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An Exploration of Climate-Responsive Design Strategies Employed by El-Miniawy Brothers in Southern Algeria

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An Exploration of Climate-Responsive Design Strategies Employed by El-Miniawy Brothers in Southern Algeria

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Abstract

In an age marked by globalisation, contemporary design, and diminishing regional distinctiveness, particularly concerning its impact on climate, the integration of passive strategies and climate-responsive design emerges as a critical element in forward-thinking architecture that embraces the unique climatic conditions of various locales. Consequently, this paper offers an in-depth examination of the climate-responsive design implemented by two pioneering architects who specialised primarily in housing projects in Southern Algeria. This investigation is further enriched by on-site measurements conducted on selected case studies. The findings reveal that, on typical scorching days, the actual indoor operational temperatures in 400 housing units situated in El-Oued range from 20.1 °C to 38.9 °C, whereas in 600 housing units in Ouled Djellal, temperatures fluctuate between 31.2 °C and 35.4 °C. It is noteworthy that outdoor air temperatures can soar to as high as 40 °C in El-Oued and 43 °C in Ouled Djellal during peak hours. The architectural achievements of the El-Miniawy brothers in Algeria's southern region stand as tangible examples of architecture that adeptly adapts to the harsh, arid climate. This study underscores the importance of climate-responsive design and passive strategies and offers valuable insights into the indoor thermal environment. Ultimately, this research is poised to inspire architects and decision-makers in their future housing projects.

Keywords: passive strategies; climate-responsive design; in situ measurements; El-Miniawy brothers; south of Algeria.

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Introduction

The energy consumption of buildings represents tangible progress in both architectural design and international policy. It's well-established that buildings contribute to roughly 40% of the world's overall energy consumption. The primary catalyst for climate change is CO_2 emissions, with electricity generation from fossil fuels being the predominant source of these emissions (U.S. Energy Information Administration - EIA -, 2020). Nonetheless, the building sector accounts for roughly 40% of CO2 emissions (International Energy Agency - IEA -, 2020).

In light of the present circumstances, it is imperative to take a determined stance against buildings that exhibit inefficiencies in both energy usage and thermal performance. This underscores the potential of climate-responsive design as a crucial element within architectural practice, making a substantial contribution to enhancing energy efficiency and thermal performance (Kaihoul et al., 2021; Nguyen and Reiter, 2014; Olgyay, 1963).

In Algeria, the government has implemented subsidies for individuals residing in the southern region. This decision stems from the notable surge in electricity consumption, particularly during the sweltering summer months when demand for cooling rises in the extremely hot and arid climate. This underscores the importance of re-evaluating climate-responsive design as a viable solution to reduce avoidable energy wastage (La Commission de Régulation de l'Electricité et du Gaz (CREG)).

The importance of climate-responsive design is evident throughout all phases of an architectural project, even when undertaking retrofitting endeavours. The essential goal is to maintain an indoor thermal environment that aligns with the comfort needs of occupants. Consequently, passive strategies are customised to align with the unique attributes of each climate and individual case (Amraoui et al., 2021; Kaihoul and Sriti, 2018a; Kaihoul and Sriti, 2018b; Kaihoul et al., 2024a; Kaihoul et al., 2024b).

This study's scope revolves around the application of specific strategies in the southern region of Algeria, characterised by a hot and arid climate. This focus arises due to the limited availability of case studies in this particular geographical area, necessitating further documentation of pioneering examples and field measurements, notably exemplified by the architectural works of the El-Miniawy brothers (MB). Consequently, it becomes crucial to underscore the effectiveness of these strategies through alignment with in-situ measurements of thermal parameters, ultimately aiming to inform future architectural practices and decision-makers.

The architectural projects undertaken by MB in the southern part of Algeria, primarily involving housing and rural villages in locations like Bou-Saada, El-Oued, and Ouled Djellal, epitomise an authentic embodiment of architecture that adeptly adapts to the local climate, thereby creating an indoor thermal environment that prioritises comfort. The significance of conducting a comprehensive analysis of multiple case studies related to MB and their respective thermal performances lies in the potential to elevate passive design practices. Additionally, it serves as a source of inspiration for architects working in analogous climatic conditions, both within Algeria and on a global scale, encouraging them to incorporate the fundamental principles and recommendations evident in these projects.

The principal objectives of this study encompass:

- Identification of climate-responsive design elements integrated into select case studies, notably Maader Village in Bou-Saada, 400 Housing Units in El-Oued, and 600 Housing Units in Ouled Djellal, all of which stand as iconic projects conceived by MB. These projects draw inspiration from the traditional local architecture of southern Algeria.
- Evaluation of the efficacy of climate-responsive design in regulating the indoor thermal environment within the aforementioned case studies, accomplished through in-situ measurements encompassing parameters such as air temperature, radiant temperature, operative temperature, relative humidity, and airspeed.

Methods

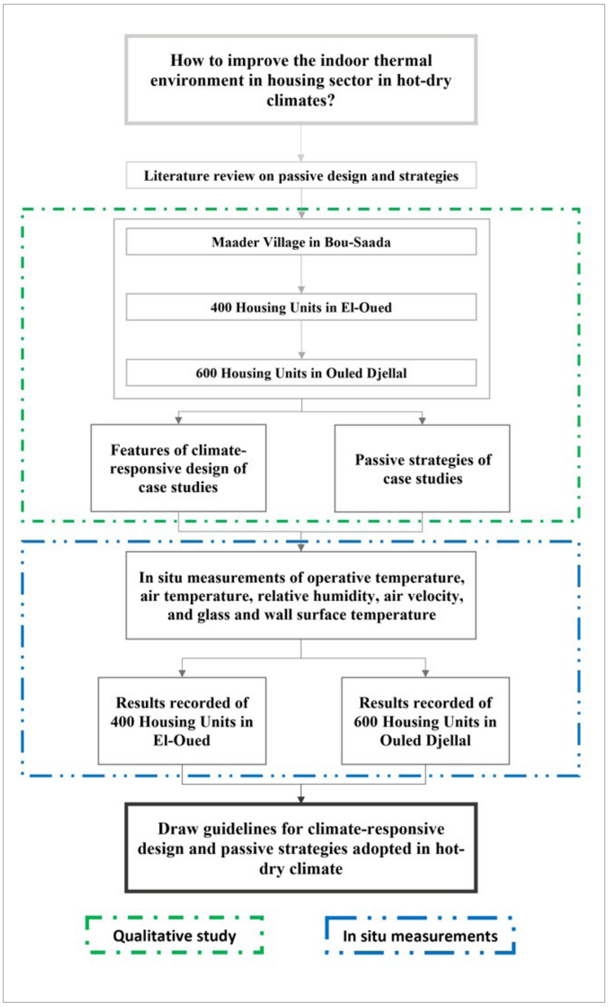


Fig. 1

Study framework.
Source: Authors

This research employs a combination of qualitative and quantitative methods to evaluate the effectiveness of passive strategies and climate-responsive design. What sets this approach apart is its unique focus on analysing renowned case studies, followed by an assessment of how they influence indoor thermal conditions. **Fig. 1** offers an overview and framework for the study's structure.

The study initiates an extensive literature review centred on climate-responsive design and passive strategies. It then proceeds to examine the features of climate-responsive design and passive strategies within specific case studies, including Maader Village, as well as 400 and 600 Housing Units. Subsequently, on-site measurements were carried out to investigate the indoor thermal environment during the hottest period of the year, typically occurring at the end of July and the start of August. The results obtained underwent a comprehensive analysis and discussion. Furthermore, the practicality and suitability of each passive design and strategy were thoroughly explored and evaluated.

Literature review on architectural and urban climate-responsive design

Liu et al. research (Liu et al., 2023) highlighted the significance of climate-responsive design and put forth a collection of practical strategies to assist architects and urban planners in mitigating extreme heat effects. Their study emphasised the cooling benefits of these strategies to enhance both indoor and outdoor thermal comfort, reduce risks to human health, and ensure energy security.

In another investigation by (Nie et al., 2019), the efficacy of climate-responsive design in improving the indoor thermal conditions of Khams dwellings in Tibet was demonstrated. The study underscored the importance of integrating settlement location and layout designs with the natural environment and religious culture, along with optimising structural seismic performance and passive solar energy technology.

(Soudian and Berardi, 2021) developed a climate-responsive façade to improve indoor thermal comfort, providing a detailed explanation of the façade's design and its specific goals.

(Zhu et al., 2020) evaluated the thermal performance of ancient cave dwellings in China's Loess Plateau. Their study introduced various passive strategies, including optimising building orientation and using underground courtyards and biomass materials. In-situ measurements validated the effectiveness of these strategies in enhancing indoor comfort.

Numerous studies have championed the implementation of climate-responsive design, particularly within the realms of building efficiency, zero-energy buildings (Dabaieh, 2022), passive solar heating (Rempel et al., 2016), and passive cooling strategies (Prieto et al., 2018).

Cortesão et al., (2020) formulated visual design guidelines for climate-responsive urban design, emphasising the importance of incorporating these considerations to improve outdoor microclimates, mitigate heat islands, and address climate change impacts. Their study aimed to raise awareness among landscape architecture students about climate-responsive design and equip them with skills to create thermally comfortable and healthy living environments.

Kamal (2012) provided an extensive review of passive cooling techniques, highlighting their role in reducing peak cooling loads, thereby conserving energy and enhancing thermal comfort. His work emphasised the significance of natural cooling methods in mitigating environmental impacts caused by mechanical cooling systems.

In his study on traditional architecture in Jeddah, Kamal (2014) evaluated various passive design features, such as Mashrabiyas, that have been employed to adapt to the hot and humid climate. He also examined contemporary designs that integrate traditional strategies to promote environmental sustainability.

Kamal (2010) focused on shading strategies as a preventive measure for passive cooling and energy conservation. He demonstrated how shading minimises solar radiation, effectively cooling buildings and improving energy performance.

Le Corbusier’s solar shading strategy, analysed by Kamal (2013), highlighted the use of ‘brise-soleil’ in tropical environments. This approach reduces reliance on artificial cooling methods, promoting sustainability and climate responsiveness in building design.

Kamal (2020) explored modern trends in high-performance building façade systems, emphasising their role in improving energy efficiency and indoor thermal comfort. His research on contemporary tall buildings provides valuable insights into sustainable façade design.

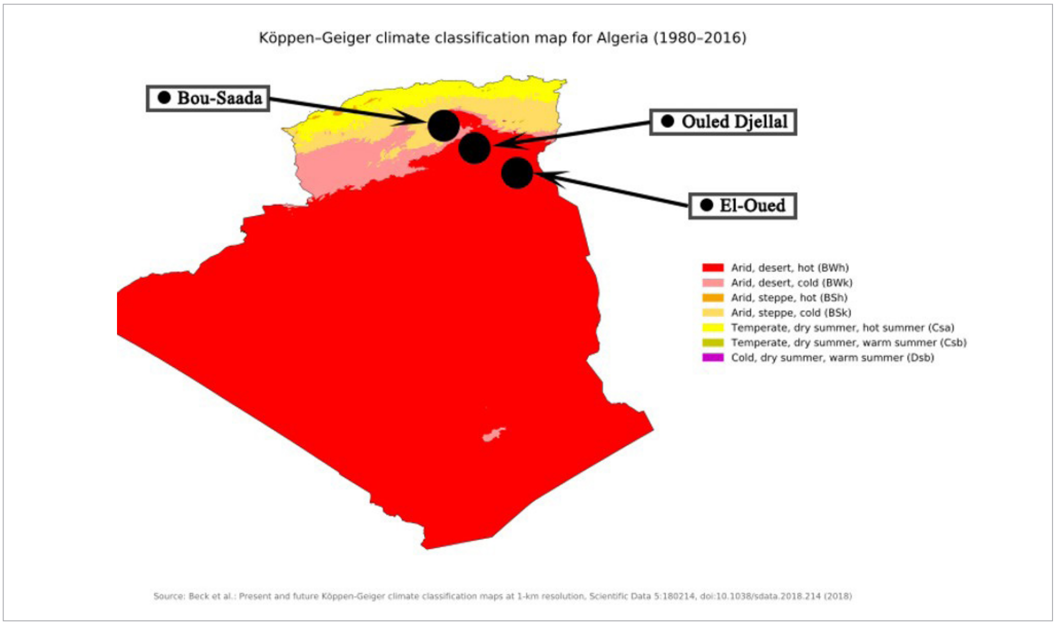
By incorporating these studies, the literature review presents a more comprehensive overview of climate-responsive design strategies and their applications in various contexts. This enhanced background reinforces the significance of passive strategies and climate-responsive design, aligning with the paper’s focus on the architectural achievements of the MB in Southern Algeria.

Climate Zoning and the Chosen Cities

Fig. 2 illustrates the three chosen sites in the southern region of Algeria. According to the Köppen-Geiger classification, Algeria encompasses seven distinct climate types. The southern part of Algeria, covering a substantial 84% of the nation’s land area, is characterised by arid desert climates, specifically hot (BWh) and cold (BWk) variants. Geographically, this region lies between 18° N and 35° N latitude and 8° W and 12° E longitude. It is situated to the north of the Saharan Atlas Mountains and high plateaus, east of the Libyan Sahara Desert, south of the Sahara Deserts in Mali and Niger, and west of the Moroccan Sahara. Notably, the observation points at these sites predominantly experience the sun positioned in the southern sky, as depicted in Fig. 2. Both locations receive abundant solar radiation and exhibit significant seasonal and daily temperature fluctuations, maintaining acceptable relative humidity levels and experiencing minimal annual rainfall.

Let’s delve into the specific climatic characteristics of each site:

Bou-Saada, situated at an altitude of 553 meters, spans between 35.10° and 35.32° north latitude and 4.07° and 4.29° east longitude. It features a cold desert climate according to the Köppen classification (BWk). Winters in Bou-Saada range from -3 °C to 23 °C for the lowest and highest recorded temperatures, respectively. Conversely, summers usher in scorching daytime temperatures of up to 45 °C, with nighttime lows of 14 °C. The average annual temperature in Bou-Saada stands at 19.9 °C (67.8 °F), while relative humidity fluctuates between 38.5% and 69.5%. Rainfall is infrequent, with slight increases during the summer season. Bou-Saada experiences the influence of northwest cold monsoon winds and southeast hot monsoon winds, resulting in varying wind speeds ranging from 5.9 m/s to 20 m/s and daily sunshine hours between 7 and 13 hours per day, as detailed in Table 1.



Köppen-Geiger climate classification map for Algeria (1980-2016)

Source: Beck et al.: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:10.1038/sdata.2018.214 (2018)

Fig. 2

Köppen-Geiger climate classification for Algeria. Source: (Beck et al., 2018)

Table 1

Monthly normal climate conditions in Bou-Saada. Source: (Climate.OneBuilding.Org)

S. No.	Station	January	February	March	April	May	June	July	August	September	October	November	December
1	Average maximum temperature (°C)	19	23	27	33	43	42	45	44	38	35	24	19.5
2	Average minimum temperature (°C)	-1	-3	2.8	5.2	7	14.6	20	18.8	11.2	5.9	1.8	2
3	Average mean temperature (°C)	9	10	14.9	19.1	25	28.3	32.5	31.4	24.6	20.4	12.9	10.7
4	Average relative humidity (%)	58.5	55	55	55	55	55.5	38.5	47.5	55	58	63	69.5
5	Average wind velocity (m/s)	8.2	8.2	5.9	8.7	6.2	6.7	8.2	8.5	8.2	20	6.7	8.2
6	Average sunshine hour per day (h)	7.2	8	9.5	10.8	12	12.9	12.8	12.1	10.9	9.4	7.7	7
7	Total rain fall (mm)	17.5	15.5	21	21.5	26.5	201	40.5	35.5	41	76.5	26	20.5

El-Oued, positioned at an altitude of 76 meters, spans between 33.29° and 33.42° north latitude and 6.8° and 6.9° east longitude. El-Oued is characterised by a hot-dry climate featuring a cold northwest monsoon in winter and a hot southeast monsoon accompanied by desert sandstorms. Winter temperatures fluctuate between 1.5 °C and 25 °C, with the lowest and highest recorded degrees representing the extremes. During the summer season, which spans five months, daytime temperatures can soar beyond 49 °C, with nighttime lows seldom dropping below 16 °C. The desert's influence results in significant daily and yearly temperature variations, necessitating protection from both extreme heat and cold. Rainfall is sparse but may slightly increase during the summer months. Relative humidity levels fluctuate between 42% and 63%, and wind speeds vary from 4.1 m/s to 7.7 m/s, with daily sunshine hours ranging from 8 to 13 hours per day, as outlined in Table 2.

Table 2

Monthly normal climate conditions in El-Oued. Source: (Climate. OneBuilding.Org)

S. No.	Station	January	February	March	April	May	June	July	August	September	October	November	December
1	Average maximum temperature (°C)	22.6	25	34.1	34	42.1	42	49	46	42.1	37	29	22
2	Average minimum temperature (°C)	1.6	2	3.5	9.8	16	21.5	23	24	16.7	13.2	6.7	1.5
3	Average mean temperature (°C)	12.1	13.5	18.8	21.9	29	31.7	36	35	29.4	25.1	17.8	11.7
4	Average relative humidity (%)	60	54.5	52	49.5	46	42	45	47	52	53.5	60	63
5	Average wind velocity (m/s)	4.1	4.1	7.2	5.1	6.7	4.6	5.1	7.7	4.9	5.1	6.7	4.1
6	Average sunshine hour per day (h)	8.8	9.6	10.5	11.5	12.4	12.9	12.7	12	11.1	10.1	9.2	8.6
7	Total rain fall (mm)	19	14.5	16	29.5	47	33	43.5	59	43	32	30	19

Ouled Djellal, located at an altitude of 276 meters, spans between 34.32° and 34.5° north latitude and 4.95° and 5.27° east longitude. This region experiences a brief cold winter, with temperatures rarely falling below 2 °C, while the highest recorded temperature can reach 26 °C during this season. Summers in Ouled Djellal bring scorching daytime temperatures, with highs reaching 47 °C and nighttime lows of 15 °C. Relative humidity generally falls within the moderate range, varying from 31% to 64.5%. Rainfall is infrequent and characterised by low intensity, typical of desert regions. Ouled Djellal, like Bou-Saada, is influenced by northwest cold monsoon winds and southeast hot monsoon winds, resulting in wind speeds that range from 5.1 m/s to 9.7 m/s. Daily sunshine hours vary from 8 to 13 hours per day, as described in Table 3.

Table 3

Monthly normal climate conditions in Ouled Djellal. Source: (Climate. OneBuilding.Org)

S. No.	Station	January	February	March	April	May	June	July	August	September	October	November	December
1	Average maximum temperature (°C)	23	26.4	29.1	34	39	46	47.1	45	40	37.9	29	23.4
2	Average minimum temperature (°C)	3	2	6.5	10	15	19	25	24.1	21	13.5	7.6	4
3	Average mean temperature (°C)	13	14.2	17.8	22	27	32.5	36	34.5	30.5	25.7	18.3	13.7
4	Average relative humidity (%)	55.5	49.5	55.5	52	47	46	31	38	54.5	50	56	64.5
5	Average wind velocity (m/s)	6.1	5.1	8.5	7.7	9.7	7.7	7.2	9	7.7	9.2	6.7	9
6	Average sunshine hour per day (h)	8.5	9.4	10.4	11.4	12.4	13	12.8	12.1	11	9.8	8.8	8.2
7	Total rain fall (mm)	18	14.5	20	21.5	24.5	32.5	36.5	50.5	46	40	28.5	27.5

Showcasing climate-responsive design in case studies

In the subsequent section, a qualitative examination of the climate-responsive design implemented in the case studies of Maader Village, 400 Housing Units, and 600 Housing Units (as outlined in Table 4) is presented:

Criteria / Project	Building materials	Building envelope	Solar shading	Building form and orientation	Patio	Wind tower
Maader village	_ Walls of stabilized earth bricks (clay, sand, cement) _ Vaulted/ dome roofs of stabilized earth bricks _ Floors with sand-cement shells and lightly reinforced concrete _ Lime-sand coating	_ Load-bearing walls (0.4m thick) _ Reinforced concrete floors and stairs _ Curved roofs (vaults and domes) _ Wooden-framed windows with single-layer clear glass _ Window-to-wall ratio below 9%	_ Vertical shading (massive walls) _ Horizontal shading (massive roofs) _ Window shutters for shading	_ Compact, closed multi-block layout * Square-style blocks with vaults and domes _ Solid façades, few openings _ Storey height: 3.1m _ Oriented NW-SE for wind and solar protection	_ Three patios: two private courtyards, one semi-private patio _ Urban courtyards _ Patios cover 50% of site area	
400 housing units	_ Walls of hollow concrete blocks _ Cross-frame roofs with hollow concrete blocks and Tufla _ Floors of lightly reinforced concrete shells _ Lime-sand coating for exterior finish	_ Double load-bearing walls with 0.4m air gap _ Reinforced concrete roofs, floors, and stairs _ Double-layer roofs (flat + vaults/ domes) _ Wooden-framed windows with single-layer clear glass _ Window-to-wall ratio below 10%	_ Vertical shading (massive walls) _ Horizontal shading (massive roofs) _ Window shutters for additional shading	_ Compact, closed multi-block design _ Staggered blocks with vaults and domes _ Solid façades with few openings _ Storey height: 3.1m _ Oriented NW-SE for wind and solar protection	_ Three patios: two private courtyards, one semi-private patio _ Urban courtyards _ Patios cover 50% of site area	
600 housing units	_ Walls of lime-sand stone _ Cross-frame roofs with hollow concrete blocks _ Floors of lightly reinforced concrete shells _ No supplementary finishing or coating	_ Single-layer load-bearing walls (0.4m thick) _ Reinforced concrete roofs, floors, and stairs _ Flat roof design _ Wooden-framed windows with narrow openings in Mushrabiyah style _ Single-layer clear glass _ Window-to-wall ratio below 20%	_ Vertical shading with massive walls _ Horizontal shading with roofs and overhangs _ Window shutters in Mushrabiyah style	_ Compact, closed multi-block design _ Staggered blocks with flat roofs _ Solid façades with few openings * Storey heights: 3.1m _ * Oriented NE-SW for solar protection	_ Three patios: two private courtyards, one semi-private patio _ Urban courtyards _ Patios cover 70% of site area	_ Air-captors and stack effect for cross-ventilation

Table 4

Exploration of climate-responsive design in the projects of MB in southern Algeria (case studies)

Building materials

Despite being unconventional for public housing projects of that era, MB strongly advocated for the utilisation of locally abundant natural materials in the region. In Maader Village, 'stabilised earth brick' was employed extensively for both walls and roofs, including the construction of vaults and domes. In the case of the 600 Housing Units, the primary material for shaping the external envelope's walls was 'lime-sand stone.' 'Tufla' was specifically chosen for the vaults and domes of the 400 Housing Units, which were designed with seismic considerations in mind. For the 400 Housing Units, where seismic studies were conducted, hollow concrete blocks were selected for the walls, complemented by a reinforced structure. In terms of structural elements, reinforced concrete played a pivotal role, serving as the main material for bearing beams, floors, roofs (excluding Maader Village), and staircases. Wooden windows were thoughtfully incorporated into the project's design.

The decision to use stabilised earth brick and lime-sand stone was driven by their high density, making them well-suited for the exterior walls of Maader Village and the 600 Housing Units. These materials provided the necessary thermal capacity required to effectively respond to the region's specific climate conditions. Regarding finishing materials, the lime-sand coating was applied in Maader Village and the 400 Housing Units, resulting in a harsh texture in the latter case. In contrast, the 600 Housing Units were intentionally left without any finishing or coating, allowing the natural beauty of the lime-sand stone to stand as the final surface (as illustrated in **Fig. 3 a, b, and c**).


(a) (b) (c)

Fig. 3

Materials and exterior finishes for Maader Village (a), 400 Housing Units (b), and 600 Housing Units (c). Source: https://www.archnet.org/sites/231 (Accessed date: August 13th, 2021)

Building envelope

In Maader Village, the building's walls and roofs, which encompass vaults and domes, are fashioned from one-layer load-bearing stabilised earth bricks, each with a thickness of 50 cm (illustrated in **Fig. 4 a and b**). Conversely, the 400 Housing Units feature double load-bearing walls with an air gap, measuring 40 cm in thickness (depicted in **Fig. 5 a and b**). Meanwhile, the 600 Housing Units opt for one-layer load-bearing lime-sand stone walls, with thicknesses ranging from 40 to 50 cm. This selection caters to the objective of optimising heat retention and influencing the indoor thermal environment, as visualised in **Fig. 6 a and b**.

The mortar used between the stabilised earth bricks in Maader Village is a mixture of earthen material and cement. In contrast, the mortar between the lime-sand stone blocks incorporates stone dust combined with cement, while cement is exclusively employed for the hollow concrete blocks. Interestingly, the structural elements such as beams, roofs, and floors are crafted from reinforced concrete. However, it's worth noting that Maader Village and the 400 Housing Units deviate from this pattern, employing stabilised earth bricks and Tufla, respectively, for their vaults and domes. This structural divergence is not immediately evident in the building envelope, except for the first-floor roof in the case of the 400 and 600 Housing Units and the ground-floor roof in Maader Village, both of which are exposed to the outdoor environment.

Concerning roofing styles, these projects generally feature flat roofs. However, Maader Village and the 400 Housing Units deviate from this convention by incorporating curved designs and integrating vaults and domes into their roof structures. This architectural choice is influenced by the dry climate and established regional architectural traditions. Despite the innovative nature of this approach, which hadn't been previously employed in similar projects, the underlying technology is straightforward and can be readily replicated in diverse regions, as evidenced in the documentation from (Archnet, 1983; Archnet, 2001; Archnet, 2001).

Fig. 4

Envelope details for Maader Village: wall detail (a) and roof detail (b). Source: Authors

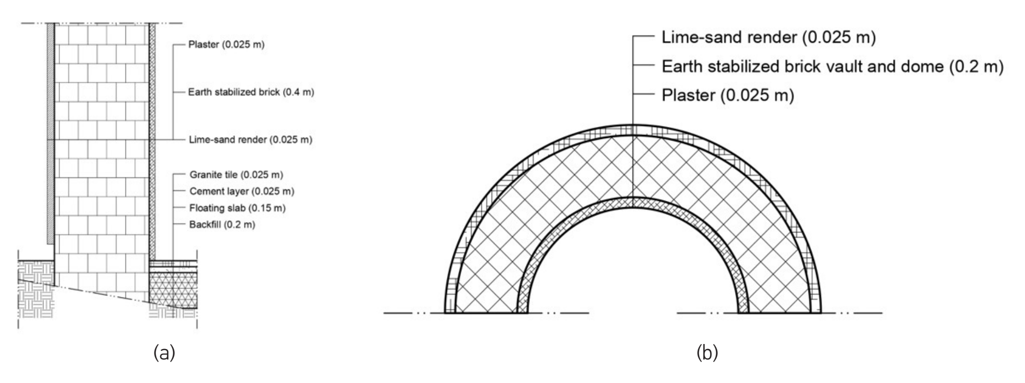


Fig. 5

Details of the building envelope for the 400 Housing Units: wall detail (a) and roof detail (b). Source: Authors

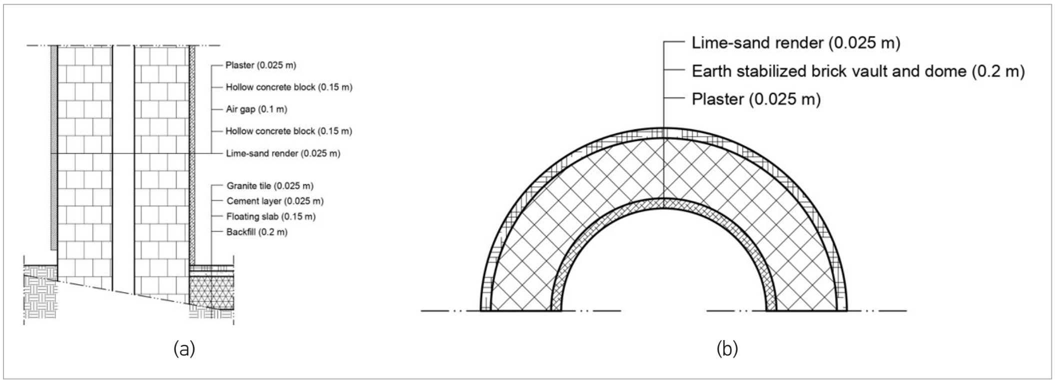
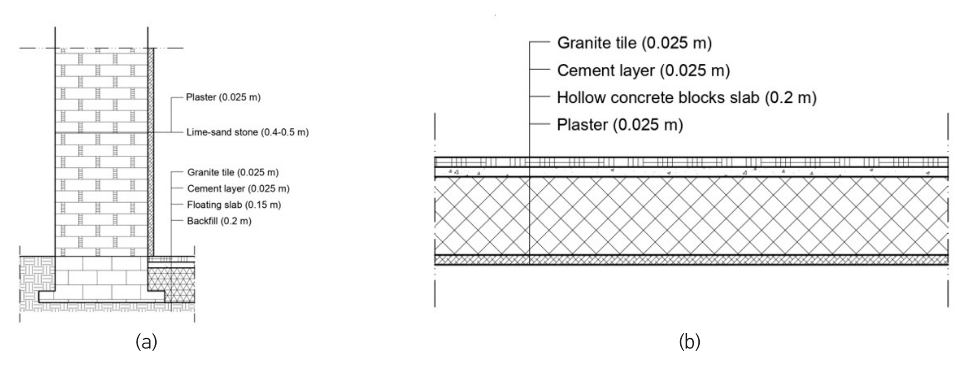


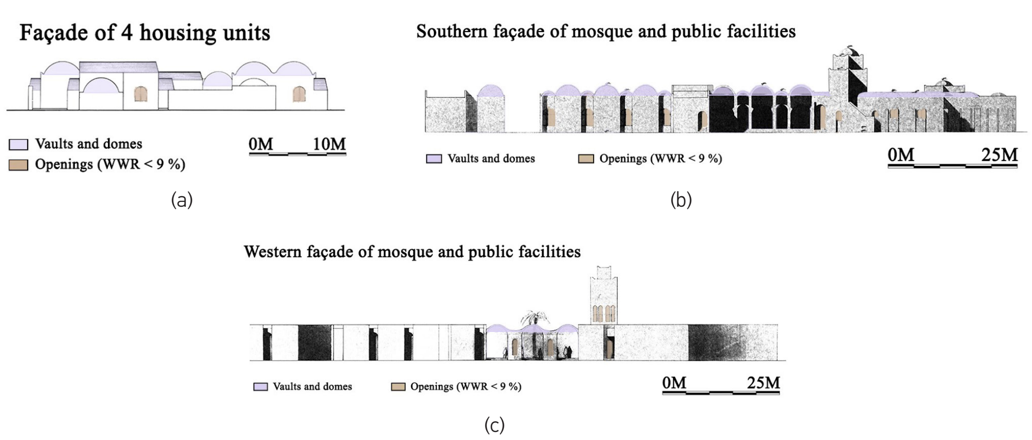
Fig. 6

Details of the envelope for the 600 Housing Units: wall detail (a) and roof detail (b). Source: Authors



The project incorporates windows featuring a basic wooden frame, casements, and shutters. In the instance of the 600 housing units, these shutters are designed with narrow openings, strategically aimed at reducing direct solar gains and providing shading. Across all scenarios, the glazing consists of a single layer of clear glass. As a fundamental guideline, the windows are oriented towards the north to optimise the infusion of natural light and ventilation. Conversely, on the eastern, western, and southern façades, small openings within the shutters, following the 'Mushrabiyah concept,' are integrated to effectively manage and minimise excessive solar heat gain and heat accumulation during the summer months.

It's important to note that the Window-to-Wall Ratio (WWR) adheres to specific limits for each case: it does not exceed 9% in Maader Village (as illustrated in **Fig. 7 a, b, and c**), remains below 10% for the 400 housing units (as indicated in **Fig.** 8), and is capped at 20% for the 600 housing units (as observed in **Fig. 9 a, b, and c**).



(a) (b) (c)

Fig. 7

In Maader Village, distinctive openings across various locations - housing units' facade (a), southern and western facade of the mosque and public facilities (b) and (c). Source: Authors

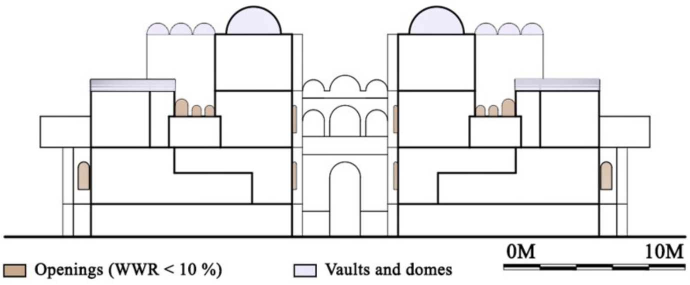
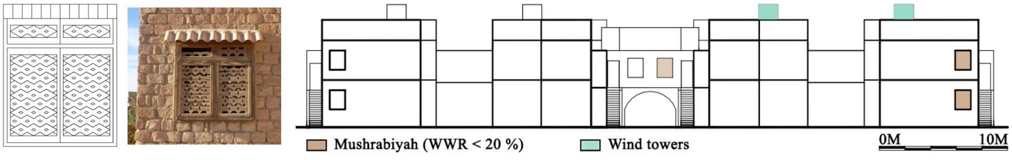


Fig. 8

Customisation of openings for the 400 Housing Units: housing unit facade (a)



(a) (b) (c)

Fig. 9

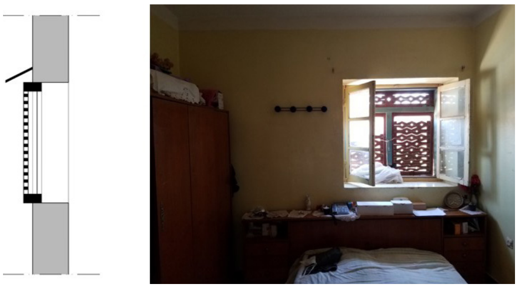
Mushrabiyah-style windows in the 600 Housing Units: specifics in (a) and (b); tailoring them on the main facade (c). Source: Authors

Solar shading

In the 600 housing units, solar shading is accomplished through fixed horizontal overhangs. In various other contexts, shading is achieved through the substantial thickness of walls and roofs. This architectural approach serves a dual purpose: it shields indoor areas from direct sunlight during the summer, preventing overheating, and in the winter, it moderates excessive illuminance due to the lower angle of the sun compared to the summer months. Additionally, the narrow

Fig. 10

Solar shading in the 600 Housing Units: window section (a) and the influence of Mushrabiyah on sunlight (b). Source: Authors


(a) (b)

openings in the shutters contribute to precise control over the distribution of natural light, effectively reducing both heat build-up and excessive brightness (as exemplified in **Fig. 10 a and b**).

Building form and orientation

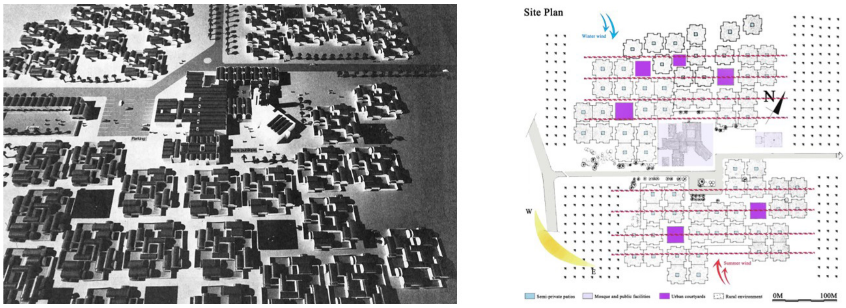
In the case of the 400 and 600 housing units, the architectural design features staggered cubic volumes, resulting in an unintentional resemblance to traditional houses commonly found in the region (Archnet, 1983; Archnet, 2001; Archnet, 2001). These volumes have been intentionally kept with minimal articulation to reduce their exposure to external surfaces and maximise shading effects through their mass. The roofing styles differ among the projects; Maader Village and the 400 housing units incorporate vaulted or domed roofs, while the 600 housing units feature flat roofs.

The overall appearance of the complexes is characterised by the use of lime-sand render in Maader Village and the 400 housing units, whereas the 600 housing units employ unfinished lime-sand stone. This choice results in a solid aesthetic with few voids, except for the inclusion of wooden windows. The storey height across all projects adheres to modern standards, measuring 3.1 meters.

Regarding orientation, Maader Village and the 400 housing units have their primary façades oriented in the northwest–southern east direction, as depicted in **Fig. 11 a and b**, as well as **Fig. 12 a and b**, respectively. In contrast, the 600 housing units are oriented towards the northeast – southern west direction. This strategic alignment takes advantage of the prevailing wind patterns, specifically the northern-west monsoon wind, while also minimising direct solar radiation on the façades, thereby providing shading for exterior spaces, as illustrated in **Fig. 13 a and b**.

Fig. 11

Maader Village: comprehensive overview (a) and site layout (b). Source: Authors



(a) (b)

Fig. 12

400 Housing Units: complete panorama (a) and site configuration (b). Source: Authors

(a) (b)

(a) (b)

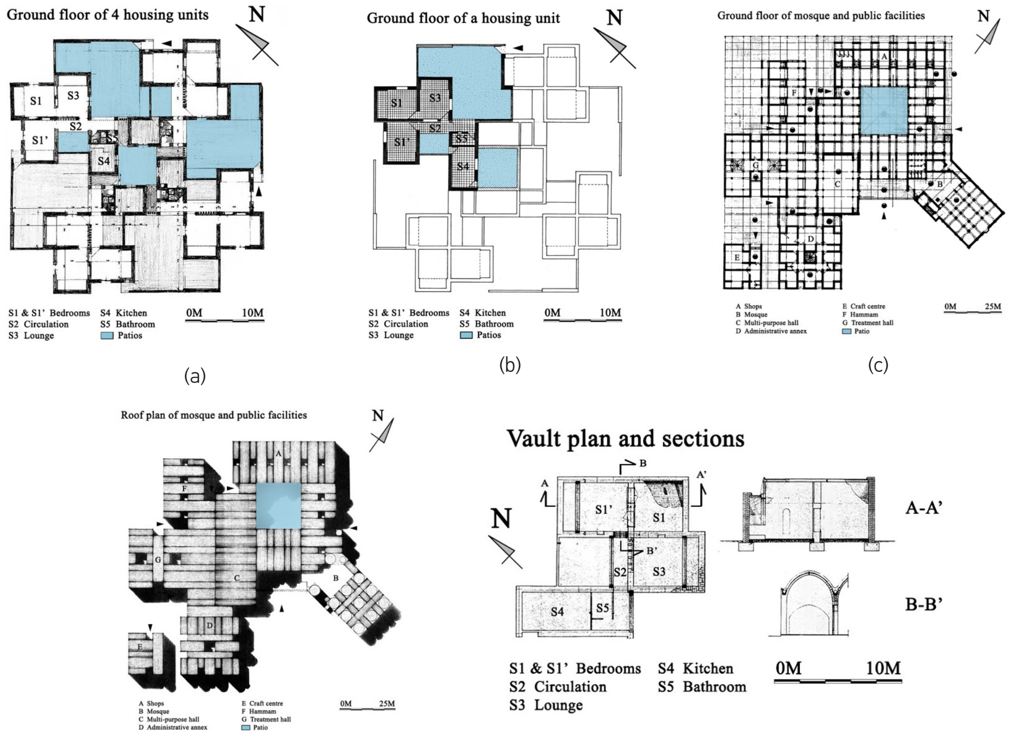
Fig. 13

600 Housing Units: panoramic perspective (a) and site blueprint (b). Source: Authors

Patio

Following MB's architectural choices, interior patios cover 15% of the site's surface area, in addition to the constructed buildings. The case studies incorporate three distinct types of patios: the first, centrally positioned patio serves as a vital conduit, facilitating movement between the 'Madiafa' doorway and private living spaces. The second patio, known as the 'Harim,' is specifically designated for women's use. The third patio, an exterior semi-private space nestled between housing units, fosters a sociable atmosphere for residents to interact. Beyond their social function, these patios also fulfil a climatic role, functioning as semi-open spaces that enhance natural ventilation.

Comprehensive floor plans for Maader Village, the 400 Housing Units, and the 600 Housing Units can be found in (**Fig. 14 a, b, c, d, and e**), (**Fig. 15 a, b, and c**), and (**Fig. 16 a and b**), respectively. Additionally, sections of Maader Village, the 400 Housing Units, and the 600 Housing Units are provided in (**Fig. 17 a, b, and c**), (**Fig. 18 a and b**), and (**Fig. 19 a and b**), respectively.



(a) (b) (c)

(d) (e)

Fig. 14

Plans for Maader Village: (a) ground floor plans of 4 housing units and (b) ground floor plans of 1 housing unit (c) ground floor and roof plans of the mosque and public facilities (d) vault plan and section (e). Source: Authors

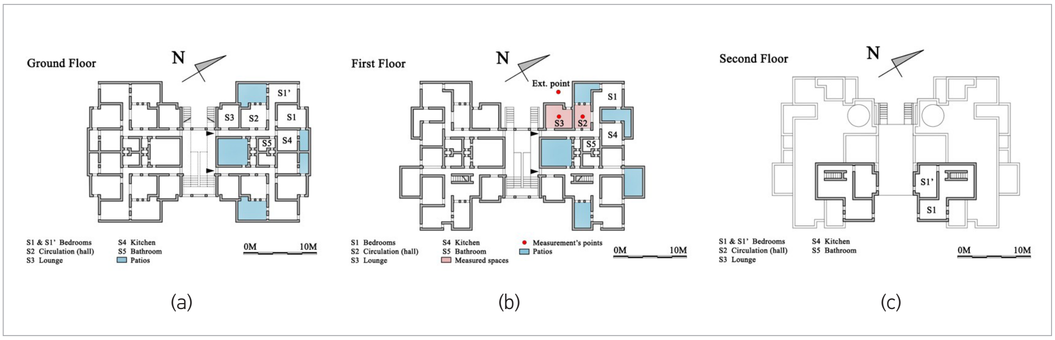


Figure 15

Plans for the 400 Housing Units highlighting relevant areas: (a) ground floor layout (b) first-floor layout (c) second-floor layout. Source: Authors

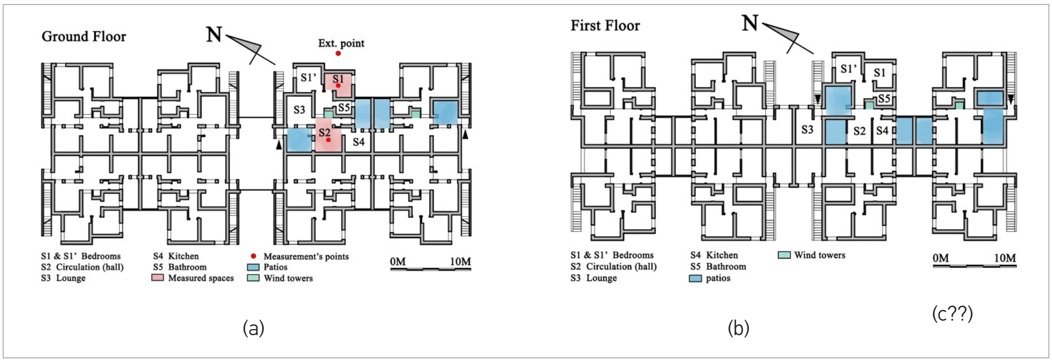


Fig. 16

Plans for the 600 Housing Units incorporating relevant spaces: (a) ground floor arrangement (b) first floor arrangement (c) second-floor arrangement. Source: Authors

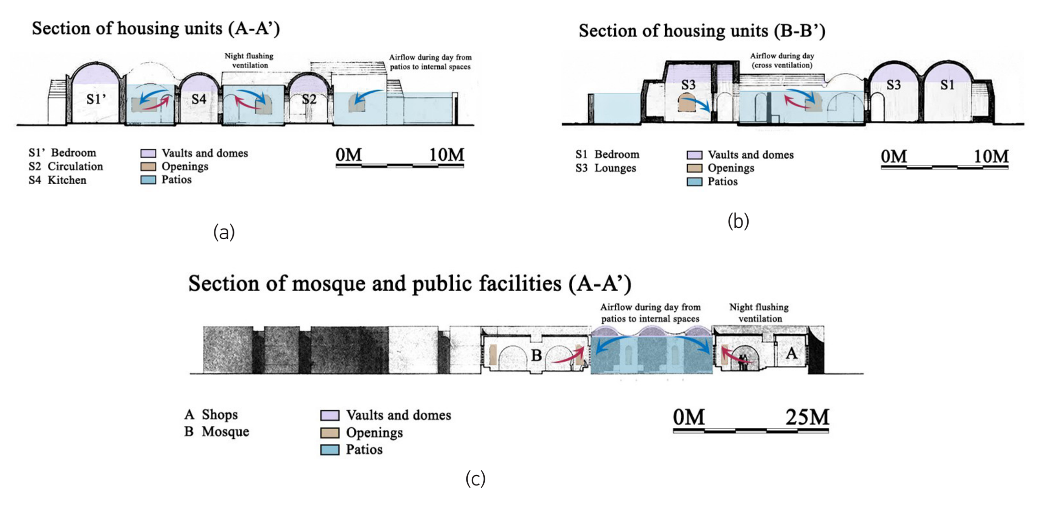


Fig. 17

Maader Village Section Views: illustration of natural ventilation mechanism and cross-ventilation impact in housing units (a) and (b), as well as in the mosque and public facilities (c). Source: Authors

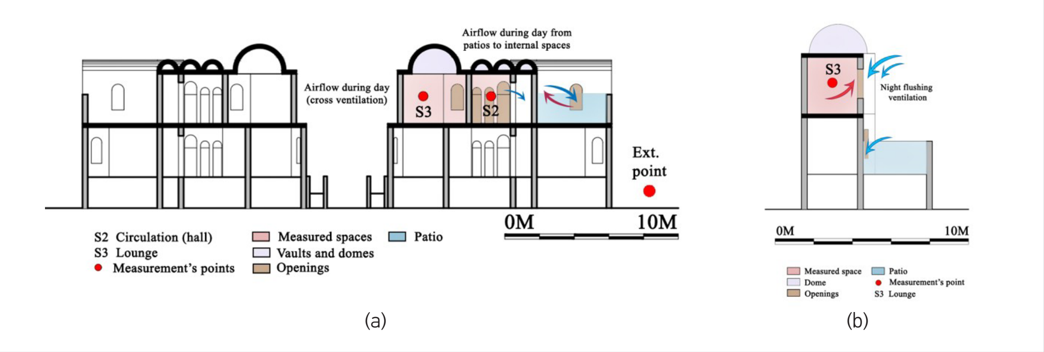
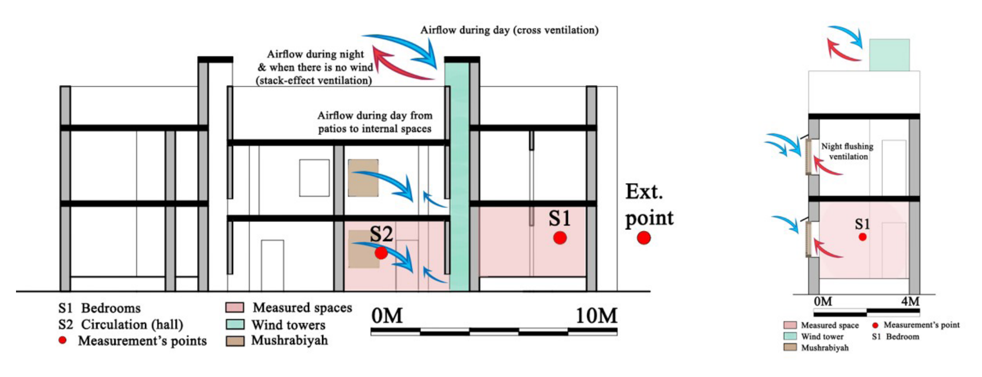


Fig. 18

Sections of the 400 Housing Units: depicting the natural ventilation mechanism and the consequences of cross-ventilation (a) and (b). Source: Authors



(a) (b)

Fig. 19

Sections of the 600 Housing Units: demonstration of the natural ventilation mechanism through cross-ventilation (a) and stack-effect (b). Source: Authors

Wind tower (in the case of the 600 Housing Units)

Air captors play a pivotal role in establishing a cooler indoor environment, thereby enhancing natural ventilation. This architectural feature, inspired by oriental civilisations, may seem unconventional in the context of local traditional architecture. However, its conceptual origins can be traced to the 'Rozna,' a prevalent element in the region's traditional building designs (as illustrated in **Fig. 20 a, b, c, and d**). The 'Rozna' typically consists of a roof opening designed to release hot air and facilitate daylighting without capturing wind.

Regrettably, some residents have removed or blocked these air captors, expressing concerns about sandstorms entering the structures. The original architectural plans and sketches did include provisions for filters and shutters on these openings. Regrettably, budget limitations prevented the implementation of these features during construction. Nevertheless, a study conducted by Mazouz and Torkia (Mazouz and Torkia, 2014), based on in-situ measurements, confirmed the efficiency of the existing wind tower in enhancing indoor thermal conditions and promoting natural ventilation (as shown in **Fig. 19 a and b**).

(a) (b) (c) (d)

Fig. 20

600 Housing Units: Rozna features in (a) and diverse wind towers in (b), (c), and (d).
Source: Authors

Passive strategies in case studies

The use of passive strategies in climate-responsive design aims to maintain comfortable indoor conditions year-round by cooling in summer and heating in winter.

Summer period

- MB's approach to summer cooling includes:
- Minimising heat gains through staggered masses, compact volumes, thick walls, thermophysical properties, and reduced window surfaces.
- Protecting from solar radiation with window shutters and small openings (Mushrabiyah).

- Using thick walls as thermal mass storage to regulate temperature fluctuations.
- Orienting buildings to optimize thermal performance, with shading and natural ventilation through patios, windows, or wind towers.
- Incorporating natural ventilation to enhance air quality and thermo-hygrometric comfort, using principles of cross-ventilation and the stack effect. These principles are elaborated upon in the study conducted by Mazouz and Torkia (Mazouz and Torkia, 2014), with illustrative depictions found in Fig. 17 a, b, and c, Fig. 18 a and b, and Fig. 19 a and b.

Winter period

- Heating strategies for winter include:
- Minimising heat loss through compact building volumes, reduced window surfaces, and materials with good thermal properties.
- Utilising passive solar heating with controlled window shutters on southern, eastern, and western walls.
- Protecting from uncomfortable ultraviolet radiation even in winter.
- Employing thick walls with high thermal mass for effective heat storage.
- In summary, MB's passive strategies are tailored for Algeria's challenging climate, focusing on summer cooling and winter heating. Detailed descriptions of these strategies can be found in Table 5, 6, and 7.

Coordination of strategies across seasons

Efficient coordination of passive strategies is essential for adapting to different seasons. Future stages will use Software Application (SA) to assess thermal performance and the impact of these strategies on indoor conditions and energy loads for cooling and heating.

In-situ measurements

To enhance the accuracy of our assessment, we conducted on-site surveys and measurements within both the 400 and 600 Housing Units. We utilised the Testo® (Testo-480, 1957) 480 devices for these in-situ measurements, gathering comprehensive data related to the indoor thermal environment. This data included air temperature, radiant temperature, operative temperature, relative humidity (RH), air velocity, as well as glass and wall surface temperatures.

Due to the relatively small dimensions of the selected spaces (bedrooms), each measuring less than 16 square meters, we assessed indoor thermal conditions at a single central point within these buildings, positioned at a height of 1.7 meters. This height aligns with the standing posture of an individual, as recommended by the International Organisation for Standardisation (ISO) 7726 (Iso, 2002) and ASHRAE 55 (ASHRAE, 2017) guidelines.

Outdoor environmental parameters were sourced from a location carefully shielded against direct solar radiation and rain. Measurements were conducted hourly, commencing at 8:00 a.m. and spanning the entire day. Furthermore, the measurement period was strategically chosen to coincide with the hottest days of the summer, covering a continuous three-day interval. These selected days closely matched the weather conditions observed during the actual measurement days, characterised by clear skies, absence of clouds or rain, and temperatures within the typical range for hot summer days.

It's important to note that these chosen days closely mirrored the weather conditions present during the actual measurement days. All measurements were conducted under natural conditions, with open windows, and in the absence of mechanical climate control systems or artificial heating or cooling.

Table 5

Designing for climate responsiveness and passive strategies in Maader Village, Bou-Saada

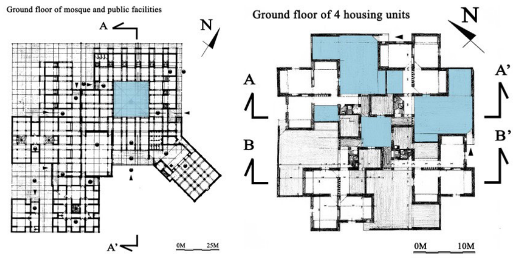
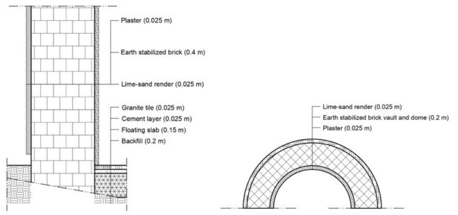
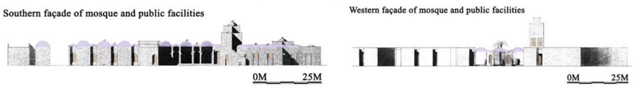
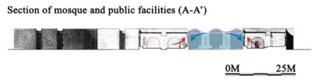
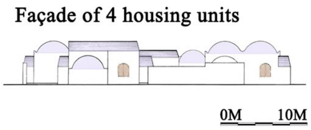
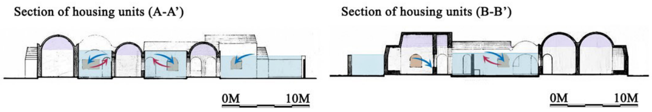
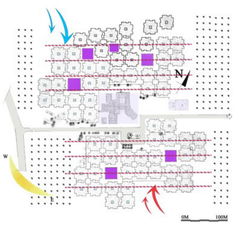
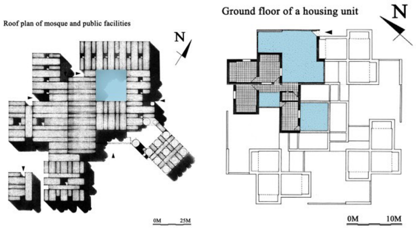
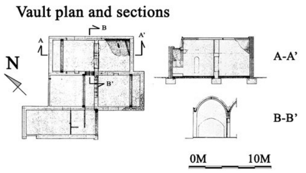
Criteria	Season	Maader Village, Bou-Saada
Passive strategies	During summers	_ Reducing heat gain through the building envelope _ Shielding against solar radiation _ Storing heat to maintain comfortable temperatures throughout the day _ Minimising direct exposure of primary living spaces to the exterior, taking into account space dimensions, storey height, and architectural typologies _ Employing various heat protection measures, including orientation, shading, window shutters, and semi-open spaces _ Adapting to monsoon winds and encouraging cross-ventilation and night flushing for natural airflow _ Incorporating semi-open spaces to facilitate sleeping during warm summer nights
	During winters	_ Reducing heat loss through the building envelope _ Harnessing passive solar heat _ Shielding from solar radiation _ Storing heat
Climate-responsive design	All seasons	① Compact volume with a favourable S/V ratio of 0.32 ② Utilisation of thick walls ③ Carefully selected envelope materials ④ Incorporation of small openings (WWR < 9%) ⑤ Implementation of window shutters ⑥ Orientation towards the northeast – southwest to harness winter winds ⑦ Integration of thermal mass within walls and roofs ⑧ Inclusion of three internal patios (comprising two private and one semi-private) ⑨ Placement of windows in each space to facilitate natural ventilation ⑩ Roof designs featuring vaults and domes ⑪ Design of energy-efficient spaces, especially in activity areas
Illustration	All seasons	 ①②⑦⑧⑨⑪  ③⑦  ①④⑤⑨  ②⑦⑨⑩  ①④⑤⑨  ②⑦⑨⑩  ①⑥⑧  ①⑧⑩  ①②⑦⑩

Table 6

Designing for climate responsiveness and passive strategies in 400 Housing Units, El-Oued

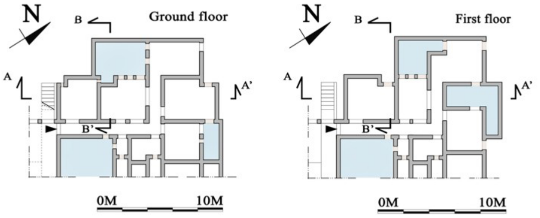
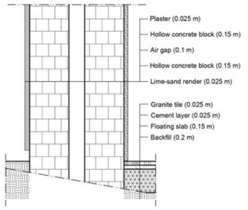
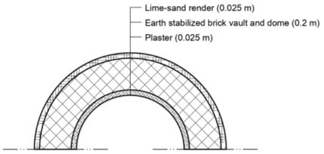
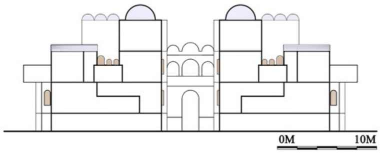
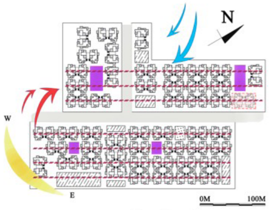
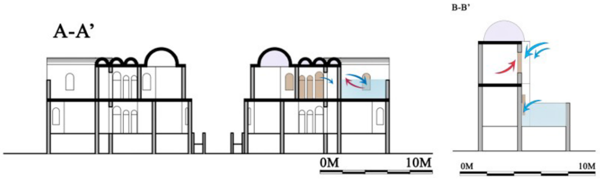
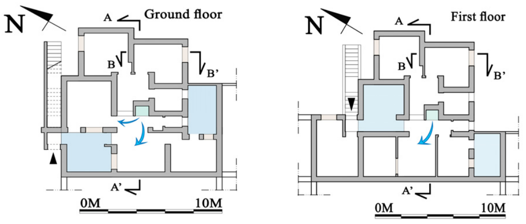
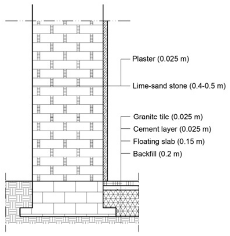
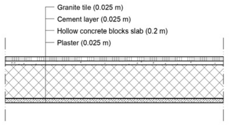
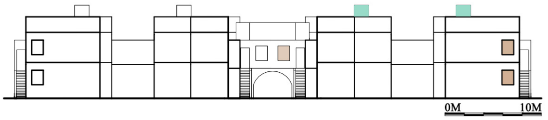
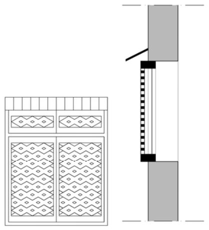
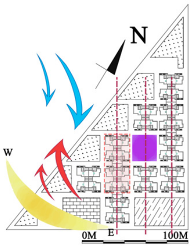
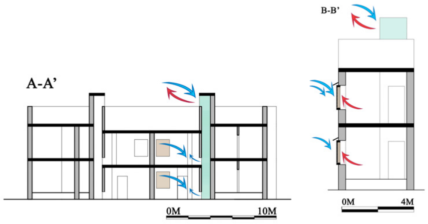
Criteria	Season	400 Housing Units, El-Oued
Passive strategies	During summers	_ Reducing heat gain through the envelope _ Protecting against solar radiation _ Utilising heat storage to retain daytime warmth and regulate indoor temperatures _ Limiting direct exposure of primary living areas to the exterior, accounting for space dimensions, floor heights, and architectural styles _ Implementing strategies for heat mitigation, including orientation, shading, window shutters, semi-open spaces, and more _ Adapting to monsoon winds and enhancing cross-ventilation, ventilation through the stack effect, and night flushing for natural ventilation _ Integrating semi-open spaces for sleeping during summer nights
	During winters	_ Reducing heat loss through the envelope _ Harnessing passive solar heat gain _ Providing protection from solar radiation _ Incorporating heat storage
Climate-responsive design	All seasons	① Implementation of staggered masses and a compact volume (S/V = 0.3) ② Integration of thick walls ③ Careful selection of envelope materials ④ Incorporation of small openings (WWR < 10%) ⑤ Utilisation of window shutters ⑥ Orientation toward the northeast – southwest to capture winter winds ⑦ Inclusion of thermal mass in both walls and roofs ⑧ Integration of two internal patios ⑨ Provision of openings in the vaults and domes of each house ⑩ Installation of windows in every space to enhance natural ventilation in conjunction with vaults and domes ⑪ Roof designs featuring vaults and domes ⑫ Creation of energy-efficient spaces, including activity areas on both lower and upper levels
Illustration	All seasons	 ①②⑦⑧⑩⑫  ③⑦  ③⑦  ①④⑨⑩  ①⑥⑧  ②⑦⑨⑩⑪

Table 7

Designing for climate responsiveness and passive strategies in 600 Housing Units, Ouled Djellal

Criteria	Season	600 Housing Units, Ouled Djellal
Passive strategies	During summers	_ Minimising heat gain through the building envelope _ Protecting against solar radiation _ Employing heat storage to retain diurnal heat and regulate daily indoor temperatures _ Reducing direct exposure of main living spaces to the exterior, taking into account space dimensions, storey height, and various architectural typologies _ Implementing measures to shield from excessive heat, including careful orientation, shading, window shutters, semi-open spaces, and more _ Adapting to monsoon winds and facilitating cross-ventilation, stack effect ventilation, and night flushing for natural ventilation _ Incorporating semi-open spaces for night-time comfort during summer months
	During winters	_ Reducing heat loss through the building envelope _ Harnessing passive solar heat gain _ Shielding from solar radiation _ Incorporating heat storage
Climate-responsive design	All seasons	① Incorporation of staggered masses and a compact volume (S/V = 0.47) ② Use of thick walls ③ Careful selection of envelope materials ④ Integration of small openings (WWR < 20%) ⑤ Installation of windows with shutters and small openings, embracing the 'Mushrabiyah' concept ⑥ Orientation towards the northeast – southwest to harness the winter wind ⑦ Inclusion of thermal mass within walls and roofs ⑧ Design of two internal patios ⑨ Placement of wind towers in the centre of each house ⑩ Provision of windows in each space to facilitate natural ventilation, in tandem with wind towers ⑪ Implementation of solar shades on the southern, eastern, and western sides (utilising horizontal overhangs) ⑫ Adoption of a flat roof design ⑬ Creation of energy-efficient spaces, both on lower and upper levels, designated as activity areas
Illustration	All seasons	 ①②⑦⑧⑨⑩⑬  ③⑦  ③⑦  ①④⑨⑩  ⑤⑪  ①⑥⑧⑨  ②⑦⑨⑩⑫

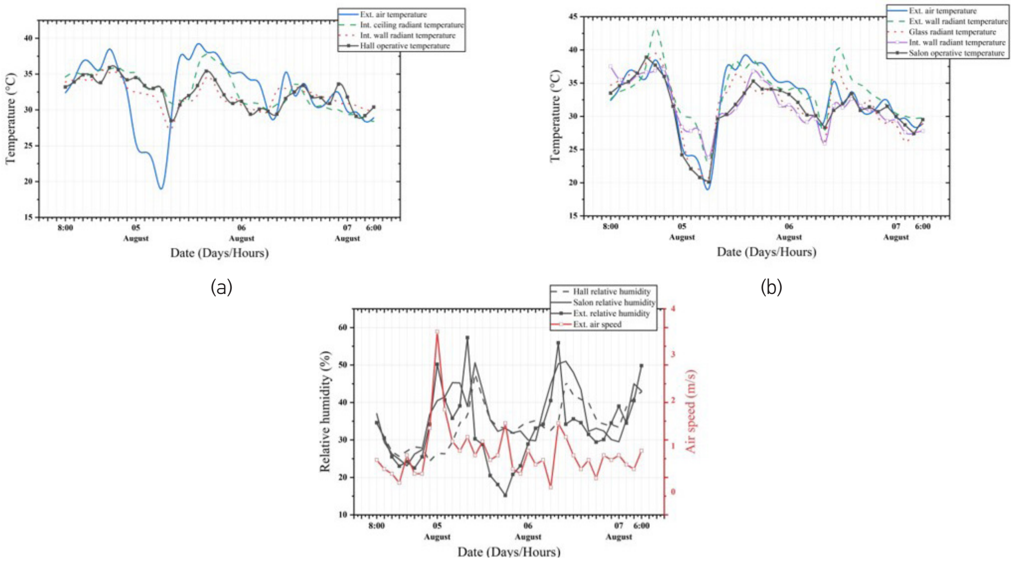
400 Housing Units (1979) in El-Oued, Algeria

During the period from August 4, 2018, to August 6, 2018, measurements were taken within the 400 housing units. These measurements were carried out on the first floor and covered a range of locations, including a bedroom oriented toward the northwest with an exterior-facing window, and a living room that opens onto the internal patio, also oriented to the northwest. During the measurements, both spaces were occupied by residents and featured various appliances.

The provided figures (**Fig. 21 a, b, and c**) illustrate the in-situ measurements conducted, which encompass air temperature, radiant temperature, RH, and air velocity, specifically for the 400 housing units.

In the hall, the indoor operative temperature exhibited fluctuations between 28.5°C and 35.9°C, while in the salon, it varied from 20.1°C to 38.9°C. External temperatures reached a peak of 40°C. Notably, the data reveals that thermal leakage is more pronounced in the roof compared to the walls. This disparity is explained by the direct sunlight that falls on the roof, resulting in greater indoor temperature increases compared to the walls, which receive less direct sunlight.

It's important to note that El-Oued is characterised by relatively low wind speeds, as indicated by the graph (suggesting that night flushing may be a viable solution in similar scenarios). Furthermore, there were no significant disparities between indoor and outdoor humidity levels, underscoring the success of indoor ventilation. However, daytime ventilation during the summer proved less effective due to the high outdoor temperatures.



(a)

(b)

(c)

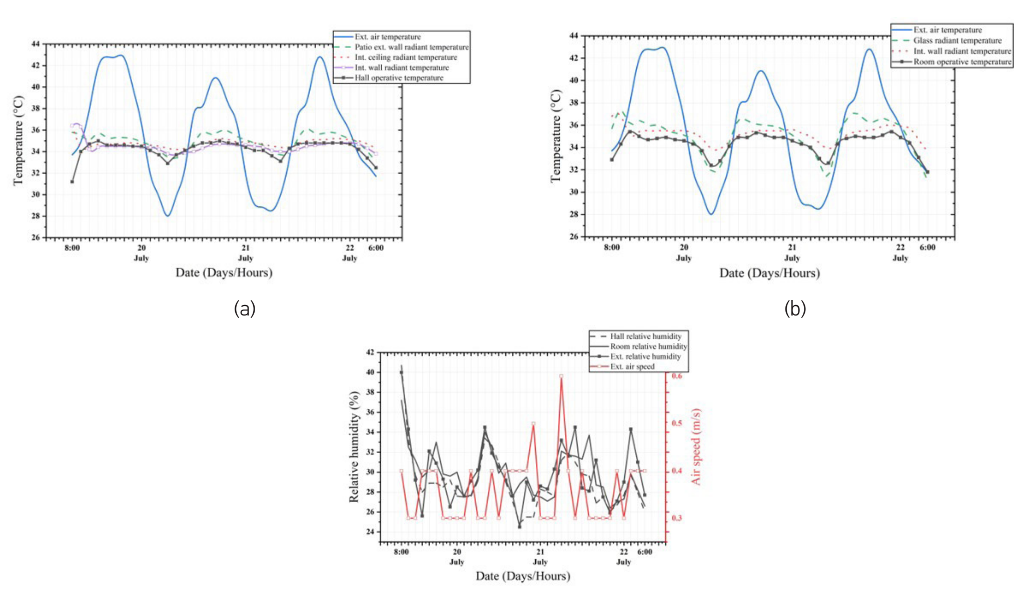
Fig. 21

In-situ measurements conducted for the 400 housing units encompassed a range of parameters. These measurements covered air, wall, and glass radiant temperatures for both the hall (a) and salon (b). Additionally, they included data on RH and air velocity, collected for both the hall and salon (c). Source: Authors

600 Housing Units (1980) in Ouled Djellal, Algeria

Measurement data for the 600 housing units were collected during the period from July 19, 2019, to July 21, 2019. These measurements were taken on the ground floor, encompassing various locations. Specifically, the bedroom, which faces the northeast and features an exterior window, and the living room, oriented toward the northwest and connected to the internal patio, were both inhabited and equipped with various appliances.

The accompanying graphs (depicted in **Fig. 22 a, b, and c**) provide a visual representation of the in-situ measurements, including air temperature, radiant temperature, RH, and air velocity, for the 600 housing units.



(a)

(b)

(c)

Fig. 22

In-situ measurements for the 600 housing units included data collection for air, wall, and glass radiant temperatures in both the hall (a) and room (b). Additionally, measurements were taken for RH and air velocity in both the hall and room (c).
Source: Authors

Within the hall area, the indoor operative temperature exhibited a range from 31.2°C to 35°C, whereas in the living room, it fluctuated between 31.8°C and 35.4°C. Meanwhile, the outdoor air temperature reached as high as 43°C during certain periods. It is noteworthy that the radiant temperature of the external walls surpassed that of the internal walls and roofs. This distinction can be attributed to the wall's effective insulation and thickness, resulting in heightened resistance to thermal transfer. Despite the scorching outdoor temperatures during peak hours, the internal operative temperature remained consistently stable throughout both day and night. This stability can be attributed to the proficient utilisation of thermal mass strategies.

While there were slight variations in relative humidity between the indoor and outdoor environments, they were predominantly minimal. These minor fluctuations primarily arose from controlled window ventilation during specific daytime intervals characterised by elevated temperatures.

Discussion and Conclusion

This study conducted a comprehensive evaluation of the design principles applied in iconic housing projects situated in Algeria's southern region. A combination of qualitative and quantitative methods was employed to assess their performance, particularly concerning indoor thermal comfort as defined by ASHRAE 55 (ASHRAE, 2017). The PMV-PPD index was computed based on the gathered data, considering specific criteria identified during in-situ measurements, which included parameters like 0.5 clo for summer, 1.1 met, relative humidity at 20%, and airspeed at 0.5 m/s. The outcomes indicated that the PMV-PPD boundaries for operative temperatures during summer were 27.3°C (lower limit) and 30.6°C (upper limit).

Conversely, the adaptive comfort model was found to be applicable within the range of mean outdoor temperatures prevailing between 10°C and 33.5°C. With the application of the standard airspeed of 0.3 m/s, the maximum proposed limits of the adaptive model were identified as 25.7°C and 30.6°C for the 90% acceptability limits, along with 24.7°C and 31.5°C for the 80% acceptability limits. Nevertheless, neither the PMV-PPD nor the adaptive comfort model achieved the desired level of thermal comfort. This indicates the necessity for further investigations into the thermal adaptive behaviour of residents in these regions, as well as potential enhancements to passive or active design solutions to achieve thermal efficiency.

Implications of the research

The findings of this study have several important implications:

- Design adaptability and flexibility: The approach utilised in this study for evaluating climate-responsive architecture has demonstrated its effectiveness and suitability for application in the assessment of housing projects across diverse regions. However, it is essential to adapt these methods to account for regional climatic, geographical, and contextual differences.
- Building performance: The study highlights that not all case studies exhibited ideal building physics. Through extensive investigations, both the strengths and weaknesses of these buildings were identified, aiming to leverage their positive attributes for current and future developments. This underlines the necessity of using appropriate and objective methodologies for evaluating climate-responsive buildings to ensure accurate findings.
- Measurement and prediction: Given the variability in weather conditions in some regions, relying solely on short-term in-situ measurements may not provide a comprehensive overview of building performance. Therefore, combining short-term in-situ measurements with long-term prediction tools, such as building simulation, is recommended to gain a more accurate assessment.
- Low-Energy design principles: The architectural work by the MB in Algeria's southern region has effectively adapted to diverse climatic conditions through the utilisation of low-energy design principles. These include strategies like natural ventilation, proper building orientation, well-conceived building shapes, solar shading, incorporation of high thermal mass, and robust thermal insulation. The presence of courtyards and patios has made significant contributions to ventilation flow rates and the effectiveness of night-flushing ventilation, particularly in rooms facing these internal spaces.
- Integration of modern systems: In the challenging climate of southern Algeria, it may not always be feasible to rely solely on traditional design strategies to maintain thermal comfort. Therefore, under extreme conditions, these buildings may benefit from the integration of low-energy mechanical systems, such as mechanically assisted ventilation, evaporative cooling, and passive solar heating. Additionally, residents' adaptive responses, including adjusting clothing insulation, engaging in specific activities, regulating window openings, and using fans, can further enhance comfort levels.
- Future research directions: This study's limitations, including the quantitative assessment being limited to only three housing projects, suggest that a more extensive investigation is warranted to provide comprehensive insights. Future research should encompass comparative assessments between the MBs' architectural work and more contemporary designs to facilitate a better understanding of their performance and offer recommendations for sustainable housing design in Algeria's southern region.

This study highlights the critical importance of climate-conscious building design, exemplified by iconic housing projects in southern Algeria. These projects demonstrate the potential for harmonious coexistence with nature and emphasize the need to preserve climate-responsive design. The research underscores low-energy design principles and modern system integration, offering insights to inspire architects and decision-makers towards sustainable development in challenging climates.

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