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The contribution of urban design in reducing the intensity of heatwaves in hot climate areas

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Abstract:

Our study, based on climatic variability and the increasing size of cities, ways to maintain outdoor thermal comfort within the urban environment during heatwave seasons in hot climates regions, given its critical importance in improving residents' quality of life. While most studies have focused on the impact of materials in generating urban heat islands, the distinctive contribution of our research lies in examining the role of urban planning in mitigating thermal phenomena present in the urban fabric. We use urban heat island (UHI) maps as a benchmark to measure the impact of design on enhancing outdoor comfort, relying primarily on a simulation-based experimental methodology to test the hypothesis that reducing the area of sun-exposed surfaces can lessen the intensity of seasonal heatwaves in hot climates, with the aim of identifying urban planning solutions that are practically implementable.

***Brahim Medjahdi**

1. Introduction:

Urban design can play a significant role in mitigating the impact of the urban heat island phenomenon through a set of strategies, techniques, and approaches—most notably by creating corridors that allow wind movement for ventilation purposes, increasing green spaces, and using light-colored materials in construction. Additionally, the implementation of green roofs, vegetated façades, and vertical gardening helps reduce energy consumption through the natural cooling process of evaporation.

1.1. Research Problem and Questions:

In light of the aforementioned points, it is essential to shed light on the current state of harmony between humans and their urban environment, and to reflect on how this relationship manifests in architectural and urban productions—ensuring that they meet users' comfort needs and enhance their efficiency. From this perspective, this research paper aims to uncover this scientific issue and address the following main research question:

To what extent does urban planning contribute to improving the environmental behavior of the urban fabric, leading to an improved quality of life for residents and users?

In order to address this main research problem, a set of related sub-questions has been formulated:

- What is the general context of our study?
- What are the most significant studies and research works that have examined this aspect of control in urban design?
- What are the key models that illustrate the general conceptual framework upon which this study is based?

1.2. Importance of the Study:

The importance of this study lies in its examination of the feasibility of developing and proposing an urban planning approach that is compatible with the constraints imposed by the climatic realities of these regions.

This study also seeks to establish a link between urban planning and the quality of life in urban areas with hot and dry climates, especially during heat waves. It then proposes a planning method that can contribute to enhancing comfort and mitigating the effects of heat in the urban environment, thereby improving the quality of life for residents in these areas.

1.3. Objectives of the Study:

This study aims to improve the behavior of the urban fabric in response to the challenges imposed by the climate—particularly during seasonal heatwaves—thereby contributing to the enhancement of users' quality of life.

Our study necessarily aims to highlight the important and fundamental role of planning in improving outdoor thermal comfort in hot climates, especially during heatwave seasons, and to emphasize the need to support it with effective construction materials, focusing on urban greening. This will help mitigate the exacerbation of heat-related phenomena within the urban fabric and improve its ability to provide the necessary outdoor comfort for a good quality of life for users.

1.4. Research Hypothesis:

Two main hypotheses can be highlighted:

- We assume that by reducing the surface areas exposed to direct sunlight and by distributing the materials that compose the urban environment according to their thermal behavior—in line with the Gestalt theory of organization—it is possible to mitigate the effects of seasonal heatwaves in hot climate regions and their negative impacts on human health and productivity.
- Through experimentation—simulation—and analysis, it is possible to generate urban planning solutions capable of reducing the effects of seasonal heatwaves within the urban fabric of hot climate regions, in a way that aligns with residents' needs and the climatic constraints imposed by current environmental realities.

1.5. Research Methodology and Approach:

Answering the previously stated research problem and achieving the intended objectives of this study require adopting a sound methodology based on observing the results of computer-based simulations before proceeding to their analysis. This approach enables us to derive insights that can contribute to forming an updated vision of urbanism capable of adapting to current climatic constraints, while enhancing users' productivity and quality of life.

To ensure the optimal use of this methodological framework, the following tools and sources are employed:

- Computer simulation using Ladybug on Grasshopper;
- Modeling of buildings used in simulations through Rhinoceros 7;
- Climatic data of the city of Biskra, with comparative analysis of different design proposals.

Based on these foundations, our study is divided into two main sections:

- The semantic context and the cognitive scope of thermal diffusion within residential clusters.
- The case study and analysis of the selected samples.

2. Semantic Context and Cognitive Scope of Thermal Diffusion within Residential Clusters:

In light of climatic challenges and the growing sizes and areas of cities, our study addresses ways to improve the environmental behavior of the urban fabric, given its critical importance in enhancing residents' quality of life and maintaining outdoor comfort. This topic has been the focus of numerous studies (Weijie Xu 2020, 31). For example, researchers have conducted digital simulations and compared them with laboratory experimental results to examine the effect of heat-absorbing paving stones PSC [Pavement solar collector] in the urban environment on outdoor air temperature, thereby evaluating the impact of materials in mitigating various urban thermal phenomena.

2.1. The Role of Reflected Thermal Radiation in Raising Temperature:

Reflected thermal radiation from various surfaces in the urban environment leads to an increase in the temperature of roads as well as building walls and façades, which contributes to the formation of urban thermal phenomena such as urban canyons and heat islands.

Researchers have concluded that heat-absorbing paving stones have a significant effect in reducing urban temperatures. In unshaded areas, these paving stones lower the temperature by approximately 10°C, whereas in areas shaded by building shadows, they can reduce it by nearly 15°C compared to surfaces paved without such heat-absorbing stones.

Their study concludes with a series of recommendations advocating the use of these heat-absorbing paving stones to improve urban thermal comfort, contribute to reducing buildings' cooling needs, and protect car tires from wear due to the lower temperatures provided.

2.2. Related Studies:

Researcher Alroheily Amina and colleagues (Alroheily 2022, 92-100)conducted a comprehensive study aimed at examining changes in the size of urban heat islands in parallel with traffic volumes during peak days and holidays, in order to identify traffic congestion hotspots. This was achieved by analyzing data on urban heat island variations obtained from remote sensing and geographic information systems (GIS).

The study concluded that there is a direct relationship between the size of urban heat islands and the density of the road network as well as areas of traffic congestion. It also revealed that the peaks of urban heat islands are associated with congestion points and intersections with traffic lights in regions with dense road networks.

These findings from the previous study reinforce the conclusions reached by Professor Yamamoto in his research on Tokyo, where he also determined that the increase in urban heat islands is an inevitable consequence of the number of vehicles and the density of the road network (Yamamoto 2015, 960).

It is worth noting that neither of these studies addressed the impact of urban planning on the environmental behavior of the urban fabric, and consequently, on residents' quality of life. This represents a critical gap linking urban planning and architectural production—precisely the gap that drew our attention and directly motivated us to explore the potential of planning in mitigating the intensity of seasonal heatwaves.

Our primary approach in this study is based on the urban heat island (UHI) phenomenon as a key benchmark for evaluating planning efficiency. The methodology relies mainly on computer-based simulation experiments, followed by the analysis of the resulting data. The objective is to propose practical urban planning solutions summarized in a set of guidelines that can help reduce the impact of thermal phenomena on the urban fabric, thereby enhancing its capacity to provide outdoor comfort essential for a good quality of life.

The climate challenges facing the world have highlighted shortcomings in current urban design, which often does not align with contemporary demands. Urban heat islands increase the need for air conditioning to cool buildings; some studies estimate that energy demand rises by 1% to 9% for every 2°F

(Santamouris 2020, 142) increase in surrounding temperatures, leading to higher electricity consumption, particularly in cities with tall buildings.

Beyond energy needs, urban heat islands also affect public health. They exacerbate the effects of natural heatwaves—periods of abnormally hot and humid weather. Vulnerable population groups, such as low-income residents, the elderly, children, women, and outdoor workers, exhibit reduced productivity and face greater health risks. High temperatures in these conditions can lead to respiratory illnesses, dehydration, and heat strokes. (Gamble 2008, 41-42)

To mitigate this urban climatic volatility, the city of Zurich established a digital system [the Meteoblue city climate monitoring system from Meteoblue AG] to monitor the city's climate. This system relies on data collected from sensors installed throughout the city, which are then analyzed using artificial intelligence in comparison with past weather patterns and their frequency. The aim is to predict the magnitude of climatic changes before they occur, enabling the optimal implementation of emergency plans.

One notable outcome of this initiative was the discovery that hot days and heatwaves have become increasingly frequent in the city. As a result, thermal comfort has been given greater consideration in all urban planning processes during new city developments.

2.3. Temporal and Spatial Framework of the Study:

This study is spatially situated in the city of Biskra, located in the southeast of Algeria at 34°51′00″ N, 5°44′00″ E, serving as a live and ideal model for a region characterized by a hot and arid climate.

The temporal scope of the study was set during the summer season, specifically at 12:00 PM, in the week from July 27 to August 3—the period identified as the hottest of the year according to the city's climatic data.

Urban planning is a human-centered practice whose primary aim is to protect people from the constraints of their environment, evolving and adapting as these constraints change. The justifications for selecting this urban area for study can be summarized as follows:

- Observing the difficulty of mobility and movement during heatwave seasons.
- Noting the decline in productivity among active population groups and the exacerbation of health complications among the elderly and children during heatwave periods.
- The near absence of public life for most hours of the day during heatwave seasons.

- The near halt of various urban services and the diminished capacity to attract and manage users within the urban environment during heatwave periods.

3. Case Study of the Selected Samples:

To obtain accurate, comprehensive, and generalizable results applicable to similar environments under the same conditions, we proposed three urban planning models, each defining a plot of land measuring 110 × 140 m.

During the simulations, which revealed variations in temperatures across different areas of the urban fabric for each selected planning scenario, we recorded the geographic location and weather data for this area during the heatwave season—the same week chosen for the study. These data included precipitation levels, humidity rates, hours of sun exposure, and prevailing wind speeds.

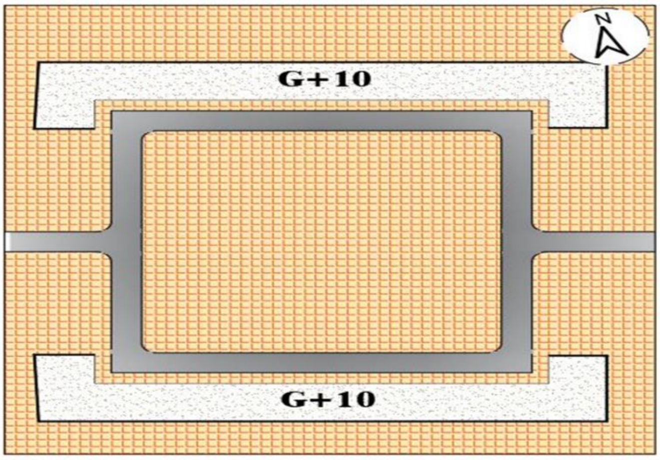
Next, we input the size and height (30 m) of the residential buildings and their positions, which served as key parameters in calculating heat gain. The results were represented through thermal maps showing the temperature distribution across urban spaces after sun exposure during the specified time period of the study.

3.1. First Urban Planning Model:

In this model, residential buildings were arranged in a checkerboard pattern. This type of design is highly recommended in Algeria for purely social considerations. However, it is unfortunately evident that its scientific validity and foundational principles remain uncertain.

From an urban design perspective, inspired by the French urban planning school, this layout has the potential to enhance the quality of the urban space. In this arrangement, the buildings form peripheral blocks, with the central area designated for parking opposite the entrances and large open spaces allocated for children’s play.

Figure No01: Layout of the First Model



site plan

From this figure, the difference in temperature between areas far from the buildings, which reached approximately 45°C, and the central play areas, at around 43°C, does not exceed 3°C. The buildings were clearly spaced apart, and it is observed that the more an area is exposed to sunlight, the greater the heat load it accumulates. This heat is then reflected back, raising the temperature of the urban fabric and contributing to the formation of urban heat islands.

Figure No02: Thermal Map of the First Urban Planning Model

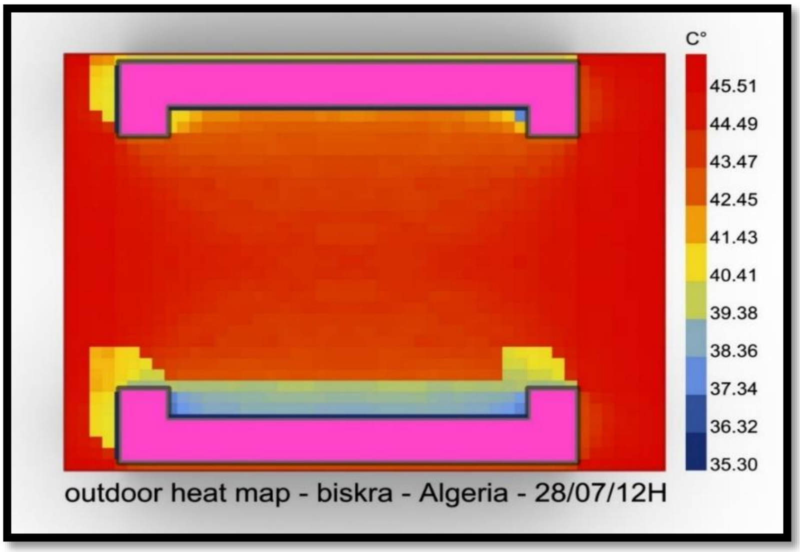


Table No01: Maximum and minimum temperatures within model number 01

Themperature	***minimum***	***Intermédiate***	***Maximum***
Value	***35.30 c°***	***40.40c°***	***45.51c°***
Percentage of Outdoor area with a temperature below 38 degrees	***974.5m2/15400m2 = 6.32%***		

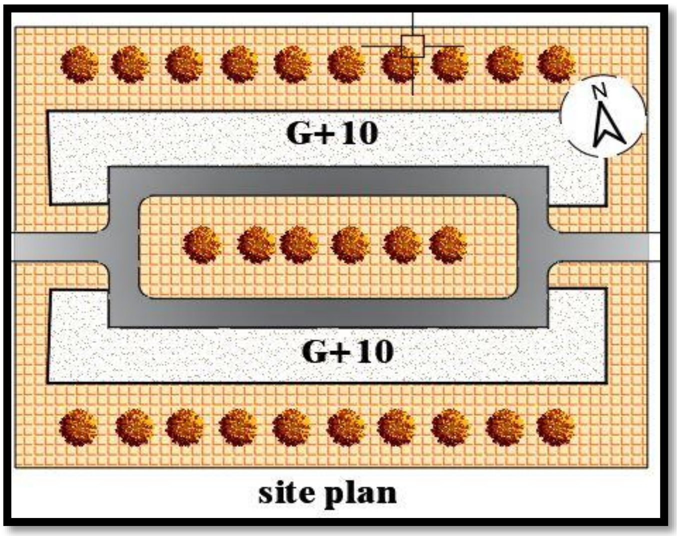
3.2. Second Urban Planning Model:

In this model, the various components of the urban space were arranged more logically in relation to each other (Hamed 2022, 71). Parking areas were positioned parallel to the main road, separated from the buildings by a corridor of evergreen trees surrounding the exterior of the residential blocks. The buildings themselves were placed closer together, forming a constructed frame for the neighborhood, with children's play areas located within this frame.

A distinctive feature of these buildings is that each has two entrances: one from the parking area and another directly from the internal play spaces defined by the built frame.

This design brings the buildings closer together without excessive crowding, optimizing the use of their own shade to create shaded areas. This approach aligns with the proposed hypothesis of reducing sun-exposed urban surfaces, thereby preventing the formation of urban heat islands, in accordance with the recommendations of previous studies.

Figure No03: Layout of the Second Model



From this illustrative figure, the difference in temperature between areas far from the buildings—exceeding 45°C—and the central play areas, which ranged between 35°C and 40°C, becomes clearly apparent. The spacing between buildings exceeded 30 meters.

This arrangement demonstrates that grouping architectural units according to their function within the urban space helped identify "hot spots" within the urban fabric. This, in turn, facilitated the strategic placement of shading and greenery, reducing heat accumulation. As a result, the temperature under shaded areas did not exceed 38°C, while surrounding exposed areas reached temperatures above 45°C.

Figure No04: Thermal Map of the Second Urban Planning Model

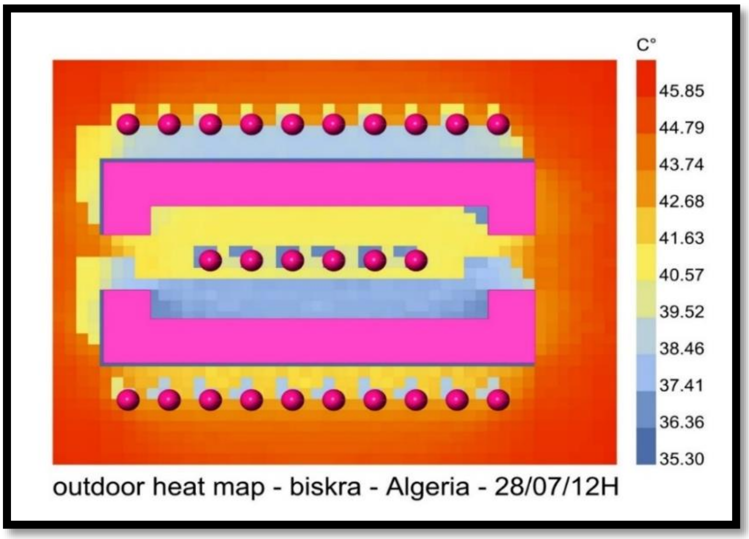


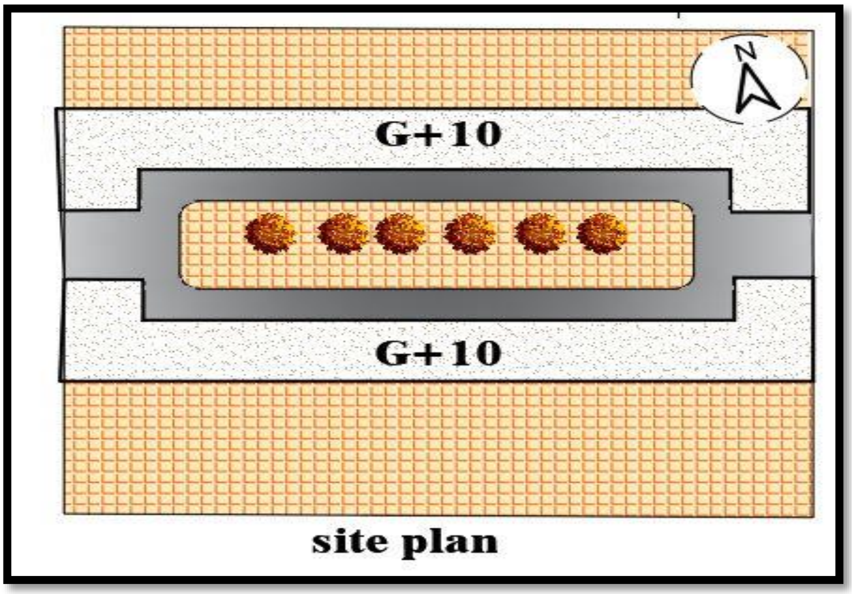
Table No02: Maximum and minimum temperatures within model number 02

Themperature	***minimum***	***Intermédiate***	***Maximum***
Value	***35.30 c°***	***40.57c°***	***45.85c°***
Percentage of Outdoor area with a temperature below 38 degrees	***2771.9 m2/15400m2 = 17.99%***		

3.3. Third Urban Planning Model:

In this model, the buildings were positioned excessively close to one another, disregarding recommended planning guidelines and principles. The aim was to create a concentrated area of overlapping shadows in the hope of reducing and lowering temperatures.

Figure No05: Layout of the Third Model



According to this illustrative figure, the temperature difference between areas far from the buildings, which exceeded 45°C, and the central neighborhood areas, ranging between 40°C and 41.5°C, was only 3.5–5°C. The spacing between buildings did not exceed 20 meters.

Figure No06: Thermal Map of the Third Urban Planning Model

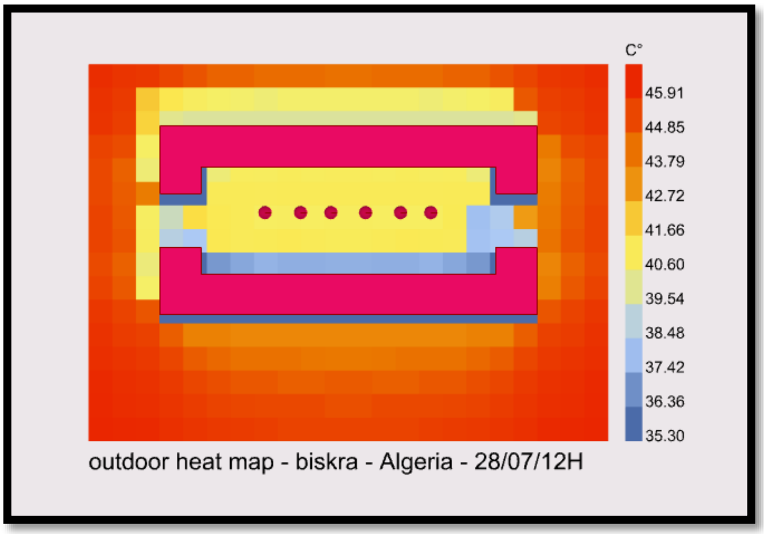


Table No03: Maximum and minimum temperatures within model number 03

Themperature	***minimum***	***Intermédiate***	***Maximum***
Value	***35.30 c°***	***40.60c°***	***45.91c°***
Percentage of Outdoor area with a temperature below 38 degrees	***1066.3 m2/15400m2 = 6.9%***		

This demonstrates that excessively increasing the density of the urban fabric did not significantly reduce temperatures, contrary to expectations.

Table No04: Comparison of the percentage of temperatures in the three studied models

	Percentage of Outdoor area with a temperature below 38 degrees
Model 1	***6.32%***

Model 2	***17.99%***
Model 3	***6.9%***

4. Conclusion:

The simulation results demonstrate that both excessive spacing and excessive clustering of buildings fail to significantly reduce heat intensity. Excessive spacing creates larger sun-exposed areas, while extreme clustering traps air masses and prevents their movement—both conditions promote the formation of urban heat islands. Therefore, the optimal strategy is to position buildings close enough to create sufficient shaded areas over the urban space, with placement guided according to the function, type, and thermal behavior of each unit within the urban fabric.

This approach helps identify the hottest points within the urban fabric, allowing them to be addressed efficiently through planning interventions—such as directing shadows and greenery toward these hotspots and promoting air movement—thus penetrating heat islands and reducing the intensity of seasonal heatwaves in hot climate regions. This ensures comfort for urban space users and decreases building energy consumption, aligning with the study's hypothesis that urban planning can control the thermal behavior of the urban fabric.

Key Recommendations and Proposals:

- **Material Selection and Distribution:** Choose building materials based on their thermal behavior and distribute them according to their physical properties, while reducing the area of sun-exposed surfaces in a calculated manner. Additionally, implement greenery and direct shadows toward urban hotspots to enhance air movement and dissipate heat. This approach helps reduce building energy consumption, alleviates pressure on electricity, gas, and water networks, lowers operational costs, preserves resources and the environment, and highlights the strong impact of planning on the environment and society. Urban planning should therefore be a central focus for stakeholders, as it underpins all related climatic, environmental, and social solutions.

- **Environmental Considerations:** Effective urban planning must account for surrounding environmental factors, including air movement, prevailing winds, humidity, building material characteristics, and solar exposure. In this study, solar exposure was the primary determinant shaping the urban fabric. In hot and arid climates, compact urban forms with strategically varied building heights facilitate air movement and generate continuous shaded areas that move with the sun throughout the day.

- **Social Considerations:** Design can also reinforce social hierarchies and gradations, from public to semi-public spaces, and create spaces suitable for different age groups and genders. Internal areas can cater to young children and women, while exterior urban spaces with evergreen trees and appropriate furnishings may be used predominantly by men, reflecting the needs of conservative communities.

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