Assessment of urban cooling strategies using a coupled model for urban microclimate and building energy simulation

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1 Introduction

For buildings in urban areas, the use of air conditioning systems increases urban anthropogenic heat during the most critical periods. Urban Heat Island (UHI) effect can mitigate the heating energy demand in winter, while the cooling energy demand during summer is increased (Santamouris et al. 2001) . This negative feedback increases UHI and building energy demand and leads to undersized air-conditioning systems. In order to improve thermal comfort and to reduce cooling energy demand, the urban environment can be designed to mitigate UHI and its consequences. A modification of urban landscaping, such as surface albedo (Doya, Bozonnet, et Allard 2012) or green areas can mitigate the UHI, which consequently reduces energy demand. Thus microclimatic considerations should be taken into account in urban planning. A simulation of the different physical processes that exist in urban areas would help urban planners determining the best urban landscapes in order to increase building energy efficiency (Capeluto, Yezioro, et Shaviv 2003) and to improve outdoor thermal comfort (Pattacini 2012).

In this presentation, vegetation impact is studied on an existing district: Part-Dieu in Lyon, France. Other techniques are also considered in this project which aims to evaluate the cooling efficiency of:

- Vegetation (tree, green wall and green roof),
- Water (watering road),
- High albedo values (Cool façades or cool roof).

Numerical mockups of the district have been set up for the model EnviBatE (Gros, Bozonnet, et Inard 2014) . The district has a high urban density and is composed of buildings which rehabilitation is expected to be difficult. It is particularly sensitive to summer heat waves which frequency of occurrence will increase with global warming. The assessment of greening strategy is applied in two streets (Moncey Street and Buire Street). The results show the impact of the cooling strategy on both urban microclimate and building energy demand. Building energy demand and microclimate are assessed for a seasonal period (from the first of May to the 30th of September).

2 Modelling tool presentation

The meshes are adapted to model heat and mass fluxes at the district scale, depending on the type of flux and the geometry in the different calculation modules of the EnviBatE simulation tool (Gros, Bozonnet, et Inard 2014). These heat and mass flows are used in the main zonal mesh of the EnviBatE simulation tool. The zonal mesh of the district is split into two domains: the ambient air volume called “urban canopy” and divided into “canopy cells”; and the buildings, which are divided into building cells (Figure 1). Outdoor air temperatures are computed for each canopy cell, and the energy demand required to maintain the indoor temperature set points is computed for each building cell. “Urban surfaces” are composed of interfaces between “canopy cells” and “building cells”, and ground surfaces. The surface mesh is discretized consistently with the zones for the building energy simulation. Each wall with a specific orientation and physical properties is defined by its own nodes.

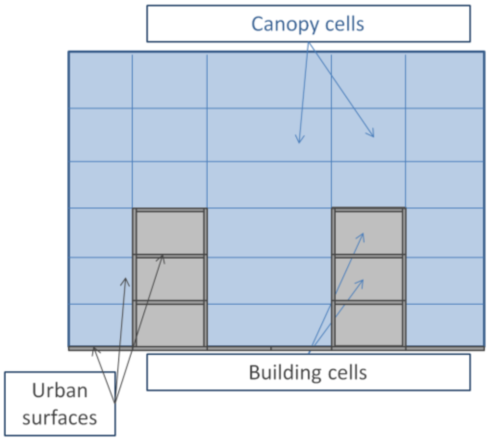

Figure 1. Representation of the different physical domains of a district in EnviBatE

2.1 Radiation model

The solar radiation simulation tool for urban spaces named SOLENE is used to compute direct and diffuse solar irradiance for each wall of a building and the ground. The main principle of this software including models for solar irradiance and sky luminance (Miguet et Groleau 2002). The solar diffuse and direct irradiance computation requires a more precise mesh surfaces to determine shading effect due to the urban environment. A submesh, corresponding to the SOLENE triangular mesh, is then generated on “urban surfaces” of EnviBatE. Direct and diffuse solar irradiances are integrated to each urban surface from SOLENE results. Total solar irradiance budget taking into account all reflections due to urban environment is then computed with the radiosity method. Moreover, longwave irradiance exchanged between each urban face is then computed through a linear model (Gros, Bozonnet, et Inard 2014).

2.2 Airflow models

The software QUIC (Pardyjak et Brown 2003) is used to compute spatially-resolved wind fields in the urban domain, and the calculation is based on empirical low based on Rockle’s model (Rockle 1990). The computation method was developed to respect mass conservation (Kaplan et Dinar 1996). This model produces quickly and accurately the velocity fields of an urban canopy at the microscale. The velocities calculated with QUIC are then used to compute the air mass flows between each canopy cells defined by the zonal mesh in EnviBatE. Lastly, the temperature fields between buildings at each time step is computed using the thermal balance of the corresponding cell, including heat sources from Urban surfaces and Buildings cells.

2.3 Thermal and Building energy models

To compute building energy demand, the different physical processes existing in a building (heat source, air renewal, longwave, shortwave, convective and conductive heat transfers) are described. The model dynamic is mainly linked to the conductive heat transfer in walls. Conductive heat fluxes are computed with the response factor method (Mitalas et Stephenson 1967) . This method is used to compute surfaces temperature for each urban surface. Vegetated surface temperature is considered equal to the ambient air (de la Flor et Domínguez 2004) as a first approximation. A reduced model based on the weighted factors method (Depecker et al. 2001), is used to compute heating or cooling power, or indoor temperature, without computing the inside surface temperature. These methods was developed in EnviBatE to calculate building energy demand, for each building cells (Gros, Bozonnet, et Inard 2014).

3 Simulation parameters

3.1 The case study

Part-Dieu is a district located at the West of Lyon, in France. Its building started in 1968 to become the second downtown of the city. Centering on the Part-Dieu train station and a mall, it is today the second-largest business district of France. The studied place, Buire is located in the South of the train Station (see `Figure 2`). It represents 70.000 m² and it is composed of about ten building blocks. Lyon is located in the broad transition zone between the Mediterranean climate of the south of the France, the Oceanic climate of the West and the Continental climate of the North. The mean temperature in Lyon in the coldest month is 3.2 C in January and in the warmest month in July is 22°C. For this study, meteorological data for the cooling season of the year 2008 were selected that is to say from May 1st to September 30th.

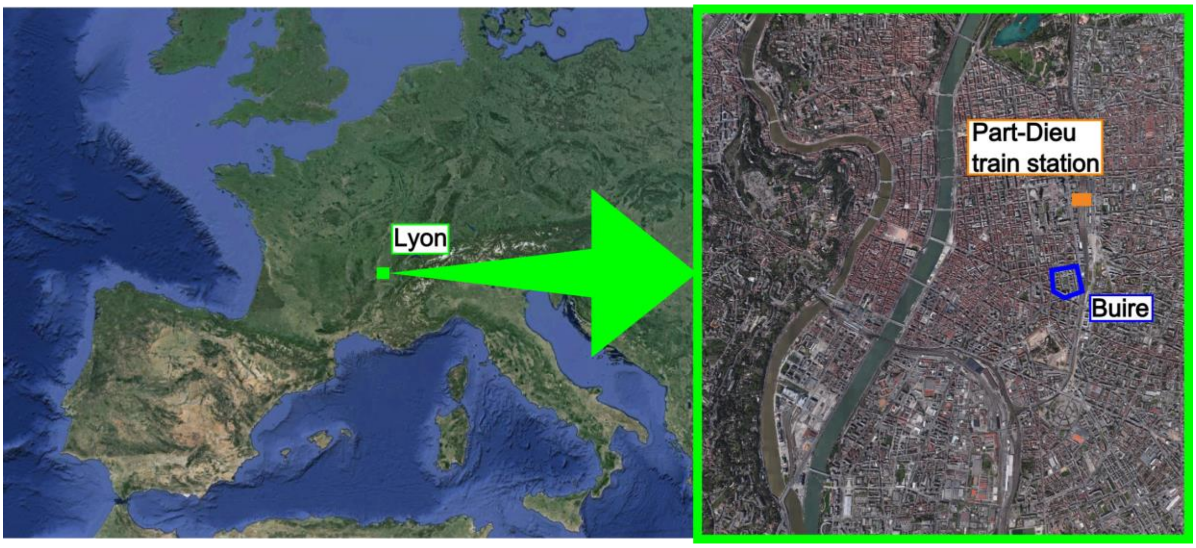

Figure 2: View of the Part-dieu district in Lyon, France.

To study the impact of the vegetation two scenario are defined. The first correspond to the actual current case of Buire place. In this case, only the central place is green. They are few trees around this place and they are about 9m high (see Figure 3 (a)). In the second scenario, all space between building are greened and the size of tree is doubled (18m high) (see Figure 3 (b)).

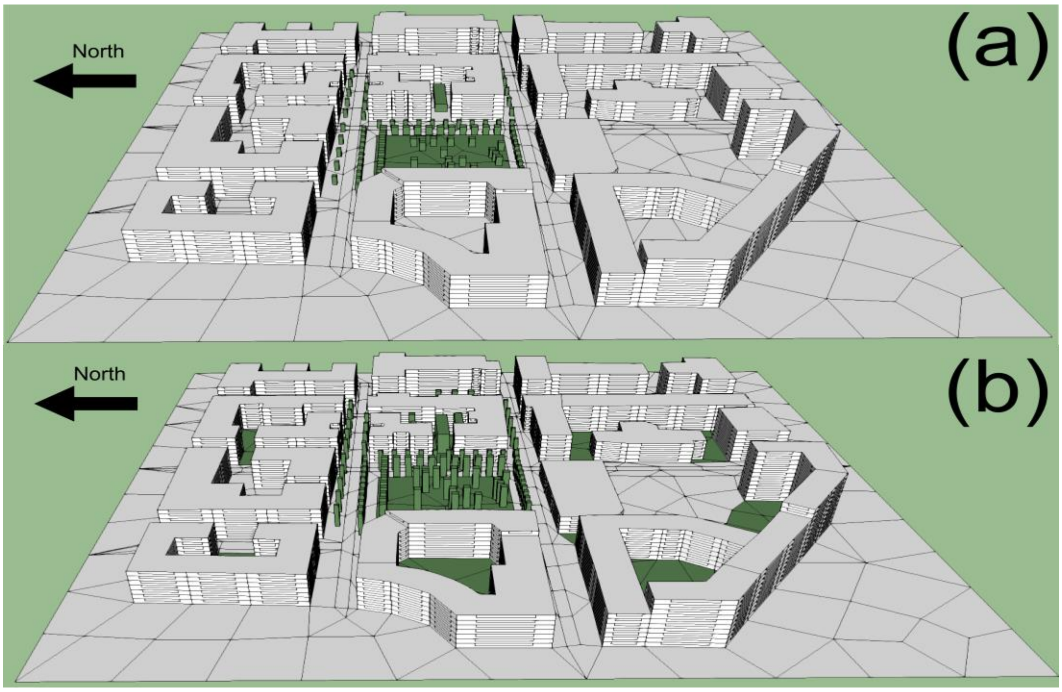

Figure 3: Scenario simulation description: reference case (a), greened case (b)

For SOLENE simulation, the size of the meshes is adapted for windows and adjacent walls, this mesh size is ranged from 3 to 10 m². For other elements, like wall without windows, roofs and streets, coarse meshes are used (ranged from 10 to 200 m²). This main mesh is refined with 19468 triangular facets. For EnvibatE simulation, the district is composed of 204 building cells. 4878 urban surfaces are used, and their areas are ranged from 10 m² to 4500 m².A regular hexahedral mesh is used for the simulation with QUIC software. Along the length and width directions, size mesh is equal to 1m whereas along the altitude direction the size mesh is equal to 3m.

3.2 Building casings

To define characteristics of buildings walls and roof, and soils, different group are defined (see Figure 4). The district building walls and roof are made of concrete and insulation. The road (corresponding to soil1) are composed of asphalt, concrete and soil. Pavement (corresponding to soil2 and soils4) are composed of concrete and soil. Soils3 group correspond to a green place Different glazing ratio was assigned for each walls group. The average glazing ratio for each walls group is given in Table 2. . Material characteristics are given in.Table 1

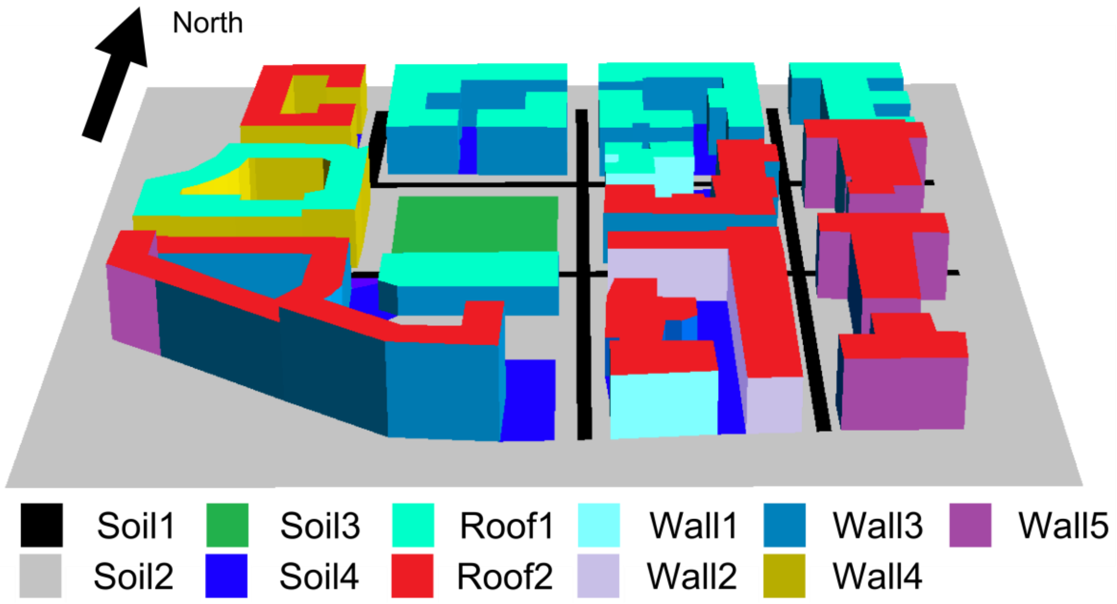

Figure 5: View of the Part-Dieu district in Lyon, France.

	Depth [m]	Thermal conductivity [W/m .K]	Density [kg/m³]	Specific thermal capacity [J/kg.K]	Solar reflectivity	Emissivity
Soil1						
Asphalt	0.05	2.6	2500	880	0.15	0.95
Concrete	0.25	1.75	2300	1000	_	_
Soil	0.3	0.7	1600	900	_	_
Soil2/Soil4						
Concrete	0.15	1.75	2300	837	0.4	0.95
Soil	0.45	0.7	1600	900	_	_
Soil3						
Soil	0.60	0.7	1600	900	0.4	0.95
Roof1/Roof2/Walls1/Wall2/Walls3/ Wall4/Walls5						
Concrete	0.15	1.75	2300	837	0.4/0.15/0.4/0.4/0.8/0.8/0.8	0.95
Insulation	0.15	0.04	30	1000	_	_

Table 1: Thermophysical properties of materials used

	Walls1	Walls2	Walls3	Walls4	Walls5
Glazing ratio (%)	15	80	40	15	80

Table 2 Average glazing ratio of each façade (%)

4 Simulation results

In this part we present the first results obtained with the EnviBatE model on the Buire Street case without considering the outdoor temperature fields. EnviBatE is used to compute the building energy demand and the outdoor surface temperature for a seasonal period (from the 1st of May to the 30th of September).

4.1 Reference case

The cooling energy demand is computed for all the buildings of the district given an indoor temperature set point equal to 26°C (Figure 6**Erreur ! Source du renvoi introuvable.**). 50% of the building zones have a cooling energy demand higher than 33 kWh/(m².year) where the surface refers to building floor area. Due to soil inertia, the lower cooling energy demand (18 kWh/(m².year)) correspond to ground floor buildings cells.

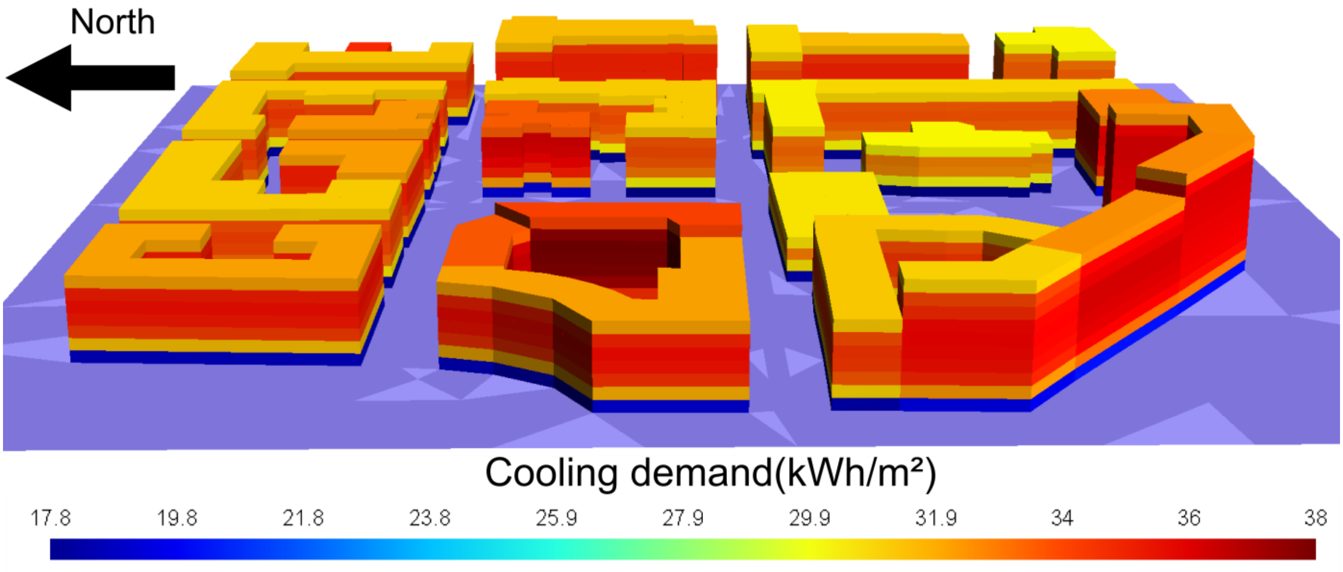

Figure 6: Cooling energy demand (kWh/m²) from May 1st to September 30th 2008

Figure 7 shows the surface temperatures calculated at 2PM (solar time), July 19th; given the weather temperature of 31,1°C. The higher value (near 55°C) correspond to soils1, soils2 and soils4 exposed to the sun. The central place which is green, keep lower value (near 31°C). As it is a dense zone, buildings are relatively close from each other. Thus shadow effect reduce building walls surface temperature (near 30°C).As there few shadow effect on roof, surface temperature are near 36°C.

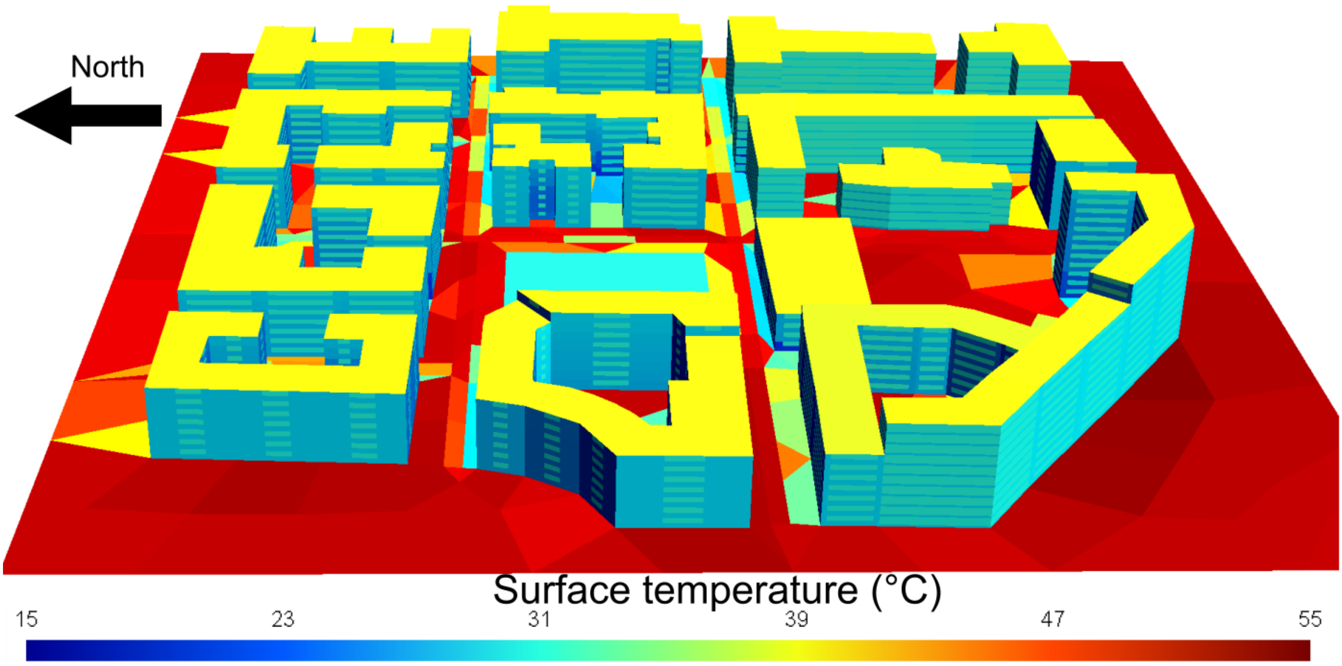

Figure 7: surface temperatures for the 19th July 2008 at 2PM (solar time)

4.2 Greened case

The cooling energy demand decrease varies between 0 to 2,8% (see Figure 8). The maximal decrease is located in the central building. Indeed, a lot of tree surrounds it. With the increase of tree size (from 9m high to 18m high) due to the green scenario, the quantity of solar radiation incoming in the building and collected by walls strongly reduced. We can see a decrease for other ground floor. Indeed, in this scenario, the space between buildings is greened. Soils surface temperatures are mitigated; that leads to reduce wall surface temperatures around and decreases cooling energy demand.

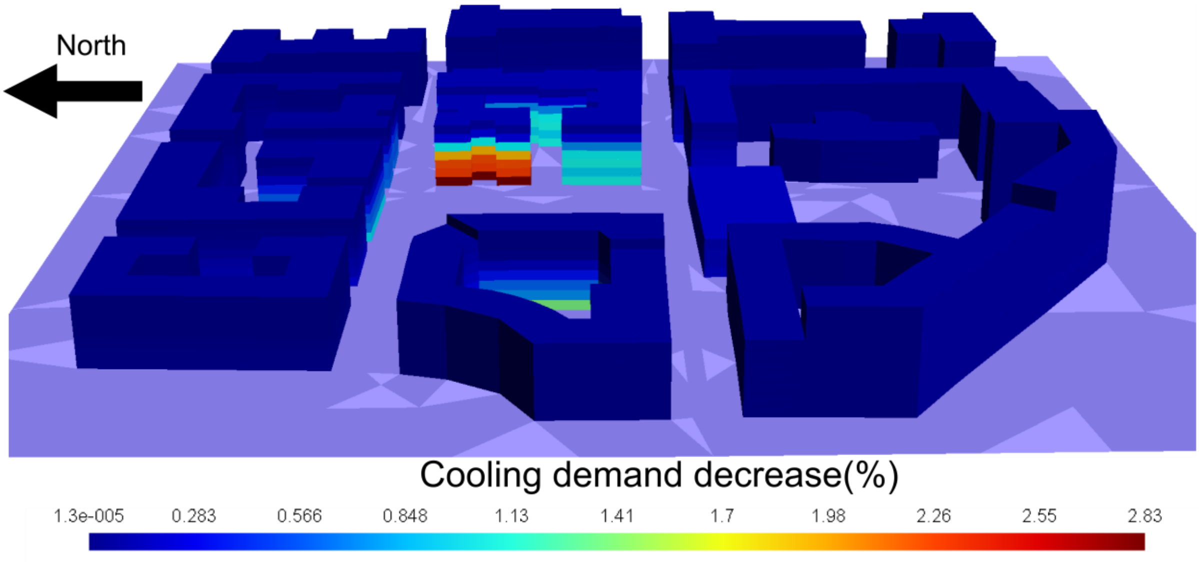

Figure 8: cooling energy demand decrease due to greened scenario

Conclusion

This study aimed to give an overview of the capabilities of a microclimatic and building energy simulation tools to study the impact of green place and trees on surface temperature and cooling energy demand. The model was used on an existing district near the Buire Street in Lyon in France to compute cooling energy demand from May 1st to September 30th 2008. A greened scenario consisting to increase high trees and add green place was applicate on this place. Results show that decrease due to greened scenario allow reduce near 2,8% the cooling energy demand.

In the continuation of this work, simulation with EnviBatE will be completed with the other cooling strategies as increased albedo of roof and façades, and pavement watering throughout the district.

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