Role of Vegetation, urban morphology and building rise in air quality and urban heat island: simulations in five Parisian neighborhoods

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1. Introduction

The European heat wave in 2003 has evidenced the vulnerability of cities to a warmer climate. . The summer of 2003 was particularly hot, bringing consequently an increase in the death rate in Europe. France was one of the countries where the death rate was among the highest in Europe, with 19 000 dead (Robine et al., 2008). Most of the victims were mainly elderly (Cochet et al, 2004). The city of Paris and the surrounding area was the most affected area. The mortality rate rose to +141% in Paris region, from an average of +40% in other geographical entities (Hémon & Jougla, 2003). This area is also the most urbanized of France and suffers from two typical urban issues: the urban heat island (UHI) and air pollution. Air quality also plays an important role in mortality in urban environments. The Clean Air for Europe program (CAFE, 2005) concluded that air pollution is the cause of the decrease in life expectancy of nine months by Europeans.

Urban planners often treat the problem of urban heat island separately from the issue of air quality. This can lead to antagonism measures. For instance the UHI mitigation such as vegetation can aggravate the problem of stagnation of air pollution. Studies have shown that urban vegetation in the streets can lead to an increase in pollutant concentrations (Wania et al., 2012). The use of urban vegetation to relieve hotspot air pollution is not expected to be a viable solution (Vos et al., 2013). Municipalities must deal with both problems, but there are no well-established lines of action to mitigate both phenomena.

Open urban morphologies are favorable to air pollution dispersion and solar access, while a denser arrangement is favorable for shelter and energy conservation (Oke, 1988). In inner Paris raising the buildings height is an historic and common practice of densification. In 2014, 35% of all construction permits were granted to increase the height of buildings (Qualificontact, 2015). This evolution in the cityscape of Paris is ongoing, but its impact on urban climate has not yet been studied. This opens a new debate on the advantages and disadvantages that the densification of Paris can have on both urban climate and air quality.

2. Objectives

The aim of this study is to understand the role of vegetation, urban morphology and building rise on both air quality and urban heat island. The goal is to identify antagonisms and find synergetic solutions to tackle both issues.

2.1 First objective: Studying the role of vegetation on air quality and UHI. The abundance of vegetation in a given area influence local temperature. This relationship between surface temperature and abundance of vegetation has been widely documented in the literature (Weng et al., 2004). In cities, trees are used to provide shade and refresh the environment by evapotranspiration (Dimoudi & Nikolopoulou 2003). In urban areas, the use of vegetation cannot be arbitrary as some trees emit volatile organic compounds (VOCs) in greater numbers than others (Curtis et al., 2014). Therefore, VOC emissions should be a factor in the choice of planting trees in urban areas. The effects of vegetation are not limited to public spaces, green roofs provide benefits in terms of the UHI, air quality, storm water management, biodiversity and urban services (Oberndorfer et al., 2007). The extensive use of green roofs can help to mitigate the UHI (Susca et al., 2011). Vegetation should be chosen carefully. Large trees can increase air pollution, while the low vegetation close to sources can improve air quality through increased deposition (Janhäll, 2015). Our goal is to better understand the effects that have trees and green roofs on air pollution and on UHI.

2.2 Second objective: Studying the role of morphology and building rise on air quality and UHI. Previous studies have shown that density factors are linked to UHI (Oke, 1973), and with pollutant concentration (Chan et al., 2003). Density may also influence the demand for motorized transport and emissions. And can also influence the overall emissions inhaled by the exposed population (Marshall et al., 2005). Studies have shown a deterioration of air quality in the areas of formation of UHI: the two phenomena may be simultaneous because their conditions are often linked (Greuillet & Galsomies, 2013). We aim to better understand the effect that has densification – in our case through building rise - on air pollution and UHI.

3. Method

The method is divided into three parts: 1. Definition of the typology and selection of the study areas. 2. Development of scenarios. 3. Simulation with ENVI-met software. ENVI-met is a micro three-dimensional climate model designed to simulate the interactions between surface-plant-air in urban areas with a 0.5 m spatial minimal resolution and a 1-5 seconds time resolution. The typical fields of application of ENVI-met are architecture, landscape architecture, design of buildings and environmental planning (Bruse, M. 2015).

3.1 Definition of the typology and selection of the study areas.

For this research, we needed a local and homogeneous characterization study of typologies at the scale of Paris. The Paris Urbanism Agency (APUR) has identified nine urban typologies characterized by its energy consummation and greenhouse gases emissions linked to heating homes (APUR, 2007). The typology chosen is based on morphology, architecture period, materials and construction techniques (figure 1). The neighborhoods built after 1975 were not selected for this study. Actually, the first thermal regulation in France was voted in 1975, thus buildings constructed after 1975 are not priority to thermal renovation. In other words, isolated buildings built after 1975 are less important to urban renovation. Thus, five typologies of Paris representative were chosen: 1. Built before 1800. 2. From 1801 to 1850 3. From 1851 to 1914. 4. From 1915 to 1939. And 5. From 1940 to 1975. All potential neighborhoods passed through a selection criteria in order to have homogeneous samples and to be representative of each period. Four homogenization criteria were established: historical unity, land use unity, flat relief and exclusion of oasis effect. Five samples of 450 m x 450 m fulfilled the four criteria homogenization.

*Typology **1800***	*Typology **1850***	*Typology **1914***	*Typology **1939***	*Typology **1975***
Le Marais	*Le Faubourg*	*Le Chaillot*	*Saint-Fargeau*	*De la Gare*

Figure 1. Typologies have been characterized by its energy consumption and emissions of greenhouse gases linked to heating homes (APUR, 2007). Satellite images (Google Earth, 2015).

3.2 Development of scenarios

Four scenarios were created: S1, S2, S3 and S4 (figure 2). A first no tree scenario (S1) to identify the effect that vegetation has on the neighborhood. The scenario S2 also removes trees and adds 2 storey all buildings (+6 meters). The scenario S3 preserves trees and adds 2 storey buildings. Finally the scenario S4 preserves the trees, add 2 storey and add green roofs on all buildings.

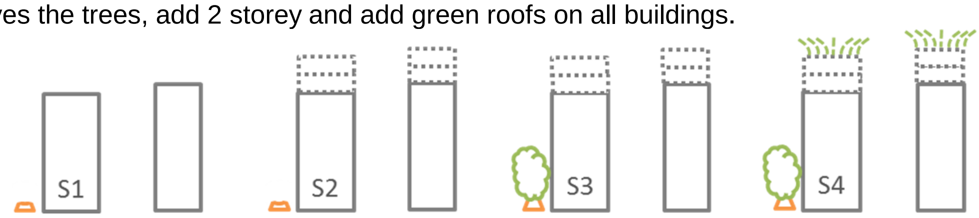

Figure 2. Sketches of the four scenarios: S1, S2, S3 & S4

3.3 Simulation in ENVI-met 3.1.

Data of the urban atmosphere and soils were supplied as input in the simulation. Temperature, humidity, wind direction and speed, albedo and thermal transmittance of buildings were entered as input in ENVI-met 3.1. The five neighborhoods have been modeled at a resolution scale of 2m by 2m grid of 450m x 450m. We use the 2003 heat wave as a reference for our simulation. The data were taken from Montsouris Park and granted by MétéoFrance.

4. Results

Three parameters are mainly analyzed: Potential temperature (°C) is taken as the comparative parameter of the UHI. PM_{10} concentration (µg/m³) as a parameter of comparison of air quality. And SVF as reference to analyze both parameters. In all simulations, the data were extracted at 1.20 m above ground level (pedestrian level).

4.1 Diagnostic of temperature

The typology of 1800 shows the highest mean potential temperature (MPT) and typology of 1975 the lowest. The average temperature of the five districts was 30.42 °C with a maximum fluctuation σ = 0.975 °C in the typology of 1939 (Figure 3).

- S1: The temperature is increased slightly in all scenarios, this can be explained by the felling.
- S2: Generally the temperature decreases, this can be explained by the shadow that provided the increase in height of the buildings.
- S3: Thanks to the preservation of trees, the temperature continued to decline.
- S4: The integration of green roofs no significant changes in temperature at this point.

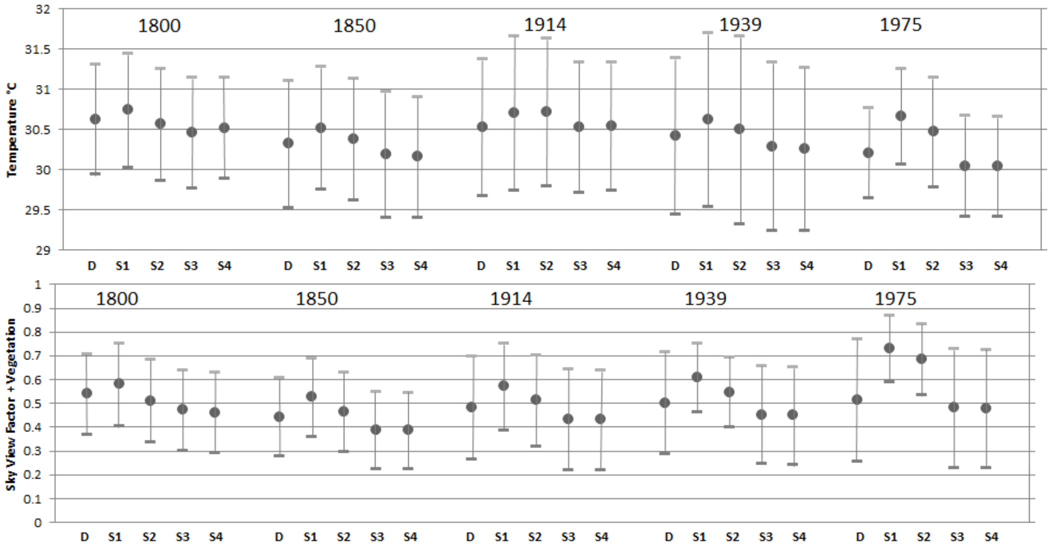

Figure 3. Temperature and SVF+V for the five typologies diagnostic (D) and scenarios S1, S2, S3 & S4

When both graphs (Figure 3) are juxtaposed, we can see a sequence. When one raises the other also, when low the other too. We can infer that the SVF is related to the temperature. When the SVF increased direct solar radiation also increases. Thus a small SVF causes more shadow in pedestrian level.

4.2 Diagnostic of air quality

The sources of pollution are not the same from one neighborhood to another, therefore we cannot estimate which neighborhood is better dispersing pollution. So in this work we can only analyze the differences from one scenario to another (Figure 4). In this graph, the trend is slightly opposite to potential temperature and SVF graphs.

- S1: The first four typologies show a decrease in the concentration of PM_{10}. The typology of 1975 shows a slight increase in concentration. The first four types correspond to a classical urban morphology, whereas the type of 1975 corresponds to a modern architecture (towers & blocks).
- S2, S3 & S4: Generally PM_{10} concentration does not display relevant data to establish a trend in air quality.

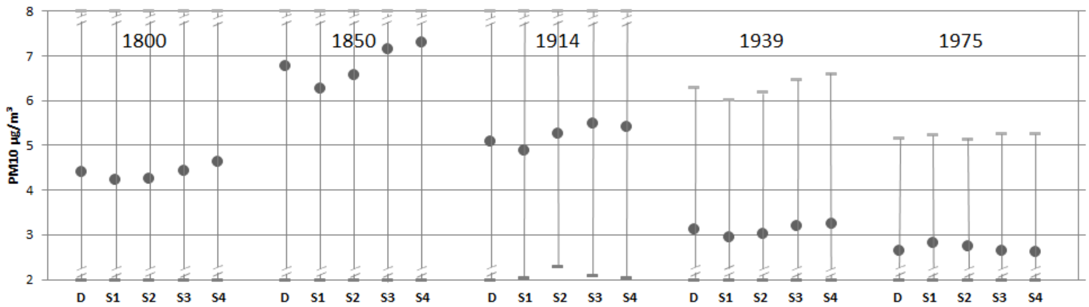

Figure 4. PM_{10} concentrations for the five typologies diagnostic (D) and scenarios S1, S2, S3 & S4

When comparing the graph of PM_{10} (Figure 4) with the graph of SVF+V (Figure 3), we can observe that graphics trends are opposite. When one rises the other falls and vice versa (except in the category of 1975).

4.3 Scenarios to reduce the temperature or air quality?

The variables in the scenarios are compared with the diagnosis. A less hot scenario will be judged as positive. In turn a scenario with reduction in the concentration of PM_{10} also will be judged as positive. Only the trend is evaluated, it is not taken into account if the change is big or small (figure 5).

D	S1		S2		S3		S4	
	MPT	MPM_{10}	MPT	MPM_{10}	MPT	MPM_{10}	MPT	MPM_{10}
1800	x	√	√	√	√	x	√	x
1850	x	√	x	√	√	x	√	x
1914	x	√	x	x	x	x	x	x
1939	x	√	x	√	√	x	√	x
1975	x	x	x	x	√	√	√	√

Figure 5. Comparison of Mean Potential Temperature (MPT) and Mean PM_{10} concentrations (MPM_{10})

No trees scenarios (S1 & S2) show a tendency to increase the average temperature of the neighborhood. The greener and raised building scenarios (S3 & S4) show a tendency to increase the mean PM_{10} concentration. Only 3 scenarios from 20 obtained favorable results in reducing both urban problems.

4.4 Temperature trends in the scenarios

To compare the scenarios, diagnostic is taken as zero point (reference point). The temperature difference between the diagnostic and the scenario shows the variation of Mean Potential Temperature (ΔMPT) (Figure 6).

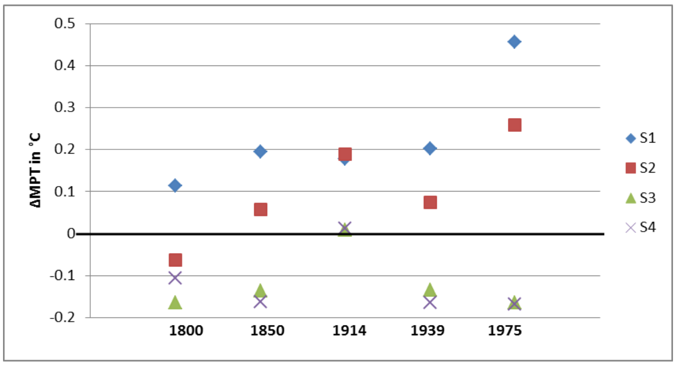

Figure 6. Scenarios of variations of Mean Potential Temperature (ΔMPT) by typology

- S1: Scenario indicates an increase in the MPT, this trend scales up to almost half a degree in the typology of 1975 (Figure 6).
- S2: Scenario shows a tendency to the increase in temperature, except in the typology of 1800.
- S3 & S4: Show improvement in the reduction of the temperature, except for a very slight increase in the typology of 1914.

4.5 PM_{10} concentration trends in the scenarios

The scenarios are compared with the diagnostic as zero. The difference between PM_{10} concentration scenario and diagnostic show the variation (ΔMPM_{10}) (Figure 7).

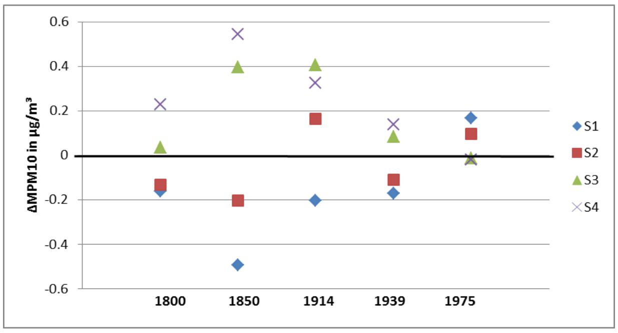

Figure 7. Scenarios of variations of Mean PM_{10} (ΔMPM10) by typology

- S1: PM_{10} concentration decreases in all scenarios except 1975. The type 1850 is the most susceptible to changes.
- S2: Data shows no relevant data to establish a trend in air quality.
- S3 & S4: show similar trends, both scenarios increase the concentration of PM_{10}, except in the category of 1975 where no significant changes are present.

5. Conclusion

No trees scenarios may reduce the PM_{10} concentrations, but increase the mean temperature of the neighborhood. Conversely, the scenarios of building height raising and vegetation increase PM_{10} concentrations and reduce the temperature of the neighborhood. Only 3 scenarios out of 20 obtained favorable results in mitigating both urban problems. These results show that most of the measures are not synergetic. However there are still uncertainties, and more simulations need to be done to enable a deeper analysis of the links between temperature, air quality and SVF.

6. Acknowledgments

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