Chapter 8
Urban Microclimatic Conditions in Arid Climates

Irene Marincic and Jose Manuel Ochoa

8.1 Introduction

Urban heat island (UHI) effects are considered one of the most important problems of the twenty-first century (Shalaby 2011). By combining the civilization growth phenomenon, the increase of land use (Ali et al. 2017), and the effects of climate change, urban warming is a consequence that is currently difficult to control in many cities, and a real challenge for urbanists, architects, landscape architects, and authorities.

The increase of urban temperature directly impacts people's thermal comfort outdoors. Furthermore, the thermal conditions of outdoor spaces around buildings can affect indoor climate, thermal comfort of the occupants, and energy consumption needed in these buildings (Önder and Akay 2014). This last consequence leads to an increased use of air-conditioning, more greenhouse gas emissions, and increase of UHI. This problem is even greater in cities built in the desert, where the local climate presents extremely hot conditions, especially during the summer period.

We will address our study in the Sonoran Desert in North America, which includes mainly Sonora in Mexico and Arizona in the United States, as well as part of California (USA) and part of Baja California (Mexico). This desert has different regions and sub-climates, but in most cases climatic conditions are very harsh. For example, the climate of Hermosillo city (Mexico), where this study is focused as a representative city of the Sonoran Desert, is characterized by high solar radiation levels, clear skies the whole year, and high temperature oscillations daily and during the different seasons. Summers are very warm, with daily temperatures between 25–30 °C and 40–45 °C, and relative humidity between 15% and 50%. Summer wind is usually warm, so it is not useful for passive cooling or for a better outdoor thermal comfort. Winters are mild, with minimum temperatures from 0 °C to 7 °C

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and maximum temperatures between 25 °C and 30 °C. During 5 or 6 months per year, the use of air-conditioning inside buildings is almost constant (day and night).

Under these harsh circumstances, local people adapt their way of life by taking a "siesta" (nap) during the afternoon hours, a very common practice. In general, the necessary physical activities and movements, such as walking, are also done very slowly. Thermal comfort surveys of local people show a wide comfort range and very high indoor neutral temperatures (T_n) (Marincic et al. 2013; Ochoa and Marincic 2016), compared with other climate comfort studies (Givoni 1998; Gómez-Azpeitia et al. 2014). Behavioral, social, and cultural factors, including people's expectations and acclimatization, can help overcome adverse thermal conditions indoors and outdoors, but in many cases, they may also decrease work productivity and, most importantly, risky health conditions make it very difficult to live in the urban desert.

Thermal sensation outdoors varies from indoors because of people's lower thermal comfort expectations. But anyway, thermal conditions, especially in summer, are extreme. Thermal comfort conditions in outdoor spaces are also important for social reasons: public spaces are naturally appropriate to get together, talk, and hang out with people between activities. If outdoor conditions are not barely comfortable, people can only walk fast to reach their car and leave.

Conscious and well-designed outdoor spaces can not only contribute to habitable outdoor spaces, but also control UHI temperatures and provide more energy-efficient buildings.

8.2 Desert Climate and Thermal Comfort

The adaptive comfort model (Nicol and Humphreys 2002) considers that people's thermal sensation depends on climatic parameters, i.e., temperature, humidity, radiant temperature, wind, and solar radiation (outdoors), among others, and individual characteristics and situations, such as age, gender, clothing, activity, and subjective issues, such as behavior, expectations, and acclimatization (Nikolopoulou et al. 2004). This approach takes into account not only the physical interaction between the subject and the environment, but also their long-term psychological and physiological interactions, incorporating the effects of acclimatization and the decisions that people can and indeed make to improve thermal sensation.

Although all aspects are important, subjective issues have a vast relevance, mainly in outdoor spaces, and especially for people adapted to local climates. The thermal sensation of this population group can be surprisingly different as expected because of their adaptation to local conditions (Marincic et al. 2005). In hot climates, people's neutral temperature is higher than expected, and if the climate has a wide range of temperature variations, such as the case of desert climates, the comfort range will also be wider (Marincic et al. 2013; Ochoa and Marincic 2016) than that reported for temperate climates, because neutral temperatures are highly related to the outdoor average annual temperature and the comfort range depends on temperature oscillations.

Thermal comfort sensation of people can be very different depending on comfort expectations, which are usually very high in permanent acclimated buildings, with a narrow range of temperature and humidity variations.

In contrast, in naturally ventilated buildings, and even more in outdoor spaces, people have fewer expectations and have more tolerance to extreme temperatures. They tend to expect less comfort as in indoor spaces, compared with people habituated to more temperate climates or constant acclimated environments. Indoor comfort has been much more studied than outdoor comfort, maybe because outdoor comfort does not usually impact energy consumption in acclimatization outdoors (Ochoa 2009). Although it is not the subject that we are going to study, considering indoor comfort in a specific climate, it can be expected that people will probably have less expectations outdoors and therefore they will tolerate more extreme conditions. In a comfort survey in indoor spaces carried out in the mentioned city (Marincic et al. 2012, 2013; Ochoa and Marincic 2016; Gómez-Azpeitia et al. 2014), the thermal comfort in low-cost dwellings was analyzed. The comfort range as a result of the adaptive comfort survey was between 29.7 °C and 34.5 °C in the summer (neutral temperature T_n = 32.2 °C) and between 23.5 °C and 31.3 °C in the winter (T_n = 26.9 °C). In terms of acclimatization, most houses included evaporative coolers and a few of them, window unit air conditioners in only one room of the dwelling. Regarding the thermal comfort outdoors, preliminary results in a field survey in the city of Hermosillo (Ochoa and Marincic 2005) indicate an outdoor neutral temperature during the summer of 36.2 °C. This could be a reasonable result, considering the obtained indoor neutral temperature.

Behavioral factors can also have a high impact on thermal sensation. Some decades ago, when the use of air-conditioning was not generalized, people had to deal with and survive in the desert urban climate using their common sense. During summer nights at their homes, people slept on moistened cots in patios or rooftops facing the clear sky, taking advantage of passive evaporative cooling and radiative cooling strategies. Nowadays, many people use evaporative coolers or, whenever possible, air-conditioning devices. However, basic outdoor space behavioral strategies must be put into action for protection from high levels of solar radiation by using hats, umbrellas, or even a folder (if there is nothing else) (Figs. 8.1 and 8.3). In addition, walking fast among tree shadows, pergolas, and outdoor corridors is also a common practice. Regardless of the high temperatures, people do not usually wear very-low-Clo clothing. For example, they tend to use long-sleeve shirts for protection from solar radiation, and they also frequently use dark clothing for the same reason (Figs. 8.1, 8.2, 8.3, and 8.4).

Aside from the high impact of solar radiation, surface temperature of outdoor space limits related to radiant temperature (and black globe temperature) have an impact on peoples' thermal sensation outdoors. So keeping away from hot surfaces, such as metal roofs and sunny walls, is also a good strategy to mitigate high thermal sensation.

Fig. 8.1 Person protected from solar radiation with an umbrella

Fig. 8.2 People under a tree shadow

Undeniably, the use of water sources to improve passive evaporative cooling could be a successful strategy for certain temperature and humidity conditions. However, this strategy is not widely used in the region, and especially in public spaces, mainly because of low water availability and to avoid maintenance costs.

On the other hand, when formulating cooling strategies for indoor or outdoor spaces in desert climates, we must take into account that some climatic parameters can have a different effect than expected. For example, hot summer winds do not refresh or improve the thermal sensation (Ochoa and Marincic 2005; Ochoa 2017), so it is important to identify which climatic variables and design parameters have more impact (and viability to apply) on microclimatic conditions and on people's thermal comfort.

Fig. 8.3 Cyclist resting under a palm tree shadow

Fig. 8.4 People gathered in a shadowed space

8.3 Impact of Vegetation on Microclimatic Spaces

Most cities in the Sonoran Desert region follow a low-density urban model and their constructions are scattered in the territory. The majority of these cities are made up of low-rise buildings and the main streets are wide due to the excessive use of individual cars. Examples of this model include cities such as Phoenix, Tucson, Mexicali, and Hermosillo, among others.

In general, urban morphology, and mostly flat topography (in the urban areas) as well as the relationship of building height to street width, allows solar radiation to hit almost during the entire day on urban surfaces and to create urban spaces that are not very friendly for pedestrians, considering the extreme climate. At the human scale, the results are few shadows, long walking distances, and few suitable microclimatic spaces to remain outdoors, regardless of the fact that in the mentioned cities, the application of microclimatic design strategies is quite different, and in some of them, efforts to create friendly outdoor spaces can be appreciated.

The climate, city morphology, and urban materials have a relevant impact on UHI effects (Palme et al. 2016), as well as the anthropogenic heat generated by cars, air conditioners, industrial activities, and other heat sources (Önder and Akay 2014). At a smaller scale, the adequate design of outdoor spaces, including the thermal design of buildings (especially the envelope), has an impact on urban climate. In addition, the results can be seen in the short and medium terms on the people's quality of life. This implies improving issues like health, social interactions, and energy consumptions in buildings (Shima et al. 2015).

As mentioned earlier, the design of outdoor spaces has a great impact on microclimatic temperatures and outdoor thermal comfort. Although the comfort sensation is a combination of factors such as radiant temperature (long-wave radiation emitted by the surrounding surfaces), air humidity, and wind speed, air temperature in the shade and solar radiation are the factors that most influence when evaluating thermal comfort in outdoor spaces, specifically in predominantly dry climates. The above has been demonstrated in field studies carried out in our case study in the city of Hermosillo (Ochoa and Marincic 2005). Different design factors, such as space proportions and dimensions, distance between buildings, shading possibilities, surface materials, presence of water sources, and use of vegetation (Önder and Akay 2014), among other aspects, have an impact on peoples' comfort sensation and on outdoor habitability. Desert urban climates have an important cooling potential by landscaping design and urban design strategies, according to studies in different Phoenix neighborhoods (Sonoran Desert), which show that urban form and landscaping design can lower the midafternoon temperatures during summer (Middel et al. 2014). Other studies in the city of Phoenix explore the impact of vegetation shading and different pavement materials to lower the air temperature, to provide better outdoor comfort for pedestrians, and to contribute to the UHI mitigation (Rosheidat and Harvey Bryan 2010).

As an example, different microclimatic spaces will be shown and analyzed in order to compare how different applied strategies work in a desert climate, and to evince how these strategies can influence thermal conditions. The spaces shown in Figs. 8.5, 8.6, and 8.7 are located in the urban area of Hermosillo city, Mexico, as mentioned in the Sonoran Desert. Microclimatic variable measurements are compared with urban and rural meteorological station data in order to visualize differences in climate conditions.

The most challenging season in this climate is definitely summer. Outdoor climatic conditions during the warm period (almost 6 months of the year) are extremely hot and living outside is exceedingly difficult. Comparative data in a summer day

Fig. 8.5 Case 1: Entrance to a building. Aerial view (left) and street view (right)

Fig. 8.6 Case 2: Little garden square. Aerial view (left) and street view (right)

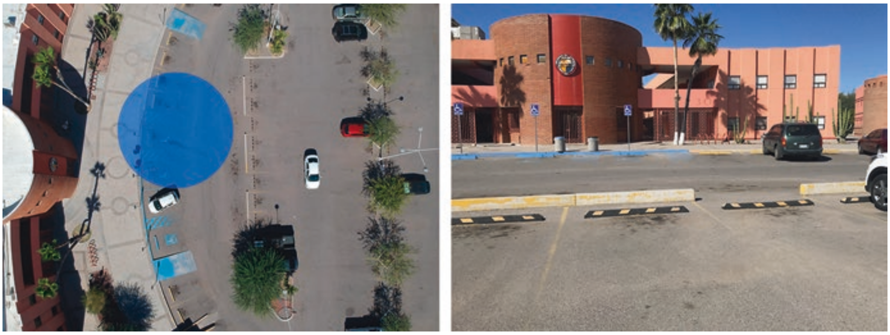

Fig. 8.7 Case 3: Parking lot. Aerial view (left) and street view (right)

are presented, to visualize the differences between climatic variables in the aforementioned microclimatic spaces and other locations within the same city.

Comparing the microclimatic conditions among the three spaces previously described and the city climate (urban) and rural climate (desert), differences in air temperature, relative humidity, and black globe temperature can be observed, where the last variable was compared only in the three microclimatic spaces. The wind speed in the microclimatic spaces varies extensively and it has gusts that are difficult to analyze, so wind measurements are not presented here but the variable was qualitatively evaluated in the site and later commented. Previous outdoor comfort studies in the city (Ochoa and Marincic 2005) also reveal that the wind does not have a clear relation with peoples' thermal sensation; the reason could be that occasionally wind gusts are very warm and do not help lower the thermal sensation (Ochoa and Marincic 2005).

In case 1 (Fig. 8.5), the space partially limited by three vertical surfaces and the floor is shown. It does not have any solar radiation protection. Two vertical surfaces are made out of a white-painted plastered brick wall; one of them is partially shaded by trees. The other vertical surface (entrance) is mainly composed of metal terracotta plates and terracotta cement boards. In this space, air temperature, solar radiation, and radiant temperature are the main variables to consider. The orientation of the façade is west, and the only shades present are the ones coming from the same building and the adjacent buildings at certain times of the day. The ventilation is low because there is a low possibility of cross ventilation due to the geometry of the space. Regarding the surface materials that limit the space, in addition to the described walls, there are concrete and gravel floor materials. Vegetation largely covers the north wall (adjacent building) and a small part of the ground. Vegetation partially protects from infrared radiation emitted by the different surfaces; thereby, it limits the radiant temperature into the space.

Case 2 (Fig. 8.6) is a small garden square with vegetation consisting of trees, shrubs, and ground cover vegetation, but also with concrete and gravel surfaces on floors. Measurements are taken in the proximity of a wooden and metal bench, which is shaded during part of the day by a tree. There are shrubs, grass, and other vegetation that partially limit the emission of the infrared radiation from the floor. It is important to point out that trees are important to shadow the resting spaces and floors and that it is an open space, where the wind can run freely.

Case 3 (Fig. 8.7) is a parking lot with asphalt floor. It is a large space, without sun protection devices, so solar radiation strikes the floor the entire day, without nearby walls and with free wind circulation.

The day measurements were taken, the meteorological air temperature in the city reached a maximum of about 45.7 °C, while the maximum horizontal solar radiation was 949 W/m^2, and it was a completely sunny day, like many others in the region (Fig. 8.8). Effect of UHI in the city can be appreciated in the air temperature differences of both meteorological stations.

It can be noticed that the air temperature (Fig. 8.8) in the microclimatic spaces is slightly lower than the temperature of the meteorological stations (depending on the daytime), and the temperature in the small square is the lowest. In general, at the maximum air temperature time, that was at about 4 p.m., the difference between square temperature and meteorological station temperature was about 1–1.5 °C lower. Analyzing the measured black globe temperature (Fig. 8.9), which is highly related to the radiant temperature, it can be clearly seen that the black globe temperature is lower in the square, which contributes to a better comfort sensation. At

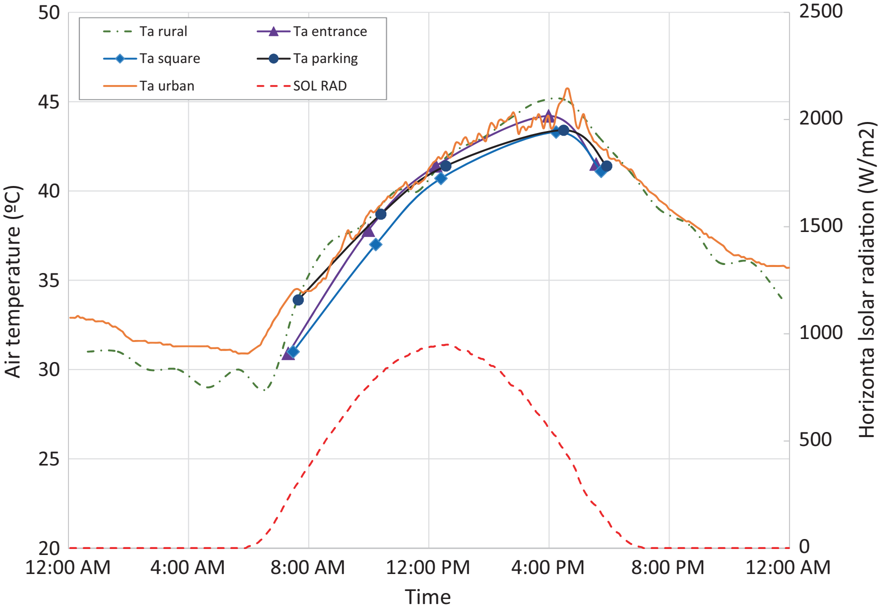

Fig. 8.8 Air temperature in three microclimatic spaces, urban meteorological station, and rural meteorological station near the city (desert) as a function of daytime. Solar radiation is also included as reference of the daylight length

noon, the square black globe temperature was more than 11 °C lower than the parking lot black globe temperature.

Regarding humidity, in the meteorological stations only relative humidity measurements are available. However, comparing relative humidity in rural and urban meteorological stations, it can be assumed that with slightly different air temperatures between both stations, there are appreciable differences in relative humidity (Fig. 8.10). This indicates that absolute humidity (water content in air) would be lower in rural than in urban areas. It is also inferred that these differences in humidity between both cases are due to water sources such as well-irrigated urban vegetation, condensation of air-conditioning devices (in the city of Hermosillo it is usual to drain them on green areas or directly to the street), as well as other human activities. In the microclimatic cases, the presence of vegetation is probably the most important cause of humidity differences.

Apart from the mentioned sources, there are no water sources such as fountains, cascades, or ponds or any other microclimatic contribution to evaporative cooling effect, which in this climate would benefit the thermal comfort. The comparison of relative humidity measurements is shown in Fig. 8.10.

The microclimatic humidity values are close to the urban weather station humidity (Fig. 8.10). However, the parking relative humidity is the lowest value probably due to the lack of vegetation (there are only a few small trees).

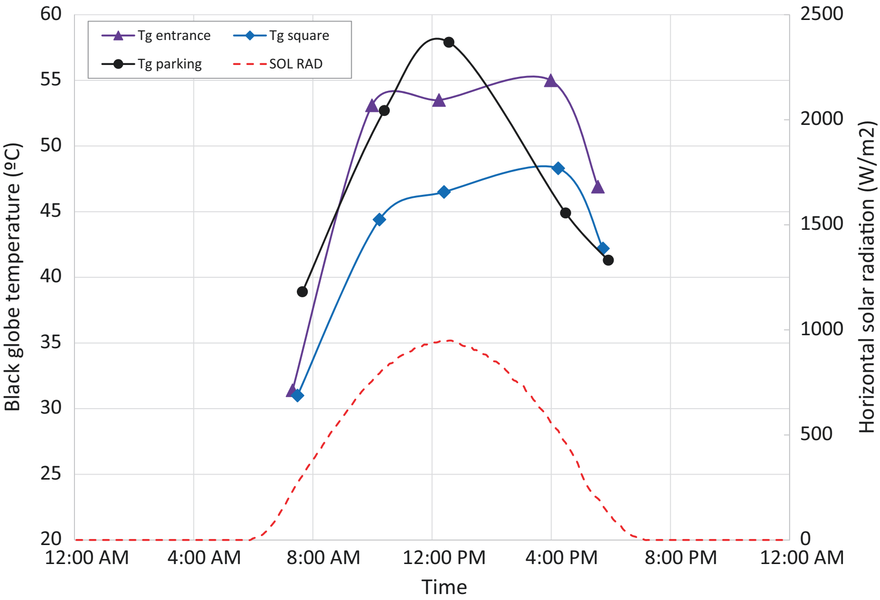

Fig. 8.9 Black globe temperature in three microclimatic spaces as a function of daytime. Solar radiation is also included as reference of the daylight length

The surface materials that limit the spaces and the presence of vegetation that protects with shades the surfaces and prevents the reflection of long-wave radiation played an important role in the results of the microclimatic measurements. It is well known that superficial vegetation temperatures, even in the sun, are similar to air temperature. In the case of very hot climates, with many hours of high radiation levels during the day, shading the space and controlling surface temperature with vegetation can be the most relevant strategies to cope with the climate and have an acceptable thermal sensation in microclimatic spaces.

The surface temperatures of the three cases at about 4:00 p.m. on a summer day can be seen in Figs. 8.11, 8.12, and 8.13, as infrared photographs (right), together with visible photographs (left). Although perspective infrared pictures do not have the same precision as those taken perpendicular to the surface (García Nevado 2018), qualitative and comparative analyses can be useful to help dimension the range of temperatures that can be reached in these spaces.

In the case of the entrance to the building space, which is west oriented (Fig. 8.11), the horizontal concrete surface exposed to the sun had a temperature of about 58 °C, and in the shadow areas, about 52 °C. The perforated terracotta painted plate, part of the sunny front façade, reached more than 46 °C; the solid terracotta plate more than 65 °C; and the terracotta cement board, about 62 °C; the superficial temperature of the white brick wall, at the shadow, was about 46 °C. In contrast, the vegetal ground cover with sun exposure had superficial temperatures between 37 °C and 38 °C, depending on the color, and at the shadow, about 35 °C. Shadowed bushes

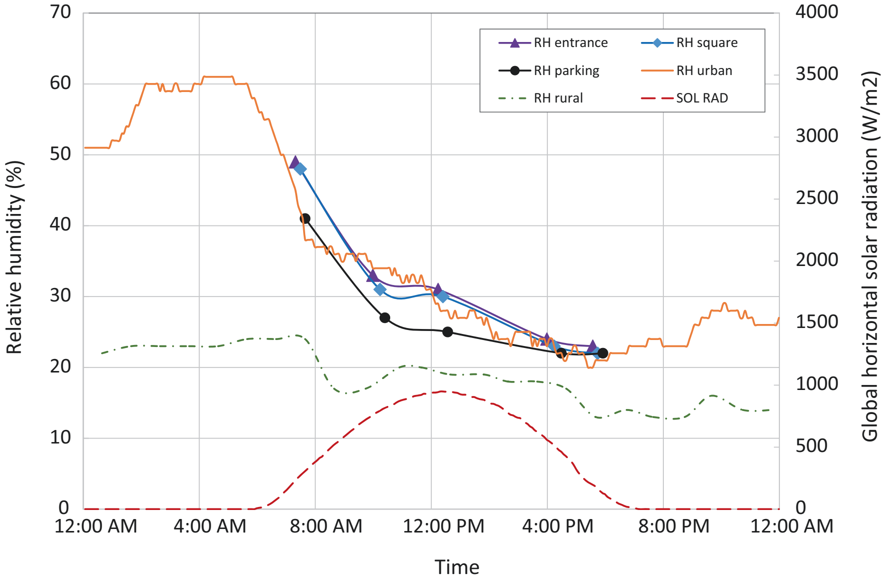

Fig. 8.10 Relative humidity in three microclimatic spaces, urban meteorological station, and rural meteorological station near the city (desert) as a function of daytime. Solar radiation is also included as reference of the daylight length

Fig. 8.11 Visible (left) and infrared photography (right) of case 1. False color scale is 30–70 °C

had a temperature of about 34 °C. The microclimate air temperature at this time was about 44.2 °C. Vegetation at the sun, therefore, maintains a superficial temperature around air temperature at the microclimatic space, or even lower, and the shaded vegetation, about 10 °C lower than air temperature.

Analyzing the infrared photography around the bench at the little square (Fig. 8.12), also at 4:00 p.m., it was possible to measure the temperature of concrete and ground cover gravel at 48–59 °C. It is remarkable that gravel can reach higher temperatures than concrete, because of the higher area exposed to solar radiation. Shaded gravel, in this case, registered a superficial temperature of 45.5 °C. Gravel

Fig. 8.12 Visible (left) and infrared photography (right) of case 2. False color scale is 30–70 °C

Fig. 8.13 Visible (left) and infrared photography (right) of case 3. False color scale is 30–70 °C

is used frequently as surface coverage in outdoor spaces due to the need for preventing rising dust from winds, and due to its low cost and almost zero maintenance.

Vegetation surfaces registered temperatures between 32 °C (vegetal ground cover) and 43 °C (grass) under solar radiation. Shaded grass was at about 37.5 °C. At this time, local air temperature was about 43.3 °C. Again, vegetation at the sun maintained a superficial temperature around air temperature and the shaded vegetation, around 10 °C lower. A difference of 10 °C (or more) of superficial temperature lower than air temperature implies that the use of vegetation really has a significant impact on the possibility of making more livable outdoor spaces in desert climates.

In these last two examples (cases 1 and 2), the ground surfaces shown are composed of several materials, which have different thermal properties, such as concrete, gravel, and vegetation. Depending on these properties and the superficial temperatures shown, a landscape design considering microclimatic effects can be planned.

The microclimate at the parking lot (Fig. 8.13), as can be expected, was not favorable. At 4:00 p.m., while air temperature was 43.4 °C, the ground surface temperature was near 66 °C in the case of asphalt and about 50 °C in the shaded concrete floor near the building, both under the sun. There is no vegetation and no shading devices in this zone. There are only a few small trees in the rest of the parking lot, which are too small to shade.

At first instance, because of the limited water availability in the region, vegetation would not seem to be a viable strategy to control the microclimate conditions in desert environments; however, there are other options, such as the use of endemic vegetation and vegetation adapted to the local environment. Urban greening is an important mitigation strategy for the UHI, but it must also be considered that the efficiency of this strategy depends on the appropriate selection of the type of vegetation, the species, and its distribution in the space. Choosing the plant species carefully and providing adequate controlled irrigation, vegetation can be very useful for landscape design and microclimatic design of outdoor spaces, even in urban deserts. These species need to withstand high levels of solar radiation, be resistant to sporadic strong winds (the region is a hurricane zone), and preferably survive with low amounts of water.

A relevant microclimatic strategy is to shade outdoor spaces with structures or with vegetation. Another design consideration is the geometry of space and its surface limits to avoid successive reflections of long-wave radiation among vertical and horizontal surfaces.

Regarding surface materials, it is desirable that traditional materials, such as concrete and gravel, be shaded. In the case of walls, these can be shaded by trees, shrubs, or vines. In the case of floors, interspersed concrete, tile or gravel floors, and vegetation covers can be used to lower the radiant temperature. Vegetation is also useful to decrease long-wave radiation reflections from floors or other buildings, through bushes, for example. There are also important urban furniture materials like benches made out of materials with low heat absorption and low thermal capacity.

During the winter, the climatic conditions in the city are very benign as described and the outdoor spaces are close to being comfortable most of the day, considering the lower expectations of people in outdoor spaces. During the hours of the day when the outdoor spaces can be inhabited, the minimum temperatures are no less than 12 °C and the maximum temperatures rarely exceed 30 °C in this period. Measurements carried out during the winter will not be presented here.

8.4 Microclimatic Spaces Around Buildings

The spaces around buildings, for example, those between constructions, front yards and backyards, garages, and parking spaces, are outdoor living spaces that must be carefully designed in order to have or look for most comfortable conditions. Further on, the microclimate generated in these spaces has a thermal impact on the heat transfer between the outdoors and indoor building space.

Particularly in desert environments, the better the design of the spaces around buildings, the lower the heat transfer to the interior, and thus there are more possibilities of having a comfortable indoor environment with lower air-conditioning energy consumption. Improving outdoor design strategies for an existing space can be simple, such as shading or properly choosing the floor material.

In low-cost housing developments, mostly tract housings (which are the largest number of buildings in some cities), in addition to the austere design and construction, there is an absence of outdoor space design, such as home access, garage, backyard, and outdoor laundry. In most cases, the appearance of outdoor spaces is that of residual space between houses. Over time, some owners try to arrange these spaces, but in most cases, probably due to scarce resources or interest, these spaces remain neglected. This implies in many cases dirt floors, lack of shadows, and lack of vegetation. As mentioned, poor design and particularly no intention of thermal design of outdoor spaces affect not only comfort but also housing thermal behavior and energy consumption for acclimatization. As known, an adequate microclimate design in spaces around buildings is a relevant thermal design strategy that impacts indoor thermal behavior.

Next, the evaluation of several strategies applied to low-cost housings (less than 40 m^2 construction area) in Hermosillo city will be shown, where the redesign possibilities and modifications of outdoor spaces are restricted because of the limited space and the scarcity of resources. In spite of this, it is possible to visualize the differences from the impact of simple strategies applied to outdoor spaces on the indoor electricity consumption.

The types of acclimatization used in these homes mainly include evaporative coolers (evaporative cooling effect) and secondly window unit air conditioners, both usually used in only one room of the house. The cooler is the most used device due to the relatively low investment and operation costs. The average electricity consumption of all analyzed houses is about 3100 kWh/year. From the total electricity consumption in houses that use evaporative coolers, it is estimated that 24% corresponds to acclimatization. Those houses that use window unit air conditioners spend 40% from total electricity consumption in acclimatization (Marincic et al. 2009). The remaining consumption in each case is used for lighting and other electrical devices and appliances.

Dwellings are generally delivered with outdoor areas without shading and almost all the exterior floors with natural soil. In certain cases, concrete footprints for the car are also added at the entrance of the house (Fig. 8.14). Over time, owners may plant vegetation and, in other cases, increase the concrete surface. Also, several homeowners may add shading to the garage area using mesh shade or tarp-awnings or a roof made of any available construction material (metal sheet, board, concrete), considering the availability of resources. Modifications in outdoor design, such as the ones mentioned previously, have an impact on the microclimate and on the thermal loads transferred to the interior of the buildings. Therefore, the analysis of how these effects influence the energy saving possibilities by air-conditioning was performed. From the multiple combinations of floor materials observed, including concrete, natural soil, gravel, tiles, grass, etc., we analyzed the most frequent combinations and their relationship with the electrical consumption. The relationship between the type of exterior floor and the average annual electrical consumption of each type of house in a specific situation is shown in Fig. 8.15.

Fig. 8.14 Typical low-cost dwelling constructed in the region (Marincic et al. 2010). View of the façade (left) and floor plan (right)

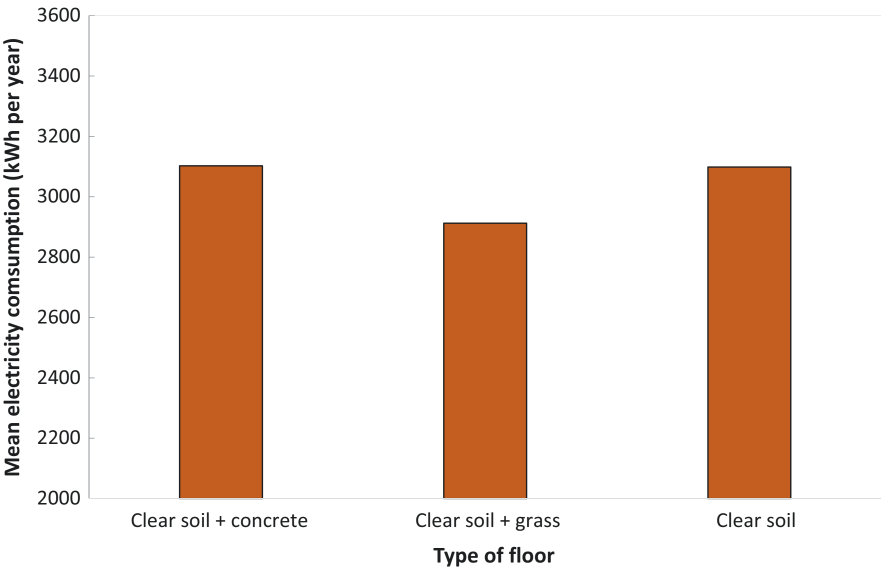

Fig. 8.15 Average annual electricity consumption in relation to the floor material in outdoor areas (own work based on Marincic et al. 2010)

As shown in Fig. 8.15, the intervention in the small available outdoor area by modifying the type of floor has an effect on the decrease in electricity consumption, particularly with the use of grass in some areas. Although this type of vegetation is not ideal for the desert climate, due to its high water consumption, it is estimated that with other type of vegetation coverings adapted to the region, similar results could be achieved. In this case, the function of the vegetation would be, on the one hand, to reflect less infrared radiation from the soil to the building during the hours of solar incidence, and on the other hand, vegetation does not store heat that could be emitted later, and its superficial temperature decreases when the air temperature drops. It is necessary to highlight the high heat capacity and emissivity of dry and clear soil (without vegetation) that affects the microclimate and the thermal loads towards the building.

Regarding shading improvements outdoors, in some cases, small trees are planted and sometimes awnings and tarps are placed as garage roofs. In few cases a garage with more permanent materials is built. In Fig. 8.16, these three observed solutions and the original situation, without any shading or only the possible shadow of the neighbor's house, can be observed. The major impact of the shading on the average annual electricity consumption of the houses is clearly shown.

Shading of the exterior areas has a great impact on the decrease of electricity consumption within the building, and the major decrease corresponds to the shade of vegetation elements, since they have the advantage of not storing or emitting heat.

Although in desert climates the maintenance and conservation of vegetation elements are laborious and constant, the adequate selection of suitable plant species adapted to the region makes maintenance more viable and allows a thermal benefit advantage from their use.

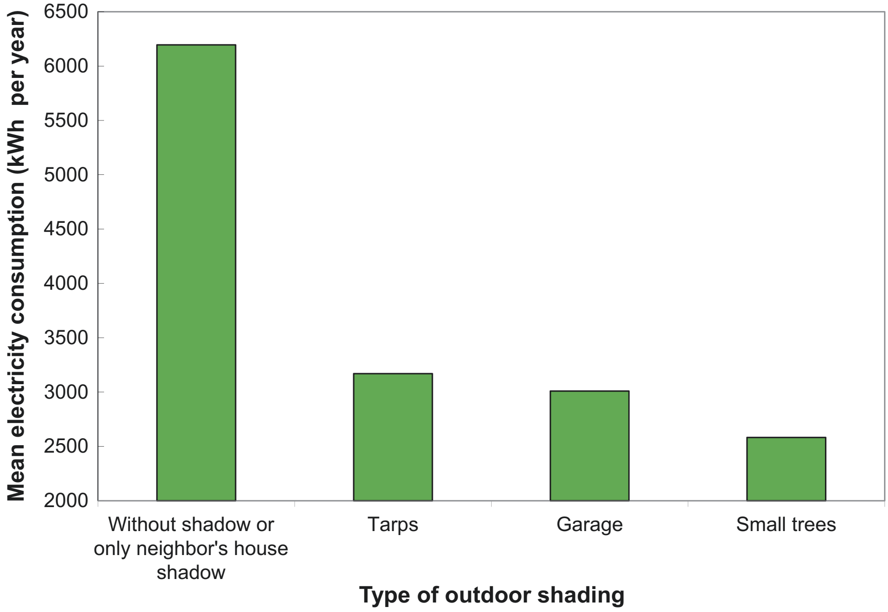

Fig. 8.16 Average annual electricity consumption in relation to the type of shading in outdoor areas (own work based on Marincic et al. 2010)

8.5 Final Comments

UHI is a complex phenomenon that involves factors such as the shape, density, and materials of the urban tissue as well as anthropogenic activities among others. The result is a modification of the urban microclimate that affects the thermo-hygrometric conditions of outdoor space and the energy behavior of buildings, and therefore the quality of life of the city's inhabitants (Román et al. 2017).

Although there is not necessarily a relationship between UHI and outdoor thermal comfort (OTC), some of the factors that cause UHI and strategies to mitigate it are similar to strategies to improve OTC (Irmak et al. 2017; Evola et al. 2017), especially in hot dry climates.

In this chapter, outdoor microclimatic conditions and particularities in a desert climate have been described and commented, highlighting the harsh climate conditions to consider during the summer period. Also, their impact on outdoor comfort and indoor energy consumption in buildings has been commented. Some examples of thermal conditions in small microclimatic outdoor spaces have been shown, demonstrating how certain thermal design strategies, especially the use of vegetation, have an impact on climatic variables that can modify thermal conditions and thus peoples' thermal sensation in these spaces.

Finally, outdoor spaces around low-cost dwellings in a tract housing development have been analyzed and design improvements made by the owners, such as the implementation of shading and the change of floor materials, have been described. These modifications have been related with the electricity consumption of the corresponding house, considering that 24–40% of this consumption is related to air-conditioning, used during almost half of the year. Also, in these cases, the use of vegetation as a design microclimatic element shows its benefits and advantages in outdoor spaces.

In order to incorporate vegetation in outdoor space design, considering operational purposes, it is necessary to select suitable vegetation species for each region, endemic or locally adapted, and also to plan an efficient irrigation system. Even in desert climates with limited water availability, the space design with vegetation and their maintenance is a great investment to improve microclimatic climates and energy consumption inside buildings and thus these are considered as actions that contribute to mitigating a city's urban heat island.

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