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A Combined Approach to Predict the Human Thermal Comfort in Downtown Guelma-Algeria

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ABSTRACT

Human thermal comfort is a key principle to promote a high life quality in outdoor spaces. This study aims to predict the human thermal comfort at the pedestrian level during summertime in downtown Guelma, Algeria. The scientific methodology of the investigation is done in three main interdependent steps. First, evaluating the thermal urban environment through a cross analysis; Microclimatic parameters/vs./Human thermal sensation. As a result, ten shelter-locations where highlighted and considered as an adaptation strategy to the thermal outdoor environment during summertime. Second, measuring the human thermal comfort level in seven selected adaptation strategies using UTCI index. Third, predicting the human thermal comfort in each strategy through a correlation between the thermal comfort level and the human thermal acceptability. The results indicate that users underwent four thermal phases in term of space and time, moderate phase in the morning period, hard phase in the hot hours, followed by the relief phase. Four adaptation strategies have been identified to adapt to thermal urban environment during summertime in downtown Guelma, vegetation strategy, mixed strategy vegetation and reflective soil, geometry strategy and mixed strategy geometry. Correlation results of UTCI index and thermal acceptability showed that the correlation between subjective and objective parameters is significant to predict the effectiveness of the adaptation strategies during summertime in Guelma's downtown.

Keywords: Human thermal comfort, outdoor spaces, thermal environment, human thermal sensation, adaptation strategies.

Introduction

Urban outdoor spaces, through their various functions, hygienic, social, cultural, aesthetic, functional, economic and ecological, are increasingly recognized as central elements to promote the environmental sustainability and the quality of life in cities (Hammadi. 2017). In recent years more interest was associated to the human thermal comfort in order to design spaces attractive and comfortable spaces (Nouri et al. 2018; Lai et al. 2014; Tsitoura, Michailidou, and Tsoutsos 2017), also it was found by many researchers that the attendance of urban outdoor spaces is directly related to outdoor thermal conditions (Cocci Grifoni et al. 2011; Sayad and Alkama 2020).

Thermal urban environment has become one of the most important research topics. The thermal environment is defined as the set of physical conditions that affect the heat exchange between human and its surrounding environment (Jendritzky and Dear 2009). Previous studies have showed that microclimatic parameters should be considered to fully describe the thermal environment (Shooshtarian, Rajagopalan, and Sagoo 2018; Ichinose 2014). In urban outdoor spaces the thermal environment is defined by the interaction of three components. Human (human thermal sensation), physical (built environment including naturel elements) and atmospheric (microclimatic parameters). According to (Jendritzky and Dear 2009), the close relationship of humans to the thermal component of the atmospheric environment belongs to everybody's daily experience.

Human thermal comfort is providing pleasurable thermal conditions in outdoor spaces for humans. However, the thermal outdoor comfort is fully considered as a guarantor of outdoor spaces utilization (Hammadi. 2017; Elnabawi and Hamza 2019). Recently several indices have been developed to assess the human thermal comfort in outdoor spaces; furthermore, these indices have been correlated to each other to select the most appropriate indices for applications in human thermal studies (Zare et al. 2018; Staiger, Laschewski, and Matzarakis 2019).

Objective thermal comfort assessment is crucial to quantify the human thermal stress, (UTCI) universal thermal climate index, (PET) Physiological equivalent temperature and other thermal indices are designed for thermal and climate assessment. Most of these indices integrate physical or microclimatic parameters (air temperature, relative humidity and wind velocity) and personnel human parameters (clothing and metabolic rate). The above indices are incorporated with urban and microclimatic design programs like Envi-met and Ray-Man. Subjective thermal comfort assessment is necessary to explore the thermal sensation of local population (Cheung and Jim 2019; Elmira Othman et al. 2019), it can be assessed by means of questionnaire or interviews that describe a person's satisfaction to outdoor thermal conditions (Neto 2016).

Throughout history, people and societies have adjusted to local climate and coped with the hard weather conditions, in both winter and summer (Nash et al. 2019). Adaptation strategies to outdoor thermal environment can be defined as the way in which users deal with their surroundings looking for better thermal sensation (Jendritzky & Dear, 2009). In summertime, urban cooling has become the key solution to mitigate the increased temperatures in urban areas (Morille and Musy 2017). Many researchers (Ojaghlou and Khakzand 2017; Taleghani 2018; Mahdavinejad, Khademi, and Sadeghnejad 2013) have focused on cooling strategies to improve the outdoor thermal and climate comfort, while Dayi Lai has addressed a review of mitigation strategies to improve the thermal comfort in outdoor spaces (Lai et al. 2019).

2. Study site

Guelma's downtown is the most influential area of the city (36° 27' 43 N; 7° 25' 33 E; 840 ft. Elevation), which experiences a semi-arid climate (classified as Csa by the Köppen-Geiger system). The existing buildings several medium rises, the built-up structures are connecting with different street geometries enclosing open spaces and hierarchical streets for interaction.

The onsite investigation carried out a pedestrian course (figure.1), which most of city's users make at least once a week.

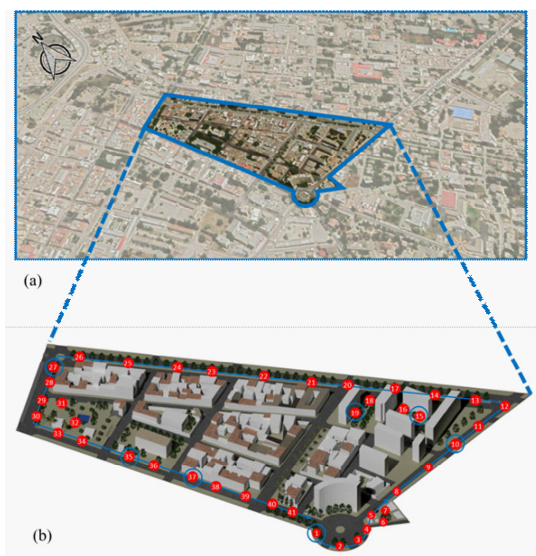


Figure1. (a) Aerial view of Guelma's downtown showing the delimited study area. (b) 3D drawing of the pedestrian course case of study illustrating the forty-one studied locations.

Methods and materials

This study proposes a combined approach for a better understanding of the outdoor thermal environment at the pedestrian level in summertime. our research intends to evaluate point-by-point the human thermal sensation (TS) of 41 different locations in downtown Guelma, highlighting the adaptation strategies outdoor thermal environment during sunny summer days. In order to provide a deeper understanding of these adaptation strategies, we have opted for an atmospheric simulation using ENVI-met model. The effectiveness of each adaptive strategy was tested by analyzing the obtained outputs (air temperature, relative humidity, wind velocity and mean radiant temperature) referring to the potential mechanisms that underlie the relationship between humans and the thermal environment. The UTCI index was used to measure the thermal comfort level in each strategy and to determine the most effective strategy in hot hours. To predict the human thermal comfort in downtown Guelma, the study correlates UTCI index (objective parameter) with the thermal acceptability (subjective parameter); Figure 2. Shows the study structure and the scientific methodology.

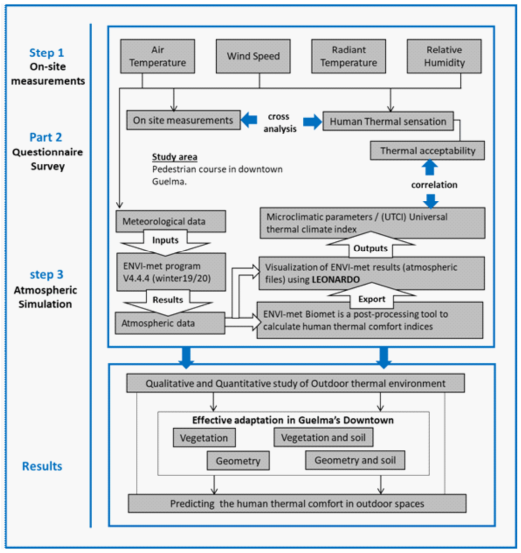


Figure 2. Explanatory diagram of the folwed methodology shows the study structure.

Field microclimatic measurements

Real microclimatic data was obtained through field measurements during the hot period from July 20th to July 22nd , 2019. Three microclimatic parameters were measured Temperature, Relative humidity, and Wind Velocity; we obtained a bi-hourly record from 09:00 to 19:00 using the portable instruments Testo 480 - AG 501 1ST, 0563 4800. It is a multifunction instrument equipped with intelligent digital probes calibrated independently used as thermo-hygrometer and as anemometer.

Questionnaire survey

A total number of 581 valid interviews were conducted simultaneously with the on-site measurements in the mentioned period (03 three successive days). Subsequently, each location has covered the number of users during the measurement report along three days. The questionnaire is structured in four rubrics, as shown in figure 3. Firstly, it questioned the interviewee profile using direct questions, then multiple choice questions were used to explore the outdoor spaces attendance, Likert scale (five-point scale) questions were used to evaluate and the thermal sensation (TS). However, the respondent was asked to choose one sensuous option for each parameter. Finally, open-ended questions were used to describe the thermal environment.

Rubric 01 — The interviewee profile

Gendre	Age	Nearness	Other

Rubric 02 — Usage and attendance

Situation	Purpose	Attendance	Stay period

Rubric 03 — Thermal sensation votes (TSV)

Parametres	Evaluation based on Six-point scale				
Air temperature	Very hot	Hot	Slightly hot	Neutral	Slightly cool
Relative Humidity	Humid	Slightly humid	Neutral	Slightly dry	Dry

Rubric 04 — Thermal acceptability (TA)

Parameter	Evaluation		
Acceptability	Acceptable	Neutral	Inacceptable

Figure 3. Diagram showing the structure of the questionnaire survey.

UTCI and outdoor thermal comfort levels

UTCI is defined as the equivalent temperature for a given combination of wind, radiation, humidity and air temperature to quantify the human thermal stress (Zare et al. 2018). It is one of the most popular indices to assess the heat stress in outdoor urban spaces (Pantavou et al. 2018; Matzarakis, Muthers, and Rutz 2014). The UTCI index includes two categories of inputs data for calculating the thermal stress level. Human inputs like clothing, metabolic rate and thermal resistance and meteorological inputs like dry temperature, relative humidity, mean radiant temperature and wind speed at 10 m elevation (Blazejczyk et al. 2012; Matzarakis, Muthers, and Rutz 2014).The thermal stress levels of UTCI are categorized into ten scales ranging from extreme cold stress to extreme heat stress as shown in table 1.

Table 1. UTCI thermal stress categorization for hot season

UTCI rang (C°)	Thermal stress category
Above +46	Extreme heat stress
+38 to +46	Very strong heat stress
+32 to +38	Strong heat stress
+26 to +32	Moderate heat stress
+9 to +26	No thermal heat stress

Envi-met simulation model

The seven selected strategic locations in downtown Guelma were investigated through atmospheric simulations using the micro-scale model ENVI-met. This program is one of the main numerical tools used in bioclimatic outdoor design, due to its function of anticipating microclimatic conditions; it helps designers to opt for judicious choices while designing outdoor spaces (Tsitoura, Michailidou, and Tsoutsos 2017; Ozkeresteci et al. 2003). Envi-met software can calculate microclimatic parameters, such as air temperature, relative humidity, wind velocity and other parameters (Sayad and Alkama 2019; Elwy et al. 2018). This atmospheric data (outputs) will be used in thermal indices calculation through BioMet process, the whole outputs generated by Envi-met will be visualized by LEONARDO module results.

The atmospheric simulation of the seven strategic locations in downtown Guelma was performed using the measured microclimatic parameters of the third day (July 22nd, 2019), it was a sunny summer day with maximum thermal stress and high sun exposure. Figure 4. illustrates an example (location P35) of the simulation methodology by Envi-met program.

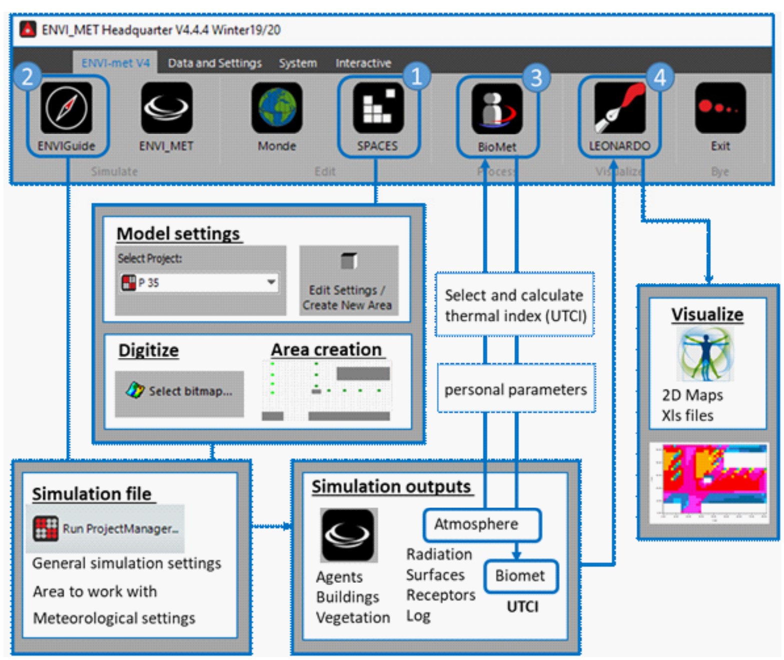


Figure 4. Diagram shows the Envi-met workflow.

Results and Discussion

General weather of the study period

The on-site investigation was carried out during the period between July 20th and 22nd, 2019 corresponding a hot period. According to the weather forecasting (Ventusky - Cartes de Prévision Météo), the highest mean tempreture was 41°C, the lowest mean relative humidity over the three days was ± 20% and the mean wind velocity was relatively normal 3.5 m/s. The on-site measurments in downtown Guelma have showed more meteorological details that can dress a precise description of the weather during the study period. Measured microclimatic parameters are shown in table 2.

Table 2. Measured microclimatic parameters during the study days.

Study days	Air temperature (C°)			Relative humidity (%)			Wind velocity (m/s)		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
July 20th ,2019	35.9	42.6	30	28.7	49.4	18.4	0.6	1.2	0
July 21st ,2019	36.4	41.4	32	31.9	50.0	21.9	0.5	1.2	0
July 22nd,2019	36.9	42.9	30.5	30.5	56.0	16.5	0.6	1.5	0.3

Thermal urban environment evaluation

We have collected microclimatic data on July 20th ,21st and 22nd , 2019 mainly from 09:00 to 19:00 spinning up 5 (five) periods. Simultaneously, the interviews were conducted in 41 (forty-one) different locations in downtown Guelma. In order to evaluate the thermal urban environment, measured air temperature (Ta) and relative humidity (RH) were correlated with thermal sensation votes (TSV). The overall results are summarized in graphs bellow (figure.6).

For the period from 09:00 to 11:00 (figure.5 a-a'), the general trend of air temperature was ascending, ranging from 30.5°C to 38.2°C. Inversely, relative humidity trend was descending, with a maximum RH = 56% and minimum RH = 33.9%. The thermal sensation (TS) used only three sensuous options "a bit cool, neutral and a bit hot" for the air temperature and four options for the relative humidity "humid, a bit humid, neutral and a bit dry". This is mainly due to thermal conditions variation in space and time, in locations from P21 to P26 microclimatic parameters were measured from 09:55 to 10:15 corresponding to an unshaded period where the air temperature reached its peak; the most of votes go to the sensation "a bit hot". Moreover, the mentioned locations are situated in Souidani Boujemaa Boulevard, which is devoid of vegetation and directly exposed to the sun; this could interpret the high proportion of the sensuous option "a bit dry".

The overall trend of air temperature and relative humidity for the period from 11:00 to 13:00 (figure.5 b-b') is similar to the previous period trends, with an increase of 3°C and 2.6°C respectively for minimum and maximum air temperature. Therefore, the two sensuous options "very hot and hot" were widely used to express user's thermal sensation. While the relative humidity was in between 41.6% and 30.5% corresponding four sensuous scales, thermal sensation in locations devoid of vegetation is almost voted as "dry". At the example of locations P21 to P26, the locations from P36 to P39 are most considered as "very hot and dry" due sun exposure and the lack of vegetation. The striking think to note in this period time that the thermal sensation in Souidani Boujemaa Boulevard (locations from P21 to P26) is voted as "a bit hot", this could be explained by the shading effect induced by the buildings along the boulevard.

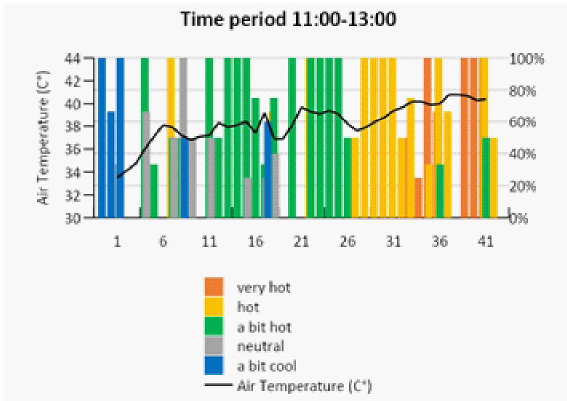
The next period time (figure.5 c-c') is considered as the hardest period of the whole day. The air temperature its daily peak 42.9°C with low relative humidity 17.1%, for these microclimatic conditions the thermal sensation was described by users as very hot and dry. Apart of the three first locations situated in shaded and vegetated areas.

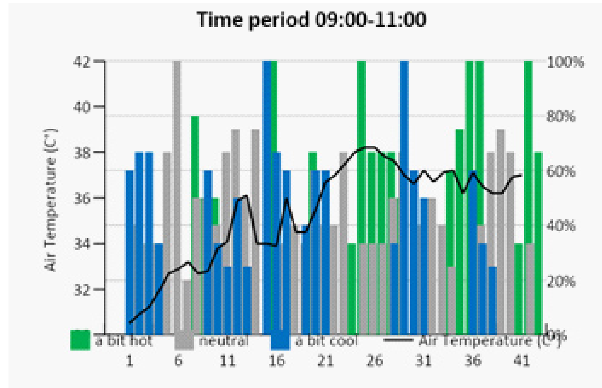
We can consider the period from 15:00 to 17:00 (figure.6 d-d') as a hard one, regarding the hard microclimatic conditions (max Ta= 41.4°C and min RH=20.8%) and user's thermal sensation votes (TSV). "Very hot" and "hot" are the only answers used by users to describe their sensation and to express dissatisfaction with the thermal environment.

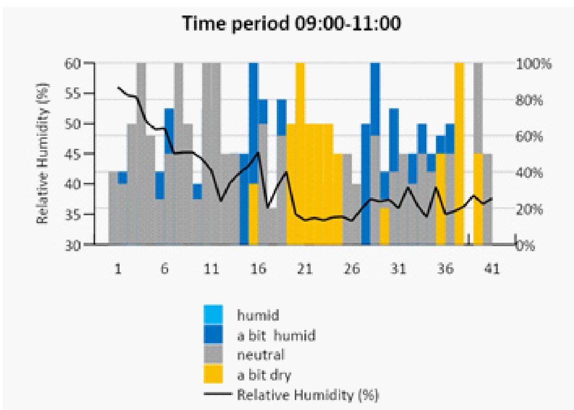
After three hard successive periods, the period time from 17:00 to 19:00 (figure.5 e-e') launched the relief time in outdoor spaces. Hence, the mean air temperature was reduced by 2.8°C and the thermal sensation was almost "a bit hot and neutral" as well as the relative humidity was most considered as "a bit humid and neutral".

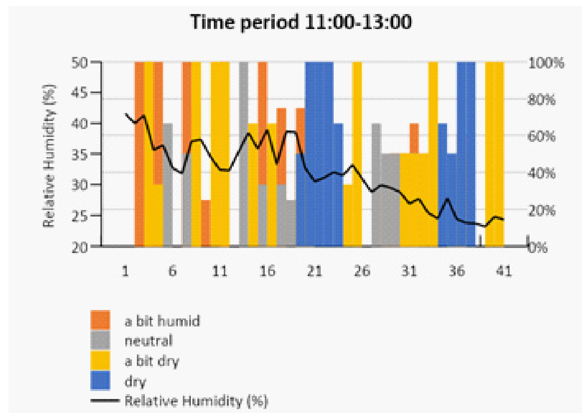
In term of time and space, acute points in the air temperature curves (highlighted locations) present a location at given time with low air temperature compared to previous and next locations (Figure.5 a-e).

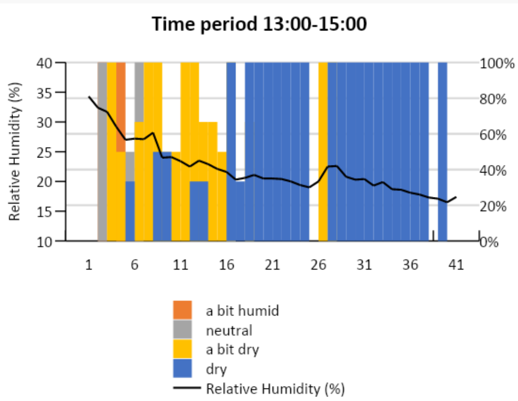
In general, the thermal conditions variation in downtown Guelma could lead to a partial evaluation of the thermal urban environment during sunny summer days. In the morning from 09:00 to 11:00, the thermal urban environment may be described as moderate. In hot periods from 11:00 to 17:00, the outdoor thermal conditions became hard to support, thus the thermal urban environment may be described as unbearable. The period from 17:00 to 19:00 is considered as a transit period from the hot to the moderate sensation; however, the thermal urban environment tends to provide the thermal relief.

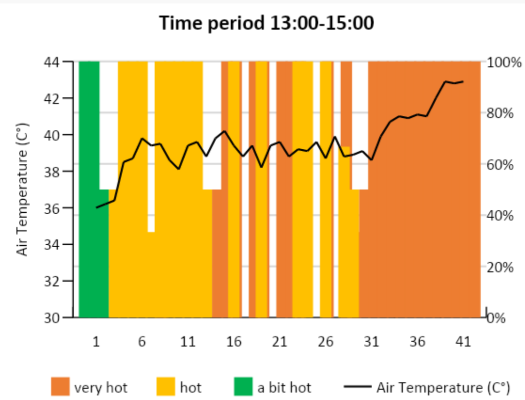


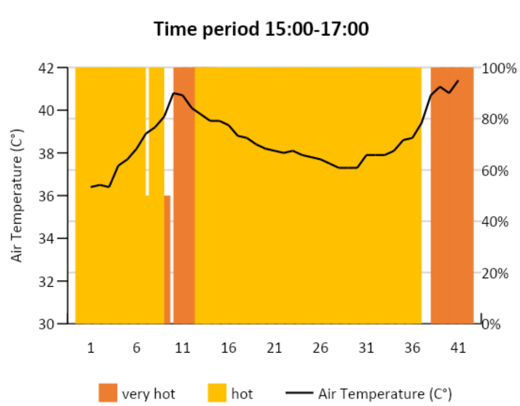


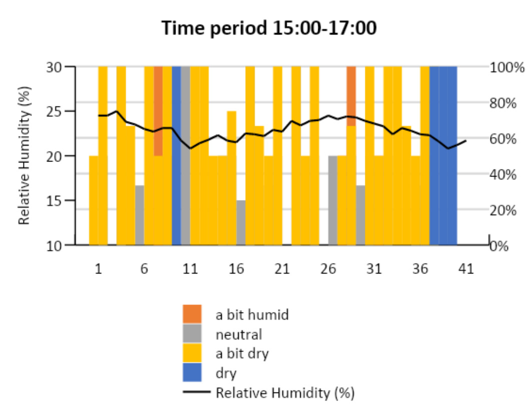












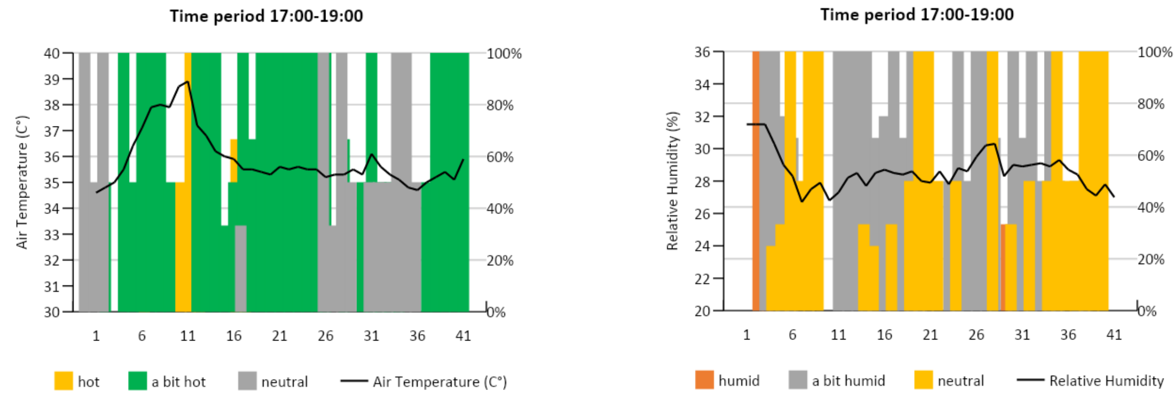


Figure 5. (a-e) Correlation between measured air temperature (Ta) and thermal sensation votes (TSV) from 09:00 to 19:00. (a'-e') Correlation between measured relative humidity (RH) and thermal sensation votes (TSV) from 09:00 to 19:00.

Adaptation to outdoor thermal environment

As aforementioned, there were highlighted locations in each of the previous evaluated periods. According to users, these locations constitute shelters to adapt to hard climatic conditions during hot days in downtown Guelma, Thus the local thermal urban environment at each of these shelter-locations meet the psychological needs of users in hot periods. This section aims to provide a better understanding of the thermal urban environment and to measure the thermal comfort level in these strategic locations in sunny summer days.

Strategic locations being studied

In order to select the most significant shelter-locations in downtown Guelma, we have developed a selection method based on thermal sensation votes (TSV), thermal acceptability (TA) and frequency criterion (FC), which represents the bi-hourly of repetitions of a location during the day. The percentages of TSV were obtained by calculating the daily votes on air temperature and relative humidity, the TA percentages were obtained by multiplication in a coefficient for each answer option (acceptable x 1.5, neutral x 1 and unacceptable x 0.5) and we obtained the FC by multiplication in a modulation coefficient. Figure.7 presents the main results of applying the selection criteria on the ten strategic locations.

The highest thermal acceptability (TA = 1.17 and TA = 1.07) was observed respectively in location P1 and P19. The location P19 was ranked third in term of total ratio (Total = 4.18). The above three locations constitute the most significant shelter-locations to adapt to outdoor thermal environment. The physical thermal environment in location P9 and P10 is almost similar, the TSV is the detrmining creteria for the selection of P10 (TSV = 1.9). Despite its total ration (Total = 3.84), P30 was not selected due to its low TSV and TA, while location P27 (Total = 3.54) was selected with smoothely high values (TSV = 1.92) and (TA = 1.03). The location P15 and P37 were selected based on its different physical thermal composition, location P37 is a canyon street devoid of vegetation, even so the local thermal environment was voted 30.8% acceptable. To sum up, we have selected seven sterategic locations (7/10) using the three aformentioned selection creteria and the local physical thermal composition as a determining cretira. The results are shown in figure 6.

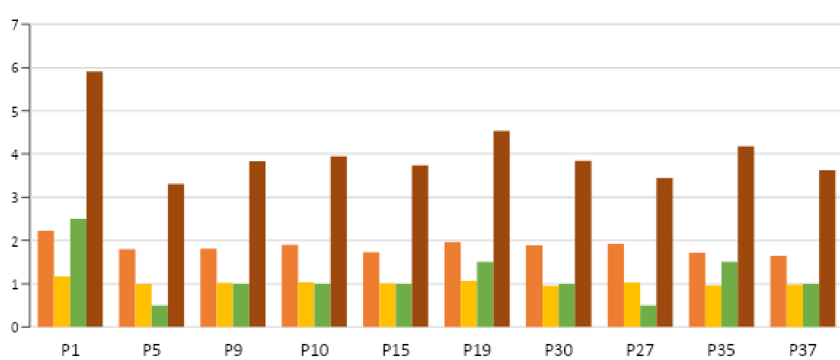


Figure 6. Selection the most significant shelter-locations in downtown Guelma

Simulation framework

The study simulated seven-selected strategic locations in downtown Guelma, our approach considers that each location represents a significant adaptive strategy to the outdoor thermal environment and provides a certain thermal comfort level.

Each of the seven locations assumes a primary analysis and expects a ranking in hot hours (15:00) to be tested through an atmospheric simulation using Envi-met program. Air temperature (Ta), relative humidity (RH), Mean radiant temperature (Tmrt) and wind velocity (Wv) are the simulation output used to test the effectiveness of each adaptive strategy. The universal thermal climate index (UTCI) was used to test the thermal comfort level. Table3. Shows the detailed framework of the simulation process and the main results.

Starting by location P1, it is a shaded transit area in Houari Boumedien midpoint. The local thermal environment has experienced the minimum air temperatures and it was voted foremost as acceptable. As a primary analysis, this location represents a vegetation strategy through shading effect and it is expected to be one of the most effective adaptive strategies at 15:00.

The next location P10 is a mineral crossroad point, giving onto Boumaaza Said Boulevard, the thermal environment is mainly composed of a sparse plant cover and medium rise buildings. This location can assume a mixed strategy, which combines urban geometry, vegetation and soil reflectivity. In view of its high non-acceptability, P10 can expect a lower ranking.

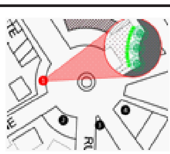
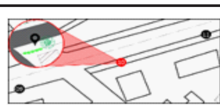
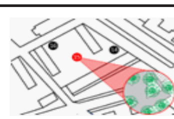
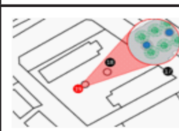
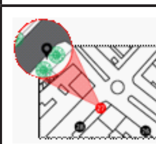
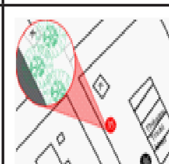
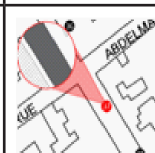
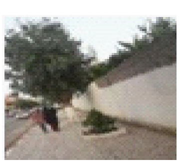
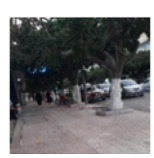
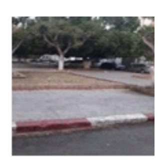
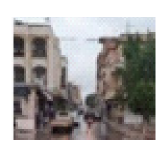
The next simulations involve two urban mixed strategies, which combine the vegetation and the soil reflectivity. Location P15 is a grassy and shaded area located in space between buildings HLM 2, with a mean thermal acceptability (TA = 50%). Location P19 is a wet and shaded area located in space between buildings HLM 1. It is expected for P19 to be one of the most effective adaptive strategies in hot hours.

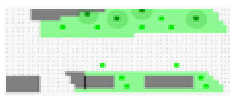
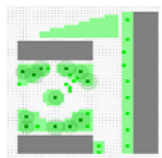
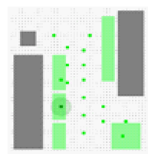
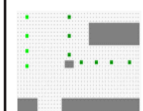
The location P27 is a low and shaded transit area located in the street November 1st. In the morning period, this location constitute the beginning of a cooler street for users coming from Souidani Boujemaa Boulevard. Given these facts, this location can assume an urban mixed strategy based on shading effect and pavement reflectivity.

The location P35 is a shaded and cool point situated in an open space near to the municipal theater of the city, the thermal environment maybe a good adaptive strategy during hot days and it is expected to be the most effective adaptation strategy to outdoor thermal environment.

The last location P37 constitutes the entrance to the last part of El Moudjahidin Street, which is a canyon street devoid of vegetation. The thermal acceptability in this location was voted as "unacceptable" from 11:00 to 19:00, considered as an urban geometry strategy in the morning period and it is expected to rank last in hot hours (at 15:00).

Table3. The detailed framework of the simulation process: input data, initial settings and outputs.

Proprieties	P1 (7°25'58''E)	P10 (7°26'06''E)	P15 (7°26'05''E)	P19 (36°27'50''E)	P27 (36°25'58''E)	P35 (7°27'53''E)	P37 (7°25'55''E)
Plan Drawn using AutoCAD program							
Description	A shaded transit area in Houari boumediene midpoint.	A crossroads point gives onto Boumaza said boulevard.	A grassy and shaded area in space between buildings.	A wet and shaded area located in space between buildings.	A first point of the street November 1, low and shaded transit area.	A shaded and cool point near to the munici pal theater.	An entrance to a canyon street devoid of vegetation.
View Photographs taken by author, July 2019							

Primary analysis	Urban vegetation strategy through shading effect.	Mixed strategy, geometry, vegetation and pavement.	Urban vegetation strategy based on shading effect and grass reflectivity.	Urban mixed strategy based on shading effect and water reflectivity.	Vegetation strategy based on shading and pavement reflectivity.	Urban vegetation strategy due to the large shaded area.	Urban geometry strategy in the evening period.
Expected ranking In hot hour (15:00)	01	05	03	02	04	02	06
Simulation Details -Model dimensions -Grid north	- x: 41 y: 41 z: 40 - 00.00	- x : 94 y: 20 z : 20 - (-15.00)	- x: 68 y: 68 z: 20 - 45.00	- x: 68 y: 68 z: 20 - 45.00	- x: 57 y: 18 z: 20 - (-45.00)	- x: 41 y: 27 z: 20 - 45.00	- x: 104 y: 48 z: 20 - 45.00
- Graphic model							
Vegetation and materials (table 4 shows more specification) -Buildings	- W:8 L: // H: 8	- W:6.8 L:// H: 4-12	- W: 8 L:// H: 14	- W: 8 L: // H: 14	- W: 8 L: // H: 8	- W: 8 L: // H:10	- W: 8 L:75 H: 8
Outputs -Microclimatic parameters	T(C°): 36.8 RH (%): 33.9 Wv (m/s): 0.5 Tmrt (C°): 65.7	T(C°): 39.7 RH (%): 29.4 Wv (m/s): 0.6 Tmrt (C°): 44	T(C°): 39 RH (%): 30 Wv (m/s): 0.5 Tmrt (C°): 60.9	T(C°): 39.6 RH (%): 26.4 Wv (m/s): 0.6 Tmrt (C°): 68.3	T(C°): 38.8 RH (%): 26.4 Wv (m/s): 1 Tmrt (C°): 56.6	T(C°): 38.5 RH (%): 27 Wv (m/s): 0.4 Tmrt (C°): 72.2	T(C°): 40.6 RH (%): 22.5 Wv (m/s): 0.7 Tmrt (C°): 64.3
Thermal Climate Index at 15.00	UCTI (C°): 49.	UCTI (C°): 53.5	UCTI (C°): 50.9	UCTI (C°): 50.9	UCTI (C°): 51.4	UCTI (C°): 48.7	UCTI (C°): 52.1

Adaptive strategies and Thermal comfort levels

The simulation results have confirmed the effectiveness of the mentioned locations on improving the thermal environment in downtown Guelma, the comparisons of the simulation outputs including the universal thermal climate index (UTCI) in the seven strategies led to the following assortment:

- Urban vegetation strategy, in Houari Boumedien midpoint and in the open space near the municipal theater of the city the dense trees have significantly improved the thermal environment through evapotranspiration and shading effect. It constitutes an effective adaptation strategy in hot days in general and the most effective in hot hours specifically where the heat stress is extreme.

- Urban mixed strategy vegetation and reflective soil, in addition to trees effects in HLM 1, HLM 2 and the street November 1St , the high albedo of the soil materials (grass, deep water and pavement light) has a positive contribution on moderating the thermal urban environment in summertime. This strategy showed less effectiveness during the day compared to the first strategy and it is ranked second in term of heat stress reduction.
- Urban geometry strategy, the height to width ratio (H/W) in in the entrance to El Moudjahidine Street presents a significant adaptation strategy in the morning periods. Compared to the previous strategies the geometry strategy in downtown Guelma has showed worsen thermal comfort level and it is ranked Penultimate hot hours.
- Urban mixed strategy geometry and reflective soil, despite the shade cast by the constructions in Boumaaza Said Boulevard in morning periods and the high albedo of the used pavement, this strategy has carried the lowest thermal comfort level and acquired the last rank in hot hours.

Predcting the human thermal comfort

For a more accurate comprehension of the thermal comfort provided in each of the aforementioned strategies in summertime, the human thermal comfort level (UTCI) was correlated to the human thermal acceptability (TA) at each location. Whereas, the R^2 represents the reconcile coefficient between the two parameters and the slope of the linear thermal acceptability represents the daily change of the thermal sensation for each strategy.

According to the coefficient R^2, a positive reconciliation was observed in the vegetation strategy (location P1 and P35). However, the thermal climate index in both locations is strongly correlated to the thermal acceptability (R^2 = 0.24 and R^2 = 0.34). This means that the thermal comfort level supplied by the vegetation is ample for users to achieve the feeling of contentment to the thermal urban environment. As well, the slope of the linear thermal acceptability in this strategy (-0.014 and -0.019) indicates a slight change in the daily sensation. Therefore, the vegetation strategy in downtown Guelma offers high thermal comfort levels in summer days.

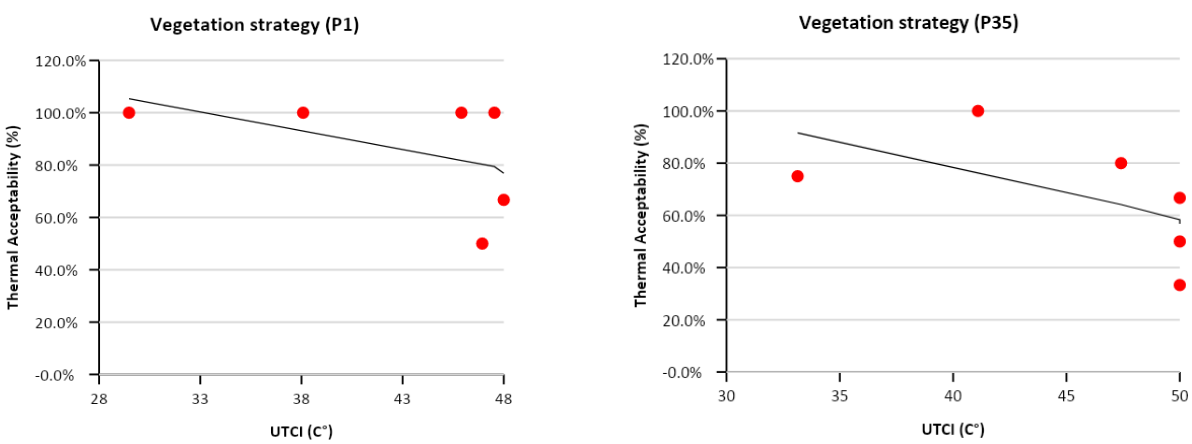


Figure 7. Correlation between UTCI and thermal acceptability in vegetation strategy

By extrapolating the R^2 coefficient in the mixed strategy “vegetation and reflective soil”, we can notice the high reconciliation between thermal acceptability in the three locations (P15, P19 and P27) and the thermal comfort level. These results indicate the effectiveness of mixing the vegetation with reflective soils to improve the thermal urban environment and impart a certain level of thermal outdoor comfort in sunny summer days. In spite of showing the heights correlation (R^2 = 0.47), the location P27 involves a significant change (-0.10) in thermal sensation compared to the other locations (P15 and P19). Which means that the daily thermal comfort level provided by mixing the vegetation and the pavement reflectivity is lesser as that in the other mixed strategies.

As a result of comparing the three mixed strategies, we can conclude that mixing water and grass reflectivity with the vegetation can significantly improve the outdoor thermal environment in downtown Guelma during hot season.

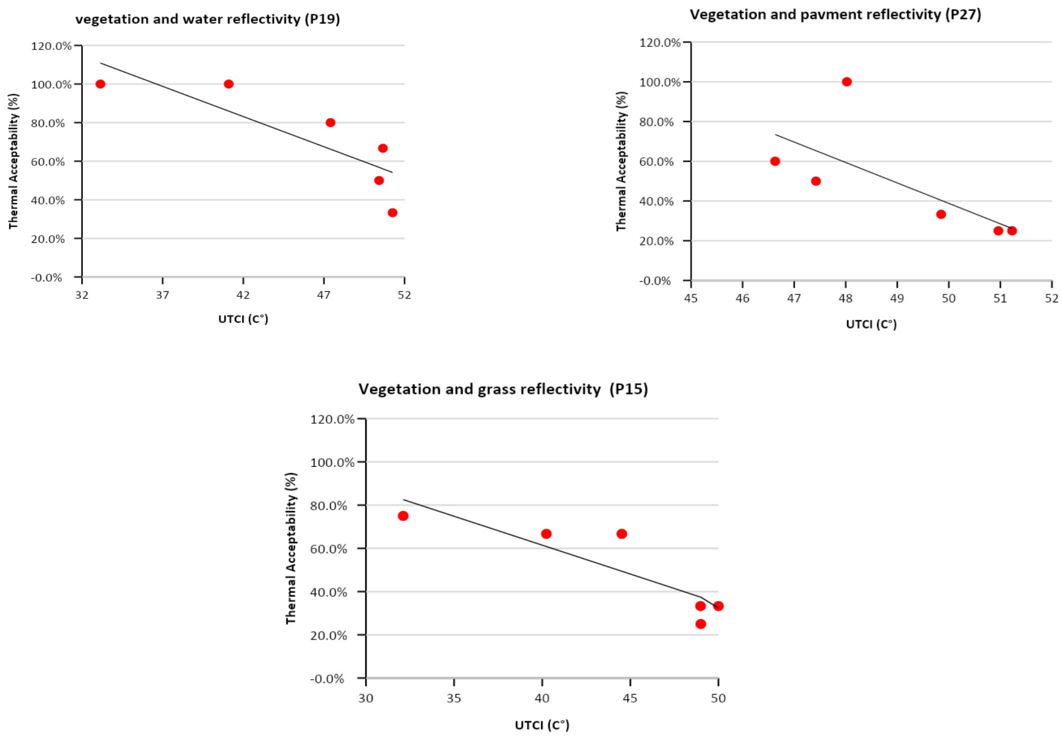


Figure 8. Correlation between UTCI and thermal acceptability in the mixed strategy "Vegetation and reflective soil".

Despite the fact that the thermal urban environment in location P37 was mostly voted as "unacceptable", a strong correlation was observed between the thermal acceptability and the thermal comfort level (R^2 = 0.38). Additionally, the slope (-0.028) enquires a tiny change in the thermal sensation during the day. Given the high values of the obtained UTCI, the existed reconciliation could be qualified as negative, which means that the studied strategy has a restrained thermal comfort level to provide to users during hot days in Guelma's downtown.

Otherwise, the mixed strategy "geometry and pavement reflectivity" has showed a positive reconciliation between the two correlated parameters (R^2 = 0.69), with a modest change in the daily thermal sensation. Thus, the mixture between the two above strategies is significant in in terms of providing human thermal comfort during summer days.

A striking observation was noticed in location P1 and P10 respectively in the period from 11:00 to 13:00 and from 09:00 to 11:00. Figure.8 and 10. The thermal climate index was above 46°, which corresponds an extreme heat stress; nonetheless, the thermal urban environment was voted 100% acceptable. In virtue of the high heat stress level in all strategies (UTCI > 49 C°), users were more likely to vote the thermal environment as "unacceptable" in hot hours, yet the location P1 was voted 66.7% acceptable. This leads us to think for a more suitable and appropriate categorization of the UTCI index for Guelma's downtown.

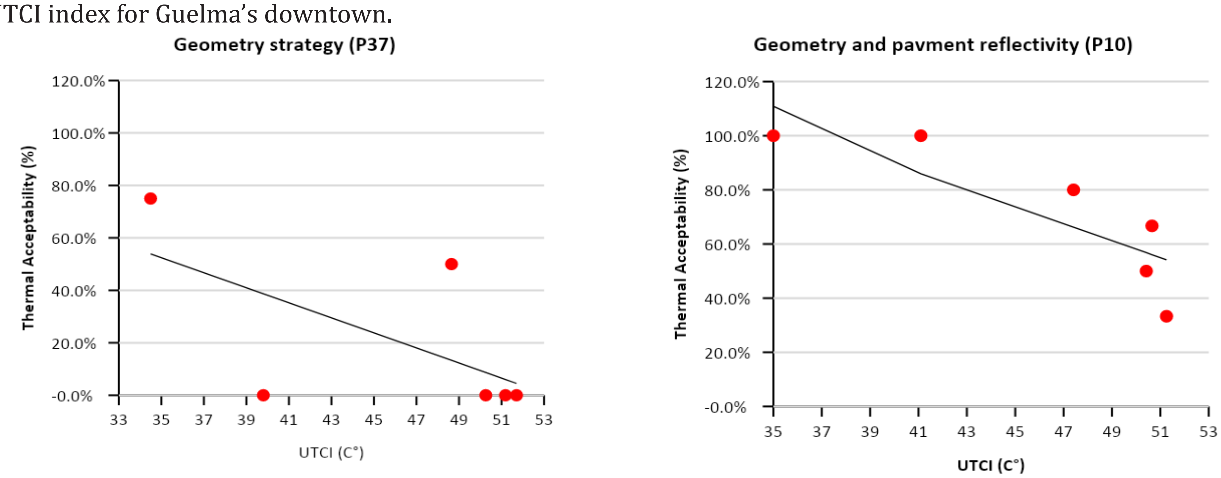


Figure 9. Correlation between UTCI and thermal acceptability in the geometry strategy and in the mixed strategy “geometry and reflective pavement”.

Conclusion

This study provides a better understanding of the thermal urban environment in summertime at the pedestrian level in Guelma’s downtown, where microclimatic measurements were conducted simultaneously with questionnaire survey.

The results indicate that users underwent four thermal phases in term of space and time. Moderate phase in the morning period, where the thermal urban environment is qualified as tolerable. Hard phase in the hot hours from 11:00 to 17:00, the thermal urban environment is described as unbearable. Followed by the relief phase from 17:00 to 19:00, where the thermal environment is tending more to provide the human thermal comfort.

Four adaptation strategies have been identified to adapt to thermal urban environment during summertime in downtown Guelma.

- Urban vegetation strategy, in Houari Boumedien midpoint and in the open space near the municipal theater of the city.
- Urban mixed strategy vegetation and reflective soil, in HLM 1, HLM 2 and the street November 1St.
- Urban geometry strategy in the entrance to El Moudjahidine Street.
- Urban mixed strategy geometry and reflective soil in Boumaaza Said Boulevard.

Correlation results of UTCI index and thermal acceptability have showed that the correlation between subjective and objective parameters is significant to predict the effectiveness of the adaptation strategies during summertime in Guelma’s downtown.

Extensive studies should be performed to test the effectiveness of the adaptation strategies in summertime for the dual purpose; providing high thermal comfort levels in new outdoor spaces generally and in downtown Guelma as a specific case. This could be achieved by applying the studied strategies on a wider scale or by searching new adaptation strategies. Thus, future studies should focus on combining two strategies or more for better results.

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