Microclimate metrics linked to the use and perception of public spaces: the case of Chillán city, Chile

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Abstract

This paper presents a research carried out in the city of Chillan, a medium size city located on the southern limit of the Chilean Mediterranean domain, at 36º 36`s south latitude. Chillán provides a good representative example of warm summers in central and southern Chilean cities. Five public spaces were selected, representing different typologies and relating to different urban background conditions. Users in these public spaces were observed, counted and photographed five times a day (12, 14, 16, 18 and 20 hours, local time) during a heat wave event in the summer of 2016, while meteorological parameters were established at different points within the public space. The variables evaluated were impervious surfaces, Skyview factor, H/W, azimuth, shadow and radiation. Local public environmental management should pay attention to the complex relations between urban climate, public spaces and thermal comfort since they affect the quality of life of the most vulnerable sectors of the population. This is particularly important given the increasing episodes of high temperatures and intense heat waves occurred in the city of Chillán in recent summers, which are related to urban heat islands and climate change.

Keywords: Thermal comfort, green spaces, South American city, urban morphology, climate perception.

1. Introduction

Public spaces are very important for the habitability and quality of urban life. Many movements, interactions, contacts, interpersonal relations and diverse activities occur within these spaces. The latter characterize the functioning and essence of the city (Bettini, 1998). The environmental conditions of public spaces depend on various factors which include regional and local climatic parameters. At the same time, these factors are modified by the morphological components of urban environment under the urban canopy layer (UCL), resulting in specific microclimatic conditions (Ochoa de la Torre, 2009; Oke, 2010). Among these parameters are vegetal cover, impervious surfaces, sky view factor, orientation, height-width ratio (H/W). These factors define thermic comfort conditions and consequently, the use of public spaces. Urban microclimate is defined as "the prevalent climate in the micro scale level", which results from the heterogeneity of the UCL, because of the atmospheric temperature, the wind speed, the balance radiation and other climatic elements (Erell et al., 2011).

At this scale, climate may change abruptly within a very short distance, because of the land type, proportion of built space, thermic and optical quality of materials, orientation and slope of the surface, vegetal cover, ground humidity, among other factors (Ochoa de la Torre, 2009). At the microscale level individual buildings and trees project their shadow and change wind direction; texturized wall coverings affect sun light reflection and radiant temperatures to which people are exposed (Erell et al., 2011).

Most microclimatic studies refer to urban canyons; they describe their behavior and relationship with building design, particularly in what respects to height-width ratio and sky view factor. At the same time, thermic comfort in public spaces has attracted scientific attention. The first studies focused in instrumental methods; later on, they included user's degree of satisfaction with local climatic conditions (Nikolopoulou & Lykoudis, 2006; Nikolopoulou, 2011; Guzmán & Ochoa de la Torre, 2014; Zeng & Dong, 2015 Lamarca et al., 2017, Smith et al., 2018). In recent years, research related with other public spaces, such as parks, squares, riverside, beaches, etc. has increased significantly.

Even though the urbanization process has been intense in Latin America, microclimatic studies are generally scarce. A research developed in the city of Buenos Aires, Argentina determined that microclimate differences inside the city depend on height and density of buildings, orientation and width of streets and presence of parks and trees (De Schiller et al., 2001). Ugeda (2013) found that in the city of Jales in Brazil, the northern built slope was always warmer than the south one. In her study, she also discovered a relationship between uncovered ground and heat. To this respect, she highlights the importance of rainfall in previous years, because it affects ground humidity and consequently, vegetation coverage.

Microclimatological perspective is relevant for the city of Chillán, located on central Chile, which presents very high summer temperatures. In the summer 2016-2017, for example, the city

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registered a maximum temperature of 41,5°C. Furthermore, as many other cities in Chile, green areas and public spaces are significantly scarce. There are no studies of urban microclimate for the city of Chillán. This research aims to analyze the morphological conditions of five representative public spaces inside the city, to evaluate its impact on microclimate and user´s thermic comfort.

2. Materials and method

Chillán is the capital city of the new region of Ñuble (created in September 2017). It is located at 36° 36´ south latitude. Its mean altitude is 124 meters above sea level (figure 1). Chillán has warm temperate climate with winter rains, Cwb, according to Köppen classification for Chile (Sarricolea et al., 2016). The average annual temperature (13,7°C) corresponds to its latitude. However, its average summer temperature (19,4°C) and the average of summer maximums (19,4°C) are similar to those of Arica and Iquique, two cities located in the northern regions of the country.

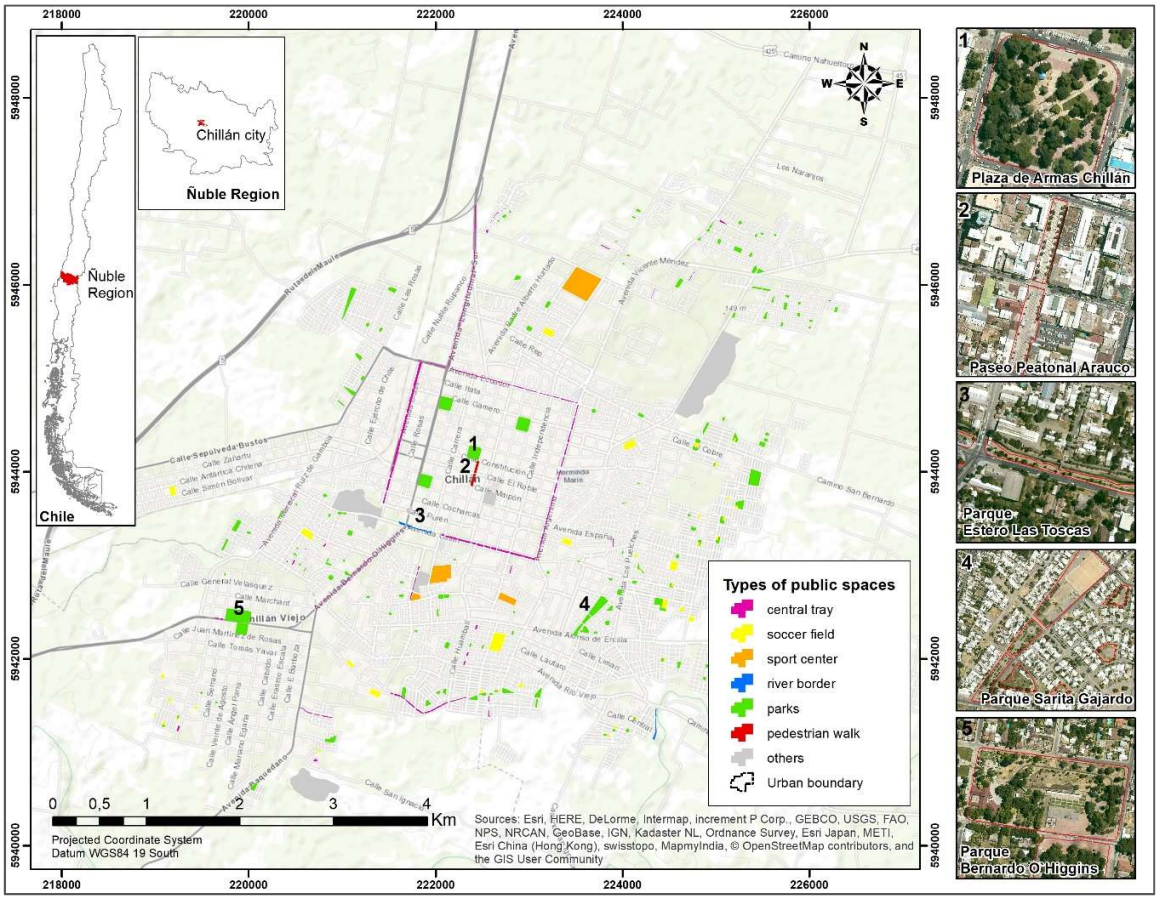

Figure 1. Study area
Source: Own elaboration.

Chillán has 204,180 inhabitants (National Institute of Statistics, 2013). According to the classification of the Ministry of Housing and Urbanism (2007) it is a medium size city. There are few green areas

within the urban surface (1,7 square meters per inhabitant). It is under the national average (4 square meters per inhabitant). The minimum average recommended by the World Health Organization (WHO) is 9 square meters per inhabitant.

The public spaces selected for this study are: Plaza de Armas, Paseo Peatonal Arauco, Parque – ribereño - Estero Las Toscas, Parque Sarita Gajardo y Parque Monumental Bernardo O´Higgins. This study uses a mixed methodological perspective, which combines quantitative and qualitative methods and data. Quantitative data was obtained by processing satellite images from SENTINEL 2 (March 5, 2016) and field data gathering (January and February 2016) through observation and instrumental measurement of climatic and urban variables. Qualitative data comes from a survey administered to selected public spaces users.

The analysis of the urban microclimate considers atmospheric temperature and relative humidity measured every 5 minutes by Logtag and Ibutton recorders, installed in various locations inside the public spaces selected or in their proximities; and every hour, by meteorological micro station HOBO, located in Campus La Castilla in the University of Biobío, 800 meters west from Parque Estero Las Toscas, which also registers wind speed and direction as well as global solar radiation. Solar radiation data obtained from HOBO was compared with the data calculated - for each public space – by a 3D model of buildings and trees constructed with Ecotect software. The adjustment parameters to determine radiation were obtained from the weather data file for the city of Chillán, available in www.meteonorm.com

The morphoclimatic description of the selected public spaces considered the following factors: Total area of each space; Ground coverage and building rate in the neighboring squares; Height – width ratio in checkpoints (figure 3); and Sky view factor and shadow availability in checkpoints (figure 3).

At the same time, a field survey was developed from January 29 to February 01, 2016, to observe and count the number of users located under the sun or in shady spots, five times every day (12, 14, 16, 18 and 20 hours, local time). Also, a survey was administered to a sample of men and women, over 18 years old, selected at random.

3. Results

3.1 Climatic description, summer 2015-2016, and heat wave from January 30 to February 01, 2016.

Data registered by Chilean Meteorological Service in Bernardo O´Higgins station – located in the rural area surrounding Chillán -, shows that during January 30, 31 and February 01, 2016, there was a heat wave with a peak of 36°C in the rural sector. This is the highest temperature registered that summer by this institution in all the country. According to the instruments used in this study, temperatures exceed 38°C inside the urban area.

During the field survey from January 29 to February 01, 2016, atmospheric temperatures in Plaza de Armas de Chillán ranged from 25°C to 33°C, with peak temperatures between 16 and 18 hours. Relative humidity reached its minimum value during the afternoon (36%). The four checkpoints located in Plaza de Armas showed comparable results. Similar behavior could be observed in Parque Monumental Bernardo O´Higgins and Parque Estero Las Toscas, where temperature reached 35°C.

In Paseo Peatonal Arauco temperatures fluctuate from 27°C to 30°C at 12 o´clock, increasing up to 35°C at 16 hours, checkpoint PP2 (figure 3) shows a greater difference with the rest of the measurement points (+2°C) while humidity differs even 3% from one checkpoint to another at the same time.

In Parque Sarita Gajardo, as well as in the rest of public spaces, temperature reaches its peak between 16 and 18 hours. Until 16 hours there are significant differences (2°C) between minimum and maximum temperatures registered in the different checkpoints. This differences tend to lessen at 18 hours with the sole exception of checkpoint SG5 (figure 2), located in the playground, which shows higher temperatures. The maximum average register is 36°C. At 20 hours, all checkpoints have similar values (near 30°C).

Figura 2. Playground Parque Sarita Gajardo.
Source: Personal archive.

As shown in table 1, average data estimated with the radiation model are quite similar to those determined by the Meteorological Micro station, with a slight difference of 60 W/m^2 at noon and only 12 W/m^2 in the afternoon.

Table 1. Comparison of global radiation (in W/m^2) estimated and measured in Campus La Castilla

Estimated data (30-01-2016)		Measured data (30-01-2016)	
12 to 13 hours	17 to 18 hours	12 to 13 hours	17 to 18 hours
403,8	312,4	462,5	325

Source: Constructed by the authors using data gathered by Ecotect and by the meteorological micro station located in Campus Castilla, University of Biobío.

Global radiation varies greatly inside each public space, particularly in the afternoon hours (17 to 18 hours) (table 3), because of the solar angle and the shadows projected by buildings and trees. During noon, average radiation is near its maximum value and covers larger areas within public spaces. In both time ranges minimum values cover a small surface.

Though all public spaces show high radiation values between noon and 13 hours, the greater spatial homogeneity for these values is found in Parque Estero Las Toscas and Parque Sarita Gajardo. In the other public spaces, the radiation values show greater diversity, because of the difference between places exposed to solar radiation and shaded sites. Such is the case of higher vegetation in Plaza de Armas and Parque Monumental Bernardo O´Higgins, or the continuous facade of the buildings flanking the Paseo Peatonal Arauco.

3.2 Morphoclimatic description of selected public spaces

Chillán public spaces were classified in 7 groups: median strip, soccer field, sports center, river border, park, square and pedestrian walk. There are 323 public spaces with a total area of 84.2 ha, which amount to 2.8% of the city´s surface. Most public spaces are squares; there are 155, scattered along the city and represent 1.2% of the whole urban surface. Their average area is 0.23 ha, but a number of them don't reach 400 square meters (0.04 ha). The 6 city Parks have a bigger average area (1.3 ha). River borders are related to natural elements of the urban environment. For example, Estero Las Toscas, which gives birth to a homonymous park. There is a considerable number of Soccer fields (38). These are generally located in low and middle income residential areas and have scarce vegetation cover.

Among the public spaces of Chillán, the biggest green area is Parque Monumental Bernardo O´Higgins (3.4 ha). The second place belongs to Parque Sarita Gajardo (3 ha), which is part of a major project sponsored by the local government. Plaza de Armas covers 1.8 ha. The smallest public spaces are Parque Estero Las Toscas and Paseo Peatonal Arauco, with 1 and 0.6 ha. respectively.

3.2.1 Land cover inside public spaces

Except Paseo Peatonal Arauco, 98% of whose surface is paved, all public spaces selected in Chillán have green patches covered with grass: Plaza de Armas - 41%, Parque Monumental Bernardo O´Higgins - 38%, Parque Sarita Gajardo – 34% and Parque Estero Las Toscas – 20,5% (figure 3).

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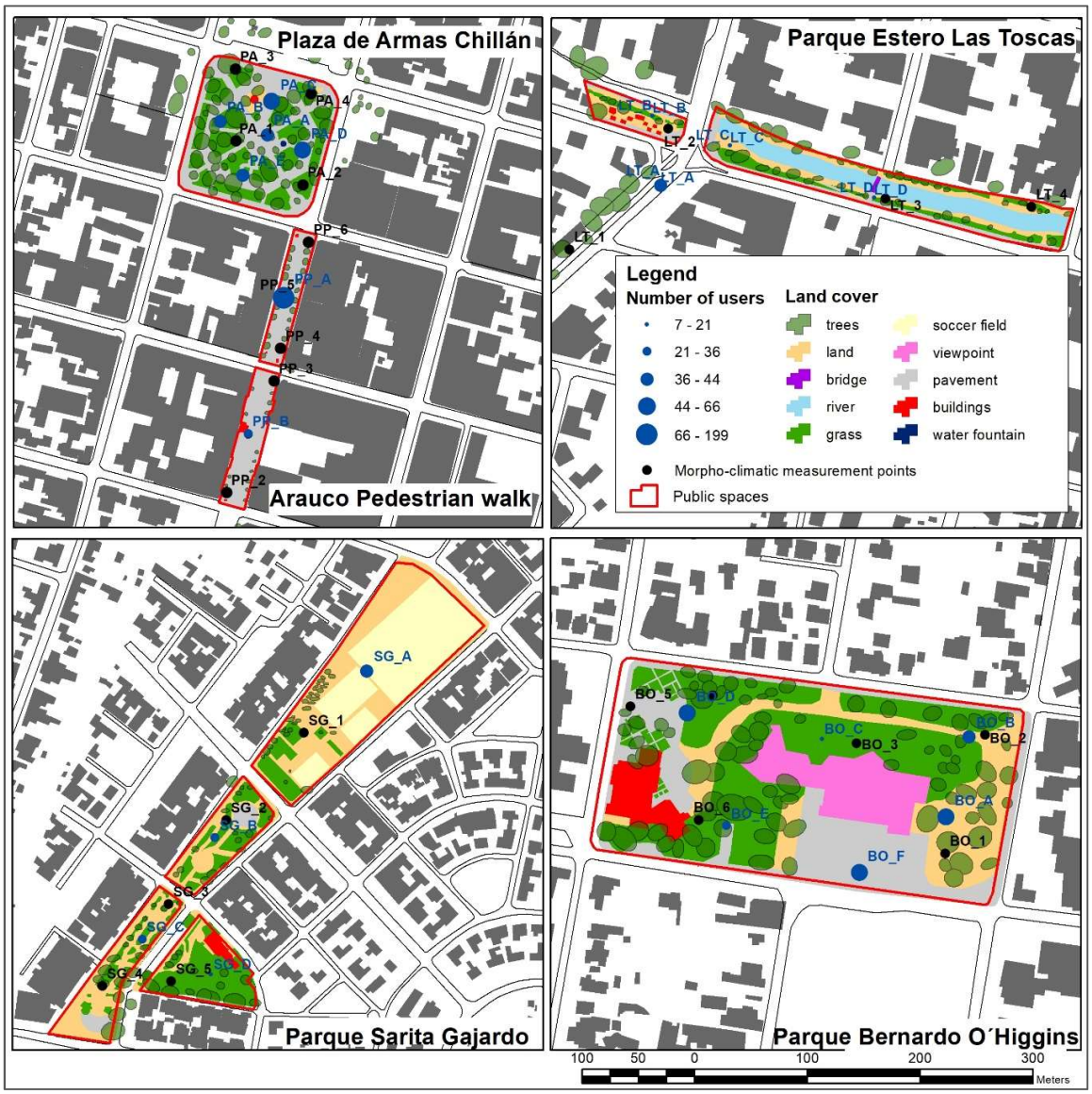

Figure 3. Land uses and coverages in selected public spaces.
Source: Own elaboration.

The smaller paved surface is in Parque Sarita Gajardo. It represents only 5.4% of the total area, with 3% occupied by two multi -courts. In Parque Monumental Bernardo O´Higgins, the paved surface accounts for 38% of its area, 10% of which houses a viewpoint (figure 4), 6 meters high.

Figure 4. Viewpoint Parque Monumental Bernardo O´Higgins
Source: Personal archive.

In Paseo Peatonal Arauco, 98% of the total surface is paved. Conversely, Parque Estero las Toscas is entirely covered by grass and gravel. The remaining public spaces show more diversity, with values near 0 in some sites (BO5, BO3, PA4, in Figure 3) and 75% in others (PA2, SG2, in Figure 3).

Parque Sarita Gajardo shows the greater area cover by ground: 69% of the total surface, 47% of which is occupied by 2 soccer fields with 6,800 and 1,500 square meters respectively. Grass in the park is poorly maintained (Figure 5); it shows several “brown areas”.

Figure 5. Soccer field Parque Sarita Gajardo.
Source: Personal archive.

The presence of water, as well as related objects and activities, was also considered in this study. As expected, the greater abundance of this element may be observed in Estero Las Toscas, where the stream channel accounts for 33% of its area. In the other public spaces, water is only available in water fonts or water play zones (Parque Monumental Bernardo O´Higgins) (Figure 6).

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Figure 6: Water play zones in Parque Monumental Bernardo O´Higgins.
Source: Personal archive.

All public spaces have built areas, which house pergolas (Plaza de Armas), kiosks (Paseo Peatonal Arauco and Parque Estero Las Toscas), ware houses (Parque Sarita Gajardo) or bathrooms (Parque Monumental Bernardo O´Higgins). They all have benches, trash cans, signals, etc.

Trees higher than 1.5 meters, as well as treetop surfaces were calculated for each public space. The greater number of individual trees is in Parque Sarita Gajardo (85) and Parque Monumental Bernardo O´Higgins (86). On the other hand, the larger treetops surface is in Plaza de Armas (32% of its area).

In the neighboring squares the average built surface varies considerably. In 3 of them, this average is over 50%: Plaza de Armas de Chillán (59.1%), Paseo Peatonal Arauco (57.1%) and Parque Sarita Gajardo (54.6%); in the other 2, it is near 30%: Parque Estero Las Toscas (33.7%) and Parque Monumental Bernardo O`Higgins (27.4%). Except Parque Estero Las Toscas and Parque Monumental Bernardo O´Higgins, over 50% of neighboring squares show more than 65% of built surface. Even though one would presume that Paseo Peatonal Arauco should be in the first place, considering that most of its neighboring squares have over 60% of built surface, this is not so, because it is next to Plaza de Armas and there is a parking lot in one of its squares.

3.2.3 Buildings height

Chillán has very few high buildings. Low structures prevail in the squares surrounding public spaces. The higher buildings are beside Paseo Peatonal Arauco and in front of Plaza de Armas, with 18 and 8 meters respectively (points PP6 / Gran Hotel Isabel Riquelme and PA4 / Governance building). All buildings around Plaza de Armas are over 3 floors. Likewise, buildings surrounding Paseo Peatonal Arauco usually have 2 or 3 floors.

There are only 3 higher buildings in the proximities of these public spaces; two of them have 9 floors (27 m) and the third has 18 floors (54 m) and is the highest structure inside the city. These buildings don´t change the H/W ratio, but they increase the available shade.

3.2.4 H/W ratio

This index affects the percentage of the total space receiving direct solar radiation and the number of hours during which this occurs. When this value tends to 0, there is greater difference between the height of buildings and the width of street; hence, the latter are more exposed to solar radiation. Conversely, when this ratio is near 1, height and width are similar, and there is more shadow available (provided by the buildings).

The sites measured in Chillán are generally under 0.1, which shows an open profile associated to parks and squares (table 2). The only exception is Paseo Peatonal Arauco, where street width is smaller than height of the buildings; this is why direct solar radiation decreases.

3.2.5 Sky view factor

Such as H/W ratio, Skyview factor (SVF) also affects direct solar radiation and shadow availability. In the selected public spaces, the average values of this indicator range from 0.51 in Plaza de Armas to 0.747 in Parque Sarita Gajardo (table 2). Thus, in the first public space mentioned, half of the sky is visible. As this value raises, sky openness also increases and solar radiation is more intense.

Even though this indicator doesn´t show much difference from one public space to another, it varies significantly along each of the selected spaces, except for Parque Sarita Gajardo (table 2), where it is over 0.7 in all checkpoints. This high value shows great sky openness, due to its width as well as to the surrounding streets.

This indicator is low in 3 of the selected public spaces: Plaza de Armas (0.37 y 0.38 in checkpoints PA1 y PA3, respectively, Figure 25); Parque Estero Las Toscas (0.39 in checkpoint LT4, Figure 2) and Parque Monumental Bernardo O`Higgins (0.46 in checkpoint BO2, Figure 2). This is due to the considerable number of trees which results in less sky visibility. In Paseo Peatonal Arauco SVF increases when moving away from Plaza de Armas (table 2); in its second block, it is over 70% (checkpoints PP1, PP2 and PP3 in Figure 2); in the remaining checkpoints (PP4, PP5 and PP6, in Figure 2), the average sky visibility is near 50%.

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Table 2. Morphoclimatic parameters and perceived thermal comfort in each checkpoint

Public space	Checkpoint	SVF	H/W	Solar radiation (12 to 13 PM) (Wm^2)	Solar radiation (5 to 6 PM (Wm^2)	Perceived thermal comfort (average)
Plaza de Armas	PA1	0.382	0.056	226.18	80.24	7.6
	PA2	0.648	0.056	371.57	300.95	7.3
	PA3	0.367	0.056	266.22	88.69	7.9
	PA4	0.646	0.043	375.27	127.37	8.1
Paseo Peatonal Arauco	PP1	0.756	0.221	398.51	310.5	7.7
	PP2	0.738	0.232	395.47	309.43	8
	PP3	0.437	0.236	296.77	232.13	7.6
	PP4	0.485	0.222	334.75	113	7.8
	PP5	0.563	0.434	352.2	119.19	8.7
Parque Estero Las Toscas	LT1	0.175	0.128	139.62	224.41	7.5
	LT2	0.723	0.130	385.37	305.84	7.7
	LT3	0.823	0.073	405.44	312.96	8.3
	LT4	0.388	0.068	232.84	275.48	8.3
Parque Sarita Gajardo	SG1	0.812	0.039	404.69	312.69	7.2
	SG2	0.813	0.053	403.47	312.26	8.3
	SG3	0.79	0.033	401.62	136.72	7.9
	SG4	0.559	0.105	334.22	287.69	7.4
	SG5	0.696	0.088	382.37	304.78	7
Parque Monumental Bernardo O´Higgins	BO1	0.799	0.018	400.19	311.1	7.9
	BO2	0.461	0.020	250.32	263.68	8
	BO3	0.801	0.078	402.7	311.99	8.3
	BO4	0.541	0.020	337.94	245.29	8.2
	BO5	0.632	0.041	372.84	126.51	8.7
	BO6	0.591	0.056	357.81	121.18	7.7

Source: Own elaboration.

During summer, shadow availability is a critical factor to increases climate comfort in public spaces. In Chillán, shadow is provided by the trees inside each public space as well as by buildings in its surroundings.

The analysis of shadow availability in all public spaces shows that the prevailing value is near 30%. In Parque Estero Las Toscas and Parque Sarita Gajardo, shadow is unavailable in as much as 70% of the total area, at any time, from 12 to 18 hours. The remaining 3 public spaces have some shadow during day time: Paseo Peatonal Arauco (30%), Plaza de Armas (14%) and Parque Bernardo O´Higgins (13.5%). Inside the Parks, shadow is related to the presence of trees. Instead, in Paseo Peatonal Arauco, it is provided by buildings. The first is permeable to solar radiation, which results in higher values for the latter.

3.3 Urban climate perception and its relationship with morphoclimatic parameters

The method used by Smith & Henríquez (2018), to determine the user's perception of urban climate considered the following elements: thermal sensation, solar exposition, wind speed, humidity and general comfort. All the questions included in the survey have an 11 points scale (0-10); values between 4 and 6 are considered acceptable for every parameter (table 3).

Table 3. Ranges of user´s climate perception

Parameter	0	1	2	3	4	5	6	7	8	9	10
Thermal perception	Very cold				Good (Comfortable)			Very hot			
Sun exposure	I want more sun							Too much sun			
Wind speed	Little wind							Too much wind			
Air humidity	Very dry							Very humid			
Thermal comfort	Cold, very uncomfortable							Hot, very uncomfortable			

Source: Adapted from Cheng (2008).

During the morning, the proportion of users who feel thermal comfort and those who feel uncomfortable is quite similar; nevertheless, in the afternoon (12 to 16 hours) and the evening, most people declare discomfort, particularly around 18 hours, when temperature reaches is peak (38°C). The individual analysis of each public space selected shows that in Parque Sarita Gajardo, positive thermal perception is near 30% of the sample. In the remaining spaces, it ranges from 10 to 15 percent. Even though Plaza de Armas has significant vegetation cover, 95% of its users are in discomfort (figure 7).

Solar exposition shows similar perceptions. Near 100% of the users surveyed in Parques Sarita Gajardo and Monumental Bernardo O´Higgins say that here is too much sun. In Paseo Peatonal Arauco and Parque Estero Las Toscas, some users enjoy solar exposition, though only 20% of the sample chose values between 4 and 6 (Figure 8). Four people went for the option: I want more sun; 2 of them in Paseo Peatonal Arauco, 1 in Plaza de Armas and another in Parque Sarita Gajardo.

Wind is a very important weather agent, since it helps to attenuate high temperatures. Its intensity is differently perceived by the persons sampled (figure 8). Nevertheless, users who perceive that there is little wind and those who feel comfortable with its intensity, are very similar in number. In Plaza de Armas, 60% of the sample chose the option "little wind". A very small group of users perceived too much wind, particularly during the evening; most of them were visiting Parque Sarita Gajardo, Parque Estero Las Toscas and Parque Bernardo O`Higgins.

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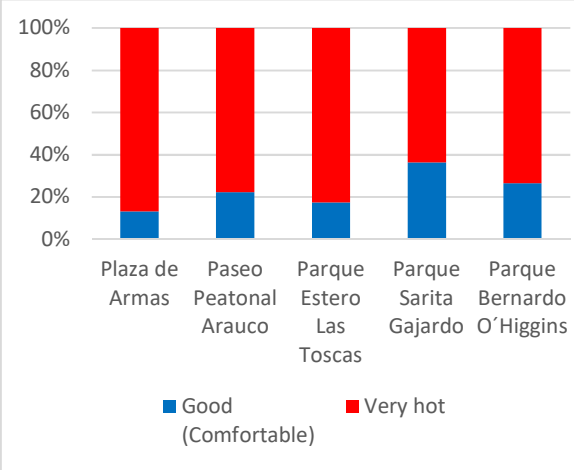

Figure 7. Thermal perception
Source: Own elaboration.

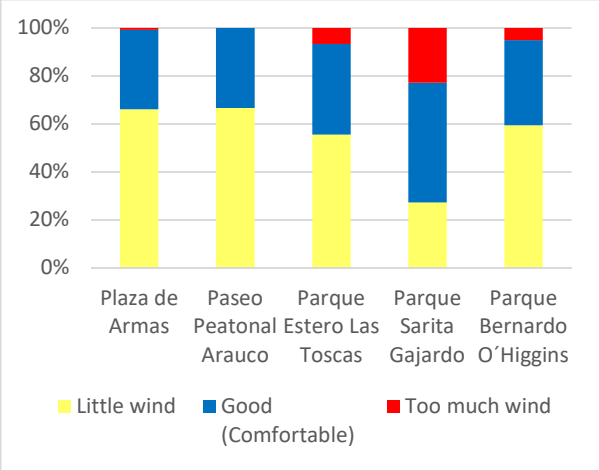

Figure 8. Wind speed perception
Source: Own elaboration.

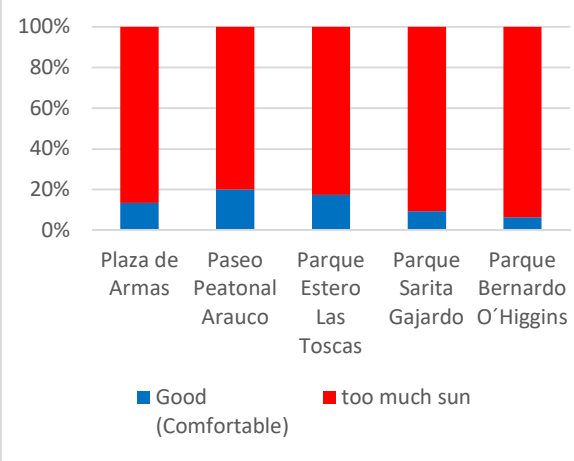

Figure 9. Sun exposure perception
Source: Own elaboration.

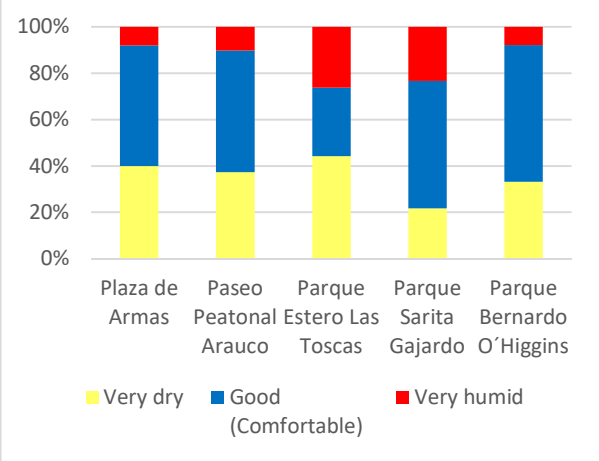

Figure 10. Air humidity perception
Source: Own elaboration.

During daytime, air humidity registered in the checkpoints located inside the selected public spaces ranges from 45% to 55%. Within the sample, humidity and wind speed show a similar perception. Anyway, during the afternoon, most people choose the option “too dry”. On the other hand, at noon, this alternative and “comfortable” show similar results (Figure 10). Even though Parque Estero Las Toscas is located in a riverbank, it has the highest proportion of uncomfortable users on account of air dryness. In the remaining public spaces, satisfaction with this parameter amounts to 50% approximately.

When crossing the responses obtained from the sample, perceptions referred to wind speed and air humidity show an inverse relation with comfort perceived by the users; its correlation coefficients amount to -0.25.

3.4 Use of public spaces and distribution of their users

About 70% of respondents recognize seasonal changes in their use of public spaces. Just over one third of them suggest the following sequence, in decreasing order: Summer - Spring - Autumn - Winter. The options in which the summer season ranks first exceed 200 respondents, which represent about 60% of the sample. None of the respondents chose the option "doesn't assist" for the spring - summer seasons.

According to survey results, the majority of respondents in Parque Estero Las Toscas and Parque Monumental Bernardo O´Higgins do not visit them in fall or winter. In the other three public spaces selected, most users choose "once or twice a week". These results might be explained by the location and function of each public space. Indeed, Paseo Peatonal Arauco and Plaza de Armas are located downtown near the business district, and Parque Sarita Gajardo, is in a mainly residential neighborhood and is equipped for sports practice.

Weather - heat, cold, rain - explains to a large extent the seasonal differences in the use of public spaces. In Parque Bernardo O'Higgins about 90% of the respondents point to the bad weather -cold, rain- as responsible of the few visitors in winter; at the same time, the increase in its users during summer would obey to "better climatic conditions" – higher temperatures - Respondents claim that "in summer it is hotter and people spend more time outdoors". A visitor in Paseo Peatonal Arauco noted that "in winter, the sole visitors are those who have to pass through the walk " because " it is colder and darkens earlier".

Other factors that affect the frequency of use of public spaces in winter are the decrease in free time, less daylight hours, fewer users and fewer activities.

Most respondents declare to attend the public space between 16 and 20 hours, during the autumn - winter seasons. In the case of the Plaza de Armas, visitors distribute from 8 to 20 hours, with a higher concentration between 12 and 16 hours. Less than 10 users remain during the whole day or beyond 20 hours, after sunset. During spring and summer seasons, there is a greater number of evening and early night attendants a, when ventilation increases and temperature decreases.

The data obtained through the survey was complemented by the observation of visitors. There are important differences in the flow of users, depending on the social role of each public space. Thus Plaza de Armas de Chillán and, Paseo Peatonal Arauco receive a greater number of attendants on Monday through Friday. In what respects to the latter, the weekend studied constitutes an exception to the above (in point A (PP_A in figure 2), since a folkloric festival took place on Saturday, January 30, at 7 hours. On the other hand, the parks evaluated - Parque Sarita Gajardo and Parque Monumental Bernardo O'Higgins - concentrate their visitors on Saturdays and Sundays.

When relating the comfort perceived by users with the environmental and urban parameters analyzed, a statistically significant direct relationship between comfort and solar radiation (0.67) is

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obtained, which means that the greater the radiation, the greater the discomfort due to heat. In turn, the radiation is related to the sky visibility factor (0.46) and the height-width ratio (-0.2). Both relations indicate that a greater opening of the sky - caused by fewer obstacles to visibility and a ratio between the height and width of the streets in which the first does not exceed the second- allows the entry of greater solar radiation to the surface.

These parameters also relate to the number of users in each point of the public space. In the case of the height-width ratio, this relationship is direct (0.5), The higher the H / W ratio, the greater presence of users. The two remaining factors are inversely related, SVF (-0.21) and solar radiation (-0.3), which means that the greater the radiation, caused by a greater opening to the sky, the lower the number of users, as a result of the lower availability of shadows, whether they are produced by vegetation, buildings or some type of particular infrastructure.

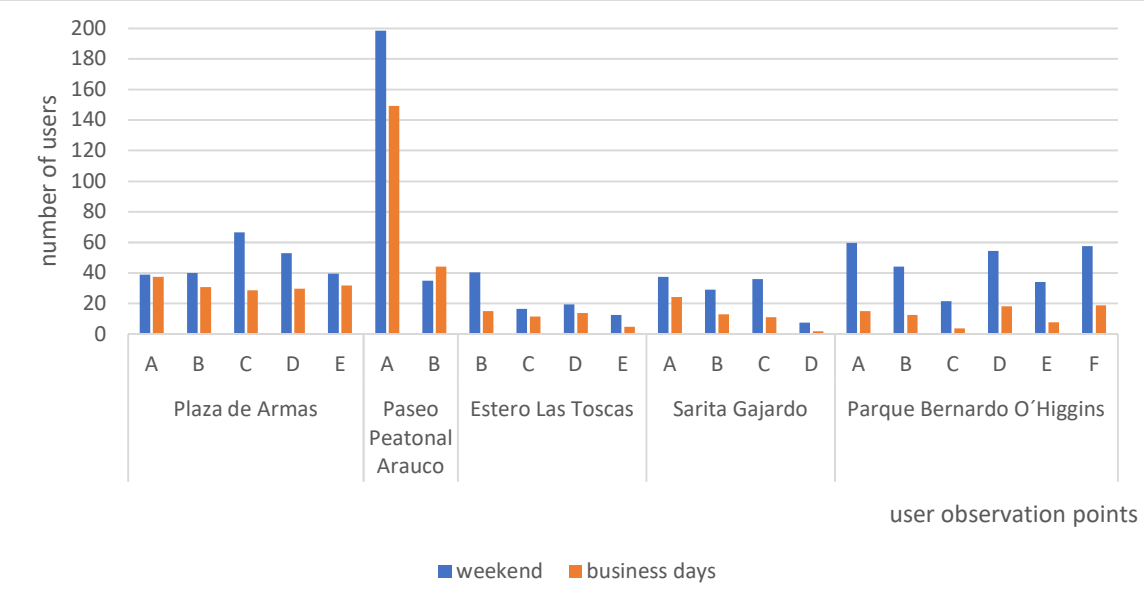

Figure 11. Frequency of users according to the moment of the week (business days/weekend)
Note: each of the visitors observation points is indicated in figure 3, using a different prefix for each public space: Plaza de Armas (PA), Paseo Peatonal Arauco (PP), Parque Estero Las Toscas (LT), Parque Sarita Gajardo (SG) and Parque Monumental Bernardo O'Higgins (BO).
Source: Own elaboration.

4. Discussion

Chillán has no local public policy regarding climate comfort and public spaces within the city. Municipal development plans and environmental ordinances of Chillán and Chillán Viejo – which make up the city- don't include this matter either. There are, however, some references in their urban planning instruments. Although both municipalities have valid Communal Regulatory Plans (PRC) - Chillán Viejo since 2012 and Chillán since 2016 – they don't provide guidelines for the

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articulation of public spaces and existing green areas. Regulatory plans set criteria for density of occupancy and maximum building heights, which can affect the urban micro-climate. Likewise, they determine the location of public spaces and green areas, as well as the allowed or forbidden uses in each of the different zones defined by them.

The density of ground occupation and building height directly affect the degrees of sky openness and the availability of shade and therefore, the comfort of public spaces. There is a gap between the allowed occupancy coefficients in the areas where the selected public spaces are located, and the current characteristics of the neighboring blocks; thus, presenting a wide margin for increasing densities. For example, the Regulatory Plan of the Commune of Chillán allows a coefficient of 1 - that is to say 100 % of the properties- for Area N° 1 (ZC-1) neighboring Plaza de Armas and Paseo Peatonal Arauco and the currently average coefficients amount to 60%.

Seemingly, there is a gap between maximum heights allowed and current building heights. The prevalence of low structures could be explained by the greater costs involved in building high structures in a country with strong seismicity. The Chillán Viejo Regulatory Plan (PRC) allows maximum heights ranging from 14 meters in the mixed use zone N° 1 (commercial and residential area), to 20 meters in the mixed use zone N° 2. However, current structures on the blocks surrounding Parque Monumental Bernardo O'Higgins don't rise over 5 meters. At present, Chillán is a low-rise city. If its structures rose to the permitted maximum, the height-to-height ratio (H / W) and the sky visibility factor (SVF) would be modified.

This (See Table 4) would cause a decrease in direct solar radiation and might favor comfort in public spaces during the summer. Nevertheless, it would have negative effects on temperature and comfort in winter. Therefore, the increase in vegetation (particularly deciduous vegetation) is the best alternative to modify sky visibility and cool the city in summer,

Table 4. Criteria set by Communal Regulatory Plans in public spaces and adyacent areas

Public space	Zone	Allowed uses *	Prohibited uses	Mínimum property area m²	Occupancy coefficient	Maximum height (m)
Plaza de Armas Paseo Peatonal Arauco	ZC-1 Central zone 1	U1, U2, U3, U4, U5, U7, U8, U10, U11, U13, U14, U15	U6, U9, U12, U16, U17	600	1	15 - libre
Estero Las Toscas	ZC-2 Central zone 2	U1, U2, U3, U4, U5, U7, U8, U10, U11, U13, U14, U15, U16	U6, U9, U12, U17	600	0.9	7 - 30
	ZM-2 Mixed zone 2	U1, U2, U3, U4, U5, U7, U8, U10, U11, U13, U14, U15, U16, U17	U6, U9, U12	500	0.8	7 - 20
Sarita Gajardo	ZH-3 Residential zone	U2, U3, U4, U5, U7, U8, U10, U11, U13, U14, U15	U1, U6, U9, U12, U16, U17	150	0.6	15
Parque M. Bernardo O´Higgins	ZH-1 Residential zone	U1, U2, U3, U4, U5, U8, U10, U11, U13, U14, U15, U16, U17	U6, U9, U12	200	0.6	15
	ZM1 Mixed zone 1	U1, U2, U3, U4, U8, U10, U14, U15, U17	U5, U6, U9, U11, U12, U13, U16	300	0.8	14
	ZM2 Mixed zone 2	U1, U2, U3, U4, U5, U8, U10, U11, U13, U14, U15, U17	U6, U9, U12, U16	300	0.8	20

Note: * Allowed uses; U1: scientific; U2: commerce; U3: religion and culture. U4: sports; U5: education; U6: energy; U7: public space and green area; U8: recreation; U9: industry; U10: residential; u11: health; u12: sanitary; U13: security; U14: services; U15: social; U16: workshops and industrial warehouses, and U17: transportation.

On the other hand, even though both Chillán and Chillán Viejo are certified as “excellent” by the National System of Environmental Certification of Municipalities (SCAM), neither has planned concrete actions for the improvement of public spaces and green areas of municipal domain.

Likewise, at the national level, there are no explicit guidelines to improve micro-climatic conditions in public outdoor spaces. The National Urban Development Policy (PNDU, 2014) includes, in the area of social integration, two objectives regarding this matter. One seeks to "insure equal access to urban public goods", and the other refers to the articulation of public spaces, by the interconnection of parks and green areas, generating tours and circuits, both at the neighborhood and city scale. Undoubtedly these proposals are very important to move towards more sustainable public spaces, but should be complemented with territorial policies that lead to the increase of public spaces with improved micro-climatic conditions and adequate relationships with their urban surroundings. The achievement of these goals depend on its coordination with urban planning and regulatory instruments, at the intercommunal, communal and sectional levels, as well as with regional urban development plans. It is also important to propose innovative urban designs that are appropriate to the geographical reality of the city.

In this context, the document "The Human Dimension in Public Space. Recommendations for Analysis and Design" of the MINVU (2017), recently published by the Program for Public Spaces of the Ministry of Housing and Urban Development, provides 80 design guidelines. It declares that “the functionality of a public space, its dimensions, climatic comfort and activities have a greater weight in the experience of its visitors than the formal characteristics typically privileged by many architects. The shape of the space must be subject to comfort and human activities, not the other way around”. Regarding Chilean reality, these principles are indeed a great change and should inspire future interventions in public spaces, following the example of those cities with wider experience in climate-sensitive urban design.

Finally, it is worth mentioning the National Plan for the Adaptation to Climate Change and its corollary, the Sector Plan for Adapting Cities to Climate Change (Ministry of the Environment, 2017). The latter, which has recently concluded a citizen consultation process, is the document that, once approved, will guide municipal action regarding climate within the city; however, the plan is focused on the risks involved in climate change; the concept of urban climate is absent and hence, the concern for temperature is restricted to the events of heat and cold waves, which are usually recorded by meteorological stations installed outside the urban limits, such as the station Bernardo O'Higgins in Chillán. It is essential that planning instruments consider urban climatology in order to understand the necessary relationships between the characteristics of planning, urban design and climate, which, in turn, affect thermal comfort and climate quality in each sector of the city.

5. Conclusion

The city of Chillán has few green areas whose joint surface only amounts to 1.7 m^2 per inhabitant. In addition, it has an urban morphology of low height and is little wooded, which allows a greater insolation of open areas, affecting the climate quality of public spaces, especially during hot summers and episodes of heat waves, such as those observed in recent years. Paseo Peatonal Arauco revealed the worst comfort conditions since it is an impervious urban canyon with very little shade.

The distribution of users in each public space throughout the day depends on its social function and the availability of sun and shade; in the recreational parks, the largest number of users were observed in the evening, from 18 hours onwards, when temperature decreased and shade availability increased. In contrast, visitors in Arauco walkway and Plaza de Armas distributed more homogeneously during the day, since these spaces are associated with the commercial activities and various city services. In all cases, around 75% of users looked for the shade. The city has high density neighborhoods and few vegetated public spaces. Consequently, parks have become the only option for facing extreme heat events (residential air cooling systems are still relatively uncommon).

Local public environmental management should pay attention to the complex relations between urban climate, public spaces and thermal comfort which directly affect the quality of people's lives. This is particularly important given the increasing episodes of high temperatures and intense heat waves occurred in the city of Chillan in recent summers, which are related to urban heat islands and climate change.

Planning and urban design proposals to improve comfort and climatic quality in public spaces are crucial elements. Undertaking actions adjusted to local climate will result in a better quality of life for the population.

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