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Urban Form and Urban Materials as Controller of Urban Climate in Valparaiso, Chile

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Abstract. The urban heat island (UHI) effect on the city and urban climate are related whit urban form and urban materials: it's an evidence of human influence in climate change. Into the cities, the air temperature increases in downtown and go to outskirts decreases. Valparaíso, Chile, is located in a Mediterranean climate in the southern hemisphere (-33°03'). The urban area of the city is 400 km2 and its population reaches 300,000 inhabitants. The behaviour of air temperature in the city in winter and summer and on sunny days and cloudy days has been recorded. In all days heat island phenomenon is registered. A greater increase of UHI in summer and in sunny day has been recorded. The variation of the temperatures of the materials that make up the urban canyons has also been recorded, presenting different dispersions and variation according to whether it is a sunny day or a cloudy day. In sunny day all day a large dispersion is registered, at afternoon spatially. An important factor in the behaviour of the street climate is its morphology. This condition has been recorded with the visible sky factor (SVF) and with the geographic orientation of the studied canyons. Both the global urban form, the visibility of the sky, the street morphology and the materials of the city affect the urban air temperature variations. City normative planning and designers should consider these variables and its influences.

1. Introduction

Today, more than the half of the world population live in cities; in Latin-America the percentage is 80%. We expect that the fast growth of cities in this continent lead to the 90% by 2050 (worldwide, more than the 60%) [1]. Research on urban impacts put in evidence that urban planning and design affect the performance and climate patterns at different scales: macro, meso and microclimatic [2]. Local climate of city's neighbours is influenced by built environment and urban context. The process affects the energy consumption of buildings, the well-being of inhabitants, the air quality and both indoor and outdoor comfort. Different studies already established these facts in many regions and cities [4] [5] [6] [7] evidencing that studied cities present higher temperatures respect to surroundings and rural zones, especially at night [8] [9]. Built environment acts in favour of urban overheating, affecting inhabitants' well being and turning cities more vulnerable to climate change [10] [11]. At the same time, built environment influences thermal performance of buildings, which demands more energy use for cooling, especially in the case of office buildings during summer time [12] [13]. These urban areas present in summary the effect known as Urban Heat Island (UHI) [14]. The phenomenon occurs due to impervious materials with high thermal capacity, which absorb heat during the day and release that during the night [15] [16]. The bigger the city, the higher the effect [17]. Recently, experimental studies have been developed for different cities: Barcelona and Rome [18], Guyaquil, Antofagasta, Lima and Valparaiso [19], Hong Kong [20], Toronto [21], Touluse [22], Paris [23], San Juan in Puerto Rico [24], Tokio [25], Salamanca [26], Mendoza [27], demonstrating that contemporary city is a complex thermo-dynamical system, which modify the climate, especially through the UHI effect [28] [2] affecting urban life conditions. In this situation, and considering fast urban growth, the buildings of the urban centres act as energy consumers especially when experimenting UHI around them [29] [30]. This is due to (among other factors) the emission of long wave radiation depending on surface temperature and emissivity [31]. In this sense, the urban pavements play a fundamental role in the thermal balance [32] [33] and in the UHI generation [34] [35].

The UHI intensity depends on many factors as topography, macroclimatic conditions, urban density, anthropogenic heat caused by buildings, cars, etc., thermal and optical properties of surfaces, urban form, and land use [36]. In summary, the existence of UHI affect mainly the energy demand of buildings, the air quality and the comfort felt by users in buildings and streets [19]. The study of urban fabric and urban canyon geometry has been used to generate microclimatic models [37] [38]. The sky view factor (SVF), for example, is a descriptor of urban morphology and density of buildings. Different researches relate SVF with the climate of urban space [39-45] and with UHI [46-50].

Moreover, climate change (CC) scenarios introduce the probability of an increase in temperatures and a decrease in precipitation [51]. Superposition of UHI and CC could produce dramatic situations of thermo-dynamical balance of cities, building energy needs, and changes in comfort of public spaces. UHI conditions increases the climate risk of urban environments, including heat stress and polluted air exposition. CC, caused by anthropogenic emission of CO_2 and other greenhouse gases, is a problem that in a long time could alter the intensity and the spatial extension of UHI in metropolitan regions [52]. The objective of this research is to analyse and present the UHI phenomenon in the city of Valparaiso in winter and summer season and relate the intensity to the urban form and materials.

2. Materials and Methods

This study is developed for the city of Valparaiso, located on the central coast of Chile (Lat 33.03 S and Long. 71.6 W). The climate is defined as Mediterranean climate following Koppen-Gaiger classification Csb. The population is estimated in 300.000 inhabitants.

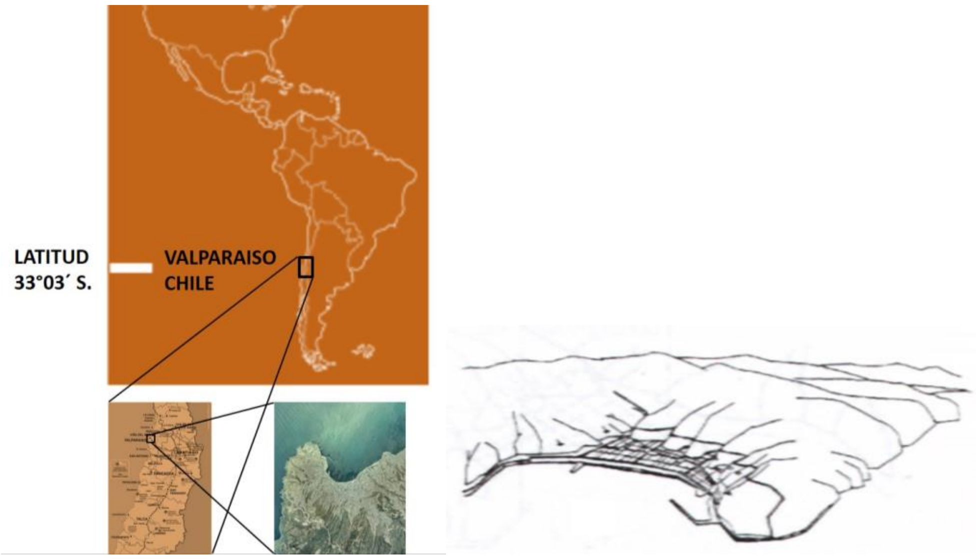


Figure 1. Valparaíso case of study. Geographic and topograpich condition is shown.

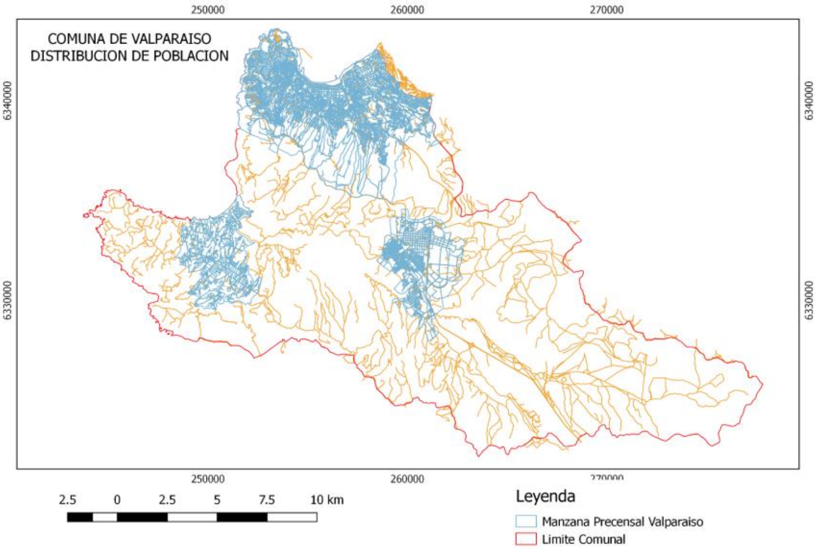


Figure 2. Administrative division https://construccion.uv.cl/docs/conferencias/01-12-2017/Sr. Guillermo Piñones Aguilera.

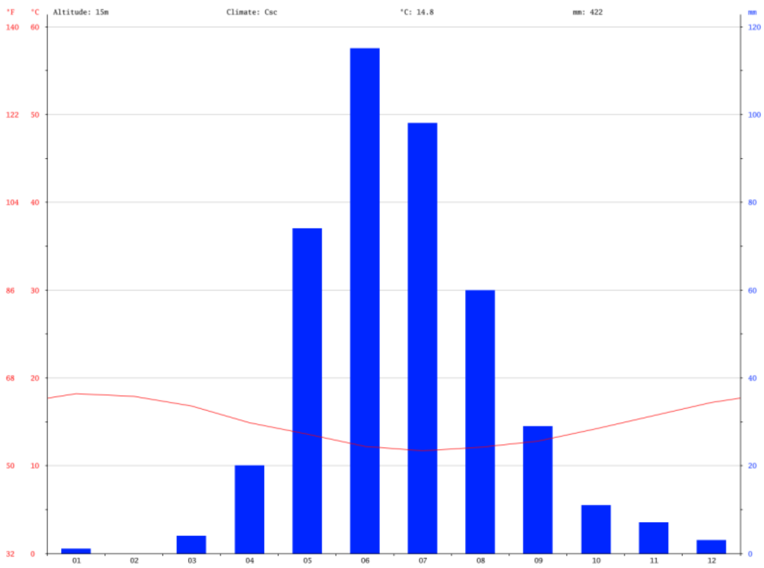


Figure 3. Climate of Valparaiso, distribution of montly average precipitation and temperature. (https://es.climate-data.org/america-del-sur/chile/v-region-de-valparaiso/valparaiso-1005664/#climate-graph).

The studied area corresponds to the zone of the Valparaiso bay. Through a methodology of transects, a record of temperatures has been carried out defining a series of places with different urban characters, from surroundings to downtown. Records have been done in three different times of the day: 10.30, 2 pm and 8 pm to put in evidence the difference between the moment of maximum activity, the hottest hour of the day and the moment with the higher UHI normally detected in cities.

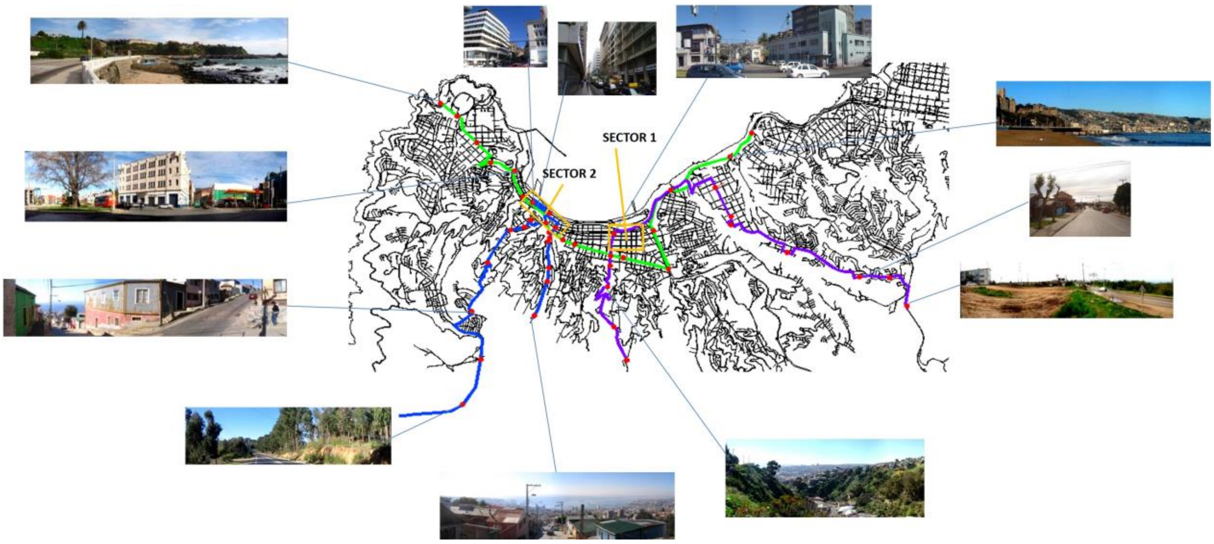


Figure 4. Structure of three transects monitoring done in winter 2016 and summer 2017.

In order to determine the relationship between urban form, materials and thermal performance of the built environment, the sky view factor is used as descriptor of the canyon morphology and related to average solar radiation on the horizontal. SVF determination is done following procedure described in [42] by using a fish-eye image for each analysed site.

3. Results

Respect to thermal performance the following results were obtained: for a winter cloudy day (figure 5), a difference of air temperature between the surroundings and the centre is 7.9 degrees Celsius. For a winter sunny day (figure 6), a difference of 5.2 degrees is observed. For a cloudy day in summer (figure 7), a difference of 6.3 is observed. Finally, for a sunny summer day, a difference of 8.8 degrees is found. The black circle evidences the hottest zones of the city.

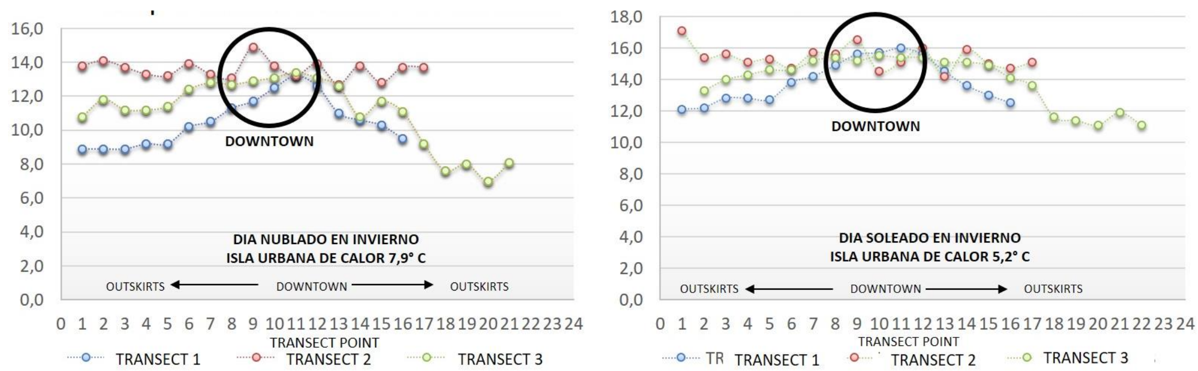


Figure 5 and 6. Air temperature for winter (left) and summer (right) season during a cloudy day at 8 pm.

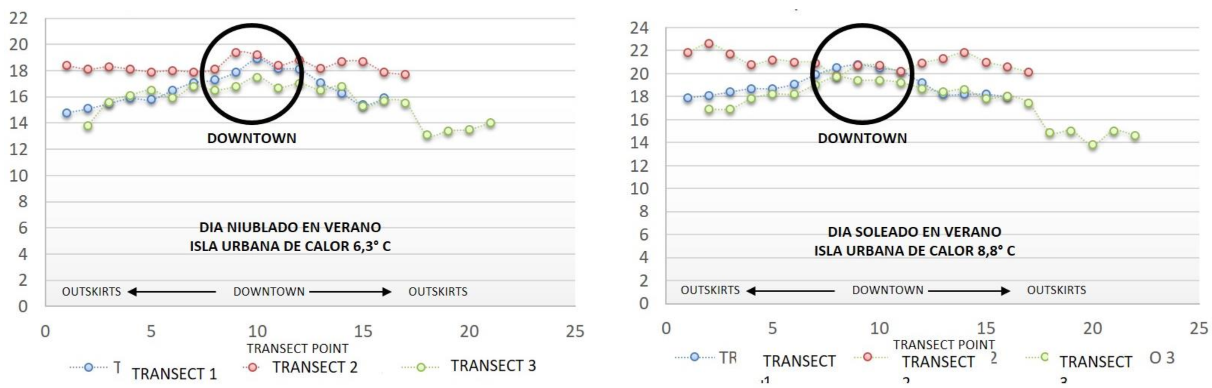
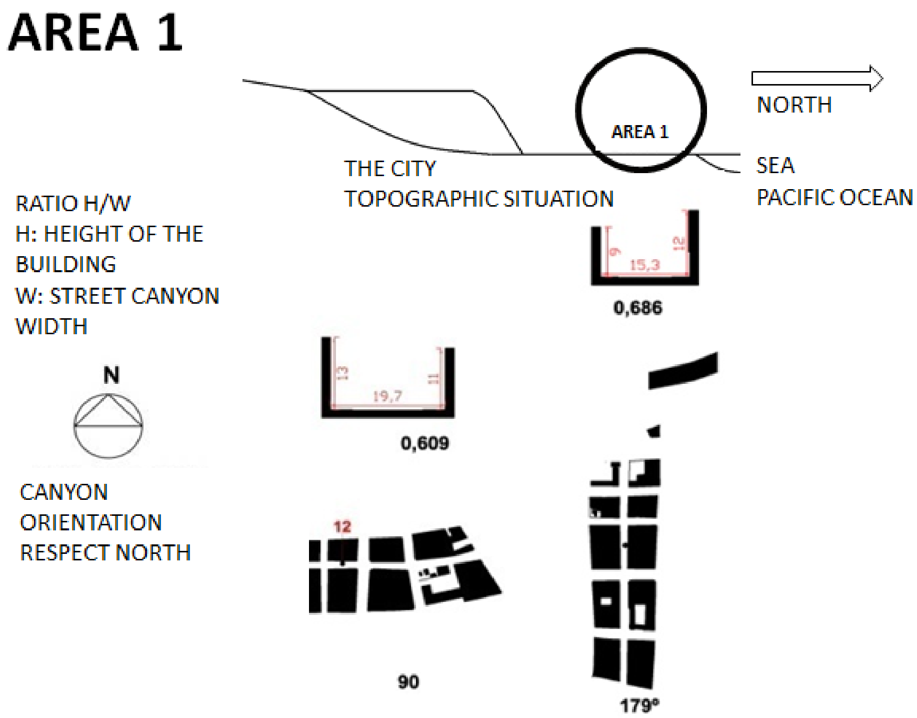


Figure 7 and 8. Air temperature for winter (left) and summer (right) season during a sunny day at 8 pm.

Once observed the general behaviour of the city and the patterns of the UHI phenomenon, the urban canyon of the city center are studied in a detailed way. After two neighbourhoods selection, 12 locations are defined and the morphological characters evaluated. Spatial distribution of air temperature is then recorded at the same time in both urban fabrics. Two urban canyons are different in terms of morphology and use. They have different sky view factors and orientations. The "El Almendral" zone present streets oriented following the four main orientations, the other has streets with 45 degrees of inclination respect to main orientations. Figures 7 and 8 show the morphology of the first canyon.



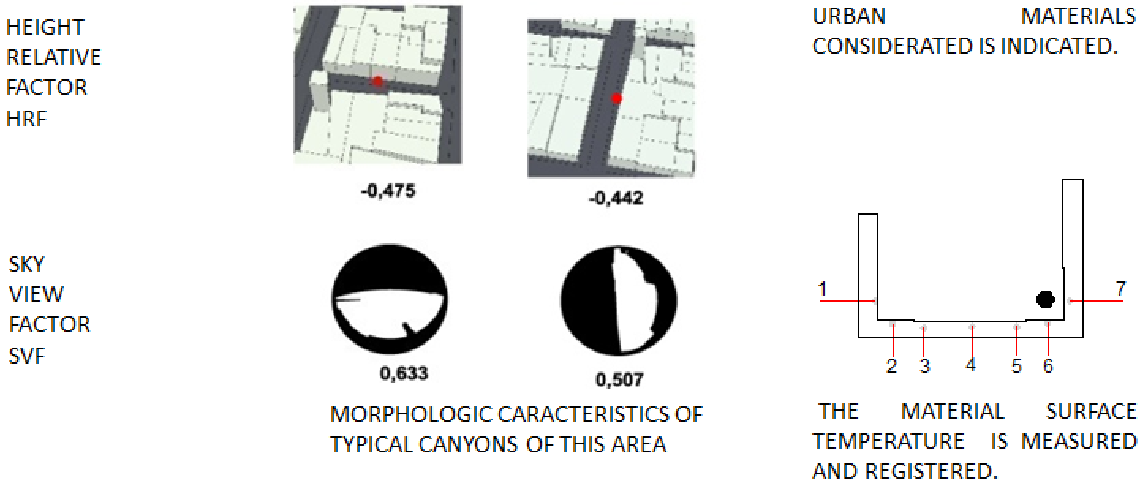
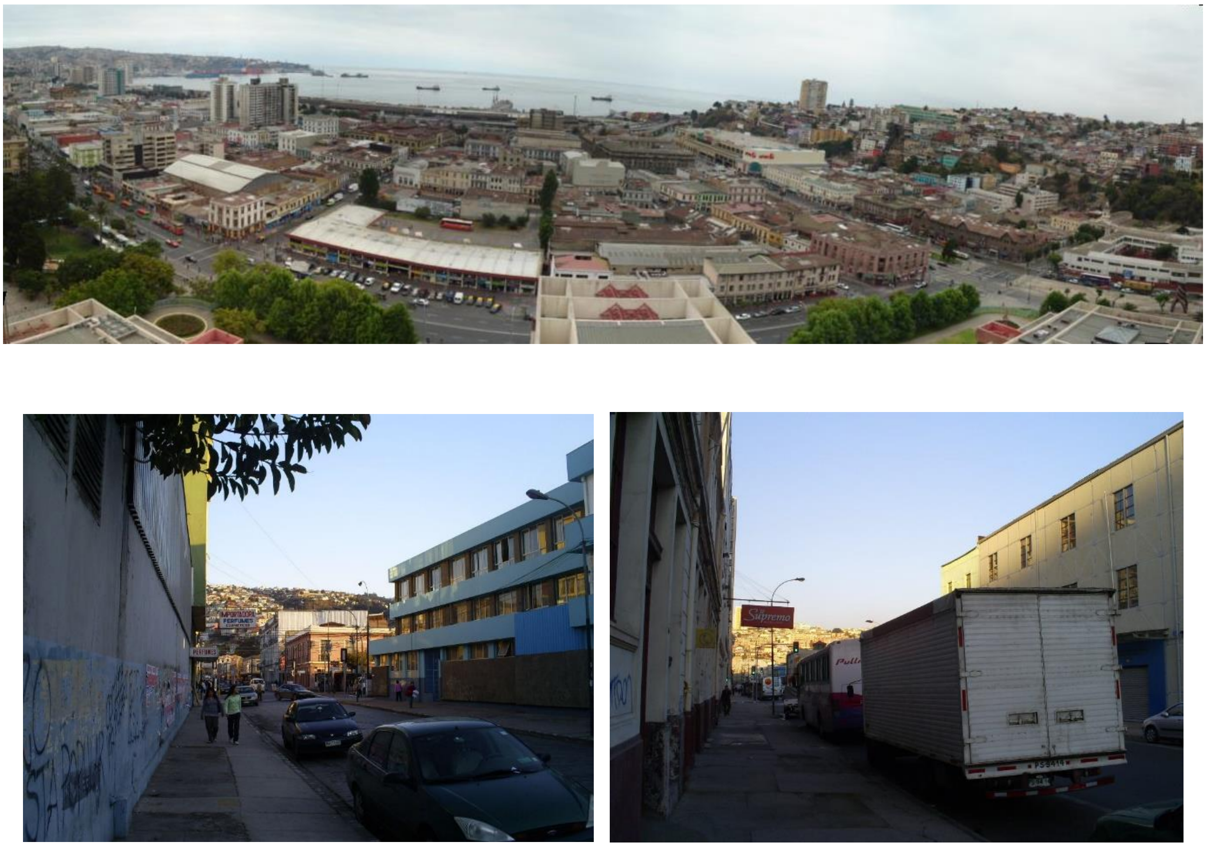


Figure 9. El Almendral sector morphology parameters



Figures 10, 11, 12. El Almendral Sector

In figures 13 and 14 average surface temperatures of each canyon are shown as a function of SVF for sunny and cloudy days at 8pm. Figures 11-14 present the morphology of the second sector.

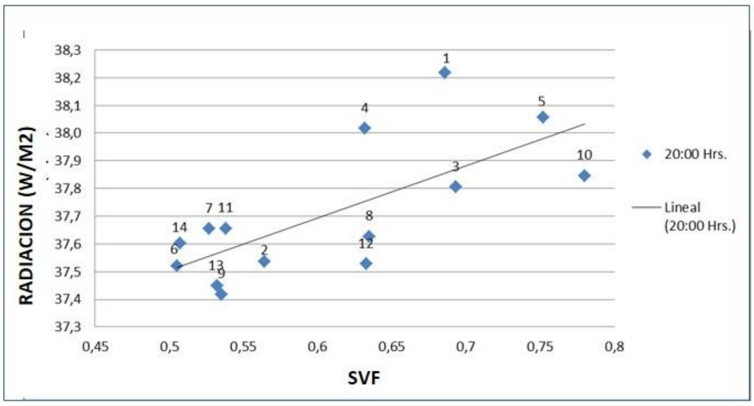


Figure 13. Façades and soil: average radiation v / s svf in every evaluated place in cloudy day at 8 pm.

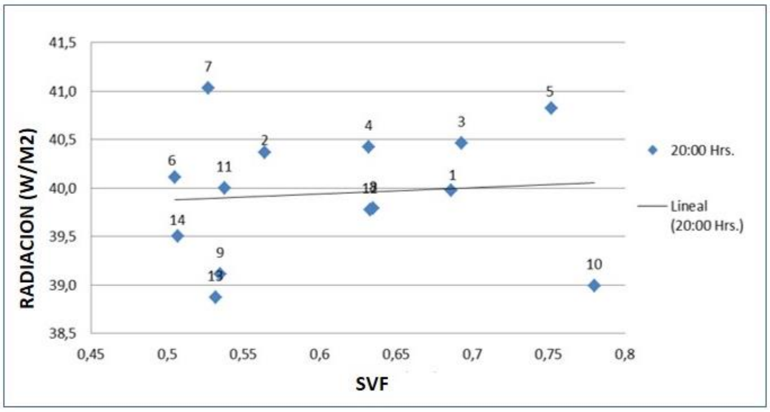


Figure 14. Façades and soil: average radiation v / s svf in every evaluated place in sunny day at 8 pm.

Figures 15, 16: Bank sector

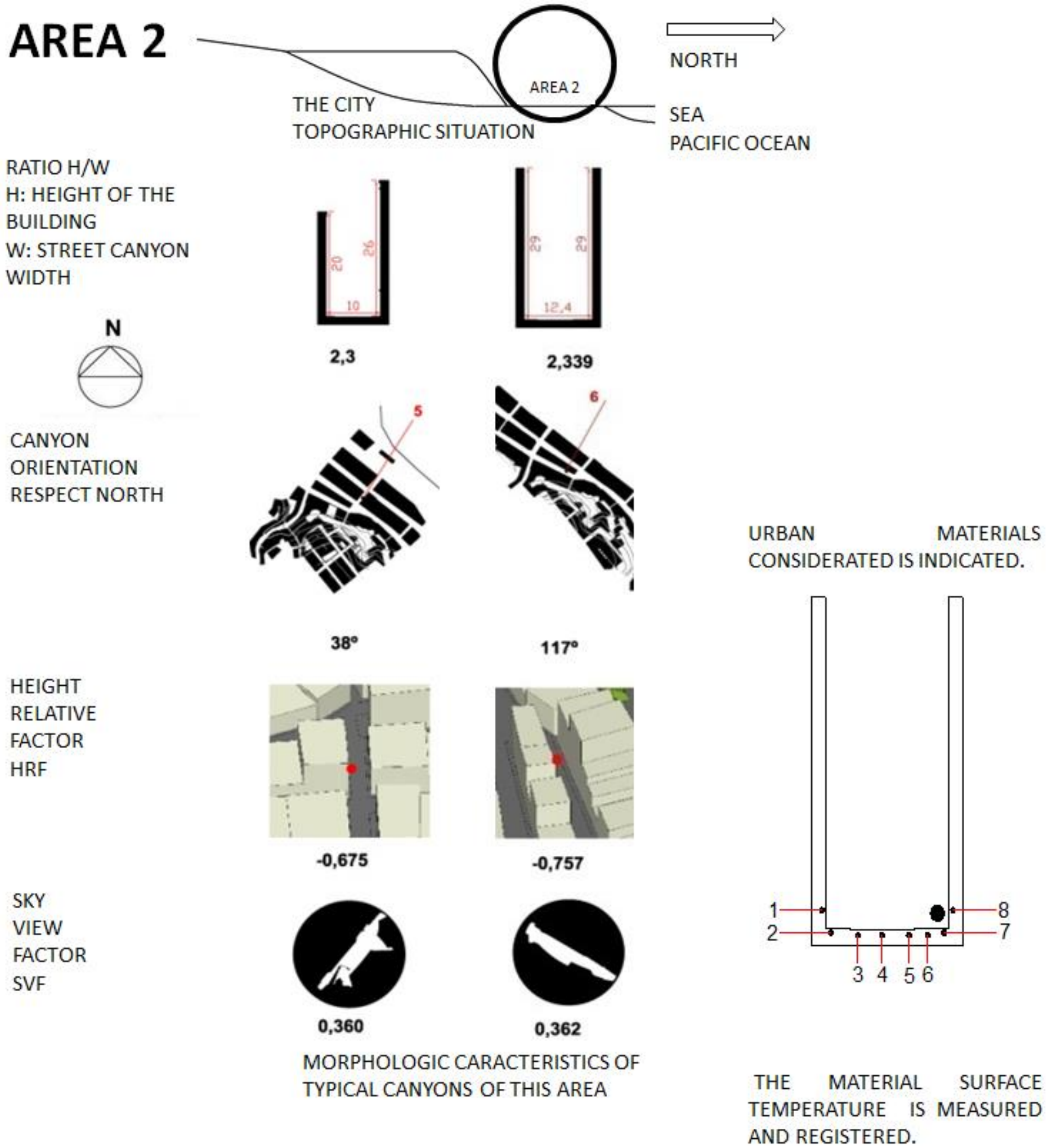


Figure 17. Bank Sector morphology parameters

In the follow average surface temperature is shown as a function of SVF, for sunny and cloudy days at 8 pm.

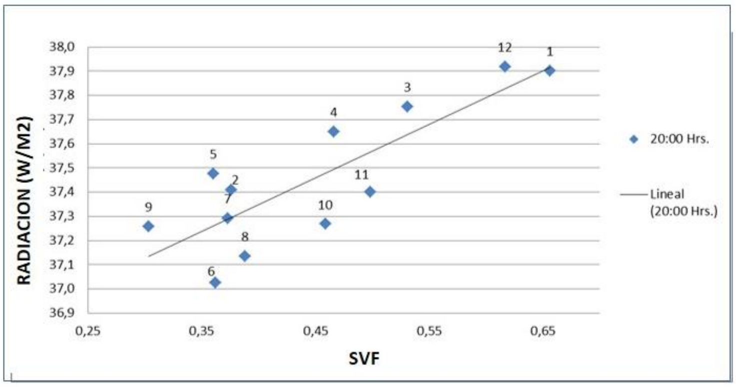


Figure 18. Façades and soil: average radiation v / s svf n every evaluated place in cloudy day at 8 pm.

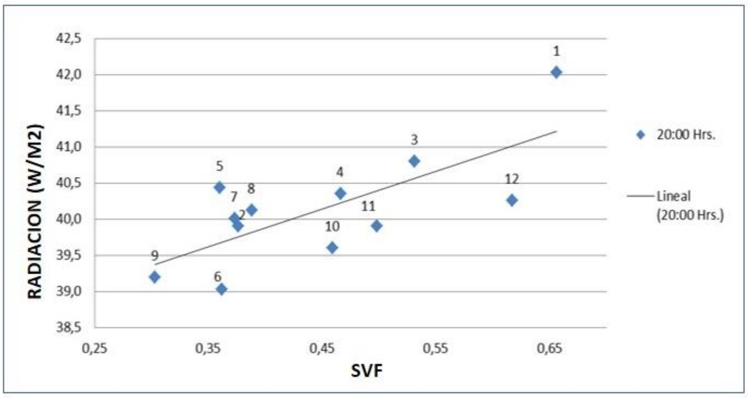


Figure 19. Façades and soil: average radiation v / s svf in every evaluated place in sunny day at 8 pm.

In figure 20-27, vertical surface temperatures and pavements temperatures for each canyon are shown, for sunny and cloudy days at 10.30 am., 2 pm and 8 pm..

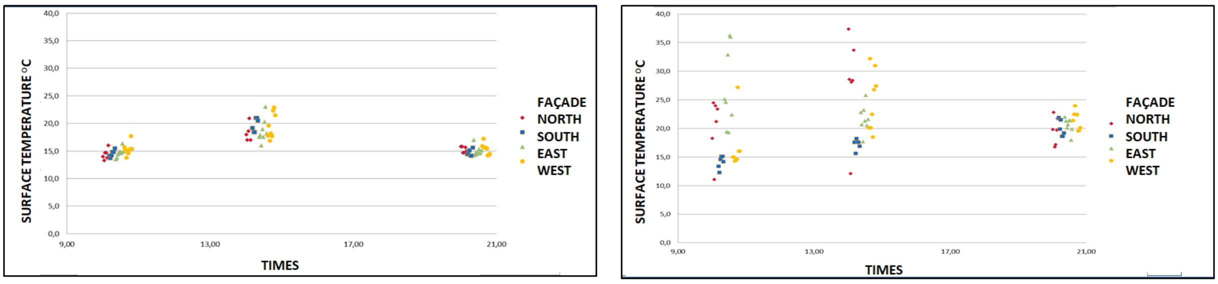
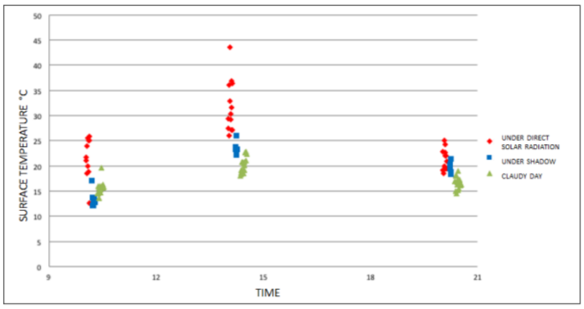


Figure 20, 21. Surface temperature of each façade according to cardinal orientation and register time, on a cloudy day (left) and sunny day (right) (Area 1 El Almedral).



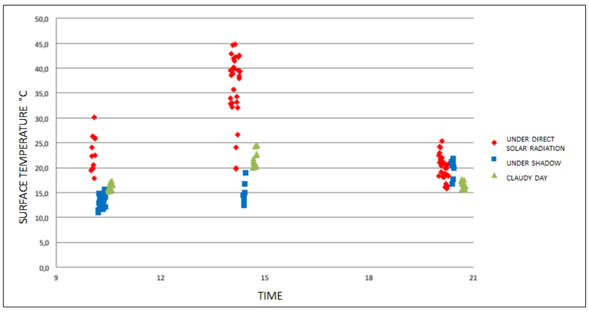
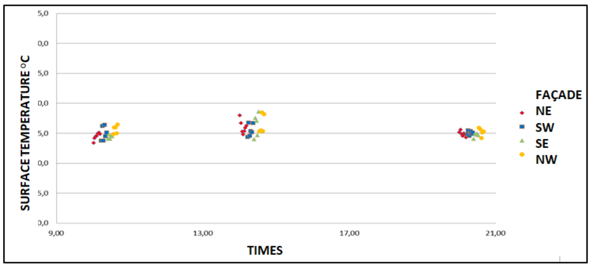


Figure 22, 23. Surface temperatures of each concrete pavement distributed by register time (left) and Surface temperatures of each asphalt pavement distributed by register time (right) (Area 1 El Almedral).



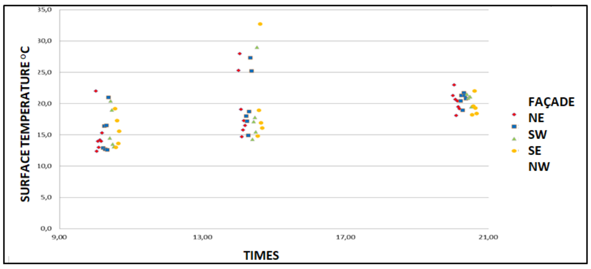
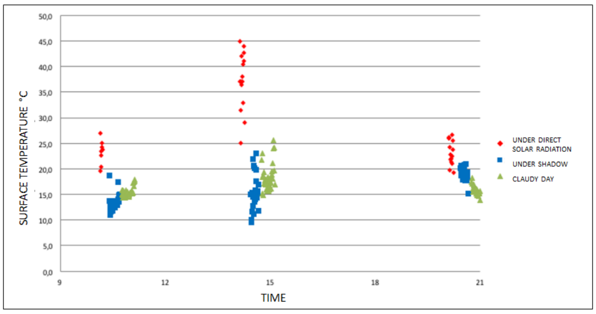


Figure 24, 25. Surface temperature of each façade according to cardinal orientation and register time, on a cloudy day (left) and sunny day (right) (Area 2 Bank zone).



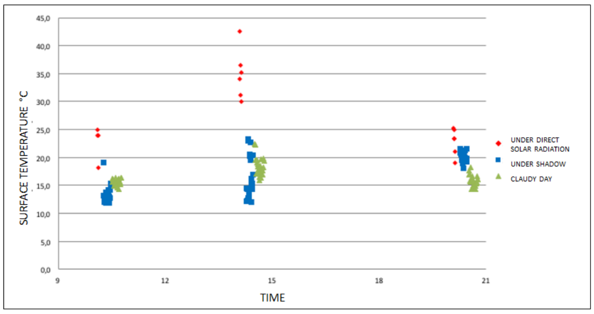


Figure 26, 27. Surface temperatures of each ceramic pavement distributed by register time (left) and Surface temperatures of each asphalt pavement distributed by register time (right) (Area 2 Bank zone).

Results of this study prove that urban form influences air temperature and mean radiant temperature in the streets during the day and the night, both in sunny and cloudy days. In the streets with high SVF values, the higher surface temperatures are recorded at 8 pm. both in sunny and cloudy days. This result should be due to better ventilation in streets with lower SVF.

Façades materials influence air temperatures and mean radiant temperatures, especially at night. It is proved that studied locations presents heat dissipation during the night independently by SVF, morphology and orientations. In general, during the night, surface temperatures are more homogenous and cooler respect to the noon.

Pavements present during the day surface temperatures higher than the façades, according also with previous studies. When the day is sunny, orientation of façades is determining the air temperature and the soil temperature. When the day is cloudy, the orientation effect is neglected.

4. Conclusions

Analysed data are useful to predict the outdoor conditions for comfort studies. Canyon morphology and materials of the façades define the variations in the thermal behaviour of the public space during both day and night and the performance is close related to the type of day, sunny or cloudy. When the day is sunny, there is more heat dissipation on surfaces, especially after the noon. In the cloudy day, air temperature is lower during the night but similar during the day. The recorded data show a clear urban heat island effect in Valparaiso, which should be mitigated in a next future.

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