

A Cool Urban Island Change 1990 - 2014. Comparative Bioclimatic Analysis in a Desert Climate, the Case of Antofagasta City Square

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Abstract. This article proposes to make a comparative bioclimatic analysis from 1990 to 2014 of the main square of Antofagasta, a coastal desert city in Chile, which was remodelled in 1995, and shows how the redesigning of green areas affects the microclimatic conditions and thermal comfort of the urban space. Ex ante measurements dating 1990 were compared with ex post results from 2014. Data were obtained in both cases in the month of September at different times of a day and in different climate conditions. The variables studied were: land surface temperature, humidity, wind speed, amount of light and square use frequency inside the square and in surrounding streets. The temperatures are not statistically different during the years 1990 and 2014 for the city of Antofagasta. The main layout of the square has not changed, and inside the square it is similar for both periods, but new species were introduced and bigger trees with shadow projection were cut down. The square had a micro-climate role in 2014 as well as in 1990. The highest frequency zone with an important surface lost it is comfort thermic condition with an increase of 1°C. Other smaller zones with less relevance for users gained in cooling with a 0.5°C reduction. The new design has been detrimental to the intensity of its micro climatic regulatory function affecting the thermic comfort of the square's internal spaces, especially those formerly protected by shadow, which mitigate a high solar radiation. The study results suggest that bio-climatic analysis of public open spaces is a key component for the design of future projects as a heat mitigating tool in the context of climate change. Research question is: How does the redesign of the square impact a cool urban island and the thermic comfort of users? Significant differences between data in situ collected in 1990 and 2014. Thermal comfort was negatively affected by the redesign in the square. The square is still a cool island but with less strength.

1. Introduction

The concept of bio-climatic analysis and thermic comfort has its origins in the research done by the Olgyay brothers [1] and Givoni [2] carried out during the 60s and 70s. These architects studied the relation of man with his environment and developed methodologies to improve the energetic efficiency of buildings. During the 70s Giancarlo Puppò [3] widened the concept of thermic comfort introducing the variables of lighting and sound improvement. The bio-climatic chart developed by Givoni [4] was used from then on in architectural design of dwellings and buildings to make decisions concerning typology, orientation and materials and to adapt their designs to the climatic conditions of the environment setting the base for what at the beginning of the 80s Izard y Guyol [5] named bio-climatic architecture.



In 1984 Bosselmann applied bio-climatic analysis and thermic comfort methodologies to the public open spaces in San Francisco [6]. He made field measurements of wind and sun exposure during a whole year at different times of the day in four city squares to determine the comfort of those places. He concluded that urban layout is crucial for the thermic and bio-climatic condition of these areas. In the design of urban space there are elements that should be considered, such as the location of the surrounding buildings that could alter or change wind direction or generate shadows, as well as the availability of green spaces together with paths of existing urban furniture and building materials because all these affect temperature and humidity. With his findings Bosselmann established a new study subject for landscape architects: the bio-climatic analysis of the urban space.

In this field, diverse approaches for the measurement of thermic comfort have been made using qualitative methodologies like making analytical observations in the same period of daytime. In terms of quantitative methods, there has been a gradual incorporation of new technologies and sensors both at the stage of in situ data capture as well as new software, to generate various bio-climatic indicators and microclimatic simulation at the analytical stage. Most studies focus on the hypothesis that there is a direct correlation between the design and layout of green areas and public space and its bio-climatic performance. [7].

A similar study was performed in 1991, in which measurements were carried out in five urban parks and their surroundings in Mexico City. It was found that T° is lower and relative humidity is higher inside the parks. There were differences between the parks and surroundings in these assessments and the thermohygro-metric human comfort [8].

Recently, the studies are working on the cool island concept in the cities. This is the case of the city of Tel Aviv, where the research examines a climatic behaviour of different designs of urban parks during hot and humid summer conditions, and their influence on human comfort in Tel Aviv [9]. We can also look at the case called “Parks cool island”, in Japan, where urban parks could help mitigate urban heat island effects and decrease cooling energy consumption in summer. This study takes 92 parks in Nagoya city in Japan, that were measured with the help of satellite data, and specific land surface temperature [10].

These studies usually analyse cases at different times of the year or season, always keeping constant the design variable. However, there is a gap in terms of measuring the effective bio-climatic performance of a public space that has undergone a significant change in its design, probably due to the difficulty of collecting time serial data ex ante and ex post to redesign time, and the delay for vegetation to reach maturity. [11].

Recommendations for using a bio-climatic 1990 study were rejected and the square was designed according to a traditional view. Today, this 1990 bio-climatic analysis study is available [12]. The study makes it possible to demonstrate that the square worked as a microclimate for the city center; in other words, it formed an urban cool island. It also confirmed a direct relation between thermic comforts and a very crucial variable, the quantity of users.

Unfortunately, bioclimatic considerations were omitted, and the new layout had a negative impact on the thermocouple comfort of nine spaces of the square. The bioclimatic conditions were badly altered.

2. Materials and methods

2.1 Study case

Antofagasta is a desert coastal South Pacific city located in Chile and crossed by the Tropic of the Capricorn. The annual average rainfall is 3.4 mm, the annual average temperature is 19°C and the

annual relative humidity is 70%. In this desert zone, the Atacama Desert, the world's highest level of UVR was recorded and it is a permanent condition during every month of the year.

The city was founded in 1868 and adopted a regular street design around its unique central square, called "Plaza de Armas" [13].

According to the last census (2012), the city has 380,000 inhabitants distributed in a territory of 30 kilometres' length north – south along the seafront, and 2 kilometres' width west - east. The main economic activities are mining services like in the past.

Since its foundation, the central square has played an important role as a public space with government buildings, financial institutions and the cathedral. Even if the city is located in a desert zone, the square was projected as an artificial big green area where green exogenous species, like trees, palms and shrubberies were introduced. Historical visual records show that in 1910 this public space was consolidated.

Nowadays, even if the city has other green public areas like parks, Antofagasta has an average of 2.5 m² of green area per inhabitant, well over 9 m² recommended by OECD [14].

Green areas like squares and parks provide benefits to inhabitants and operate as genuine oases of shadow and flora even in winter. Squares and parks reduce acoustic levels of noise contamination, increase shade protection, and mitigate high levels of UVR.

Antofagasta city is also exposed to climate changes like increases in average air and sea surface temperature, and sporadic and unusual rain falls during the winter season. In parallel, traditional and consolidated green areas are in danger with a clear reduction of surfaces and loss of species. Thus, these green spaces are losing their original cooling and climate power, and thermic comfort is not as it used to be. Further, historical green spaces in Antofagasta are stressed by economic and development urban interests and needs.



Figure 1. Square of Antofagasta city, 2014

Antofagasta's main square and surrounding streets were considered as a case study. When the city was founded, the traditional urban model with regular streets was inherited from Spanish colonial heritage with a central square with four streets around the edges (Indian Laws). Since 1868, the square and surrounding streets have held the same pattern. In the last 25 years, the urban normative has been inhibiting changes in the urban forms and buildings.

A grid was drawn to represent the streets (340 m) inside the main area of the square (100x100 m). The square is oriented in a diagonal direction north-south.

2.2 Methods

To allow the comparison between 1990 and 2014, the same methods of measurement were used. First, all data were collected on the same variables: temperature, relative humidity, wind speed, amount of light and frequency of use by residents. The variables were taken on the same points of the grid, 72 points in the square and 44 points on surrounding streets (11 points for each one of the four streets).

Data were collected in sunny and cloudy days and each one in four different intervals of time: 8 - 9am, 12 - 1pm, 4 - 5pm and 7 - 8pm during the month of September. Mobile measurements were taken by foot at 1.7 m height from ground, in each 116 points on different days and moments of the day. The frequency of residents was established by observing and counting each person who was walking, sitting or doing other activities.

The main difference of collecting data between 1990 and 2014 were the instruments. In 1990, analogical instruments were used for temperature, humidity and wind, but light was registered with a digital instrument. In 2014, digital technology was prevalent.

With data collected, the statistical treatment was statistical inference about the difference between two samples means for paired data (1990 and 2014) considering each variable in several moments of the day, type of day and sectors. Hypotheses were defined as H_0 (difference between a variable in 1990 and the same one in 2014 is 0) and H_1 (difference between a variable in 1990 and the same one in 2014 is not 0). The t-statistic was used with $\alpha = 0.05$. Degrees of freedom were $n-1$, 10 for the surrounding streets and 17 for each sector. Critical values were compared to t statistical to accept or refuse hypothesis. At level of $\alpha = 0.05$ conclusions are made in terms of statistical significance or not between variables in 1990 and 2014 to support the research question.

1. Results

There were significant differences ($p < 0.05$) between 1990 and 2014 temperature measurements in two of the surrounding streets (Table 1) oriented north-west and north-east (Washington and Sucre) for all the 4 time periods considered (8-9 am, 12-1pm, 4-5pm, 7-8pm). In the two other sectors oriented south-east and south-west, significant differences were found only between 8-9 am and 7-8 pm, but in the case of the south-east street (Prat) at 12-1pm and 4-5pm, there were no differences when comparing data from 1990 and 2014. In the case of the south-west street (Sucre) no significant difference in temperatures was detected only at 12-1pm. In the case of the internal areas of the square, in the south-east (Prat) only no difference was detected at 7-8pm and for the south-west sector the temperatures at 8-9am and 4-5pm were similar. For the north-west and north-east sectors, significant differences in temperature were calculated at 8-9am and 7-8pm.

Regarding relative humidity in the surrounding streets at 8 – 9am, 12 - 1pm and 7-8pm there were significant differences ($p < 0.05$) between 1990 and 2014. For the internal square, comparison of relative humidity shows that there are significant differences between 1990 and 2014 in all sectors at 7 - 8pm (Table 1). Values of temperatures and relative humidity are reflected in Table 2 and Figure 2.

Table 1. *t* values of T and RH between 1990 and 2014

Internal Sectors	T				RH			
	8-9am	12-1pm	4-5pm	7-8pm	8-9am	12-1pm	4-5pm	7-8pm
Prat	-10.9653	-9.1043	-2.7884	0.7167	-0.5832	3.9117	1.8612	-6.0359
Sucre	-6.3002	-0.2174	-2.7884	0.7167	1.6824	-0.8375	-1.1385	-4.0902
Washington	-6.1169	-0.9822	0.0000	17.6002	-0.5035	-1.8703	-6.3219	-11.0286
San Martin	-17.5435	-2.5176	0.6869	-2.5653	1.3721	0.6273	-1.7572	-7.3532
External Sectors	T				RH			
	8-9am	12-1pm	4-5pm	7-8pm	8-9am	12-1pm	4-5pm	7-8pm
Prat	-18.0566	-0.1740	0.8048	-7.2634	-2.2318	7.1993	-0.4873	-0.9196
Sucre	-10.1510	-1.8460	-4.8218	-19.7620	0.6256	7.5629	-0.4221	-4.0185
Washington	-12.6017	21.7363	3.7130	6.4747	-2.9400	0.0000	0.9535	-5.1077
San Martin	-20.4065	-3.2343	-9.6353	-17.7991	-4.7611	7.5516	-0.3813	-5.6154

In the case of winds, the dominant direction of wind for the city is the same for 1990 as well as for 2014: north-east at 8-9am and changing to the south-west at 12pm. Inside the city, and in the square, streets that register higher wind speeds are south-oriented streets (Washington and San Martin). The measures detected that the winds at 12-1pm are higher in 2014, compared to 1990. Even more, the intensity of wind (m/s) changes inside the square and Figure 3 shows the behaviour of wind from the extreme west to the east of the square at 8-9am, 12-1pm and 4-5pm.

The frequency of use of the square has changed in 24 years due to the increase of population, but the interesting comparison is between the distributions of users in different sectors of the square.

Table 2. Values of T and RH 1990 and 2014

	8-9 h				12-13 h			
	T°	RH%	T°	RH%	T°	RH%	T°	RH%
	1990	1990	2014	2014	1990	1990	2014	2014
Mean	15.72	76.39	18.30	77.71	19.44	76.06	22.09	64.73
SD	1.10	9.59	0.55	2.24	1.12	11.04	0.83	2.49
Max	18.00	100.00	19.70	85.30	21.00	100.00	23.60	71.00
Min	14.00	62.00	17.30	75.20	17.00	59.00	20.50	60.70
	16-17 h				19-20 h			
	T°	RH%	T°	RH%	T°	RH%	T°	RH%
	1990	1990	2014	2014	1990	1990	2014	2014
Mean	19.22	66.39	21.04	68.94	16.71	67.89	16.44	76.61
SD	2.10	8.99	1.27	2.92	1.42	7.43	0.42	1.91
Max	22.00	80.00	23.90	74.20	18.00	90.00	17.30	80.30
Min	15.00	50.00	18.90	62.30	14.00	58.00	15.60	74.10

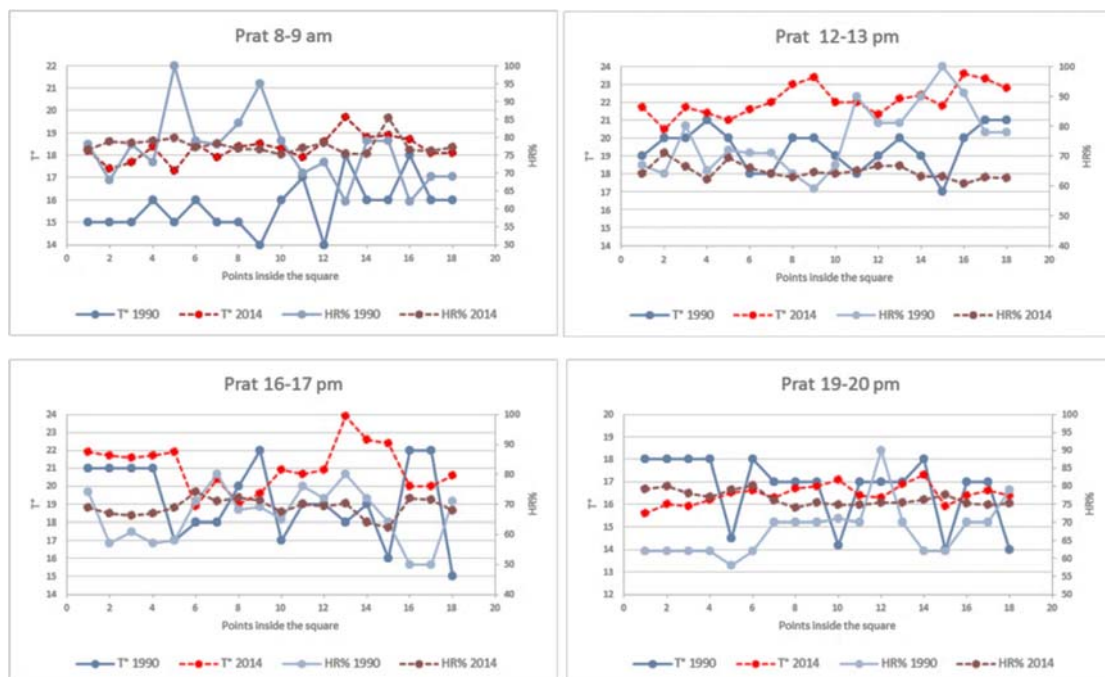


Figure 2. Comparison Values of T and RH 1990 and 2014

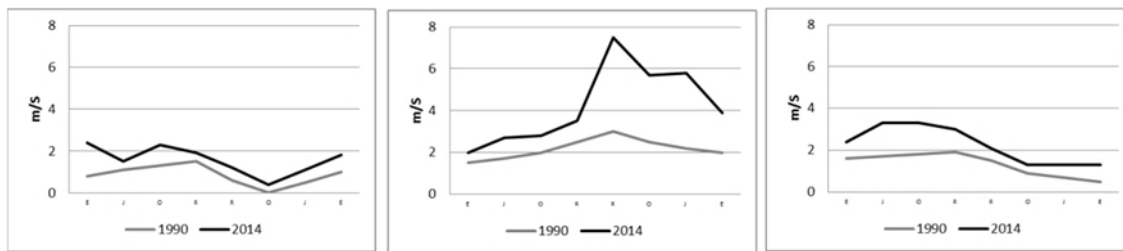


Figure 3. Winds 8-9am, 12-1pm, 4-5pm

Figure 4 shows that there is no significant difference in user distribution between 1990 and 2014. The south-east sector (Prat) is predominant on sunny days with 49% of all users (sitting or standing) and on cloudy days the concentration of users increases to 51%.

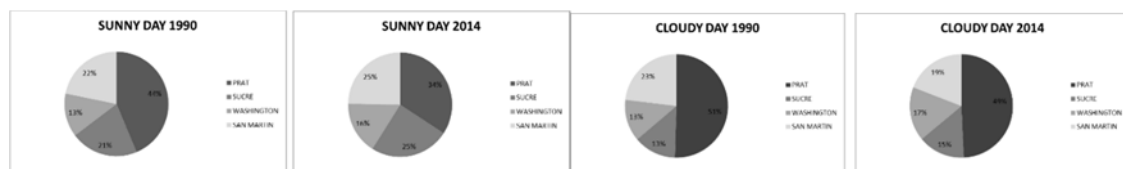


Figure 4. Square occupation sectors

In the case of the most-used sector, a comparison of different moments during the day shows that for 1990 as well as for 2014, the peak is reached between 12:00-12:30pm, and the highest use is between 12-1pm (Figure 5).

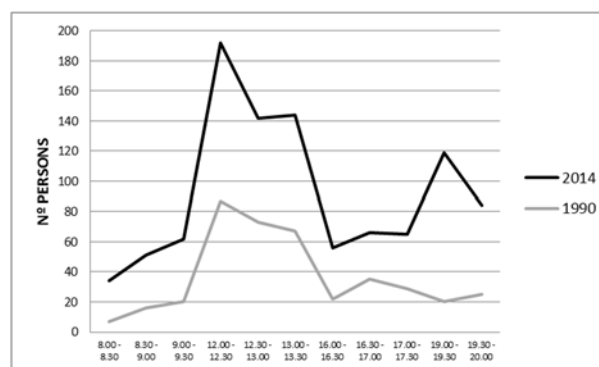


Figure 5. Square flow

Data from 1990 and 2014 show that the square has changed its temperature distribution. First, an increase of temperature has been registered and the localisation of the coolest spaces moved (Figure 6). In 1990, the coolest places were located south-east and south-west. In 2014, the south-east sector gained in temperature (1°C) and also lost relative humidity (Figure 7). In high frequency sectors, it is important to note that the square has higher temperatures and lower relative humidity. The south-east sector (Prat) that is still the highest user occupation sector presents higher temperatures and low relative humidity.

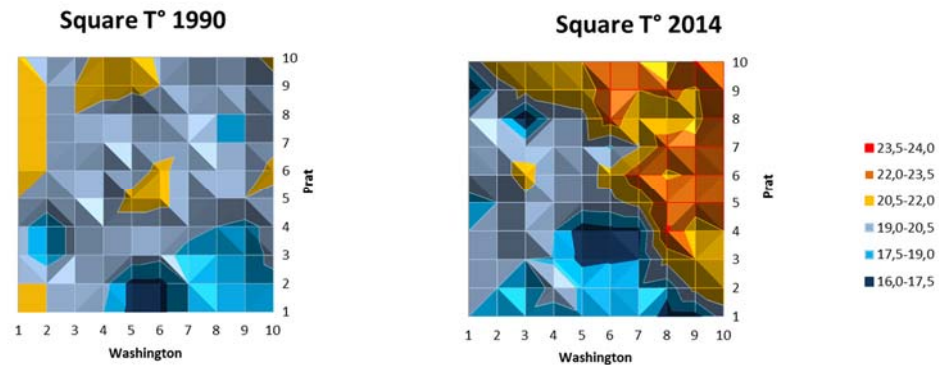


Figure 6. Square temperatures map 1990 - 2014

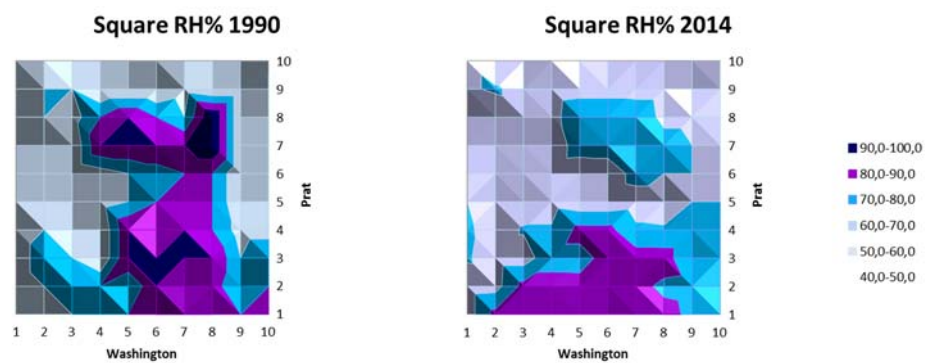


Figure 7. Square RH% map 1990 - 2014

The redesign of the square, including the elimination of big species, the reduction of green surfaces and the introduction of a water fountain was negative for this sector. This trend is also present for the other sectors with the exception of the south-west sector (Washington) that maintains its condition. In terms of impact on users it is not so relevant but it allowed the square to be a microclimate in 2014 as well as in 1990. In 2014, the square was still a cool island but it had lost intensity (Table 3).

Table 3. T° and RH for two sector in the square

	Prat		Prat		Washington		Washington	
	RH% 12-1pm		T° 12-1pm		RH% 12-1pm		T° 12-1pm	
	1990	2014	1990	2014	1990	2014	1990	2014
Extern	50.18	66.04	20.89	21.03	61.9	74.5	21.0	16.9
Internal	76.06	64.73	19.44	22.09	75.9	80.3	17.6	18.1
Δ	25.87	-1.30	-1.45	1.07	14.0	5.8	-3.4	1.1

3. Discussion and conclusions

Results show that the square, in 1990 as much as in 2014, played a microclimatic function in the city centre of Antofagasta. The study verified that at the most critical time of the day (12.00-1pm) there are several zones inside the square offering lower temperatures than the surrounding streets. However, it has also been observed that the distribution and surface of zones of higher thermic comfort has changed over time for the 12-1pm period. In the Prat Street sector, existing cold islands have increased their temperature by 1°C in 2014 in respect to 1990 and the cool surfaces have decreased in size. In

Washington Street, cool islands remain unchanged except for an isolated point of small surface where the situation has improved to -0.5°C . In the Sucre Street, cool islands have not suffered changes in temperature or extension. In contrast, for the San Martín Street sector temperature for the cool islands remains but the cool island of higher temperature of 1990 increased its size by 2014 (Prat Street sector). Relative humidity in 1990 and 2014 is clearly different inside and outside the square. In the case of the Prat Street sector, relative humidity in 2014 is lower and at the same time wind speed in 2014 increased inside the square.

These changes can be attributed to the square's redesign that took place in 1995. Certain tree species like eucalyptus (11) that reached height of 8m were cut down as well as some pimientos (Schinus Molle). The reason behind this decision was the high-water consumption of these species and also their roots damaging the piping and sewage system. Other species were introduced like Bougainvillea (*Bougainvillea spectabilis*) and small bushes offering little shadow and providing no protection barriers inside the square. Another factor that influenced the square's microclimate, affecting the temperature of its cool island, was the reduction of the vegetal surface due to the installation of four (4) water fountains replacing trees, bushes and turf, and affecting relative humidity (evapotranspiration). Pedestrian space also increased and some statues were added. In Antofagasta's climate, the fountains cannot accomplish a regulatory function because the element having the greater impact in thermic comfort terms is vegetation producing protection and shade.

The Prat sector concentrates the major number of users, verifying the same trend in 2014 as well as in 1990. This sector should offer a better thermic comfort for its users. However, compared to 1990 it lost this capacity in 2014.

The study presents some limitations that should become future investigation lines. Analogical measuring devices used in 1990 and digital ones used in 2014 should probably produce errors. On the other hand, measurements were performed during September, the time of the Equinoctial Spring and were collected in situ by scholars. A tendency to use monitoring instruments of the meteorological centres can be observed.

The time between the first and the second measurements was big so as to ensure that the new vegetation introduced to the square reached maturity. Also, in 2014 some older species like palm trees reached maximum growth reducing the size of their leaves system and thus projecting less shade. Adding to that, these days palm trees are pruned for sanitary reasons more often than in the past. To continue with this kind of study in areas larger than 1 hectare, meteorological centres are required.

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