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## To cite this version:

Georgios-Evrystheas Kyriakodis, Maxime Doya, Emmanuel Bozonnet, Peter Riederer. Eco-district design and decision process through building energy and local microclimate assessment. PLEA2017, Jul 2017, Edinburgh, United Kingdom. hal-02005525

**HAL Id: hal-02005525**

**https://hal.science/hal-02005525v1**

Submitted on 4 Feb 2019

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# Eco-district design and decision process through building energy and local microclimate assessment

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**Abstract:** The study presents how numerical simulations can be used and complexity to define key indicators for microclimate in eco-district modelling. For eco-district design, policy makers require decision support tools for integration of local environment issues with building design. In a first approach we analyse main environmental parameters that impact building energy performances and open-space thermal comfort. This is a key issue considering the local urban heat island impacts on energy and health. The urban area Cité Descartes is located in Paris suburbs (France) and has been selected in the French eco-district program. One objective is to renew the surroundings of a local train station that separates a low-income residential area and a business district. The study focuses on the central block of buildings covering a total area of 120,200 m$^2$. The objective of the study is to evaluate main micrometeorological parameters influencing thermal comfort and building energy efficiency in the selected urban scenes; e.g. the wind flow patterns highlight discomfort zones for winter and summer periods. Finally, numerical simulations tools are used to underline the spatial and temporal variability of urban states which makes both difficult the analysis of one urban design and the decision process between several urban cooling strategies. The perspectives to develop new decision support indicators for energy and environmental performance are reviewed and proposed to develop both necessary simulation tools and decision support systems.

**Keywords**: Coupled simulation platforms, UHI mitigation, Cool materials, Passive Cooling, Urban Indicators

## Introduction

In an emerging plan of sustainable and resilient development of urban landscape, stakeholders, urban planners and building physicists have to collaborate to produce the optimum results for decision processing with respect to roadmap for a competitive low carbon economy. Buildings, outdoor spaces, energy systems and networks interact with the ambient environment and this bidirectional process leads to a holistic perspective of evaluating the total footprint of each renovated or newly built area. Furthermore, local climate change, resulting from Urban Heat Island (UHI) effect constitutes a significant threat to the thermal balance of the cities which has to be properly addressed (Santamouris et al., 2015).

Ongoing trends in rehabilitation projects and computational platforms require simulations at urban-quarter level in order to take into account all the important physical

interactions of the urban microclimate as well as to produce robust and accurate results for entire districts. Previous studies of coupled heat and mass transfer simulations indicate that energy demand could rise from 100% to 140% for a typical summer month, when the produced heat of a typical air conditioner system is taken into account (Bozonnet et al., 2007).

To this end, simulation tools are identified to take into account coupled effects of local microclimate and building energy, as in EnviBatE platform (Gros et al., 2014), and district energy systems and networks, as in DIMOSIM (Riederer et al., 2015). Coupling methodology is discussed regarding common physical parameters and outputs in terms of environmental parameters and energy systems concurrently. The conceptual design of NZEB or ZEB communities becomes tangible and a zero carbon emission development is looming. Then, main simulation outputs have to be consistent with quantitative Key Performance Indicators for district level regarding environmental, social and economic performance. As a matter of urgency the general objectives of this complex system in decision processing, arising from changes in the simulation field, have to be established.

In the case study of this paper, one key issue is to determine the optimum retrofitted solution concerning the energy demand of buildings with respect to indoor and outdoor environmental comfort of the urban area. This district has been selected in the framework of the national eco-district program. Cité Descartes is located in Paris suburbs, and this development of new quantitative indicators for energy and environmental performance will be integrated with other design parameters by urban planners.

**Coupled simulation tools and parameters**

The methodology and the different steps that will be taken to couple the simulation platforms and to prioritize the necessary parameters for designing an optimum Decision Support System architecture is presented analytically in this section.

Environmental and building energy tools are assessed through EnviBatE (Figure 1-left part). This modelling approach is based on a zonal model for the urban canopy layer around buildings which is meshed consistently with the building multizone approach (Gros et al., 2014). This allows us to assess UHI effect and its impact on building energy consumption. The necessary inputs correspond to weather data, geometrical and thermophysical properties of urban structures, activity schedules including occupancy. External weather phenomena are pre-processed: solar radiation with SOLENE (Miguet and Groleau, 2007) and prevailing wind airflows with QUIC (Singh et al., 2008). Annual simulations perform both indoor and outdoor thermal conditions for an hourly time step, while energy loads are also computed. These detailed results have to be compared in order to support the decision process and to assess the passive cooling strategies at a district scale. In parallel the simulation platform DIMOSIM (Riederer et al., 2015) consists of a building model (grey R7C4 model), a thermal network model and a local/central generator model. This has been developed to simulate the key phenomena for the dynamic analysis of energy systems and networks in districts (Figure 1-right part). The definition of the district (building and occupants typologies, appliances) is defined by a top-down approach from statistical data. The housing and district load curves are built through a bottom up approach based on stochastic triggering appliances scenarios (Gay and Schetelat, 2013). Generation of abovementioned data is required, as well as necessary geometrical data, to perform an annual simulation and obtain results regarding energy consumption, loads and renewable production. Moreover it is capable to simulate efficiently the implementation of district networks. The modular approach of the tool could

allow the user to apply an alternate level of detail model, depending on the objectives of the study.

As a compromise between the triptych of accuracy, robustness and speed the main calculation cores and physical simplification are kept on both platforms. Coupling the abovementioned platforms is possible through the common building envelope and thermal zones. The main outputs given for a whole year or season with an hourly time step will allow the optimisation of district energy concepts (building retrofit, smart grids, local/district systems) as well as the possible UHI mitigation strategies. Nevertheless, these results given at a detailed spatial and temporal scale, as illustrated in the next part, require a substantive and comprehensive performance analysis.

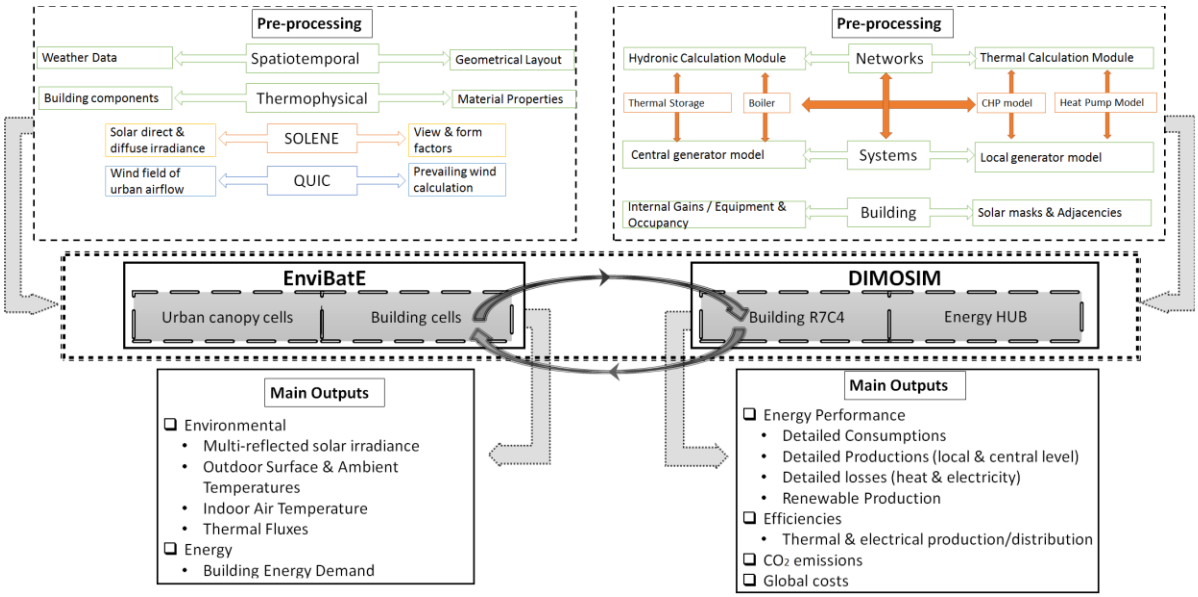


Figure 1: Concise presentation of the referenced models.

## Environmental impacts - case study

### *The ecodistrict Cité Descartes*

The refurbished urban area Cité Descartes is located in Paris suburbs (France) and intends to develop the surroundings of a local train station with residential and office buildings (Figure 2). The first sketch data were processed to build the numerical mock-up for our thermophysical study. Three building blocks are organized north and south of the suburban train station network and perpendicular to main boulevards of road traffic. A vegetated corridor crosses the built environment and participates to the mitigation of urban heat island effect. The study focuses on the central building block which includes dwellings (15,000 m²), offices (85,000 m²), commercial buildings (3,200 m²) and underground parking lots (17,000 m²). The higher buildings are 50m high and the pedestrian area is decomposed in several height levels between 6 and 15 meter above the rails. The composition of building envelopes and other necessary parameters including occupancy schedules, infiltration rate, electrical equipment, heating and cooling set-points have been imported to the simulation platform respecting national standards and regulations, as described in (*RT2012*, 2010). The existing building (residential, offices or commercial premises) were represented as made of conventional building materials (Table 1) and are not insulated. The in-work building and future buildings were also made of conventional building materials and insulated according

to current energy regulations, without presenting any innovative UHI mitigation technique including smart coatings or PCM. Thus, simulations are prepared covering three additional case studies.

Figure 2: A satellite image (left) and the respective architectural design (right) of the referenced area, Cite Descartes.

Table 1: Thermophysical properties of building materials.

| Construction Components | Thickness [m] | Thermal Conductivity [W/m K] | Density [kg/m$^3$] | Sp. Thermal Capacity [J/kg K] | Reflectance - | Emissivity - |
|---|---|---|---|---|---|---|
| **Traffic Axis** | | | | | | |
| Asphalt | 0.100 | 0.75 | 2100 | 950 | 0.10 | 0.9 |
| Concrete | 0.500 | 1.75 | 2300 | 1000 | 0.25 | 0.9 |
| **Building Envelope** | | | | | | |
| Concrete | 0.150 | 1.75 | 2300 | 1000 | 0.25 | 0.9 |
| **Building roof** | | | | | | |
| Concrete | 0.200 | 1.75 | 2300 | 1000 | 0.30 | 0.9 |
| **Glazing** | | | | | | |
| Glass | 0.060 | 1.00 | 2100 | 750 | 0.60 | 0.9 |
| Air | 0.012 | 0.04 | 1.25 | 1000 | - | - |
| Glass | 0.060 | 1.00 | 2100 | 750 | - | - |

The meteorological data were imported from Meteonorm closest station (Marne la Vallée) and were interpolated to 2030 according to the A1B future scenario of forcing agents given in the IPCC Special Report, describing a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies.

The average ambient temperature during the entire cooling period was 18.97°C while the warmest month (July) presented a value of 21.03°C respectively. The peak ambient temperature is monitored at 21st of July reaching 33.9°C (Figure 3), while the corresponding relative humidity presented a value of 43%. In addition, wind speed presented a local minimum value of 0.7m/s enhancing buoyancy phenomena and the impact of building materials into the thermal regime of the area.

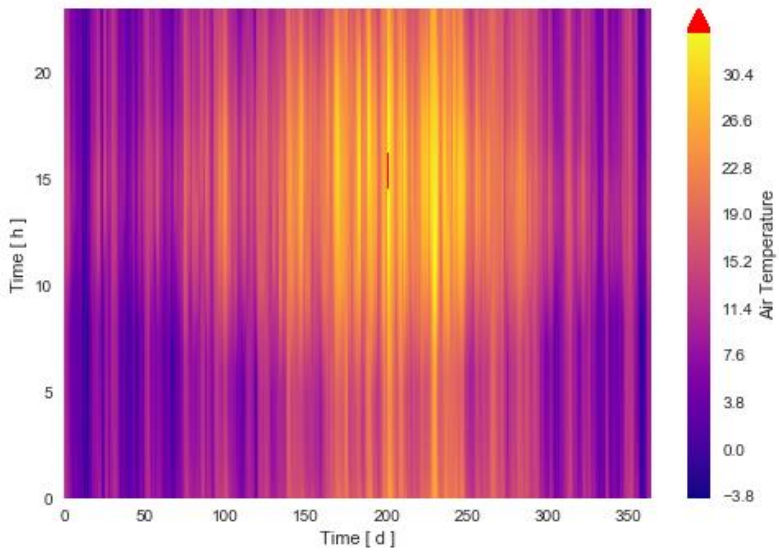


Figure 3: Air Temperature variations of the implemented meteorological scenario for an annual period (x: day of the year, y: hour of the day).

Furthermore, the dominant wind speed and direction for the entire cooling season (May-September) is depicted in Figure 4 (left part). A leading west wind of up to 10.9 m/s is observed with a frequency of 11.1%, while NWW (292.5°) and SWW (247.5°) were also significant presenting a range of up to 10.9 m/s (10%) and 10.9 m/s (9.8%) respectively. In parallel the Global Solar radiation presented a maximum value of 950 W/m$^2$ in early June while the average monthly values during the entire cooling season are shown in Figure 4 (right part).

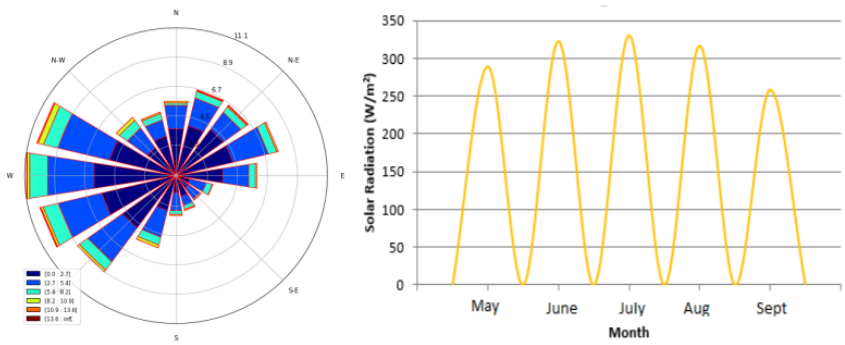


Figure 4: Wind distribution (left) and monthly average Global Solar Radiation (right) during the summer period.

### *Spatially detailed microclimate parameters*

Microclimate, local UHI effects and district energy performance outputs are directly dependent on radiative (longwave and shortwave) and prevailing wind distributions as underlined in the simulation method (Figure 1). Urban albedo is one of the prevailing parameter. The overall reflectivity index is depicted in Figure 5. It is observed a poor albedo performance, as most of the surface values ranging between 0.10-0.30. The central block exhibits also clear mineral pavement with albedo 0.4 and accessible rooftop with albedo 0.5. Several publications report that the average and maximum air temperature drops per 10% increase of the albedo are 0.23K and 0.62K for the cool roofs, 0.27K and 0.94K for the cool pavements and 0.35K and 0.91K for their combination, with respect to the specific technologies (Santamouris et al., 2016).

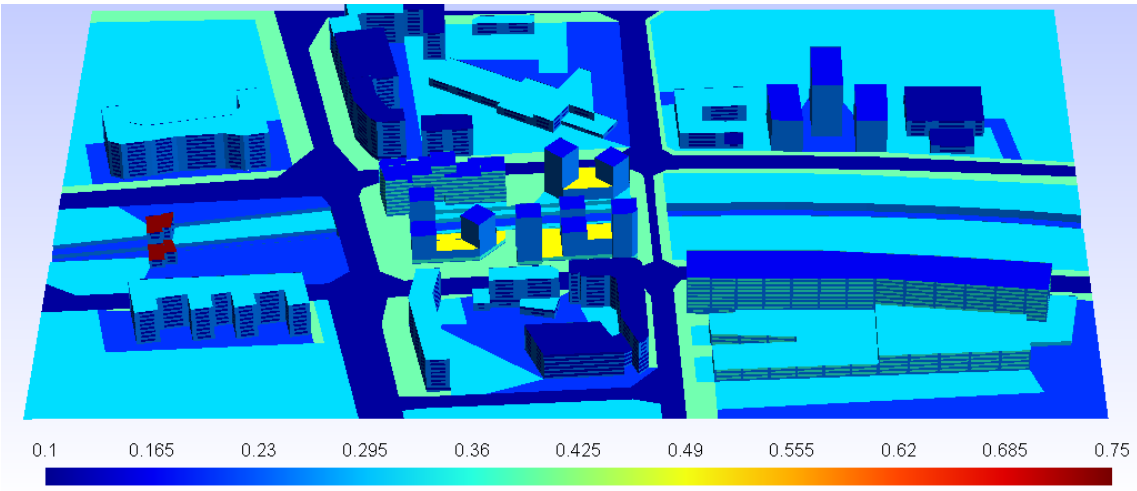


Figure 5: Albedo variations of the referenced district.

Furthermore, building roofs are totally exposed to solar radiation gains (Figure 6-Plain). Due to this fact the overheating of the adjacent floors is ineluctable, leading to higher indoor air temperatures, significant indoor discomfort and increased energy loads. In parallel, Figure 6 (East and West view) could provide some crucial outcomes regarding the pedestrian area by choosing the best option of where the shading objects (trees/overhangs) could be installed to enhance the outdoor thermal comfort.

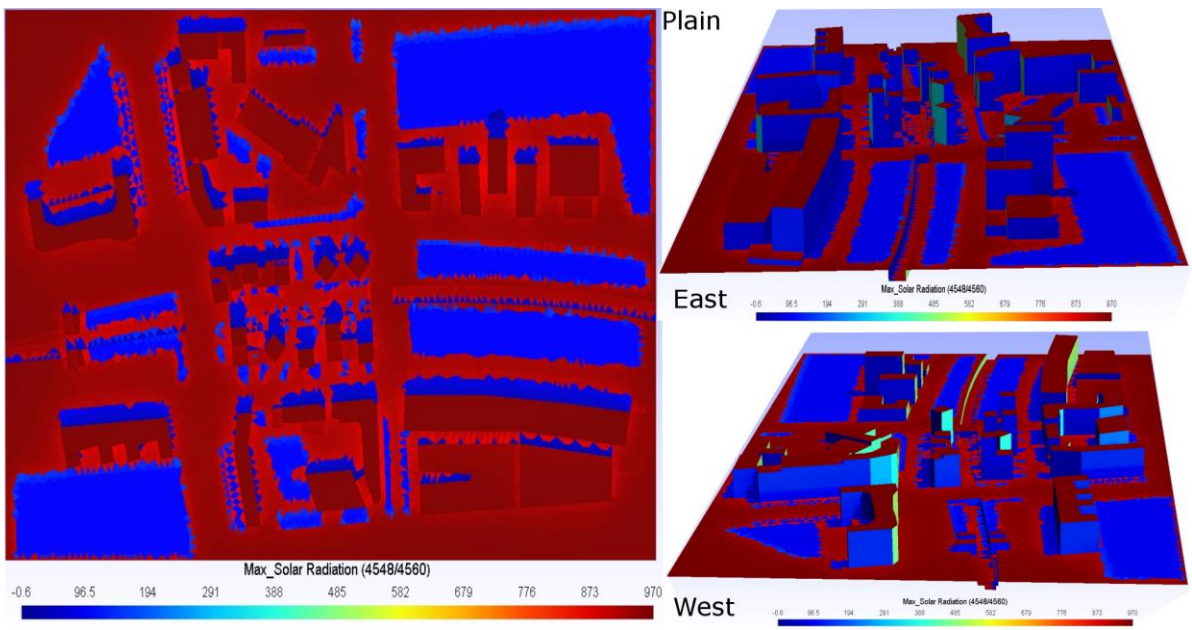


Figure 6: Global Solar Radiation distribution during the hour of maximum exposition for a Plain (left), East and West view.

Concerning wind speed and direction, numerical assessment of the prevailing wind at the entire district has shown that a leading NNE'n or a WWS'n wind (20°/240°) could affect mainly the centre block of the referenced study on cooling period (Figure 7). Specifically, at a height of 7.5m, which corresponds to the pedestrian height, the predicted wind speed could reach 4m/s, approximately 25% more intense than that observed in the remain domain. Moreover, for the East or West wind scenarios (80°/280°) it is possible the canalization of the

air through the traffic axis, as advection phenomena dominate, assisting the passive cooling mitigation potential and protecting the pedestrian area from overheating.

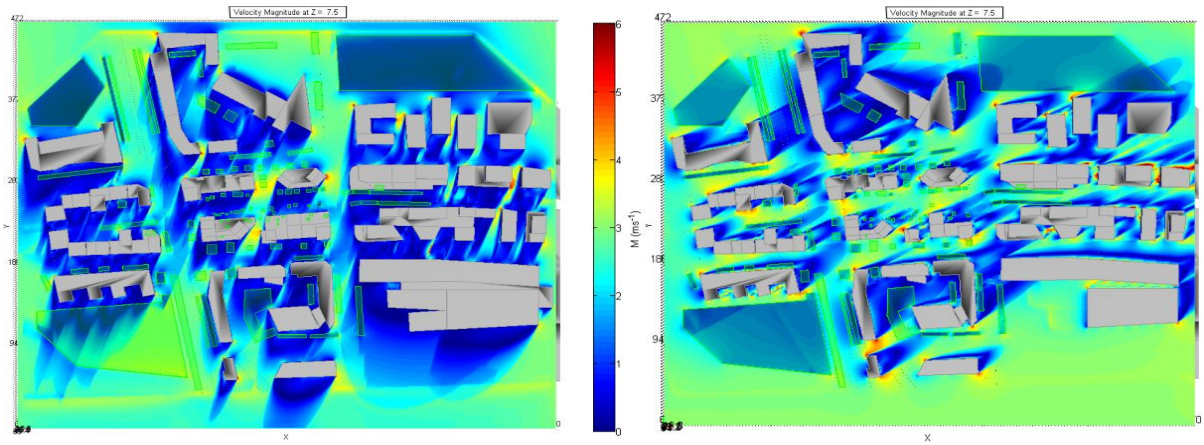


Figure 7: Predicted wind speed at a height of 7.5m for wind orientations equal to 20° (left) and 240° (right).

**Indicators for decision process and perspectives**

From previous results, some interesting tendencies can be highlighted but those key environmental parameters are strongly variable (spatially and temporally) and not simple enough to facilitate the decision process. Considering other KPI, well-known rating schemes (HQE, LEED, BREAM, etc.) settle the thresholds while the link between the Indicators and the objectives are established from collection criteria. In this perspective, further work has to be developed with sensitivity analysis in order to determine the desired indicator weights, suitable for each objective.

Moreover, the possible indicators depend strongly on the capability of platforms to produce outputs. As reported in (Mittermeier et al., 2014) a first classification between building and district scale could be taken as acceptable. The literature on various studies (Chrysoulakis et al., 2013; Gros et al., 2016; Mittermeier et al., 2014) shows a variety of approaches depending on the objectives and the available simulation platforms. The issue of promiscuous microclimatic conditions in each district should be addressed efficiently. As an example, the overall possible ambient temperature reduction through passive cooling mitigation techniques could not describe properly the thermal sensation in a certain place. Our target is to eliminate the depended parameters such as climatic conditions, spatial alterations, etc., thus data normalization will has a dominant role. Our method is possible to cover the requirements of all possible actors, from a macroscale point of view, consisting of urban planners, energy providers and eco-district planners to a microscale one depicting building owners and constructors, users and occupants. All of the abovementioned could take advantage and facilitate from the coupled district energy and microclimate perspective. Further study of the issue is required after the completion and the analysis procedure of the on-going simulations.

The rehabilitation projects of large districts should be designed properly taking into account the important interactions between buildings, systems, networks and the local microclimate. A holistic evaluation should be conducted in terms of energy and environmental parameters, providing the necessary outcomes and assisting stakeholders, urban planners and energy providers to choose the optimum renovating scenario. Thus, a substantive and comprehensive performance analysis is required through the

implementation of appropriate Indicators which will address properly the results obtained from such interoperable platforms.

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