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Characterizing Two Types of Urban Air and Surface Heat Island according to Urban Design -Case of Casablanca Neighborhoods-

* [1] Dr. **Laila El Ghazouani,** [2] Full Prof. **Majid Mansour** , [3] Full Prof. **Hassan Radoine,** Associate Chief **Dr Lahouari Bounoua** [4], Dr **Kenza Khomsi** [5] , Dr **Khalil Idrissi** [6], Full Prof. **Hassane Jarar Oulidi** [7]

[1 & 3] School of Architecture, Planning and Design, Mohammed VI Polytechnic University, Ben Guerir 43150, Morocco
[2] Laboratory of Sustainability in Architecture and Urban Planning, National School of Architecture, Madinat Al Irfan Instituts, Rabat 10001, Morocco
[4] Biospheric Sciences Laboratory, NASA GSFC, Greenbelt, MD 20771, USA
[5] National Meteorology Headquarters, Casablanca, Morocco
[6] Mohammed VI Polytechnic University, Ben Guerir 43150, Morocco
[7] Hassania School of Public Works, Casablanca, Morocco
Email: 1: Laila.elghazouani@um6p.ma Email 2: emamansour@gmail.com Email 3 : hassan.radoine@um6p.ma Email 4 : lahouari.bounoua@nasa.gov Email 5 :k.khomsi@gmail.com Email 6 : khalil.idrissi@um6p.ma Email 7 : hassane.jarar@gmail.com

Abstract
The urban heat island (UHI) is a recognized signature of the urban climate, however beyond this characterization; it is still a relevant phenomenon to study in urban design. In this paper, we seek to characterize UHI in differing urban forms, comparing air and surface temperatures to characterize Air UHI (AUHI) and Surface UHI (SUHI) respectively. The analysis site corresponds to the districts of Casablanca, Morocco's largest city, covering coastal and central neighborhoods with different urban planning styles. We used land surface temperatures (LST) from the Landsat-8 satellite and both observed and simulated air temperatures from the Copernicus reanalysis. We argue that LST is always higher than air temperature and that there is a shift between SUHI and AUHI that we have quantified for daytime and nighttime monitoring. We also concluded that UHI depends on four criteria: location, land use, building height, and road width.
Keywords: Air temperature; Land Surface Temperature; Urban climate; Urban design; Urban Heat Island.

1. Introduction

Rising temperatures are one of the major concerns of the century in terms of their impact on human health and sustainability on Earth. More than peri-urban areas, cities are particularly vulnerable to extreme heat events due to the physical and morphological properties of their urban components (Amen, 2021; Amen et al., 2023; Jacob, 2023; Moretti, 2023). This phenomenon, commonly known as the Urban Heat Island (UHI), refers to the temperature difference between the city center and its outskirts, as defined by (Oke,1987), (Imhoff et al., 2004), (Gartland,2008), (Erell,2011),(Bounoua et al. 2015). The air or surface temperature record takes shape as a “dome” or parabola with the apex at the center of the city where the buildup is dense. Overall, this phenomenon is a consequence of rising temperatures due to trapped thermal energy (Voogt, 2002).

With more pronounced UHI intensities, the concentration of air pollution is higher (El Ghazouani, 2019) and therefore potentially harmful in cities. Combined with rising global average temperatures and heat waves, the effect of UHI exacerbates health risks (Tewari et al, 2019), including heat stroke, dehydration, and exacerbation of cardiovascular, pulmonary, and cerebrovascular diseases and mortality (Tan et al, 2010). In addition, several studies have shown that rising temperatures can influence various aspects of animals, such as morphology, physiology, life cycle, or even behavior and community composition (Hirsch, 2017).

Further studies, in the context of the energy security drive, put a figure on the additional consumption induced by rising temperatures. For Akbari, rising temperatures are responsible for a 5-10% increase in air-conditioning energy consumption (Akbari, 2001), and for Santamouris, air-conditioning electricity consumption rises by 3 to 5% when the temperature rises by 1°C (Santamouris, 2004). It's then a positive feedback, between rising temperatures, increased UHI, and electricity consumption. Whether environmental, natural, health-related, or energy-related, the consequences are far-reaching, and we need to comprehend and model the phenomenon of UHI in order to mitigate it.

Morocco has a diverse climate and urban areas and, like the rest of the world, is subject to the hazards of global warming, but the issue of UHI has only recently been assessed by the scientific community. The impact of urbanization on climate has been addressed by (Lachir et al, 2016) who have to quantify the influence of the built environment in urban areas on the different surface climate perspectives, in contrast with the various natural areas in and around the city of Marrakech, Morocco. This was done by calculating the turbulent exchanges of energy, water, and carbon between the land-atmosphere interface. The authors demonstrated that during the growing season (February, March, and April) the difference in temperature between urban and rural areas is between 1.6°C and 6.0°C at 1 pm, and between 0.7°C and 1.1°C at 5 pm. The role of vegetation as an important modulator in the cooling of Marrakech urban area has also been discussed (Lachir, 2016).

Taking a single city as the object of research, this work did not allow us to generalize and give a clear picture of the issue of UHI on the scale of the whole territory, particularly in view of the diversity of climates according to

geographical areas and human settlements according to their own urban history. The subsequent research by Fathi et al. (2019) fills this gap by assessing UHI in several Moroccan cities. This involved mapping the urbanization of urban centers and assessing UHI in relation to city size, normalized vegetation index (NDVI), and the impervious surface Area (ISA) as an indicator. The results show that the warming brought about by urbanization is 1.5°C during the day and 1.12°C at night, which of the same order of magnitude than the warming threshold stipulated in the Paris Agreement (Fathi, 2019).
Another combined Land Surface Temperature from Landsat-8 and land cover information from the European Space Agency (ESA) to characterize UHI and Urban Heat Sink (UHS) in 5 cities using a method of urban cross-sections. In terms of amplitude, the study revealed that in coastal cities UHIs of around 20°C were observed at the seaside, while the amplitude dropped to 11°C towards the center. The study also looked at cities in desert environments, where the UHI was defined as between 9°C and 12°C in Smara and Marrakech (El Ghazouani et al, 2021).
In this sense, this paper takes up the characterization of UHI by varying and comparing the data used: Land Surface Temperature and air temperature (both observed and simulated). The goal is to understand the difference between these two aspects of UHI, not only in terms of physical characteristics but also in terms of a spatial relation to urban design and building density.

2. Material and Method

The aim of this paper is to study urban heat islands in a comparison between surface and air temperature and to characterize them according to urban specificities. To do so, we selected as a study site the districts of Casablanca, Morocco's largest city (Fig. 1).

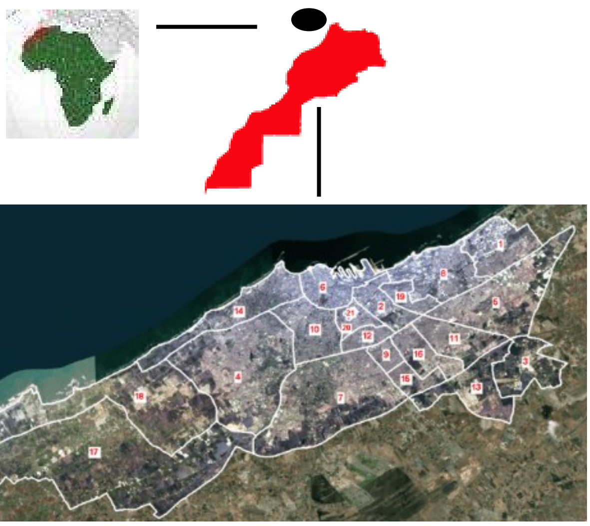

Figure 1: Study site. The regionf CASABLANCA (Morocco) and its districts

This sampling covers central and peripheral districts over continental depths of up to 25 km. The first part, relating to surface temperature, covers all the urban districts of Casablanca, while the second part, relating to air temperature, focuses on 5 districts. These 5 units were chosen on the basis of different urban morphologies, as follow: The Hay Hassani neighborhood is a mix of industrial units and housing, with a checkerboard urban morphology and an almost complete saturation rate. Meanwhile, Sidi Bernoussi district is the site of an industrial zone and is still characterized by urban wasteland that will be studied in the light of air and surface temperatures. Still in the industrial district, Ain Chok is home to both factories and housing where this juxtaposition will be examined in the light of the UHI. Finally, the downtown Maarif district was questioned in terms of its functional mix, and the Ain Sebaa district in terms of its coastline and the high density of its urban fabric.
The measures to be assessed relate to 2016. It is important to note that the UHI study is a temperature differential study and that the actual choice of year is not relevant in itself. Auxiliary research on a 10-year sample has confirmed that this year was not exceptionally cold or hot. To cover the year in its integrality and to overcome the constraint of seasonal climate, we covered the study according to the two extreme seasons (winter and summer). For measurement times, the aim was to match satellite passing times over Morocco: 11 am for Landsat-8 and 1 am-1 pm for Modis.
We used observed and simulated air temperatures (extracted from the ERA-5 platform) to overcome some data availability constraints noted at the level of observed air temperatures. When simulated temperatures were entered, it turned out that these data underestimated actual temperatures, and the 1km resolution proved to be coarse. We therefore had to find an approach that combined the advantages of both observed and simulated air temperatures, while remaining faithful to the site climate. To achieve this, we first superimposed simulated ERA5

reanalysis data on observed data over five years. We applied bias correction for both spatial and temporal criteria. The average difference between observed and simulated data is calculated for each station and season. This led us to deduce the corrected simulated data by adding the mean difference (by station and season) to the simulated temperature. Finally, to check the accuracy of the corrected simulated data, we compared them with with a set of independent observed data that were not included in the correction procedure. The average temperatures differences between the corrected and the observed temperatures were less than 0.8°C.

3. Results and discussion

3.1 Assessing Land Surface Temperature to characterize surface UHI and the direct impact of urban materials

3.1.1 Analysis according to the extreme season-temperate season duality

The tables below show the average LST for all Casbalnaca districts, based on Landsat-8 satellite images processed at 30m resolution. In winter, Sidi Bernoussi records the highest LST at 17.9°C, followed by Ain Sebaa (on the coastal front) at 17.8°C and Hay Mohammadi at 16.9°C. While Sidi Bernoussi is an industrial district, Ain Sebaa, and Hay Mohammadi are known for their high density and finally Maarif, is the coldest district with 15.6°C. This trend reveals the presence of an urban heat sink in the downtown, a major concept addressed by (Carnahan, 1990). This unexpected result can be explained by the albedo of the color white (Casablanca is a Spanish word referring to the house -casa- blanche-blanca-) and the urban vegetation, which helps to cool this district.

Table 1: Breakdown of LST in all Casablanca districts in winter and summer seasons

		Average LST (°C)	
ID	District	Winter	Summer
1	Anfa	16,9	37,2
2	Maarif	15,6	39,2
3	Sidi Belyout	17,4	38,8
4	Hay Hassani	16,6	41,3
5	Ain Chok	16,9	43,6
6	Mers Sultan	16,5	40,0
7	El Fida	16,5	41,7
8	Assoukhour Assawda	17,1	41,6
9	Hay Mohammadi	16,9	41,9
10	Ain Sebaa	17,8	40,1
11	Sidi Bernoussi	17,9	39,7
12	Sidi Moumen	16,8	43,7
13	Sidi Othman	16,5	43,0
14	Moulay Rachid	16,5	44,0
15	Ben Msik	16,2	42,3
16	Sbata	16,7	40,2

In summer, the trends are identical, but the rankings change slightly, with Moulay Rachid the hottest district at 44°C, followed by Sidi Moumen, the slum district, at 43.7°C. In fact, the sheet metal used to roof these units absorbs the sun's rays, which justifies this reflectance and therefore this high temperature. Covering an area of 30 hectares, Casablanca's large city park is a major contributor to Sidi Belyout's average low LST. Indeed, the dense, irrigated vegetation of the urban park is behind this cold signature, due to the phenomenon of evapotranspiration provided by the plants.

Regardless of the season, some districts remain the hottest and the coldest: Ain Chok, Sidi Moumen, Sidi Bernoussi, and Ain Sebaa are the hottest districts, due to their dense occupation, the nature of the land use (industrial and logistical activity) -and the slum clusters. The Anfa district, characterized by its coastal aspect, its golf courses, and its single family housing, has low LSTs due to its seas proximity, and also to low density of the built-up area.

3.1.2 Diurnal Analysis

The Landsat satellite does not provide nighttime surface temperatures, so we turned to data from the MODIS instrument aboard the Aqua platform, whose crossing time over Morocco is 1 am and 1 pm. The results show that at 1 a.m. temperatures drop considerably from those of daytime, with a daily temperature range of 11°C in winter and 22°C in summer. This observation was conducted for the densely populated regions because of their dense urban design and low skyview factor, which significantly inhibits heat dissipation.

Table 2: Temperature distribution across all Casablanca neighborhoods by both day and night

		Winter		Summer	
ID	District	Day	Night	Day	Night
1	Anfa	21,1	10,7	39	17,3
2	Maarif	21,5	9,2	39,8	18,7
3	Sidi Belyout	21,2	10,2	39	19,1
4	Hay Hassani	21,2	9,4	42,1	18
5	Ain Chok	21,3	8,5	40,8	17,3
6	Mers Sultan	20,4	9,8	41,1	19,6
7	El Fida	21,9	9	42,1	18,8
8	Assoukhour Assawda	21,5	9,1	41,8	19,8
9	Hay Mohamadi	21	9,2	42,7	19,8
10	Ain Sebaa	21	8,7	38,7	18,5
11	Sidi Bernoussi	23	9,1	41	18,1
12	Sidi Moumen	20,4	9	43	18,4
13	Sidi Othman	22	9,4	42,2	18,5
14	Moulay Rachid	21,3	9,5	41,8	18,8
15	Ben Msik	21,7	9,5	43,1	18,8
16	Sbata	21,8	8 ,5	41,7	18

Extending the sampling beyond the prefecture of Casablanca to the outlying districts, we find that the lowest nighttime temperatures and the daily temperature ranges are quite remarkable. In the Casablanca perimeter, for example, we record a difference of 16°C in winter and 26°C in summer, due to the dominance of vegetation (and agriculture), a low sky view factor, and absence of buildings, which are considered obstacles to wind corridors. Their absence will allow better wind circulation and therefore significant cooling.

Finally, and unexpectedly, seafront neighborhoods do not cool down quickly, due to their industrial character and the dominance of asphalt and metal roofs. Ain Sebaa, the industrial district, cools by only 12.2°C in winter and 21.3°C in summer. Proximity to the coast is therefore not a determining factor in the cooling performance of these neighborhoods.

3.2. Assessment of air temperature to characterize air UHI in a time series study

Given this scale of assessment, it was not possible to extract information for all districts, due to the lack of stations throughout the city. We were therefore constrained to limit our sampling to five districts of the Casablanca prefecture, the choice of which was explained above. These data come from stations provided by the Directorate of the National Meteorology with the support of the Mohammed VI Foundation for Environmental Protection.

3.2.1 Interpreting five-year and annual averages

To assess air temperature, we began with a broad five-year time scale from 2012 to 2016. The aim was to reveal general trends in temperature change between the locations of the measuring stations. The results show that air temperatures are very high in industrial districts. These sites are home to concrete mixing plants and cement factories, a highly polluting form of production that tends to exacerbate air temperatures (El Ghazouani et al., 2019). The coldest neighborhoods are the sea-front districts and the city center, due to the Urban Heat Sink, previously explained.

The annual reading marks a turning point, and the trend observed over the five-year period is confirmed: Industrial areas are the hottest districts, while the downtown continues to confirm the previously observed UHS. Continuing our investigation of the air UHI field, this time we explore the UHI for the two extreme seasons, tending to maintain the dates on which measurements were taken in preparation for an a posteriori comparison. It's interesting to note that the coldest neighborhoods in winter are not automatically the coldest in summer, due to the **intersection** with another criterion - the coastal front. Bouskoura, on the outskirts of the city, is cold in winter, but in summer it's the coastal front neighborhood that becomes the coldest, regardless of its urban morphology.

Table 3: Observed air temperature distribution across 5 Casablanca neighborhoods by winter and summer

District	Winter	Summer
Hay Hassani	13,6	20,2
Bouskoura	12,2	21,9
Sidi Bernoussi	14,6	21,6
Ain Chok	14,4	21,7
Maarif	15,4	17,2
Ain Sebaa	14,2	21,9

3.2.2 Interpreting the duality of day and night

In this section, we are interested in the daily variation in air UHI over a 12-hour interval between day and night. The significance of this reading lies in the study of district cooling and will lead us to clarify the urban form-ICU causality. The results are as follows:

Table 4: Observed air temperature distribution across 5 Casablanca neighborhoods by winter and summer, day and night

Season	**Time**	**Districts**					
		Hay Hassani	**Bouskoura**	**Sidi Bernoussi**	**Ain Chok**	**Maarif**	**Ain Sebaa**
Winter	11am	15,0	Not available	16,1	17,2	17.6	15,0
	11 pm	12,0	Not available	14,0	12,0	13,1	13,1
Summer	11 am	26,8	29,0	Not available	30,5	29,8	30,5
	11 pm	22,6	22,4	Not available	24,0	24,3	24,7

For all neighborhoods, daytime temperatures are higher than nighttime temperatures in all seasons. This difference averages 3.3°C in winter but rises to 5.7°C in summer, and is due to stronger, more intense radiation in summer, along with a longer insolation. As a result, surfaces take longer to cool down, especially in urban areas. At the same time between winter and summer, summer nights are 12°C warmer in Ain Chok and 10.6°C warmer in Hassani. In summer, Bouskoura and Maarif are almost at the same temperature during the day, but Bouskoura cools down more quickly to 22.4°C, while Maarif remains at 24.3°C. This is where Maarif's dense, tightly-packed urban form is the cause of the heat-trapping at night. In contrast, the urban form and abundant vegetation of Bouskoura contribute to its rapid cooling.

3.2.3 Interpreting the daily average and correcting data unavailability

Continuing the investigation of air temperature in the various districts on different scales, we turn in the following lines to the daily average recorded over 24 hours. The choice of day corresponds to the winter and summer solstices, i.e. December 21 and June 21. The results are as follows:

Table 5: Observed, simulated, and corrected simulated air temperature across 5 Casablanca neighborhoods by winter and summer

District	Temperatures in 2016	Winter	Summer
Hay Hassani	Observed air temperature	14	23
	Simulated air temperature	9,4	20,1
	Corrected simulated air temperature	11,3	21,7
Bouskoura	Observed air temperature	Not available	26
	Simulated air temperature	8,3	20,9
	Corrected simulated air temperature	9,9	24,5
Sidi Bernoussi	Observed air temperature	14	24
	Simulated air temperature	9,2	21,6
	Corrected simulated air temperature	12,6	24,5
Ain Chok	Observed air temperature	14	25
	Simulated air temperature	8,8	20,7
	Corrected simulated air temperature	12	24,4
Maarif	Observed air temperature	Not available	25,9
	Simulated air temperature	8,8	20,7
	Corrected simulated air temperature	12,9	23,9
Ain Sebaa	Observed air temperature	14	25
	Simulated air temperature	8,8	20,7
	Corrected simulated air temperature	11,8	24,1

3.3 Comparison of surface and air temperatures

We suggest a restoration and a confrontation between the air and surface ICUs, or rather a confrontation between two sources of temperature data: the air and the LST.

For the first, we considered the corrected simulated data built according to the bias correction, as explained above that we compared to the LST obtained from Landsat. Practically, it was a question of locating the points of the measurement stations to superimpose the LST map and extract the temperature at this point.

The restitution of these data is shown in the table below:

Table 6: Different temperature data in winter and summer across 5 Casablanca neighborhoods

District	**Different temperature data**	**Winter**	**Summer**
Hay Hassani	Corrected simulated air temperature (CSAT)	11,3	21,7
	Land Surface Temperature (LST)	16,4	32,0
	Difference (LST-CSAT)	5,1	10,3
Bernoussi	Corrected simulated air temperature (CSAT)	12,6	24,5
	Land Surface Temperature (LST)	15,9	35,2
	Difference (LST-CSAT)	3,3	10,7
Ain Chok	Corrected simulated air temperature (CSAT)	12	24,4
	Land Surface Temperature (LST)	15,4	36,7
	Difference (LST-CSAT)	3,4	12,3
Maarif	Corrected simulated air temperature (CSAT)	12,9	23,9
	Land Surface Temperature (LST)	14,7	28,3
	Difference (LST-CSAT)	1,8	4,4
Ain Sebaa	Corrected simulated air temperature (CSAT)	11,8	24,1
	Land Surface Temperature (LST)	18,0	38,9
	Difference (LST-CSAT)	6,2	14,8

e notice that there is always a difference between the air temperature and the surface temperature which is always the highest. This is explained by the nature of urban materials and their albedo which cause them to heat and record high temperatures. The air temperature recorded at 2m from the ground, here the corrected simulated temperature, is greatly influenced by the wind with cooling power.

After this general finding on this comparison the surface temperature and the air temperature, we will be interested in the amplitude of this difference by season and by district. Indeed, the differences in amplitude between air and surface ICU are less pronounced in winter with an average difference of 3.9°C compared to 10.5°C in summer. This is influenced by solar radiation in summer which increases the surface temperature and the quasi-absence of wind which reduces the air temperature. In terms of analysis by district, the districts on the seafront have the largest difference, 14.8°C in summer because of the proximity to the coast that cools the air temperature, which is the reason for a larger difference.

4. Conclusion

The purpose of this paper was to describe the urban heat island in several neighborhoods of Casablanca, Morocco's largest metropolis. Such can be done by combining two data sets: air temperature and surface temperature. This activity of confrontation was carried out on multiple time scales and was subject to an interpretation of urban and geographical order.

The various results revealed that the nature of urban materials and their albedo always cause the LST to be greater than air temperature, as evidenced by the use of many data sources. Indeed, low albedo causes materials to heat, and the LST to rise. The breeze with cooling effect has a significant influence on the air temperature measured at 2 meters from the ground, whether observed or simulated. Furthermore, the characterization of the UHI is temperature dependent: we distinguish between Surface UHI (SUHI) and Air UHI (AUHI).

Also, the refreshing influence of neighborhoods is a unique feature of this paper, which sought to investigate the impact of urban patterns based on diurnal and nocturnal data, as well as surfaces based on the four seasons. According to a temporal analysis, the same district took longer to cool in summer than in winter due to high solar radiation and longer hours of sun exposure. Furthermore, communities that were less densely developed, less saturated, and had wider streets cooled faster. Because of this arrangement, the city captures less solar radiation and allows for faster dissipation of the energy accumulated during the day.

If this paper is a contribution and the first examination of Casablanca's neighborhoods, it draws upon the intersection of temperatures and urbanism, using a variety of data sources and convergent approaches. This paper also tried to address a number of problems and conduct additional research on urban and architectural design, as well as the UHI. Some research perspectives embedded in the temporal continuity and geographical complementarity of this problem can be investigated related to a prospective reading of the data in light of ongoing urban, legal, and environmental changes. Furthermore, at the end of this paper, we believe that this research could have a practical application and aid decision-making. We thus emphasize the need of taking into account the climatic impact, particularly thermal, in all architectural and urban designs for sustainable and resilient communities.

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Conflict of Interests

The Author(s) declare(s) that there is no conflict of interest.

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