Urban Heat Island in Residential Areas of Brasilia

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ABSTRACT

Brasilia is the designed capital city of Brazil inaugurated in 1960. Its plane like form has in its wings the residential sectors. Initially it was in its south wing the concentration of the residential buildings during its first years. Years later the building regulations changed and allowed for the newer residential buildings in the north wing sector to be larger and with a higher occupation. Consequently the urban building density of the north sector became higher than the opposite south sector. This reflected directly in the reduction of open spaces and greenery and consequently causing urban heat island effects. This paper compares both residential sectors and sheds a light on how new building regulations and construction are affecting the more recent buildings and interfering on the local microclimate and environmental comfort. Research included analysis of climatic data collected locally, urban morphologic studies, and computer simulations. The objective of this investigation was to see the effects caused by changes in design permitted by modified regulations in the two main residential areas of the urban plan of Brasilia. For two years, Romero's research group analyzed 42 residential buildings, 22 in the north wing and 20 in the south wing. The data collected allows us to state that the later buildings constructed from the 90's are altering the local microclimate with a negative impact to its users, in contrast with the initial units built in the 60's to the 80's according to the original plan and regulations, with greater percentage of greenery.

Introduction

Brasilia, the designed capital city of Brazil, was built from scratch and was fully functional after only three and a half epic years of construction. Its innovative and revolutionary urban design is often seen as the idealization of the garden city principles on a vast urban scale, and the implementation of the Athens Charter, lead and promulgated by Le Corbusier in the CIAM (International Congress of Modernist Architecture) of 1933. The translation of the ideals of the integration of the natural environment with the built environment promoted in different eras by *avant garde* architects such as Robert Owen, Ebenezer Howard, and Le Corbusier reaches its culmination with Brasilia, as greenery in all its form of urban vegetation is treated as the main agent and protagonist of the city. This has led to Brasilia to be planned and now enjoy of around 120m² of greenery per inhabitant, around 6 times the UN Habitat recommendations. This is part of the reason that Brasilia has been object of interest and study since its inauguration in 1960.

The urban design of Brasilia, known as the Pilot Plan, an unparalleled landmark in the history of town planning, idealized by urban planner Lucio Costa, was entitled World Heritage property by UNESCO in 1987. Costa's biggest merit was planning the capital city around 4

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urban scales: the monumental scale, the gregarious scale, the residential scale, and the bucolic scale. Its plane like form has in its wings the designation for the residential sectors. In these sectors, north and south, horizontal residential buildings configure superblocks which were planned and built to be self-contained in what is called Neighborhood Units. In a walking distance of around five hundred meters, one would be able to attend to all its daily needs and duties. Initially it was in its south wing the concentration of the residential buildings during its first years. Years later the building regulations changed and allowed for the newer residential buildings in the north wing sector to be larger and with a higher land occupation. Consequently the urban building density of the north sector became higher than the opposite south sector. This reflected directly on the percentage of open spaces and greenery and consequently causing effects of urban heat islands.

The Pilot Plan and the Superblocks

When designing the superblocks, Lucio Costa thought of semi-autonomous cells in relation to education, health, leisure, culture, and religion. He concentrated residences in height, removed the buildings from the ground level by use of pilotis (stilts) and separated pedestrians and vehicles through specialized hierarchy pathways, thereby giving rise to extensive public spaces. A vegetation framework surrounding the superblock, forms a green belt of 20 meters wide on each block. According to Akbari and Taha (1992), strategically planted trees and shrubs near buildings can reduce the cost of consumption of air conditioning in the summer between 15 and 35%.

Trees can also mitigate the greenhouse effect, filter pollutants, mask noises, prevent erosion and have a calm soothing effect on people (Jauregui 1991, Emmanuel 2007). The performance of the vegetation depends on its intensity, shape, dimensions and location (Cantuaria 2001). In the recent design of superblocks in Brasilia, the landscaping abandoned the basic elements of Lucio Costa's, "large trees", implanting an unsuitable vegetation which does not provide shade, nor fruit, nor the visual impact, only to align awkwardly a number of palm trees in a dubious aesthetic composition. It’s worth emphasizing that Lucio Costa created for Brasilia the concept of city park, where the city should be covered by a large green carpet, with lots of trees, providing shading and a green belt around the residential blocks to protect from noise, and humidify the environment, as the first residential blocks testify.

Due to its rough texture and low chromatic value, a grass surface absorbs more solar radiation and radiates less heat than any other paved or asphalt surface. In general, both the air temperature and the radiant temperature are much lower in the areas covered by grass than those paved or asphalted with the same exposure (Oke 1987). The grassy surface also eliminates the occurrence of glare, reduces dust and mitigates noise by not echoing as in hard surfaces.

Trees absorb gaseous pollutants, either by directly absorbing ozone, or by reducing the air temperature, which in turn reduces hydrocarbon emissions and ozone formation. Trees reduce and filter noise, Akbari and Taha (1992) says that leaves, twigs and branches absorb high-frequency sounds that are most troublesome to humans. The same authors say that a belt of 33m in width and 15m in height can reduce the noise of a road in 6 to 10 dB.

According to Romero (2011a) studies of Ficher et al. (2003) point out that the requirements of the first Building Code of Brasilia in 1960 induced the integration of the ground floor with its surroundings, with most residential buildings being required to be built on stilts. Reviewed codes authorize the closure, though discontinuously, of up to 40% of the ground for the use the block itself. A bigger contradiction does not seem possible: a city that is built to be entirely open, transparent, without internal obstacles other than the distance and then it begins to be systematically gated and compulsively blocked, as if all the buildings mutually rejected each other. The trend throughout Brasilia, is that each residential block closes entirely by hedges and/or fences, despite being built on pilotis to allow free movement of passersby and ventilation.

The Building Regulation for Brasilia has gone through three changes between 1960 and the present. The most significant occurred in 1998 in which it was allowed for blocks to pass from a width of 12.5 meters to 18.5 meters (Figure 1). It was observed that the buildings got closer to each other, making it difficult for air circulation. Ventilation is also impaired and the heated air is stagnant in the urban canyons formed between nearby buildings (Figure 2). Moreover, what was to be a space for movement of pedestrians - the ground beneath the pilotis - ends up being not only a passage obstruction, but also obstruction for local breezes.

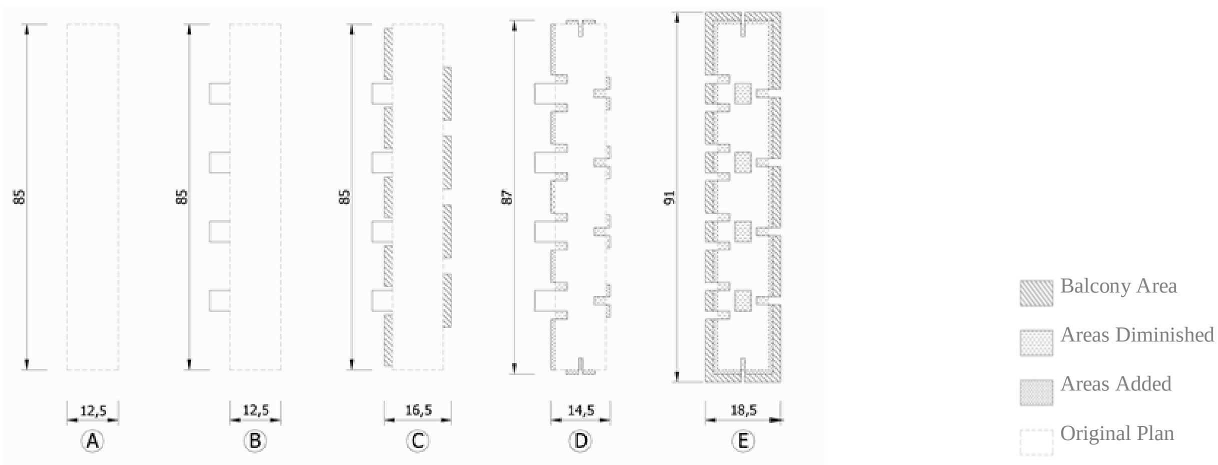

Figure 1. Changes of building width due to changes in building regulation. Source: Romero (2011a, p. 44)

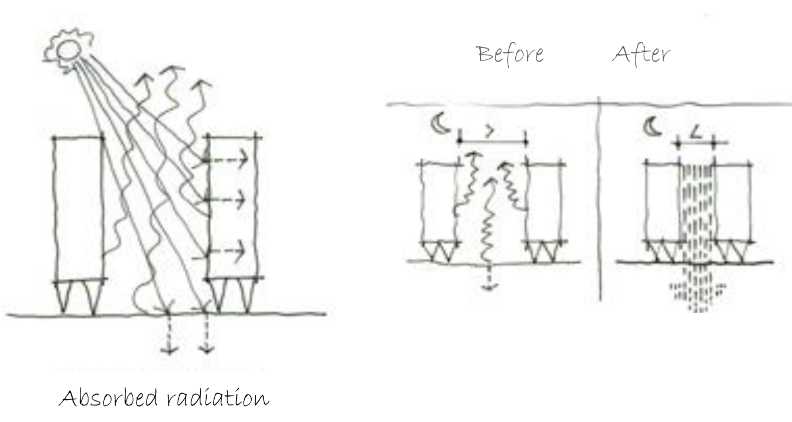

Figure 2. Superblock urban canyon. Source: Romero (2011a, p. 110)

With the changes made to the Building Code in 1998, the residential buildings increased from 48 to 96 apartments which quadrupled the need for parking, as two parking spots are expected per flat. Therefore, areas that were previously empty and lawns became paved with asphalt, helping to form heat islands between buildings.

The buildings of the superblocks, were mostly implemented individually and parallel or perpendicular to the Monumental Axis and the Highway axis, Brasilia's two main streets. Consequently, according to Silva (2007) in Romero (2011a) there is a predominance of rectangular buildings whose facades with opposite orientations are: 108º/288º (East/West) and 18º/198º (North/South) (Figure 3). Silva (2007) found that in buildings with 108º/288º (approximately east/west) direction, the East (108°) facade receives insolation all morning throughout the year, being more intense in the months from December to February, where the sun shines directly from 05:30 to 12pm approximately. The West facade (288º) receives the afternoon sun throughout the year, especially the winter months, starting from 11am. The buildings with North/South orientation benefit from less hours of direct solar radiation. Always when this situation is noted we can recall the pioneering research of Olgyay (1963), applying the "Heat Flow Method", based on the combined effects of air temperature and radiation, to define the best shape and orientation of the building with respect to the thermal impacts it receives. Olgyay concluded, and warned us that all elongated forms on the north-south axis (with facades facing east and west) operate less efficiently in both summer and winter.

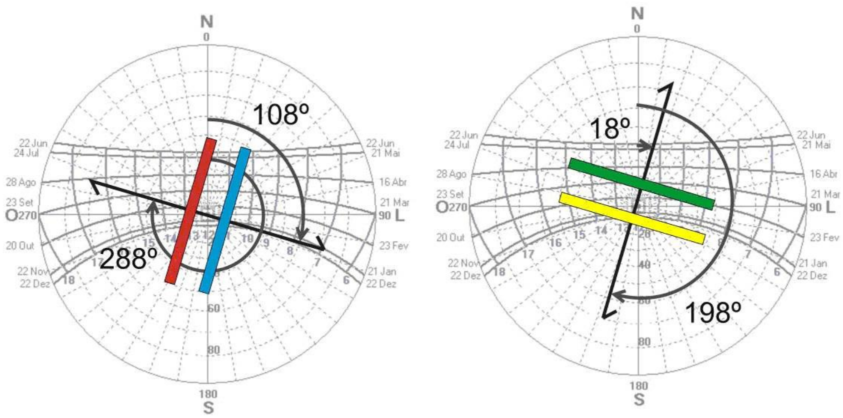

Figure 3. Prevailing orientations of existing buildings. Source: Romero (2011a, Adapted from Silva, 2007).

Environmental Comfort in the Superblocks of Brasilia

Combining field research with environmental simulations, it is possible to identify appropriate correlations between environment and comfort conditions. The level of comfort was investigated by Romero in superblocks, 105, 108, 405, 207, 504, 714, 102, 109, 308, 410, 703, 713 of the South Wing, and 308 and 309 of the North Wing (Figures. 4, 5 and 6). Based on the analysis of wind direction of prevailing winds, daylighting with low thermal load, the relative humidity and heat gains by insolation, measured and simulated, one can conclude that there is a large area exposed to radiation, possibly mitigated by vegetation and the pilotis displayed in blue, brown and red colors. It is also possible to observe that the passage areas have higher green area, while public living spaces have greater exposure to direct sunlight. Heat islands between the residential blocks were perceived.

In the case of Brasilia, Romero founded that cooling in the excessively shaded areas happens by channeling winds which can generate thermodynamic effects caused by temperature differences, thus interfering with local ventilation. To address the potential of the local climate for the use of natural ventilation, the research aims to contribute to the reduction of energy consumption, since the use of air conditioning is widely accepted by the population as the only effective means for environmental comfort of internal spaces.

Figure 4. Location on the pilot plan wings of the superblocks investigated. Source: Romero (2011a, p. 45)

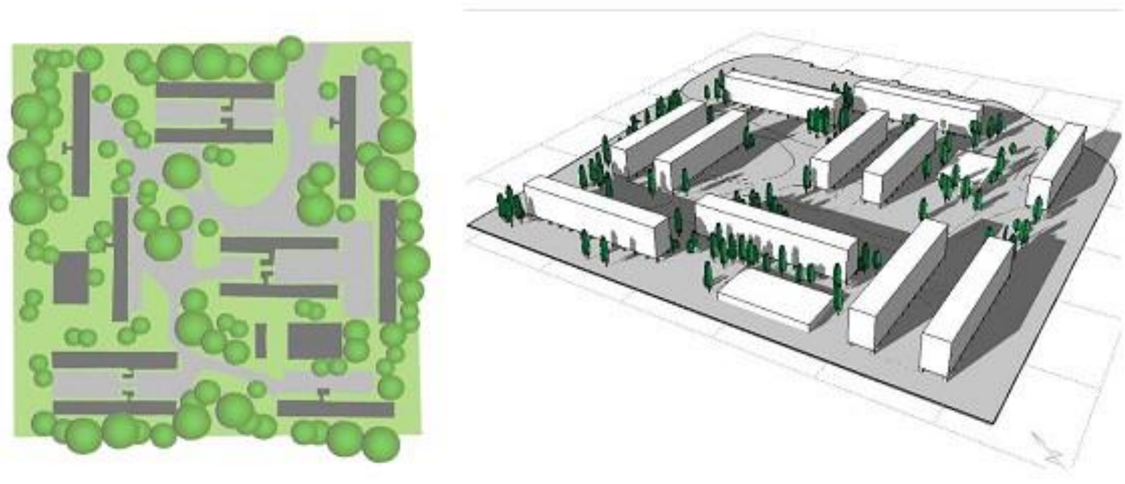

Figure 5. SQS 108 (Superblock 108 South) – Urban design with vegetation and analysis of solar radiation exposure to solar radiation on 17 December at 16 hrs. Source: Romero (2011b, p.16)

Paradoxically, the urban legislation of Brasilia treats the question of ventilation in a generic way. The criteria for size openings has always been associated with natural lighting and takes in consideration the fraction of the floor area of the room, unlike analysis of environmental performances which is based on wall area. Furthermore, in relation to ventilation, it considers a separation of only 0.6m to any of the sides, not taking into account for example, the ideal W/H relation for Brasilia (between 1 and 3) for the recuperation and capitation of natural ventilation, established by Romero in 2009.

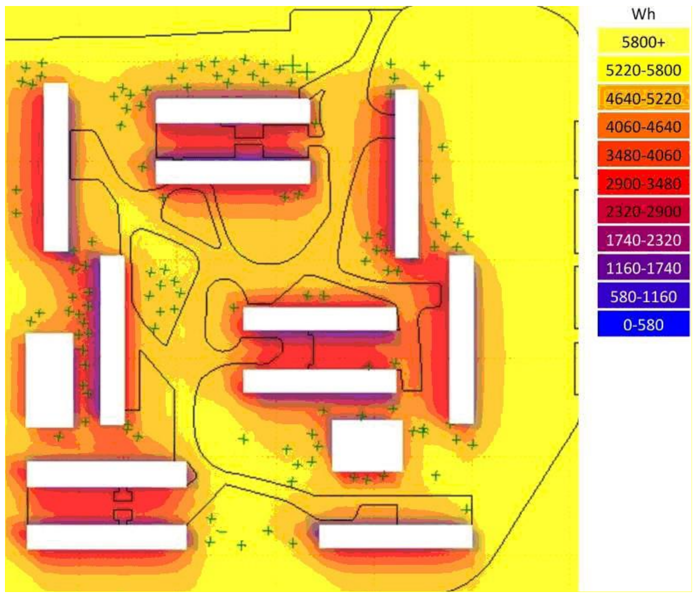

Figure 6. SQS 108 Analysis of solar radiation exposure. Modeling done on Ecotect. Source: Romero (2011b, p.16)

In one of the analysis for superblock 308 North, the buildings south of the court, being very close, suffers wind shadow of each other, especially the lower buildings and parallel to each other. The parallelism in location and height contributes to the formation of wind shade, areas of low wind speed for thermal comfort, and even generate wind stagnation, as was indeed observed in some points of buildings to the south.

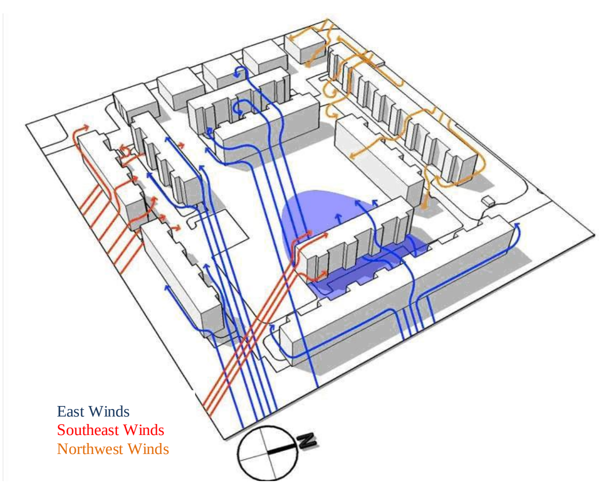

Figure 7. SQN 308 Wind distribution and wind shade. Source: Romero (2011a, p. 67)

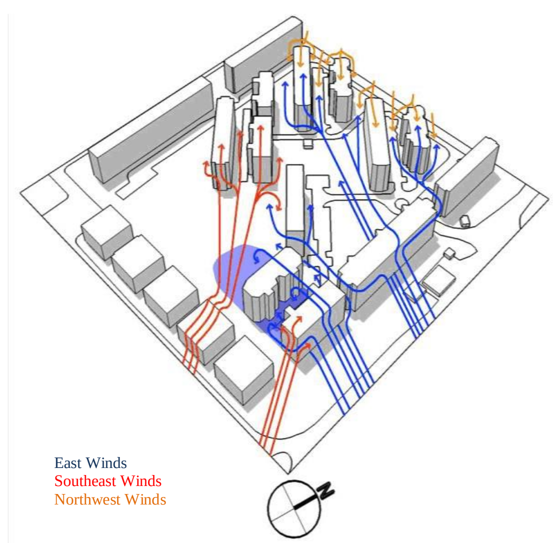

Figure 8. SQN 309 Parallelism and wind shade. Source : Romero (2011a, p. 69)

The farther away a building is in relation to one another, the less influence of wind shade. However, by having recesses in its form, the areas facing these parts suffer practically nil wind speed or in swirl, with the exception of the east recess that receives directly the east wind. In buildings facing the East whose length is much greater than the width, the corner effect can be perceived, accelerating the wind velocity (Fig. 7, 8 and 9).

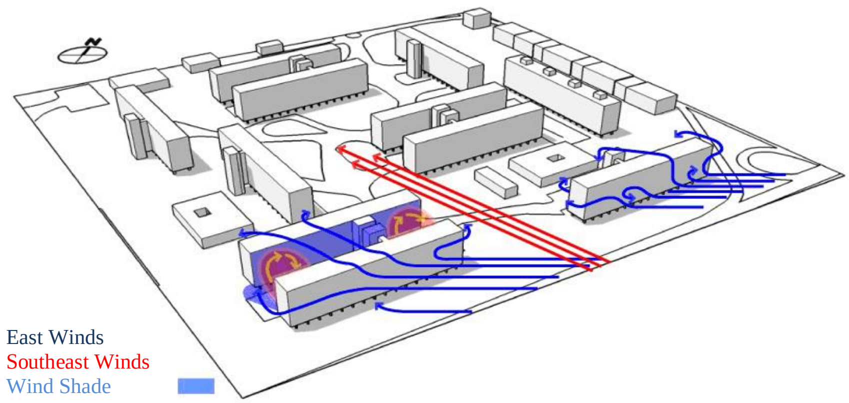

Figure 9. SQS 108 Exposed "heated" surfaces. Wind shade and confined hot air. Source: Romero ,(2011a, p. 77)

Measurements

Measurements were taken of both superblock 308 North composed of regular morphology and blocks with parallel and perpendicular directions to the East/West orientation, as well as in superblock 309 North, with oblique morphology, with blocks parallel to the peripheral streets and in angle internally within the superblocks. Blocks identified with the best rates can be considered optimum (Fig. 10, 11, 12 and 13).

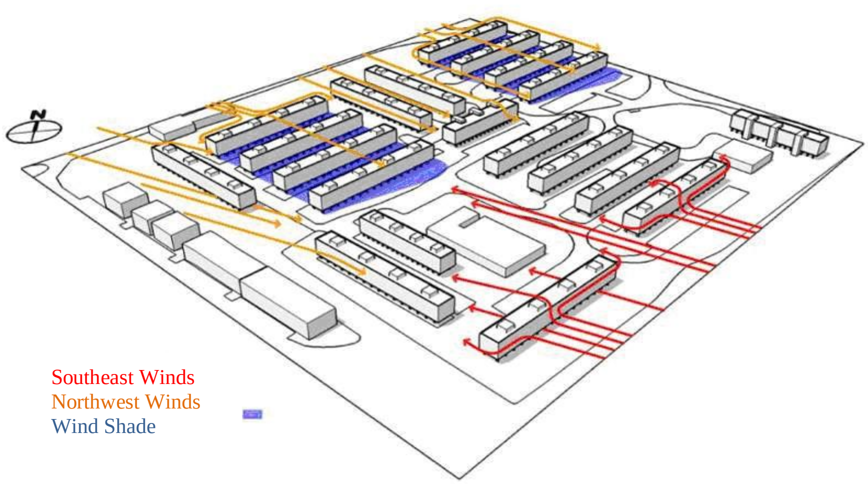

Figure 10. Wind shade shown in blue and wind distribution. Source: Romero (2011b, p.18)

Measurements of thermal variables such as external temperature, humidity and surface temperature for calculations of radiant temperatures were conducted over several seasons of the typical tropical climate of altitude. The albedo and emissivity were verified from the results of simulations with Ecotect, ENVI-MET and EIS software.

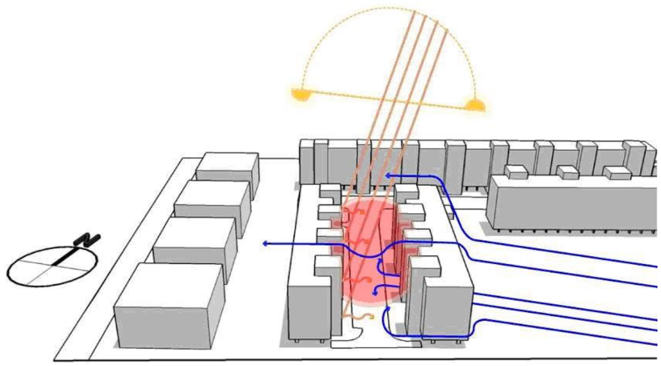

Figure 11. Formation of a heated cavity in the urban canyon. Source : Romero (2011a, p. 68)

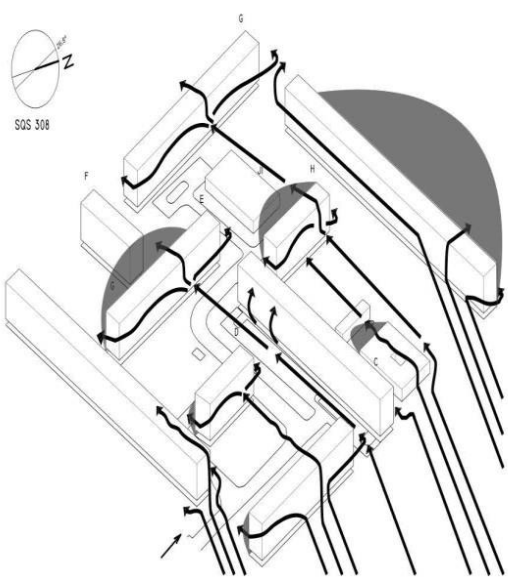

Figure 12. Superblock 308 South - Sun exposure and losses from exchange of long wave radiation and wind shade. Source: Romero (2011b, p.19)

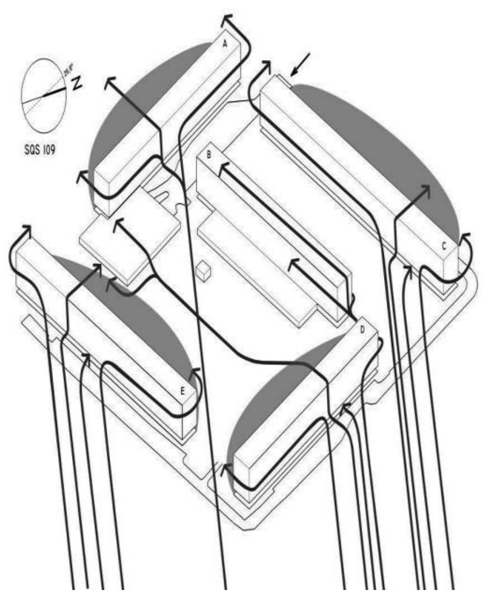

Figure 13. Superblock 109 South – Thermal exchanges maximized and wind shade. Source: Romero (2011b, p.19)

Temperature (dry bulb) and air humidity measurements were taken simultaneously throughout the day and in different seasons of the typical Tropical Climate Altitude at 9am, 15h and 21h. Average hourly data was used for the period of days studied.

Measurements were performed during both the dry season and the rainy season, in three different spots: (1) the shade; (2) the sun; (3) the sun, but protected in relation to the wind, at 9:00, 15:00 and 21:00 (according to the schedule of readings at INMET - National Institute of

Meteorology and according to data from typical days seen in Goulart (1993). The choice of the selected spots was similar in the spaces for the empirical work (blocks with the same orientation and location, but with different urban configuration).

In superblock 308 North with a regular morphology and blocks arranged parallel and perpendicular to the East/West orientation, the selected spots were respectively: 1 – in an exposed and ample parking area in the rear of the blocks, open to the East ventilation coming from the Lake;. 2 - In the square with vegetation and 3 -In the shaded parking area, in the direction of the prevailing winds, but with increased heat and pollutants due to heavy use.

Similarly, in superblock 309 North of oblique morphology (Fig. 14), with the buildings parallel to the peripheral street part and in angle within the superblocks itself, the chosen spots were respectively: 1 – in an exposed and ample parking area in the rear of the blocks, with the same orientation of superblock 308 North;. 2 - In the square with vegetation and 3 -In the shaded parking area, in the direction of the prevailing winds, but with increased heat and pollutants due to heavy use.

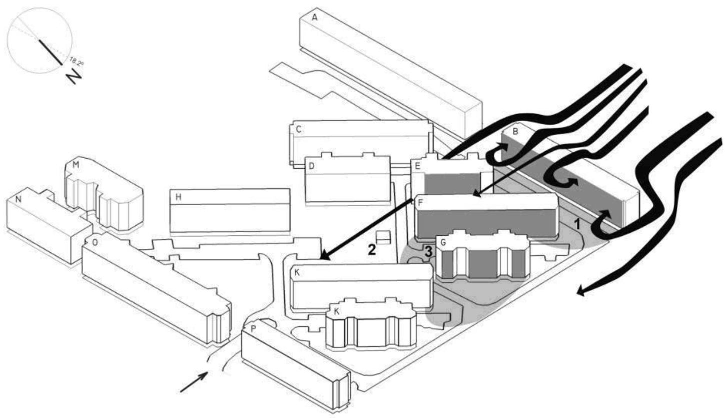

Figure 14. Superblock 309 North. Source; Romero (2011b, p.20)

Final Considerations

The recent loss of public spaces in Brasilia due to enclosures and consequently disappearance of peaceful coexistence in the capital compromises the sustainability of the urban space. This issue is disturbing because the original urban design for Brasilia is an increasing distortion process. The most preserved residential superblocks are 207, 105, 104, 308 South and 308 North which are the first ones built and fully respecting the original ideas and ideals of a city park as initially proposed. Inversely, the most misrepresented projects correspond to the younger superblocks, as the ones in 212 and 214 North.

The findings leave no doubt of the loss of thermal comfort in the superblocks, and the appearance of the heat island phenomenon at night, when the heat stored during the day is dissipated by the buildings at night, raising the ambient temperature. The linear correlation between the green areas (midrange trees) and the temperature was negative for the three analyzed times: 9, 15 and 21 hours, certifying that the existence of a dense vegetation canopy in open space decreases the ambient temperature, providing shade and blocking the direct radiation on the floor.

In the squares milder surface temperatures were observed. This situation is true even during the vegetation retraction period of the dry season, because the trees continue to provide shade. Even when the grass is dry and completely disappears in parts by excessive pedestrian traffic, it does not decrease its effect as thermal attenuator. The exception is the thin shade provided by deciduous trees that lose their leaves during the "winter" of Brasilia, which corresponds to the dry season with high temperatures during the day.

However, the vegetation does not absorb all the solar radiation received. Part of the radiation falling on the plant is reflected, some is absorbed so as to become physiologically effective, and the remainder is radiated back to the atmosphere. In this sense, from the total solar heat gain, about 30% is reflected, 50% is absorbed and only 20% is transmitted back to the surroundings. Nevertheless, the percentage transmitted is intercepted by the next layer of leaves, so that the gain on the ground surface is virtually zero (Cantuaria 2001).

In excessively exposed areas, whose surface material is impermeable (pavements), thermal exchange of latent heat is smaller, thus reducing the heat loss through evapotranspiration. The linear correlation between impervious areas and the temperature is positive, therefore the larger the amount exposed the higher temperatures were recorded.

Analyzing the less exposed areas it was observed the negative correlation between the data, in other words where the space between the buildings is smaller and more confined (greater sky obstruction), higher were the temperatures, especially in the superblock with the oblique arrangement of buildings. This is because the facade facing East gets sun in the morning and after midday only receives diffuse short-wave radiation and in the afternoon it receives radiation reflected by the opposite facade. The floor receives direct radiation around noon in greater quantity than the walls, because the albedo is lower. At night the balance of long-wave radiation from all surfaces is smaller than in other horizontal surfaces, due to the lower visible sky factor in the urban canyon.

Even in these cases there are aggravates provided by the current design of the blocks that no longer present themselves with cross ventilation, having distinct individual apartments on both facades and with mirrored surfaces; moreover, in many cases, a new surface "West " façade is created, and therefore the buildings receive intense "radiation" even if reflected, in both facades simultaneously.

The empirical method allows to generate guidelines as to the urban morphology (building separations in based on height, allocation of vegetation depending on the breeze direction), favoring the inclusion of technical issues in the definition of urban indicators. Through this inclusion, possibly, the temperature would be mitigated, the humidity increased (during the dry season), introducing to the urban fabric shade with low transmissivity at the pedestrian level and cooling near the building.

The measurement results of thermal variables suggest that trees should have dense and tall canopies to shade the surface of the facades, blocking direct sunlight and providing a mild climate in the residences. If tree cover was removed of the superblocks and asphalt put in place, there would be an increase of up to 5 ° C in temperature.

It was also observed that changing the thickness of the outer walls of the newer residential blocks, from the formerly 15 cm to the present 9 cm, is no longer sufficient to retard the passage of radiation and reduce the heat inside. It´s worth remembering that the diurnal temperature variation is considered large in Brasilia (13.5ºC in summer - October - and 13.8ºC in winter - June, and therefore it´s necessary to exist a certain thermal inertia in the envelope.

It´s been noted that the wind regime in Brasilia can be completely used and the wind shadows avoided, promoting the internal ventilation of buildings. The effect of surface roughness, which results in the transition of the different airflow regimes and drag coefficients of the spaces analyzed between the urban microclimate and the residential area of Brasilia, may contribute to the best use according to wind orientation.

It was also shown that the specific features of the building added to the incident wind upon it (immediately upstream in the angle of incidence relative to the plane containing the facades and the measurements of the building itself) dictate the flow field of the atmospheric wind in its surroundings. We emphasize that the open spaces within the superblocks, allow the wind to return to its original flow.

In short, it is necessary to build spaces which are able to combine interiority and exteriority and only a landscaping policy in its broadest sense and a resumption of intensive urban afforestation can maintain uniformity of the urban configuration, prioritizing environmental comfort, encouraging a sense of community and allowing to sustain the urban quality of the superblock.

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