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Research article

Effects of urban green areas on air temperature in a medium-sized Argentinian city

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Abstract: Urban climate is the result of both atmospheric and geographic factors affecting a region, as well as the morphology, structures and human activities in a city. Urban vegetation in particular affects this climate at a local scale and provides many other social, economic and ecological benefits. Thus, it is important to explore the effects of different green areas used for urban and periurban agriculture and forestry activities (UPAF) on daily atmospheric temperature and the required degrees of cooling or refrigerating temperature. Comfort temperatures were defined using a range 18–24 °C and analyzed using actual measured as well as forecasted temperatures using a future scenario. Actual temperatures were recorded from September 2013 to August 2014 using digital sensors across eight sites in Rosario, Argentina: three in the central core with no vegetation, one in the central core with street trees, one in an urban agriculture site, one in a public park and two in periurban agricultural areas. Results show that air temperature in the central core with no vegetation were higher than those in other sites with vegetation during day and night, with the exception of the temperatures measured at the central core site with street trees. Findings also show that temperature effects in urban agricultural gardens of approximately 0.2 ha were similar to those of gardens and public parks 2–3 ha in size. Three UPAF types were classified according to cooling degree days, which decreased in order from (1) central core with no trees; (2) central core with street trees and public parks; and (3) urban and periurban agriculture areas. Conversely, the opposite trends for heating degree days were found. Results from this study can be used for integrating UPAF measures into climate change mitigation and urban planning policies in medium-sized cities in the developing world.

Keywords: climate change; cooling requirements; heating requirements; green infrastructure; urban agriculture; urban forestry; urban heat island

1. Introduction

Climatic conditions across large areas of the Earth's surface are influenced by atmospheric factors such as solar energy and the Earth's rotation, shape and dimensions. Geographic factors can also affect these dynamics that lead to existing climate variability [1]. At the local scale, the influences of these geographical factors are often more influential, generating microclimates with specific characteristics that differentiate them from overall regional climates. Urban climates can thus be considered a microclimate that results from the combined effect of buildings and human activities that can cause a noticeable effect on the thermal energy dynamics of a city [2]. Considering that approximately 70% of the world population will be living in cities by 2050 [3], and that cities currently consume approximately 75% of the total energy demand [4]; urban climate has been receiving much recent attention by the scientific community. Climate modeling based studies [5] have documented the effect of an increase in extreme events on increases in extreme high temperatures as well as decreases in extreme low temperatures.

The urban heat island (UHI) effect can be defined as the development of higher temperatures in the city core compared to adjacent rural areas [6], and is considered a unique climatic modification that has resulted as urban areas expand into the adjacent rural countryside. Urban morphology such as impervious area, building height [7] and distances among them [6,8], type of construction materials [9], heat released by human activities *per se* [6], and topography [10] are the main influences that shape the UHI effect. Given the importance of global warming effects on human well-being [11], awareness of UHI is increasing and is focused on developing local strategies to minimize its effects [12]. Measurement of the UHI is however not trivial since by definition, the meteorological stations are placed mainly in rural areas and few cities in developing countries have available high quality spatial-temporal data required for such studies. Additionally, the higher temperatures within cities increase building cooling energy demand, resulting in higher anthropogenic gas emissions that the most recent Intergovernmental Panel in Climate Change (IPCC) Report containing relevant data for Argentina [11] considers a leading cause of climate change.

Local urban climate models have been developed by interdisciplinary research teams of meteorologists, built environment and energy scientist, public health specialists, planners, urban and building designers [13], and are becoming useful tools for cities trying to adapt to global warming. In urban subtropical and temperate areas, Fisher et al. [14] described that the UHI effect is most pronounced at night. Possible and unprecedented increases in energy demand in developing countries from the sole use of air conditioning systems have also been reported by Sivak [15]. Elsewhere, analyzing energy consumption and related carbon dioxide (CO_2) emissions for heating and cooling of a London UK office building, Kolokotroni et al. [16] concluded that energy cooling demands will cause a five-fold increase by 2050. These temperature effects are not trivial as increased urbanization and temperatures can affect human well-being and periurban ecosystems particularly in developing countries [13,14,17].

In Argentina, a developing Latin American country, urban climate has been analyzed in several cities. A preliminary analysis conducted in Rosario [18] showed that the UHI effect reached a maximum of 7.3 °C between 07:00 and 08:00 hours in February 1991, with the highest values being related to clear sky conditions and south-southeast winds. Urban heat islands were identified for two contrasting Argentine cities: highly populated Buenos Aires (34°35′S 58°22′W) and less populated Río Gallegos (51°38′S 69°14′W) [19]. Despite being characterized by high vegetation and tree cover in an arid area, the existence of UHI conditions in the medium-sized city of Mendoza (32°53′S; 68°49′W, approximately 115,000 inhabitants) has been determined [20] as well as in Córdoba, a city of 1.3 million inhabitants and surrounded by small mountains (31°25′S 64°11′W) [21]. In Santa Rosa (36°37′S 64°17′W), a study showed that inhabitants could not live during the summer months with acceptable thermal comfort conditions without some type of energy-based refrigeration [22].

It is well known that vegetation can mitigate increased urban temperatures in several ways such as: evaporative cooling or the energy used for transpiration instead of heating the air, through shading by trees and tall vegetation that directly shadow and intercept solar radiation and by albedo effects that alter the reflection and absorption of solar radiation [23-25]. Although improved urban planning approaches and highly reflective construction materials can be used in building roof and walls to reduce the UHI effect, vegetation management can also reduce the negative effects of increased urban temperatures in cities [24,25]. The physical mechanisms and thermal balances behind these effects are well explained in several studies [7,8,14]. Specifically, vegetation such as agricultural areas, green areas, gardens, parks and grass, shrub and tree cover can reduce the UHI effect [17,24,25].

The interest in urban agriculture, defined as production of crop and livestock goods within a city's boundaries [26], is growing as a way of addressing urban food security problems [17]. In addition, urban and periurban agriculture and forestry (UPAF), or the management of trees and woody plants in and around cities, are two documented strategies for mitigating climate change effects and for providing other social, economic and environmental co-benefits to society that are referred to as ecosystem services [17,27,28]. But, further research is needed on the role UPAF strategies in developing countries can have on reducing climate change effects and yet provide other co-benefits and ecosystem services. Given the existing and projected effects of urban temperatures and the documented mitigating effects of UPAF on these temperatures; information on this effect is particularly pressing in Latin America. Therefore, the objectives of this study were to use Rosario, Argentina as a case study to: (i) assess the influence of different UPAF types on atmospheric temperature and its role in determining the heating and cooling energy demand and human comfort and (ii) determine increase in heating and cooling energy demand according to future climate projections in the city.

2. Materials and Methods

Rosario is Argentina's third most populous city located in a plain along the Paraná River

(32°52′18″–33°02′22″S; 60°36′44″–60°47′46″W; 22.5–24.6 m above sea level). There are about 1 million inhabitants within the city limits that encompass 178.69 km^2 and another 200,000 people reside in the periurban areas that together comprise its metropolitan area. The northeast, east and southeast of Rosario's limits (approximately 17 km) are delimited by the Parana River (Figure 1), one of the largest rivers in South America. The river with approximately 60-km wide islands and wetlands along the city, belongs to the Paraná Delta. Rosario's central core area is characterized by narrow streets 7–9 m wide and mostly 4–10 multistory buildings that are likely a major influence on the area's climate characteristics. The modern building construction in the downtown central core area began in the 1960s. This process, which was reduced significantly during the 1970s and 1980s, had new impetus during the last decades, and currently Rosario has an urban area of approximately 120.37 km^2, with only 11.27 km^2 devoted to green spaces [29].

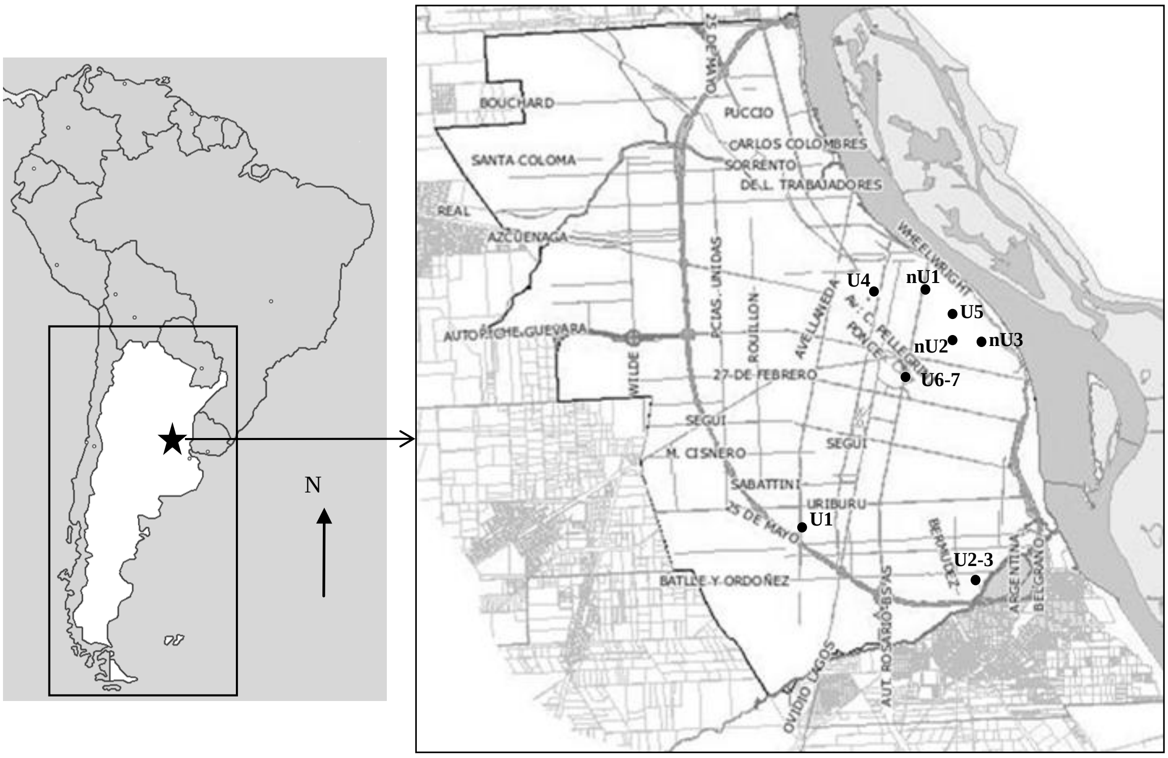


Figure 1. Argentina and the location of temperature sensor/ dataloggers within Rosario, Argentina's 179 km^2 city limits.

Mean, maximum and minimum temperatures and precipitations per season in Rosario are presented in Table 1. Data averages are over 30 years average and were provided by the Servicio Meteorológico Nacional, the Argentinean Meteorological Office [30].

Besides parks, plazas and squares typical of South American cities, Rosario is unique in that some of its parks have been dedicated to urban agriculture activities since 10 years ago and has a long tradition of treed streets and parks. These areas are referred to hereafter as UPAF areas. These urban agriculture parks were established and are maintained by technical specialists in the municipality as well as by unemployed citizenry using agro-ecological farming techniques as both sources of food and additional income [31]. Governmental policy support for urban agriculture initiatives were a response to Argentina's 2001 economic crisis, when gross domestic product shrunk and unemployment reached levels of 25%, the rate of inflation climbed to unprecedented levels and the peso, Argentina's currency, lost 75% of its value [32].

Table 1. Mean, mean maximum and mean minimum temperatures and mean precipitation of Rosario, Argentina.

Season	Temperature (℃)			Precipitation (mm)
	Mean	Mean maximum	Mean minimum	
Summer	23.8	30.0	17.7	315.7
Autumn	17.2	23.2	11.9	273.1
Winter	10.7	16.8	5.5	80.0
Spring	17.5	23.6	11.4	264.4

Atmospheric temperatures were measured using Hobo outdoor temperature sensor/ dataloggers (five model #U23-001 and three model #U23-003 units) that were installed in different UPAF types (U1; U2; U3; U4; U5; U6; and U7) as well as in non-UPAF sites (nU1; nU2; and nU3) across Rosario (Figure 1 and Table 2). The sensor/ dataloggers were protected from rain and direct solar radiation by a double wooden structure and located 5 m above the ground that were designed for improving the protection of the instruments against solar radiation, precipitation and strong winds. The U2 and U3 sites as well as U6 and U7 were at the same site. Some sensor/ dataloggers were located beneath tree crowns in direct shade (U3 and U7), while others were outside tree crown in open sunlight (U2 and U6) (Table 2). Measurements were recorded every hour for a full year from September 2013 to August 2014. Instruments were tested and calibrated, and were determined to have a mean error of ±0.2 ℃. Similar approaches have been used in other urban climate studies [33,34], but it is noted that all sensors had the same north-facing direction. Non-UPAF sites were selected in highly populated areas with a heavy traffic flow (mainly cars and buses). Also, in Argentina, the local hour equals Universal Time minus 3 hours.

Table 2. Details and locations of the analyzed sites in Rosario, Argentina (see Figure 1).

Site	Description
U1	Periurban agriculture park
U2	Periurban agriculture park, under a tree
U3	Periurban agriculture park, 2 m outside tree dripline
U4	Urban agriculture park
U5	Under a street tree
U6	Urban park, under a tree
U7	Urban park, 2 m outside tree dripline
nU1	Non-UPAF
nU2	Non-UPAF
nU3	Non-UPAF

The mean, mean maximum and mean minimum temperatures were calculated from the instruments data set on an hourly basis according to the Southern Hemisphere's seasons: spring

(September, October and November); summer (January, February and March), autumn (April, May and June) and winter (June, July and August). Temperature range was obtained for each season considering mean maximum and mean minimum data. A *t*-test was used to determine if there were significant differences between the temperatures under the shaded tree crown at a midway point between tree stem and crown dripline and 2 m outside the tree crown's dripline (U2–U3; U6–U7; $p <$ 5%). Differences among all measured sites temperatures were established using analysis of variance (ANOVA) and Duncan's range test ($p = 0.05$).

Hourly data for all measured stations were grouped according to season and mean hourly temperatures were obtained. Mean hourly differences among non-UPAF (nU2 and nU3) and UPAF types were determined for each season and were depicted in scatter plots. Temperature differences of each season were grouped into classes, and the percentage of thermal differences in each class was then calculated.

A full mean hourly temperatures × recording sites matrix was constructed for each season and analyzed. A principal component analysis (PCA) was performed using a covariance matrix, and results were depicted using scatter plots (one per season). A nonparametric multiple response permutation procedure (MRPP) was performed to test for temperature differences between UPAF and non-UPAF sites. All multivariate analysis were done using the PCOrd program [35].

Effect of temperatures on energy requirements for cooling and heating

To estimate the effect of UPAF on energy requirements for inner ambient cooling or heating, the cooling or heating requirements (CR or HR, respectively) were considered based on [36]:

$$CR = CDH \times q \qquad \text{(Equation 1)}$$

$$HR = HDH \times q \qquad \text{(Equation 2)}$$

where:

CDH: cooling degree hours

HDH: heating degree hours

CDH/HDH: the requirements for cooling or heating (°C or K) necessary to achieve the comfort zone, were obtained using [36]:

$CDH = \sum (T_{hourly} - T_{comfort})$ for all the hours of the analyzed season

$HDH = \sum (T_{comfort} - T_{hourly})$ for all the hours of the analyzed season

q: building conductance (specific heat loss rate *W/K*)

Degree Days measure the difference among actual temperature data and a set base or thermal comfort temperature [36]. Thermal comfort zone temperature is defined as a condition in which human expresses satisfaction with the thermal environment is achieved and thus 18 ℃ for autumn and winter, and 24 ℃ for spring and summer were used.

Heating and cooling requirements were represented by CDH and HDH in order to be independent of the q specificity for every type of building. Once CDH and HDH were obtained, they were used to calculate cooling degree days (CDD) and heating degree days (HDD), where *CDD=CDH/24* and *HDD= HDH/24*. All analyses were for one full year of actual measured data and an additional analysis using projected or forecasted temperature from a future scenario. For the future scenario HDD and CDD were calculated for each season by considering a 1-℃ increase. Differences among CDD and HDD for UPAF and non-UPAF conditions (considering these sites as replicates of UPAF or non-UPAF conditions) were determined using ANOVAs and Duncan tests (p = 0.05). Except for multivariate analyses, all statistical analysis were done using the Infostat program [37].

A 1- ℃ increase in the future scenario analysis was assumed based on [38] who report a mean annual warming between 0.1–1 °C between 1960–2010 for Rosario and regional climate modeling for Argentina that reports mean annual temperatures increase of 2.5 ℃ for IPCC emissions scenario B2 [39], and 3.5 °C for the IPCC emissions scenario A2 [39] for the period 2081–2090 relative to the 1981–1990 decade [40]. For the A2 scenario, warming can reach up to 4 ℃ during the spring months. Based on this, a 1 ℃ increase can be considered representative of future climatic conditions in Rosario, Argentina over the next 25 years (i.e. present to 2038) assuming: extreme greenhouse gas (GHG) emissions or over the next 50 years (i.e. present to 2063), and moderate GHG emissions and no substantial annual seasonality changes during both time periods [38,40]. To better assess the effect of UPAFs on HDD and CDD in the future, it was assumed that the effect of green areas will remain consistent in future warming climates. Such assumptions should be tenable given the complexity of urban areas and climate change dynamics. Indeed the IPCC regularly uses these types of assumptions in their climate change scenarios [11,17,39].

3. Results and Discussion

Mean temperatures of UPAF sites were not statistically different ($p < 0.05$) in every season of the year, except U5, which showed a lack of variability despite being at a suburban area (U1, U2 and U3) or within the city (U4, U6 and U7). Non-UPAF sites showed a different pattern where: nU3 means were statistically different than nU1 and nU2 ones, probably due to high building density and particular urban morphologies, specifically urban street-building canyons [6] (Table 3).

Non-UPAF urban sites had higher mean temperatures than UPAF sites during both spring and summer, a similar trend presented as in smaller Mediterranean cities [34]. The low ΔT in nU3 site during autumn could be the result of an increase in shading of high buildings in the area and the lower height of the sun angle. U5 had a very low temperature range during autumn and winter, probably because trees receive and absorb energy from the buildings, producing long wave irradiation and reflected radiation, and preventing temperature drop, i.e. producing a natural greenhouse effect [34], as will be evident in the figures presented in later analyses.

Temperature differences among sites directly under the tree crowns or 2 m outside the tree's crown were negligible in UPAF sites (U2 and U3; U6 and U7) (t Test, $p > 0.05$), probably because air is heated by irradiation from the ground and not by solar energy. This could also be a result of soil-water and vegetation conditions under and outside the tree crown being similar, and thus not presenting different vegetation (i.e. park soils are mostly wet year round from irrigation) irradiative balances as would be observed in impervious covers with concrete or asphalt.

In spring and summer, minimum temperatures in UPAF sites were at 06:00 hours with the exception of U5 which had a 2-hour delay, while in non-UPAF sites minimum temperatures were 1 or 2 hours later (Figure 2). The opposite trend was depicted by the maximum temperature values: they were earlier in the day in non-UPAF than in UPAF sites.

In spring, non-UPAF sites reached higher temperatures than UPAF ones (Figure 2a). During evening hours, U5 remained with higher temperatures than the other UPAF and non-UPAF sites. U3 showed the lowest temperatures in evenings with a minimum value at 06:00 hours during spring and summer and 1 or 2 hours later during autumn and winter, respectively. All UPAF sites showed similar trend during summer (Figure 2b), with U5 and nU3 denoting the highest evening values.

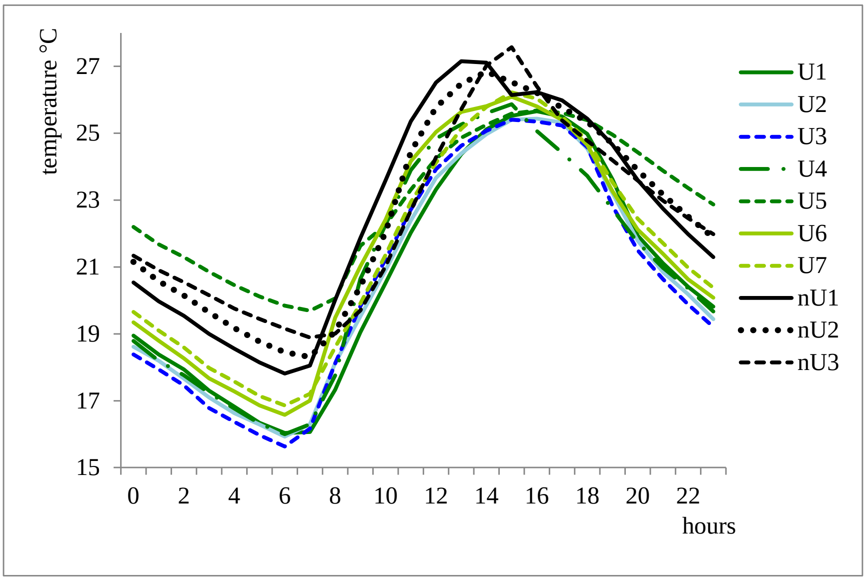
Table 3. Mean (Tm), maximum (Tmax) and minimum temperature (Tmin), and temperature range (ΔT) recorded in the different sites in Rosario, Argentina (U1–U7: UPAF sites; nU1–3: non-UPAF sites; for each variable, values followed by the same letter show no statistical differences).

Site	Spring				Summer			
	Tm	Tmax	Tmin	ΔT	Tm	Tmax	Tmin	ΔT
U1	20.8 a	26.6 a	15.7 ab	10.9 c	25.1 a	30.6 a	19.9 ab	10.7 c
U2	20.9 a	26.4 a	15.6 ab	10.8 c	25.2 a	30.6 a	20.1 ab	10.5 c
U3	20.8 a	26.5 a	15.4 a	11.1 c	25.1 a	30.6 a	19.9 a	10.7 c
U4	21.3 a	26.8 ab	16.0 ab	10.3 c	25.7 a	30.8 a	20.6 ab	10.2 c
U5	23.8 b	26.4 a	19.7 e	6.62 a	25.1 c	30.3 a	24.3 d	6.05 a
U6	21.5 a	27.0 ab	16.2 ab	10.8 c	26.8 ab	31.1 a	20.7 ab	10.5 c
U7	21.5 a	26.9 ab	16.4 c	10.5 bc	25.7 ab	31.1 a	21.0 b	10.1 c
nU1	22.6 b	28.1 b	17.5 c	10.7 c	27.0 c	32.6 b	22.a c	10.6 c
nU2	22.6 b	25.5 ab	18.1 cd	9.4 b	26.7 bc	30.2 a	22.6 c	8.6 b
nU3	22.7 b	28.4 b	18.9 de	9.3 b	28.4 d	34.1 c	24.3 d	9.7 a
Site	Autumn				Winter			
	Tm	Tmax	Tmin	ΔT	Tm	Tmax	Tmin	ΔT
U1	17.5 a	22.2 b	13.3 ab	8.9 cd	13.2 a	18.4 b	8.4 a	10,1 cd
U2	17.6 a	22.4 b	13.2 ab	9.2 cd	13.2 a	18.8 b	8.0 a	10.9 de
U3	17.6 a	22.7 b	13.0 a	9.7 d	13.1 a	19.4 b	7.6 a	11.8 e
U4	17.9 a	22.1 b	14.4 c	7.7 b	14.0 a	18.9 b	10.0 c	8.8 b
U5	20.1 b	22.9 b	18.0 e	4.9 a	15.8 b	22.0 e	11.4 d	10.6 de
U6	18.0 a	22.9 b	13.8 abc	9.11 cd	13.5 a	19.1 b	8.8 ab	10.3 cd
U7	18.1 a	22.7 b	14.3 bc	8.4 bc	13.7 a	18.6 b	9.6 ab	9.0 b
nU1	19.5 b	24.5 c	15.6 d	8.9 cd	15.1 b	20.6 cd	11.38 d	9.3 bc
nU2	20.0 b	25.6 c	16.3 d	9.3 cd	15.6 b	21.5 de	12.0 d	9.6 bc
nU3	18.0 a	20.2 a	16.1 d	4.1 a	13.3 a	15.1 a	11.6 d	3.6 e

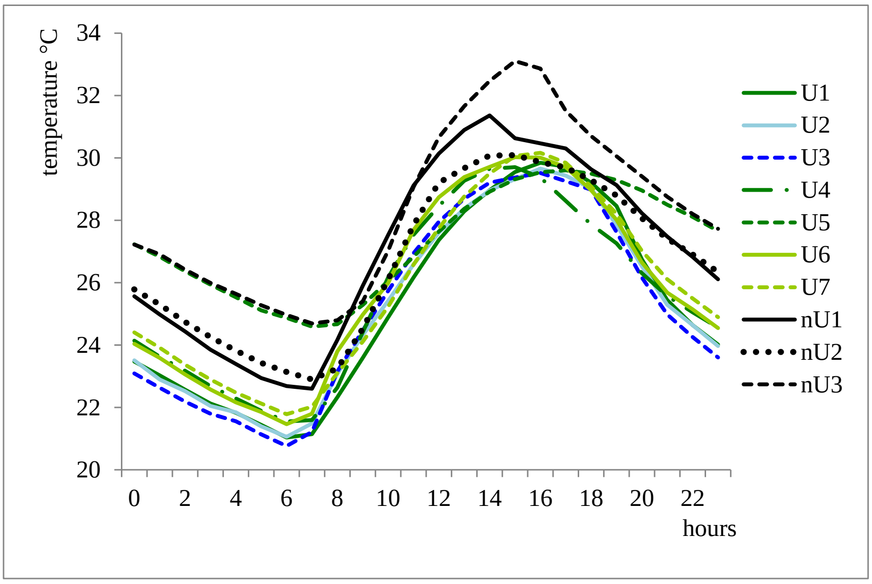
A delay in minimum and an advance in maximum temperatures was still evident along the cold seasons in non-UPAF sites with respect UPAF ones, with the exception of nU3. The high thermal capacity of the building materials likely caused heat inertia that delayed minimum temperatures [34] and in the afternoon, long shadows determined earlier maximum temperatures, when the sun continues warming UPAF sites. Except U5, all UPAF sites were almost coincident along autumn (Figure 2c); nU1 and nU2 had the highest maximum temperatures and nU3 the lowest, at midday hours. During winter (Figure 2d), U5 maintained the temperature at night, while all other UPAF sites had the same pattern and nU1 and nU2 had the highest temperatures.

Peaks of highest temperatures were registered at 15:00 hours during spring and summer and 1 hour before in autumn and winter (Figure 2). Spring and summer highest temperatures were recorded in nU3 while during autumn and winter nU2 reached the highest temperature values. Therefore, nU2 and nU3 were considered non-UPAF reference temperature stations in order to compare with UPAF locations during the cold and the hot seasons, respectively.

(a)



(b)



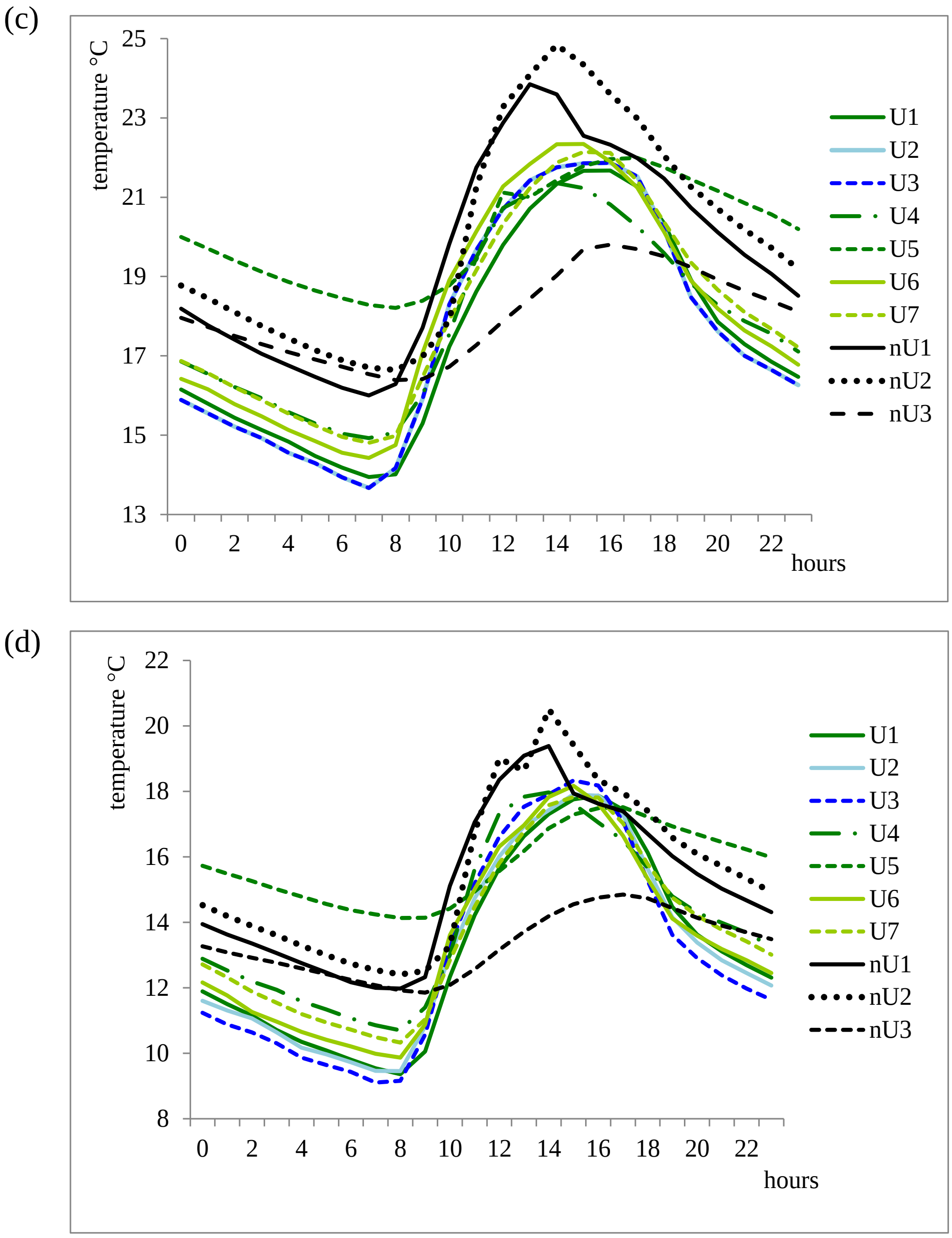


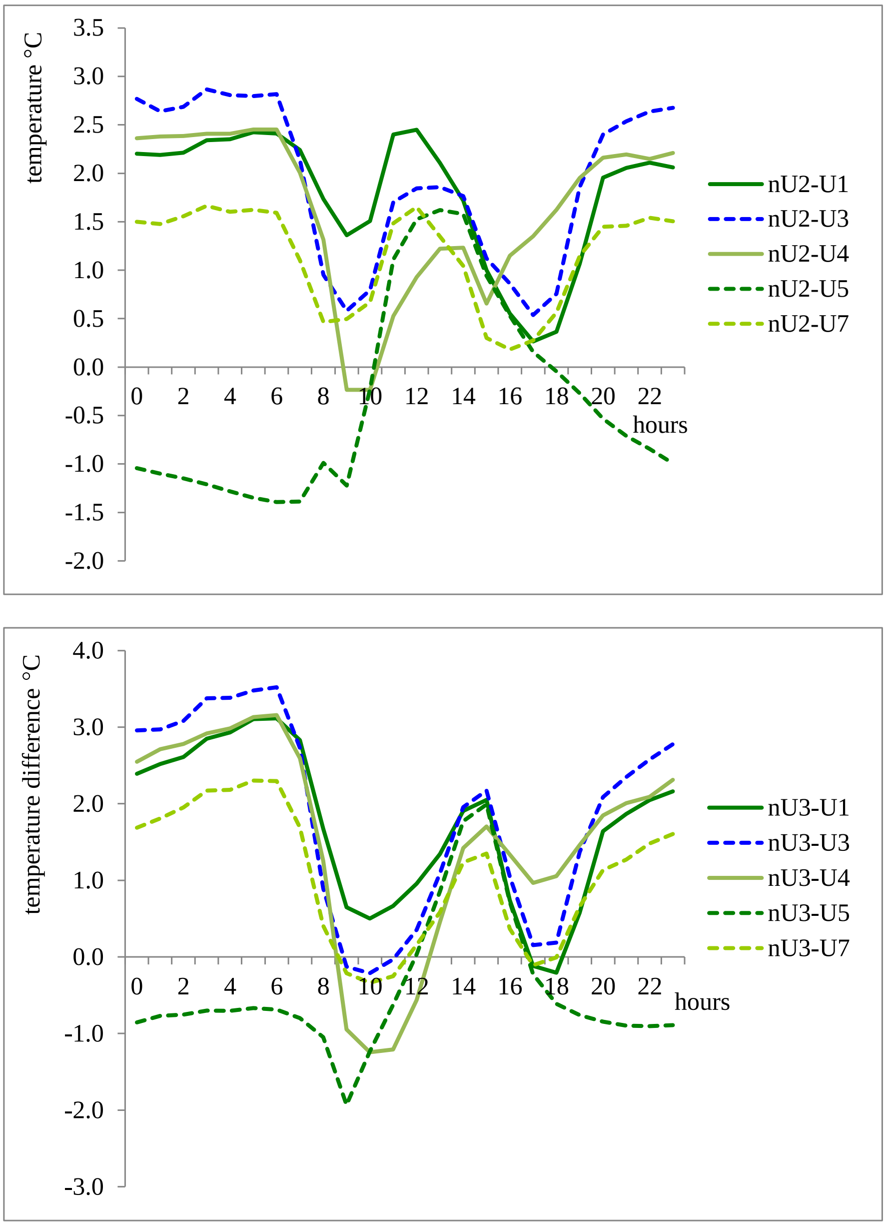
Figure 2. Mean temperature values during the day in the different locations in Rosario, Argentina in spring (a), summer (b), autumn (c) and winter (d).

Mean hourly air temperature differences, with respect to nU2 and nU3, exhibited wave-like behavior and during spring presented two daily minimums, the first between 09:00 and 12:00 hours, and the second between 15:00 and 18:00 hours. The two minima of nU3 and UPAF sites occurred also in summer, and besides some differences with nU2, the same behavior was repeated throughout the year. During the initial morning hours, non-UPAF environment reacted slowly to the solar radiation compared to UPAF environment [31]. The second minimum could be due to earlier shadows of the high buildings in non-UPAF sites than UPAF.

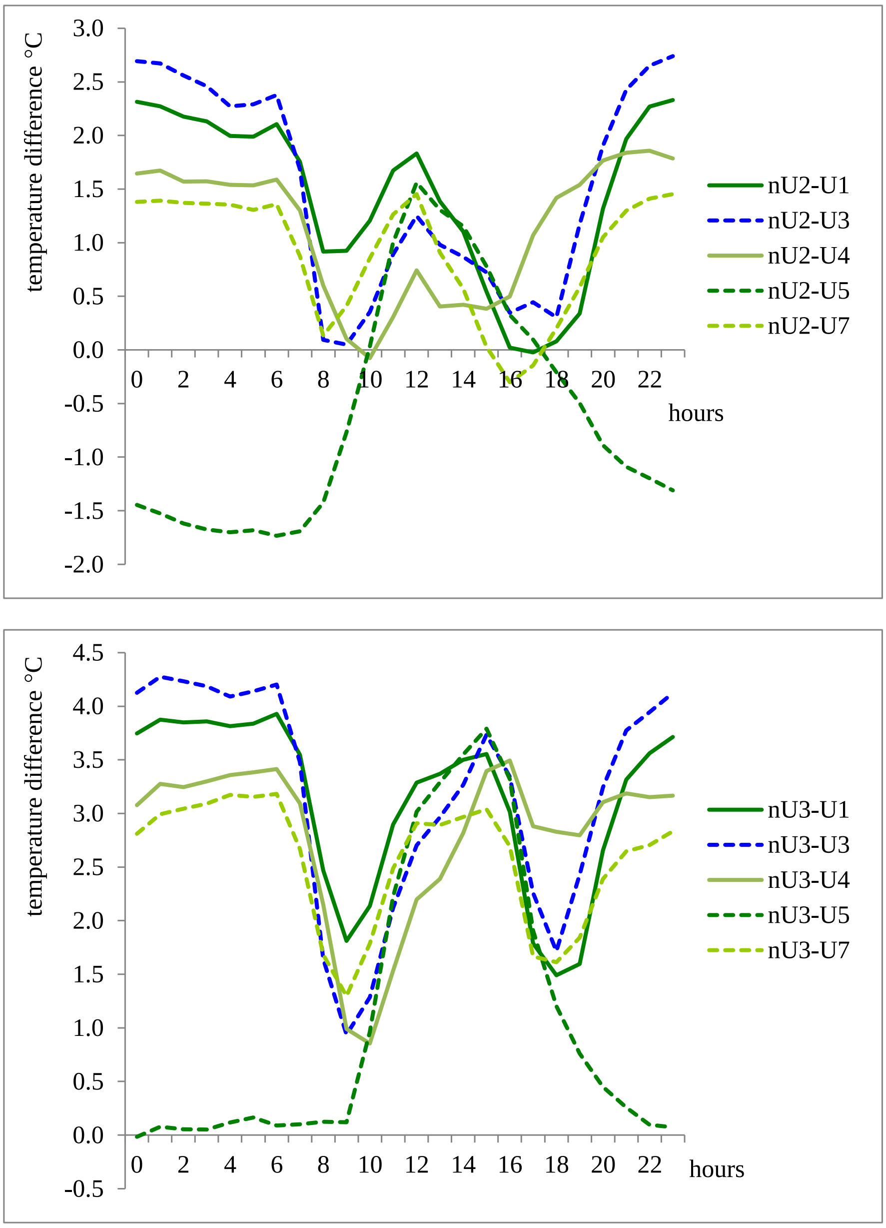
Air temperature in nU2 and nU3 was always higher than in UPAF sites, regardless of day and night and season (Figures 3a–d), except in U5 during early in the morning and late night, as it was previously shown in Figure 2, and sometimes during the two daily minimums. One explanation for this particular U5 behavior is tree transpiration where relative humidity reacts with and absorbs heat released by the buildings resulting in an increase in air temperature beneath them. On the contrary, UPAF sites have cooling effects during day and night as well, except at U5.

Both non-UPAF sites had a different behavior during the cold seasons, with nU2 showing an autumn pattern very much like the warm period while nU3 had lower temperatures during daylight hours which can be a results of its placement under complete shade during most of the day due to high buildings surrounding it. Seasonal analyses show that the mean hourly air temperature differences intensity is strongest during summer (4.3 ℃ comparing nU3 with U3).

(a)



(b)


temperature difference °C
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hours
nU2-U1
nU2-U3
nU2-U4
nU2-U5
nU2-U7
temperature difference °C
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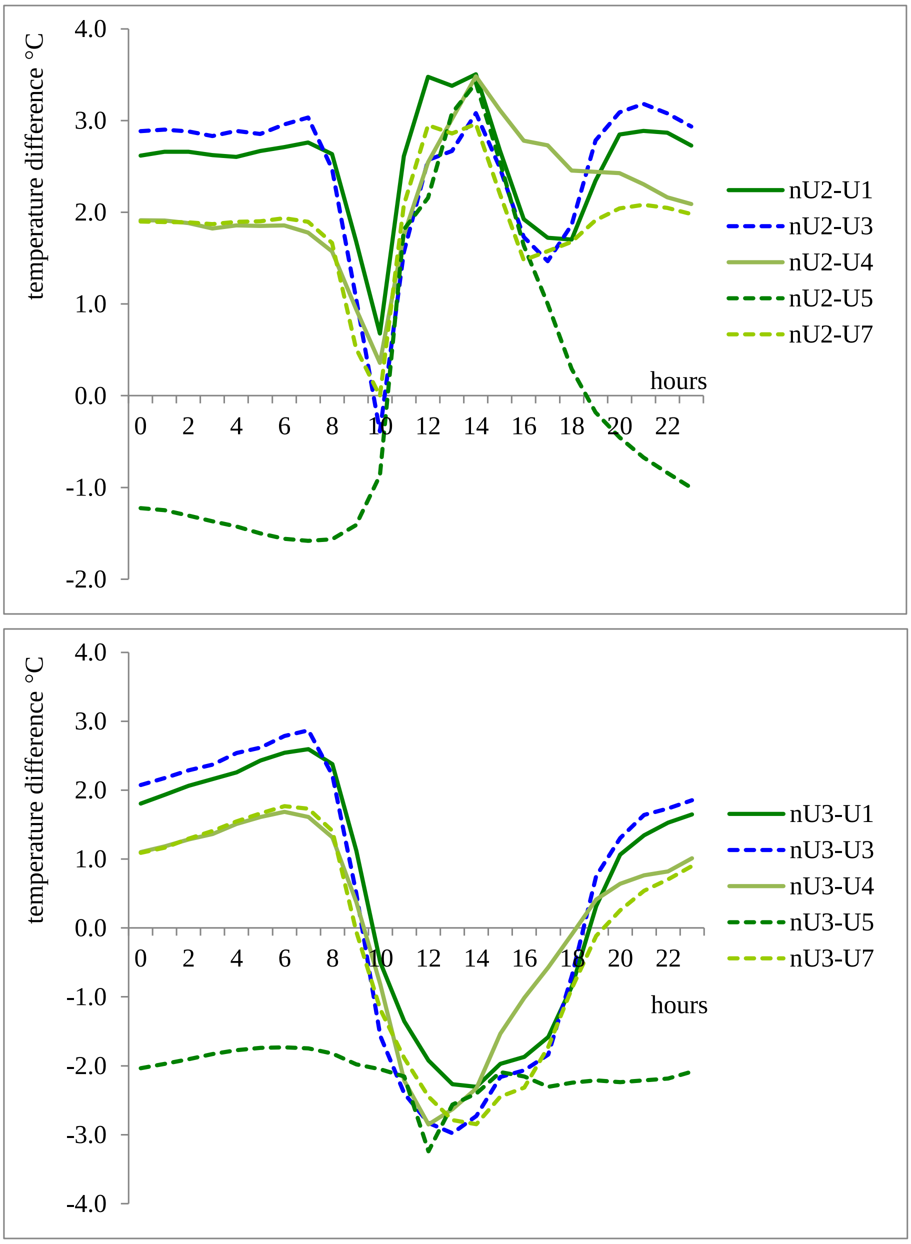
nU3-U7

(c)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-2.0
-3.0
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temperature difference °C
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nU3-U7

(d)

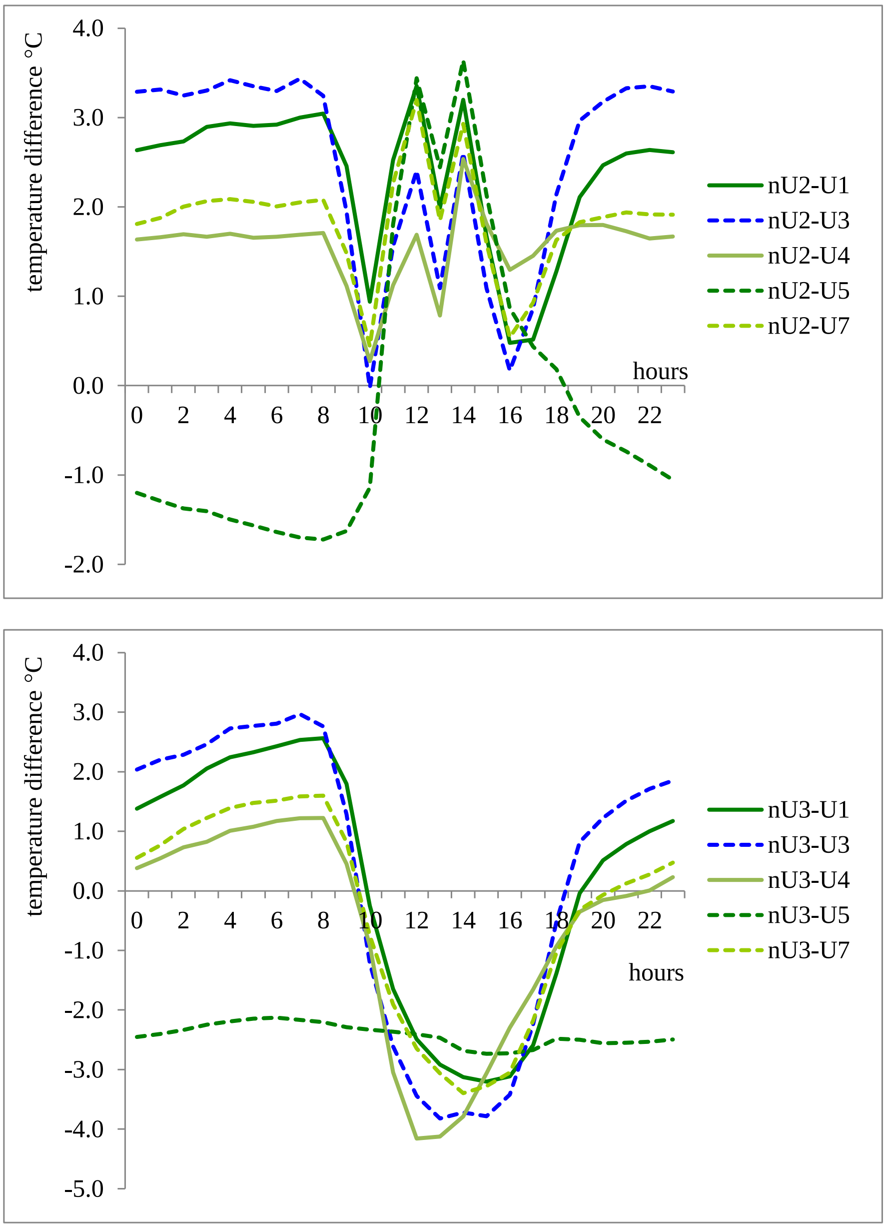
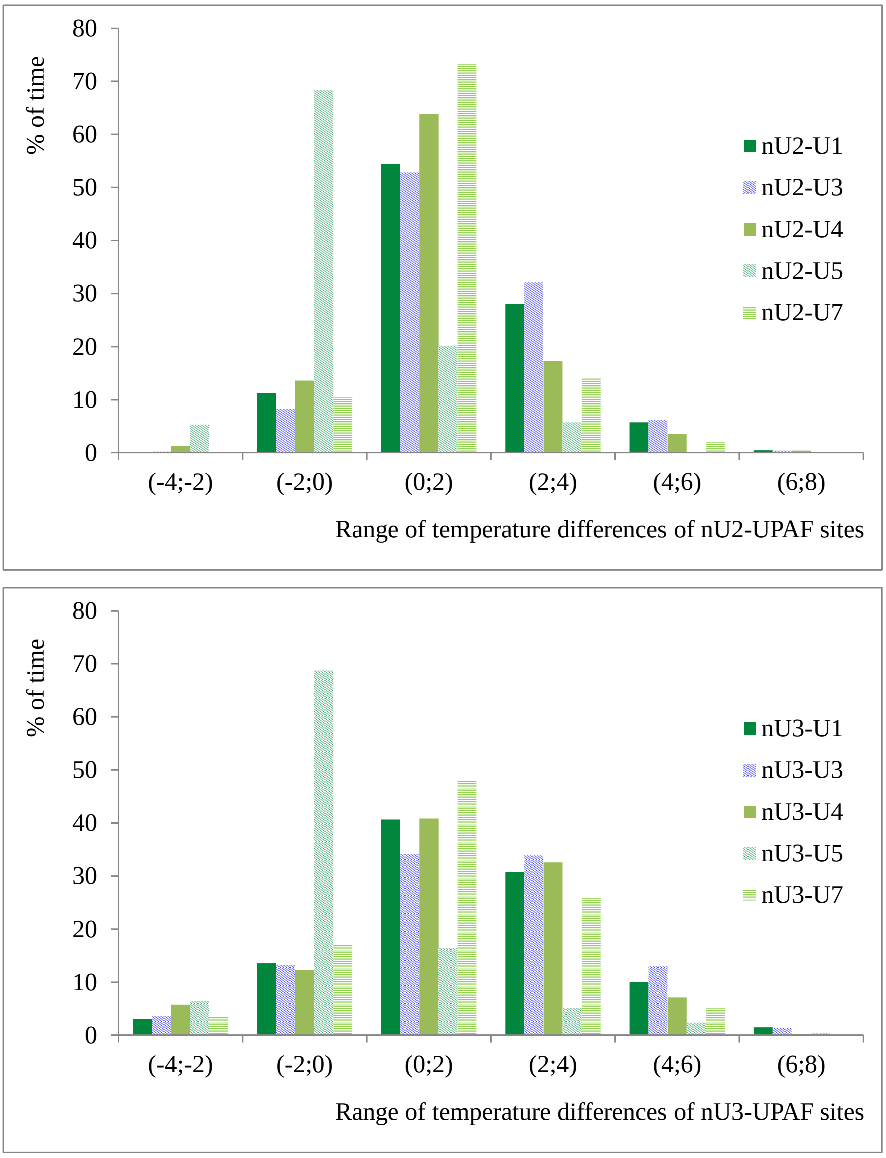


Figure 3. Mean temperature differences between non-UPAF sites (nU2 and nU3) and UPAF sites during the day in spring (a), summer (b), autumn (c) and winter (d) in Rosario, Argentina.

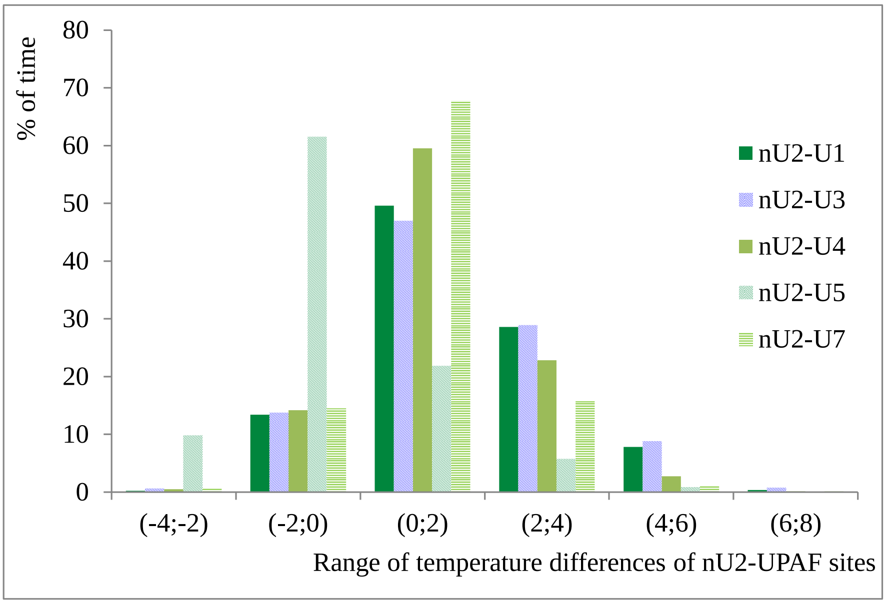
Temperature differences between non-UPAF and UPAF sites reached maximum values of 8.1, 8.1, 9.7 and 10.6 ℃ in spring, summer, autumn and winter, respectively (Figure 4). The increase of these differences in autumn and winter is evident and coincident with other Argentine cities such as Buenos Aires [41]. However, the population in Buenos Aires and its metropolitan area is one order of magnitude greater. Higher frequencies of negative values were registered mainly in the hours of minimum differences shown in Figure 3 and ranged from −2 to −4 °C.

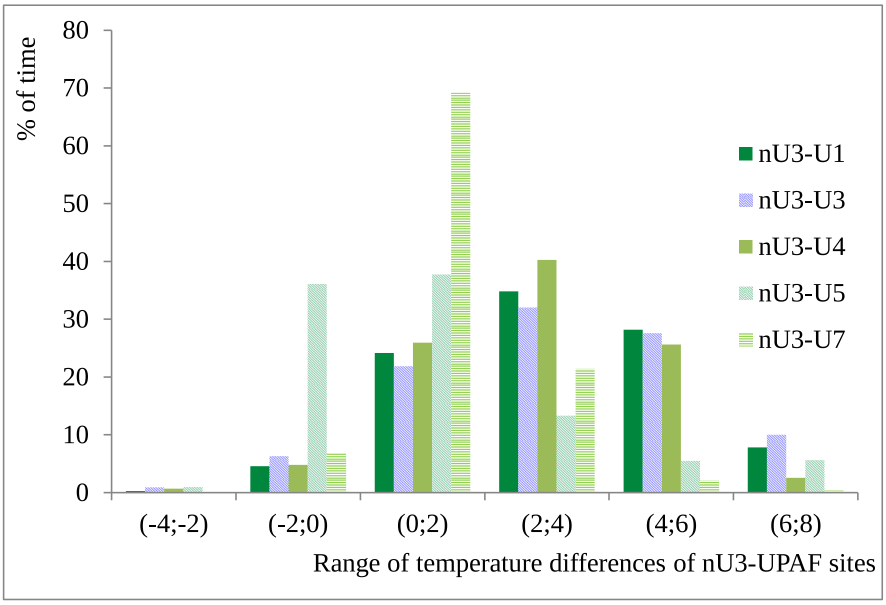
Overall, the UHI effect was evident during the warm seasons, showing the higher frequencies of positive non-UPAF/ UPAF differences (in nU2 as well as in nU3), while along the cold period non-UPAF sites showed different patterns: nU2 kept the heat and nU3 clearly resembled an urban cold island (UCI) during the day (Figures 3c–d) [42] because the oblique solar elevation angle results in interactions with taller buildings and reduces the intercepted and stored solar energy. The highest percentage of differences between nU2, nU3 and U5 was close to zero and often fell into the range of negative values.

(a)

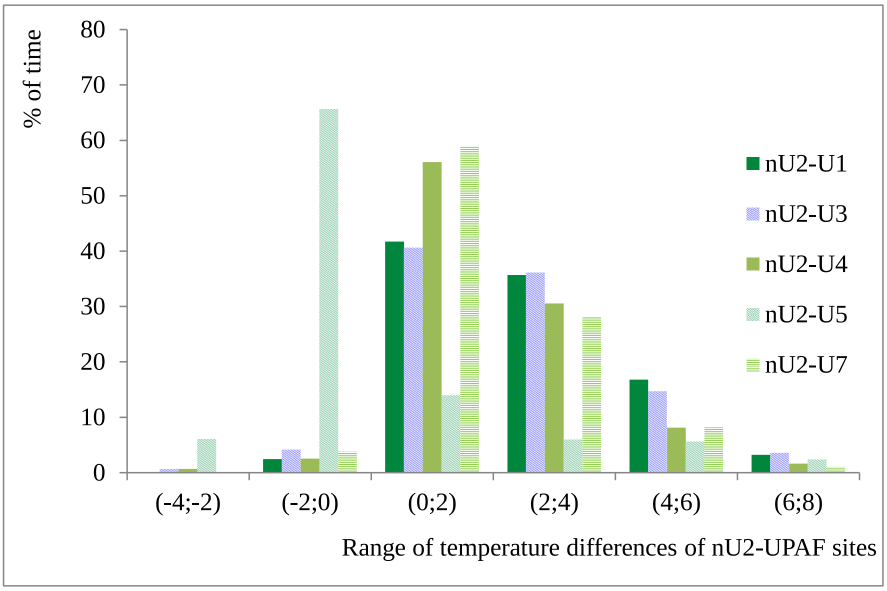


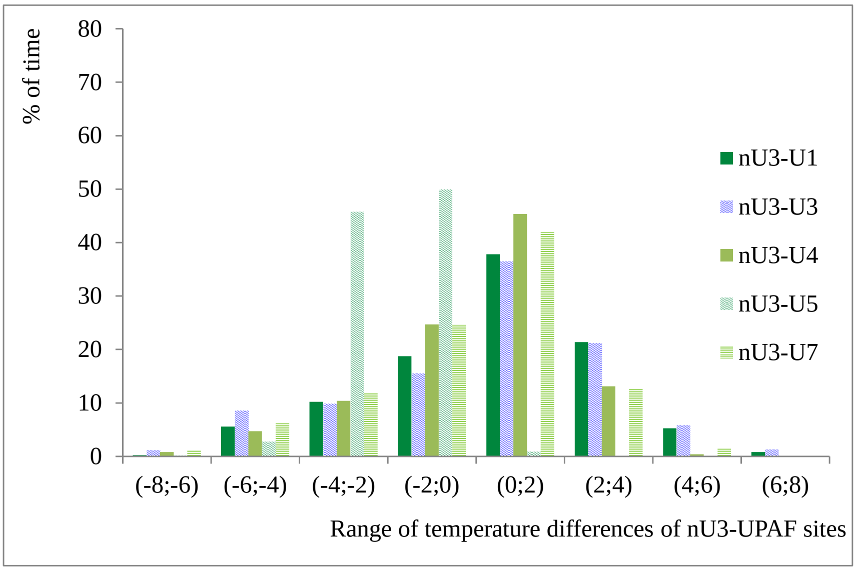
(b)


% of time
80
70
60
50
40
30
20
10
0
nU2-U1
nU2-U3
nU2-U4
nU2-U5
nU2-U7
(-4;-2)
(-2;0)
(0;2)
(2;4)
(4;6)
(6;8)
Range of temperature differences of nU2-UPAF sites

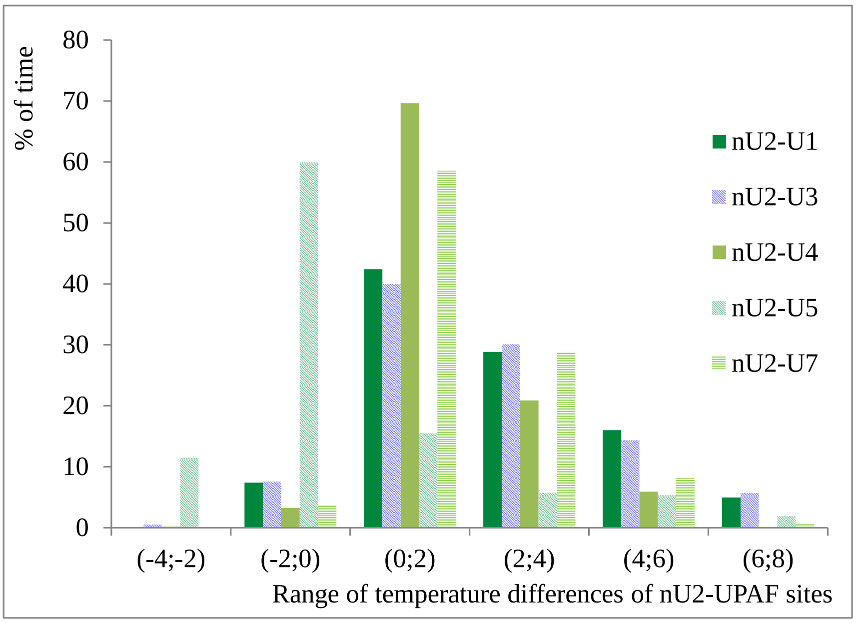

% of time
80
70
60
50
40
30
20
10
0
nU3-U1
nU3-U3
nU3-U4
nU3-U5
nU3-U7
(-4;-2)
(-2;0)
(0;2)
(2;4)
(4;6)
(6;8)
Range of temperature differences of nU3-UPAF sites

(c)


% of time
80
70
60
50
40
30
20
10
0
nU2-U1
nU2-U3
nU2-U4
nU2-U5
nU2-U7
(-4;-2)
(-2;0)
(0;2)
(2;4)
(4;6)
(6;8)
Range of temperature differences of nU2-UPAF sites


% of time
80
70
60
50
40
30
20
10
0
nU3-U1
nU3-U3
nU3-U4
nU3-U5
nU3-U7
(-8;-6)
(-6;-4)
(-4;-2)
(-2;0)
(0;2)
(2;4)
(4;6)
(6;8)
Range of temperature differences of nU3-UPAF sites

(d)


% of time
80
70
60
50
40
30
20
10
0
nU2-U1
nU2-U3
nU2-U4
nU2-U5
nU2-U7
(-4;-2)
(-2;0)
(0;2)
(2;4)
(4;6)
(6;8)
Range of temperature differences of nU2-UPAF sites

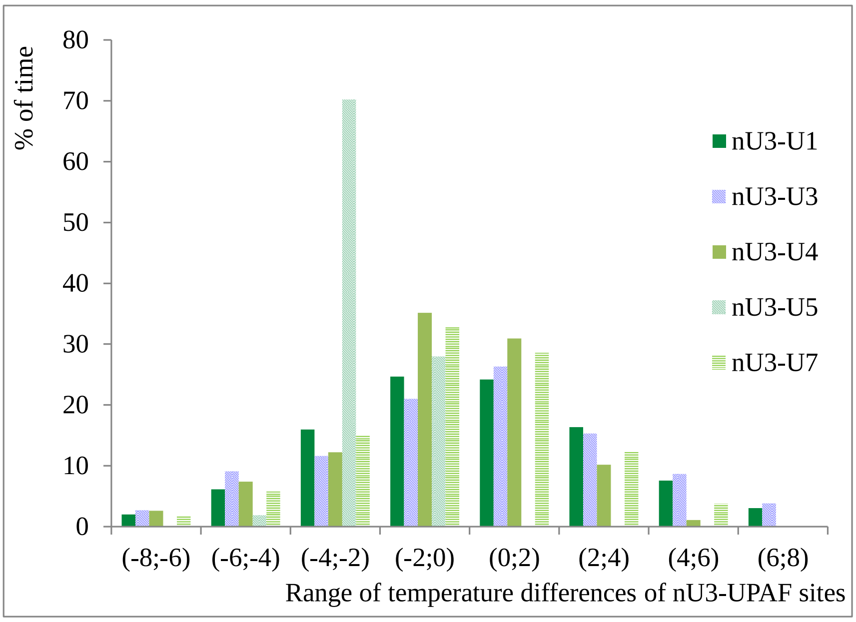

% of time
80
70
60
50
40
30
20
10
0
nU3-U1
nU3-U3
nU3-U4
nU3-U5
nU3-U7
(-8;-6)
(-6;-4)
(-4;-2)
(-2;0)
(0;2)
(2;4)
(4;6)
(6;8)
Range of temperature differences of nU3-UPAF sites

Figure 4. Frequency distribution percentage of thermal differences between nU2 or nU3 and all other UPAF sites and types during the year in the spring (a), summer (b), autumn (c) and winter (d) in Rosario, Argentina.

The UPAF and non-UPAF sites were consistently segregated in the PCA's scatterplot axis 1 according to whether they were UPAF or non-UPAF and distance from the city core except for U5, which despite being a treed site was well within a highly built area (Figure 5). In all seasons, the first two axes accounted for very high percentages of the total variance (93.77, 95.02, 96.39 and 98.25% for spring, summer, autumn and winter, respectively). Differences between UPAF and non-UPAF sites were detected by the MRPP in each season (spring, $p = 0.0151$; summer, $p = 0.0152$; autumn, $p = 0.0239$; and winter, $p = 0.0369$).

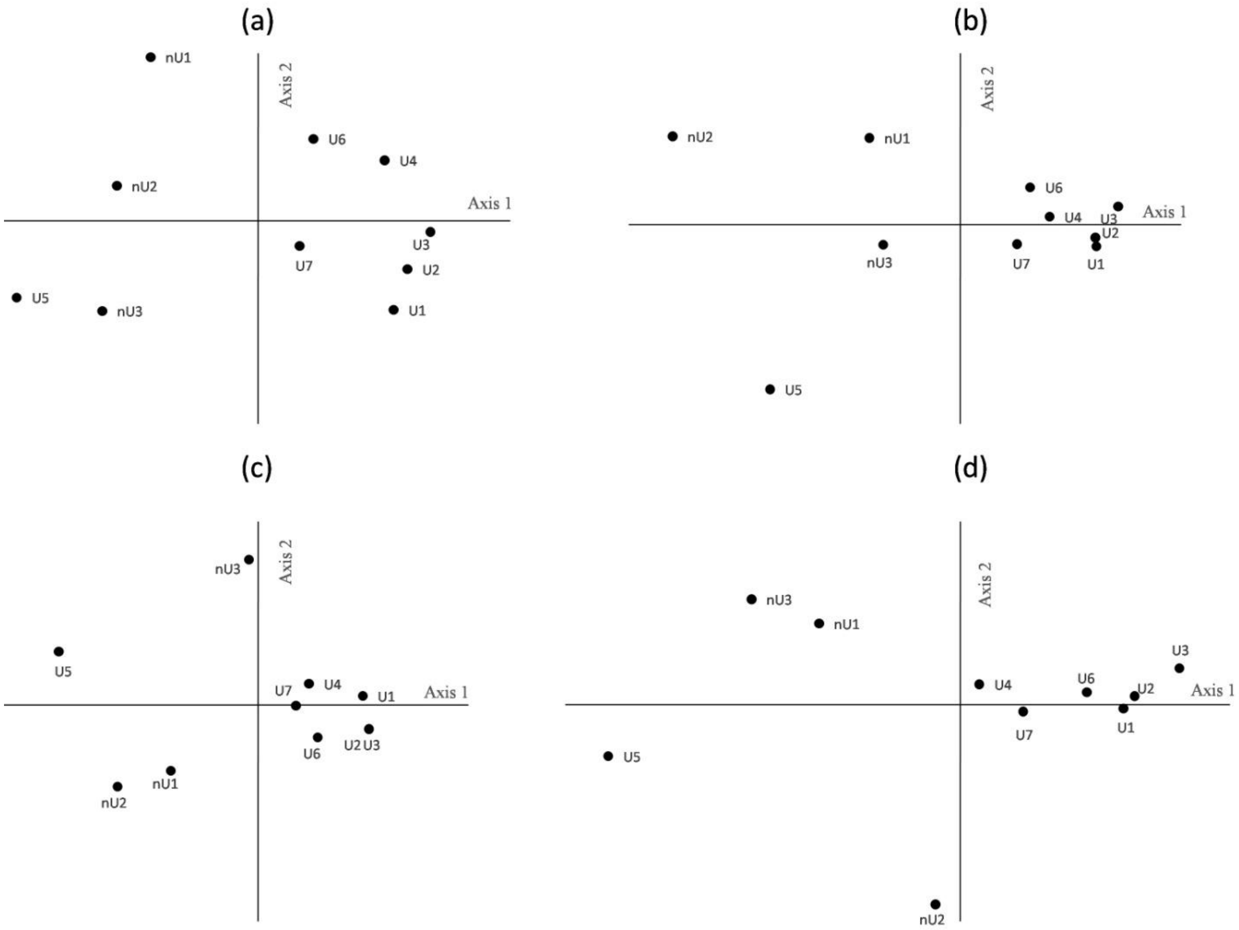


Figure 5. Principle component analysis plots of the first and second component of UPAF and non-UPAF sites during the (a) spring; (b) summer; (c) autumn; and (d) winter in Rosario, Argentina.

In summer the three non-UPAF sites showed different CDD; nU3 had the highest value due to its condition of being the site with the highest temperatures (Table 4). The UPAF sites in general had lower CDD, except U5 due to its high nighttime temperatures, although differences among UPAF versus non-UPAF sites were significant ($p < 0.001$). Considering the analysis period, the non-UPAF site with highest CDD (nU3) would need 1.77 times more energy to cool than U3, the site that presented the least amount of CDD.

Table 4. Cooling degree days (CDD, a) and heating degree days (HDD, b) per season for each measured site in Rosario, Argentina.

(a)

	UPAF							non-UPAF		
	U1	U2	U3	U4	U5	U6	U7	nU1	nU2	nU3
Spring	49	45	45	49	58	56	52	76	67	72
Summer	240	240	238	247	329	267	262	349	315	443
Autumn	15	17	21	11	20	25	20	41	55	6
Winter	6	5	7	6	2	7	6	8	14	0
TOTAL	310	306	310	313	409	354	340	474	451	521

(b)

	UPAF							non-UPAF		
	U1	U2	U3	U4	U5	U6	U7	nU1	nU2	nU3
Spring	41	40	43	32	6	32	30	18	15	12
Summer	13	11	13	7	0	7	6	2	2	1
Autumn	197	187	199	158	52	172	158	104	86	133
Winter	423	433	437	362	211	400	383	291	266	372
TOTAL	674	671	691	558	270	611	577	415	369	518

Heat emitted by construction materials in the non-UPAF sites decreased heating demand in these areas at all times of the year relative to UPAF sites, by 163% less than UPAF during the winter period and by 185% less than the analyzed year. The U5 site had the lowest HDD due to its low temperature range, while all other UPAF sites had high HDD figures, mainly due to higher night-time temperature in relation to other measured sites. Heating demand of non-UPAF sites decreased with respect to UPAF sites all times of the year due to the heat emitted by construction materials, but differences among UPAF/ non-UPAF were not statistically significant ($p < 0.05$), with U1 having the highest HDD demand.

Increases in the demand for cooling and decreases in the demand for heating in each measured site using actual and a projected future climate scenario are presented in Table 5. At all UPAF sites, with the exception of U5, the increased demand for cooling along summer period is offset by decreasing winter demand for heating.

Overall, the results show an evident variability and heterogeneity in atmospheric temperatures across Rosario, with higher temperatures found in the urbanized core's built-up area and the presence of an UHI in UPAF sites as compared to non-UPAF areas. Therefore, differences in energy requirements required to achieve a thermal comfort zone will generates variations in energy demand for heating in the cold months and for refrigeration during warmer periods. Findings show that the use and presence of UPAF areas statistically lowered the UHI in summer with corresponding projected decrease in energy demand for cooling. The study also showed that in areas with street trees, parks and urban agriculture, temperatures were 8–10 ºC lower on average throughout the year. It should be noted however that tree cover from evergreen trees in winter blocks solar radiation that warms surface and building walls, and results in increased energy demands for heating. But, an overall reduction in cooling demand was higher than increase in heating demand.

Table 5. Total CDD and HDD considering present conditions and a future scenario (Future Scenario; *Δ%*: percentage of increase or decrease) in Rosario, Argentina.

	UPAF							non−UPAF		
	U1	U2	U3	U4	U5	U6	U7	nU1	nU2	nU3
CDD										
Spring										
Present	49	45	45	49	58	56	52	76	76	72
Future scenario	66	62	63	65	84	76	71	99	91	94
Δ %	*35*	*38*	*38*	*33*	*45*	*35*	*35*	*31*	*35*	*30*
Summer										
Present	240	240	238	247	329	267	262	349	315	443
Future scenario	292	289	289	302	404	324	320	414	382	513
Δ %	*22*	*21*	*22*	*23*	*23*	*21*	*22*	*19*	*21*	*16*
total										
Present	289	285	283	296	387	323	314	425	391	515
Future scenario	358	351	352	367	488	400	391	513	473	607
Δ %	*24*	*23*	*24*	*24*	*26*	*24*	*25*	*21*	*21*	*18*
HDD										
Autumn										
Present	197	187	199	158	52	172	158	104	86	133
Future scenario	149	141	151	115	32	128	116	71	58	91
Δ %	*−24*	*−25*	*−24*	*−27*	*−38*	*−26*	*−27*	*−32*	*−33*	*−32*
Winter										
Present	423	433	437	362	211	400	383	291	266	372
Future scenario	335	335	349	279	145	311	295	209	194	298
Δ %	*−21*	*−23*	*−20*	*−23*	*−31*	*−22*	*−23*	*−28*	*−27*	*−20*
Total										
Present	620	620	636	520	263	572	541	395	352	505
Future scenario	484	476	500	394	177	439	411	280	252	389
Δ %	*−22*	*−23*	*−21*	*−24*	*−33*	*−23*	*−24*	*−29*	*−28*	*−23*

An interesting finding was that temperature effects in small urban agricultural gardens (approximately 1620 m^2) were similar to those of larger gardens and public parks 2–3 ha in size. This would imply that including small UPAF areas in new or upgraded housing and neighbor settlements could have a desired effect on human comfort levels. Larger UPAF areas may however have temperature impacts on building areas located at further distances from the UPAF areas, as compared to smaller UPAF areas. However, further research in needed; temperature data and effects need to be collected and analyzed in various distances and spatial arrangements away from UPAF areas. This should provide information as to what extent (distance) temperature effects expand outside specific green areas of different size.

In addition, in middle latitude cities such as Rosario in the developing world, CDD can be considered an appropriate indicator for energy demand, while HDD were found to be less reliable as they tend to over-estimate energy heating requirements. During a typical winter day, air temperature can exceed 18 ℃ (i.e. the locally relevant comfort temperature). However, during these hours with a temperature above comfort temperatures heat is stored within buildings, thus delaying heating requirements in the evening and night when air temperatures fall below 18 ℃. Hence, and as is typical of these types of cities, CDD are a good indicator of energy demand, but the HDD are not because they over estimate energy heating requirements. Therefore the findings conclude that UPAF can be considered a useful approach and policy for high temperatures mitigation in Latin American cities such as Rosario [43].

4. Conclusions

Our results highlight the importance of preserving existing UPAF areas and promoting the incorporation of new UPAF areas within cities. Temperature findings show that UPAF can be considered a useful approach for high temperatures mitigation within the city. Recently, for example in 2013 during Rosario's summer months, electrical outages due to extreme cooling energy use were found to be related to high temperatures; therefore the findings of this study are of immediate relevance to municipal decision-makers. Rosario also has an established urban planning tradition that includes measures such as strategic plans for the city and its metropolitan area that include food security and environmental quality; therefore, UPAF measures could easily be incorporated into existing policies to make the city more resilient to climate change. Incorporation of such planning ordinances or urban design concepts will promote green infrastructure projects instead of urban in-fill, protect valuable ecosystems and biodiversity hotspots and preserve natural corridors. Designating flood plains in the Parana Delta for agriculture can protect low-lying areas from flood damages as well.

Rosario's municipality is also now determining the choice of urban tree species to be planted in terms of their temperature impacts. Rosario will not only continue to promote urban forestry and urban agriculture activities in parks, but also the inclusion of smaller urban agriculture gardens in new housing settlements. It is expected that next to social benefits, such urban greening will also help reduce energy demand for cooling. With increasing urbanization, climate change and growing urban demand for food, cities need to address the triple challenge of climate change mitigation, adaptation and improving urban food security. This study in Rosario shows that UPAF may be a viable strategy to address this triple challenge. Local and Regional governments can play a further proactive and coordinating role by: (1) integrating urban agriculture and food security into climate change adaptation strategies; (2) maintaining and managing agriculture as part of the urban and periurban green infrastructure; (3) identifying open urban spaces prone to floods and landslides, and protecting or developing these as permanent agricultural and multifunctional areas; (4) integrating urban agriculture and forestry into comprehensive city water(shed) management plans, development plans, building codes and housing programs; (5) recognizing urban agriculture as an accepted, permitted and encouraged land use; and (6) developing a municipal urban agriculture and food security policy and program.

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