DOI: https://doi.org/10.14256/JCE.3568.2022

Primljen / Received: 16.7.2022.
Ispravljen / Corrected: 4.9.2022.
Prihvaćen / Accepted: 10.11.2022.
Dostupno online / Available online: 10.12.2022.

The impact of urban form on urban heat island variation in a Mediterranean city

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Research Paper

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The impact of urban form on urban heat island variation in a Mediterranean city

The Urban Heat Island (UHI) effect has increased with the increase in urbanisation and climate change, especially in cities with arid climates. This study aims to understand the influence of urban forms on creating UHIs by assessing seven sites in a case study in Mostaganem city, which is located on the Mediterranean coast in northern Algeria. A weather station and an infrared thermometer were used to collect the thermal data from the selected sites (S1 to S7). Site S1 was modelled and simulated using ENVI-met software to evaluate the UHI effect on the open area bounded by the surrounding buildings. The simulation data was then validated by the real time data collected from the actual site. Thereafter, seven common urban form configurations were identified and modelled around the same site (S1), and simulated for their individual impacts, one by one. The simulation results were compared in terms of air temperature, wind speed, and ground surface temperature, not to mention that the influence of the different urban forms contributed to the UHI effect in the bounded area. Semi-enclosed configurations of the urban forms that were protected from direct solar radiation recorded the lowest air and ground temperatures, while the difference between temperatures on the site rose to 2 °C in the hottest hours of the day.

Key words:

urban heat island, urban forms, numerical simulation, field measurements, Mediterranean city

Prethodno priopćenje

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Utjecaj urbanih oblika na varijacije urbanih toplinskih otoka u mediteranskom gradu

Učinak urbanih toplinskih otoka (UTO) povećao se s urbanizacijom i klimatskim promjenama, što je dovelo do još veće izraženosti nepovoljnih učinaka toga problema, osobito u gradovima sa sušnom klimom. Cilj ove studije jest razumjeti utjecaj urbanih oblika na stvaranje urbanih toplinskih otoka istraživanjem sedam lokacija u sklopu studije slučaja u sjevernome Alžiru, odnosno u gradu Mostaganemu koji se nalazi na obali Mediterana. Za prikupljanje toplinskih podataka s odabranih lokacija (od S1 do S7) korištena je meteorološka postaja uz infracrveni termometar. Situacija S1 modelirana je i simulirana softverom ENVI-MET za procjenu učinka UTO-a na otvorenom prostoru omeđenom građevinama. Zatim su simulacijski podaci potvrđeni podacima prikupljenima u stvarnom vremenu na konkretnoj lokaciji. Nakon toga evidentirano je i modelirano ukupno sedam konfiguracija urbanih oblika na istome mjestu (S1) te je potom kreirana simulacija koja odražava njihove pojedinačne utjecaje. Rezultati simulacije uspoređeni su s obzirom na temperaturu zraka, brzinu vjetra i temperaturu površine tla te je utjecaj različitih urbanih oblika pridonio učinku UTO-a na tome omeđenom području. Uočeno je to da su poluzatvorene konfiguracije urbanih oblika koje su bile zaštićene od izravnoga Sunčeva zračenja zabilježile najniže temperature zraka i tla, dok je temperaturna razlika na lokaciji u najtoplijim satima dana bila veća za 2°C.

Ključne riječi:

urbani toplinski otok, urbani oblici, numerička simulacija, terenska mjerenja, mediteranski grad

1. Introduction

The urban heat island (UHI) effect was observed for the first time in the early 19th century by Luke Howard who, while taking thermal measurements at different locations in London, noticed that there was a temperature difference between the urban and rural sites [1]. This higher urban heat was described as a "pool of warm air", or an island of heat in the urban areas; hence, the term "UHI effect" was coined. [2] Akbari explains "Urban areas tend to have higher air temperatures than their rural surroundings because of gradual surface modifications that include replacing the natural vegetation with buildings and roads". This difference in temperature can be as high as 5 to 15 °C [3], and can generate risks in urban areas, ranging from thermal discomfort to mortality [4, 5]. Additionally, these high temperatures lead to an increase in the cooling energy consumption in urban areas [6], while the cooling equipment itself generates anthropogenic heat, which is one of the causes of urban heat islands [7]. Thus, a vicious circle starts that needs to be disrupted. Urban heat mitigation strategies can be organised into three categories as follows [8]:

a) Vegetation: research has shown that trees in urban areas have a valuable effect in reducing air temperature because of evapotranspiration [6, 7].

b) Surface materials: Materials used in urban fabrics play a significant role in the thermal balance of the city. They absorb incident solar radiation and dissipate a portion of the absorbed heat in the atmosphere via convective and radiative processes, raising the ambient temperature [9, 10]. In addition, changes in surface colours, absorptivity, or reflectivity of materials can prevent heat accumulation, e.g., many researchers have evaluated reflective roofs and concluded that cool roofs can reduce air temperature at the pedestrian level [11, 12].

c) Urban factors: Oke [13] and Olgyay [14] were the first to investigate the interaction between the built form and microclimate. Stewart [15] used morphological parameters such as urban density, sky view factor (SVF), and surface albedo to identify local climate zones (LCZs).

Some researchers investigated street geometry; Ali-Toudert and Mayer [16] simulated thermal comfort of different orientation of the urban canyon in the hot and arid climate of Ghardaia, in Algeria, and found that the air temperature decreases when the height-to-width ratio (H/W) increases. Bourbia and Awbi assessed the impact of the H/W ratio and sky view factor of building clusters on air and surface temperatures in the hot and arid climate of the city of El-Oued in Algeria, and concluded that high temperatures can be prevented in urban canyons by controlling the SVF and street configuration [17]. In Fez, Morocco, Johansson took several measurements and showed that a dense urban area with deep canyons is favourable for summer seasons; however, in cold seasons, wider streets can be more suitable [18]. From above, it is concluded that arid and semi-arid climate canyons with high W/H ratios that produce shaded zones and are more suitable for urban heat mitigation.

Other studies have assessed the impact of form and orientation of urban blocks on UHI. For example, six archetypal generic urban forms were proposed for London [19], and were analysed and compared in terms of day lighting admission and building characteristics. This study concluded that courtyards perform best in colder climates. Similarly, Taleghani evaluated the impact of three types of urban blocks (single, linear, and courtyard shape) on outdoor thermal comfort in the temperate climate of the Netherlands [20]. This study showed that the courtyard allows a limited amount of solar radiation which creates the best comfort conditions. This is in contrast to linear blocks which are more exposed to solar radiation, and thus cause uncomfortable conditions in summer. Another study done by the same researchers [21] on different types of courtyards evaluated three urban heat mitigation strategies that improve the courtyard's microclimate: changing the albedo of the surface, and including urban vegetation and water elements. The results show that courtyards oriented N–S are favourable for hot climates, whereas courtyards oriented E–W are recommended for colder climates.

In summary, researchers around the world have used different techniques in different climates to investigate the effect of urban morphology on creating urban heat islands, as well as measures to mitigate the build-up of heat in urban areas. It becomes more crucial to investigate the environmental performance of existing urban forms and to detect urban parameters that influence the formation and development of urban heat islands. This study presents the outcome of research carried out on the UHI impact of different forms of urban blocks that have become the prescribed configurations for designing new city extensions, as per the planning policies in Algeria. After colonisation, housing policies in Algeria focused more particularly on the mass production of residential buildings, while the environmental quality of the new settlements was neglected in favour of cost and speed of construction. Moreover, this study evaluates one of the most important urbanisation policies of the post-colonial era: 'Les zones d'habitat urbain nouvelles (ZHUN)', i.e., the 'new urban living areas', and analyses the form and orientation of urban blocks in the ZHUN for their UHI effect.

2. Methodology

This study is based on four research approaches, namely field measurements, numerical simulations, model validation, and comparison of design configurations. Thus, to study the UHI effect, the following steps were taken:

- Thermal and wind data was gathered from selected sites in the urban case study area.

- One of the sites was modelled and simulated to map the UHI effect.
- Data obtained from the simulation was validated with the measured data from the actual site.
- The various urban block configurations around the virtual site were modelled and simulated to compare their UHI effects.

Details on the research material and methods are given in the following sections.

2.1. Study area

The study was carried out in Mostaganem, a small city in the N–W of Algeria (35.933 latitude and 0.08 longitude), 334 km to the west of the capital city of Algiers (Figure 1). Mostaganem has a semi-arid climate in summer and winters are mild with an average annual rainfall of 350 to 400 mm [22]. In addition, winter temperatures lie between 10 and 18 °C and summer temperatures range from 22 to 32 °C, although in August, the temperatures can go up to 35 °C.

Figure 1. a) Location of Mostaganem city in Algeria; b) location of Kharrouba municipality in Mostaganem; c) location of the study area district 348 in Kharrouba

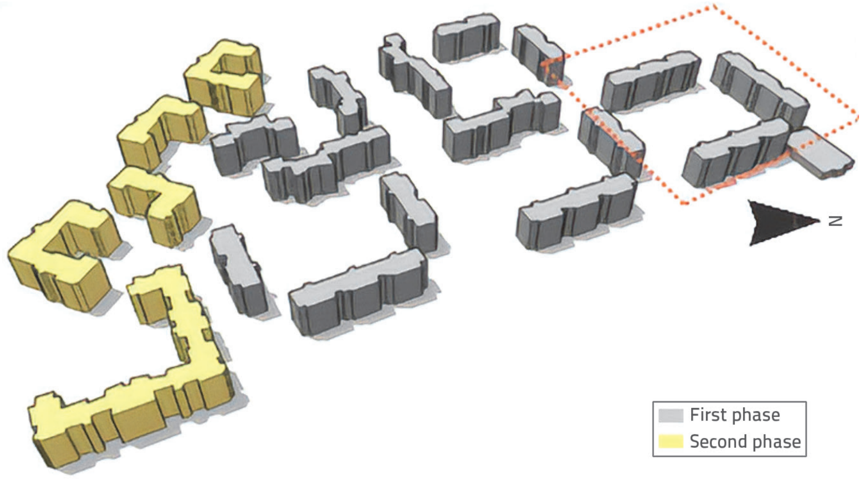


Figure 2. 3D view of the urban housing in district 348, showing the case study block marked with a red boundary

The purpose of this investigation is to assess the influence of urban morphology with respect to the form and orientation of urban blocks on the outdoor thermal conditions. For this purpose, an open midrise residential urban section of district 348 in the Kharrouba municipality (Figure 1) was selected as the case study area from the new urban zone development in the N–E of Mostaganem city.

The first phase of the district was built in the 80s for the academic staff of the local university. Here, the blocks have the same linear form, reflecting the policy of the ZHUN. On the other hand, the second phase was built later, under a social housing programme to solve the housing deficit urgently; thus, the available land blocks with different forms and orientations were fitted into the site (Figure 2).

2.2. Field measurement

Two devices (Figure 3) were used to measure the air temperature, relative humidity, wind speed and direction, and ground surface temperature. The Froggit weather station was fixed on a tripod at a height of 1.75 m above the ground (at pedestrian scale), and the infrared thermometer that was used to measure the ground surface temperatures at exactly under the weather station was handheld. This operation was repeated for each site every two hours, noting that the instruments were manually transported between the sites. Specifications of these two measurement instruments are listed in Table 1.

Figure 3. Froggit WH4000SE weather station to take temperature, RH and wind data set up in site S1 (right), and infrared thermometer UNI-T UT301A to take the ground surface temperature (left)

Table 1. Specifications of the two measuring instruments; weather station and infrared thermometer

Parameter	Device	Range	Accuracy
Air temperature at 1.7m height [°C]	Froggit weather station model WH4000SE WI-FI	-40 to +60 °C	±1 °C
Relative humidity [%]	Froggit weather station model WH4000SE WI-FI	10 to 99 %	±5 %
Wind speed [m/s] and Wind direction	Froggit weather station model WH4000SE WI-FI	0 – 50 m/s	±1 m/s (for wind speed < 5 m/s) ±10 % (for wind speed > 5 m/s)
Ground surface temperature [°C]	Digital infrared thermometer model UNI-T UT301A	-18 to +350 ° C	±1.8 °C

Weather data was collected on the 6th of August 2019 from 07:00 AM to 07:00 PM (GMT+1), with a sunny and cloudless sky in the morning and cloud cover in the afternoon. The temperatures ranged between 24 and 34 °C, with a relative humidity (RH) between 56 and 85% and wind speed of 4.4 m/s. The mobile weather station was used to record the temperature, humidity, and wind data at seven predetermined locations that had different block configurations to represent the sample urban forms in the district. Sites S1, S3, S5, and S6 were located in semi-enclosed blocks, S2 was located at the intersection of three linear blocks, and S4 and S7 were located near parallel linear blocks, as shown in Figure 4.

Figure 4. The seven selected sites (S1 to S7) having different urban configurations in the case study area district 348 where the weather station and infrared thermometer were used to collect air and ground surface temperatures, humidity and wind data

Air and ground temperature, RH, wind speed, and direction were measured every 2 h for 10 min at each site and the average values were recorded. Therefore, at each location (Figure 4) six sets of data were collected in a 12 h period.

2.3. Numerical simulations

ENVI-met, an urban simulation software, was used to simulate the urban microclimate first by producing a three-dimensional urban model of the case study area to simulate the combined effects of the building and ground surfaces, plants, and wind flow. This software provides reasonable control on certain variables and flexibility for others, and gives temporal accuracy of 10 s and a spatial accuracy of 0.5 to 10 m for the urban grid model (https://www.envi-met.com). Researchers have used this software to simulate urban built environments and landscaping, and it has been validated for evaluating different climates [20, 23, 24].

The spatial resolutions used in the present simulations are 2.5 m horizontally and vertically, some variables such as vegetation and albedo which may affect the microclimate were assumed constant in all simulations.

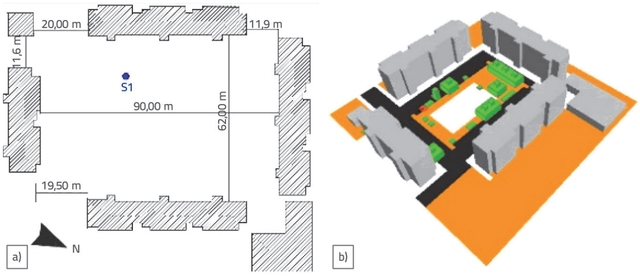


Figure 5. a) Site plan of the selected portion of the urban area around S1 in district 348 taken from the cadastral archive; b) 3D simulation model of the selected residential blocks

To build the 3D model in ENVI-met, the building geometry was input according to the cadastral plans and the in-situ survey, while meteorological data were taken from the infoclimat website. As shown in Figure 5, a 50 x 50 x 40 grid was used to model the case study residential blocks, and the simulations were run for 12 h, from 07:00 am to 07:00 pm. The required inputs for the simulations are listed in Table 2.

Table 2. Input data for ENVI-met simulations

Input variable	Input data
Simulation day	06.08.2019
Simulation period	From 07:00 am to 07:00 pm
Spatial grid resolution	2.5 m horizontally, 2.5 m vertically
Initial air temperature	Max 34 °C, Min 24 °C
Wind speed	4.4 m/s
Wind direction	310°
Relative humidity	Max 85%, Min 56%

In previous studies, in which urban blocks were examined, certain variables were also investigated, such as floor area ratio and building coverage ratio. In this study, the case study buildings have an identical height (17 m); therefore, the investigation was performed in terms of block form and orientation, and different urban morphology scenarios of the real case were evaluated.

The actual urban block, which was simulated as the base case, has an open rectangular space measuring 90 x 62 m surrounded by four linear residential blocks. The scenarios for seven block configurations around this space were designed as follows: the first variation of the urban block had a closed courtyard form; the second was parallel linear blocks with a N–S orientation; the third was parallel linear blocks with an E–W orientation; the fourth were L-shaped blocks with an E–W orientation around a semi-open courtyard; the fifth were L-shaped blocks with a N–S orientation around a semi-open courtyard; and the sixth and seventh were U-shaped blocks with the open courtyards oriented west and east, respectively (Figure 6).

The courtyard and linear blocks were inspired from previous studies [19, 20, 25], while blocks with a U and L forms are common in Algerian housing projects.

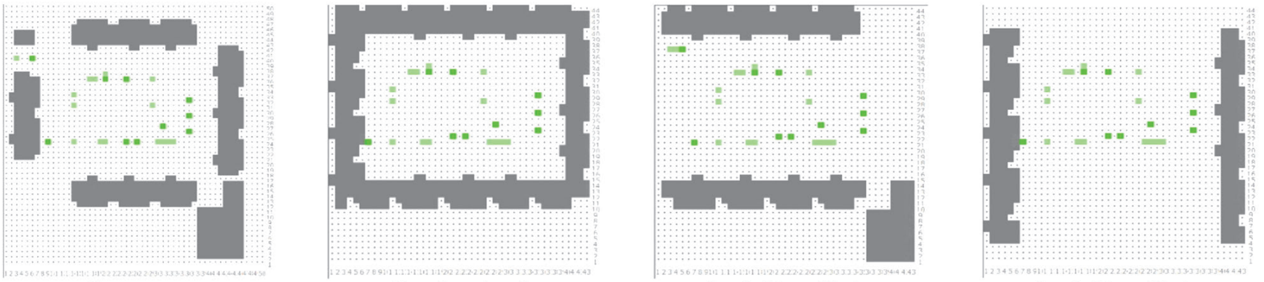
3. Results and discussion

Results obtained from field measurements and numerical simulations are presented, compared, and discussed in the following sections.

3.1. Field measurements

Data on the air temperature, RH, wind speed and direction, and ground surface temperatures were collected from the seven sites in proximity to different urban building forms in the Kharrouba district of Mostaganem city. The data presented in Figure 7 show that the differences in air temperatures between the seven sites range from 2 to 4.5 °C due to the impact of urban geometry and, therefore, the incoming solar radiation on temperature varied.

Between 07:00 and 13:00 at site S6, the weather station recorded the highest air temperature (T_{air}= 27.8°C from 07:00 to 09:00; 30.7 °C from 09:00 to 11:00; and 30 C from 11:00 to 13:00), while at sites S1, S2, S3, and S4, the lowest T_{air} were recorded.

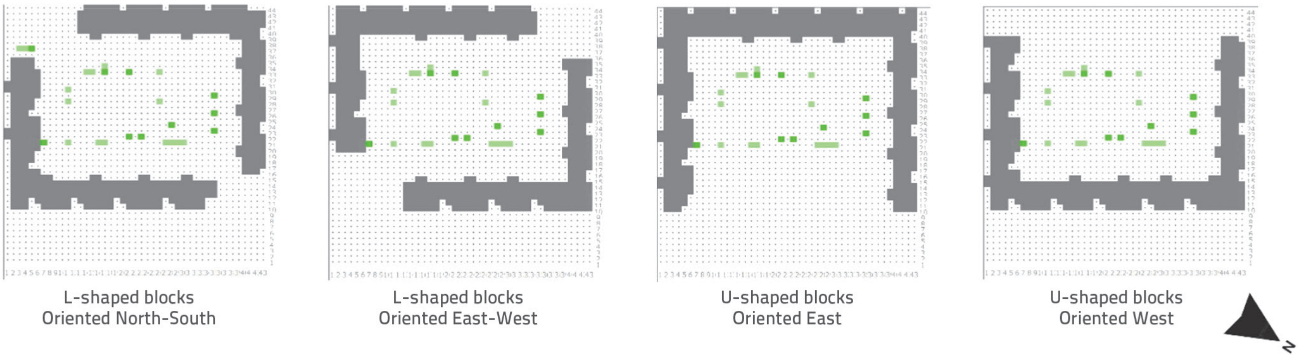


Base case

Closed courtyard

Parallel linear blocks
Oriented North-South

Parallel linear blocks
Oriented East-West



L-shaped blocks
Oriented North-South

L-shaped blocks
Oriented East-West

U-shaped blocks
Oriented East

U-shaped blocks
Oriented West

Figure 6. Variations of the urban block forms used in ENVI-met simulation scenarios

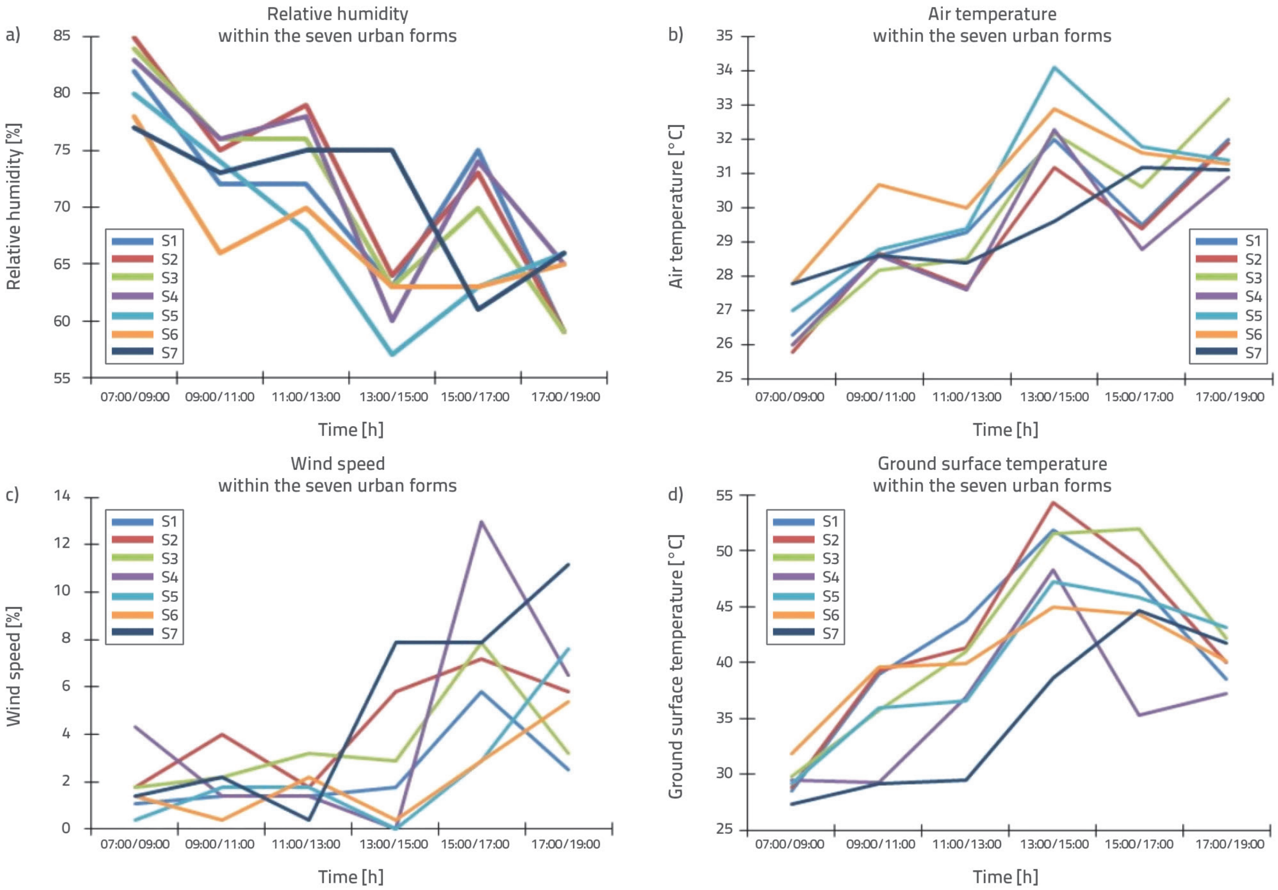


Figure 7. A comparison of measured climatic data from the seven sites: a) Air temperature; b) Relative humidity; c) Wind speed; d) ground surface temperature

On the other hand, S5 and S6 had high air temperatures and low wind speed between 13:00 and 17:00, S4 showed low T_{air} and high wind speed between 15:00 and 17:00, and uniform conditions prevailed from 13:00 to 15:00 at S7.

The values of the ground surface temperature (T_{gs}) were higher than T_{air}. T_{gs} in site S3 increased from 15:00 to 17:00 to reach 52 °C and then decreased; S2 shows the same behaviour, where T_{gs} increased until it reached 54.3 °C between 13:00 and 15:00.

Low T_{gs} were recorded between 07:00 am and 15:00 pm in S7 because the station was shaded during this period.

3.2. Numerical simulations

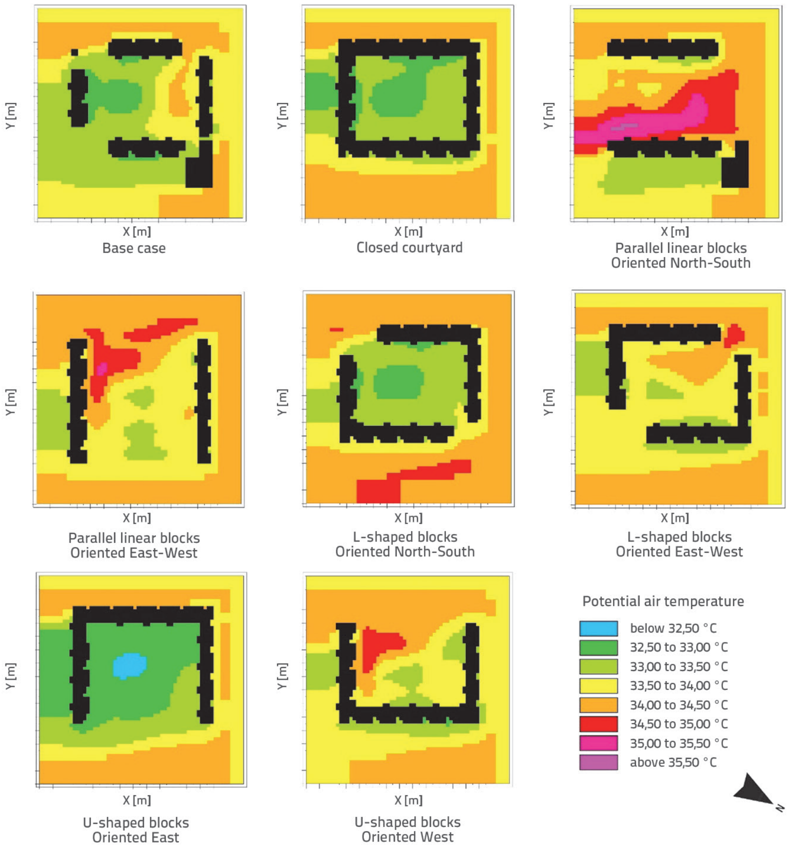
Simulations of the 3D models of the base case and its seven variation scenarios in ENVI-met were run for a 12 h period from 7:00 am to 7:00 pm. Results for air temperature, Wind Speed, and ground surface temperature variables were downloaded to compare the simulation data for the different scenarios.

The results of scenarios are complex since there are numerous outputs for each hour of the simulation period at different levels, from the bottom of the model grid to the top. The following figures present the spatial and temporal distribution of T_{air} and T_{gs} as well as their relationship to wind speed and urban form. Figure 8 shows the spatial distribution of air temperature while Figure 9 shows that of wind speed for the real case and the seven scenarios at the hottest hour of the reference day, i.e. at 2 pm. The two figures present visually mapped data at a height of 1.75 m above the ground.

As shown in Figure 8, the two linear blocks, the U block oriented west, and L2 recorded the highest T_{air} (between 34.5 °C and 35.5 °C); while the lowest temperature values were seen in the U form oriented east, the closed courtyard, and L1 blocks (between 33 °C and 33.5 °C).

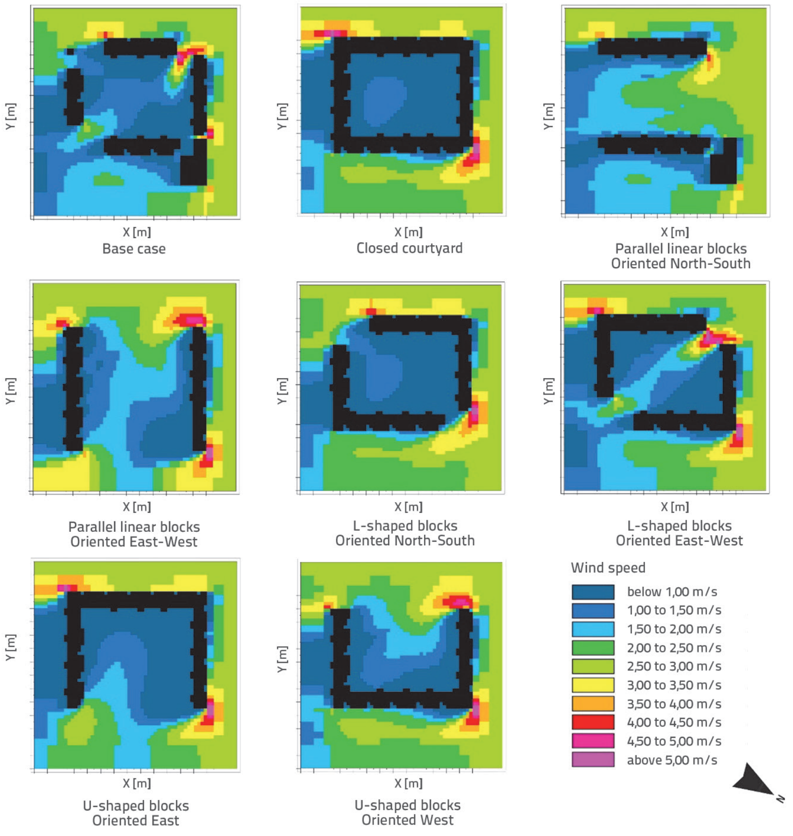
As shown in Figure 9, the open area between the linear blocks recorded the highest wind speeds (Ws) (between 2 m/s and 3 m/s) because of the canyons formed by the two parallel blocks that function as a wind channel. In the closed courtyard and semi-enclosed courtyard blocks (U form oriented east and L forms), the highest wind speed was seen in the central area owing to turbulence.

Air temperature presents variability across the different urban forms (up to 2°C) and has different profiles. This is because the wind coming from the east has been obstructed



Base case
Closed courtyard
Parallel linear blocks Oriented North-South
Parallel linear blocks Oriented East-West
L-shaped blocks Oriented North-South
L-shaped blocks Oriented East-West
U-shaped blocks Oriented East
U-shaped blocks Oriented West

Figure 8. Simulated air temperature (T_{air}) for the chosen sites with different urban forms, at 14:00 pm. Data mapped at a height of 1.75 m from the ground



Base case
Closed courtyard
Parallel linear blocks Oriented North-South
Parallel linear blocks Oriented East-West
L-shaped blocks Oriented North-South
L-shaped blocks Oriented East-West
U-shaped blocks Oriented East
U-shaped blocks Oriented West

Figure 9. Simulated Wind Speed (Ws) for the seven sites with different urban forms at 14:00 pm. Data mapped at a height of 1.75 m from the ground

by the structure to the south of the linear block oriented E–W, by the structure to the east of the U block oriented west, and by the structure to the east of the linear block oriented N–S. Consequently, hot stagnant zones are created around the buildings because the obstructed airflow is not able to dissipate the built-up heat.

In the courtyard and L1 blocks heat exhibits different behaviour, the N–W area appearing in the map is subjected to solar radiations, and since wind speed is low, this heat cannot be dissipated. The U block oriented east has a similar profile except that it is open from the east which allows heat to dissipate easily, while in L2, the hot air enters the area enclosed by the blocks from the west direction, and this model generates a Venturi effect.

3.3. Model validation

To assess the accuracy of the numerical simulations, a validation was performed through a comparison between the 3D simulated model's data and the weather station data from the in-situ measurement campaign at site S1 in district 348. Figure 10 shows similar trends in the daily variations of simulated and observed air temperature, and Figure 11 gives the positive correlation between the two data sets, which is quite strong (R = 0.862).

Root mean square error (RMSE) is used to measure differences between predicted values (here simulated) and observed values (here in-situ measurements). The RMSE between simulated and measured air temperature is approximately 2.16 °C with a Pearson correlation coefficient of 0.862. These values are better than those presented in other studies where the simulation results were still acceptable with a RMSE of 3.7 °C [24].

On the other hand, the simulated model overestimated the air temperature in the afternoon by 3.4 °C, while the peak of the hottest hours was at a different time from the real peak at the location. This discrepancy can be justified by the fact that the ENVI-met software is normally run for cloud free sky conditions and this input was neglected, but on the day when real time data was measured, the latter was cloudy in the afternoon and the solar rays were blocked.

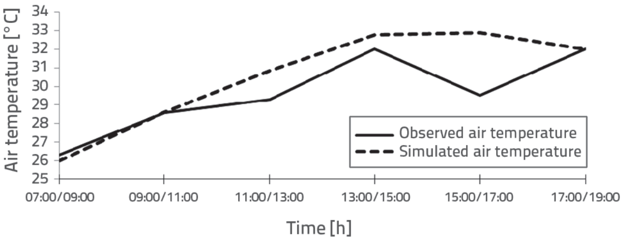


Figure 10. Daily variation of simulated and observed air temperatures, showing a similar trend

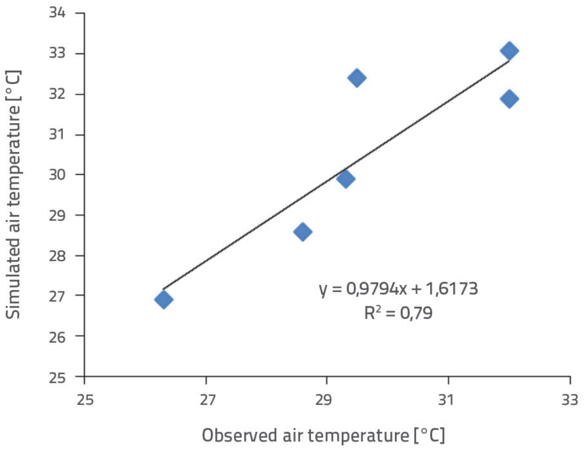


Figure 11. Correlation between simulated and observed air temperature for the six time periods is fairly strong; R2 is almost 0.8

3.4. Comparison of data from urban morphology simulations

To understand how each scenario creates vulnerable areas and comfort zones, and to find out which scenario improves the thermal conditions and reduces air temperature compared to the real conditions. All eight urban forms contain a rectangular open space measuring 90 m x 62 m that was delineated by the residential blocks; hence measurement points were selected in the four corners and the centre of the open space, as shown in Figure 12. Five measurement points, P1 to P5, were identified in the eight simulated ENVI-met models; i.e., seven urban forms tested around the open space (S1 to S7), and the real site (Figure 12). Simulated microclimatic parameters; i.e. air temperature, wind speed, and ground surface temperature at each point are presented in the comparison charts (Figures 13 to 15, respectively), and discussed for each hour, from 08:00 am to 07:00 pm.

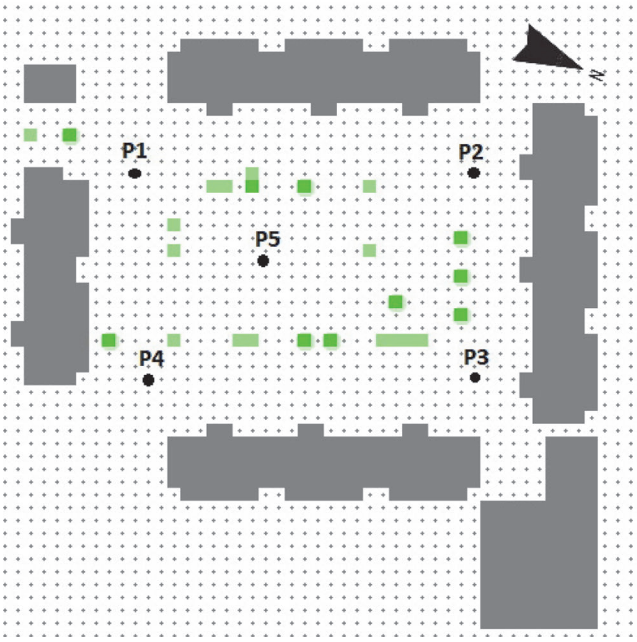


Figure 12. Measurement points in the 3D simulation model of the actual site S1

3.4.1. Air temperature

In the morning from 08:00 am to 10:00 am (Figure 13), T_{air} presents low differences between several scenarios. The U form oriented west has generally the lowest values at all points (between 25.7 and 29 °C), while L1 recorded the highest T_{air} values (between 26.5 and 29.5 °C).

From 10:00 am to 05:00 pm, the linear block oriented N–S recorded the highest temperature at P3, P4, and P5, while at P1, U form oriented west and linear block oriented E–W presents the highest values (T_{air} reach 35.45 °C). The lowest temperatures appear at almost all points in the U block oriented east, the closed courtyard, and L2.

From 05:00 pm to 07:00 pm, the temperature decreased at all points of the U form oriented west and had one of the lowest values amongst the blocks. In contrast, the measurements calculated in the courtyard and L1 blocks increased to reach higher values, while the linear blocks recorded the highest values at all points.

3.4.2. Wind speed

As shown in Figure 14, data for the linear block oriented N–S presents the highest wind speed at points P1, P3, and P5 (between 1.5 m/s and 2.3 m/s), while L2 presents the highest values at points P2 and P4. The lowest wind speed is recorded at

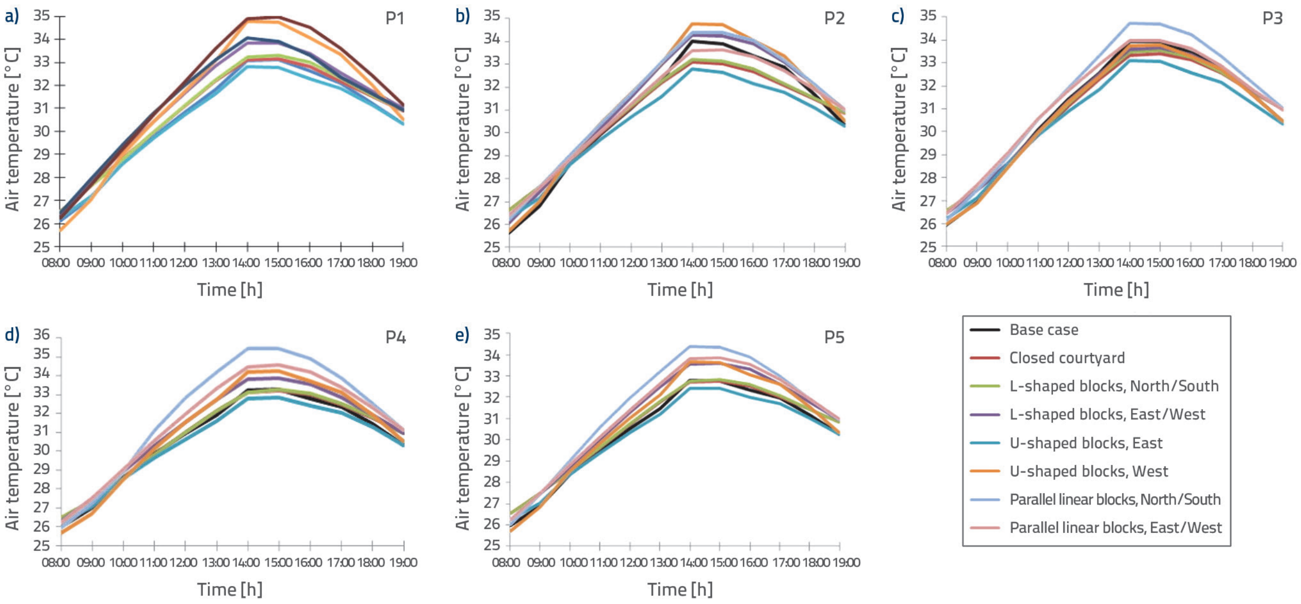


Figure 13. Daily variation of air temperature (T_{air}) simulated for each site, at the five measurement points: a) P1; b) P2; c) P3; d) P4; e) P5

all points in the courtyard, as expected; L1 and U form oriented east wind speed at each point is influenced by the incoming N–W wind and block arrangement, which produces the Venturi effect or the canyon effect.

The curves of each point have different trends except for P5, because it is situated at the centre of the open spaces and far from obstacles in all scenarios (Figure 14).

3.4.3. Ground surface temperature

The ground surface temperature measurements at the four corner points present slightly different trends (Figure 15) except for P5, which is located at the centre of the open spaces, and thus is mostly exposed to the sun during the whole day in all the scenarios. Consequently, the variations in temperature

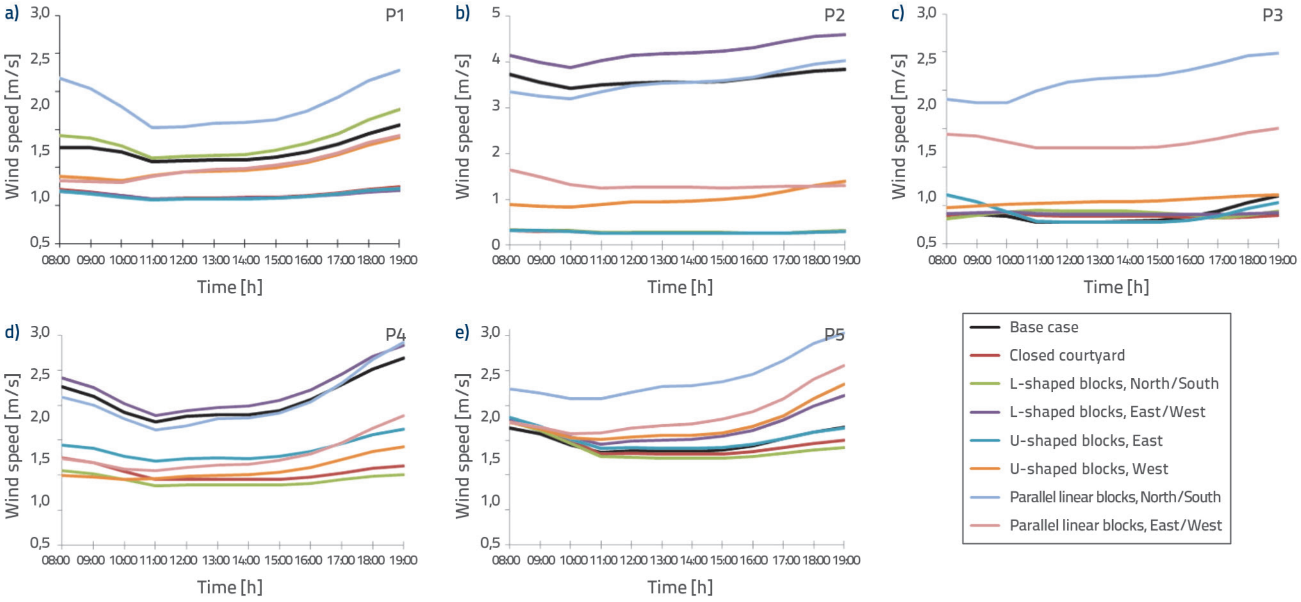


Figure 14. Daily variation of Wind Speed (Ws) simulated for each site at the five measurement points: a) P1; b) P2; c) P3; d) P4; e) P5

between the eight urban scenarios are low (between 0 and 1 °C) at P5.

Some points follow smooth curves; such as P4 in L2, and P2 in linear blocks, base case model, L2 and courtyard blocks, with different values and slopes. Although other points reveal different behaviours; such as P4 in courtyard, P1 in L2, and P2 in U block oriented east, this is due to the differences in exposure to solar radiation and shading effect; points with smooth curves are exposed to the sun all day while the others are shaded sometimes, according to solar insolation direction and block orientation.

The interaction between meteorological parameters and urban form leads to a modification in the local climate (microclimate). In this study, the air temperature is mainly related to the exposure to solar radiation, and so enclosed forms protected from the sun can mitigate the UHI. On the other hand, heat will not dissipate easily due to low ventilation produced by reduced airflow in the enclosed forms; hence, heat mitigation strategies for the city of Mostaganem favour urban ventilated areas protected from direct solar radiation. These findings deal with other studies [16-18, 24, 26].

The next step in future investigations will consist in introducing period of insolation in analysing results as well as comparison of the different parameters presented (air temperature, ground temperature, wind speed) and for different urban forms.

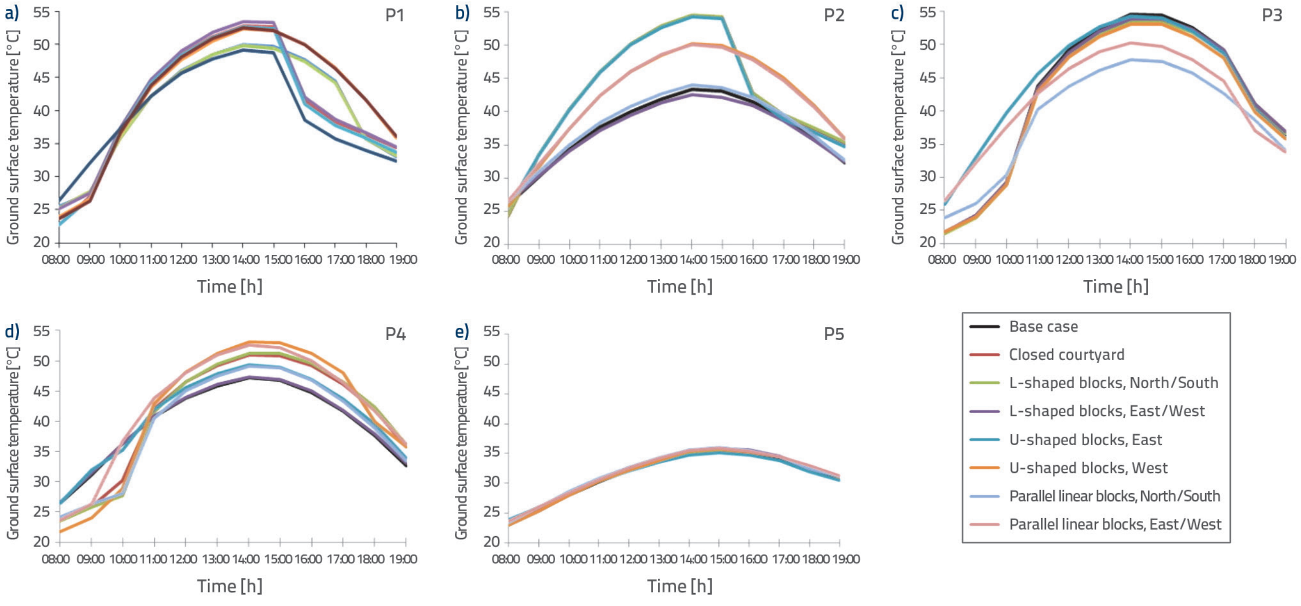


Figure 15. Daily variation of ground surface temperature (T_{gs}) simulated for each site at the five measurement points: a) P1; b) P2; c) P3; d) P4; e) P5

4. Conclusion

The effect of urban block forms and their orientations was studied in a midrise urban area in Mostaganem city on the daily air temperature and ground surface temperature variations using numerical simulation and ENVI-met software that were also validated by real time measurements. Consequently, it was concluded that the urban form and spatial configurations of the urban blocks can influence the UHI in spaces within the urban fabric. These findings lead to the following conclusions:

- Exposure to the sun has the most effect on air and ground surface temperatures; blocks that can protect open spaces from solar radiation provide better climatic performance than others.
- Air temperature is related to wind speed and direction; however, wind speed was not observed as the principal influencer on reducing air temperature. In some situations, as in the linear block oriented N–S, the highest air temperature and highest wind speed were concurrently observed.
- Even though it helps ventilating the open areas between the blocks, this flow may provide a cooling or heating effect depending on the ambient temperatures.
- In the context of the case study location, enclosed forms are preferable in the morning and semi-enclosed forms are preferable during the rest of the day.

In the case study area, it is possible to reduce air temperature during the critical hours of the day (14:00 pm and 15:00 pm) by using the U form oriented east, the courtyard, or the L2 forms.

In this study, the lite version of ENVI-met presents limitations in the domain of study. For future research, the simulation of the whole quarter will also be necessary; it will be interesting to compare different existing urban fabrics in term of thermal performance. Further investigations may focus on introducing period of insolation in analysing results as well as comparison of the different studied parameters (such as air temperature, ground temperature, and wind speed) and for different urban forms.

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