Evaluation of thermal comfort in outdoor public space: Case of study: City of Annaba – Algeria

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Abstract. Outdoor public spaces play an important role in the articulation of a city. The thermal comfort of these spaces has become a problem because of climate variations. Our work aims to study thermal comfort in outdoor public spaces in order to tackle the variability between microclimatic parameters which were taken from several field stations. Furthermore, it aims to identify the effect of the different factors and thermal conditions on both the microclimate and the external thermal comfort. A comparative study between three public spaces of the city of Annaba (course, square and garden) has been conducted. The method adopted for this research is based on the measurement of microclimatic parameters. The measurement took place during August 2016. It was performed by a thermal hygrometer to cover air temperature and relative humidity. Then, a thermal anemometer was used in order to estimate wind speed, every 2 hours from 06:00am until 08:00pm. The obtained results confirm the variability of the thermal environment in an urban environment and the impact of vegetation, urban morphology and water on outdoor thermal comfort.

1. Introduction
The sensitive quality of a site is related, for a large part, to its climate, especially its microclimate. The collection of climate data contributes to analyzing the site and solving its climatic problems by enhancement methods [1]. In order to understand the change of the different climatic parameters and the relation of the external thermal comfort with the urban public spaces, a climatic study of the city of Annaba has been conducted over the last 10 years. In the external public spaces, the climatic parameters that are employed in this research, temperatures of the air, relative humidity and wind speed, are the most responsible for the thermal comfort of the individual [2].

2. Problematic
Climate change has created multiple problems in urban areas. High temperatures, bad air quality, and strong winds can respectively cause heat stroke, dyspnoea, and injury [3]. Therefore, in recent years, outdoor thermal comfort has become a problem owing to natural phenomena such as global warming, and artificial ones such as urbanization.

As a result, these variations can affect the health, the individual thermal comfort, the physical environment, including air movement, temperature distribution and access to the sun. Architectural conception also affects the users’ perceptions, which are related to particular sites [4] because the quality and intensity of each activity are affected by the level of thermal discomfort exerted by individuals, when they are exposed to the microclimatic conditions of the site [5].
3. Presentation of the investigation site

The city of Annaba is located in the extreme east of the country –Algeria-. In its entirety, it presents a Mediterranean climate [6] with seasonal variations marked by a hot summer and cold humid wintertime, which is rainy [7]. So, Annaba is characterized by a humid climate (60 to 70%). The maximum average temperature was recorded during the month of August with a value of 31.4°C, whereas, the minimum average temperature was recorded during the month of February with a value of 6.60°C (2005-2015) [8]. The selected investigation sites are part of the city center of Annaba. They are realized according to different conceptions. They also differ in the location, arrangement, components and urban furniture, density of the vegetation, and the presence or absence of water.

3.1 Revolution course

Table 1. Characteristics of measuring stations in revolution course.

| Orientation          | Station     | Characteristics                                                                 |
|----------------------|-------------|---------------------------------------------------------------------------------|
| North-South          | Station 01  | Vegetation composed by grass, shrub, Araucaria, pine, and palm.                 |
|                      | Station 02  | Discovered.                                                                     |
|                      | Station 03  | Dense vegetation.                                                               |
|                      | Station 04  | Intersection of the ventilation corridor.                                       |
|                      | Station 05  | Move away by 25 m from the S4.                                                   |
|                      | Station 06  | Nearest point to the sea.                                                        |

3.2 Square el Houria

Table 2. Characteristics of measuring stations in the square el Houria.

| Orientation                  | Station     | Characteristics                                                                 |
|------------------------------|-------------|---------------------------------------------------------------------------------|
| North-East and South-West    | Station 01  | Locate in intersection of several alleys, semi covered.                        |
|                              | Station 02  | Large density of vegetation.                                                    |
|                              | Station 03  | Low density of vegetation.                                                      |
|                              | Station 04  | Discovered, locate in the playground.                                           |

3.3 Boukhatouta Hocine garden

Table 3. Characteristics of measuring stations in the Boukhatouta Hocine garden.

| Orientation                  | Station     | Characteristics                                                                 |
|------------------------------|-------------|---------------------------------------------------------------------------------|
| North-East and South-West    | Station 01  | Large mass of vegetation.                                                       |
|                              | Station 02  | Densest point in vegetation.                                                    |
|                              | Station 03  | Discovered, locate in the playground.                                           |

4. Methodology

The measurement of air temperature, relative humidity and wind speed was performed during 03, 04 and 05 August 2016 for all investigation sites. These days were chosen because of the heat accumulation during the days that preceded the overheating period, and the reduction of ventilation.
The climate measurements were taken at a height of 1.20 m. It was done every 2 hours from 06:00 AM to 08:00 PM. This chosen duration represents the space usage period and represents the change of the thermal balance of the exterior space.

Measurements were carried out in 13 stations in the three chosen public spaces, 06 of which were fixed in the revolution course, 04 in the square of el Houria, and 03 in Boukhatouta Houcine garden. Their distribution was made according to shade, presence or absence of vegetation and water, ventilation corridors, and frequented spaces.

Measurements were performed by means of a thermo hygrometer and a thermo-anemometer. The thermo hygrometer was used to hold air temperature and relative humidity. It is composed of a probe with an electronic sensor and a screen that displays the measuring units (° C, ° F, %), the minimum and maximum values of temperature (0-60 ° C) and humidity (20-95%). The thermo-anemometer was used to measure the wind speed. This instrument is characterized by a telescopic probe of high precision (0-25m / s) that can be stretched up to 1m of useful length. The device allows changing the unit of measurement.

5. Results and discussion
5.1 Revolution course

![Figure 1](image.png)

Figure 1. (a) Evolution of the air temperature in the revolution course. (b) Evolution of the relative humidity. (c) Evolution of the wind speed.

5.1.1 Evolution of the air temperature. The temperature values homogeneously increase in the 06 stations between 06:00 and 10:00. For all the stations, the minimum values are recorded at 06:00. Most of the measuring points present maximum temperatures at 14:00. The values were approximate; the hottest value of temperature recorded in the S2 was 33.1 ° because it does not contain solar masks. In addition, the measurement was at a distance of 1.20 meters above the ground. The surfacing of the latter is made by a concrete slab which is very absorbent material to heat and solar radiation. The points (03 and 04) present cooler temperatures almost all day. This is mainly due to the density of the vegetation, and the presence of ventilation. The Station 06 presents the nearest point to the sea which justifies the cooling of the air in this station.
5.1.2 Evolution of the relative humidity. Station 06 records the maximum value of the relative humidity with 66.4% at 20:00. This is mainly due to the proximity of the sea and the decrease in temperature. Therefore, it confirms the important effect of the water in the humidification of the air. The relative humidity depends on the temperature and the amount of water that the air contains because when the temperature decreases the relative humidity increases and vice versa. Station 01 has the minimum value of relative humidity at 12:00 with a value of 46.9%. It also represents the lowest rates because it is the furthest point from the sea. Also, the effect of transpiration is not important in this area because of the low density of vegetation. It confirms the role of its effect in the humidification of the air by increasing humidity in the station 04 at 14:00 which is owed to the density of vegetation, and the flow of fresh air.

5.1.3 Evolution of the wind speed. For a first analysis, the speed of the air is low during the morning. Its minimum value is retained at 06:00 in the stations (S1, S4, S5 and S6) with an average of 0.2m/s. From 10:00 to 18:00 the speed of the air has become stronger and it reverses until 20:00. In general, station 01 is the calmest point in the course. It is well protected from the air by gigantic buildings and large trees (palm, pine ...). This explains the humidity decrease and the rise of the temperatures. Station 06 is the most windy and disturbed. The maximum speed was at 16:00 with a value of 3.7 m/s. This trend is explained by the sea breezes. Station 03 is less windy compared to point 06. However, it also has high speeds because of the airflow from the ventilation lanes. During the period from 10:00 until 16:00 (overheating period), the temperatures are increased. The relative humidity is decreasing and the wind speed is high. This is explained by the flow of hot air and dry.

5.2 Square of el Houria

![Figure 2](image.png)

*Figure 2.* (a) Evolution of the air temperature in el Houria square. (b) Evolution of the relative humidity. (c) Evolution of the wind speed.

5.2.1 Evolution of the air temperature. For a first observation, all the stations recorded minimum temperatures at 06:00. Station 02 recorded a value of 22.8 °C whereas station 04 presents warmer values compared to the other points. It reaches its maximum at 14:00 with a value of 34.8 °C because of the cumulative heat due to solar radiation and the absence of sun protective masks. During the whole day, the stations (S1, S2) present cooler values compared to the S3 S4, because they are protected from solar radiation by vegetal mass and thus offer cooling area. From 18:00, the values become almost
identical in all the stations because the solar rays start to disappear and a current of air has refreshed the entire square.

5.2.2 Evolution of the relative humidity. The maximum relative humidity was recorded at 08:00 in all the measuring points. Station 02 recorded a value of 63.2% due to the effect of the transpiration which was due to the large vegetal mass. However, the minimum humidity was recorded at 14:00. Point 04 has taken a value of 43.8% due to the absorbed and stored heat. This is due to the rising temperatures, the exposure to the sun and lack of vegetation which reduced the effect of plant leaves evaporation. Stations 01 and 02 recorded more humid values throughout the day because they contained dense vegetation which allowed having a large effect of transpiration. Therefore, the air contained large amount of water.

5.2.3 Evolution of the wind speed. At the beginning of the day, the air was calm in all the measuring stations. Station 04 records a minimum speed at 08:00 with a value of 0.3 m/s. Point 03 recorded a maximum speed with a value of 2.7 m/s because it contains a low density of vegetation which facilitated the air flow into the area. Despite the density of vegetation it contained, the second station was the windiest during the morning and afternoon. This is due to the ventilation corridors made by the various existing alleys in the square. Station 04 was the quietest place during the whole day because it was protected by buildings. So, the mass of vegetation contained in point 02 slowed down the wind speed in point 03 because of the wind`s direction. Thus, the air in this zone was very hot and dry because the station had the hottest temperature values and the driest humidity.

5.3 Garden of Boukhatouta Hocine

![Figure 3](image_url)  
**Figure 3.** (a) Evolution of the air temperature in Boukhatouta garden. (b) Evolution of the relative humidity. (c) Evolution of the wind speed.

5.3.1 Evolution of the air temperature. Overall, the temperature values increase from 06:00 until noon. The minimum temperature is recorded in the second station at 06:00 with a value of 22.9 °C. However, the three stations present a reconciliation value before noon. This similarity is due to the vegetation density in point 01 and 02, the flow of air and to the shadows carried by the surrounding buildings in point 03. At noon all the stations have maximum temperatures, because the sun was perpendicular and
the solar rays were well exposed in the zone. In the afternoon, the temperatures gradually decrease, except in station 03 where the highest temperature kept its recorded at 12 o'clock because of the heat accumulation. Station 02 recorded fresh values during the whole day. This is explained by the vegetation mass that protects the area from solar radiation.

5.3.2 Evolution of the relative humidity. Overall, the values of the relative humidity were balanced at the 03 points during the day. At 08:00, all stations had maximum values owing to the effect of the vegetation on the air humidification. The highest rate was recorded in station 02 with a value of 64.6%. This station had the most humid zone during the whole day (the densest point in vegetation). From 08:00 the humidity levels dropped. At midday, the stations 01 and 03 recorded minimum humidity with values of 47.9% and 47.7% respectively. The warming caused by the rise of temperature contributes to this decrease. During the afternoon, the humidity values raised attentively because the temperature dropped. They were close to 20:00.

5.3.3 Evolution of the wind speed. In general, there was a disturbance of values throughout the day in the 03 measurement points. The values vary between 0.2 m/s and 2.4 m/s. The first was recorded in station 01 at 06 o'clock. The second was retained in station 03 at noon. Station 01 had low airflow. It was the quietest point compared to the other points because of the vegetation density. So, the wind speed was slowed down by the trees lamination. Its speed was high in stations 02 and 03. The air penetration in this zone was made by the ventilation corridors. At noon station 03 had a maximum temperature. It also had maximum airflow with minimal humidity during the same hour. So, the area was exposed to hot, dry winds.

6. Conclusion:
Based on the results obtained in this study, the variability of the thermal environment in an urban scene is demonstrated. Microclimatic parameters (air temperature, relative humidity, and wind speed) differ from one measuring station to another and from one public space to another. Among other, the impact of vegetation on outdoor thermal comfort is well demonstrated by these measured parameters. This efficiency depends on the type, arrangement and vegetal density contained in each station.

The urban morphology also has an important effect on thermal comfort in the studied spaces, through its shadows and the ventilation corridors generated by the buildings.

The presence of water can also improve the microclimate and thus improve thermal comfort. This impact increases or decreases all depending on the absence or situation of the measuring point with respect to water.

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