

Urban Heat Island of Valparaíso, Chile - A Comparison between 2007 and 2016

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Abstract. The urban heat island phenomenon shows that the city changes the climate of the planet and affects it negatively by favouring the global warming. Urban morphology and city metabolism defines this behaviour. The city of Valparaíso, Chile, located in coastal Mediterranean climate in southern hemisphere is a city with around 295,000 inhabitants. In this research, the differences between UHI phenomenon in winters of 2007 and 2016 are evaluated. The city presented a temperature difference of 4.6 °C between the outskirts and the urban centre as a manifestation of this phenomenon, in 2007. By 2016 the city in population not increases and has had small morphological variations; the city presents an average temperature difference of 5.2 °C between the outskirts and the urban centre as manifestation of urban heat island. This higher temperature occurs in the higher density built area, mainly of offices buildings. Here is the highest density of metabolic activity of the city, same as 2007.

1. Introduction

The processes of urbanization caused by the increase of population in the cities have caused changes in soil use, morphology and the materials of environmental. These changes are considered incidents in urban heat and earth global warming. Currently, more than 50% of the world's population lives in cities and is expected to be 70% for 2050 [1]. Today, nearly 80% of Latin America's population lives in cities and is expected to 2050 this exceed 87% [2]: a larger number than the average expected around the world. This accelerated growth of the city Latin America produces urban densification, vertical growth and loss of green areas [3]. The local climate of neighbourhoods in the city is influenced by the built environment and the urban context. This process affects energy consumption into buildings and well-being of inhabitants of the city, affects the air quality and comfort in buildings and public space too. This was reflected in the increase of temperature and waves of heat on European cities and United States mainly [4]. The impact of climate change and of heat waves could be extreme on cities [5]. The urban heat island (UHI) phenomenon occurs in cities. In the last years, many studies have recorded the UHI effect for many cities, especially in Europe, Asia and Australia [6]. Thermodynamic processes of climate in the city depend on different factors [7], [8], [9], [10], originated in form, materials, and metabolism of the city and in the conduct of its inhabitants, who determining the behaviour of the microclimate in the urban space and in particular of streets or urban canyons and favour the phenomenon of UHI [11].



The urban canyon decreases the night-time radiative cooling and ventilation, maintains high levels of air temperature during the night, especially in district offices and commercial buildings [12]. Solar obstruction by urban canyon produces cooler air during the day. Solar radiation arrives differently to surface depending of orientation, geometry and the visibility respect to direction of solar radiation [13]. Canyon with less visibility of sky (with high relationship high/wide canyon) has less variation daily of air temperature [14] and, if it increases, canyon presents greater variation [15]. Greater visibility of sky, favours more ventilation. Is characteristic also decrease of the street global albedo [16] and the heating of air in day and night; some studies indicate that increase of green surfaces would generate an opposite effect [17], [18]. The generation of heat into buildings, is dissipated into the air of the street, causing its warming day and night. These phenomena increase requirements for buildings air conditioning [19] and increase energy consumption in cooling [20]. The new workspaces, offices, computers, etc. the heat released from combustion of fossil fuels, whether from sources mobile as transit or from sources fixed favour these dynamics. The thermal storage and ventilation of street space are important variables in pedestrian comfort, energy saving in buildings and in the warming of the city [21]. If we evaluate this seeing the patterns of growth of cities in Latin America, we are in a very unfavourable scenario.

The objective of this work is researching the urban morphology in a medium size city, Valparaíso, and to correlate this with this urban climatic behaviour. In this research, the UHI phenomenon in winters of 2007 and 2016 are evaluated. The hypothesis is that the city of Valparaíso climate behaviour, expressed as urban heat island, is maintained over time and tends to be more extreme.

2. Materials and Methods

The city of Valparaíso, Chile, locates in coastal Mediterranean climate in southern hemisphere (figure 1) is a city with 295,000 inhabitants. Valparaíso is a city in growth that, on the one hand, develops new fabrics in its expansion urban on the territory and, on the other hand, develops a process of densification of the current tissue urban, especially in the sector El Almendral. The dwellings of city urban periphery are mainly low-rise buildings (1 or 2 floors 3-5 m) and an outskirts perimeter of vegetation at the upper edge of the hills to its around (figure 2 and 3). Downtown is completely urbanized. There are tall buildings over 12 m up to 40 m. in sectors next to the coastline (first sea coastline) and there are small spaces of urban vegetation in its public space with a highly mineralized pavement (figure 4 and 5).

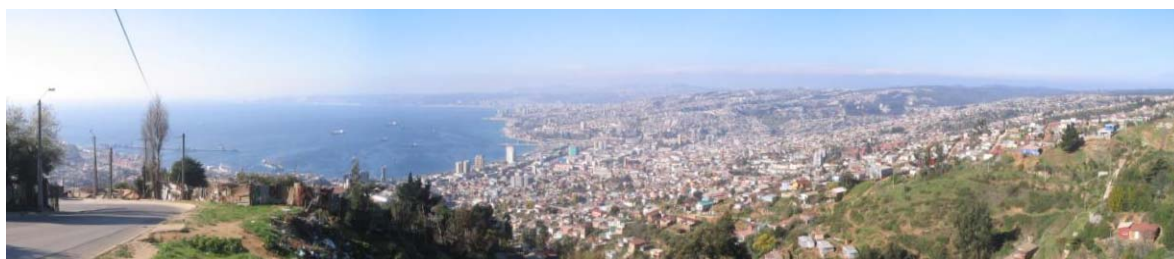


Figure 1. Valparaíso, latitude 33 degrees Sout



Figure 2. A top view of Valparaíso City



Figure 3. A top view of Valparaíso City

Figure 4. The commercial and offices downtown of Valparaíso City



Figure 5. Sotomayor square into downtown of Valparaíso City. Source: C. Carrasco.

The methodology considers the study of the climate of the city of Valparaíso to determinate of the urban heat island phenomenon, according to methodology of urban transects [22]; for reference value of air temperature is considered the value recorded in the meteorological station of Technical University Federico Santa Maria. The temperature of the air in three tours done at same time in winter 2007 and winter 2016 is registered. They has approximate length of 5 km. It is registered in three moments of the day: morning (10,30 h), afternoon (14.00 h) and evening (20.00 h) (figure 6). These routes beginning and ending in nonurban zones from and into the periphery, giving account of the varied urban morphology of the city and varied topographical conditions: hill slope, downtown of the city, urban basins and hill top (figure 7).

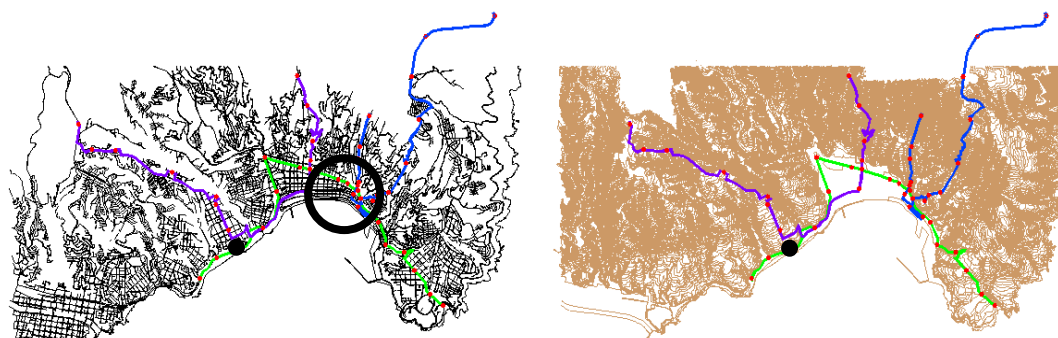


Figure 6. General map of Valparaíso, its urban structure (left) and topographic (right). The three transects by color lines are indicated (Transect 1 blue, Transect 2 green and Transect 3 purple) and the registered places points are on red. Black point indicated USM, the reference local weather station. The commercial and offices downtown of Valparaíso City into the black circle is indicated.

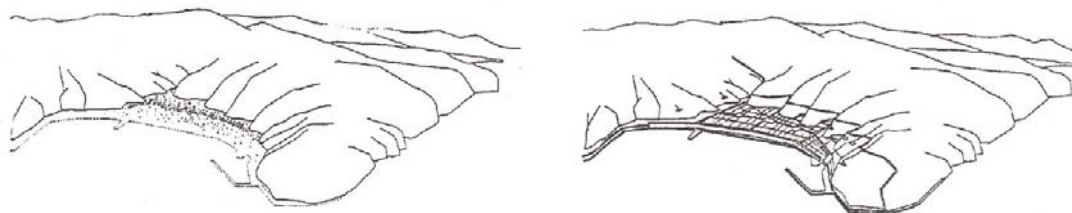


Figure 7. Three-dimensional visions of the topographic conformation and the location of Valparaíso. Natural topographic situation (left) and urban topographic situation (right). Source: Oyarzún et. al. 1996.

The altitude conditions location respect to sea level has been analyzed. Respect urban morphology, the sky opening conditions, and the slope and orientation conditions, along with the mineralization or naturalization conditions of each studied situation, have been reported. conditions location respect to sea level has been analyzed. Respect to urban morphology, the sky opening conditions, and the slope and orientation conditions, along with the mineralization or naturalization conditions of each studied situation, have been reported.

3. Results and discussions

At 10, 30 h. in the morning, a high dispersion of air temperature between the points reported, being the overall temperature of the points of these transects greater than the air temperature on meteorological station of reference is verified. Note that those more open spaces have greater temperature variation from day to night and spaces oriented to the Northeast have higher temperatures during the morning. There is a higher surface temperature when the urban space has an orientation toward Northeast and when it has a greater slope (figures 8 and 9).

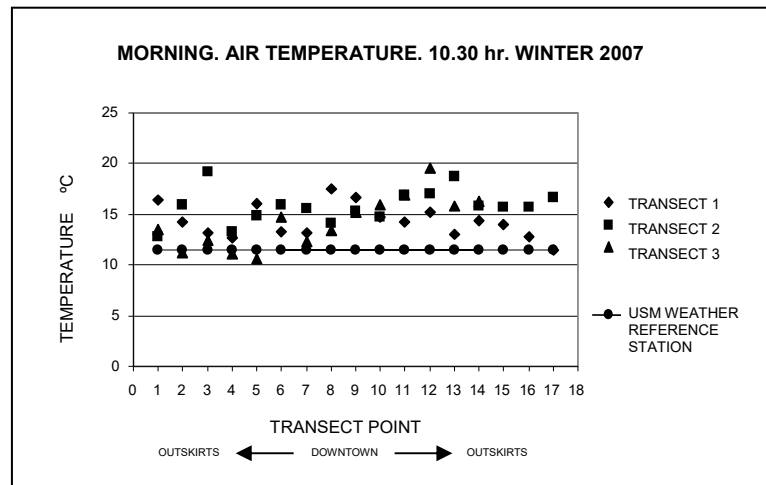


Figure 8. Air temperatures, winter morning 2007

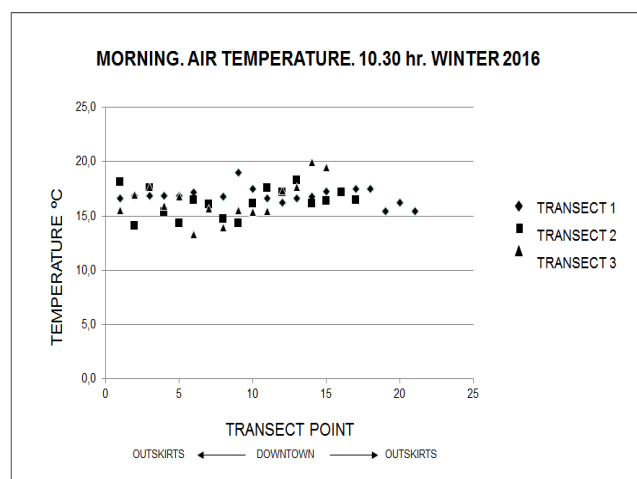


Figure 9. Air temperatures, winter morning 2016

At 14.00 h. the air temperatures is closer to value registered in reference weather station (figures 10 and 11). At evening, 20.00 h., a more homogeneous air temperature behavior is observed: the city climate behavior shows the urban heat island phenomenon in Valparaíso: lower temperature in the outskirts and higher topographic zones and a higher temperature in areas located in the city's downtown. The air temperature is greater in the area of higher density built (banking and offices area) and in the area of greater urban activity (banking and offices area). In 2007, there is 5.1 ° C of difference of air temperature differences between the downtown and the outskirts (figures 12 and 13). In 2016, there is 6.2 ° C of difference of air temperature between the downtown and the outskirts.

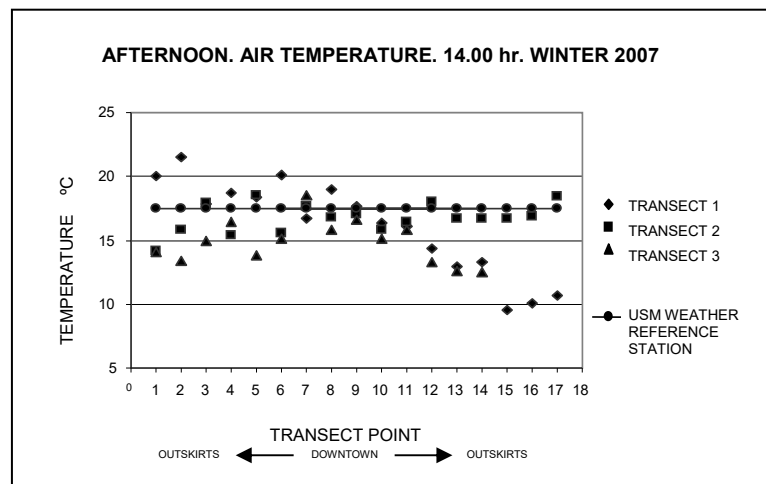


Figure 10. Air temperatures, winter afternoon 2007

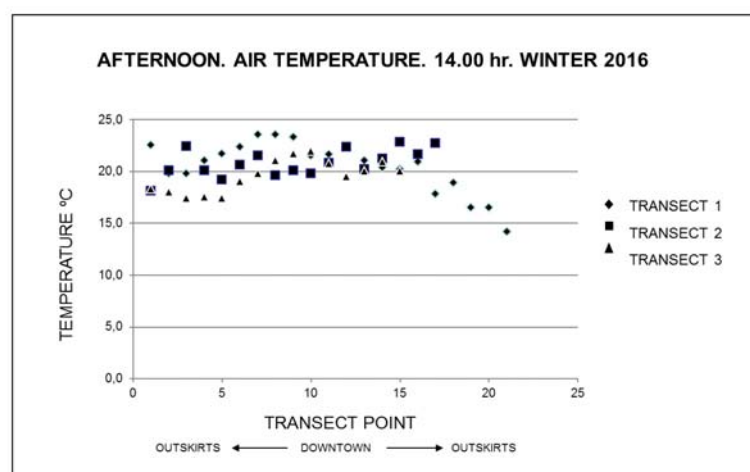


Figure 11. Air temperatures, winter afternoon 2016

Variations between air temperatures of various points in the city are related to variations in morphology, buildings material and location, as well as the buildings use. From the morphological point of view, the amount of visible sky and the orientation of the slope are two relevant variables in the results.

The analysis of the three transects confirms the phenomenon of heat island and the existence of different temperatures in city at the same time. In the morning, a high variability of air temperature in the different registered points is stated and at evening (20 hrs.) there is a more homogenous air temperature (figures 13 and 14): In 2007, 5.1 °C and 2016, 6.2 °C.

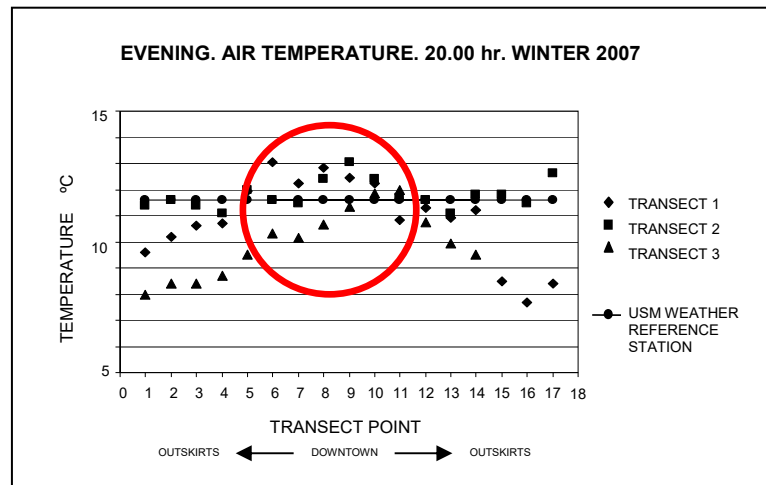


Figure 12. The air temperature of places into the commercial and offices district is indicated. Into red circle the hottest places at evening are indicated (2007)

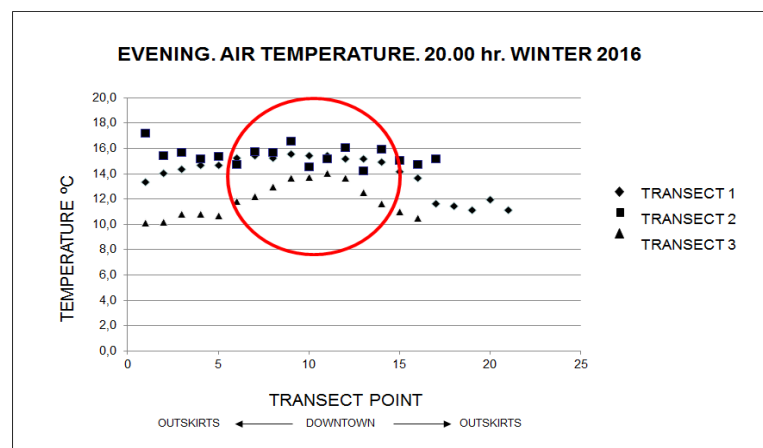


Figure 13. The air temperature of places into the commercial and offices district is indicated. Into red circle the hottest places at evening are indicated (2016)

At evening, there is a higher air temperature in areas of higher density built in the city and which corresponds to offices buildings and banks. This area is mainly built with mineral materials (concrete, stone and glass).

The sky view factor conditions and the slope orientation have been two important variables in results. The more open spaces with streets wider present a high air temperature variation from day to the night and the spaces oriented to the northeast present a bigger temperature during the morning. It has been stated, that at 10:30 a.m., there is a maximum surface temperature when the slope has a direction towards the northeast and when it has a steeper incline. It has been stated that the variations of urban temperature in the city are correlated to the variations of morphology (open or canyon), materials (natural or mineral) and location (top or down into city).

The relationship between morphology and the microclimate in the area presenting the register of higher air temperatures at 20.00 h in the transect study (down into city), is explored. Twelve places of this downtown district (figure 14) are defined and High / Wide relationship (H/W) and Sky View Factor (SVF) are defined in each case.



Figure 14. The banking and offices district, Valparaíso City.

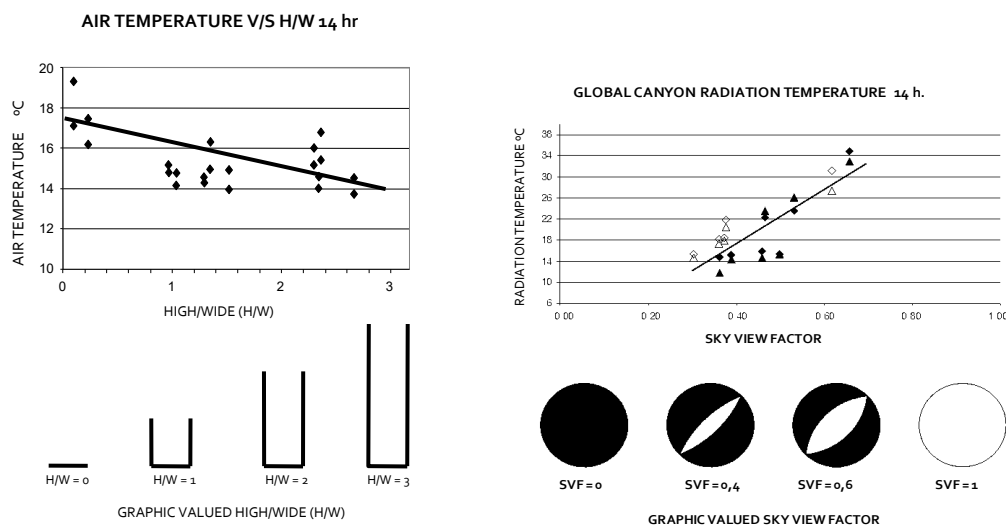


Figure 15. Global canyon air temperature respect H/W ratio (left).

Figure 16. Global canyon radiation respect Sky View Factor (SVF) descriptor (right).

At 14 h. with a canyon with low number of relationship morphological high/wide (H/W) the air temperature is greater (figure 15). Regarding the temperature of global radiation of canyon that makes up the urban space, is observed in the cases studied in the commercial district and offices, which at 14.00 h this is greater when higher the sky view factor (SVF) (figure 16). In the cases studied in the center of the city, there is a correlation between canyon global radiation temperature and sky view factor SVF. Shown, for example, at 14.00 o'clock, the global radiation temperature increases 6.4°C by each 0.1 factor of sky visible; in these cases, as it increases the visibility of the sky and the canyon is more open, at 14.00 o'clock, the temperature of radiation is greater. However, at 20.00 h, independent of the SVF, the temperatures of global radiation of the canyon tend to taken a homogenous temperature in cases studied.

Into narrow canyons, the incidence of the climate of the city in their microclimates decreases: places with less SVF have greater control on its microclimate and minor air temperature variations. This is evident at evening when, regardless of the canyon section, the tendency is to homogenize the temperature of the air and homogenize the global radiation of walls and pavements (similar radiation W/m^2) in all the canyons in the center of the city.

If the space of the street is more sunk regarding the surroundings, the variation of the temperature of the air is lower in the different periods of the day, which also has been stated when considering only the profile of the street H/W. At evening, if the space of the street is deeper regarding to the

surroundings, the temperature of the air is higher. It is bigger when the height/width (H/W) relationship into canyon is bigger.

4. Conclusions

This research confirms the phenomenon of urban heat island in Valparaíso, Chile. And it is more intense in winter 2016 than winter 2007. The morphologic urban characteristics (Sky view factor and Hide/Wide factor), the topographic shape and the building materials don't completely determine the microclimatic behaviour of a place, but they define tendencies. A smaller visible of sky and less exposure to wind in the city, as a characteristic of the most densely built-up area, would favour a greater accumulation of energy in urban space that eventually translates into a higher temperature of the air at sunset. When the place is in the low level of the city, the urban morphology and the shape of the canyon have a bigger influence in its microclimate in comparison to urban canyons located in the high level at the city and sloping areas, because they are more exposed to the solar radiation and the local wind: for similar material surfaces, the locations in a higher zone favour a greater cooling at evening and a further decrease in temperature. It has shown that the canyon morphology and its materials are incidents in the microclimate and that this is most evident when canyon is narrower, especially in air temperature and global radiation of canyon, where lesser influence of local climate, was evaluated with SVF descriptor. This descriptor recognizes the context as a condition morphological for microclimates into urban spaces. The thermal inertia and the albedo of the surfaces into downtown zone is typical. A smaller sky view factor of urban canyons defines smaller exhibition to wind. A buildings greater density zone favours a greater heat accumulation at evening. It is translated in a greater temperature of the air, favouring the phenomenon of urban heat island, as well as similar research conclusions [23], [24]. If we want to define a microclimate mathematical model of the outside spaces of an urban fabric, it is necessary to consider both the urban climatic context and the city climatic behaviour, because the city affects its own climate.

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References

- [1] United Nations (2010). World urbanization prospects: The 2014 revision population database. [accessed 05/2017] <https://esa.un.org/unpd/wup/>
- [2] United Nations (2010). World urbanization prospects: The 2014 revision population database. [accessed 05/2017] <https://esa.un.org/unpd/wup/>
- [3] Palme, M., Carrasco, C., Lobato, A. Quantitative Analysis of Factors Contributing to Urban Heat Island Effect in Cities of Latin-American Pacific Coast, *Procedia Engineering* 169, pp. 199-206, 2016.
- [4] Davis, R. E., Knappenberger P. C., Michaels P. J. and Novicoff W. M., Heat Wave Mortality in Large U. S. Cities, *16th Conf. Biometeorol. Aerobiol. and the 17th ISB Cong. Biometeor., Vancouver, British Columbia, WA, paper n°. 6A.3, 2004.*
- [5] WMO, UNEP, Fifth Assessment Synthesis Report-Climate Change 2014 Synthesis Report, Intergovernmental Panel on Climate Change IPCC, *Fifth Assess. Synth. Report-Climate Chang. 2014 Synth. Rep., 2014.*
- [6] Santamouris, M. (2016). Urban Climate Mitigation Techniques. Earthscan, London.
- [7] Cleugh, H. A. and Oke, T. R., Suburban-rural energy balance comparisons in summer for Vancouver, B.C, *Boundary Layer Meteorology* 36, pp. 351-369, 1986.
- [8] Grimmond, C. S. B. and Oke, T. R., Comparison of heat fluxes from summertime observations in the suburbs of four North American cities, *Journal of Applied Meteorology* 34, pp. 873-889, 1995.
- [9] Christen, A., Vogt, R., Rotach, M.W. and Parlow, E., First Results from BUBBLE II: Partitioning of turbulent heat fluxes over urban surfaces, *4th Symposium on the Urban*

- Environment, Norfolk VA, pp. 137-138, 2002.*
- [10] Grimmond, C. S. B. and Oke, T. R., Heat storage in urban areas: observations and evaluation of a simple model, *Journal of Applied Meteorology* 38, pp. 922-940, 1999.
 - [11] Roset, J., Serra, R. (t), Isalgué, A. and Coch, H., Energetic analysis for an urban sector of Barcelona, *3rd European Conference on Rebuilding: Rebuilding the City of Tomorrow, Rebuild*, pp. 206-209, 1999.
 - [12] Kikegawa, Y, Ohashi Y . & Kondo H. Observed and simulated effects of urban canopy on air temperatures in summer Tokyo, *7th Conference on Urban Environment. San Diego, CA. September 2007.*
 - [13] Voogt, J & Krayenhoff E. Modeling urban thermal anisotropy. International Society of Photogrammetry and Remote Sensing, *ISPRS joint conference. Tempe, AZ, USA, March 2005.*
 - [14] Ali-Toudert, F. & Mayer H., Numerical study on the effects of aspect ratio and solar orientation on outdoor thermal comfort in hot and dry climate, *Building and Environment n° 41*, pp. 94–108, 2006.
 - [15] Gal, T., Lindberg F. & Unger J. Computing continuous sky view factors using 3D urban raster and vector databases: comparison and application to urban climate, *Theoretical and Applied Climatology n° 95*, pp. 111–123, 2009.
 - [16] Akbari H., & Konopacki, S. Calculating energy-saving potentials of heat-island reduction strategies, *Energy Policy n° 33(6)*, pp. 721–756, 2005.
 - [17] Susca. T., Gaffin, S. R., & Dell’osso, G. R. Positive effects of vegetation: Urban heat island and green roofs, *Environmental Pollution, 2011, n° 159 (8–9)*, pp. 2119–2126.
 - [18] Takebayashi, H., & Masakazu, M. Surface heat budget on green roof and highreflection roof for mitigation of urban heat island, *Buildings and Environment n° 42 (8)*, pp. 2971–2979, 2007.
 - [19] Bozonnet, E., Belarbi, R. and Allard, F., Energy demands research for air conditioner for mediterranean urban buildings. *Tecnología y Construcción vol. 22, n° 3*, pp. 27-34, 2006.
 - [20] Santamouris, M., Argirious, A. and Papanikolaou, N., Meteorological Stations for Microclimatic Measurements, *Report POLIS Project, E. U.*, 1996.
 - [21] Kolokotroni, M., Ren X., Davies M., Mavrogianni A. London’s urban heat island: Impact on current and future energy consumption in office buildings. *Energy and Buildings, n° 47*, pp. 302–311, 2012.
 - [22] Martin Vide, J. and Moreno, M. C., Progress of results in heat island of Barcelona and other Catalan cities heat island, *VI Trobades Científiques de la Mediterrània. Energia, Medi Ambient i Edificació CIRIT, Generalitat de Catalunya*, pp. 55-68, 1992.
 - [23] Jauregui, E., Possible impact of urbanization on the thermal climate of some large cities in Mexico, *Atmósfera 18 (4)*, pp. 249-258, 2005.
 - [24] Carrasco, C., Palme M, Gálvez M. A. Sky view factor and the heat island effect in Valparaíso. *Urbano n° 34*, pp. 26 - 33 ISSN 0717 - 3997 / 0718-360, 2016.