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Full Length Research Paper

A study of how tall buildings influence climatic factors and the need to create a different microclimate in a district

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The gradual change of climatic factors in a large agglomeration is primarily related to the expansion of urbanization. The construction of high-rise districts is currently in fashion worldwide, in part because high-rise buildings provide an image of prestige and prosperity for the country. However, the essential purpose of constructing high-rise buildings is to group together a large community in a restricted space. The aim of this study is to understand how tall buildings influence climatic factors and create a different microclimate in the district. This study is based on a 4-year series of measurements of the influence of the high-rise district of La Défense in Paris, France on climatic factors and air-pollution patterns. The results show that the construction of high-rise district creates a microclimate having higher temperatures than otherwise. Thus, high-rises tend to reinforce the phenomenon of urban heat islands. The construction of high-rises also has advantages as shown in this study, the upper-floor quarters benefit from natural air conditioning and a lower concentration of pollution. The construction and management of high-rise districts within cities is thus very important, and can generally lead to ecosystems with microclimates that are more favourable to urban dwellers

Key words: impact, tall buildings, climatic factors, air pollution.

INTRODUCTION

In recent years, there is a very strong tendency to construct buildings that are part of a sustainable development approach. The construction of landmark buildings in major cities around the world is justified by a lack of space and a desire for prestige, prosperity, and the development of architecture and tourism (IngegaÈrd, 2000). We are currently witnessing a renewed interest in high-rise districts in major cities worldwide and less interest in green spaces (Berkowicz et al, 1996). The construction of a high-rise adds value to the surrounding district. However, the impact of this type of urban development on the climate of the megacities, on public health and urban planning, and on the environment has been the subject of few studies (Escourrou, 1981). Research in this area is important, if only to minimize modifications of the microclimate and to monitor noxious emissions.

The objective of this study is to see the influence of the construction of buildings of great heights and climatic factors on the distribution of air pollution.

This article is part of a 4 years long study devoted to “the influence of urban development on the climate and air pollution in the Paris region”. To compare the results, several measurement locations were chosen. The Point 1 measurement is outside the high-rise towers; the measuring point 2 is located between the high-rise towers and the Point 3 measurement is located between Parisian buildings with an average of 5-6 floors. We identified these three measurement points which we considered essential to this study as periphery, centre, out of the area. Other points have been studied in this long study, but in this article, only these three measurement points are mentioned. To compare the evolution of climatic factors between one place and another, it is necessary that the measurement points are the same.

These are the three different points (just outside the towers, in the towers, and far from the towers) that show the significant impacts of towers on climatic factors and the distribution of air pollution. In this article, the examples chosen give the best results and an overview of the numerous campaigns of measurement that have been undertaken.

The present study, we intended to focus exclusively on the determination of the repartition of the air temperatures, humidity, pollutants surrounding the area towers.

This study offers some new elements in order to increase the understanding of the importance of a good planning of the cities on climate and pollution.

MATERIALS AND METHODS

This article is part of a study on "An example of the changing climate due to the constructions in the Paris region". This study required an intensive measurement campaign over a period of four years. We tried to see the influence of local amenities on the different climatic factors (temperature, humidity and wind) and the distribution of air pollution.

The examples given (average of several measurements distributed over 4 years) refer to the most frequent cases found during our measurement campaigns in different seasons of the year.

In this study, measurements of air temperature and relative humidity are taken outside at height of about 1.80 meters with a probe. The final value is recorded on an average of 20 seconds, time it takes for the probe to give the most accurate value.

The measurements of the factors climate and the pollutants have been taken in different locations. In this paper, to compare the climatic factors and the rate of pollution in this area, we focused the study on 3 measurement sites.

The principle of measurements is to record climatic factors (temperature, humidity, direction and wind speed) and the rate of pollutants (CO, CO_2 and SO_2) in different places in a district at a period of time with the same apparatus.

The device to measure temperature and humidity is a portable air intake. Wind measurements are taken with nanometer. The device of measurement of pollutants is a gas detector (the manufacturer of these devices is TROTEC).

In this article, the examples summarize most cases in the measurement campaign. The pollutant measurements are limited to two pollutants:

- Carbon monoxide (CO), a colorless, odorless and toxic gas. It is produced during incomplete combustions,
- Sulfur dioxide (SO_2) emitted from domestic homes and industrial sources.

Concentrations of pollutants are given in ppm = 2900µg/m3; values are recorded over 20 seconds (time necessary for the conditioner unit of measurement gives an accurate value) at one meter above the ground surface. The wind speed (m/s) was measured with a manometer, the recorded direction is that found with a wire.

If variations in measurements are not significant between the beginning and the end at a given point, the estimate is considered exact (few variations of the climatic factors were observed during the measurement process).

The apparatus made it possible to compare two recorded values in two different places. The apparatus does not always find the same values as those recorded by weather stations, as recorded and provided by weather forecast of France. Others have been published in the monthly departmental bulletins of the Paris region, which exist in the Library of National Meteorology, Avenue Rapp, in Paris.

This work provides a new contribution to consideration of spaces to improve the urban climate and mitigate air pollution. The results can be used in future planning of the urban development.

RESULTS

Effect Of High-Rise Towers On Temperature

La Défense, in the west of Paris, is the first European business district by the extent of its office park. It is located in the Hauts-de-Seine in the territories of Puteaux, Courbevoie and Nanterre in the wake of the historic axis of Paris that starts at the Louvre and continues with the Champs Elysees, the Arc of Triomphe, and beyond to the bridge of Neuilly and the Arche de La Défense. The architectural ensemble known as the district of La Défense in Paris (France) is a development model inspired by American urban planning in which high-rise buildings reach significant heights and have glass exteriors (Figure.1). The general layout of the neighborhood of Défense has been designed according to the principles of the modern movement between 1960 and 1980. This type of district is increasingly common worldwide, especially in large cities of developed countries.

The development of this kind of district in the western Parisian periphery is certain to have repercussions on local climatic factors. Another factor in the strengthening

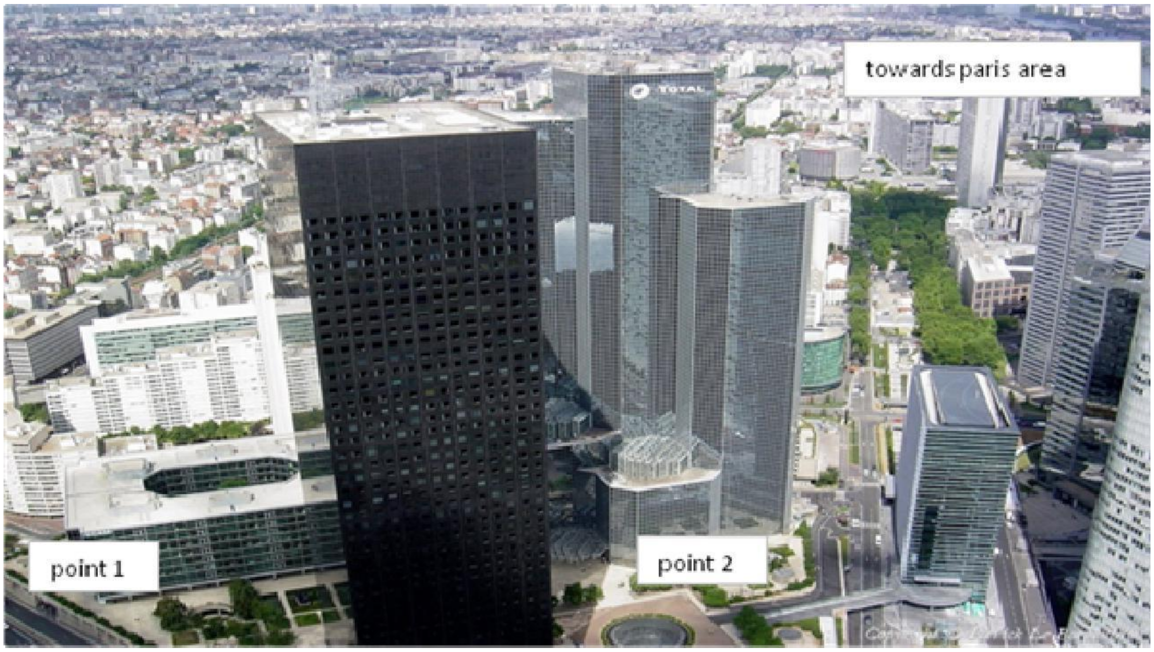

Figure. 1 View of the La Defense and various point of measurement

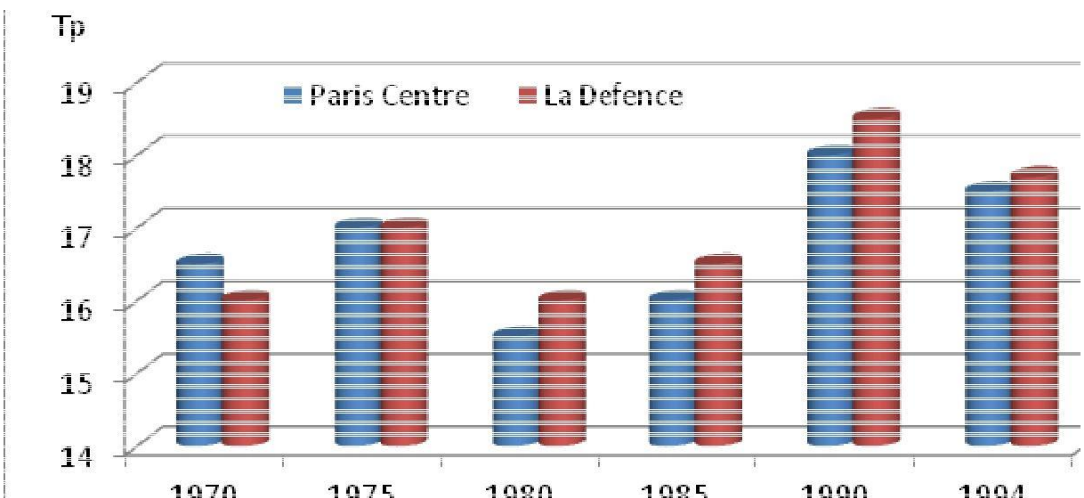

Figure. 2 The maximum average air temperatures between the area towers of La Défense and the Paris centre

and expansion of the urban heat island in Paris is that this region is one of the most populated in the world. Its population increased from 1,35 millions in 1805 people has more than 15 million in 2008 (Escourrou, 1981). The intensity of the heat island is Proportional to the number of population (Escourrou, 1981).Central Paris has seen its temperature rise because of intense urban development (Calvet, 1984), and the temperature increase is especially pronounced in western areas because of the construction of this high-rise district (Escourrou, 1981). An examination of the maximum average air temperatures (Figure. 2), between the towers of La Défense and central Paris over a 24 years period reveals that the central Paris was hotter when

Table 1. Air temperature and humidity around the large high-rise buildings of La Défense during cold and hot periods (average of 10 measurements)

Measurement	Period	Tp°C	HR %
Outside tours (point 1)	Cold period	10,5	60
Between towers (point 2)	Cold period	11	57,8
Outside tours (point 1)	Hot period	23	50
Between towers (point 2)	Hot period	25	45

construction La Défense started. During the expansion of this region in the west of Paris and the acceleration of urbanization, the Defense became hotter than the centre of Paris.

The construction of the La Défense district started in 1970, at which time the maximum average air temperatures in central Paris were greater than those at La Défense. From 1975 the district of La Défense became hotter than central Paris, which itself has air temperatures significantly above those of the wider Paris region. This island of urban heat that accumulates over major cities (Fukuoka, 1983) is due to

- Human activities such as heating and lighting,
- Restitution of diurnal and nocturnal thermal energy stocked in the housing,
- The capacity to reflect solar radiation. The non-absorbent ground and the exterior building walls allow the passage of a large fraction of the incident energy, and the accumulation of this energy within the buildings increases its intensity. This phenomenon is well known in cities, especially in summer when the solar radiation flux is greater (Eliasson and Holmer, 1990).

An area that is built up absorbs much more energy (85%) (Escourrou, 1995), so the formation of a heat island is understandable, although several urban measurements can reduce the magnitude of the heat island, such as the establishment of green spaces or waterways. These developments are increasingly rare in major cities and new urban projects.

The city centre is generally the warmest part of a town throughout the year (Kwi-Gon-Kim, 1989). Diurnal energy storage in urban areas by impervious soil and into buildings is restored to the atmosphere especially at night. This phenomenon is very common during summer, when the contribution of Luminous Efficiency is very important. During cold periods, during our measurement campaigns, the temperature difference between large urban areas and surrounding areas is quite small (average of 10 measurements distributed over 4 years) (table. 1), which is due mainly to the large spaces between towers and consequent breeze circulation, which minimizes the accumulation of heat and the formation of urban heat islands, which minimizes the accumulation of heat and the formation of urban heat islands. Knowing that the breeze is a light wind, whose speed is low (1m/s) blowing from a cold to a warm place. This phenomenon is very common in urban areas (Retting and al, 2003).

Outside the high-rise district, the warming effect due to the heat transfer is reduced compared to areas between or very close to the high-rise buildings (Nethery, 2007).

The outer walls of the facades of buildings are characterized by good thermal insulation. Much of the radiating sun is refracted outward participant increasing ambient air temperature (Spiller, 1993). The outer sheathing of the large buildings reflects a significant part of the incident solar radiation away from the building, encouraging a temperature increase between the high-rises, and the formation of an urban heat island (Spiller, 1993). This explains why, during hot periods, La Défense becomes hotter than central Paris from 9 in the morning to 8 in the evening (Figure. 3). In winter, to make towers area more livable, enormous amounts of energy are consumed (heating, lighting and human activities) before being discharged to the outside: the tower district is warmer than in the surrounding area without having necessarily more comfortable. The planner must focus not only on the maps of urbanization but also to the comforts of urban and microclimates generated by the various urban developments, which can have very negative effects.

During sunny periods, during our measurement campaigns, the temperature difference between the inside and the outside of high-rises in La Défense may exceed 2 °C (average of several measurements distributed over 4 years). This excess of temperature is mainly due to reflection of solar radiation by the outer coating of the glass towers of La Défense. Indeed, when two environments show significant differences in temperature, a breeze, whose speed is generally less than 1m/s, comes from the cold space to the warm space. These homes have natural air conditioning and are well suited to people that do not support an increase in temperature. The warming effect is felt primarily between buildings (Park, 2002), where the wind speed is reduced because of the high-rise heights. In relative terms, the atmospheric humidity outside high-rises is significant.

During sunny weather, districts with glass-sheathed high-rises (such as La Défense) are more rapidly warmed

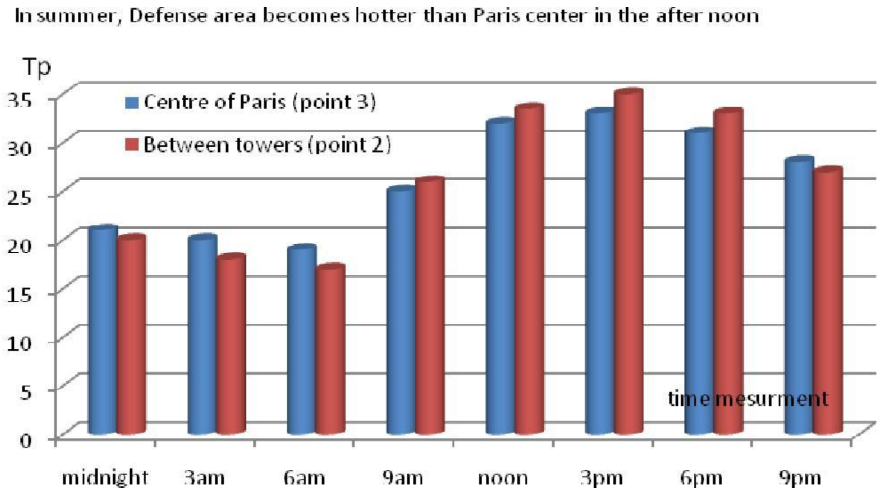

Figure. 3 Air temperature evolution between central Paris and La Défense (towers area) during hot periods (average of 4 summers)

Table 2. Difference in pollution levels between a Parisian street and La Défense (between high-rises) (Average of 10 measurements distributed over 4 years)

Kind of wind	Between the towers (point2)	Centre center of Paris (point3)
CO (ppm)	1	9
SO2 (ppm)	0,1	0,3

than other areas. The glass-sheathed facades of the high-rises reflect a large portion of the incident solar radiation, contributing to the rapid increase in the ambient external air temperature. The temperature in the district abruptly increases above that of more traditional districts, and the relative humidity decreases (Svensson *et al.,* 2002). The air temperature variation as a function of high-rise floor level is very large (table.2) (average of 2 measurements). During hot periods, it is usually quite hot on the ground floor of high rises, and the temperature tends to decrease with height (Park *et al.,* 2002). The air temperature difference can be quite large during very hot and very cold periods. Residences and offices on upper floors are much cooler and therefore consume much less energy in air conditioning. Lower floors suffer from high temperatures due to thermal emission into the atmosphere by the non-absorbent ground of some solar-derived heat, contributing to raise air temperatures near ground level and a decrease in relative humidity (Hicks *et al.,* 1989).

The example cited show the difference of air temperatures and humidity in this area. In this city, during the summer months, the sun's rays darts on concrete surfaces, which, in a state of overheating, reflect and trap energy, which is rendered into streets and buildings. So, the city becomes a furnace. The cladding glass buildings reinforced by the concrete of the area, which have replaced the trees and natural vegetation, stores heat (De Leeuw et *al*, 2002). Urbanites are obliged to use air conditioners, which consume a large amount of electric power and tend to increase heat stress.

In winter, the urban heat island is much more experienced next to the ground. The lower local towers are much more energy compared to the upper floors of premises. The upper floor premises experience much cooler air temperatures than those of the lower floors (Faix, 1991). The upper floor premises therefore require slightly more energy for heating. Conversely, during hot periods, people working on upper floors enjoy the advantage of cooler air temperatures and, compared with those on lower floors, reduce their energy consumption involved in air conditioning.

The tall buildings, vertical construction and towers have been able to identify, as desired by Le Corbusier, the intermediate spaces in which we have drawn large, wide and straight arteries planted with trees for ventilation and

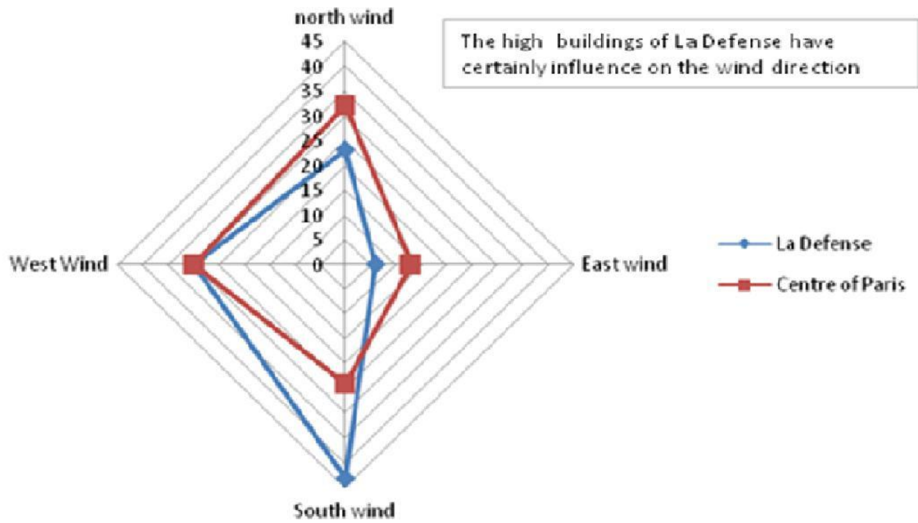

Figure. 4 Average wind direction (number of times) in summer in the Paris region (average on 4 years)

adaptation to the environment and the local climate. But these areas are extremely hot in summer. In fact, it will be the data climate that must be integrated into the architecture; the solution is in a series of steps on the location, exposure, the thermal behaviour of materials and surface treatment.

Response Of High-Rise Buildings To Wind Speed And Direction

Cities are characterised by numerous relatively high buildings. The effect of buildings on winds is a result of their height, their architectural form, and their layout. High-rises affect winds mainly by:
reducing wind speed; average measurements taken over a period of 4 years indicate that there is 15% calm wind (zero wind) at La Défense between the high rises, compared with 2% in Paris
Suppressing or reducing winds at the building facades,
Concentrating the air flux in the tight spaces between high rises (Venturi effect).
Towers act as a barrier against the winds on arrival. Note that there is also the effect of the state of the weather station. The weather station in central Paris is located at the Saint Jacques Tower in a garden and that of Defence is housed behind Arche of La Défense.
In summer, prevailing winds in the Paris region are generally north. Analysis of wind data for summer Between La Défense and the Centre of Paris (Figure. 4) (average on 4 years) reveals significant changes in direction during a single interval and over a single region.
The average wind directions recorded by the meteorological stations at La Défense to the west of Paris and at Saint Jacques (central Paris) exhibit numerous differences in the summer. The wind at La Défense (the high-rise district) is generally from the south, whereas the wind at central Paris is from the north or west. The wind direction changes because of the urban morphology (Svensson et *al.,* 2002).

Also noticeable is that, in summer, the high-rise district has the lowest average wind speed of the Paris region (Figure. 5). This is because the high rises play a significant role in changing wind direction and in reducing wind speed.
Urbanisation is responsible for the changes in wind direction (Won et *al.,* 2003). The deviation of wind directions is related to the urban heat island. This phenomenon occurs more in summer, during the passage of unstable air masses. Winds can be deflected in the direction cyclonic (direction of rotation of the earth) to the extent that the roughness increases.

Analysis of three-hourly data for summer from the four-city region that surrounds Paris leads us to the following conclusions:
The high-rise buildings act obstacles to the wind (Pelletier, 1987). The wind speed in the high-rise district of La Défense is the weakest, which may also be explained by the location and orientation of the meteorological station.
The frequency of average wind speeds that exceed 3 m/s is recorded only in the stations of the Paris suburbs, with the exception of La Défense.
These high-rise buildings reduce the wind force and typically create vortices (Gomez, 1998).

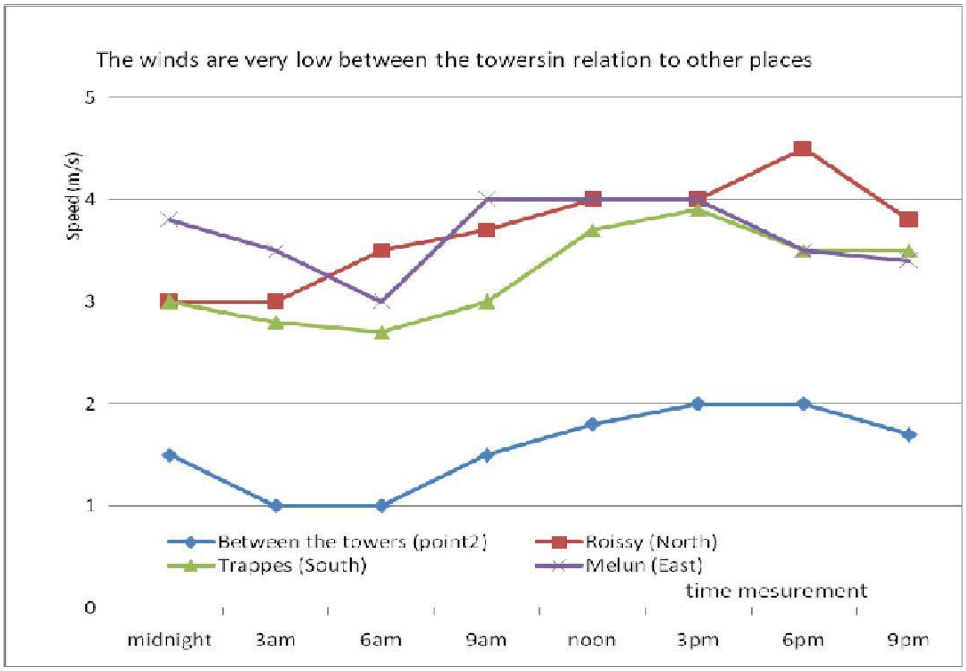

Figure. 5 Average wind speed in summer in the Paris region (average on 4 years)

Note that along the towers, a breeze of wind flows fluently. These breezes are generally low speed: the nanometre indicates zero speed or less than 1m / s.

Urbanization has certainly influence the speed and wind direction. Transformations can occur by piping winds in some streets. When wind direction is parallel to the street, there is usually faster wind speed. If the wind is not parallel to the street, there may be the creation of specific phenomena such as eddies and the reduction of wind speed.

The shape and architecture of buildings and their layout also create specific phenomenon, as the acceleration of winds between the narrowed areas facing the wind. The height of buildings and multiplication form a barrier that significantly reduces wind speed

Effect Of High-Rise Buildings On Precipitation

It is known that high-rise buildings influence precipitation. As a rule, they are correlated with an increase in rain (Givoni, 1989). High-rises increase the surface roughness, which tends to slow the lower layers of the atmosphere, leading to upwells of air and an increase in precipitation (Kwi-Gon, 1989). Comparison of precipitation from 1950 to 1980, 1980 to 1987, 1987 to 1993 and 2000 to 2004 (Figure. 6) confirms that only the meteorological station of La Défense saw a consistent increase in rain (construction of La Défense began around 1970). The construction of La Défense clearly led to an increase in precipitation of several millimetres over neighbouring regions.

Comparison of the Average monthly precipitation in the western suburbs of Paris (Figure. 7) (average 13 years) between La Défense, Nanterre and Colombes (west of Paris) leads us to make the following observations:

- The high-rise buildings receive more precipitation than other outlying areas.
- For almost the entire year, La Défense receives the most precipitation.

It is certain that high rise buildings (e.g., La Défense) influence precipitation over large agglomerations. The effect of the heights of these buildings on the increase in rain is due primarily to:

- an increase in the surface roughness: The high rises reduce the wind speed and increase the surface roughness, slowing the lower atmospheric layers and leading to the development of air upwells, which generates an increase in precipitation (Eliasson and Upmanis, 2000);
- High air temperatures and low relative humidity as a consequence of the impermeable ground and the restitution of energy into the air, especially in summer

. These effects favour instability and air upwells

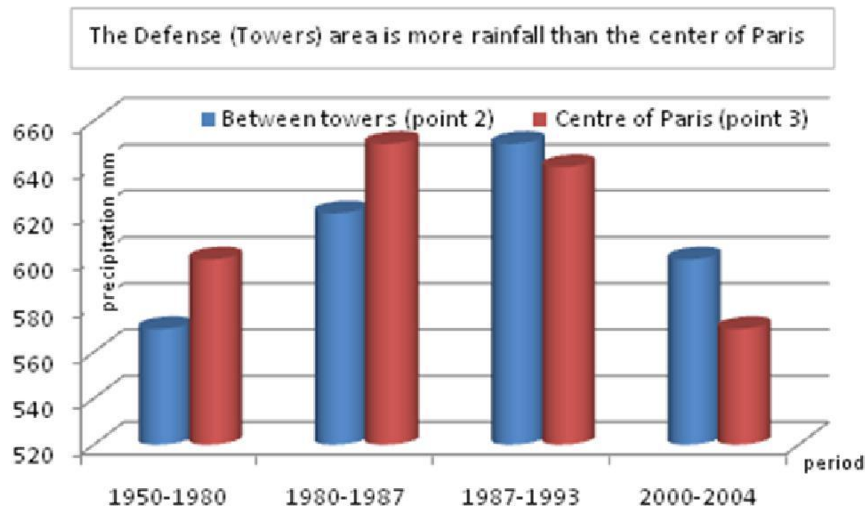

Figure. 6 Annual precipitation between La Défense and centre of Paris

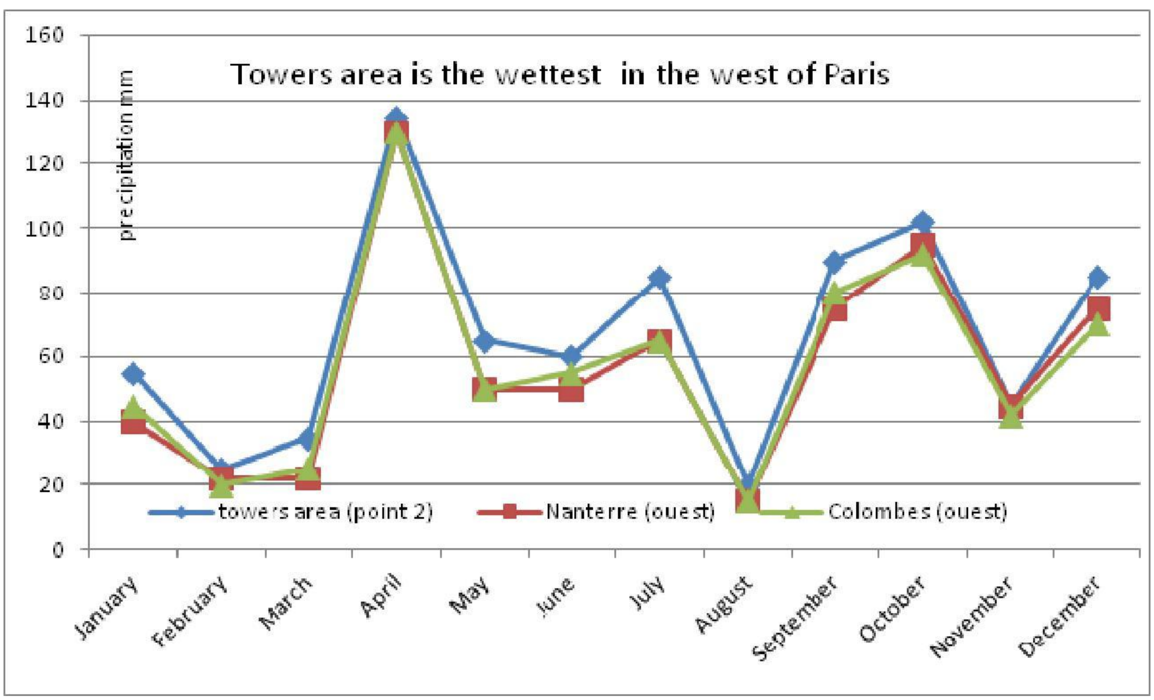

Figure. 7 Average monthly precipitation in the western suburbs of Paris (average 13 years)

that trigger storms and an increase in rain (Unger, 1999). In large agglomerations, the ground is largely impermeable, so that water which falls quickly flows into drains. Trees are rare and evapotranspiration is very limited. It is therefore certain that urbanisation and other human activities modify the relative humidity and rainfall.

In general, urbanisation increases precipitation (Escourrou, 1995). Several factors explain how urbanisation leads to an increase in precipitation:

- High pollution concentration facilitates condensation inside air masses and, in general, leads to acidic rains.
- High air temperatures, especially during hot periods, facilitate the destabilization of air masses, which triggers rain. Urban heat islands act in the same manner.
- Significant evaporation occurs in cites because of the impermeable ground.
- Increased roughness causes a descent of the air mass and a wave system develops: when the air rises there is more rain, when the air sinks, the rain fall. The extension of urbanization on the outskirts of the city changes the roughness that affects the wave system.

The construction of high-rise districts increases precipitation. In urban areas, the warm air masses tend to rise. In fact, this type of major construction influences rain because of the significant roughness it causes and by the excessive and rapid heating that is a result of the impenetrable ground and the glass facades. The influence of the unstable and sensitive temperature promotes the rise of air masses. This ascension occurs through thermal gradient, which determines its speed and creates an increase in precipitation. The district of La Défense to the west of Paris receives more rain than central Paris.

Effect Of High Rises On The Distribution Of Pollution

The design of a high-rise district generally incorporates the notion of green spaces between the high rises. The district of La Défense to the west of Paris has a low concentration of pollution, because it benefits from its urban morphology: space between the high rises permits air circulation and the ready dispersion of air pollution (Touma, 2006). Winds are usually winds reduced or stopped by the height of buildings and slowing the wind speed is also linked to increased roughness. The flow of air between the towers is usually a movement of breezes thermal, regional or local, whose speed does not exceed 1m / s.

This air circulation is very favourable to the dispersion of pollution between towers in district of La Défense. In most of our measurement campaigns, we found low CO and SO_2 concentrations in the district of La Défense, increasing markedly in the direction of Paris (IngegaÈrd, 2000). In winter, variations in the pollution concentration are very small.

During cold periods, the distribution of pollution in the morning is similar to that in the afternoon, although the SO_2 concentration tends to diminish in the afternoon (Roussel, 1993). In summer, the pollution distribution is identical at La Défense and Paris. In spite of the weakness of the wind, the pollution concentration is very small between the high-rises at La Défense, but increases considerably toward the traditional districts where space is reduced (Sax and Isakov, 2003). Table 2 shows the distribution of pollution at the high-rise district and a Parisian district (average of 10 measurements distributed over 4 years).

Regarding the vertical distribution of pollution around the high-rises (buildings with over 30 floors), pollution measurements taken ascending a high rise (Tour Montparnasse, 58 floors) show significant differences in pollution concentrations as a function of floor elevation (Berkowicz et *al.,* 1996). Pollution is significant at the lower floors because of the dense street traffic (Mayer 1999), tending to diminish at the upper floors of the high-rise (Nethery, 2007).

The concentration of the pollutant SO_2 is very slight for the higher floors compared with the lower floors (Park 2002). Carbon monoxide, which is very widespread at ground level, diminishes significantly toward the upper floors (Borrego et al 2003) (Figure. 8) (average of 3 measurements distributed over 4 years).

This pollution is mainly due to traffic. These pollutants (CO and SO2) are mainly concentrated near the ground and that pollution does not rise along the floors of the towers of La Défense. The lower floors of buildings receive a pollution rate much higher than the upper floors, especially in the area where winds are generally weak. The distribution of pollution in an urban environment depends on the architectural layout; it also depends on the shape of the arteries, and the proximity of green space. Wide spaces between the towers promote the circulation of air pollutant dispersion is better (Elvik, 2001).

The pollution measurements were made along a tower (Tour Montparnasse, 58 storeys), to see the distribution of pollution in height. The pollution measurements were made along a tower (Tour Montparnasse, 58 storeys), to see the distribution of pollution in height.

During our measurement campaigns, the distribution of pollution was almost identical. Pollution is concentrated next to the ground and tends to decrease in the upper floors. This concentration is due to the fact that at ground level winds are very low and the pollution does not disperse easily. People working on upper floors enjoy a much lower pollution concentration than those working on lower floors or in offices in traditional low-rise districts (Williams, 2006).

Two factors explain the poor distribution of levels of pollution in the area of Defence. Low car traffic in the neighborhood of Defense and the movement of breezes that discharge pollutants into the hottest parts. Pollution low in this type of neighborhood tends to concentrate near the ground (Waller, 2004).

The upper floors, pollution is low due to winds which are more active than the lower floors.

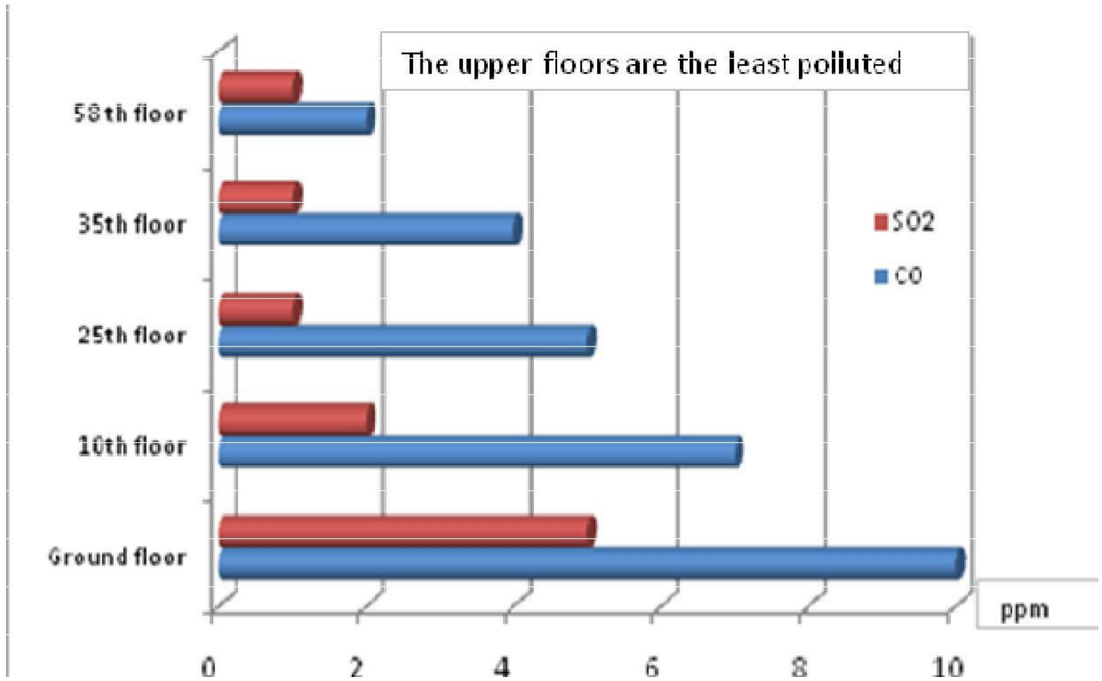

Figure. 8 Pollution concentration at successive floors of a high rise building (average of 2 measurements, Tour Montpanasse)

DISCUSSIONS AND CONCLUSION

This study shows that from a measurement campaign in a few points of a neighborhood, it is possible to understand the dynamic behavior of an urban area. This type of analysis shows the interest that could be a campaign of several measurement points, highlighting the microclimate and urban traffic with a cheap hardware. The many examples cited show the role of development in the evolution of climate. The layout plays at various scales:

- At the local level or variations in temperature, moisture can occur. Small breezes are created to promote the regulation of microclimate and pollution dispersion
- At the regional scale: a district can encourage urban heat island and lead to higher rainfall.

Good management should avoid heat accumulation and concentration of pollution

The study of the microclimate is very complex, but it is essential to limit climate risks in particular the high peaks of pollution.

This study leads us to the following results:

Upper-floor real estate enjoys lower air temperatures in summer, allowing air conditioning to be eliminated or replaced by simply opening windows.

High-rises create microclimates by reinforcing the phenomenon of urban heat islands.

Upper floors benefit from a lower concentration of pollution compared with lower floors, where the pollution concentration is generally quite high. We have also noticed that upper floors suffer less noise pollution than lower floors.

The construction of towers in a region plays a significant role in changing local climate. The large spaces between the towers promote wind circulation and therefore the dispersion of pollutants. The construction of high towers increase rainfall and therefore promotes the quality of air in the city.

This study provides new information concerning the effect of high rises on the improvement of microclimates, and increases our understanding of the effect of urban development on the climate and the distribution of air pollution. The results may be used for planning for future urban developments.

The undertaking of a study devoted essentially to the influence of development and the environment is a significant project. Currently, two major concerns for authorities are urban planning and environmental protection, the latter of which is constantly threatened by urban growth, the development of large agglomerations, and the negative effects of air pollution. It is therefore at the local level that human actions carry the greatest weight. This is where people should act to avoid the disastrous consequences of climatic extremes.

It is also at this level that people should concentrate their efforts and planning to reduce the urban-heat-island phenomenon or eliminate pollution.
In coming years, and with global warming, the urban-heat-island phenomenon and air pollution will perturb urban life, and it is then that the urban planner will be held accountable to some extent for the resulting problems.

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