

Original scientific paper

UDC 551.58:72(65)  
<https://doi.org/10.2298/GSGD2502001L>

Received: March 18, 2025

Corrected: April 28, 2025

Accepted: May 6, 2025

**Daraf Labdi<sup>1\*</sup>, Khalfallah Boudjemaa<sup>\*\*</sup>, Hafid Layeb<sup>\*\*\*</sup>**

*<sup>\*\*</sup>Faculty of Earth Sciences, Geography and Territory Planning; Université Constantine 1-Frères Mentouri.; Urban and Environmental Technologies Laboratory, University of M'sila, Algeria*

*<sup>\*\*</sup> Department of City Management, Urban Technology Management Institute, Director Urban Technologies and Environment Laboratory, University of M'sila, Algeria*

*<sup>\*\*\*</sup> Faculty of Earth Sciences, Geography and Territory Planning; Université Constantine 1-Frères Mentouri*

## **STRATEGIES FOR CLIMATE DESIGN TO ENHANCE ENERGY EFFICIENCY IN RESIDENTAL BUILDINGS: THE CASE OF BOU-SAADA CITY, ALGERIA**

**Abstract:** This work investigates passive architecture-based solutions to increase household energy economy and examines climate-responsive design. The research makes use of passive design techniques suited for the hot, semi-arid climate of the city. Using Mahoney Tables, psychrometric chart analysis, and Climate Consultant.6, the research produced interesting results using analytical tools. The study notes significant design strategies that lower energy consumption and increase thermal comfort. According to the study, the foundation of energy-efficient house design is small courtyard design mixed with perfect building orientation. To keep inside temperatures constant, the study advises combining low-key patio designs with high thermal mass materials. Sustainable Especially important methods for combined natural ventilation with passive solar heating systems and evaporative cooling systems are the project mostly deals with building summer cooling and winter heating. The study emphasizes the need for passive architectural solutions in lowering mechanical system reliance and greenhouse gas emissions. Passive design methods help one to be less dependent on mechanical climate control systems, so lowering greenhouse gas emissions. According to the study, new building techniques should fit the specific surroundings of Bou-Saada city. Analysis of Bou-Saada city climatic characteristics helps in attempts at sustainable urban development in semi-arid and dry environments. The results give builders and urban

---

<sup>1</sup> labdi.daraf@doc.umc.edu.dz (corresponding author)

Daraf Labdi (<https://orcid.org/0000-0003-0141-4443>)

Khalfallah Boudjemaa (<https://orcid.org/0000-0002-9050-7141>)

designers practical direction for using them in their projects. Residential building designers and legislators have to give top priority to energy economy that satisfies cultural and environmental needs. The study confirmed, by means of energy-saving architectural design strategies, enhancing the thermal comfort of residential buildings.

**Keywords:** climate-responsive design, energy efficiency, passive strategies, Bou-Saada city, bioclimatic architecture, sustainable urban development

## Introduction

The increasing worldwide concern over energy shortages and the effects of global warming has elevated energy efficiency to top importance in modern policy debates. Governments all around have promised to lower greenhouse gas emissions since the Kyoto Protocol was adopted in December 1997, so effective energy use becomes a top priority in energy strategies.

Given their high energy consumption, buildings are among the most important players in this scene. Within IEA nations, buildings account for nearly half of all electricity use, one-third of natural gas usage, and more than one-third of overall greenhouse gas emissions (Nejat et al., 2015) . As such, tackling these issues now depends critically on sustainable design and building techniques. Although architectural practices have always been impacted by sustainability, as shown by ideas going back to Vitruvius, the basic problems of design and construction have stayed essentially the same despite developments in materials and technology (Tabb & Deviren, 2017). These technological advancements have, however, also brought significant negative effects, which emphasizes the necessity of much thought about their use.

Along with high levels of solar radiation, Algeria has a varied spectrum of temperature zones ranging from very hot to cold (Sahabi ABED & Matzarakis, 2017); (Laidi et al., 2017). The nation is split into five separate climate zones (see fig.1) (Ketfi et al., 2017) , each of which has unique architectural design and environmental problems (Daraf et al., 2016). Focused on Bou-Saada City, in a hot, semi-arid environment, this research on climate design techniques for energy-efficient residential structures aims to, based on earlier studies and the adaptive comfort hypothesis, show that people who live in hot areas finally adjust to higher temperatures. In winter, the recommended inside comfort temperature is from 20°C to 24°C; in summer, from 23°C to 26°C. With an eye on increasing energy efficiency while preserving ideal thermal comfort for occupants, this research looks at passive design decisions catered to Bou-Saada city's climatic circumstances.

Suggests three main strategic stages to follow: the design stage of component building, the planning stage, and the conceptual strategy stage (Givoni, 1992). Mahoney tables and other analytical tools, such as the psychrometric chart and Climate Consultant.6, help methodically evaluate thermal comfort and environmental conditions. These tools give architectural signals that control the form, orientation, and construction of the design, thereby guiding the direction and shape of energy-efficient home development. These indicators have to be customized to the particular bioclimatic circumstances of every place, as climatic variables vary depending on the area.

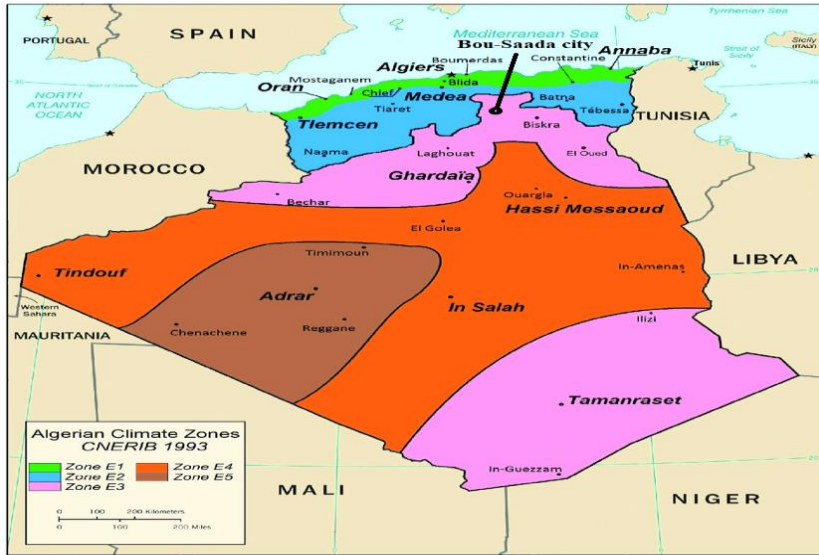


Fig. 1. Climate zones in Algeria (CNERIB<sup>2</sup>, 1993)

This research examines the city of Bou-Saada in Algeria, which is characterised by its hot, semi-arid climate and offers great potential and challenges for sustainable development in the region. Passive design techniques save energy consumption and improve thermal comfort, according to the study conducted using Mahoney tables, psychrometric charts, and climate consultants. The study takes into account the natural and cultural environment of the Bou-Saada city, with the aim of contributing to the development of guidelines for the design of climate-responsive residential buildings in accordance with global energy sustainability goals.

## Literature Review

Defining and strictly applying bioclimatic architecture concepts is a difficult task, as this approach is closely related to the surroundings. Based on the local temperature, bioclimatic construction in Bou-Saada city generally makes use of architectural techniques that match indigenous architecture. The evaluation of common design solutions depends on methods considering necessary thermal aspects, particularly the building envelope, to assess their impact on energy efficiency.

Three main tools are used in hot places like Bou-Saada city to assess design strategies that respond to the climate: the bioclimatic graph (Olgyay, 2015), the psychrometric diagram (Szokolay, 1986), and the Mahoney tables (Affairs et al., 1971); (Givoni & IZARD, 1978). With particular focus on the Mahoney tables, recent studies have examined the climatic context in which these techniques are applied. This study emphasizes their relevance in identifying effective climate design strategies to improve residential building energy economy.

The study aims to provide strategic pre-design advice to maximize passive solar energy utilization in building design and urban planning, therefore enhancing internal thermal

<sup>2</sup> CNERIB: National Center for Integrated Studies and Research in Buildings in Algeria

comfort and lowering energy consumption. The method uses manual techniques such as Mahoney tables and the ARCHIPAK software to define comfort zones and control potential zones (CPZs) based on 25 years of regional meteorological data. Critical results show that the combination of passive solar control (18%), the mass effect with nighttime ventilation (22%), and air movement with evaporative cooling (40.2%) greatly improves interior comfort, thereby lowering the need for active cooling to only 30% of the year. To reach sustainable, energy-efficient architectural designs fit for Nicosia's climate, the study advocates the adoption of passive solar strategies, including compact building configurations, substantial walls and roofs for thermal mass, minimal openings to reduce heat gain, and natural ventilation methods (Rabah, 2005).

The study aimed to develop and assess a universal Climate-Energy Index (CEI) and Building Energy Index (BEI) to gauge how climate may affect global building energy performance. Using Mahoney's chart and simulations for different buildings in various climates, the method created indices to estimate energy needs based on climate data. Except in extreme conditions, the data showed that CEI fairly projected climatic effects; BEI regularly evaluated building energy use, particularly those following optimum norms. Particularly for hot, humid situations, the study argued for the improvement of the indices and underlined their possible global standards for sustainable building design (Emmanuel et al., 2013).

This study looked at the climatic characteristics of Indonesian regions, especially Jakarta, to help develop a passive house design guideline for domestic construction. To find appropriate passive design strategies, the research examined climate data, including temperature, relative humidity, and precipitation, using the Olgvy Bioclimatic Chart, the Givoni Milne Bioclimatic Chart, and the Mahoney Table. The Olgvy chart showed an always humid and uncomfortable atmosphere that needed higher wind speeds to reduce humidity. The Givoni Milne chart suggested methods of natural shade and ventilation. The Mahoney Table suggested several architectural elements like building orientation, large expanses, single-banked rooms with constant air circulation, composite window apertures, strong walls and ceilings, and protection from heavy rain. The study supports the effective passive method of lightweight wall materials autoclaved aerated concrete (AAC) in combination with night ventilation to reduce discomfort hours in Indonesian residential buildings. Further research is encouraged to look at other passive strategies, such as improved ventilation systems, shadow, and open space design (Matsumoto et al., 2017).

To provide ideas for climate-responsive building design, this research looked at environmental elements and passive design strategies used in traditional Nepalese construction. Further examined utilizing bioclimatic charts and Mahoney tables was data from 2006 to 2015 covering air temperature, relative humidity, and precipitation for subtropical (Biratnagar), temperate (Lalitpur), and cold (Jomsom) regions. The findings show that the higher temperatures in subtropical areas necessitate designs that improve air circulation. In temperate climates, passive solar heating with air circulation techniques in warmer months is advantageous. In frigid conditions, robust passive solar heating systems are very vital. The study indicated that many building designs follow ideas such as east-west elongation, significant thermal mass in colder regions, and low thermal mass in subtropical environments. These findings will greatly help designers and builders in the first design stages to create more climate-responsive and energy-efficient buildings for Nepal (Lamsal et al., 2021).

This study, employing Givoni Bioclimatic charts, Mahoney Tables, and Autodesk Ecotect for energy modeling, sought passive design solutions for buildings in the hot and semi-

arid climate of Dire Dawa, Ethiopia. Initially, design ideas were obtained from the examination of meteorological data using psychrometric charts and Mahoney Tables; subsequently, energy simulations on a common condominium building model evaluated the effectiveness of these strategies. Key results showed that effective cooling options for the region were natural ventilation, raised thermal mass with nighttime ventilation, solar shading systems, and small courtyard designs. The energy simulation confirmed that increasing wall thickness and orienting buildings along a north-south axis significantly reduced cooling energy consumption. The recommendations included strong walls and roofing with an 8-hour thermal lag, placing windows on the north and south walls at human eye level, maintaining minimum window-to-wall ratios (15–25%), and ensuring protection from direct sunlight and precipitation. These ideas aim to lower energy consumption in the climate of Dire Dawa while still enhancing indoor thermal comfort (Alagaw & Yonas, 2021).

The research aims to evaluate how conventional vernacular architecture could guide sustainable design principles for contemporary homes in hot desert environments. The method emphasizes case studies from El-Oued in the Souf region, utilizing qualitative analysis synthesised from literature and field research. The study looks at passive cooling methods in traditional homes and assesses climatic conditions using Mahoney Tables and ASHRAE's psychrometric chart. Important results show that conventional architecture effectively reduces heat input by means of domes and vaults to lower sun exposure, strong brick walls for thermal inertia, compact urban designs for mutual shadowing, and courtyards with sand flooring that cool rapidly at night. Emphasizing the need for local materials, small building forms, strategic orientation, and natural ventilation techniques, the research advocates the integration of passive design solutions in modern architecture to improve thermal comfort and energy efficiency in hot desert locations (Femmam & Sriti, 2022).

With the aim of promoting a sustainable living environment despite urban development and environmental issues, this study sought to provide design recommendations for Chennai using Mahoney tables. The approach included the use of Mahoney tables to determine appropriate design solutions and the study of meteorological data for Chennai, including temperature, humidity, precipitation, and solar radiation. Essential results showed that Chennai, classified as a warm and humid climate, requires targeted strategies including north-south orientation (long axis east-west), open spaces to facilitate breeze penetration while shielding from extreme winds, single-banked rooms to enhance air circulation, substantial openings (40%-80%) situated on the windward side at body height, light walls exhibiting minimal thermal lag, lightweight insulated roofs, and sufficient rainwater drainage systems. Emphasizing the need for air circulation, rain protection, and thermal comfort in building design and materials, the standards support energy efficiency and sustainability in construction methods fit for Chennai's climate. These ideas are meant to help designers and builders make appropriate use of natural resources, thereby preserving thermal comfort for residents (Suresh & Ramamurthy, 2022).

This study aimed to examine bioclimatic design solutions in Esfahak hamlet, a hot desert town, to assess their effectiveness in attaining thermal comfort and energy economy. The Mahoney method employed a qualitative and descriptive-analytical approach, integrating architectural analysis, climatic data, and case studies of 45 residential units. Through dense urban planning, strong walls, restricted apertures, courtyard patterns, and wind-harvesting elements, Esfahak's vernacular architecture clearly adapted to its adverse environment. These passive design features reduced reliance on mechanical equipment and improved thermal

comfort. While preserving cultural legacy, the study promotes the application of traditional bioclimatic approaches into contemporary architecture in comparable climatic locations to increase sustainability, energy efficiency, and climate resilience (Hosseini, 2022).

The study aimed to create dwellings utilizing bioclimatic ideas and construction methods made from indigenous materials for Oaxaca, Mexico families affected by the 2017 earthquake. To find suitable bioclimatic strategies, the study comprised a climatic characterization of the site supported by comfort triangles and Mahoney tables. Important strategies for the region turned out to include natural cross ventilation, thermal inertia in walls and ceilings, and solar radiation during winter. The psychometric chart showed that 94.40% climatic comfort hours could be obtained with window protection (33.10%) and cooling/dehumidification (61.30%). Emphasizing important bioclimatic elements catered to local conditions; traditional homes in the area deftly employed high ceilings, halls, and adobe walls. Emphasizing passive tactics over active systems, recommendations include the use of bioclimatic approaches consistent with the climatic area to improve habitability and support of traditional construction methods. Measurements or simulations should be part of later research to confirm the effectiveness of these strategies after their introduction. This approach promotes environmentally friendly, energy-efficient, climate-change-resistant sustainable dwelling choices with little impact (Hassina et al., 2024).

A review of past work reveals agreement among academics on the fundamental ideas of climate-responsive design. The findings show that many towns and sites with similar climatic circumstances might be able to effectively use bioclimatic architectural techniques. Moreover, these solutions have demonstrated effectiveness in improving interior thermal comfort for occupants and in increasing energy efficiency in household buildings.

## **Materials and Methods**

### ***Research Phases***

The purpose of this study is to investigate how common strategies could influence passive ambient comfort in hot semi-arid environments of Algeria. The paper uses a two-stage approach to reach this goal.

The first part consists in using the Climate Consultant program to investigate Bou-Saada city bioclimatic features. This study assesses the impact of common approaches on energy efficiency by means of cofactor (indicator) identification of fundamental traits influencing habitat energy performance. This bioclimatic study offers a foundation for the next step, so guiding the creation of architectural recommendations.

The next level stresses the need of including common approaches into architectural design. Appropriate design solutions resulting from bioclimatic data obtained through the Climate Consultant program are found using the Mahoney Tables. This approach helps passive technology to be integrated in order to raise the thermal efficiency of buildings. In the end, using the research results, designers can decide which most effective solutions will improve energy performance.

## ***Program used***

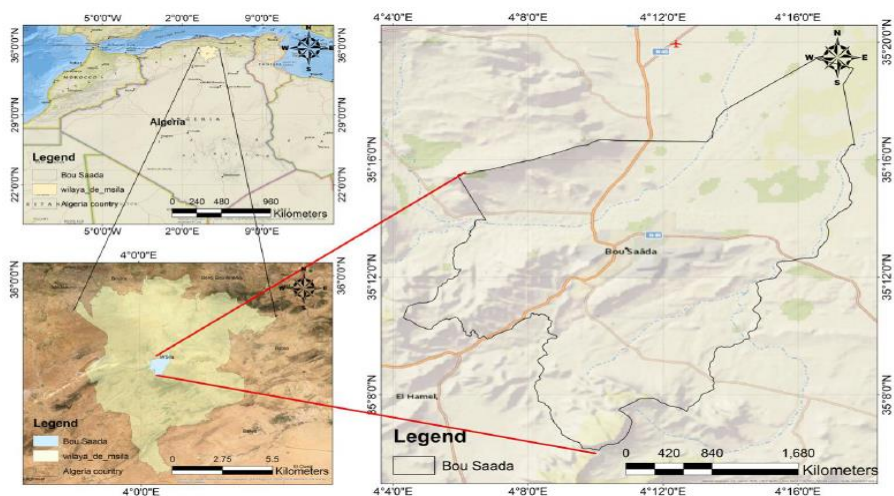
A user-friendly and cooperative tool, Climate Consultant 6.0 offers climatic data in several ways that would be helpful to users, including architects. It offers hourly records on temperature, wind direction, humidity, solar radiation, sundials, and sky cover all year round (Kumar & Sharma, 2018).

The psychrometric chart, which enables the most efficient passive design techniques to be found, is one of its main characteristics. The program's wind wheel also lets users see wind direction and speed with temperature and humidity data, therefore enabling weekly, daily, or monthly visualization of these elements (Mwizerwa & Gupta, 2020).

Using the EnergyPlus Weather File (EPW) format provided by the Department of Energy Climate Consultant software (Flores-Larsen et al., 2019). compiles climatic data. Various elements affecting climate change have been under analysis by the Climate Consultancy Program; they are listed below.

## ***Geographical and Climatic Features of Bou-Saada City***

Located 250 kilometres southeast of Algiers, Bou-Sada City holds the title of being the oldest oasis in Algeria. The 461-metre elevation along with its 225 km<sup>2</sup> area makes this location an essential point connecting the Mediterranean to the Sahara desert. Sheeted by arid desert conditions, Daira de Bou- Saada city brings intense sunlight in combination with large temperature differences. Bou-Saada City sits near the meeting point of desert plains and high plateaus and experiences both intense temperature differences and powerful solar reflections. Most of the winter season features mild temperatures, yet several occasions during the period reach freezing points at night. Figure 2 displays the environmental temperature measurements in Bou-Saada City, where the summer reaches 39°C during July and August, and winter reaches its lowest point at 6°C during January and December. Bou-Saada City experiences hotter conditions than typical for a semi-arid climate, as its annual average temperature is 22.7°C.



*Fig. 2. Bou-Saada city location*

The climate conditions in Bou-Saada City reveal summer temperatures exceeding 39°C, while the winter period brings temperatures down to approximately 6°C. The environmental conditions in Bou-Saada City lead to substantial energy requirements for residential utility buildings. Design approaches that respond to climate changes need to be implemented effectively since they help decrease energy use and consumption while ensuring thermal comfort. By integrating passive cooling techniques, apartment buildings should optimize their orientation and incorporate highly efficient material selection that contributes to sustainable goals. The implementation of sustainable residential architecture methods enables people to cut dependence on heating and cooling systems. Research conducted within Bou-Saada City helps understand essential study methods. The planning framework of sustainable development works best in areas that experience dry environments and similar conditions.

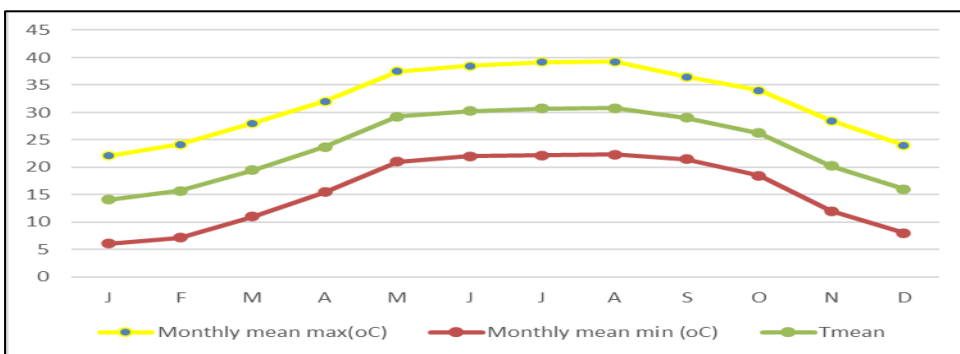


Fig. 3. Temperatures Bou-Saada City

## Results and Discussion

### Climate analysis

#### Temperature analysis

Temperature research in Bou-Saada City displays major climate changes across different years, which support the idea of aridity in the zone. The yearly trend of relative humidity shows declining percentages from 63% during January until summer. The environment is arid because the city experiences temperature fluctuations from 10°C in January to 39°C in July. The wind speed reaches its maximum value of 4 m/s in January, yet the summer months of July and August demonstrate reduced wind velocities at 3 m/s. Wind velocity exhibits seasonal variation. The research establishes that the period of July through August should receive top priority due to excessively high temperatures in addition to devalued values.

Given in the figure, the hourly average temperature for Bou-Saada city accentuates monthly fluctuations using the abscissa representing months and the ordinate displaying temperatures. Like latitude, longitude, and elevation, the top-right corner of the map displays the features of the site. August is among the most critical months for learning. Represented by the grey-colored area, the graph displays adaptive comfort and temperature fluctuations. The average temperature range is shown on the bar chart; the yellow part in-

dicates the standard high and low temperatures between 23–35°C and 22–10°C, respectively. Low-temperature conditions cover 15–0°C; high-temperature conditions fall between 30 and 39°C.

WEATHER DATA SUMMARY		LOCATION: Bou-Saada, -, -											
		Latitude/Longitude: 35.33° North, 4.2° East, Time Zone from Greenwich 1											
		Data Source: MN7 605150 WMO Station Number, Elevation 461 m											
MONTHLY MEANS													
Global Horiz Radiation (Avg Hourly)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	329	367	465	488	514	545	558	533	458	403	345	289	Wh/sq.m
Diffuse Radiation (Avg Hourly)	597	499	572	527	505	542	580	560	479	542	550	538	Wh/sq.m
Global Horiz Radiation (Max Hourly)	78	116	120	148	163	159	143	145	155	111	90	77	Wh/sq.m
Direct Normal Radiation (Max Hourly)	657	758	921	961	1033	1014	1005	975	890	818	667	572	Wh/sq.m
Diffuse Radiation (Max Hourly)	988	981	1000	964	960	960	896	886	917	956	978	965	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	294	353	400	450	473	463	308	335	413	394	301	288	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	3262	3922	5495	6321	7146	7824	7872	7092	5602	4464	3501	2795	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	5912	5337	6750	6807	7030	7776	8194	7438	5851	5995	5578	5194	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	775	1235	1427	1920	2271	2290	2018	1935	1901	1239	914	744	Wh/sq.m
Direct Normal Illumination (Avg Hourly)	35172	39187	49576	52479	55436	59036	60676	58002	50074	43903	37318	31217	lux
Direct Normal Illumination (Avg Monthly)	55848	46809	54463	50127	47373	51691	55908	53512	44503	51683	51326	49979	lux
Dry Bulb Temperature (Avg Monthly)	10	11	16	19	25	31	35	33	26	22	14	11	degrees C
Dew Point Temperature (Avg Monthly)	3	2	3	4	8	9	11	11	12	10	6	4	degrees C
Relative Humidity (Avg Monthly)	63	54	44	38	35	28	25	27	43	49	59	66	percent
Wind Direction (Monthly Mode)	260	250	240	250	290	60	30	10	230	270	250	270	degrees
Wind Speed (Avg Monthly)	3	3	4	4	4	3	2	2	2	2	2	3	m/s
Ground Temperature (Avg Monthly of 1 Depths)	18	16	15	16	18	21	25	27	28	27	25	21	degrees C

Fig. 4. Weather data Bou-Saada city (Climate Consultant tool)

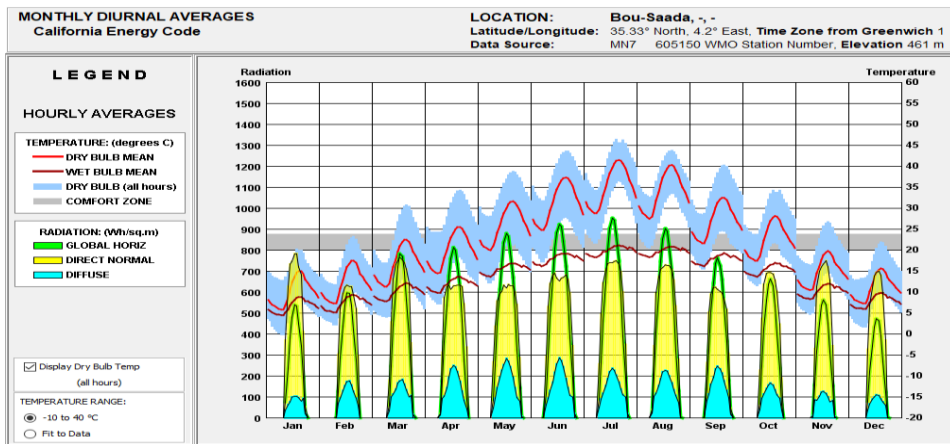


Fig. 5. Bou-Saada city Hourly Average temperature (Climate Consultant tool)

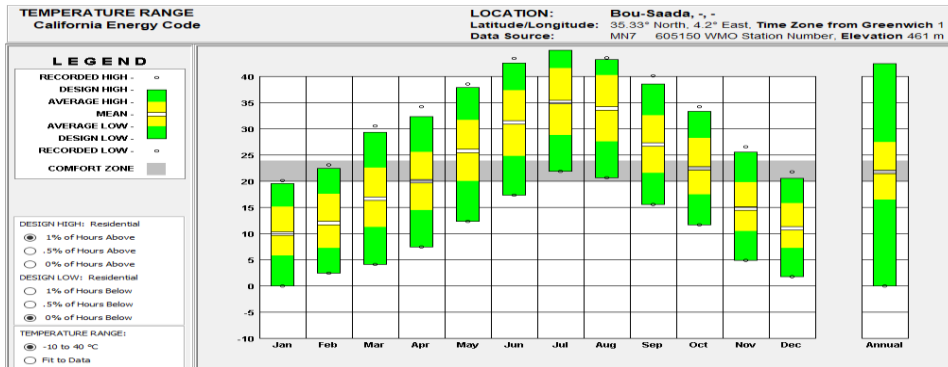


Fig. 6. Temperature Range Bou-Saada city (Climate Consultant tool)

### Wind analysis

Examining the wind speed and direction of Bou-Saada city reveals significant monthly variations caused by temperature differential driven air movement. Measured in degrees clockwise from the north, the wind direction exhibits consistent seasonal patterns.

The wind wheel diagram's presentation of the climatic data analysis shows average speeds between 1 and 5 m/s and maximum wind speeds of 12 m/s. The wind rising shows the predominating wind frequency, strength, and direction with the primary wind speeds displayed in dark orange for high velocity and light orange for low speeds. Red indicates temperature ranges between 26 and 26–39°C; strong red tones suggest temperatures over 39°C. Medium green indicates the general city environment with relative humidity levels of 30–70%.

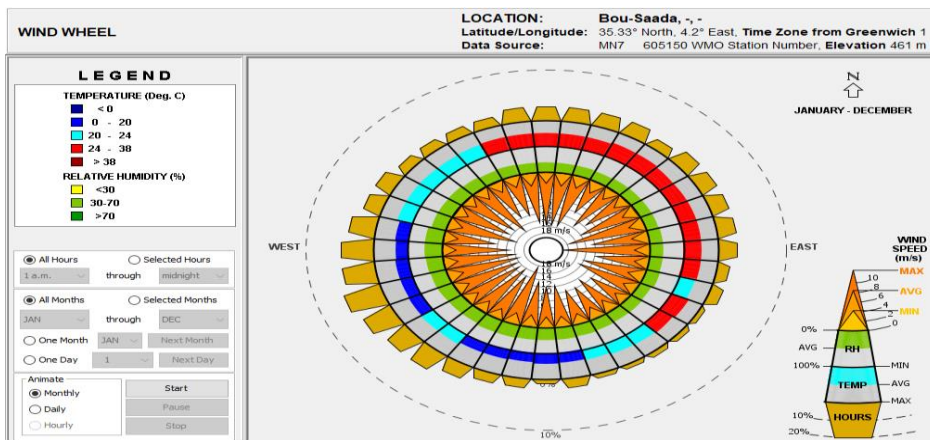


Fig. 7. Wind speed Bou-Saada city (Climate Consultant tool)

### Mahony Tables Analysis for Bou-Saada city

Mahoney Tables evaluate hot, cold, wet, and dry conditions by compiling climatic data including temperature, humidity, and precipitation. These criteria direct architectural choices, including functional design adaptations, spatial organization, and solar exposure control (Attia, 2012).

Thermal comfort is assessed worldwide using bioclimatic analysis and thermal indicators, which provide useful input in the early design stage. These indications should not, however, be taken straightforwardly into energy-efficient designs without further thought (Dae-meï et al., 2019). This study provides a design guide to let builders grasp bioclimatic approaches. Additional tools are required in hot, dry, and desert areas to attain thermal comfort and lower energy usage, thereby complementing green building techniques (Evans, 2007).

Key meteorological data like monthly minimum and maximum temperatures, temperature ranges, relative humidity, and precipitation are examined using the Mahoney tables to pinpoint appropriate design options for Bou-Saada City. Derived from the meteorological data analysis in Section 4.1, these values provide inputs for the Mahoney tables. Using Mahoney's humidity classification, Table 1 ranks Bou-Saada's mean relative humidity in Groups 2 and 3.

Starting with a thorough review of Bou-Saada City's climatic data shown in Table 2, the climate study for it proceeds. Equation (1) computes the annual mean temperature (AMT); Table 3 offers relative humidity levels for monthly maximums and minimums. According to the statistics, January has the greatest average humidity at 75%; July and August have the lowest at 11%. Equation (2) lets one get the annual mean range of humidity (AMR). Moreover, Bou-Saada city reflects its hot, semi-arid environment by having an annual average rainfall of only 19 mm. The creation of architectural designs sensitive to climate depends on this kind of study.

$$AMT = (Highest + Lowest) / 2 = 22.7^{\circ}C \dots\dots\dots (Eq. 1)$$

$$AMR = Highest - Lowest = 64\% \dots\dots\dots (Eq. 2) \quad (1)$$

Table 1. The Classification of Mean Relative Humidity Regarding the Humidity Group

Mean Relative Humidity	Humidity Group (HG)
Below 30%	1
30-50%	2
51-70%	3
Above 70%	4

Table 2. Climatic Data Analysis Bou-Saada city

Month	J	F	M	A	M	J	J	A	S	O	N	D	AMT
Monthly mean max( <sup>o</sup> C)	22.1	24.2	28	32	37.5	38.5	39.2	39.3	36.5	34	28.5	24	22.7
Day comfort upper( <sup>o</sup> C)	29	29	31	31	31	34	34	34	31	31	29	29	
Day comfort lower( <sup>o</sup> C)	23	23	25	25	25	26	26	26	25	25	23	23	
Monthly mean min ( <sup>o</sup> C)	6.1	7.2	11	15.5	21	22	22.2	22.3	21.5	18.5	12	8	
Night comfort upper( <sup>o</sup> C)	23	23	24	24	24	25	25	25	24	24	23	23	
Night comfort lower( <sup>o</sup> C)	17	17	17	17	17	17	17	17	17	17	17	17	
Thermal stress day	C	N	N	H	H	H	H	H	H	H	N	C	
Thermals tress night	C	C	C	C	N	N	N	N	N	N	C	C	
HG	3	3	2	2	2	1	1	1	2	2	3	3	

\*Where: C - below comfort limit; N - within comfort limit; H - above comfort limit; HG - Humidity Group.

Table 3. Monthly Relative Humidity Means Max, Min., Range in Bou-Saada City

Month	J	F	M	A	M	J	J	A	S	O	N		D	AMR
Monthly mean max.(%)	75*	67	46	40	37	38	39	43	47	51	61		72	64
Monthly mean min.(%)	51	41	42	36	33	18	11#	11#	39	47	57		60	
Monthly mean range(%)	63	54	44	38	35	28	25	27	43	49	59		66	
HG	3	3	2	2	2	1	1	1	2	2	3		3	

\*Highest monthly mean; #Lowest monthly mean; RH: Relative Humidity

### ***The thermal comfort limits in Mahoney tables***

Thermal comfort limitations are assessed using the Mahoney tables by means of citizen climate adaptation throughout many climatic zones. Three temperature ranges of the Annual Mean Temperature (AMT) define comfort zones in these tables: > 20°C, 15–20°C, and <15°C. As Table 4.

#### *The analysis of comfort limits in every month*

In order to minimize the temperature disparity between day and night comfort levels, they also consider differences in attire, behavior, and daily activities. Referencing the yearly averages in Table 4, the site's monthly mean maximum and minimum temperatures are matched with comfort limits for both daytime and nighttime in monthly analysis. Analyzed are also humidity classifications and comfort levels, which relate to humidity and temperature stress indicators described in Table 5.

Using information including humidity groups (HG), thermal stress levels, and monthly mean temperature ranges from Table 2, Table 6 aggregates overall comfort indicators generated from Table 5. Labeled H1 through A3, these indicators specify as follows:

- **H1 (Substantial Air Circulation):** Needed when low diurnal temperature variance (<10°C) is combined with significant daytime thermal stress (H) either with moderate humidity (HG = 2 or 3) or with high humidity (HG = 4).
- **H2 or desirable air movement:** advised when day = N temperatures above comfort levels with high humidity (HG = 4) but without significant thermal stress.
- **H3 (Rain Protection):** Indicating possible water-related problems even with little precipitation, this is needed when monthly rainfall approaches or surpasses 200 mm.
- **A1 (Thermal Storage):** Required when variable humidity levels (HG = 1, 2, or 3) coincide with significant diurnal temperature change (≥10°C).
- **A2 Outdoor Living Suitability:** Ideal when overnight thermal stress is high (H) with low to moderate humidity (HG = 1 or 2), or when daytime heat continues despite cooler evenings owing to thermal mass effects.
- **A3 (Cold Season Challenges):** Usually in winter, this refers to the necessity of cold weather adaptations during times of daylight thermal stress (C).

Discussed in the next parts, the cumulative monthly indicators guide appropriate architectural design solutions.

Table 4. The Confort limites

Comfort Range Average RH	HG	AMT over 20°C		AMT 15-20°C		AMT nder 15°C	
		Day	Night	Day	Night	Day	Night
Below 30%	1	26-34	17-25	23-32	14-23	21-30	12-21
30-50%	2	25-31	17-24	22-30	14-22	20-27	12-20
51-70%	3	23-29	17-23	21-28	14-21	19-26	12-19
Above 70%	4	22-27	17-21	20-25	14-20	18-24	12-18

Table 5. Marking of Humid and Arid Indicators

	Indicator	Thermal stress Day Night	Month ly Rain- fall	HG	Monthly ean Tem. Range
<b>H1</b>	Air movement essential	H		4	
		H		2,3	-10°C
<b>H2</b>	Air movement desirable	N		4	
<b>H3</b>	Rain Protection		+200mm/mont h		
<b>A1</b>	Thermal storage			1,2,3	+10°C
<b>A2</b>	Outdoor sleeping	H		1,2	
		H	N	1,2	+10°C
<b>A3</b>	Cold season problem	C			

\*Where: H - Hot; N - Comfortable; C - Cold

Table 6. The Indicators for Each Month

Month/ Indicator		J	F	M	A	M	J	J	A	S	O	N	D	Total
<b>Humid</b>	H1	Air movement essential												0
	H2	Air movement desirable												0
	H3	Rain Protection												0
<b>Arid</b>	A1	Thermal storage	*	*	*	*	*	*	*	*	*	*	*	12
	A2	Outdoor sleeping					*	*	*	*	*			6
	A3	Cold season problem	*										*	2

Table 7. Urban and Architectural Design Recommendations for Bou-Saada City

Indicators							BUILDING STRATEGY GROUPS
H1	H2	H3	A1	A2	A3	ID	Building Strategy
0	0	0	12	6	2		
							<b>a: LAYOUT OF BUILDING</b>
			0-10			a1	Orientation N&S (long axis east - west)
			11,12		5-12	a1	
			11,12		0-4	● a2	Compact court yard planning
							<b>b: SPACING BETWEEN BUILDINGS</b>
11,12						b1	Open spacing for breeze penetration
2-10						b2	Open spacing for breeze penetration, protect from H&C wind
0,1						● b3	Compact lay-out of Estates
							<b>c: AIR MOVEMENT</b>
3-12						c1	Single banked rooms, permanent provision for air movement
1,2			0-5			c1	
1,2			6-12			c2	Double banked rooms with temporary provision for air movement
0	2-12					c2	
0	0,1					● c3	No air movement required
							<b>d: SIZE OF OPENING</b>
			0,1		0	d1	Large openings, 40-80% of wall area
			0,1		1-12	d2	
			2-5			d2	Medium openings, 25-40% of wall area
			11,12		4-12	d3	
			6-10			d4	Small openings, 15-25% of wall area
			11,12		0-3	● d5	Very small openings, 10-20% of wall area
							<b>e: POSITION OF OPENING</b>
3-12						e1	Openings in N&S walls at body height on windward side
1-2			0-5			e1	
1-2			6-12			e2	Openings in N&S walls at body height on windward side as well as in internal walls
0	2-12					e2	
						● e3	Has no climate related value
							<b>f: PROTECTION OF OPENING</b>
		0,1			3-12	f1	No special protection necessary
					0-2	● f2	Exclude direct sun light
		2-12			0-2	f3	Protection from rain & direct sunlight
		2-12				f4	Provide protection from rain
							<b>g: WALL AND FLOOR</b>
			0-2			g1	Light walls, short time-lag
			3-12			● g2	Heavy external & internal walls, over 8 hour time-lag
							<b>h: ROOF</b>
10-12			0-2			h1	Roof light, reflective surface, cavity
10-12			3-12			h2	Light well insulated roofs
0-9			0-5			h2	
0-9			6-12			● h3	Heavy roofs, over 8 hour time-lag
							<b>i: OUTDOOR SLEEPING</b>
				1-12		● i1	Space for out-door sleeping required
				0		i2	No space for out-door sleeping
							<b>j: RAIN PROTECTION</b>
		2-12				j1	Protection form heavy rain needed
		0-1				● j2	No protection form heavy rain needed

● In the table is an indication of the appropriate strategies for a building design for bou-saada city

Mahoney's Table 7 shows architectural and urban recommendations based on Table 6 concepts. The components of Table 6 form the basis for the suggestions Mahoney creates for Bou-Saada city. Table 7 shows a clear link between the environmental observations of Bou-Saada city and the design implementation solutions backed by (●) to identify particular design techniques.

These specific suggestions are based on the general indicators. For instance, if  $A_3 = 2$ , as shown in Table 6, the relevant star shows in the layout recommendations section of Table 7. This star points to a single-banded design with open space for air penetration or a small courtyard. This design guarantees shade protection during high temperatures and lowers the surface area to volume ratio, so supporting great ventilation.

Table 7 underlines the importance of lowering heat accumulation by lightweight designs by suggesting compact courtyard layouts with single-banded rooms surrounding the garden. The ideal window-to-wall ratio (WWR) is ten to twenty percent, which balances ample sunlight and lowers heat absorption.

Regarding windows, they are suggested to face the north and the south, depending on solar radiation, to maximize cooling and shade. Effective ventilation is quite vital throughout the warmer months of June, July, August, and September because of the high temperatures and humidity. In the cooler months of January, February, November, and December, we recommend dense exterior walls and ceilings to enhance passive solar heating.

The results highlight how important it is to design buildings that respond to climate, especially by using basic, logical methods to reduce environmental impact with regular, everyday structures. These techniques not only meet Bou-Saada city specific climatic needs but also might be used for modern building designs using sustainable, energy-efficient technology.

### Psychrometric analysis

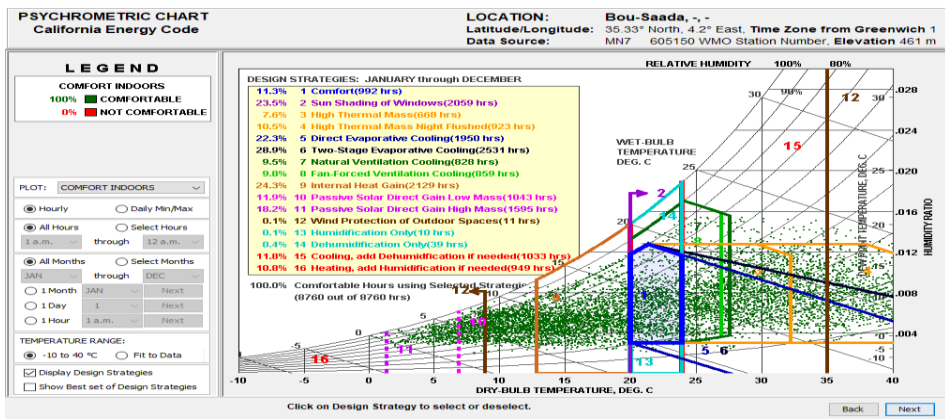


Fig. 8. Psychrometric analysis Bou-Saada city (Climate Consultant tool)

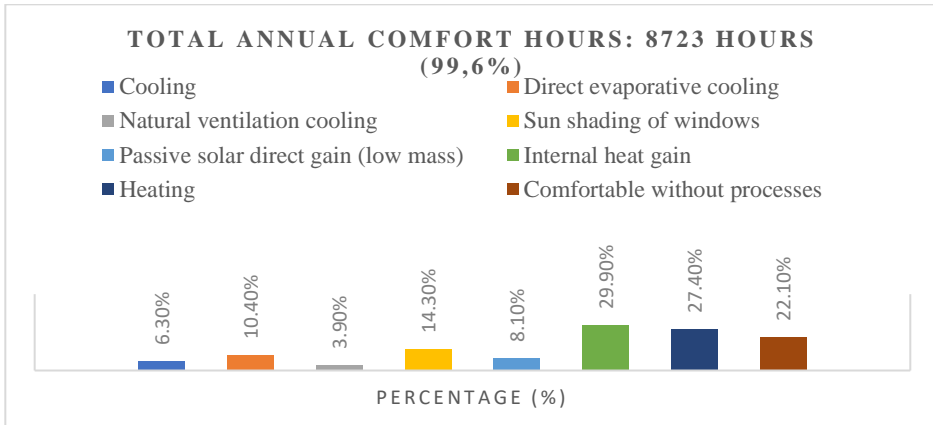


Fig. 9. Annul comfort Bou-aada city

The plotted data and the findings of the psychrometric study underline the required actions to preserve suitable interior conditions in Bou-Saada city's dry and hot environment by reducing energy consumption. The following explains the consequences of the findings:

<p>✓ <b>Predominance of Evaporative Cooling:</b> Based on Bou-Saada city's dry environment, two-stage evaporative cooling (28.9%) and direct evaporative cooling (22.3%) show excellent effectiveness in lowering interior temperatures dependent on one another. These instruments lower the temperature by adding humidity to the atmosphere, which is fitting for this environment.</p>	<p style="text-align: center;">50</p> <p style="text-align: center;">An Evaporative Cooler can provide enough cooling capacity (if water is available and humidity is low) thus reducing or even eliminating air conditioning)</p>
<p>✓ <b>Importance of Sun Shading:</b> The importance of shading the sun cannot be overstated, especially during the summer months when window solar screening (23.5%) is crucial to prevent overheating. It reduces the heat entering buildings, therefore cutting cooling energy consumption and increasing comfort.</p>	<p style="text-align: center;">Window overhangs      Seasonal position of the sun</p>

<p>✓ <b>Thermal Mass for Temperature Stabilization:</b> Maximizing notable daily temperature fluctuations depends much on high thermal mass (7.6%) and thermal mass with nocturnal cooling (10.5%). These devices gather thermal energy during the day and release it at night, therefore minimizing interior temperature variations.</p>	
<p>✓ <b>Use of Passive Solar Heating in Winter:</b> The need for passive solar direct gain (24.3%) underlines the need for optimizing solar heat acquisition all during the winter. This approach reduces heating expenses by heating houses using solar energy</p>	
<p>✓ <b>Minimal Need for Dehumidification:</b> Seldom utilized methods like dehumidification (0.4%) and humidification (0.1%) point to a mostly dry environment. Still, comfort depends much on heating with humidification (10.8%) during cold, dry months.</p>	
<p>✓ <b>Supplementary Ventilation and Heat Gains:</b> Heat gains and greater airflow. Particularly for appliances or occupants, internal heat gains (24.3%) considerably contribute to providing passive heating in the winter. Fan-assisted ventilation cooling (9.8%) and natural ventilation (7.5%) provide airflow to effectively cool surfaces under mild circumstances.</p>	

## Discussion

Bou-Saada City experiences a hot semi-arid climate, characterized by significant seasonal temperature variations. The climate of Bou-Saada City produces major thermal stress situations because summer temperatures exceed 39°C and winter temperatures drop below 6°C. The temperature data from Figure 5, along with Table 2, indicates that January records the lowest temperatures, but December holds the record for most minimum values until temperatures surge throughout July and August. Table 3's analysis places Bou-Saada city in both groups 1 and 2, based on humidity levels, which confirms the arid environmental conditions.

The Mahoney Tables (Tables 6 and 7) serve as fundamental tools for designing buildings that adhere to local building regulations. Results indicate that systems for storing heat year-round (A1) are mandatory, as well as outdoor daytime use possibilities (A2) and thermal protection measures needed for January and December (A3). Building orientations should run from north to south, courtyard designs should remain narrow, and construction elements should be as substantial as possible, taking into account the climatic conditions. These align with the findings of (Femmam & Sriti, 2022) and (Hosseini, 2022) about dry climates. A study by (Alagaw & Yonas, 2021) establishes that building openings should occupy 10-20% of total wall space and show uniform ventilation patterns throughout single-story rooms. The building structure requires aperture placement at human height to establish air current direction control and protection against solar heat.

Adapting two-stage evaporative cooling with direct evaporative cooling allows Bou-Saada city to achieve annual thermal comfort at levels reaching 28.9% and 22.3%. The study's results demonstrate that courtyard design with thick walls constitutes an effective mechanism for managing temperatures inside buildings. The combination of window sunshading and passive solar heat utilizes 23.5% and 24.3% of the capabilities to maintain indoor comfort levels throughout summer and winter months. Research proving traditional architectural methods shows support from (Lamsal et al., 2021); (Givoni, 1992).

The study emphasized the development of residential building design methods in Bou-Saada city that maximize energy savings and improve occupant comfort. The research Climate Consultant.6 with psychrometric chart and Mahoney tables to develop superior passive strategies for the semi-arid environment of Bou-Saada city. And the need for design selected single-sided residential buildings, oriented north-south, to take advantage of the natural ventilation and solar shading provided by courtyard spaces. These applied methods enable better management of the mechanical system, supporting overall sustainability goals.

The research confirmed data points that matched observations made in locations with similar semi-arid environmental characteristics, (Rabah, 2005) discovered through his Nicosia research in Cyprus that thermal mass systems created by passive solar panels successfully controlled room temperatures during the hot summer evenings, (Alagaw & Yonas, 2021) conducted their study in Dire Dawa, Ethiopia, to demonstrate that the combination of thermal mass and natural ventilation yielded beneficial results. Research investigations confirm that passive systems retain lasting effectiveness for maintaining comfort in hot and semi-arid environmental conditions. According to this academic study, the authors (Lamsal et al., 2021) emphasize that building energy-efficient designs should begin with local climatic measurements.

Several situations show how passive approaches remain adaptable based on research conducted by (Matsumoto et al., 2017) in Jakarta, Indonesia. The different climate conditions between Bou-Saada city and Jakarta exist although both areas benefit from recognized shading and circulation approaches. To reduce greenhouse gas emissions and enhance energy efficiency in construction, specific applications of thermal mass, natural ventilation systems, sun shading elements, and passive heating principles are required. An assessment of temperature and humidity readings obtained from Climate Consultant.6 along with Mahoney Tables enables complete comprehension of sustainable resource management strategies suitable for Bou-Saada city.

The research proves that establishing residential building designs based on local climate knowledge from bioclimatic science leads to energy-efficient buildings with comfortable indoor environments. To deliver sustainable outcomes with seasonal comfort for buildings, architects should implement passive mass thermal storage, compact courtyard arrangements, and precise site orientation in their designs. The advanced architectural concepts present vital requirements that experts need to follow while working in semi-arid and hot temperature zone areas of physical spaces.

## **Conclusion**

Building homes with climate in mind has many advantages, including better indoor comfort and more energy economy. This kind of design stresses natural raw materials and reduces non-renewable energy use at the same time, therefore improving thermal comfort and occupant satisfaction. Based on a thorough study of climatic data and local architectural features, especially those that show how people historically adjust to their environment through cultural practices, bioclimatic planning guidelines have been developed in Bou-Saada city, Algeria.

Using Mahoney tables, which are equally important for evaluating architectural designs in hot and humid or warm and dry surroundings, the semi-arid climate of Bou-Saada city is well evaluated. The information obtained from the Mahoney tables helps to identify important design options to solve the rather low temperatures in winter within the area and the high summer temperatures. Given the notable daily temperature swings in Bou-Saada city, buildings should make use of passive cooling techniques to control indoor comfort without mechanical intervention and natural strategies, including thermal inertia, which is the capacity of materials to absorb heat during the day and release it at night.

Apart from Mahoney's tables, understanding of the psychrometric chart could offer crucial information about Bou-Saada city comfort level. Identifying passive design techniques, including evaporative cooling, nocturnal ventilation, and sun shading, all of which significantly lower summer heat loads, is made easier by the chart.

Furthermore, influenced by the surrounding circumstances, there is a software program called Climate Consultant.6 that provides climate analysis data and passive technique recommendations for Bou-Saada city. Examining the results of particular strategies, such as high thermal mass, cross-ventilation, and courtyard integration, which are common in Algerian traditional architecture, is dependent on this method.

The guidance obtained from this study might help architects decide on the design of ecologically friendly buildings. Design strategies that can greatly lower energy consumption

include, for instance, building small buildings with shaded outdoor areas, orienting buildings to maximize wind while minimizing direct sunlight exposure, and using low embodied energy materials obtained locally with excellent thermal capacity.

Apart from passive solar solutions, which improve heating and cooling, wind catchers and solar chimneys are other ways. The combination of Mahoney's chart, the psychrometric chart, and Climate Consultant.6 concepts for climate design provide necessary guidelines for building low-energy homes in Bou-Saada city. Combining passive design ideas with traditional architectural elements helps builders to lower running energy use while maintaining occupant thermal comfort. Moreover, these approaches forward the sustainability agenda by lowering environmentally harmful building methods in the housing sector and conserving the cultural aspects unique to Bou-saada city architecture. This approach will give professionals direction and help architects to better grasp their field of work so they may help to create a better living environment for all.

Conflicts of Interest: The authors declare no conflict of interest.

Publisher's Note: Serbian Geographical Society stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

© 2025 Serbian Geographical Society, Belgrade, Serbia.

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution-NonCommercial-NoDerivs 3.0 Serbia.

## References

- Abed, S. S., & Matzarakis, A. (2017). Seasonal Regional Differentiation of Human Thermal Comfort Conditions in Algeria. *Advances in Meteorology*, 2017(1), 1–14. <https://doi.org/10.1155/2017/9193871>
- Alagaw, A., & Yonas, N. (2021). Climate Responsive Housing design for hot and semi-arid Climate of Dire Dawa Town by using Givoni Bioclimatic Chart, Mahoney Table and Autodesk Ecotec analysis. *International Journal of All Research Education and Scientific Methods*, 9(4), 2455–6211.
- Attia, S. (2012). *A tool for design decision making: zero energy residential buildings in hot humid climates*. Univ. de Louvain.
- Daemei, A. B., Eghbali, S. R., & Khotbehsara, E. M. (2019). Bioclimatic design strategies: A guideline to enhance human thermal comfort in Cfa climate zones. *Journal of Building Engineering*, 25, Article 100758. <https://doi.org/https://doi.org/10.1016/j.jobe.2019.100758>
- Daraf, L., Khalafalla, B., & Hafid, L. (2016). Urban and architectural sustainability indicators use energy hot climate areas in Algeria. *Annals of the University of Oradea, Geography Series*, 26(1), 71–85. [http://dx.doi.org/10.1007/978-3-031-12015-2\\_20](http://dx.doi.org/10.1007/978-3-031-12015-2_20)
- Department of Economic and Social Affairs, United Nations (1971). *Climate and House Design*. Université de l'Illinois à Urbana-Champaign.
- Emmanuel, R., Kumar, B., Roderick, Y., & McEwan, D. (2013). A universal climate-based energy and thermal expectation index: Initial development and tests. *Energy and Buildings*, 58, 208–218. <https://doi.org/https://doi.org/10.1016/j.enbuild.2012.12.008>

- Evans, J. M. (2007). *The comfort triangles: a new tool for bioclimatic design* [Unpublished Dissertation, Technical University of Delft, Netherland].
- Femmam, A., & Sriti, L. (2022). Towards Sustainable Residential Buildings in Hot Arid Climates: Learning from Traditional Architecture of the Souf Region (Algeria). *Technium Social Sciences Journal*, 37, 683–700. <https://doi.org/10.47577/tssj.v37i1.7724>
- Flores-Larsen, S., Filippín, C., & Barea, G. (2019). Impact of climate change on energy use and bioclimatic design of residential buildings in the 21st century in Argentina. *Energy and Buildings*, 184, 216–229. <http://dx.doi.org/10.1016/j.enbuild.2018.12.015>
- Givoni, B. (1992). Comfort, climate analysis and building design guidelines. *Energy and Buildings*, 18(1), 11–23.
- Givoni, B., & Izard, J.-L. (1978). *L'homme, l'architecture et le climat*. Editions du moniteur Paris.
- Hassina, A., Toufik, M., & Slama, I. (2024). Bioclimatic design approach in colonial office buildings architecture in Algeria. *South Florida Journal of Development*, 5, Article e4073. <https://doi.org/10.46932/sfjdv5n6-015>
- Hosseini, A. (2022). Evaluation of bioclimatic design strategies in Esfahak village using Mahoney method. *Journal of Cultural Heritage Management and Sustainable Development*, 15(6). <https://doi.org/10.1108/JCHMSD-12-2021-0210>
- Ketfi, O., Merzouk, M., Merzouk, N. K., & Bourouis, M. (2017). Feasibility study and performance evaluation of low capacity water–LiBr absorption cooling systems functioning in different Algerian climate zones. *International Journal of Refrigeration*, 82, 36–50. <https://doi.org/https://doi.org/10.1016/j.ijrefrig.2017.07.002>
- Kumar, A., & Sharma, A. (2018). Climate consultant: A software for designing energy efficient building. *International Journal for Research in Applied Science & Engineering Technology*, 6(9), 605–611.
- Laidi, M., Hanini, S., Rezrazi, A., Yaiche, M., Hadj, A., & Chellali, F. (2017). Supervised artificial neural network-based method for conversion of solar radiation data (case study: Algeria). *Theoretical and Applied Climatology*, 128. <https://doi.org/10.1007/s00704-015-1720-7>
- Lamsal, P., Bajracharya, S., & Rijal, H. (2021). Guidelines for climate responsive building design in three regions of Nepal. *Building and Environment*, 2(1), 63–74.
- Matsumoto, H., Tsuzuki, K., & Susanti, L. (2017). Bioclimatic Analysis in Pre-Design Stage of Passive. *Buildings*, 3(1), Article 24. <http://dx.doi.org/10.3390/buildings7010024>
- Mwizerwa, F., & Gupta, M. K. (2020). Establishing climate responsive building design strategies using climate consultant. *International Journal of Recent Technology Engineering*, 8(5), 3620–3624. <http://dx.doi.org/10.35940/ijrte.E6167.018520>
- Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Majid, M. Z. A. (2015). A global review of energy consumption, CO<sub>2</sub> emissions and policy in the residential sector (with an overview of the top ten CO<sub>2</sub> emitting countries). *Renewable and Sustainable Energy Reviews*, 43, 843–862. <https://doi.org/10.1016/j.rser.2014.11.066>
- Olgyay, V. (2015). *Design with climate: bioclimatic approach to architectural regionalism*. Princeton university press. Princeton University Press.
- Rabah, K. (2005). Development of energy-efficient passive solar building design in Nicosia Cyprus. *Renewable Energy*, 30(6), 937–956.

- Suresh, K., & Ramamurthy, S. (2022). Design recommendations for buildings in Chennai using Mahoney table. *Open Access Repository*, 9(2), 72–78
- Szokolay, S. V. (1986). Climate analysis based on the psychrometric chart. *International Journal of Ambient Energy*, 7(4), 171–182.
- Tabb, P. J., & Deviren, A. S. (2017). *The greening of architecture: A critical history and survey of contemporary sustainable architecture and urban design*. Routledge.