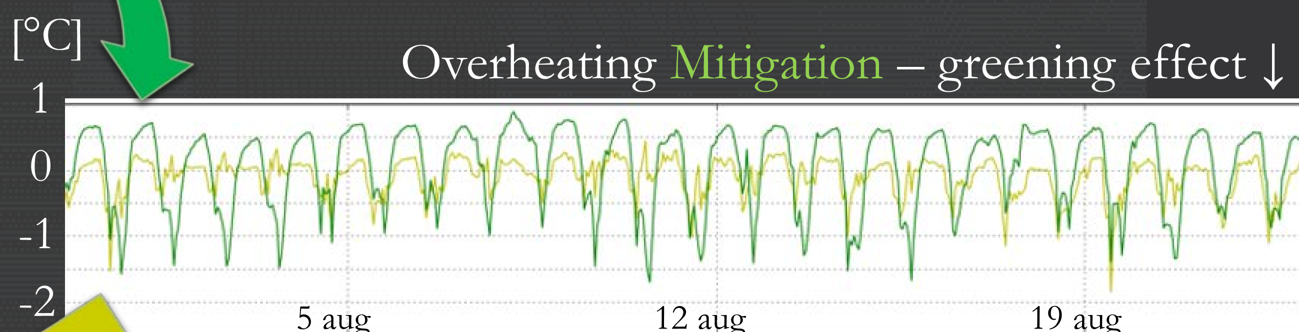
GREEN ENVELOPE – EXPERIMENTAL STUDIES

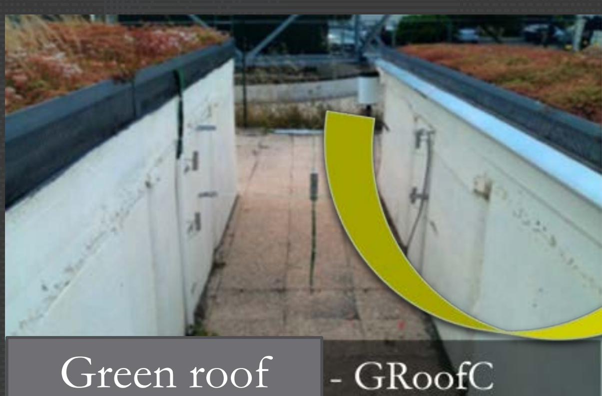


Mineral canyon – thermal Confinement ↑

$\Delta T_{airCanyon}(Green\ wall\ - Ref)$

Overheating Mitigation – greening effect ↓





$\Delta T_{airCanyon}(Green\ roof\ - Ref)$

3

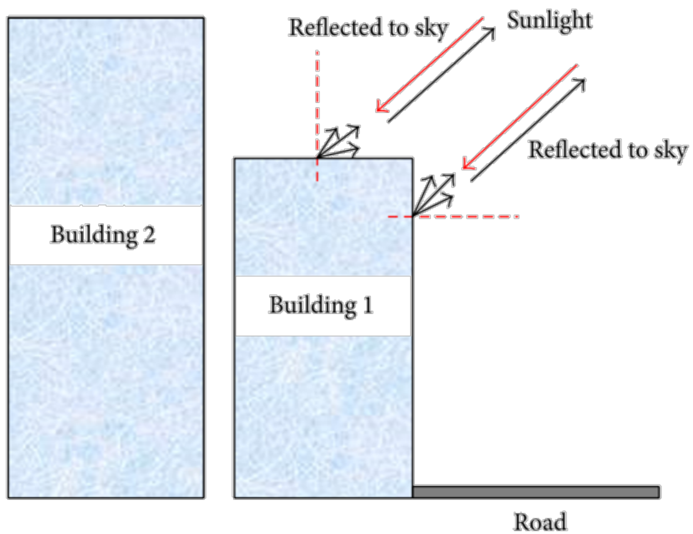
NEW CHALLENGES

New cooling techniques and new physical models to be developed

Which indicators for decision making and UHI mitigation?

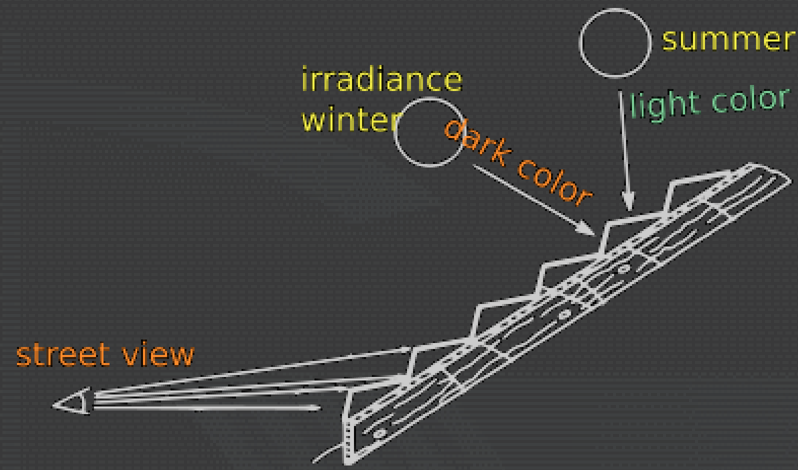
Methods and tools for district design and material design

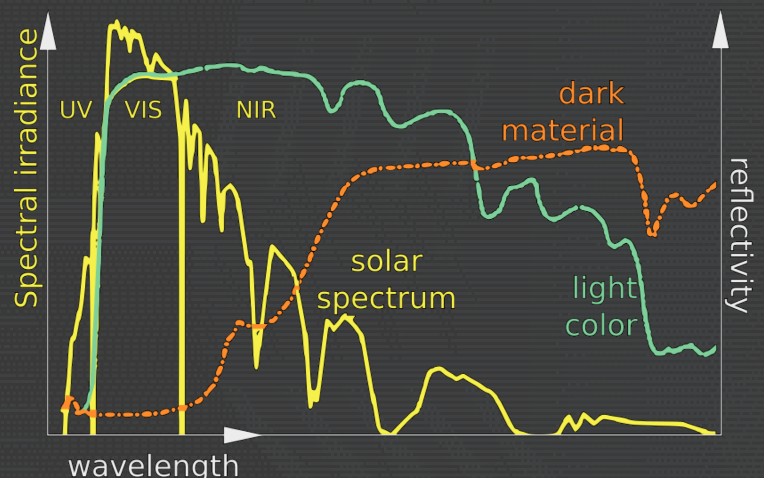
Diffuse Vs. Retroreflective material



Yuan et al., 2015

Asphalt with hybrid reflectance





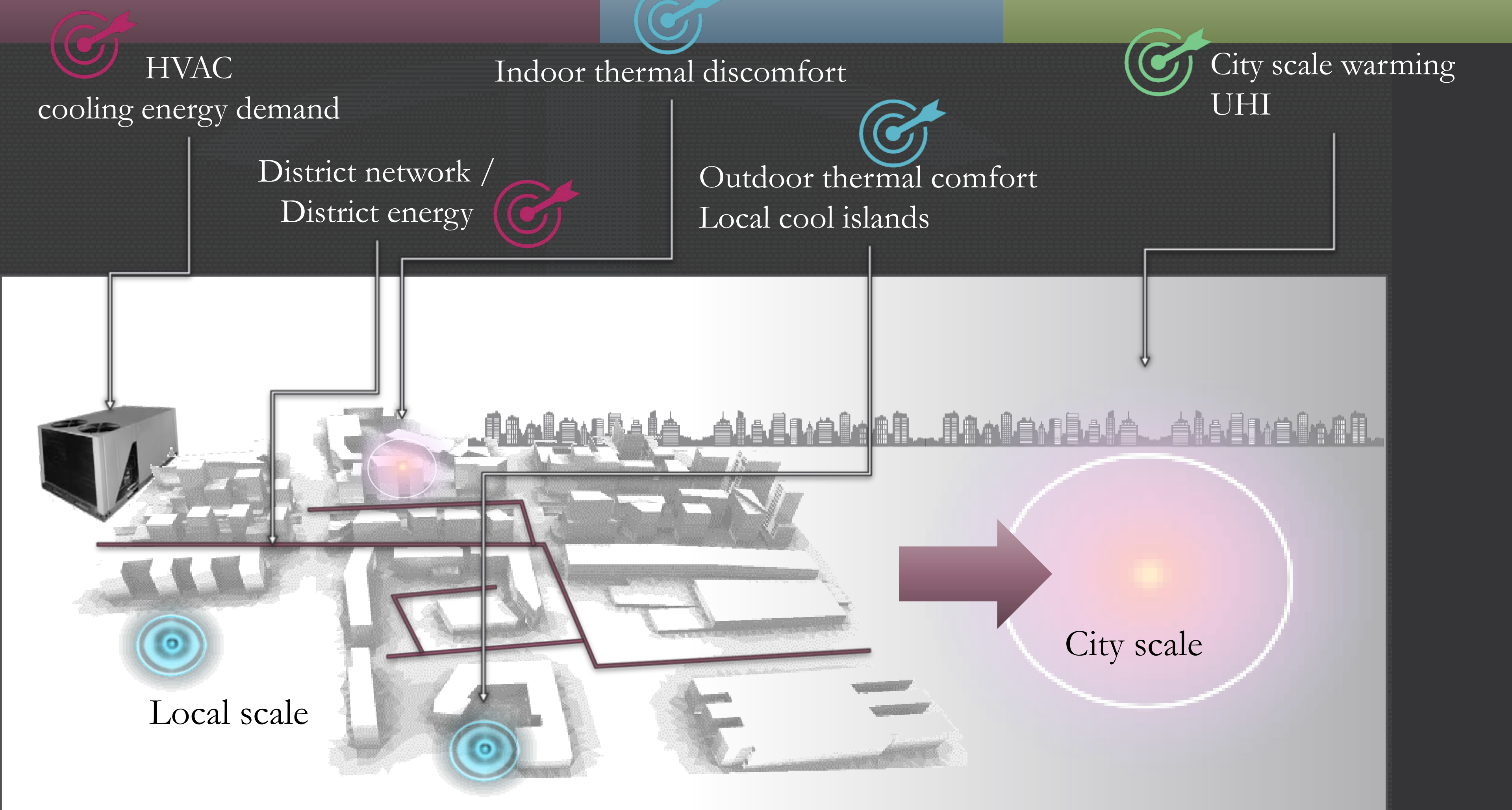
TARGETS

Model adaptation
Limitations of standard radiosity methods

Optimal material surface design

Cooling strategies vs. KPIs

Energy	Comfort	Environment



Eco-District - from adaptive material (microscale) to adaptive district design (local scale)

Conclusion & outlooks

Some new cooling techniques and some new physical models to be developed

Which indicators for decision making and UHI mitigation?

Increased performance…

- Wind velocities and thermal buoyancy coupling effects
- Limitations of CFD approaches for coupled effects and long periods (especially for heatwaves effects)
- Fast radiative calculations (LW and thermal coupled effects)

… & new abilities for physical models

- Selective materials (3 bands calculations)
- Diffuse vs. Specular radiations
- Systems and district network coupling

Outlooks

- Monte Carlo models
- CFD alternatives
- Open source codes for coupled districts / buildings / energy networks

Definition of KPIs vs. end users…

- Urban climate >> Urban planner
- Eco district design >> Local stakeholder

Thermal comfort…

- Local climate change

>> local cool island effect

- Inhabitant behavior & open space use

… & experimental validations

- Local scale effects (street and district)
- Errors and sensitivity analysis of KPIs

Outlooks

- Numerical & experimental sensitivity analysis of KPIs
- Coupling effects and design methodologies
- KPIs for district design standards

Targets and context

Villeneuve-les-Salines district (France)
Variety of building typologies
Multidisciplinary approach
Use of research methods developed in labs
Documentation of the real case study for rehabilitation

Thanks for attention