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The Influence of Urban Morphology on Thermal Comfort and Energy Needs in Bechar, Algeria: A Comparative Analysis of Traditional and Modern Urban Forms

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***Abstract*— Cities in extreme arid climates like Béchar, Algeria, face growing challenges in ensuring thermal comfort and energy efficiency. This paper examines the influence of urban morphology on these issues by comparing traditional ksar settlements with contemporary urban layouts. The analysis reveals that the compact structure, shaded courtyards, and high thermal mass materials of traditional districts significantly enhance passive cooling and thermal comfort. In contrast, modern extensions—marked by wider streets, low-density planning, and inadequate material choices—intensify heat gain and energy demand. Drawing from bioclimatic design principles and literature, the paper outlines a conceptual framework for adapting urban form in Saharan contexts, integrating vernacular knowledge with modern planning for climate-responsive development.**

***Keywords*— Bechar, arid cities, urban morphology, thermal comfort, passive design, bioclimatic urbanism, energy efficiency**.

I. INTRODUCTION

Bechar, a city situated on the edge of the Algerian Sahara (Figure 1), is characterized by an extremely hot and dry climate, further complicated by harsh diurnal and seasonal temperature variations. During the summer months, average high temperatures regularly approach 40°C, often peaking at 46°C on the hottest days (Figure 2), significantly exceeding standard thermal comfort thresholds. Conversely, winter nights can see temperatures drop below freezing, and substantial daily temperature swings, typically ranging from 20 to 25°C, are commonplace (Benslimane et al. 2020). This challenging arid environment underscores the critical role of a city's physical form, or its urban morphology, in influencing both the thermal comfort of its inhabitants and its overall energy needs (Gao et al. 2024). Traditional Saharan settlements, exemplified by the ksour (fortified villages), have evolved over centuries, developing sophisticated design strategies to mitigate these extreme climatic conditions (Bouchahm et al. 2011). These vernacular urban forms in Southern Algeria have historically achieved a remarkable balance with nature, providing appreciable indoor comfort and airflow even within one of the world's harshest climates (Bekkouche et al. 2013).

The old ksar (citadel) of Bechar, also known as Taghit's ksar, stands as a prime illustration of this adaptation, featuring dense mud-brick architecture and a network of narrow alleys (Figure 3) that collaboratively create shaded microclimates and passively cooled interiors (Fathy 1986). In stark contrast, modern urban expansions in Bechar have frequently adopted layouts and construction techniques borrowed from milder regions, often neglecting the imperatives of the local climate (Benslimane et al. 2020). This departure from climate-responsive design has resulted in a noticeable degradation of thermal comfort within contemporary neighborhoods and a consequent surge in cooling energy demands (Benradouane and Benyoucef 2006). Indeed, numerous field and simulation studies conducted across Algeria have consistently demonstrated the superior indoor comfort provided by vernacular houses compared to more recent constructions, with many new houses proving effectively unsuitable for the desert climate without the extensive use of mechanical cooling systems (Benradouane and Benyoucef 2006; Bouchahm et al. 2011).

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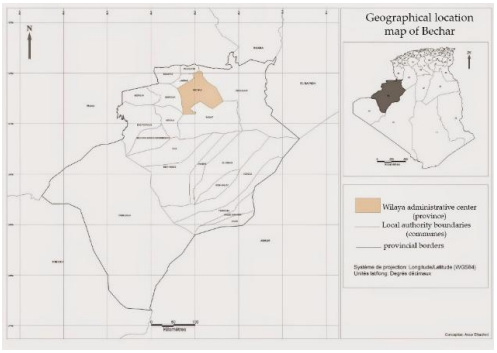

Figure 1: The geographical situation of Bechar

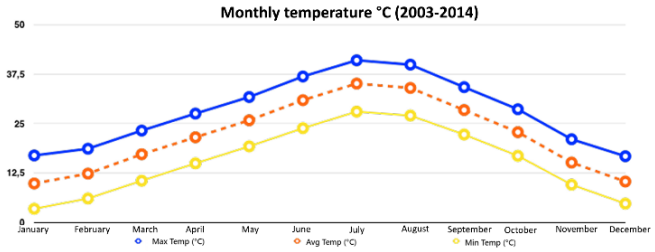

Figure 2: Variation in Air Temperature (2003-2014)

Given the increasing urgency of sustainable design in the face of a warming global climate, it is paramount to carefully examine and learn from these time-tested traditional solutions (Taleghani et al. 2015). This report undertakes an analysis of the urban morphology of Bechar through a comparative lens, specifically contrasting the traditional ksar fabric with the modern city form. The study will examine how each of these distinct urban forms impacts thermal comfort, passive cooling performance, and overall energy efficiency. To provide a broader context for Bechar's case, this analysis will draw upon international literature in the fields of arid architecture, thermal design, and urban heat dynamics (Aina et al. 2021). Key questions that this report will address include: How do the spatial configuration and building design of the old ksar promote thermal comfort passively? What are the shortcomings of the modern layout in this climate? And how can we integrate vernacular principles into a conceptual framework for bioclimatic urban form adaptation in Saharan cities? Following this introduction, the report will outline the methodology employed for the comparative analysis, subsequently present the results and discussion focusing on the thermal implications of traditional versus modern urban forms, and finally conclude with a proposed framework for climate-responsive urban design in arid regions (Hesam and Mostafa 2014).

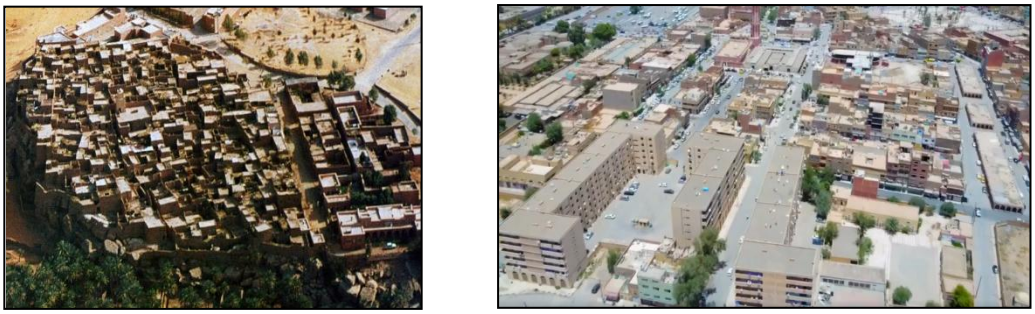

Figure 1:Comparative aerial views of distinct urban morphologies in Bechar: (on the left) The dense, organic layout characteristic of a traditional ksar district; (on the right) A grid-based layout typical of a modern residential district.

II. METHODOLOGY

This study employs a comparative analysis approach to investigate the influence of urban morphology on thermal comfort and energy needs in Bechar, Algeria. The analysis contrasts the urban fabric of the old ksar of Bechar (Taghit's ksar) with its modern urban expansions. The characteristics of the old ksar, including its urban density, street layout and orientation, building materials, and traditional climate-responsive features such as courtyards and shading elements, are examined based on descriptions provided in the user query and supported by the literature review (SEBTI et al. 2024). Similarly, the features of modern urban expansions in Bechar, particularly their deviations from traditional designs and their adoption of layouts and construction techniques from milder regions, are analyzed using information from the user query and relevant literature (SEBTI et al. 2024). The comparative analysis then draws upon insights from international literature in the fields of arid architecture, thermal design, and urban heat dynamics to contextualize the observations and interpret the differences in thermal performance and energy efficiency between the two urban forms. Specifically, findings from comparative studies on traditional versus modern buildings in arid climates (Magali and Philippe 2023), research on the impact of urban morphology on thermal comfort and the urban heat island effect (Chen et al. 2021), principles of microclimate creation in traditional desert settlements (Pearlmutter, n.d.), existing bioclimatic urban design frameworks ("Africa-Europe BioClimatic Buildings for XXI Century - ABC21,"

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n.d.), and climate-responsive architecture guidelines for arid regions ("Best Practices for Climate-Responsive Building Design - Archova Visuals," n.d.) are used to support the analysis and provide a broader understanding of the implications of different urban forms in the context of Bechar's climate.

III. Results and Discussion

A. *Passive Thermal Comfort in the Old Ksar of Bechar*

The spatial configuration and building design of the old ksar of Bechar (Taghit's ksar) effectively promote thermal comfort passively through a combination of interconnected strategies. The dense mud-brick architecture, utilizing local materials like earth and mud-brick (figure 5), provides significant thermal inertia (AHRIZ et al. 2017). This high thermal mass allows the walls to absorb heat during the day, delaying its transmission to the interior spaces, and to release the stored heat slowly during the cooler nights, thus moderating the indoor temperature fluctuations (Mekherbeche et al. 2020). The network of narrow (figure 4), winding alleys within the ksar creates shaded microclimates by limiting direct exposure to the intense solar radiation (SEBTI et al. 2024). These narrow streets also enhance natural ventilation by creating a Venturi effect, where wind speed increases as it passes through the constricted spaces, aiding in cooling (SEBTI et al. 2024). Many houses in the ksar feature a central courtyard (El-huch), which serves as a vital element for passive cooling and thermal comfort (AHRIZ et al. 2017). The courtyard facilitates natural light penetration into the interior while also promoting air circulation through convection, helping to dissipate heat (Gherraz et al. 2023). The overall compact urban form of the ksar minimizes the surface area exposed to the harsh desert environment, reducing heat gain during the hot summer months and heat loss during the colder winter nights (SEBTI et al. 2024). The orientation of the ksar's streets and buildings is often strategic, designed to take advantage of prevailing winds for ventilation and to minimize direct solar exposure, particularly on east and west facing walls (SEBTI et al. 2024). Additionally, the presence of half-covered streets, formed by upper floors connecting adjacent houses, provides further shade for pedestrians and can generate localized air movement, contributing to a cooler outdoor environment [10]. The principle of internalization, where outdoor spaces are minimized in favor of internal courtyards, also contributes to the ksar's energy efficiency by reducing the building envelope's exposure to extreme temperatures (AHRIZ et al. 2017).

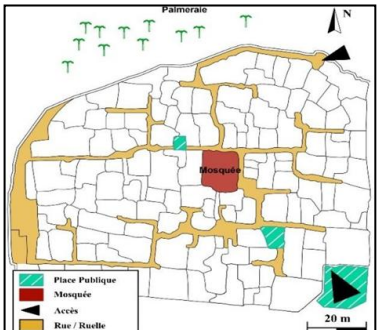

Figure 2:Urban layout of Taghit's Ksar, Bechar, illustrating key passive design strategies.

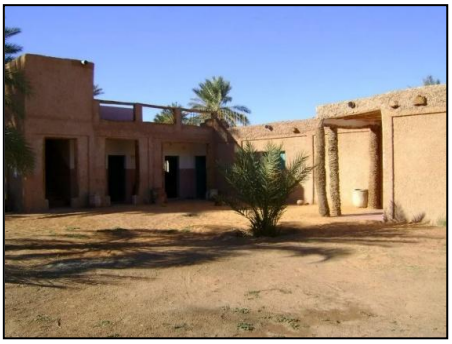

Figure 3:A central courtyard (El-huch) in Taghit's Ksar, Bechar, surrounded by traditional mud-brick structures.

B. *Shortcomings of the Modern Layout in Bechar's Climate*

Modern urban expansions in Bechar often exhibit several shortcomings that compromise thermal comfort and increase energy consumption in the region's harsh climate. A significant issue is the tendency to mimic urban layouts and construction techniques prevalent in milder regions, which are ill-suited to the extreme heat, temperature swings, and low rainfall of the Algerian Sahara (SEBTI et al. 2024). This neglect of the local climate has led to a noticeable degradation of thermal comfort within contemporary neighborhoods compared to the traditional ksar (Mekherbeche et al. 2020). Consequently, there has been a substantial increase in the demand for cooling energy in modern buildings, as they often lack the passive cooling capabilities inherent in traditional designs (SEBTI et al. 2024). The urban layouts of modern expansions, characterized by wider streets and less compact building forms, result in increased exposure to direct solar radiation, exacerbating heat gain during the summer. Furthermore, the shift towards the use of modern building materials like hollow terracotta brick and cinder blocks, while perhaps offering different structural advantages, may not provide the same level of thermal inertia as the traditional mud-brick used in the ksar (Mekherbeche et al. 2020). This reduced

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thermal mass means that modern buildings heat up more quickly during the day and cool down more rapidly at night, leading to greater indoor temperature fluctuations and discomfort. The lack of integrated passive cooling strategies, such as courtyards designed for ventilation and shading, in many modern houses further contributes to the problem (Khoukhi and Fezzioui 2012). Additionally, the increased prevalence of impervious surfaces and the potential reduction in vegetation in modern urban areas can contribute to the urban heat island effect, where urban temperatures are significantly higher than in surrounding rural areas, further increasing the need for energy-intensive cooling (Salameh and Touqan 2022).

C. Integrating Vernacular Principles into a Conceptual Framework for Bioclimatic Urban Form Adaptation in Saharan Cities

To address the challenges of thermal discomfort and high energy consumption in Saharan cities like Bechar, a conceptual framework for bioclimatic urban form adaptation should integrate the proven principles of vernacular architecture with contemporary knowledge and technologies. This framework should prioritize a return to compact urban planning, mirroring the dense layout of the traditional ksar to minimize solar exposure and maximize shading at the city scale (SEBTI et al. 2024). The design of street networks should emphasize narrow, shaded streets, strategically oriented to optimize shade throughout the day and enhance natural ventilation (SEBTI et al. 2024). Encouraging the incorporation of internal courtyards in both residential and public buildings can significantly improve natural light, ventilation, and temperature regulation (AHRIZ et al. 2017). The framework should strongly promote the use of locally sourced materials with high thermal mass, such as mud-brick, earth, and stone, in construction to leverage their natural ability to moderate indoor temperatures (SEBTI et al. 2024). Traditional passive cooling techniques, such as wind catchers for ventilation and potentially evaporative cooling systems where water resources allow, should be considered for integration into modern designs (AHRIZ et al. 2017). The strategic planting of native, drought-tolerant vegetation, including palm groves where appropriate, can provide valuable shade, act as windbreaks, and contribute to localized cooling through evapotranspiration at both urban and building scales (AHRIZ et al. 2017).

Figure 4:Conceptual framework for bioclimatic urban form adaptation in Saharan cities like Bechar. (Source: Authors)

Optimizing building orientation, with a preference for elongation along the east and west façades, is another crucial aspect of the framework (SEBTI et al. 2024). Furthermore, considering the use of light-colored, high-albedo materials for building roofs and walls (Figure 6) can help to reflect solar radiation and reduce heat absorption (Sayad et al. 2022). This integrated approach should be guided by established bioclimatic design principles that specifically address the unique climatic conditions of Saharan regions (Mekherbeche et al. 2020). Finally, the framework should encourage the thoughtful integration of appropriate modern technologies to enhance energy efficiency and occupant comfort without compromising the fundamental principles of sustainability and climate responsiveness learned from the vernacular architecture of the region.

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4. Conclusion and Proposed Framework for Climate-Responsive Urban Design

The analysis presented in this report highlights the significant influence of urban morphology on thermal comfort and energy needs in the context of Bechar, Algeria's harsh desert climate. The traditional ksar of Bechar, with its dense mud-brick architecture, narrow alleys, and compact urban form, demonstrates a remarkable capacity for passive thermal regulation, offering a stark contrast to the modern urban expansions that often neglect these climate-adaptive principles. The shortcomings of modern layouts, characterized by increased energy demands and reduced thermal comfort, underscore the urgent need for a paradigm shift in urban design for Saharan cities. Based on the insights gleaned from the literature review and the comparative analysis of traditional and modern urban forms in Bechar, a conceptual framework for climate-responsive urban design in Saharan cities is proposed. This framework emphasizes the integration of time-tested vernacular principles, including compact urban planning, narrow and shaded streets, courtyard-centric design, the use of high thermal mass materials, traditional passive cooling techniques, strategic vegetation, optimized building orientation, and high-albedo surfaces. By adopting a synergistic approach that combines the wisdom of traditional Saharan architecture with contemporary knowledge and appropriate modern technologies, it is possible to create resilient, sustainable, and comfortable urban environments that are well-adapted to the unique challenges of the desert climate. This framework provides a foundation for future research, the development of specific design guidelines, and the implementation of policies aimed at promoting bioclimatic urban development in Bechar and other Saharan cities facing similar environmental pressures.

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