Research Paper

Heat-Resilient Urban Morphology: Design Strategies for High-Temperature Cities

A Case Study of the Riyadh Region, Saudi Arabia

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Abstract

Cities with arid desert climates, such as Riyadh, are witnessing an intensification of the urban heat island (UHI) phenomenon due to rapid urban expansion and the adoption of planning models that are not climate adaptive. This paper aims to analyze the relationship between urban form and thermal resilience with a specific application to the city of Riyadh. The methodology relies on morphological analysis using Geographic Information Systems (GIS) through a comparative study between two different urban fabrics in Riyadh: one traditional and the other modern. Four main factors Will be examined: Building height, Built-up Ratio, Street and building orientation, Urban compacte. Spatial data is collected and analyzed to derive indicators such as shadow ratio, Sky View Factor (SVF), and solar exposure ratio. Thermal satellite images (LST) are used as supporting data to compare the impact of both patterns on surface temperatures. The results indicate that the two-dimensional Built Coverage Ratio (BCR) shows that horizontal expansion tends to increase impervious surfaces, and the increase in impervious surfaces leads to greater heat retention. Meanwhile, the physical air barrier in densely built environments can exacerbate the UHI-effect by hindering natural ventilation. Additionally, the rise in nighttime temperatures is positively correlated with the rate of expansion and building density. Through the analysis of urban characteristics and the discussion of heat mitigation measures, this paper emphasizes the role of proactive urban planning in balancing urban expansion and cooling needs, and the importance of an integrated cooling strategy in urban design. Heat mitigation measures, especially greening, reflective surfaces, and district cooling systems, can partially offset the UHI-effect. A sustainable design framework is proposed, inspired by traditional fabric, to enhance heat resilience in Riyadh's future urban development.

Keywords

Urban Morphology, Urban Heat Island, Expansion, Hot Climate.

1.Introduction

The intensified Urban Heat Island (UHI) effect increases the likelihood of large-scale climate change, particularly in densely populated areas with complex infrastructure. This phenomenon magnifies the changing climatic conditions in urban areas (Q. Fu et al., 2024). This anomaly is characterized by a higher temperature in urban areas than nearby rural districts. To understand the phenomenon that occurs in cities, it is important to note differences in the energy balance across regions, particularly in solar energy absorption within each development type and in solar energy retention during urbanization (Wang et al., 2024). In this sense, cities differ from rural areas, with larger vegetated areas and fewer impermeable

surfaces, resulting in better energy retention (Q. Fu et al., 2024).As urbanization rages around the world, new cities are springing up everywhere, existing ones have developed and some are being redeveloped to accommodate the increasing numbers. Yet one of the significant challenges of this urban sprawl has been the emergence of UHIs, which has created a greater obligation for urban designers to make living and working ecosystems that offer microclimates within local climates that are thermally comfortable for the average city dweller. Without climate-sensitive urban forms, surface temperature increases contribute to a more complex relationship between urban form and land heat levels. In this light, the UHI is increasingly being both a direct response to climate insensitive expansion and the most helpful metric by which to check urban transformations worldwide, highlighting the importance of specific policies to manage the effects imposed by climate change. But UHI isn't just a product of greater urbanization everywhere. Several factors directly at play and in a system of consolidation have resulted in an expansion of heat in various cities located within diverse climatic zones or different socio-economic conditions, which has become the consistent signature of increasing city temperatures in the last few years. Hence, the UHI phenomenon has become a useful tool for monitoring city-specific urban changes currently worldwide to help implement targeted strategies and tactics that require careful development of targeted tactics that are specific to the scenario (Técher et al., 2023).

From a local perspective, it is also seen in Riyadh the capital of Saudi Arabia and the biggest city with more than 8 million inhabitants of its entire country, which illustrates the case well: economic development and industrial growth have to be expected for a large oil-exporting nation. Oil has thus far represented the dominant form of the Saudi economy since the oil boom of the 1920s and the identification of large oil reserves in the Kingdom (Salman et al., 2021). This has predictably brought an influx of expatriates and hence population growth and increased industrialization. Furthermore, an accompanying increase in urbanization has been observed to facilitate this phenomenon. The process of development also requires the increase of chemicals, the release of more pollution, an increase of structures over the unrefined ground, destruction of low-density vegetation(Arifuzzaman et al., n.d.; Salman et al., 2021) . Affecting also one of them is a rise in the heat and temperature in cities. Urban heat island (UHI) is an urban area, city or island that shows a higher temperature than the typical temperature of the place, environment or even the city to the surrounding rural areas(Q. Fu et al., 2024).This article explores both urban form and urban sprawl: their contributions to the intensity of the Urban Heat Island (UHI) phenomenon, focusing on a traditional neighborhood, and a new developing one in Riyadh, Saudi Arabia. This study addresses the problem that contemporary patterns of urban expansion often generate spatial configurations which contribute to the intensification of the Urban Heat Island (UHI) effect. Such patterns, characterized by extensive impervious surfaces and reduced vegetation cover, exacerbate thermal stress in cities like Riyadh, thereby posing challenges for environmental sustainability and urban livability.

1.1 Research questions

- What are the effects of spatial form determinants on temperature on the surface?
- How are the morphological parameters connected to explain thermal variations??
- Can cooling solutions rooted in the city's traditional urban fabric be used to support the sustainable growth of modern cities?

1.2 Research objectives

To investigate the impact of contemporary patterns of urban expansion on the intensification of the Urban Heat Island (UHI) phenomenon in Riyadh, with a focus on comparing traditional and newly developed neighborhoods.Through specific objectives :

- To examine how spatial form factors influence surface temperature levels in different urban contexts.
- To analyze the role of morphological indicators in interpreting thermal variations between traditional and modern neighborhoods.
- To explore the potential of adopting cooling strategies inspired by traditional urban fabric to enhance environmental sustainability in contemporary urban development

2.Methodology

Study based on comparative morphological analysis between two contrasting urban fabrics in Riyadh (Traditional VS Modern) to assess thermal variation .

2.1Study Area:

Riyadh, sprawling urban area of 1550 km². with desert climate with average temperatures ranging from 49°F to 110°F (Alshehri et al., 2023). Its urban fabric evolved from climate-responsive organic neighborhoods and planned districts to contemporary car-dependent suburbs dominated by heat-absorbing asphalt, concrete, and steel (Figure 1).

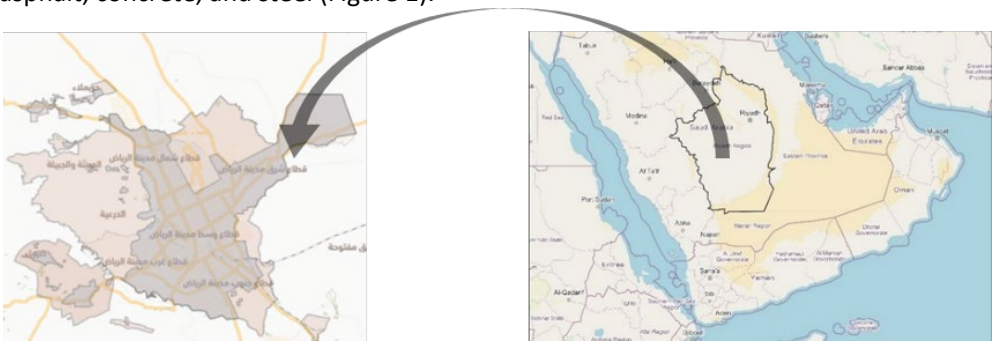


Figure1: Illustrates Riyadh Location in Gulf Country and the Riyadh Region Border. Source: Google Search

2.2 Criteria for selecting depend on contrasting urban fabrics:

Those shaped before the oil boom, representing traditional forms, and those developed more than fifty years after the capital's relocation, reflecting modern planning trends.

- **Traditional fabric (Addaho District):** A Najdi neighborhood characterized by clustered houses, shaded alleys, and central courtyards.
- **Modern fabric (Al-Yasmin District) :** A planned neighborhood defined by wide streets, detached villas, and sparse vegetation.

The two cases were identified based on the examination of four main factors that serve as indicators for morphological comparison: Building Height, Built-up Ratio, street and building orientation, and urban compactness (Figure 2).

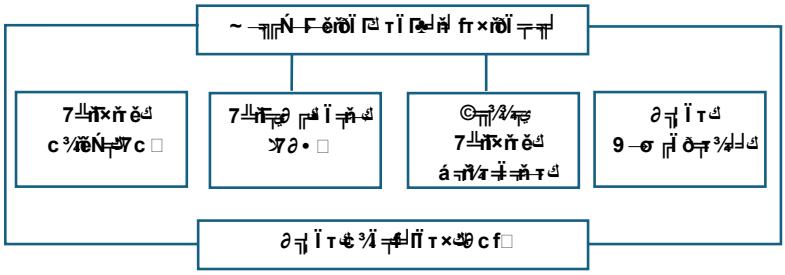


Figure 2: Methodology Diagram

Thermal analysis uses Landsat 8/9 LST imagery, while NDVI is used to assess vegetation cover. GIS-based spatial overlays support the interpretation of land surface temperature variations.

By comparing these two contrasting urban models, the study provides deeper insight into the role of urban design in shaping thermal resilience. This understanding enables the formulation of scalable, evidence-based recommendations that can inform broader applications in sustainable urban planning.

3.Theoretical framework

3.1Urban Heat Islands (UHI): Layers and Scales

Urban Heat Islands (UHI) is the phenomenon where urban areas experience significantly higher temperatures compared to their surrounding rural areas (Benaomar & Outzourhit, 2024). This temperature difference arises from the interaction between various urban surface characteristics and atmospheric processes(Oke, 1982), creating different types of urban heat islands(Table 1 , Figure 3), each characterized by its own spatial extent and thermal behaviour(Benaomar & Outzourhit, 2024).

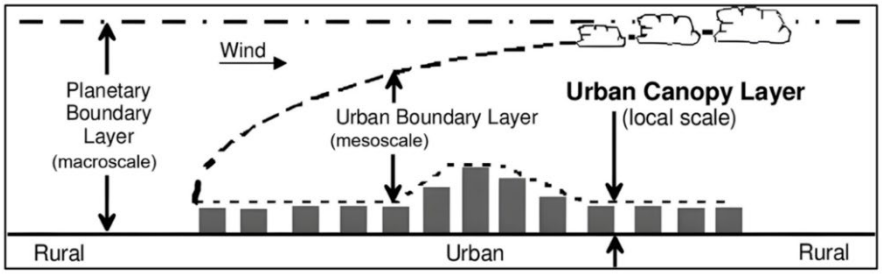


Figure 3 Atmospheric layers of the UHI-effect in urban areas compared to rural areas.(Benaomar & Outzourhit, 2024).

Table 1 Scales of UHI study Source: (Benaomar & Outzourhit, 2024)

Scale	Horizontal (m)	Vertical (m)
Microscale	10^{-2} to 10^{2}	10^{-2} to 10^{1}
Local scale	10^{2} to 10^{4}	10^{1} to 10^{3}
Mesoscale	10^{3} to 5×10^{5}	10^{1} to 10^{3}
Mesoscale	2×10^{5} to 5×10^{5}	10^{1} to 10^{5}

Microscale: examines the impact of surfaces and materials on very small-scale heat variations.

Local scale: focuses on neighborhoods and districts within the city.

Mesoscale: covers the influence of an entire city or multiple cities on the surrounding climate Land Surface.

3.2 Land Surface Temperature (LST):

Land Surface Temperature (LST) measured by satellites, reflects the thermal energy emanated from buildings, roads, soil, and vegetation. Remote sensing is a good approach for both tracking land use transformations and growing urban areas, as well as seeing changes to LST over time. Studies show that population growth, urbanization, and climate change all affect LST dynamics, making spatial and temporal evaluation vital for understanding energy transfer processes as well for assessing climate-related impacts (Alshehri et al., 2023; Lin et al., 2024; Schmugge et al., 1998; Sobrino et al., 2004). LST is a relative value which has increased steadily in Riyadh in the recent 30 years, attributed to rapid city growth and the change in land use patterns, with estimates of values in Riyadh expected to reach close to 47 °C by 2030, particularly in places with predominantly bare soil and recently urbanized surfaces(Alshehri et al., 2023).

3.3 Urban Design morphological Factors

Urban design features are essential in shaping the local microclimate and surface urban heat island (SUHI) intensity. Some GIS- and remote sensing-based urban morphological parameters include surface albedo, sky view factor (SVF), vegetation cover ratio (VCR), floor area ratio (FAR), building density (BD), ground emissivity, total surface area ratio (SAR), average building height, and height-to-base dimension ratio (HBDG) (Shi et al., 2019). These factors influence solar access, shading, radiative exchange, and heat storage. Urban Heat Islands (UHIs) are heavily influenced by neighborhood building configurations, such as building geometry, height-to-width ratios, and the thermal properties of surface materials. Poor urban fabric design, including low-albedo pavements, limited vegetation, and improper street layouts, can hinder ventilation, increase radiation trapping, and raise local air and surface temperatures in hot-arid cities (Mohamed et al., 2021) .Elements like lower albedo, higher building density, limited vegetation, and reduced SVF trap shortwave radiation and reduce long-wave heat loss within urban canyons, thus raising surface temperatures. Geometry plays a particularly important role; in early work by Oke (P. Fu & Rich, 2002; Oke & R., 1981; Oke, 1981; Stewart & Oke, 2012),canyon geometry and sky view factor directly affect nocturnal cooling rates by controlling radiative loss to the sky. Later studies (Lindberg & Grimmond, 2011; Shi et al., 2019a; Steyn, 2010; Yuan et al., 2022) have emphasized the importance of SVF, building design, and surface conditions in urban thermal behavior. Shi et al.'s statistical analysis of 625 LCZ samples shows that building density, vegetation cover, ground emissivity, and FAR are key predictors of SUHI, highlighting the critical role of climate-responsive urban design options in reducing heat buildup in densely populated housing areas. The building height-to-width ratio of urban canyons and their longitudinal orientation influence the Urban Heat Island (UHI), as shown in the study of Riyadh (Bakarman & Chang, 2015). Results indicate that compact urban form is an effective strategy to lessen UHI effects (Figure 4).

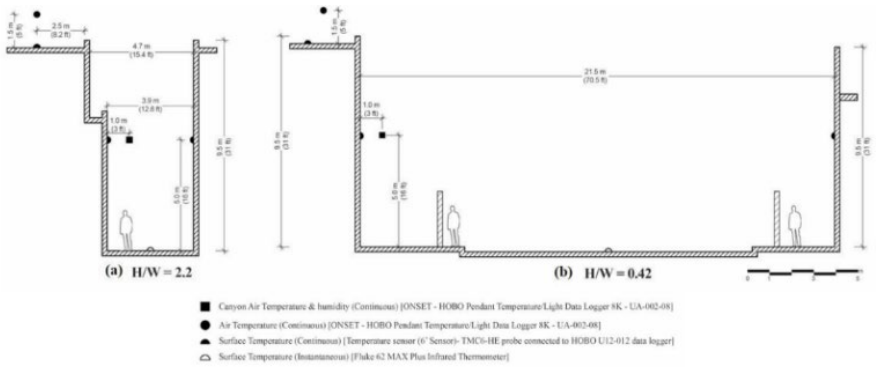


Figure .4: Ratio between building height and width of streetin (a) the shallow and (b) the deep canyons. Source :(Bakarman & Chang, 2015)

Four primary factors were analyzed to compute microclimatic indicators:

1. **Building Height & Canyon Geometry (H/W and SVF):** Determines shading and solar exposure. SVF quantifies the openness of the urban canyon to the sky.
2. **Built-Up Ratio (BUR):** The proportion of building footprints relative to the total district area.
3. **Street Orientation:** Evaluated using rose diagrams to assess alignment with prevailing winds and solar paths.
4. **Urban Compactness Index (CI):** Calculated as CI = 4πA / P² (where A is area and P is perimeter) to measure spatial enclosure and density.

3.4 Derived Spatial Indicators

Spatial data is analyzed to compute several microclimatic and morphological indicators that explain thermal performance (Table3) :

- **Shadow Ratio**: Measures the proportion of shaded areas at different times of day, influenced by building height, spacing, and orientation.
- **Sky View Factor (SVF)** : Quantifies the openness of the urban canyon to the sky.
  Lower SVF = more shading + reduced heat gain
  Higher SVF = greater exposure to solar radiation
- **Solar Exposure Ratio** :Calculates the amount of solar radiation reaching surfaces (streets, roofs, open spaces) based on geometry, orientation, and building height.

Table 3. Spatial Indicator Calculations

Factor	Equation	Symbol Definitions	Source of Equation
Shadow Ratio (SR)	$\frac{\boldsymbol{A}shaded}{\boldsymbol{A}\,Total}$	A_{Shaded}shaded area (m²) A_{total}= Total study area (m²)	(Lindberg & Grimmond, 2011)
Sky View Factor (SVF)	$SVF_{Canyon} = cos(\mathbf{2}arctan\frac{\boldsymbol{H}}{\boldsymbol{W}})$	H= building Weight (m) W = street width (m) H/W= canyon aspect ratio	(Oke & R., 1981)
Sky View Factor (SVF)	$SVF = 1 - \frac{\sum_{i=1}^{n}\sin(\gamma_i)}{n}$	-	(Shi et al., 2019b)
Solar Exposure Ratio (SER)	$SER = \frac{\boldsymbol{A_{sunlit}}}{\boldsymbol{A_{Total}}}$	or when shading and sunlight complement each other: $SER \approx 1 - SR$ A_{sunlit}= sunlit area (m²)	(P. Fu & Rich, 2002)

4. Applied study:

4.1 Traditional urban fabric: Addaho District:

The historic core of Riyadh comprises traditional districts such as and Ad-Deira, clustered around Qasr Al-Hukum and Al-Masmak. The focus is on the Addaho District, covering approximately 44,000 m²(**Error! Reference source not found.**6), exemplifies Riyadh's historic organic urban fabric characterized by narrow shaded alleys, low-rise buildings of local materials, and a compact layout centred around mosques, markets, and communal spaces. As a traditional *"ḥillah"* unit (Figure 5), Addaho evolved naturally from its environmental context, with its dense, self-shading morphology reflecting a climate-adaptive response to the desert setting.



Figure 5. Old Riyadh historic heart Addaho district

Source :((Royal Commision For Riyadh, 2012)



Figure 6. Addaho district and building height and Street depth

Source :(Report and Photography by Abdullah Al-Fuhaid) Al-Riyadh Newspaper

Source :(https://mapservice.alriyadh.gov.sa)

The district shows a diverse spectrum of H/W ratios, where medium-width streets achieve the most favourable balance of shading and heat reduction. In contrast, wide streets are the least suitable for the local hot-arid climate due to excessive solar exposure and elevated surface temperatures (Figure 6).

Investigating Building Height, Built-up Ratio, street and building orientation, urban compactness:

- **Canyon Geometry and SVF:** Addaho features narrow alleys (1.7–6 m wide) with building heights of 3–14 m, yielding high H/W ratios (up to 5.3). This creates deep urban canyons with an exceptionally low average SVF (0.26) (**Error! Reference source not found.**). Also, achieves a high shadow ratio (48%), drastically minimizing daytime solar exposure (Solar Exposure Ratio = 0.52).
- **Density and Compactness**: Addaho District covers 78,413 m², with about 40,000 m² of building footprints, resulting in a Built-Up Ratio (BUR) of 0.51and a high Compactness Index of 0.727, Addaho maintains a tight spatial enclosure.
- **Street Orientation:** The rose diagram shows a predominantly orthogonal grid aligned along northeast–southwest and northwest–southeast axes. Long, continuous asphalt corridors aligned with prevailing wind directions limit natural ventilation and maximise heat absorption, reducing the district's capacity to dissipate heat effectively (Figure 7).
- **Urban compactness:** Using the formula $CI = 4\pi A / P^2$, Addaho records a Compactness Index of 0.727, placing it at the upper end of the moderately compact category. This fine-grained structure, with compact blocks and a relatively short perimeter-to-area ratio, enhances walkability, shading, and microclimatic performance.
- **Thermal Performance (LST):** Spatial analysis of Addaho District shows a clear link between its compact traditional fabric and lower UHI intensity. Despite a high compactness (CI = 0.727) and a built-up ratio of 51%, the district's narrow, organic streets provide continuous shading, reducing solar exposure and keeping the historic core cooler. In contrast, higher LST values appear along the eastern and southeastern edges, where wider streets and exposed paved areas absorb more heat.
- **Interpretation with UHI Map:** Thermal mapping confirms hotspots concentrated along major roads, intersections, and high-asphalt-exposure areas, particularly in the central and southern parts of the district. Cooler zones correspond to small green-space clusters and areas with lower pavement density(Figure 8).

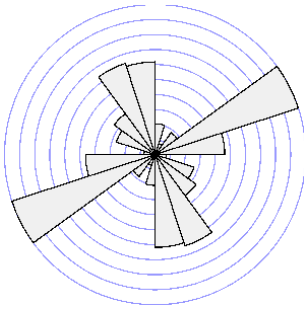


Figure 7: Street orientation in Addaho District source :QGIS

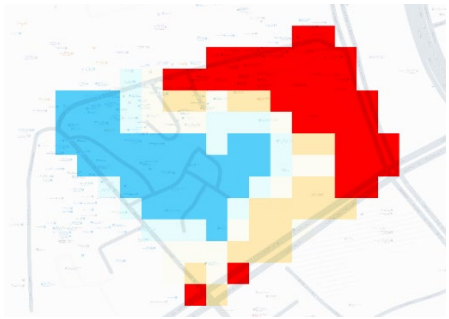


Figure 8: Spatial distribution of LST in Addaho District showing higher temperatures in dense built-up and asphalted areas(QGIS)

4.2 Modern urban fabric AL Yasmin District:

Al Yasmin District in the North of Riyadh is a planned District defined by wide streets, detached villas, and sparse vegetation. total land area of 11356547.59m^2 (The Spatial Portal of the Riyadh Region Municipality, 2025) The building mass consists mainly of low-rise villas (two to three floors), with belts of tower buildings on some of the main edges, creating a gradual transition from lower density in the residential core to higher density on the commercial edges (Figure9,10).

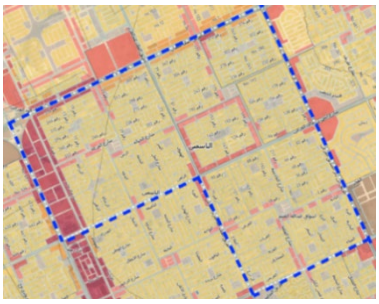


FIGURE 9: NORTH OF RIYADH: AL YASMIN DISTRICT

SOURCE :(HTTPS://SUHAIL.AI/RIYADH/METRICS)



Figure 10: Streets wide in Al Yasmeen neighborhood (60m, 36m, 20m, 15m, 14m)

Source (https://mapservice.alriyadh.gov.sa/

Investigating Building Height, Built-up Ratio, street orientation, urban compactness:

- **Canyon Geometry and SVF:** Al Yasmin is characterized by wide streets (14–60 m), low-rise villas (9–12 m) Figure 11, and tower belts along some edges, producing generally low H/W ratios and high SVF values. This increases daytime solar exposure and pavement heating, while localized higher H/W ratios near taller edge buildings may restrict ventilation and intensify nocturnal heat retention.
- **Density and Compactness:** The selected cluster covers 946,653.77 m² with a Built-Up Ratio (BUR) of 0.419, indicating moderate urban density. However, much of the open space is occupied by roads and parking areas rather than vegetation, increasing surface heat storage and UHI intensity.
- **Street Orientation:** The street network follows a predominantly orthogonal grid aligned along northeast–southwest and northwest–southeast. This layout combined with extensive asphalt surfaces reduces effective heat dissipation and contributes to heat accumulation Figure 11
- **Thermal Performance (LST):** LST analysis shows that the district's modern, low-compact urban form is strongly associated with higher UHI intensity. Wide exposed streets and impervious surfaces increase solar gain, while limited vegetation reduces cooling potential.

- **Interpretation with UHI Map:** Thermal mapping identifies hotspots along major roads, intersections, and highly paved areas, particularly in the central and southern parts of the district. Cooler areas are limited and correspond mainly to small green clusters and zones with lower pavement density(Figure 12).

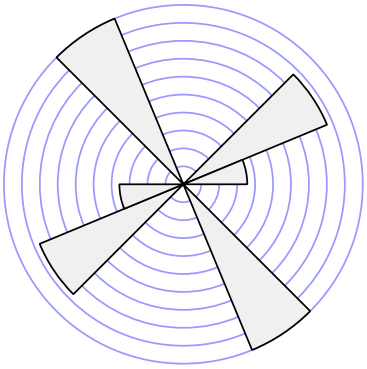


Figure 11 Street orientation in Al Yasmin District(QGIS)

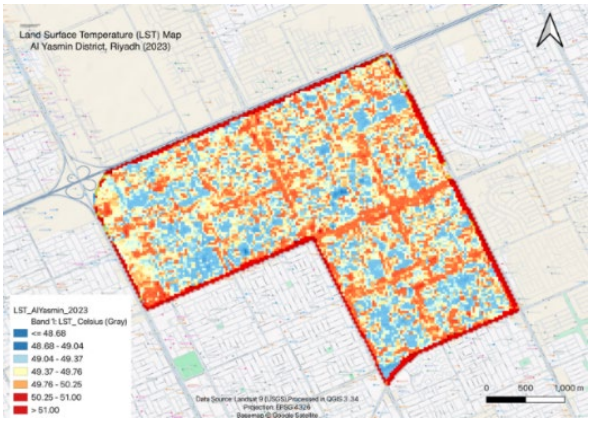


Figure 12 Land Surface Temperature Map – Al Yasmin District (2023)

4.3Discussion

The analysis shows clear differences between Al Yasmin and Al Dahou neighbourhoods in terms of temperature levels and the impact of urban fabric on thermal resilience (Table 4):

Table4: Comparative Summary of Urban Morphology, Indicators, and Thermal Performance

Parameter	Addaho (Traditional)	Al Yasmin (Modern)
Urban Form	Organic, compact, narrow alleys	Planned grids, wide roads, detached villas
Building Height	3–14 m	9–12 m villas; mid/high-rise edges
Street Width	1.7–6 m	14–60 m
H/W Ratio	2.2–5.3	0.17–0.71
Sky View Factor (SVF)	0.26 (Low)	0.69 (High)
Shadow Ratio	48%	23%
Solar Exposure Ratio	0.52	0.77
Built-Up Ratio (BUR)	51%	41.90%
Compactness Index (CI)	0.727	0.556
Street Orientation	Organic; varied; promotes shading and airflow	Orthogonal grid; long corridors
UHI / LST Pattern	Cooler interiors; heat at wide edges	Hotspots at roads and intersections
Thermal Resilience	High passive cooling through geometry	Low high exposure and impervious surfaces
Design Lesson	Traditional geometry reduces heat despite density	Low density alone does not mitigate heat

The results demonstrate that compact, self-shading urban forms as exemplified by Addaho offer substantially greater thermal resilience than the expansive, impervious suburban morphology of Al Yasmin. Crucially, the findings confirm that building density alone is not a reliable predictor of thermal performance; rather, it is the quality of spatial configuration, canyon geometry, street orientation, and surface composition that determines microclimatic outcomes. The indicators presented in the Table5 suggest that recent urban expansion characterized by higher building density may result in greater heat retention due to increased built-up surfaces. In contrast, the traditional urban fabric tends to exhibit relatively lower thermal variation, influenced by its spatial configuration and historical climate-responsive design strategies (Table 6).

Table 5: Indicators interpretation :

Compactness Level	CI Range	Meaning
High Compact	0.75 – 1.00	Dense, walkable, traditional urban fabric
Moderate Compact	0.50 – 0.74	Suburban planned development
Low Compactness	< 0.50	Sprawled, dispersed, car-dependent patterns

Table 6 Derived Spatial Indicators

Factor	Al-Dahho	Al-Yasmin
Shadow Ratio (SR)	SR ≈ 0.48 (48% of the district is shaded during the day)	SR ≈ 0.23 (23% shading on average)
Sky view factor (SVF)	SVF (avg.) ≈ 0.26Range: 0.00–0.53	SVF (avg.) ≈ 0.69Range: 0.14–0.94
Solar Exposure Ratio (SER)	SER ≈ 1 − 0.48 = 0.52	SER ≈ 1 − 0.23 = 0.77

The indicators in the table suggest that recent urban expansion, characterized by higher building density, may lead to greater heat retention due to increased built-up surfaces. In contrast, the traditional urban fabric tends to exhibit relatively lower thermal variation, influenced by its spatial configuration and historical climate-responsive design strategies(Figure 13).

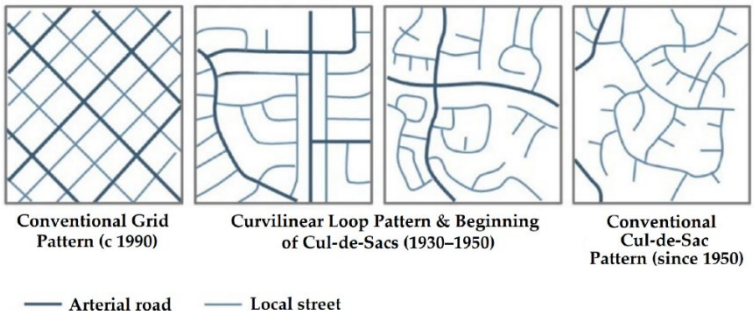


Figure 13 :Different street types.(Marshall & Garrick, 2010)

5. Conclusion

The study revealed how certain factors, particularly building height, built-up ratio, street orientation, and urban compactness, contribute to shaping and spreading the Urban Heat Island (UHI) in Al Yasmin District. Analysis suggests that the design of new urban environments is oriented toward meeting higher population growth and improved living conditions through a human-centered approach, yet it can increase heat in urban areas unless corridors for ventilation and green space are well integrated into urban plans.

5.1 Key Findings of the Study: Sustainable Design Framework for High-Temperature Cities

To address the deficiencies of modern urban expansion, we propose a design framework inspired by traditional morphological principles:

1. **Optimized Canyon Geometry:** Reintroduce higher H/W ratios in pedestrian zones to lower SVF and maximize daytime shading, without entirely blocking nighttime long-wave radiative cooling.
2. **Strategic Street Orientation:** Shift away from rigid, wind-blocking grids. Utilize staggered or angled street layouts that promote natural ventilation while minimizing direct solar penetration.
3. **Surface Material and Albedo:** Replace extensive dark asphalt with high-albedo, reflective, or permeable paving materials to reduce sensible heat storage.
4. **Integrated Green Infrastructure:** Mandate the incorporation of vegetation and district cooling strategies in open spaces to offset the thermal mass of sprawling developments through evapotranspiration.

The study highlights the importance of an integrated urban design framework and a proportionate consideration of all morphological elements in mitigating the UHI effect and increasing the quality of life present in modern urban areas like Al Yasmin District. Therefore, it provides a pragmatic blueprint for other cities to embrace similar urban landscapes with similar environmental impediments and solutions.

6.References

Alshehri, F., Abuamarah, B. A., & Abd El-Hamid, H. T. (2023). Impact of land use dynamics on land surface temperature using optical remote sensing data integrated with statistical analysis in Riyadh, Saudi Arabia. *Advances in Space Research*, *72*(5), 1739–1750. https://doi.org/10.1016/j.asr.2023.04.051

Arifuzzaman, M., Islam, M., Rahman, M., & Islam, A. (n.d.). The Causes and Effects of Urban Heat Island in Saudi Arabia. *Researchgate.NetM Arifuzzaman, MK Islam, MM Rahman, A Islam, MM Islam, MT Bhuiyan, KM Darain…researchgate.Net*. Retrieved October 8, 2025, from https://www.researchgate.net/profile/A-B-M-Islam-2/publication/360515738_The_Causes_and_Effects_of_Urban_Heat_Island_in_Saudi_Arabia/links/627b89333a23744a727645c1/The-Causes-and-Effects-of-Urban-Heat-Island-in-Saudi-Arabia.pdf

Bakarman, M. A., & Chang, J. D. (2015). The Influence of Height/width Ratio on Urban Heat Island in Hot-arid Climates. *Procedia Engineering*, *118*, 101–108. https://doi.org/10.1016/j.proeng.2015.08.408

Benaomar, K., & Outzourhit, A. (2024). Exploring the Complexities of Urban Forms and Urban Heat Islands: Insights from the Literature, Methodologies, and Current Status in Morocco. In *Atmosphere* (Vol. 15, Number 7). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/atmos15070822

Fu, P., & Rich, P. M. (2002). A geometric solar radiation model with applications in agriculture and forestry. *Computers and Electronics in Agriculture*, *37*(1–3), 25–35. https://doi.org/10.1016/S0168-1699(02)00115-1

Fu, Q., Zheng, Z., Sarker, N. I., & Lv, Y. (2024). *Combating urban heat: Systematic review of urban resilience and adaptation strategies*. https://doi.org/10.1016/j.heliyon.2024.e37001

Lin, L., Di, L., Zhang, C., & Guo, L. (2024). The Global Land Surface Temperature Change in the 21st Century-A Satellite Remote Sensing Based Assessment. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *17*, 1756–1764. https://doi.org/10.1109/JSTARS.2023.3338980

Lindberg, F., & Grimmond, C. S. B. (2011). Nature of vegetation and building morphology characteristics across a city: Influence on shadow patterns and mean radiant temperatures in London. *Urban Ecosystems 2011 14:4*, *14*(4), 617–634. https://doi.org/10.1007/S11252-011-0184-5

Marshall, W. E., & Garrick, N. W. (2010). Street network types and road safety: A study of 24 California cities. *URBAN DESIGN International 2010 15:3*, *15*(3), 133–147. https://doi.org/10.1057/UDI.2009.31

Mohamed, M., Othman, A., Abotalib, A. Z., & Majrashi, A. (2021). Urban heat island effects on megacities in desert environments using spatial network analysis and remote sensing data: A case study from western Saudi Arabia. *Remote Sensing*, *13*(10), 1941. https://doi.org/10.3390/RS13101941/S1

Oke, & R., T. (1981). Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations. *IJCli*, *1*(3), 237–254. https://doi.org/10.1002/JOC.3370010304

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1–24. https://doi.org/10.1002/QJ.49710845502

Royal Commision For Riyadh. (2012). *Old Riyadh*. https://old.rcrc.gov.sa/wp-content/uploads/2019/10/old-Riyadh.pdf

Salman, A., Al-Tayib, M., Hag-Elsafi, S., Zaidi, F. K., & Al-Duwarij, N. (2021). Spatiotemporal assessment of air quality and heat island effect due to industrial activities and urbanization in Southern Riyadh, Saudi Arabia. *Applied Sciences (Switzerland)*, *11*(5), 1–16. https://doi.org/10.3390/app11052107

Schmugge, T., Hook, S. J., & Coll, C. (1998). Recovering Surface Temperature and Emissivity from Thermal Infrared Multispectral Data. *Remote Sensing of Environment*, *65*(2), 121–131. https://doi.org/10.1016/S0034-4257(98)00023-6

Shi, Y., Xiang, Y., & Zhang, Y. (2019a). Urban Design Factors Influencing Surface Urban Heat Island in the High-Density City of Guangzhou Based on the Local Climate Zone. *Sensors 2019, Vol. 19, Page 3459*, *19*(16), 3459. https://doi.org/10.3390/S19163459

Shi, Y., Xiang, Y., & Zhang, Y. (2019b). *Urban Design Factors Influencing Surface Urban Heat Island in the High-Density City of Guangzhou Based on the Local Climate Zone*. https://doi.org/10.3390/s19163459

Sobrino, J. A., Jiménez-Muñoz, J. C., & Paolini, L. (2004). Land surface temperature retrieval from LANDSAT TM 5. *Remote Sensing of Environment*, *90*(4), 434–440. https://doi.org/10.1016/J.RSE.2004.02.003

Steyn, D. G. (2010). *The calculation of view factors from fisheye-lens photographs: Research note*. https://doi.org/10.1080/07055900.1980.9649091

Técher, M., Ait Haddou, H., & Aguejdad, R. (2023). Urban Heat Island's Vulnerability Assessment by Integrating Urban Planning Policies: A Case Study of Montpellier Méditerranée Metropolitan Area, France. *Sustainability (Switzerland)*, *15*(3). https://doi.org/10.3390/su15031820

Wang, C., Zhang, H., Ma, Z., Yang, H., & Jia, W. (2024). Urban Morphology Influencing the Urban Heat Island in the High-Density City of Xi'an Based on the Local Climate Zone. *Sustainability (Switzerland)* , *16*(10). https://doi.org/10.3390/su16103946

Yuan, B., Zhou, L., Hu, F., & Zhang, Q. (2022). Diurnal dynamics of heat exposure in Xi'an: A perspective from local climate zone. *Building and Environment*, *222*, 109400. https://doi.org/10.1016/J.BUILDENV.2022.109400