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# Characterization of Urban Heat Islands based on the treatment of the urban planning regulations of the French Local Urban Plan

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***Abstract***

*For over 30 years, Urban Heat Island (UHI) have been increasing in intensity, exacerbated by increasing population, urban density and by global warming. These phenomena lead to the emergence of challenges for the life of urban environments: excess mortality and deterioration of comfort conditions, vulnerability of urban networks and infrastructures.*

*French planning policies are institutional tools intended for the governance of urban territories development. With more and more frequent heat episodes, these tools make it possible to manage the evolution of urban morphology and thus anticipate the development of Urban Heat Islands. The impact of urban form on UHI having been attested for many years.*

*As part of a thesis PhD, a methodology is developed to map the sensitivity of urban planning regulations to UHI. This method is being tested in municipalities in the Montpellier Méditerranée metropolitan area.*

*This method is aimed at local authorities and actors of the French territory. It aims to provide a tool and indicators to characterize and anticipate the UHI during the elaboration of French urban planning documents, define issues and guide urban planning policies. The methodology is based on the classification of the urban planning regulations of the French Local Urban Plan (PLU). This urban planning regulation is characterized by a set of articles, which determine urban morphology: land use, architectural characteristics, volume, unbuilt area, etc. Based on this classification, Landsat-8 images are used to determine the Land Surface Temperature (LST) to enrich the classification of the urban planning regulations. By associating the classification of urban planning regulations with temperature treatments, this work allows numerous territorial diagnostic supports:*

*The expected results are relevant for French local authorities. The maps produced will support urban planning documents by making it possible to visualize the vulnerability and behavior of urban morphology and anticipate urban heat islands.*

***Keyword:*** *Urban Heat Island, urban planning, urban form, regulation, Land Surface Temperature*

## Introduction

The combination of the effects of global warming with the phenomenon of Urban Heat Island (UHI) present in cities leads to an intensification of heat stress, which causes vulnerability of infrastructures and inhabitants, discomfort, even excess mortality, etc. (Arnfield and al., 2003 ; Viguié and al., 2020).

Urban Heat Island is characterized by a degradation of urban microclimate with an increase in urban temperatures (Hien, 2016). This phenomenon results from a set of modifications of urban environment. The urban form that characterized cities: buildings, roads, squares and public parks disturb by their presence, the environment and the urban microclimate compared to the rural environment. Impervious surface, land use, disruption of urban ventilation and heat exchange, reduction in natural spaces and the heat generated by human presence are the factors most cited in increasing in urban temperatures (Mohajareni and al., 2017).

The scientific community and urban decision-makers study and attempt to implement strategies to mitigate Urban Heat Islands. Among the solutions most often identified, there are urban geometry and density which influence radiative exchanges and air circulation in cities (Nakata-Osaki and al., 2018). Establishment of vegetation and natural spaces have recognized effects on the reduction of Urban Heat Islands (shading, decrease in air temperature, humidification, $CO_2$ absorption, etc.) and are also subject of numerous studies (Al-Saadi et al., 2020 ; Aboelata and Sodoudi, 2019). Furthermore, urban planning policies can have an important impact because they define the urban form and must therefore be taken into account within the framework of an effective mitigation policy (Bernard and al., 2020).

## Background

Faced with the intensification of Urban Heat Island issues in a context of climate change, it becomes essential to better understand the influence of urban form parameters on the development of this phenomenon.

French urban planning policies are the tools intented to manage and control the development of territories. The Local Urban Plans are the operational documents that control the urban planning at a municipal and, since the ALUR law of 2014, at an inter-municipal scale (Ministère de la Cohésion des Territoires, 2017).

These documents consist, among other things, of an urban planning regulation which sets rules for territorial development (Figure 1). These rules determine land uses, urban, architectural and landscape form of the territory that any construction project must respect.

ARTICLE UA 9 - EMPRISE AU SOL

En UAa, l'emprise au sol des constructions ne dépassera pas 80% de la superficie du terrain. Cette disposition ne concerne pas les projets de surélévation, de transformation, de changement de destination, de réhabilitation et d'amélioration architecturale de bâtiments existants qui occupent déjà 80% ou plus de la superficie du terrain.

*" ARTICLE UA 9 - FOOTPRINT*

*In UAa, buildings footprint will not exceed 80% of the parcel. This provision does not concer elevation, transformation, change of destination, rehabilitation and architectural improvement o existing buildings projects which already occupy 80% or more of the parcel. "*

**Figure 1.** Extract from the urban planning regulation in the Local Urban Plan of Saint-Drezery municipality (article 9 Building Footprint)

The urban planning regulation appears to be a suitable document for studying the relationship between the urban form that it determines and various environmental phenomena (Urban Heat Island, climate change, marine submersion, etc.).

This study proposes a methodology to analyze the distribution of the Surface Urban Heat Island on the territory of Montpellier Méditerranée Métropole. According to urban planning policies at municipals level, it focuses more particularly on urban planning regulations. It offers an analysis of the impact of urban form on the development of Surface Urban Heat Islands. The integration of a regulatory approach to an analysis of urban form and urban microclimate constitutes a new method for taking into account urban planning policies. It makes possible to highlight the role of various parameters of regulatory urban form in a perspective to help the decision-making in the choice of future mitigation urban policies.

## Study site and methods

### 1. Presentation of the study area

The Montpellier Méditerranée Métropole has a surface of 421,8 $km^2$ and is home to more than 481,000 inhabitants (INSEE figure in 2018). Metropolis born in 2015, it is made up of 31 municipalities (Figure 2.b). Located in the south-east of France (Figure 2.a), within the Occitanie Region, it has a temperate climate (Csa) characterized by hot and dry summers (according to the Köppen-Geiger classification).

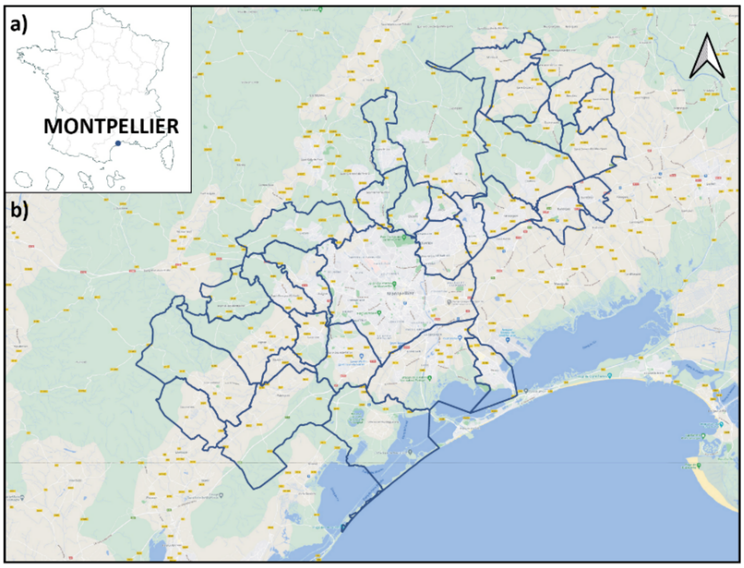


***Figure 2.*** *a) Location of Montpellier city in France b) Map of the 31 municipalities of Montpellier Méditerranée Métropole*

This territory faces challenges. For several years, the metropolis has had the highest demographic growth rate in France. To meet this need, this growth is accompanied by a significant urban expansion. From 2006 to 2012, artificialization of soils accelerated from a rate of 110 hA per year to a rate of 160 hA per year. With an average temperature of 10,4°C per year, with a monthly minimum of -15°C in January and a maximal monthly of 28,9°C in July (climatic norms 1981-2010, Météo France), it knows an Urban Heat Island phenomenon.

### 2. Material et methods

• Acquisition of data / parameters from urban planning regulation documents

This work was carried out using vector data gathering information from Local Urban Plans by municipality and by type of urban zoning (urban U, to be urbanized AU, natural N and agricultural A). This database, at the urban zoning scale, is relevant for the study of the regulatory urban form parameters because urban planning regulations of the Local Urban Plan are declined according to the type of zoning.

It was completed by characterizing each zoning. Each article of urban planning regulations has been incorporated (16 articles). Montpellier Méditerranée Métropole has 1978 zonings, for each zone, 33 pieces of information characterizing the urban form were recorded.

• Acquisition of Land Surface Temperature data

Remote sensing is used to acquire Land Surface Temperature (LST). This method is common to assess Surface Urban Heat Island and their relationship to urban form (Bahi and al., 2020; ADEME, 2017; Benmecheta, 2016; Chen and al., 2020a).

This paper acquires data from Landsat-8 satellite from the United States Geographical Survey (USGS) official website for four dates in 2019 (February 12, March 6, July 22 and October 16) for Montpellier Méditerranée Métropole. The key step in determining Land Surface Temperature includes: first a calculation of the Top of Atmosphere (TOA) spectral radiance (infrared thermal bands are converted to TOA radiance scaling factors provided in the metadata file). Then the TOA radiance is converted to TOA brightness temperature (converting spectral radiance to the upper brightness temperature using thermal constants provided in the metadata file). Finally, the satellite brightness temperature is converted in terrestrial Land Surface Temperature. For this last step, Land Surface Temperature is obtained from calculations of NDVI (proportion of vegetation Pv) and emissivity (ε).

• Calculation of the intensity of Surface Urban Heat Island

The intersection of the urban regulatory classification data and the Land Surface Temperature makes it to possible to assign a Land Surface Temperature for each zone of the territory.

The intensity of the UHI (ΔT) at an instant T is a function of the parameters of the urban form. It is obtained by taking the average temperature difference between urban areas and those to be urbanized (U and AU) sharing the same values of regulatory parameters and natural zoning (N) defined by the Local Urban Plan (articles of urban regulations). The calculation formula for each value of parameters of urban form is as follow:

$$\Delta T\ (9\_10) = T(9\_10) - T(N)$$

In this example, ΔT (9_0,1) represents the intensity of the Surface Urban Heat Island for zones where the building footprint coefficient (article 9) is equal to 10 % of the parcel, T(9_10) represents the average Land

Surface Temperature of zones where the building footprint coefficient (article 9) is equal to 10 % of the parcel and T(N) represents the average Land Surface Temperature of natural zoning (N), which is used as a reference.

## Results

In this paper, the analysis of the distribution focuses on regulatory parameters affecting Surface Urban Heat Island, namely impervious surface, lack of natural spaces and radiative exchanges. Numerous studies concerning cities have already highlighted the role of these parameters in the intensification of Surface Urban Heat Island (Mohajerani and al., 2017; Bokaie and al., 2017; Hulley, 2012).

### 1. Distribution of Surface Urban Heat Island according to parameters affecting impervious surface

To understand the effects of impervious surface, the distribution of Article 9 (relating to the building footprint) is analyzed (Figure 3.b). The building footprint coefficient represents the ratio between the built area and the total area of the parcel. The correlation with ΔT is positive and is consistent with the results highlighted in the scientific literature (Philipps and al., 2020; Chen and al., 2020b). A higher footprint coefficient characterizes a higher density, which is at the origin of the formation of Urban Heat Island. The intensity of Urban Heat Island appears to be greater when the footprint coefficient of the parcel is greater than 50%.

Likewise, the correlation between ΔT and pavement width is positive (Figure 3.a). The hottest areas are defined by pavement widths greater than 5m (0,4°C more than areas where this width is less than 5m). Indeed, a wide roadway indicates a large impervious surface (asphalt, tar, concrete, etc.) characterized by a low albedo which accumulates and emits more heat causing the degradation of urban microclimate (Carpio and al., 2020; Mathew and al, 2016).

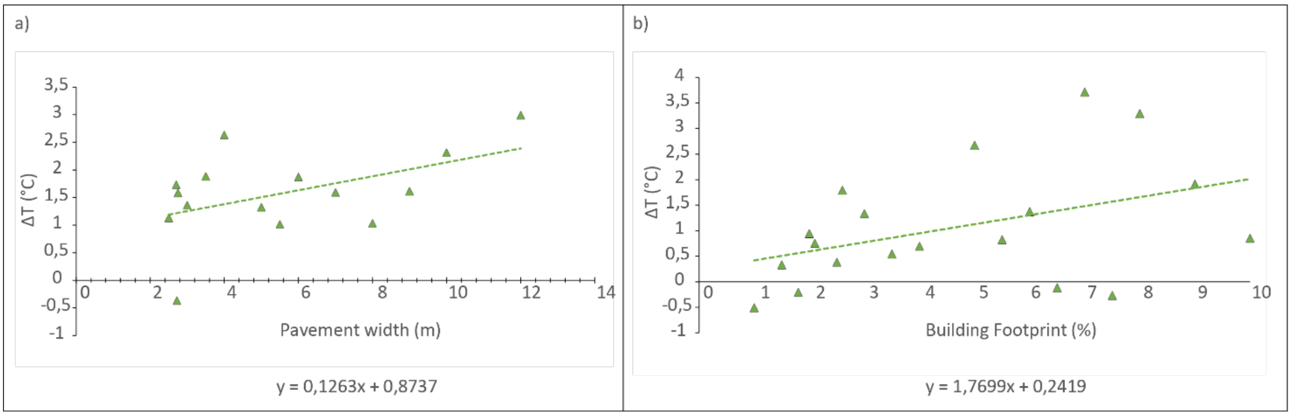


***Figure 3.*** *a) Linear regression between ΔT and pavement width. B) Linear regression between ΔT and building footprint. (March 16, 2019)*

Others parameters such as the distribution of land use coefficient (article deleted since the ALUR law of 2014), characterizes the buildable floor area per square meter of the plot. This is an indicator of regulatory built density, however due to its removal (in more than 12% of urban regulation) and non-regulation (in more than 72% of urban areas), its analysis is to take with care. Comparison of the average surface temperatures observed for each value reveals that the hottest temperatures (on average 1,2°C) are observed when the land use coefficient is greater than 0,5.

**2. Distribution of Surface Urban Heat Island according to parameters affecting natural spaces**

Analysis of the distribution of free spaces (article 13) reveals a low percentage (less than 50% of the parcel) within the most affected areas (0,5°C more on average). Likewise, the analysis of planted spaces (Figure 4) is inversely proportional to the building footprint coefficient. Below 20% of planted spaces on the parcel, the intensity ΔT is greater (1,4°C more on average) while this intensity ΔT is only 0,5°C more average in areas where planted spaces represent more than 50% of the parcel. When all the values of the percentage of planted spaces are represented, the correlation is weak (R2= 0,16). However, if the areas representing less than 0,5% of all areas studied are removed from the analysis, the mitigation potential appears more clearly (R2=0,32). This correlation confirms the results obtained in previous research that demonstrated the relationship between vegetation and Urban Heat Island mitigation (Philipps and al., 2020). The lower the percentage of planted spaces, the more it causes a lack of natural spaces in urban areas and impacts the development of Urban Heat Islands.

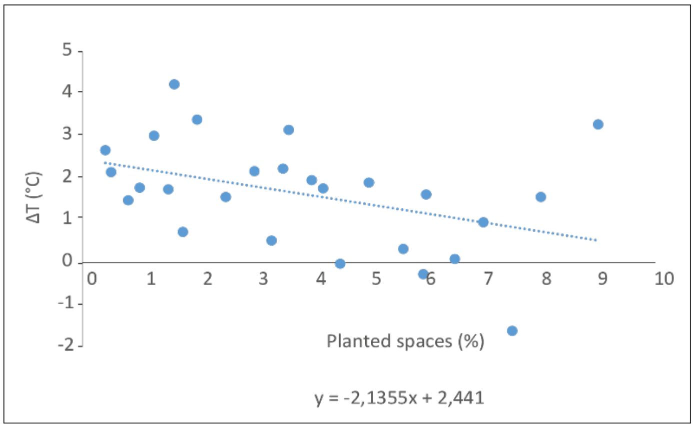


***Figure 4**. a) Linear regression between ΔT and planted spaces. (July 22, 2019)*

**3. Distribution of Surface Urban Heat Island according to the parameters affecting heat exchanges**

Thermal exchanges are influenced by the types of materials and the parameters of the prospect. The types of materials and their colors authorized by urban planning regulations are analyzed for the facades and roofs of buildings, the intensity ΔT is greater (3,2°C more in average) if the regulation is not explicit, by not defining color, precise type and appreciating the study on a case-by-case basis or mixed materials are authorized (stone, metal, etc.) in different urban zonings.

Analysis of height distribution reveals that the hottest areas (around 60% of areas) have regulations that impose average building heights between 8 and 12m. These heights combined with average pavement widths

(6m on average) give prospect values between 1,3 and 2. These combinations can accentuate the phenomenon of exposure of unbuilt areas to solar radiation and contribute to their temperature rise (Soydan, 2020; Chen and al., 2020b; Andreou, 2014;).

Therefore, more than the analysis of the role of each parameter in the intensification of Urban Heat Islands, it is the different combinations of urban planning regulations that must be taken into account, with a greater or a lesser influence on Urban Heat Islands.

## Conclusions and development prospects

The study of the distribution of Land Surface Temperature as a function of the parameters of the urban form from the Local Urban Plan of Montpellier Méditerranée Métropole is relevant, both thanks to the establishment of a map and statistical results.

The potential represented by vegetation and urban geometry in the mitigation of Urban Heat Island is no longer to be demonstrated and the results obtained in this paper are consistent with the scientific literature (Al-Saadi and al., 2020; Philipps and al., 2020; Algretawee and al., 2019; Nakata-Osaki and al., 2018). Combining all of these parameters in a favorable manner provides the best results. As a result, this Urban Heat Island phenomenon can only be mitigated if all parameters in planning urban form are taken into account.

This work of assessing Land Surface Temperature is promising for the study of Surface Urban Heat Island in the French context. Particularly it allows to assess the hottest and coolest areas. However, it requires future improvements, in particular the establishment of a network of measurement points which measures air temperature and allows better estimation of Urban Heat Islands and even thermal comfort. Finally, it would be a prospect of coupling these results with data such as age of population, density of inhabitants, household incomes or age of buildings. It would then be possible to better map the vulnerability of the territory to face Urban Heat Islands and thus support decision-making within the framework of the development of urban planning policies.

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