Thermoregulatory effect of green spaces and wetlands in Paris

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Introduction

Since the beginning of the industrial era, the world average temperature is increasing. According to the last GIEC report (report name), this phenomena should continue during the 21th century, which will directly impact the outdoor comfort for people and the energy consumptions. According to the same report, the frequency and the intensity of heat waves should increase as well, which could lead to human health issues (...). The impacts of this climate change are even more problematic at city scale, because of the so-called Urban Heat Island (UHI) phenomena (first described by Howard (1833)), which makes the air temperature higher in urban parts than in rural parts of a territory. This issue raises a real challenge for researchers and urban councils : how to adapt cities to climate change (ie how to reduce the impact of UHI during heat wave periods) ? Oke (1987) shows that UHI is mainly caused by the urban fabric constitution (form and ground cover type) :

- The absence of vegetation or the low vegetation density has a direct impact on the urban energy balance, through an increase of the Bowen ratio (Musy et al., 2012).

- Large open areas, when compared to dense building areas, induce lower heat storage flux (mainly driven by thermal mass) and higher short-wave radiation cooling potential during night-time.

For those reasons, the presence of urban parks and water surfaces may then play a major role for temperature mitigation in and around their edge. Several studies have shown the park cooling potential through the "Park Cool Island" (PCI) effect, defined as the temperature difference between a park and its surroundings (Spronken-Smith and Oke, 1999). Most of those studies took place during night-time, under clear sky and calm wind periods, conditions suitable for PCI observation. Jauregi (1991) and Spronken-Smith and Oke (1999) showed that the cooling effect is observed up to one park-width (diameter) away from the park. Nevertheless this information remains qualitative in terms of temperature decrease which makes estimation of the cooling potential of any park difficult. Concerning the water surfaces, several studies have highlighted their potential cooling effect but the conclusions depend on the type. Some studies have shown that large water surfaces (oceans) decrease the air temperature up to far from their edge (Suomi et al., 2012; Svensson et al., 2002; Oke, 1987). Givoni et al. (2003) showed that smaller water surfaces (ponds, lakes) could have a cooling effect on the day-time UHI above and around them whereas Steeneveld et al. (2014) showed a negative effect during night-time. Concerning rivers, Hathway and Sharples (2012) reported an air temperature reduction near their edge all along the day. Then the cooling effect of water surfaces seems to be dependent of its size, its flow rate and of the time of the day. The aim of this study is to verify the capacity of eight different Paris "green and blue" area types to cool their surroundings air temperature during summer-time. A qualitative analysis is first used to understand which urban form and ground cover characteristics are the key parameters to explain the air temperature evolution for each of the site. Then the air temperature inside and outside each "green and blue" areas are compared during night-time to evaluate their cooling capacity.

A - Study area and study sites

Paris : study area

The city of Paris is located 33m above sea level and has 2,125,246 inhabitants (21 289 inhabitants/km²). 450 green spaces are distributed in 20 districts of Paris for a total area of 2380 ha. In accordance with the *"Direction des Espaces Verts et de l'Environnement (DEVE)"* of the City of Paris, seven sites were selected to observe the thermoregulatory effect of these "green and blue" areas types in Paris:

- six parks : Parc Monceau, Square Montholon, Square Georges Cain, Small Railway Belt in the 15th district and the Jardin Atlantique ;
- a canal with roadside trees : Canal Saint Martin ;
- a green roof : near the Jardin Atlantique.

B - Methodology

Main site and peripheral zone

Each site was the subject of a dedicated analysis before weather stations implementation. The main characteristics of green spaces were determined or estimated on site : type and size of green space, presence of water, presence of sprinkler systems, vegetation (high and low) versus mineral (light and dark colour) density, trees size, site elevation of the green space and its periphery, sky view factor, thermal inertia of the soil, level of soil permeability, peripheral building density and building height, peripheral roads, city network of heat ... Three stations per site were used to qualify its climatic conditions : one within the blue or green space, one in its close periphery (from 5 to 50 m away) and the third further in the periphery (50 to 150m).

Instrumentation of sites

Several climatic parameters were measured on each station: the air temperature at 2m, 0m and the ground surface temperature, the relative humidity at 2m and 0m, rainfall, solar radiation, wind speed and wind direction. These sensors were protected by a metallic cage solidly set to the street furniture. The COFRAC certified sensors were checked before and after the measurement campaign ground to verify the absence of sensor drift. The location of the main station and both peripheral stations in each site was defined according to the Oke (2004) recommendations for temperature and humidity measurements (representativeness, distance from the walls of buildings ...). Then technical constraints (poles availability to set the equipment on, etc.) had to be taken into account to identify the final location of each station. Measurements were taken every fifteen minutes.

Climatic context

The climate of Paris is oceanic and results in fairly hot summer (19.7°C on average). On the Paris area, the effect of UHI can reach up to ten degrees during heat waves. In summer 2003, France has experienced an intense and long heat wave period. Measurements have been recorded for forty-six days from July 24th to September 7th (in 2014). Two days were selected for our analysis. During this period, the weather conditions were favorable to the development of heat island with less than 25% of cloud covering, wind speeds lower than 3,3 m/s (Svensson et al, 2002), the absence of rain during the previous days, minimum temperatures above 16°C and maximum temperatures above 25°C (in summer 2003, differences of 8°C were recorded between the center of Paris and rural areas of Ile-de-France. The city of Paris has been badly affected, with temperatures reaching 40°C during the day and never falling below 25°C at night. On average minimum temperature was 28°C in the center of Paris against 23 to 26°C in the most airy southwestern and northern Paris and the Bois de Vincennes and Boulogne areas. The 2nd, 3rd, 9th, and 10th districts have been identified as the hottest areas).

Qualitative analysis of sites

The 7 sites and measurement points are detailed in Table 1 and Figure 1.

Table 1 : Site characteristics -

| N°	Site	Size	Altitude	Peripheral building density	Specific characteristics	Sky View Factor	Thermal inertia	Surface type
1	Small Rail Belt (15th)	Long but narrow width (15 to 40 m)	Main : 42m Peripheral : 33m	Medium	High vegetation	Medium	Medium	More mineral than vegetated
2	Parc Monceau (8th)	83 300 m²	Main : 48m Peripheral : 47m	Very High	Small pond ; Low and high vegetation ; Clear mineral surface	Low to high	Low	More vegetation as mineral
3	Square René Le Gall (13th)	33 450 m²	Main : 37m Peripheral : 34m	High	1 area with high vegetation ; 2 areas with clear mineral surface	Low and high	Medium	Station implemented in clear mineral surface
4	Square Georges Caïn (3th)	2 100 m²	Main : 35m Peripheral : 35m	Dense urban peripheral environment with vegetated spaces	High vegetation ; Clear mineral surface	Low	Medium	More vegetation as mineral
5	Canal Saint Martin (10th)	Width canal: 16 in 24m ;	Main : 35m Peripheral : 37m	High	Canal with roadside trees	High	High	Water with average depth of 2,2m
6	Square Montholon (9th)	4 400 m²	Main : 39m Peripheral : 36m et 39m	Very High	High vegetation ; Clear mineral surface	Low	Medium	More vegetation as mineral
7	Jardin Atlantique (15th)	34 200 m²	Main : 70m Peripheral : 65m	Medium	Clear and dark mineral surface ; Low and high vegetation	High	Low	Hanging garden ; Site enclosed by buildings of important heights.
8	Green roof (15th)	1 000 m²	68m	Medium	60 in 120cm of substratum ; low vegetation	High	Low	Only low vegetation

- Figure 1 : Aerial views of sites with setting-up of meteorological stations -

1 - Small Rail Belt (15th)

2 - Parc Monceau (8th)
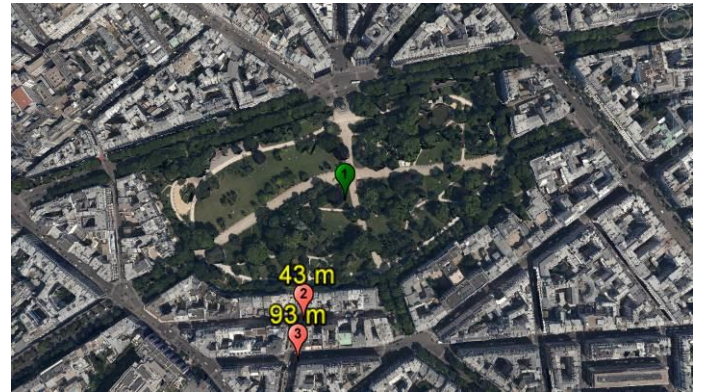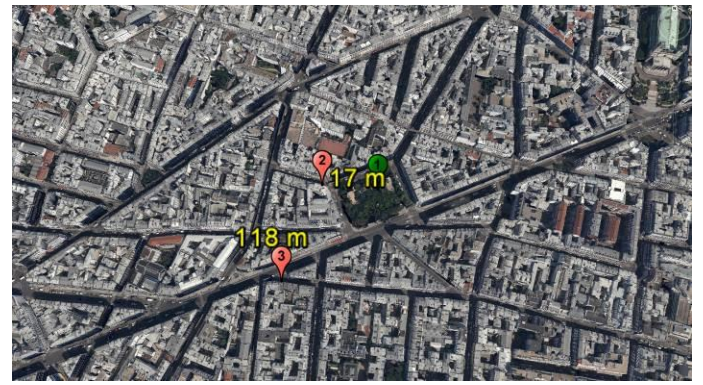
3 - Square René Le Gall (13th)

4 - Square Georges Caïn (3th)
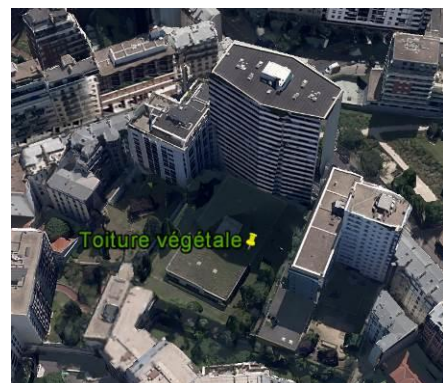
5 - Canal Saint Martin (10th)

6 - Square Montholon (9th)

7 - Jardin Atlantique (15th)

8 - Green roof (15th)

Temporal analysis

Figure 2 shows the time evolution of the temperature near a blue space (Canal Saint Martin), a large green space with low thermal inertia (Parc Monceau) and a small green space with high thermal inertia (Square Georges Cain).

The daily temperature range is the least important for the Canal Saint Martin. It may be explained because of the hight thermal inertia of the water: the temperature rises slightly during the day, but decreases slightly during the night as well.

Lowest temperature is reached on the Parc Monceau, potentially due to a strong ability to remove heat with its important vegetated areas (high SVF). The presence of high vegetation (shading) can limit the day temperature rise. Rapid temperature variations are characterized by both a low thermal inertia and a high SVF of the site (or "sun view factor" at a certain time).
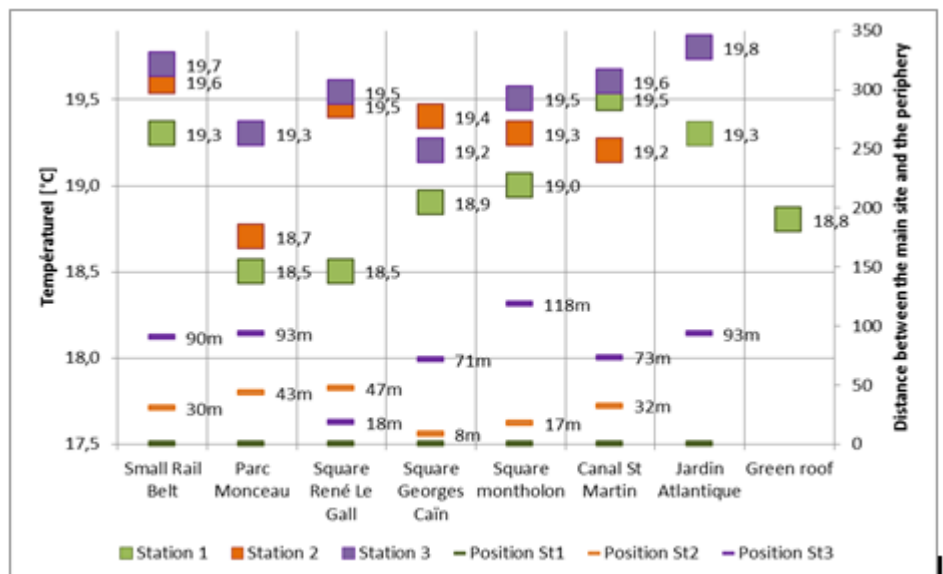
The Square Georges Cain has a high sky view factor which results in the highest maximum temperature of our three sites. Due to the high building density close to the park, it also has a higher thermal inertia than in the Parc Monceau, resulting in a lower cooling rate during night-time.
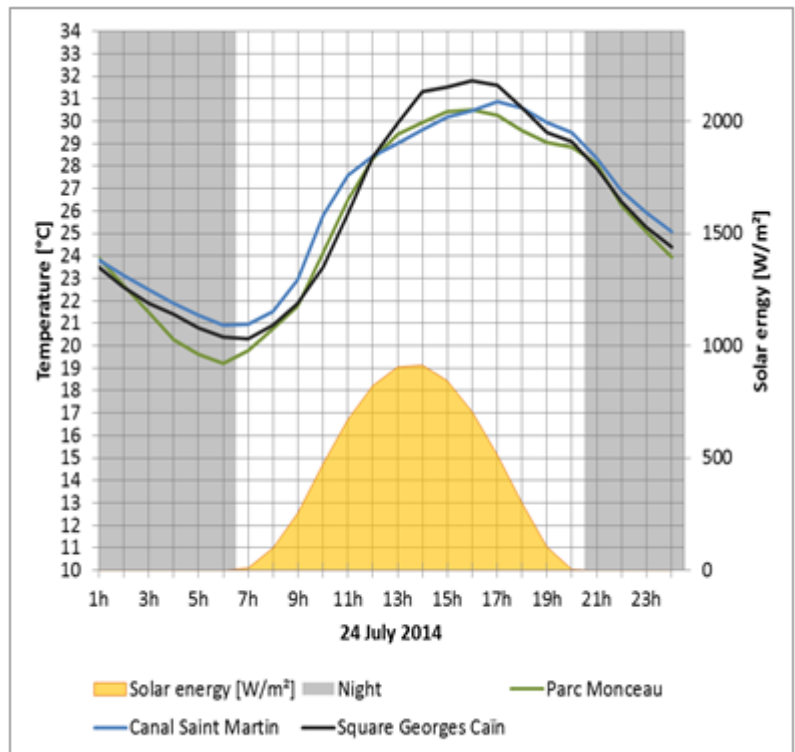
- Figure 2 : Temperature in 3 sites studied typologies -

Quantitative analysis of sites

Figure 3 presents the lowest average temperatures observed during the hottest period of the summer, 2014. These temperatures are observed at the theoritical maximum UHI (ie after the sunrise (Oke and Maxwell, 1975) and the sunset - between 4 am and 7 am (UTC+01:00 - Paris). The temperature range if we consider all the stations is pretty low (about 1.3°C). Nevertheless all the main stations except the one located near the canal show lower temperature than their surrounding stations. The coolest parks are Parc Monceau and Square René Le

- Figure 3 : Diffusive ability of « green and blue » areas during the coolest 4h -

Gall, which could be explained by a high Sky View Factor (SVF) and a low thermal inertia, two main characteristics which drive the PCI potential (Spronken-Smith and Oke, 1999). Although they see direct solar radiation during a larger part of the day, they can cool quickly during night-time. Square Georges Caïn and Square Montholon are 0,4°C and 0,5°C hotter than the coolest parks (18,9°C and 19°C respectively). These green spaces are smaller and mainly covered by high vegetation, which leads respectively to a higher thermal inertia and a lower capacity to evacuate the heat during night-time (lower SVF). The green roof and the Smal Rail Belt are hardly comparable with the other main stations since they are located at a higher elevation than their close surroundings (then has a specific thermal behavior) and are small. Jardin de l'Atlantique has a high temperature which may be explained by its medium SVF, medium thermal inertia (because of mineral surfaces) and uncapacity to be ventilated due to the height of the building around. At last, the high temperature of the canal may

be explained by the high thermal inertia of the water and the low SVF due to the high tree density. A PCI effect of a park on its surroundings may be assumed mainly for the Monceau Park. Indeed a small temperature difference (0,2°C) exists between the main station and the closest station and a bigger difference (0,6°C) is noticed between the closest station and the furthest. The temperature is 18.5°C at the center of the park, 18.7°C at 43m from the park and then increases to 19.3°C at 93m from the park. This behavior is almost invisible for the other sites (Little Belt Railway Square René Le Gall and Canal Saint Martin), even if a small temperature difference remains between the second and the third stations. We observe unusual behavior on the site of the Square Georges Cain: the temperature observed on the furthest station is 0,2°Clower than the one of the nearest station. This might be explained by the presence of an underground parking entrance right besides the furthest measurement station, which might decreases the air temperature.

C - Conclusions

Some preliminary conclusions can be drawn from this work. The smaller the green space, the lower will be the cooling of the park and its periphery (square Georges Caïn and green roof). Two main characteristics may explain the weak potential of a park to cool down : significant proportion of mineralized surface (high thermal inertia) and large part of high vegetation surface, conclusions met by Spronken-Smith and Oke (1999). In the first case, the mineralized surfaces induce considerable thermal inertia of the soil that prevents the rapid dissipation of heat (Square René Le Gall, Atlantic Garden, Little Belt Railway 15th). In the second case, the volume of high vegetation reduces the cooling potential by longwave radiation decreasing the SVF (Square Montholon and Square Georges Cain). The Canal Saint Martin does not effectively refresh its periphery during the night because of the high thermal inertia of its water. Indeed the water temperature is a bit higher than the air temperature during night-time and then the water releases heat to the air. Only a large green area composed of low vegetation and a judicious distribution of high vegetation seems to be efficient to decrease the temperature inside and outside of the park (Parc Monceau). However the conclusions of this analysis derived from a qualitative analysis of the interactions from the urban fabric characteristics to the air temperature. Geographical indicators such as facade density, vegetation density (low and high) might be calculated in a future analysis in order to confirm the conclusions emitted in this article. Concerning the data itself, two main improvements may be achieved to make the results more accurate. First, the number of stations per sites could be higher in order to verify the representativeness of each station (or mobile campaign could be implemented). The summer climatic conditions should be closer from a heat-wave period than the one of 2014, which was not suitable for a UHI analysis (maximal temperature of 40°C in the daytime and 25°C minimum at night during the summer 2003, against 32°C and 18°C during summer 2014).

References

Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N., Becker, S. (2003). Outdoor comfort research issues. *Energy and Buildings*, *35*(1), 77-86.

Jauregui, E. (1991). Influence of a large urban park on temperature and convective precipitation in a tropical city. *Energy and buildings*, *15*(3), 457-463.

Hathway, E. A., Sharples, S. (2012). The interaction of rivers and urban form in mitigating the Urban Heat Island effect: A UK case study. *Building and Environment*, *58*, 14-22.

Howard, L. (1833). *The climate of London: deduced from meteorological observations made in the metropolis and at various places around it* (Vol. 2). Harvey and Darton, J. and A. Arch, Longman, Hatchard, S. Highley [and] R. Hunter.

Musy, M., Gutleben C., Inard C., Long N., Mestayer P., Rodriguez F., Rosant, J.M., 2012. VegDUD project: role of vegetation in sustainable urban development. In: Presentation at the 8th International Conference on Urban Climate and 10th Symposium on the Urban Environment. Dublin.

Spronken-Smith, R.A., Oke, T.R., 1999. Scale modelling of nocturnal cooling in urban parks. Bound-Lay. Meteorol. 93 (2), 287–312.

Steeneveld, G. J., Koopmans, S., Heusinkveld, B. G., Theeuwes, N. E. (2014). Refreshing the role of open water surfaces on mitigating the maximum urban heat island effect. *Landscape and Urban Planning*, *121*, 92-96.

Suomi, J., Hjort, J., Käyhkö, J. (2012). Effects of scale on modelling the urban heat island in Turku, SW Finland. *Clim Res*, *55*, 105-118.

Svensson, M. K., Eliasson, I., Holmer, B. (2002). A GIS based empirical model to simulate air temperature variations in the Goteborg urban area during the night. *Climate Research*, *22*(3), 215-226.

Oke and Maxwell (1975) Urban heat island dynamics in Montréal and Vancouver. Atmos. Environ.

Oke. T.R. (1987) Boundary layer climates. Methuen and co. London, 2nd edition.

Oke, T.R (2004). *Initial guidance to obtain representative meteorological observations at urban sites* (Vol. 81). Geneva: World Meteorological Organization.