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IMPACT OF CLIMATE CHANGE BY 2100 ON THE MICROCLIMATE OF PUBLIC PLACES

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Abstract
Climate change has been mankind's main concern over the last century, with its many impacts such as rising temperatures, water stress, increase in natural disasters and reduced thermal comfort in urban spaces due to the Urban Heat Island (UHI) effect, a phenomenon that causes several deaths around the world every year and for which measures must be taken to mitigate its impact. The aim of this paper is to assess the impact of climate change on the urban microclimate and the resulting thermal comfort. The Place de Ettoute in Blida city centre, Algeria, is considered as a case study. This case is considered as a reference on which 3 scenarios, B1, A1B and A2 are applied representing three possible ways of the future of climate change according to the prospective study for 2100 of the IPCC for future periods. Envimet V3.1 is used to model the Ettoute urban square, in a 120x120m square with a 3x3m grid. It is based on a three-dimensional digital model that takes into account fluid dynamics and thermodynamic models to simulate the impact of surfaces, vegetation and the atmosphere at the micro-scale of the square. The comparison between the four scenarios shows an increase in temperature (from 0.5 to 1.24°C), particularly at night (8.8 to 10.03°C), which would reduce thermal comfort in Ettoute square, but scenario B1 has less impact on the urban microclimate and scenario A2 represents the worst case. In addition, a reduction in relative humidity (up to –19%) is expected for the scenarios A1B and A2 while a relative increase would be observed for the B1 scenario up to 2%. This study highlights the urgent need for adequate mitigation measures to reduce the impact of UHI for future periods.

Keywords: urban microclimate; climate change; envimet; public spaces

INTRODUCTION

Climate change is the most important phenomenon facing mankind in the 21st century. Its unpredictable impact and its harmful effects on both man and the earth make it particularly worthy of study, because its impact affects people's quality of life and makes the elderly even more vulnerable, with a growing number of cases of morbidity caused by increases in heat during the summer, with significant morbidity observed in Paris [B. Dousset et al. 2011], while in England UHI was responsible for half of the mortality observed during August 2003 [C. Heaviside et al. 2015]. According to various IPCC reports since its creation in 1988 [I. Tumini, C. Rubio-Bellidol 2016], despite all the actions taken by governments around the world, the earth will experience an increase in temperature of at least 0.1 degrees Celsius per decade until 2100 [IPCC 2014]. Natural disasters will accelerate with greater aggressiveness and impact on humans, infrastructure and the built environment in general [R.S. Tol 2018; T. Emilsson, A. Sang 2017]. The main constraint limiting control of the impact of climate change is the fact that it is unpredictable and intimately dependent on four driving forces: economic development, demographic development, the rapprochement between countries and the mode of development [N. Nakicenovic et al. 2000].

Among the phenomena that are being further accelerated by the impact of climate change is the urban heat island phenomenon, which accentuates the temperature in urban areas by increasing it more than in rural areas [T.R. Oke 2011]. This phenomenon gen-

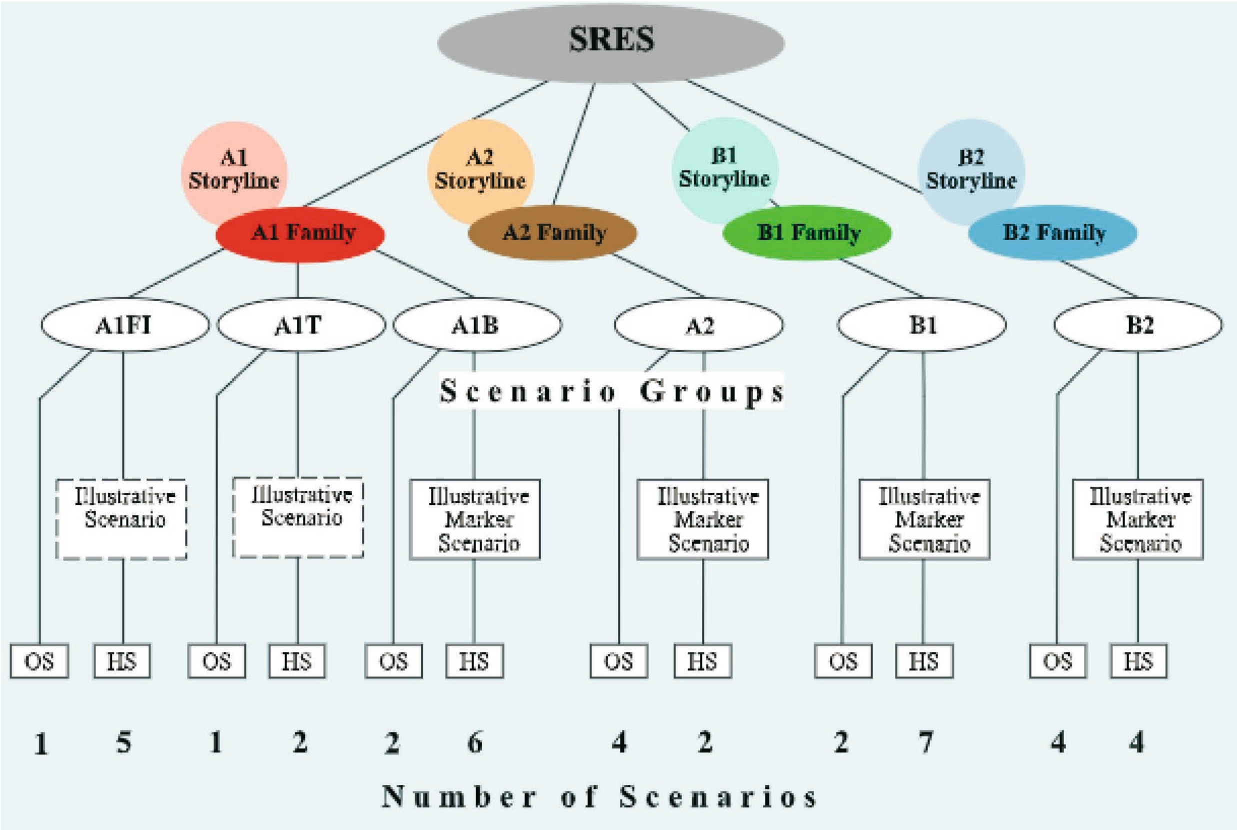


Fig. 1. The 40 scenarios of climate change; source: N. Nakicenovic et al. 2000

erates a particular microclimate that depends on the weather conditions, urban morphology, human activity, Green-blue urban grids and the thermal characteristics of building materials [T.R. Oke 1980; M. Santamouris et al. 2001]. According to the IPCC report, the mode of future development is the key factor in predicting climate change. In order to limit the scope for uncertainty, the IPCC has developed around forty models, organised into 4 main categories of possible climate change development, namely the A1, A2, B1 and B2 families, the development of which is summarised in the figure below. On the basis of these possible scenarios, the IPCC and the world meteorological organisation state that it would be possible to predict emissions and climate change. In this context, several authors have contributed to climate data morphing operations and have made it usable in common formats such as EPW, see M.F. Jentsch et al [2008] or A.L.S. Chan [2011] and A. Mylona [2012]. All these contributions have made it possible to develop databases that can be used to study more precisely the impact of climate change on different aspects of urban space.

The Covid-19 health crisis has highlighted the importance of public spaces in health resilience, that is why we are focusing our attention in this paper on the Ettoute public square in the city centre of the city of Blida (36.46N, 2.82E), Algeria, in order to assess its environmental quality and its microclimatic variation under different climate change scenarios for the summer period and for the hottest day of the year for the current state and according to the climate change scenarios. This study would make it possible to propose potential adaptation scenarios to future climate variations with a view to improving the hygrothermal comfort of the public square, which would improve its habitability.

1. METHOD

This paper aims to explore, on the basis of a simulation campaign, the impact of climate change on the hygrothermal comfort of the *Ettoute* public square in the city of Blida. The elements defining the microclimate are air temperature, relative humidity, wind speed, and mean radiant temperature (MRT). Some studies go so far as to quantify the amount of air exchange between the upper and lower parts of the urban canopy [S. Kitous 2013], or the energy budget expressed in terms of energy balance [T.R. Oke 1989] or air quality by assessing carbon emissions into the air; while other authors directly target the impact of a morphological device on the microclimate by addressing atmospheric pressure and wind speed [L. Khelifi et al. 2019; S. Boukarta, A. Mokhtari 2017]. In this paper, we will focus on the elements that define the microclimate and hygrothermal comfort, i.e. potential air temperature, MRT, air speed and humidity.

Morphing is an important step in the implementation of climate data for simulation. There are now a number of programs available for converting climate data for future periods and making it transferable. A recent study by Tootkaboni et al. [2021] exploring the quality of the predictions made by the 3 simulation models shows that the quality of the above-mentioned programs is almost identical, which makes morphing accessible to different disciplines and also makes it possible to make better use of climate data in terms of its impact on the various elements of the built and natural environment.

1.1. Future scenarios

In this paper we will focus on the current state of the Ettoute public square and three future scenarios, B1, A1B and A2, whose impact is to be considered in ascending order. Scenario B1 represents a future world that will experience population growth until 2050 and then decline until 2100. Economic development will be service-oriented with well-established regional convergence and the use of universal solutions and renewable energy. The A1B scenario is a sub-scenario of the A1 family, characterised mainly by continuous demographic growth until 2050 and then a decline until 2100, with rapid economic growth and the rapid introduction of more efficient technology. Regional convergence will also be strong, characterised by significant cultural and social exchange, with less variation in terms of GDP per country. The particularity of this scenario is that, despite rapid economic growth, it tends towards a world that is fairly balanced in terms of the use of fossil fuels and renewable energy. The A2 scenario describes a very heterogeneous future world whose development principle is based on local identities and weak regional convergence, with an increase in population without any decrease in growth. Technological exchange and use is slow and fragmented, not going beyond the scale of a single region [N. Nakicenovic et al. 2000; S. Boukarta 2019].

1.2. Morphing climate data

The morphing of climate data into Envimet was carried out using Meteonorm for the 2100 projection, based on the guidelines of the IPCC's fourth report [J. Remund 2010]. The climatic data thus obtained was transposed to Envimet version 3.1. The day chosen was the hottest day of the year, i.e. 20 July for the current period and 21 July for the future period, in order to assess the impact of the worst-case scenario and evaluate the role of the development of the public square on hygrothermal comfort. Also, in order to reduce the calculation time for the simulations, we focused on the critical periods of the day, i.e. 3 p.m. and 11 p.m., because the first period is the time of the earth's thermal inertia, which coincides with the temperature peak, and the second period is linked to the urban heat island phenomenon, the peak of which is often felt three to five hours after sunset [T.R. Oke 1975].

The climatic data obtained is presented in the graph below, including the temperature recorded during the chosen hour, the wind speed and the relative humidity.

Tab. 1. Weather data for the different scenarios

Scenario	3pm			11pm		
	Air temp °C	Relative humidity (%)	Wind speed km/h	Air temp °C	Relative humidity (%)	Wind speed km/h
Current	40	40	6,1	30,7	57	0,7
B1	41,6	40	6,6	32,7	74	0,7
A1B	43,1	26	6,5	32,5	56	0,7
A2	43,9	27	6,8	33,1	57	0,7

Source: own preparation

1.3. Presentation of Envimet software

Envimet is a three-dimensional grid-based prediction software designed to model microclimates under different configurations and is widely validated by the scientific community [S. Tsoka et al. 2018]. It is capable of predicting the complex interactions between air-surface-water and vegetation to give in return data characterising the microclimate; such as air temperature, humidity, wind speed, wind direction and radiative exchange etc, with a resolution of up to 0.5m grid in a time span ranging from 1 to 5 seconds [S. Huttner 2012]. In order to reduce the simulation time and given the size of the Ettoute square, we opted for a 3x3m grid model, specifying the simulation periods to include the critical periods in terms of heat.

1.4. Presentation of the case study (morphology)

The square of Ettoute is right in the centre of the city of Blida, at 36.28N and 2.49E. The city of Blida is in the humid climatic zone according to the DTR C3-2 classification, characterised by cold winters and hot, humid summers, with annual rainfall averaging over 600 mm and summer humidity exceeding 70%. The urban density surrounding Ettoute public square is medium, with buildings having an average of 2 storeys above ground level. The layout of the square is characterised by a predominance of mineral features, with two tree lanes surrounding the square on all four sides. The square is almost square in shape, with 67m-long sides. The centre of the square contains a monument surrounded by a fountain (Fig. 2).

Fig. 2. Ettoute public square, Blida city, Algeria (36.46N, 2.82E); source: left – Google Earth, top right, Flickr.com, bottom right: Wikimedia commons. Licensed under the CC BY-SA 3.0

The thermal characteristics of the building materials and those of the surface of the square are characterised by the heat transmission coefficient and the albedo of the walls and roof. See table below.

From the outset, it would appear that the current layout of a predominantly mineral square is not suitable for improving hygrothermal comfort, except at its periphery or even in the centre of the square. The habitability of the square is subject to the layout and it is only really used as a passageway.

Tab. 2. Materials' thermal characteristics

Thermal characteristics	Values
Walls' heat transmission	1.94 W/m^2.K
Roofs' heat transmission	2.00 W/m^2.K
Walls' albedo	0.275
Roofs albedo	0.25

Source: own preparation

1.5. Assessment method and limits of the investigation

Based on the modelling of the Ettoute square and on current and 2100 climate data for the 3 future scenarios presented above, the approach followed in this paper is based on the comparison of a series of simulations between the data characterising the microclimate. In this paper, we have limited the study to comparing 3 future scenarios with the current situation of the square. The other possible scenarios are not considered in this paper.

2. RESULTS AND DISCUSSION

The Ettoute square is modelled in Envimet using an image obtained from Google Earth with a grid of 3x3m (Fig. 3).

The results of the simulations are presented in the two tables below at 3pm and 11pm, comparing the microclimatic data, air temperature at 1.2m, wind speed, mean radiant temperature and relative humidity. A first reading of the maps obtained allows us to distinguish three different zones, a central zone constituting of the most vulnerable part, the vegetation zone of the trees, and the zone close to the buildings.

2.1. Ettoute square at 3pm

The most unfavourable air temperature seems to develop in the least shaded zone of the square and in future scenarios, the air temperature in the same central zone increases by 0.5°C, 0.94°C and 1.24°C respectively. The air temperature decreases relatively towards the vegetated periphery of the square by an average of 1.15°C. See table below.

The average radiant temperature follows the same logic, rising from 58.45 to 58.25 and 59.22 to 59.12°C for the actual, B1, A1B and A2 scenarios respectively. The increase is relatively small and even falls below the current level by almost 0.2°C for the scenario B1.

Relative humidity will increase by +2% in scenario B1 compared with the current situation (from 79% to 81% on average) and will fall by –19% and –16% respectively in scenarios AB1 and A2 at 3 pm on the hottest day of the year.

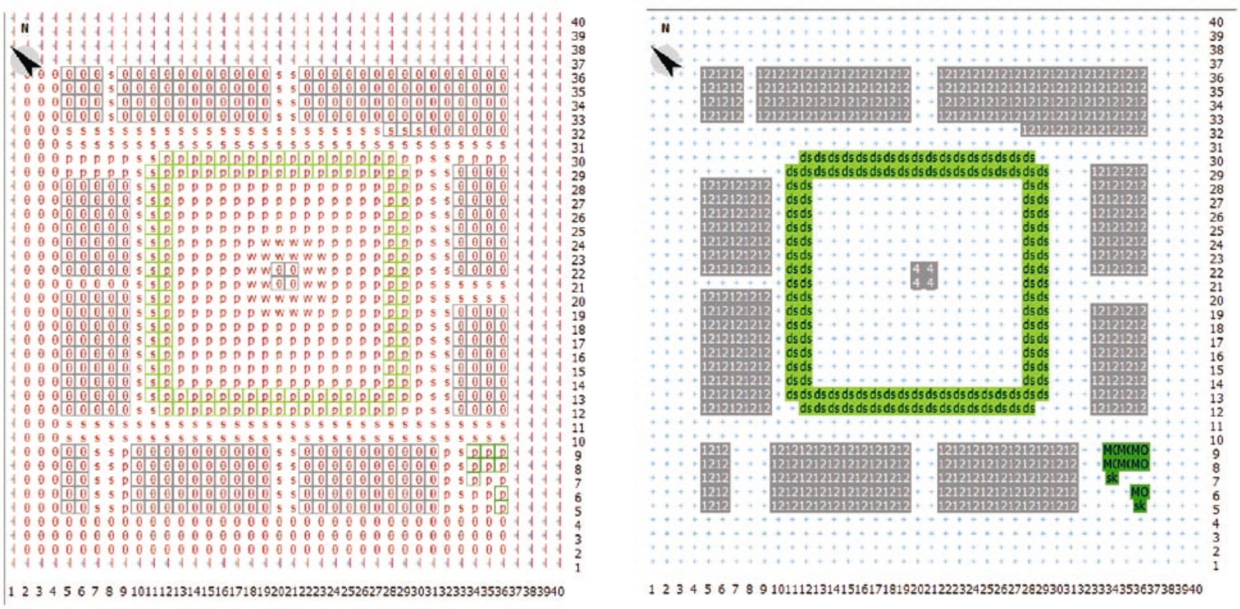
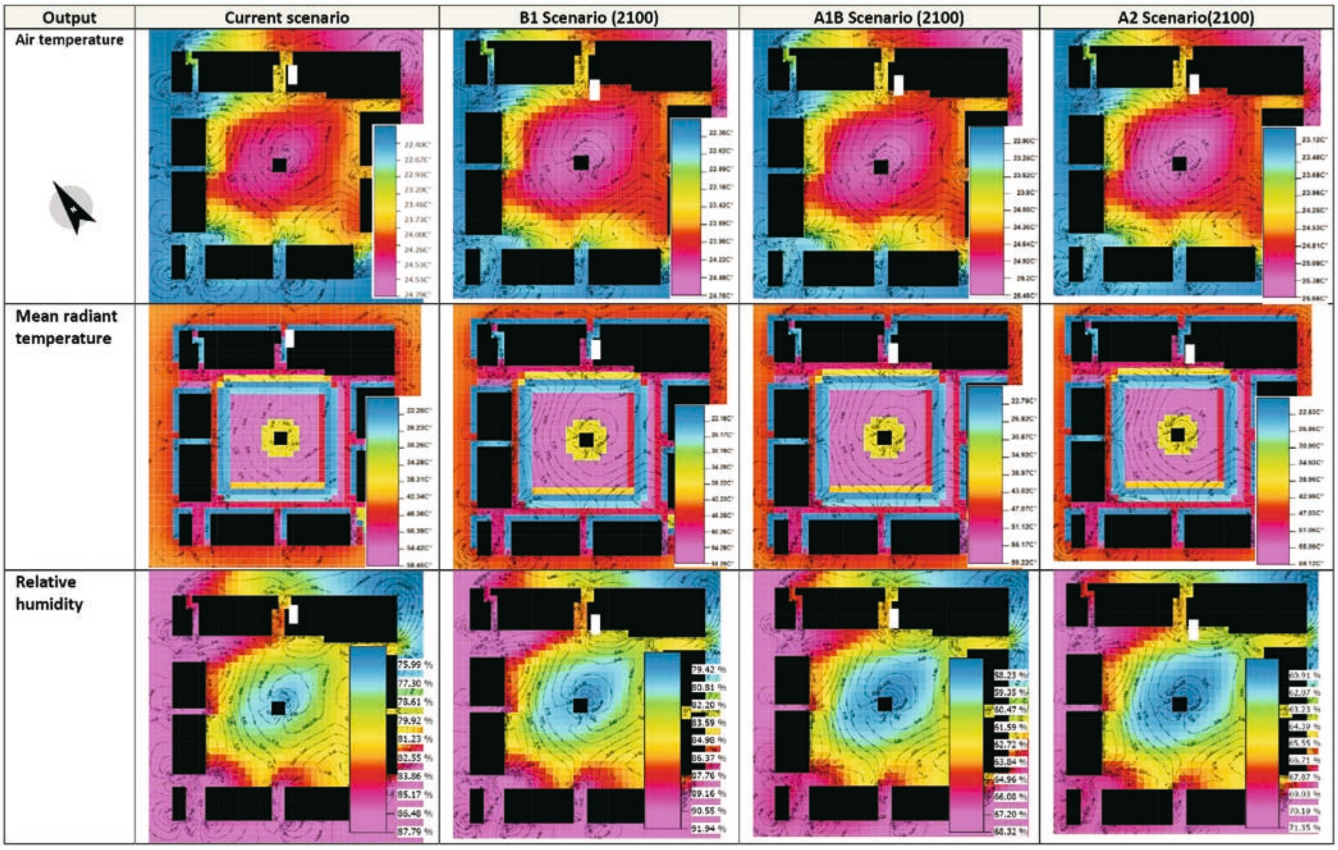


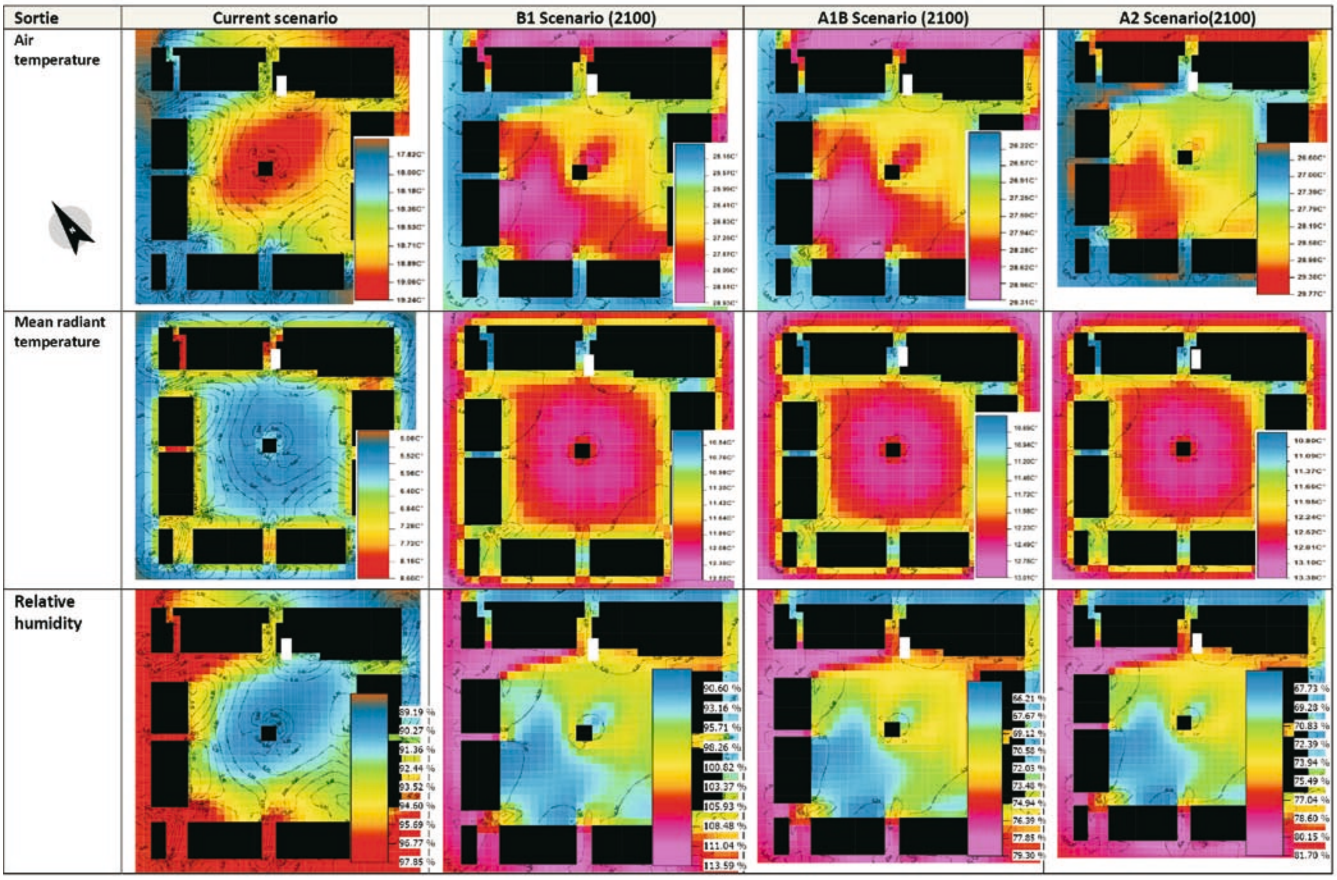
Fig. 3. 3D modelling of the Ettoute square; source: prepared by the author

Tab. 3. The Ettoute square at 3pm



Source: own preparation

Tab. 4. The Ettoute square at 11pm



Source: own preparation

2.2. Ettoute square at 11 pm

The simulations carried out at night (11pm) clearly show a significant rise in temperature between the current baseline scenario and the future scenarios for the 2100 horizon, rising from 18.95°C for the current period to 27.81, 28.37 and 28.98°C for scenarios B1, AB1 and A2, i.e. a rise of over 10°C for the worst case (A2).

The surface of the square is divided into three zones for the three future scenarios when considering air temperature. The central zone will see the greatest increase, as it is completely mineral and will experience a temperature of almost 30°C in the A2 scenario. The vegetation zones, on the other hand, will experience an air temperature of almost minus 2°C compared with the central zone.

The average radiant temperature will also rise by almost 7°C compared with the current situation. Lastly, relative humidity will increase slightly in scenario B1, by almost 2% compared with the current situation (90.84%), while the other two scenarios will see a fall in relative humidity of 69.41% and 70.91% respectively in scenarios AB1 and A2.

CONCLUSIONS

This paper highlights the importance of studying the impact of climate change on microclimatic variations and hygrothermal comfort of public spaces, based on a comparison of simulation results between 4 scenarios: a baseline case (current), and 3 IPCC potential scenarios, namely, B1, A1B and A2. The comparison of the future scenarios in relation to the current state of the microclimate in Ettoute square clearly shows an increase in air temperature, particularly visible during the night hours, with an increase of over 10°C for the most unfavourable scenario. Relative humidity increases slightly for scenario B1, and drops to 69 and 70% for scenarios AB1 and A2. Scenario B1 is the most conservative scenario with the lowest increase in daytime air temperature and a slight increase in relative humidity. The vegetation area is 2°C cooler than the mineral central area of the *Ettoute* square. This conclusion highlights the importance of vegetation in mitigating the effect of the urban heat island. Urban vegetation plays an important role that is already well documented in the scientific literature. Through its urban multifunctionality, such as shade generation, plant evapotranspiration, urban greenery helps to soften the urban microclimate, helps with air purification, and it can even play the role of a natural insulator for buildings by reducing the incidence of solar radiation on facades, without losing sight of the aesthetic aspect that vegetation can play in enhancing public spaces. The gradual integration of vegetation in public spaces will enable the microclimate to be more resilient and better adapted to future climate change. Potential areas of research include combining vegetation with the introduction of innovative construction materials such as TiO2, which can reflect solar radiation and even reduce urban pollution through its photocatalytic properties.

LITERATURE

1. **Boukarta S. (2019)**, *Déterminants de la forme urbaine générant le potentiel de maîtrise de l'énergie en zone semi-aride. Application sur le cas de Djelfa en Algérie*, doctoral dissertation, EPAU.
2. **Boukarta S., Mokhtari A. (2017)**, *Analyse multicritère pour une caractérisation énergétique des formes Urbaines*, "Courrier du Savoir", 24, 163–174.
3. **Chan A.L.S. (2011)**, *Developing future hourly weather files for studying the impact of climate change on building energy performance in Hong Kong*, "Energy and Buildings", 43(10), 2860–2868.
4. **Dousset B., Gourmelon F., Laaidi K., Zeghnoun A., Giraudet E., Bretin P., Mauri E., Vandentorren S. (2011)**, *Satellite monitoring of summer heat waves in the Paris metropolitan area*, "International Journal of Climatology", 31(2), 313–323.
5. **Emilsson T., Ode Sang Å. (2017)**, *Impacts of climate change on urban areas and nature-based solutions for adaptation*, in: *Nature-based solutions to climate change adaptation in urban areas. Linkages between science, policy and practice*, eds. N. Kabisch, H. Korn, J. Stadler, A. Bonn, Springer, Cham, 15–27.
6. **Heaviside C., Cai X.M., Vardoulakis S. (2015)**, *The effects of horizontal advection on the urban heat island in Birmingham and the West Midlands, United Kingdom during a heatwave*, "Quarterly Journal of the Royal Meteorological Society", 141(689), 1429–1441.
7. **Huttner S. (2012)**, *Further development and application of the 3D microclimate simulation ENVI-met*, dissertation, Universität Mainz.
8. **IPCC (2014)**, *IPCC Fifth Assessment Report – Synthesis Report*, IPPC Rome, Italy.
9. **Jentsch M.F., Bahaj A.S., James P.A.** (2008), *Climate change future proofing of buildings – Generation and assessment of building simulation weather files*, "Energy and Buildings", 40(12), 2148–2168.
10. **Khelifi L., Soufiane B., Rafik B., Youcef K. (2019)**, *Le passage couvert comme régulateur socio-climatique dans le tissu traditionnel, Cas d'étude: le ksar de Timimoun (climat chaud aride)*, in: International Conference on Materials, Patrimony and the Environment in Arid Zones.
11. **Kitous S. (2013)**, *Le rapport entre morphologie et climat urbain dans le ksar de Ghardaïa: le cas de la ventilation naturelle*, doctoral dissertation,

École Polytechnique d'Architecture et d'Urbanisme d'Alger.

12. **Mylona A. (2012)**, *The use of UKCP09 to produce weather files for building simulation*, "Building Services Engineering Research and Technology", 33(1), 51–62.
13. **Nakicenovic N. et al. (2000)**, *IPCC Special Report: Emissions scenarios: Summary for policymakers, Intergovernmental Panel on Climate Change*, Genf.
14. **Oke T.R. (1980)**, *Thermal environment in urban areas*, Swedish Council for Buildings Research.
15. **Oke T.R. (1982)**, *The energetic basis of the urban heat island*, "Quarterly Journal of the Royal Meteorological Society" 108(455), 1–24.
16. **Oke T.R**. **(2011)**, *Urban heat islands*, in: The Routledge Handbook of Urban Ecology, eds. I. Douglas, D. Goode, M. Houck, R. Wang, Routledge, New York, 120–131.
17. **Oke T.R., Maxwell G.B. (1975)**, *Urban heat island dynamics in Montreal and Vancouver*, "Atmospheric Environment" (1967), 9(2), 191–200.
18. **Tootkaboni M.P., Ballarini I., Zinzi M., Corrado V. (2021)**, *A comparative analysis of different future weather data for building energy performance simulation*, "Climate" 9(2), 37.
19. **Remund J., Müller S., Schilter C., Rihm B. (2010)**, *The use of Meteonorm weather generator for climate change studies*, in: 10th EMS Annual Meeting Abstracts, 13–17 September, Zürich.
20. **Santamouris M., Papanikolaou N., Livada I., Koronakis I., Georgakis C., Argiriou A., Assimakopoulos D.N. (2001)**, *On the impact of urban climate on the energy consumption of buildings*, "Solar Energy", 70(3), 201–216.
21. **Tol R.S. (2018)**, *The economic impacts of climate change*, "Review of Environmental Economics and Policy", 12(1), 4–25.
22. **Tsoka S., Tsikaloudaki A., Theodosiou T. (2018)**, *Analyzing the ENVI-met microclimate model's performance and assessing cool materials and urban vegetation applications*, "Review of Sustainable Cities And Society", 43, 55–76.
23. **Tumini I., Rubio-Bellido C. (2016)**, *Measuring climate change impact on urban microclimate: A case study of concepción*, "Procedia Engineering", 161, 2290–2296.