Creating Urban Cool Islands effects for summer season in Toulouse new area

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1. Introduction

Urban population has been growing exponentially over the past decades all across the globe. Cities currently concentrate more than half of the world population. In France, around 80% of its population is settled in urban environments. Such concentration of people along with their different activities has produced major stress on the natural and built environment.

The current urbanization models are marked by important changes in the natural surfaces and in the built morphology, which alters, thermal (mainly radiation), moisture and aerodynamic properties of these environments, leading to a new human induced climate. This new urban modified climate, defined by urban heat islands (UHI) (Oke, 1982), affects environmental quality of outdoor spaces, leading to human heat stress, particularly in summer conditions, and a significant increase of energy demand in buildings.

Cities typically present a microclimate patchwork of urban heat islands, which accentuate global warming and worsen episodes of heat waves. Indeed, because of their morphology, materials and activities, cities often present average temperatures higher than temperatures on their outskirts or in the countryside.

The consequences of the UHI effects also include the reduction of the efficiency of passive cooling modes, the increase of air pollution, the increase of discomfort, and significant risks for human health and biodiversity (Colombert, 2008).

In the French context, most of its urban metropolitan areas spread themselves and burst progressively their limits. In the city of Toulouse, some new areas in the outskirts of its ancient centre have been entirely planned to accommodate multiple activities, based mostly on functional, social, patrimonial, and economics aspects.

The UCI project (from "Urban Cool Islands") is a national French research project that has discussed with urban planners and investors, procedures aiming to incorporate a set of reasoned measures of local climate adaptation to a particular new urban area in the city of Toulouse that will be set as landmark reference.

This research aims at analysing and comparing different adapted and resilient urban design strategies to provide support for their application in the particular case of the Montaudran district plan at Toulouse, focusing on mitigating UHI effects in summer season conditions.

Our study approach aims at combining knowledge from theoretical and applied research to local urbanism decisions, integrating the evaluation of planners demand, compatibles strategies, microclimate modelling and energy impact estimation of a certain number of design choices.

2. Method

To achieve the above-described objective, the following main methodological steps were undertaken:

(1) Assessment of the urban plan proposed by the local practitioners regarding its design opportunities and constraints toward climate adaptation and creation of urban cool islands for summer season based on specific literature review;

(2) Definition of a set of urban adaptations the initial plan based on the local plan guidelines and on main microclimate adapting measures;

(3) Analysis of the initial urban plan and its variations regarding their microclimate and energy effects using computer-modelling simulations.

2.1 The Montaudran Aerospace urban district in Toulouse: constraints and opportunities

The work conducted by this research project integrates the design process of an important urban planning in Toulouse-France: « Toulouse Montaudran Aerospace ».

This new district, covering more than 56ha at the southeast of Toulouse, will replace the historical Montaudran airdrome, one of the first airmail services in the world. The district of Montaudran currently holds a 1.8km long and 30m wide emblematic tarmac. This landmark and its surroundings will be refurbished and transformed into a mixed-used urban site, the Aerospace valley, with residential buildings, commercial, sportive, educational, scientific and cultural activities.

The Toulouse community holds as well a strong ambition regarding the environmental quality of the urban planning, concerning transport network, energy efficiency, biodiversity, rainwater management as well as bioclimatic design of buildings (355 000m^2) and renewable energy equipment installations.

To cope with the task of adapting the urban plan to face climate change challenge, the Montaudran district plan presents few linking points to support the integration of important devices and strategies to reduce UHI effects:

a) Concerning the planning opportunities:

- It presents a total built density of 0.63, which is a relatively low density for projects of this magnitude. A wide potential area of green spaces allows then considering satisfactorily the use of local vegetation to promote shading and evapotranspiration as cooling devices for public and private spaces.
- Urban planners wish to capture storm water by hydraulic valley and pond systems to clip the effects of floods, and readdress water to permeable spaces where the quality of the soil allows a safe percolation down into the water table (low-pollution, permeability...).
- It was also considered the possibility of integrating water fountain or sprayer along and at the borders the ancient runway (at the central square and playground square).
- The height of certain buildings at the border of the road could still be reasonably modified.
- Montaudran lays into the greenway of the Rangueil university campus.

b) Regarding the planning constraints:

- An important footprint of asphalt surfaces including the 1.8km long to 30m wide of the ancient runway (that may not be modified) should produce an important overheating zone.
- The urban form and implantation of buildings previously defined may not be modified.
- Cool paving materials is not primarily envisaged due to its high investment cost.
- It presents an important commercial and services building area where the use of air-conditioned is primarily imposed.

These few points supported the choice of urban scenarios to be explored and evaluated in this research.

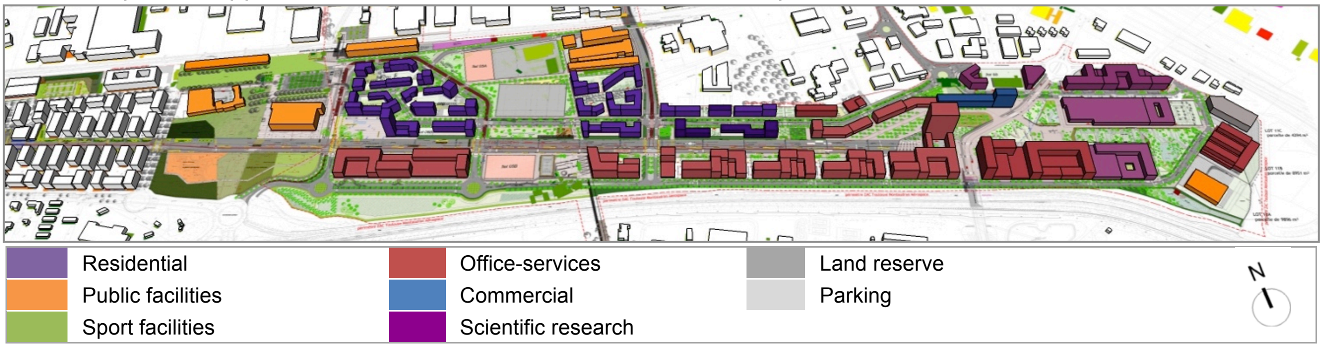

Figure 2: urban plan and surroundings of Montaudran new district displaying its main activity areas.

2.1.2 Temperate climate in Toulouse

Toulouse is a city situated in the south western of France, at 43˚36' north latitude and 1˚26' west longitude. It is located at 263m of altitude and it lies on the banks of the river Garonne. The climate of Toulouse is temperate with oceanic, Mediterranean and continental influences, characterized by very warm and dry summers.

In a typical day of summer, air temperature can fluctuate between 15˚C with 90% of relative air humidity early in the morning and 30˚C with 50% of relative humidity late in the afternoon (Figure 3). Nevertheless, summer season in Toulouse is often marked by extreme hot waves episodes with temperatures that can rise above 40˚C. In urban environments this thermal conditions can be even more exacerbated due to the strong mineralization of urban surfaces.

With the urbanization of sites located nearby Toulouse centre, such as Montaudran, it becomes imperative to deal with bioclimatic design strategies to face climate change by creating adaptive new living urban areas.

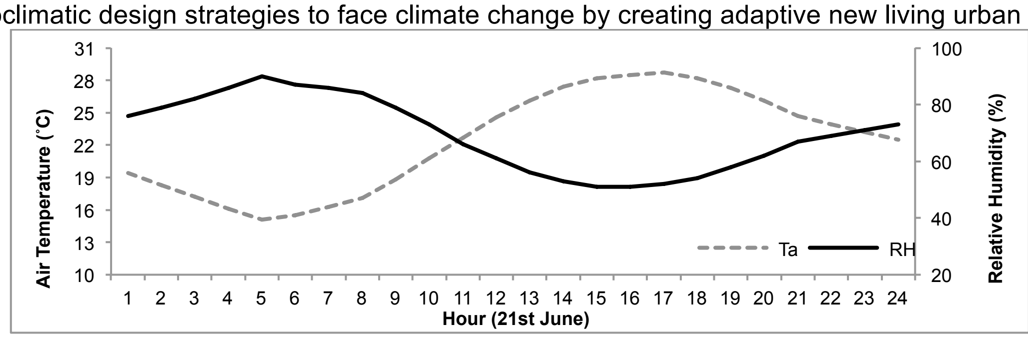

Figure 3: Weather data for air temperature and humidity recorded at Blagnac airport for a summer day (MeteoFrance, 2014).

2.2 Elaboration of reference scenarios

The research proposes different planning strategies that could allow creating urban cool islands during great hot waves episodes in summer season.

To apply and test these strategies for the Montaudran district, we have initially considered the evaluation of just a few numbers of public spaces presenting potential use in summer season. These spaces include the public squares, sportive and recreational parks as well as the main student residential blocks of buildings (Figure 4), for which the use of air-conditioned was not anticipated. The study will be conducted for the zone highlighted below.

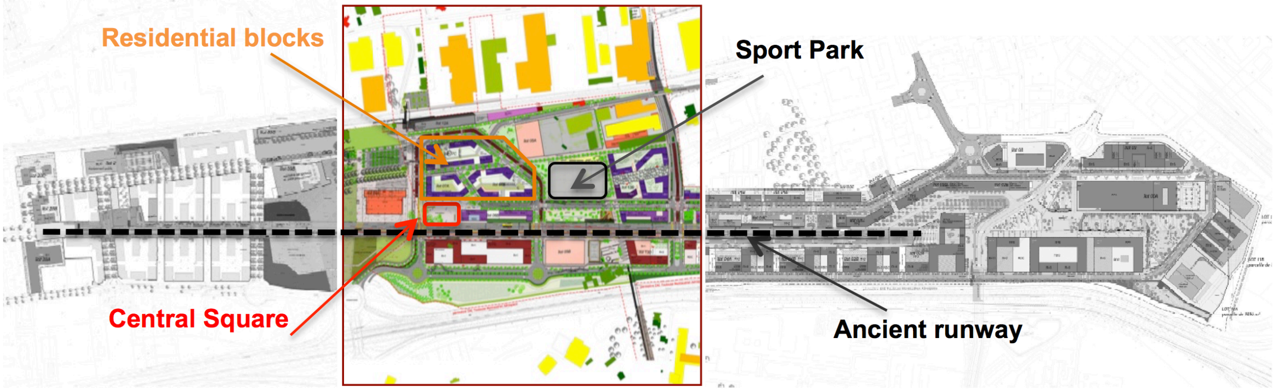

Figure 4: delimited zone of interest to the study.

To propose urban design strategies of climate adaptation, this research work focused on the main well-known factors contributing to UHI in cities.

One of the main reasons for the nighttime warming in cities is its extensively *mineralization* that changes thermal properties of surface materials. Generally, dark concrete and asphalt absorb solar energy during the day, and urban structure makes it difficult to be released during the night (Solecki et al., 2005).

The lack of evapotranspiration due to the absence of vegetation in urban areas reduces solar masks and cooling effect of trees, the low albedo of their leaves, and also the removal of carbon dioxide.

Other causes of a UHI are due to geometric effects. The tall buildings within many urban areas provide multiple surfaces for the reflection and absorption of sunlight, increasing the efficiency with which urban areas are heated : the "urban canyon effect" (Oke, 1987).

Based on these foremost UHI influencing factors, it was possible to reasonably build a set of contrasted scenarios representing main climate strategies to mitigate UHI effects. From the base case plan, four major variations will be evaluated here as reference scenarios:

- *Blue* Scenario: adding water surfaces with fountain next to emblematic road;
- *Green* Scenario: a vegetal density two times stronger than the base case;
- *White* Scenario: façades and roofs set with very high level of albedo;
- *Aspect* Scenario: building Height to street Width ratio (H/W ratio) two times stronger than the base case.

The applied study of these strategies will allow us understanding which devices or combined devices present significant effect for the initial real plan proposed.

2.3 The microclimate simulation

Given the nonlinearity and the complexity of the climate-energy phenomena in urban spaces, it turned out essential to call for a dynamic numerical modelling enabling comparative analyses of the relative potential of the different proposed devices and the base case. We have used the urban modelling tool ENVI-met, which reproduce the complexities of an urban climate system: simultaneous and interactive calculations of radiation, thermal and hydric balance as well as aerodynamics in urban spaces at multiple scales.

The model includes the calculation of the airflow between buildings, the impact of vegetation and water surfaces in the microclimate, exchanges between the soil surfaces and building walls, bioclimatology and pollutants dispersion (Bruse, 2009). However, two important drawbacks are currently imposed: the software does not allow the complex energy calculation of buildings, and the calculation time is prohibitive (typically more than 15 days of calculations for a single simulated day of a relatively complex urban scene with a powerful calculator). Despite of these drawbacks, ENVI-met remains one of the only software in the world enabling realistic microclimatic simulation today.

Given the dimensions of the Montaudran plan including its close surroundings, the numerical modelling of its geometry involved a judicious choice of the spatial resolution of the analysis grid. ENVI-met is designed for micro scale with a typical horizontal resolution from 0.5 to 10 m and a typical time frame of 24 to 48 hours with a time step of 1 to 5 seconds. This resolution allows analysing small-scale interactions (Bruse, 2009).

The urban zone delimited to this study was modelled into the ENVI-met analysis domain comprising 230 x 230 x 26 grids for a 3m-grid resolution (Figure 5). As already described above, four variations of this delimited plan were also modelled in order to compare and contrast the relative performance of the considered devices (vegetation, water fountain, mean aspect ratio and low albedo building surfaces).

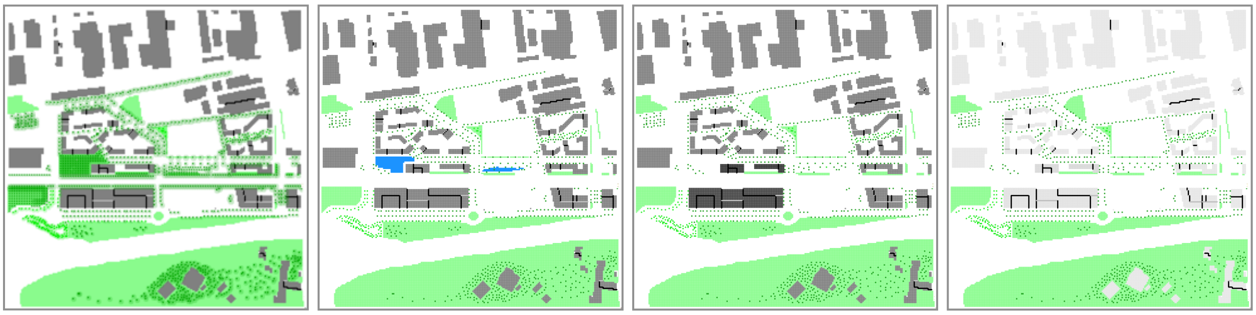

Figure 5: Four variations for the base case study of Montaudran urban plan. From left to right: the green, blue, aspect and white reference scenarios.

2.3.1 Initial and boundary conditions: simple forcing and model data

In order to initiate dynamic calculations of the urban microclimate, one has to define the model boundary conditions.

The Montaudran district presents similar morphology and climate conditions and is equidistant from the downtown to Toulouse Blagnac Airport, it was considered therefore acceptable to apply the meteorological data recorded at Blagnac airport as the input climate data of our numerical model into ENVI-met. For this study, it was considered an hourly weather data for the day 21st June (summer solstice) for the analysis. For a simple climate forcing, ENVI-met only allows the forcing of air temperature and humidity. For the wind speed and direction, a mean value observed by the weather station at ground level was considered. Then a simple logarithmic interpolation, spatially and temporally, is applied for the calculation of the vertical 1D wind profile (lateral and top boundaries conditions imposed to the 3D model) for the considered day of simulation; the wind direction is kept constant at all levels; the humidity profile of the atmosphere is interpolated linearly, according to data observed at the ground level and the specific humidity input at 2500 m above ground. Furthermore, we have considered the soil temperature and moisture at several depth levels. These data were also obtained from weather station of Toulouse.

3. Results

Some of the research results are discussed below. A set of microclimate maps is presented for the base case plan of Montaudran and its variations. These maps show the spatial distribution of the air temperature for the base case at day and nighttime and are followed by four maps presenting the air temperature difference between a particular scenario (green, blue, white and aspect) and the base case.

3.1 Microclimate analysis

UHI effects can occur year-round during the day or night, depending on the built and non-built area configurations. Urban-rural air-temperature differences are often largest during clear evenings, since rural areas can cool off faster at night than cities, which retain much of the heat stored in roads and buildings.

The base case plan of Montaudran presents a certain spatial heterogeneity of air temperature at day and night time. The higher air temperature was found over the asphalt roads around the residential blocks and the sportive park (Figure 6). It is possible to verify the combined effect of ground mineralisation and the local reduction of solar mask, especially around the sports park. Lower temperatures can be verified inside building blocks, due to the low sky-view-factor (SVF) and to the solar mask effects. As expected, the effect is inversed during nighttime (Figure 6).

As we can see from the picture below (Figure 6 – right), the ancient runway, the residential blocks and the central square are important heat islands in this initial plan. From this observation, this research has explored different device strategies to see how these heat islands can be reversed.

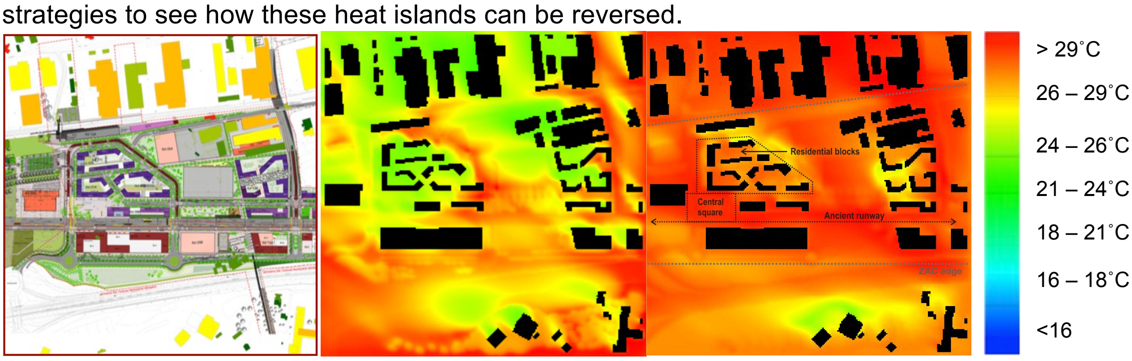

Figure 6: The original plan of Montaudran followed by its spatially distributed air temperature during daytime at 12 a.m. (left) and nighttime at 12 p.m. (right).

The following maps and analysis bring out the air-temperature difference between a specific variation of the plan and the base-case ($\Delta T = T_{variation} - T_{base\text{-}case}$).

As it can be verified from the pictures below for the “White” variation of the original plan, high albedo surfaces may generate slightly cooler nights than base case, but on the other hand, it may produce slightly hotter daytime (Figure 7), especially around buildings with a low SVF and surrounded by mineral dark soil surfaces (such as asphalt or dark concrete), due to radiation trapping effect into these kind of urban features.

Different from what was expected, applying cool façades and roofs may not always represent an optimal strategy for creating urban cool islands, regarding air-temperature. Urban form and structure as well as paving materials must be simultaneously considered. In this particular case, light pavement was not initially a possibility for investors, but will necessarily be considered subsequently in the research project.

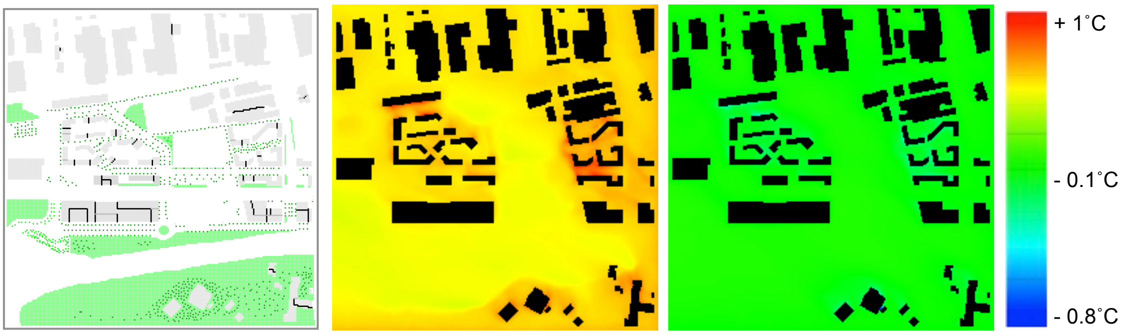

Figure 7: Air temperature difference between the “White case” and the Base case, during daytime (left) and nighttime (right).

The implantation of two large water surfaces with high fountains allowed the creation of two important cool islands, during day-time and night-time, with punctual temperature reduction of 6˚C, in the central square and in the surroundings of the residential blocks of buildings, compared to the base-case. We can highlight here the important interaction effect of this kind of water device associated to the wind flow. A local air-temperature reduction of 2˚C was found on the wind outlet area (Figure 8).

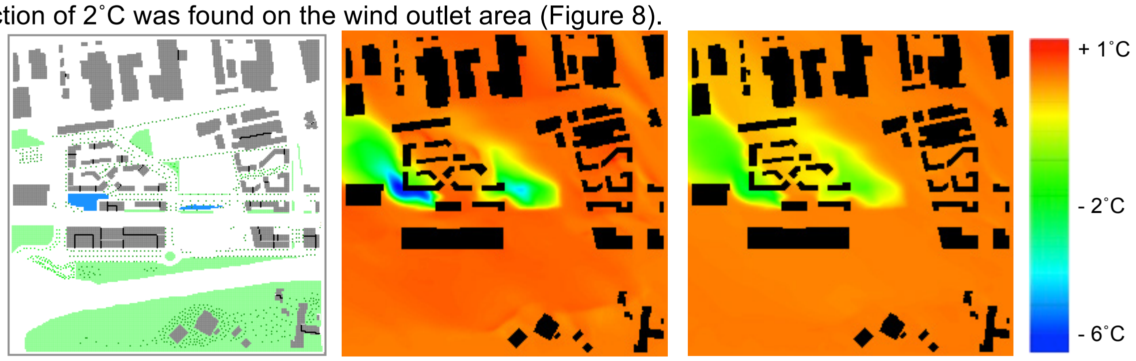

Figure 8: air temperature difference between the “Blue case” and the Base case, during daytime (left) and nighttime (right).

For the mean aspect scenario, very punctual and slight increase and reductions of air temperature could be verified around buildings compared to the base case. Great spatial temperature homogeneity is verified since the original unchangeable urban form (notably regarding building implantation) does not actually represent a real canyon street, which could play decisive role in producing cooler daytime temperatures (by solar mask effect) (Figure 9).

Similarly to the “White” case, the punctual height variation (as permitted by local planners) disregarding the kind of implantation and the contiguity of the form, may not always represent an ideal solution to provide cooler daytime effects. As we can see from the pictures below, the non-contiguity of the buildings at the border of the ancient runway makes surfaces heat-up early in the morning, generating a local heat island effect.

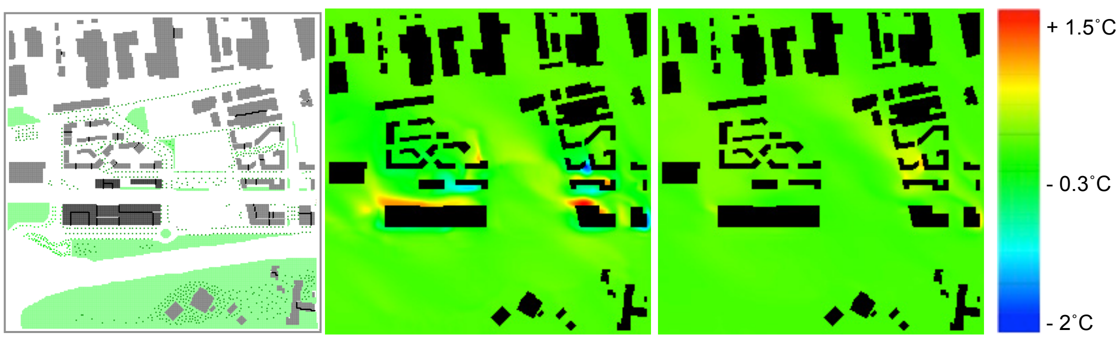

Figure 9: air temperature difference between the “Aspect case” and the Base case, during daytime (left) and nighttime (right).

Applying vegetation two times denser than in the base-case allowed creating cool islands punctually along the main road and in the central square (Figure 10). No important changes in air-temperature can be however verified in the night compared to the base-case.

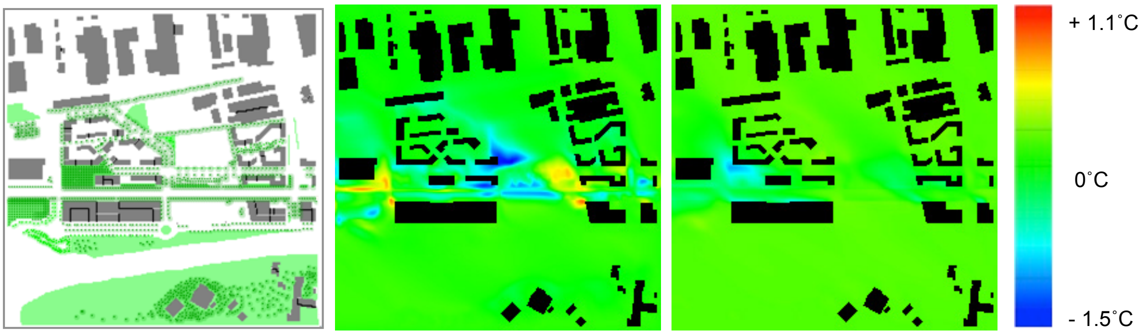

Figure 10: air temperature difference between the “Green case” and the Base case, during daytime (left) and nighttime (right).

4. Conclusions

Cities are complex systems with a wide range of interactive factors on changing urban climate. Therefore, it still remains very difficult to measure and distinguish their isolated effect, despite of the many statements found in specific literature about UHI.

This work consists of an on-going applied research project that aims at evaluating climate-adapting devices to mitigate the UHI effects in summer season for the new urban plan of Toulouse Montaudran district.

Working with a real urban design in progress means copy with its program, constraints and opportunities. Thus, instead of studying multiple punctual actions at a time, this research sought preferably to apply a referential contrasted scenarios approach, which aims at distinguishing appropriate solutions from a set of main potential strategies.

However, the numerical simulations allowed comparing devices and their influence on daytime and nighttime UHI, while taking into account their response to an existing urban plan.

The impact of certain variables known for their major influence on the UHI effects, such as the aspect (H/W) ratio and albedo, turned out to produce way less impact on mitigating UHI effects than other devices such as vegetation density and presence of water spaces. The use high water fountains coupled with airflow not only creates punctual cool islands, as expected, but also amplifies considerably the effect in the downwind areas.

The integration of detailed local vegetation associated to the strategically placed water fountains (regarding all climate repercussions verified in this first stage), as well as their impact on outdoor thermal comfort of pedestrians and on energy demand of buildings will be subsequently modelled in the next stage of the research.

Factors such as the coverage of urban vegetation and water spaces are important devices that could directly affect on-going design process by decision makers, but should be carefully studied for each case. This is where policies and programs to reduce the impacts of heat islands – and achieve related environmental and energy-savings goals – can be most effective.

Acknowledgment

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