CIVVIH SYMPOSIUM SCIENTIFIC
Climate change in historic towns and villages of the Mediterranean area
CIVVIH Mediterranean sub-committee
SEPTEMBER 2024 - SINASSOS - CAPADOCIA -TURKY

The Agdal of the High Atlas, natural, social, and cultural heritage value, facing climate changes due to extremes of heat and cold

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Editor in chief « African and Mediterranean Journal of Architecture and Urbanism »
https://revues.imist.ma/index.php?journal=AMJAU

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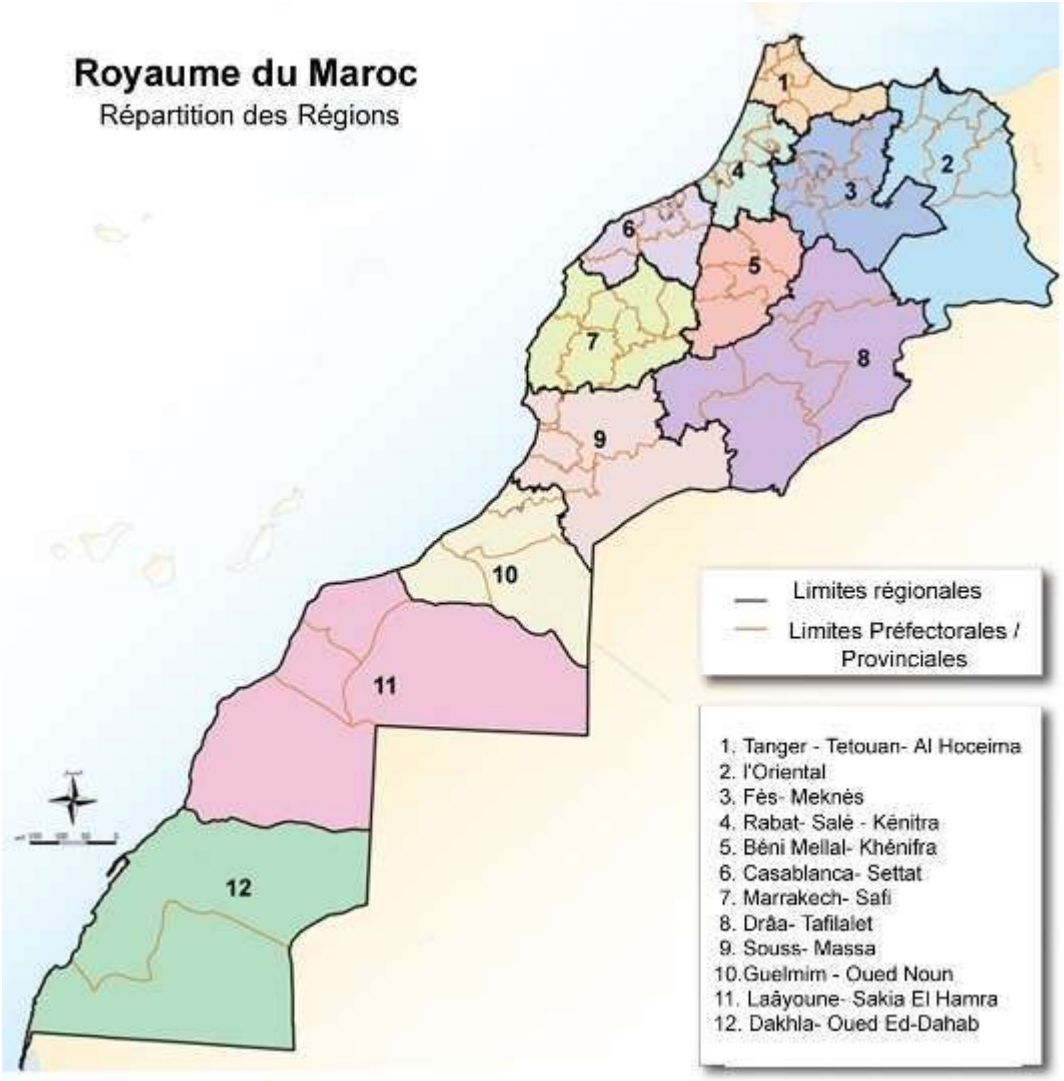
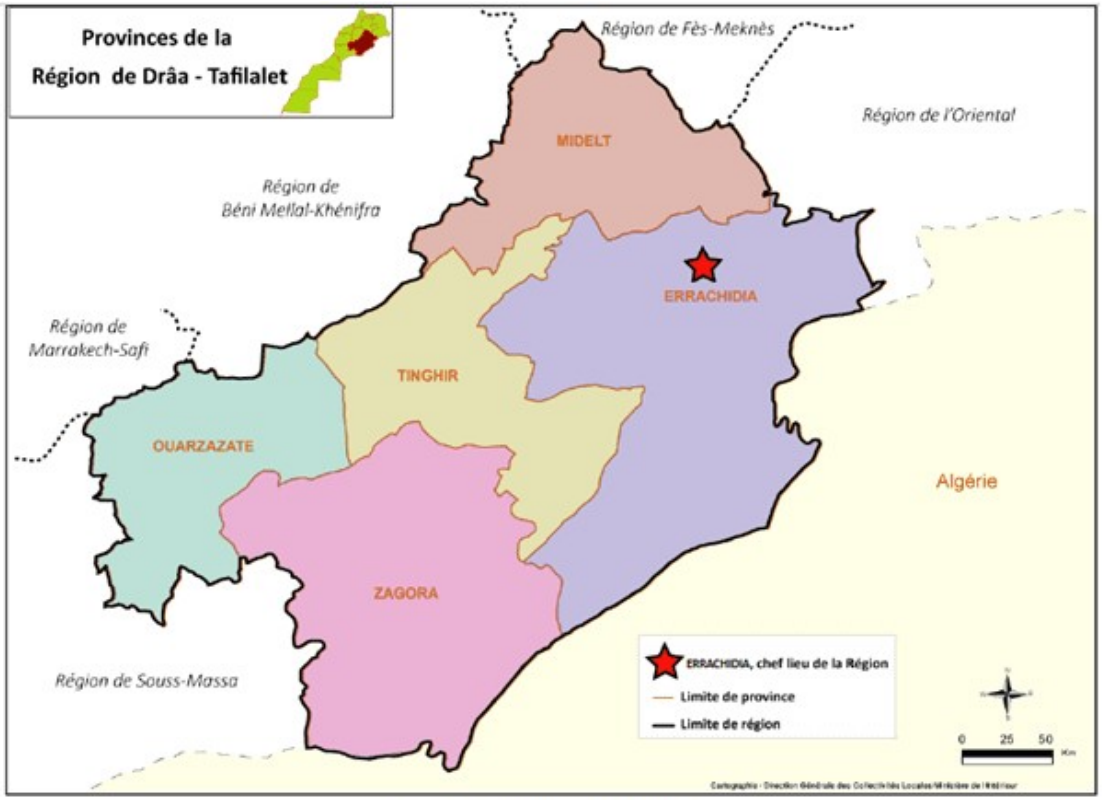
INTRODUCTION

Moroccan map, including its Regions

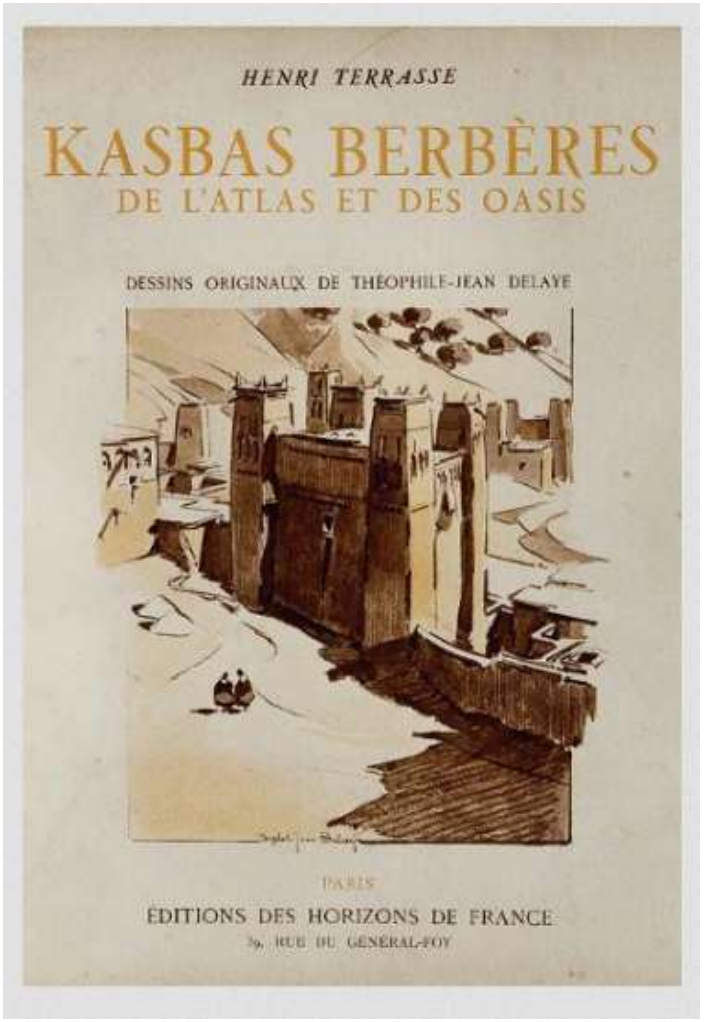


First site (earthen architecture): Draa Tafilalet Region, including its Provinces



Carte 1: Provinces de la Région

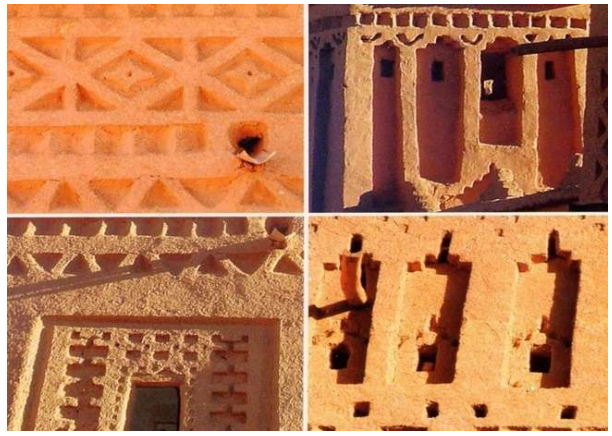
"According to the rules of an outdated military art and in the manner of the monumental gates of cities"



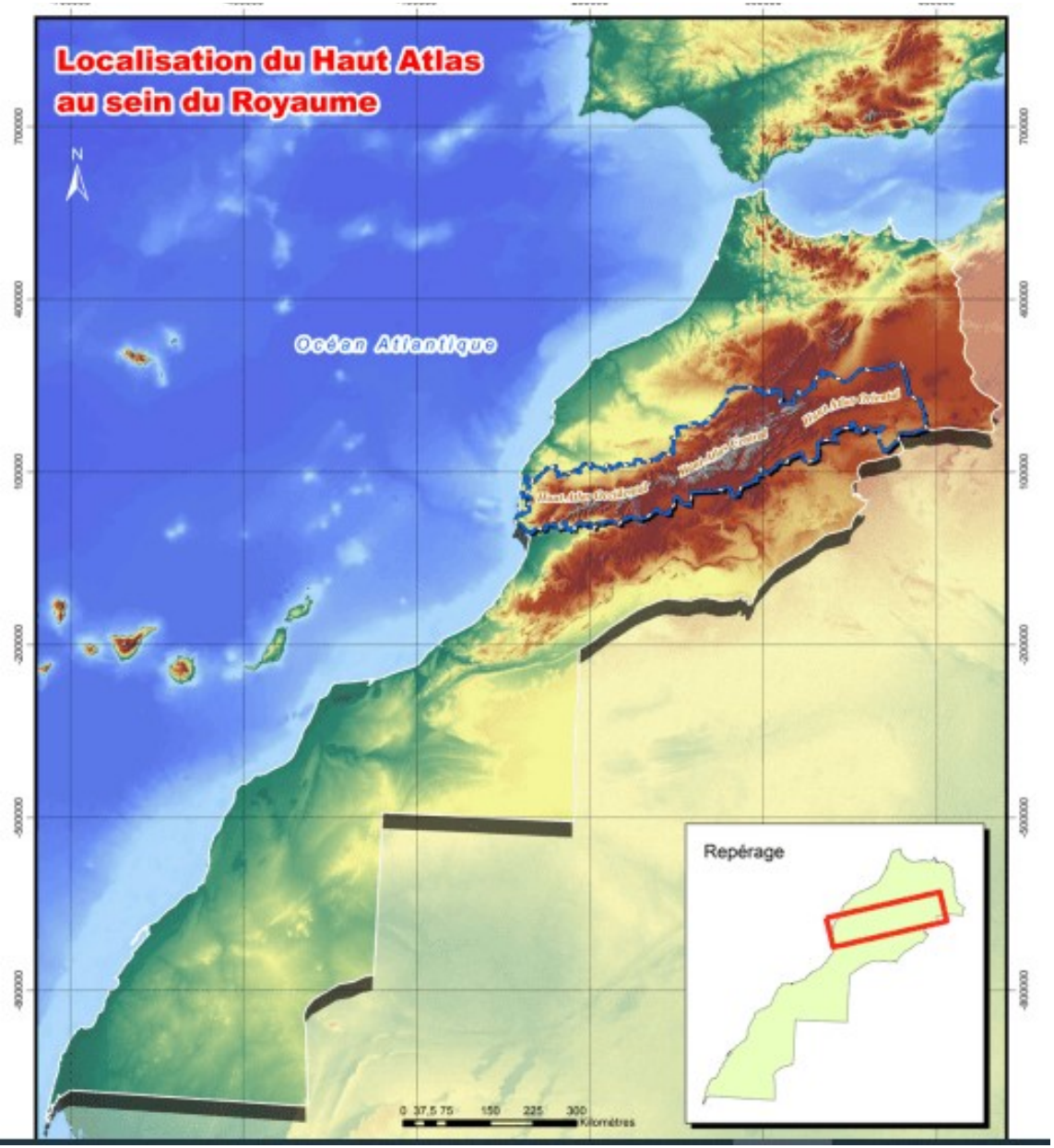
Terrace H., Berber Kasbas of the Atlas and the Oases, Ed. des Horizons de France, Paris, 1938

Mosque with terrace, Goulmima (2005)

Entrance gates of the Haratines and the ImazighnsKsar Ayt Yahya O'athmane

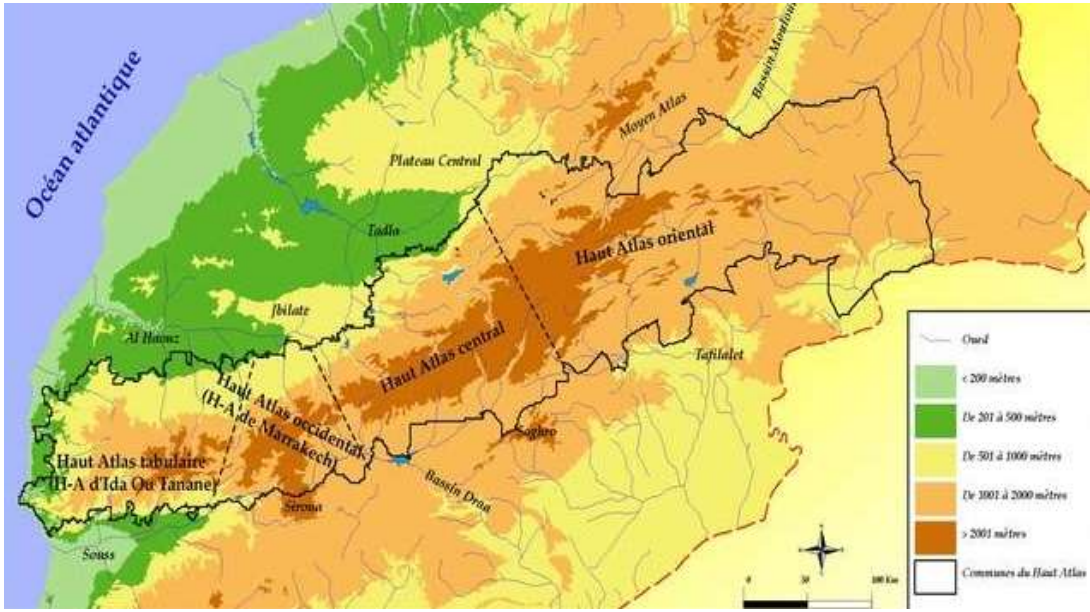


Ksar Ait Ben Haddou
in Ouarzazate
(UNESCO World Heritage)

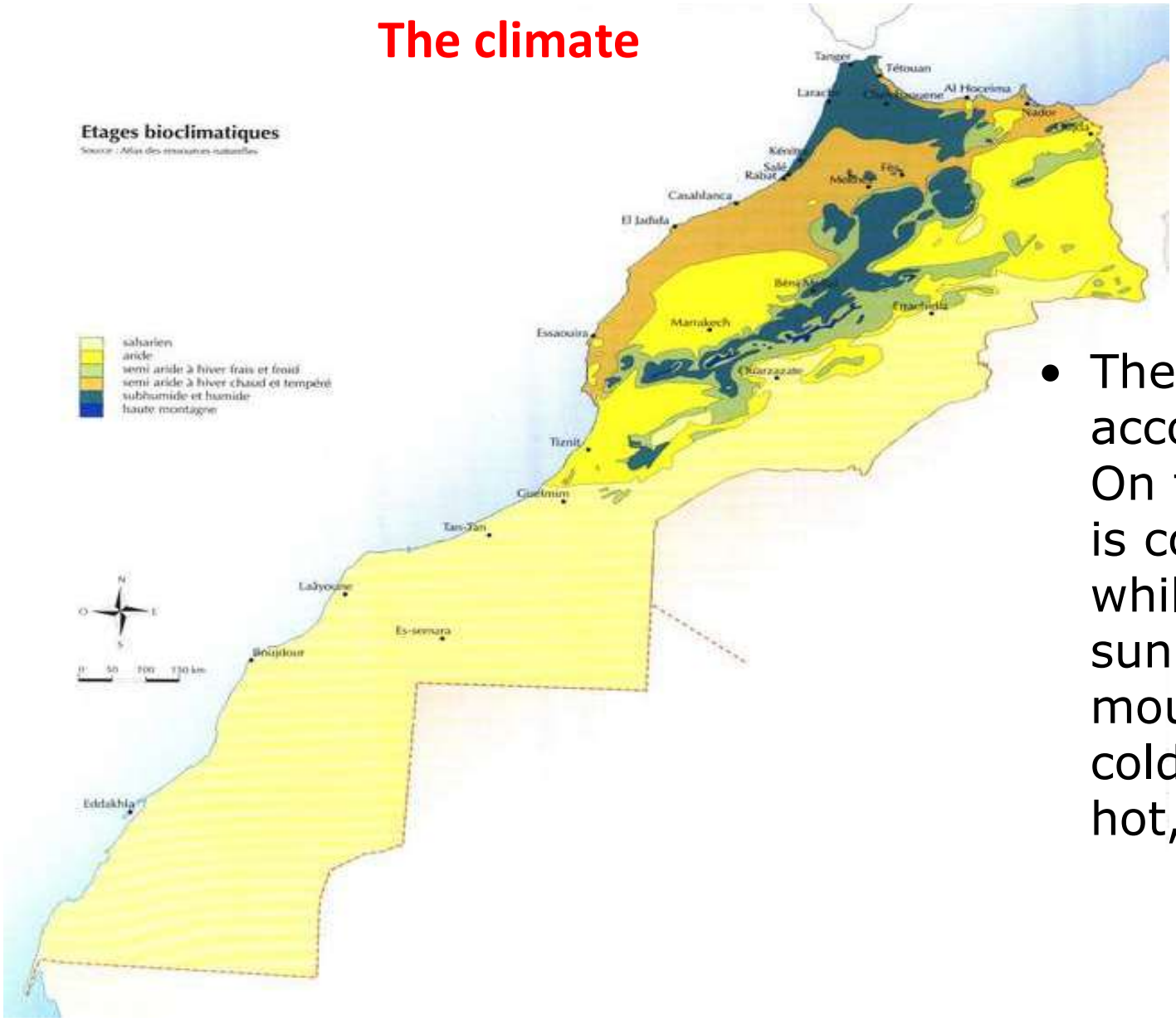


The Moroccan Occidental High Atlas, Geographical Area and the Climate, including Marrakech-Tensift-Al Haouz Region

2nd Site (Stone and Earthen Architecture)

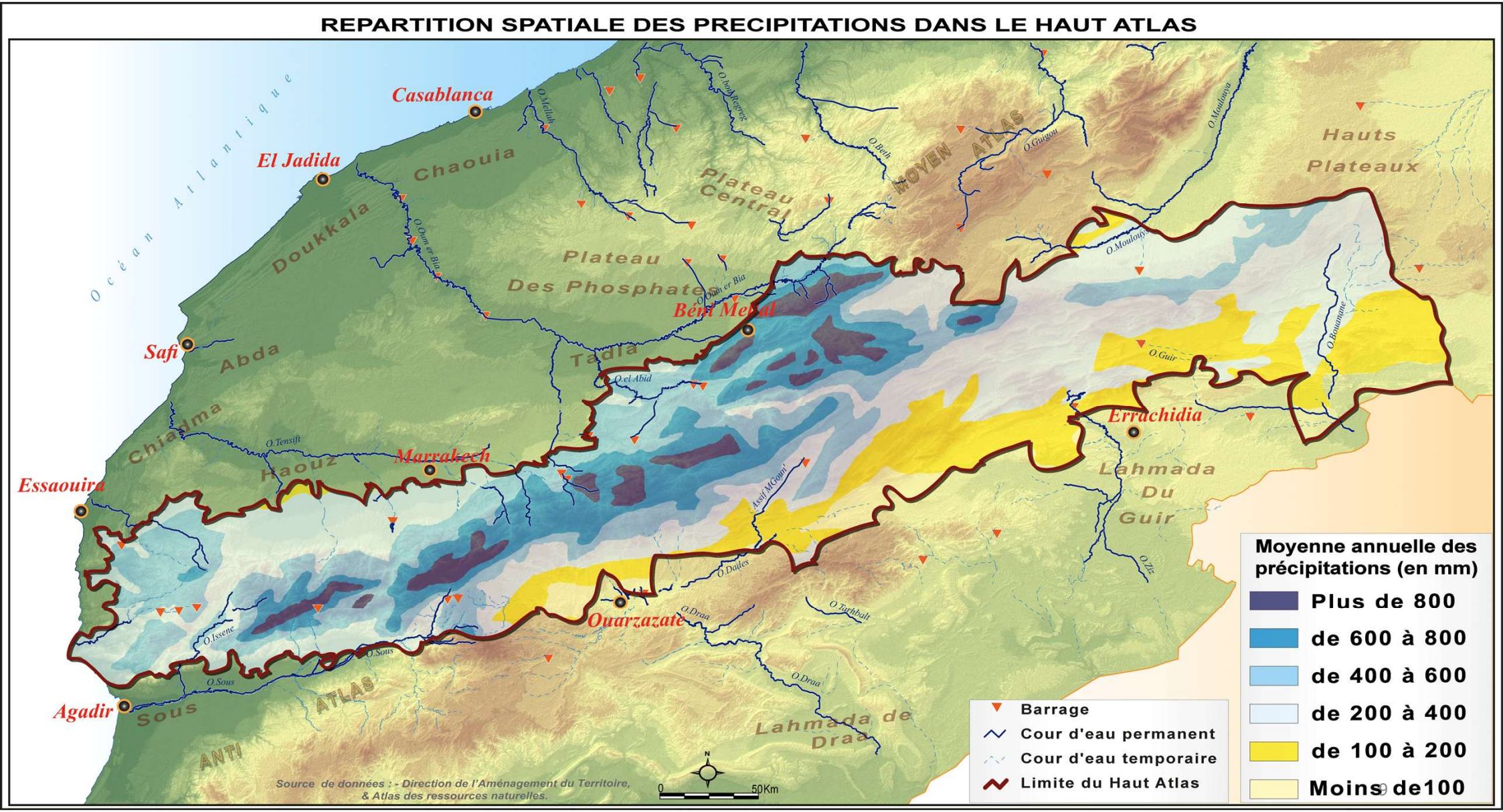


The climate

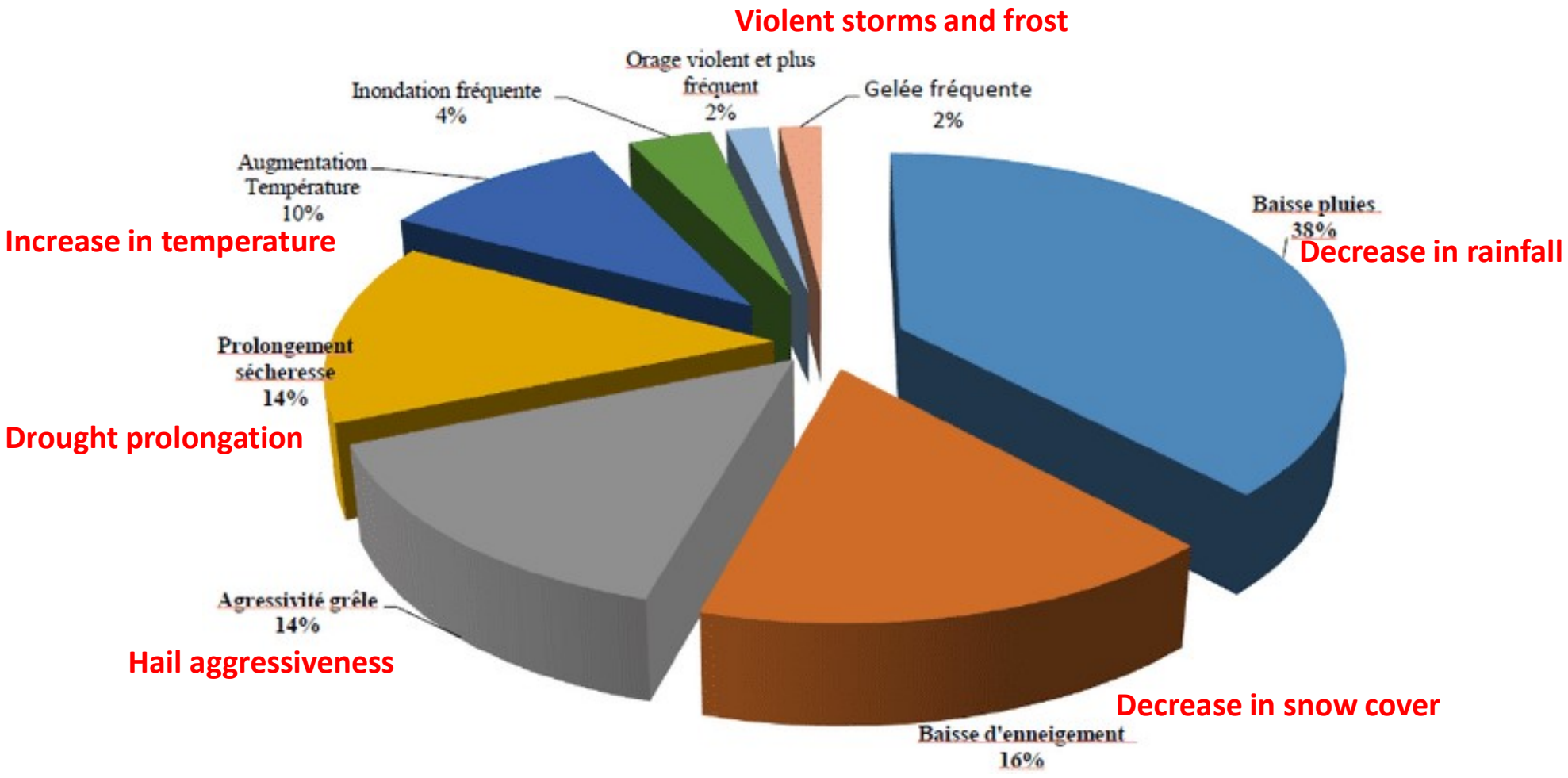


- The climate varies according to the region. On the coast, the winter is cool with some rain, while the summer is sunny and mild. The mountain ranges have cold winters and fairly hot, dry summers.

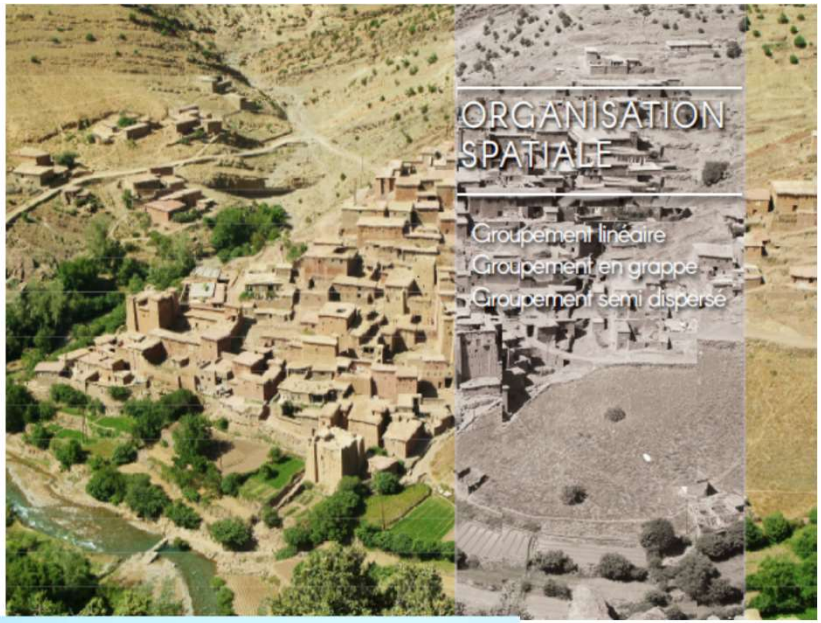
REPARTITION SPATIALE DES PRECIPITATIONS DANS LE HAUT ATLAS

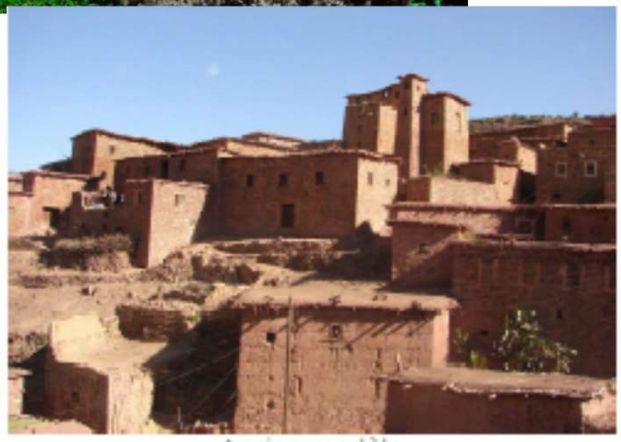


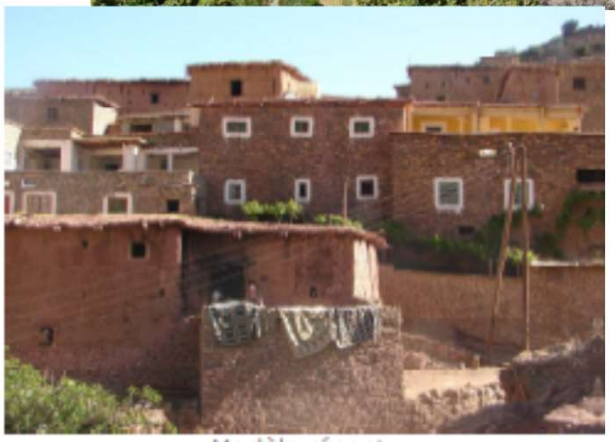
Perceived Changes in Ait Bouguemaz, High Atlas



The Moroccan High Atlas entities: the territories and the human settlements (Agdal, Ighrem, Tighremt, Granary, etc.) as socio-ecological systems




Ancien modèle

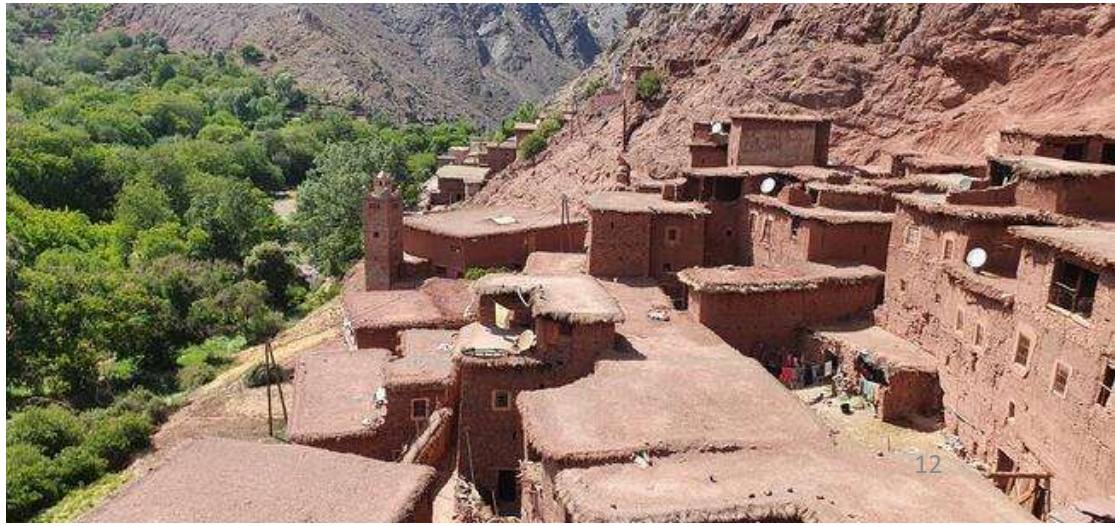

Modèle récent

Source: Charte architecturale du Haut Atlas Central, Agence Urbaine de Béni Mellal

The Agdal

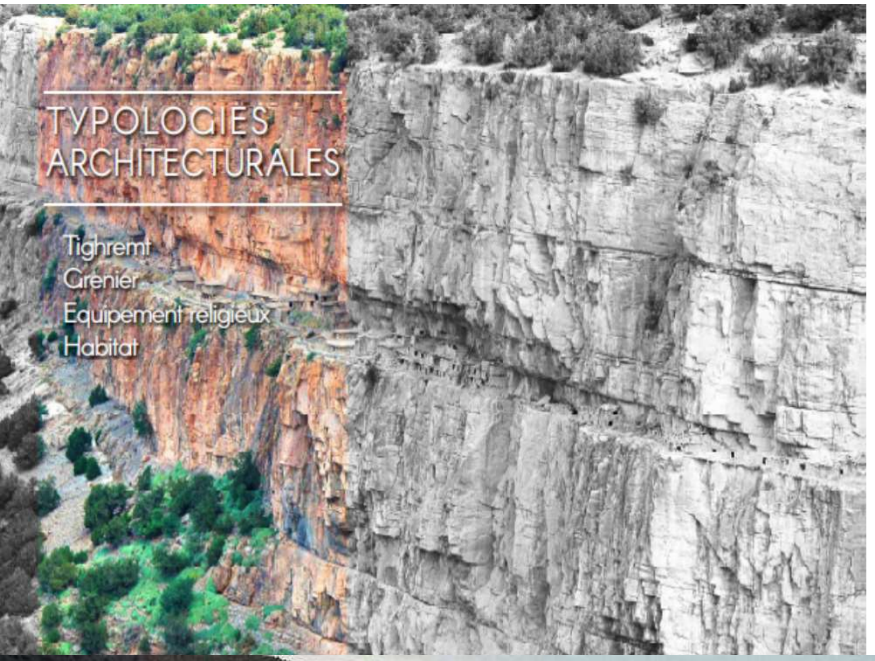
The Agdal in the Moroccan High Atlas refers to all areas in common property whose access and uses are regulated by a local group (village, tribal fraction, etc.). Agdal is a strictly delimited territory.

First, It is a spatial, geographical, and agroecological concept, characterized by a physical environment and specific biotic resources (trees, pastoral, agricultural resources, etc.)



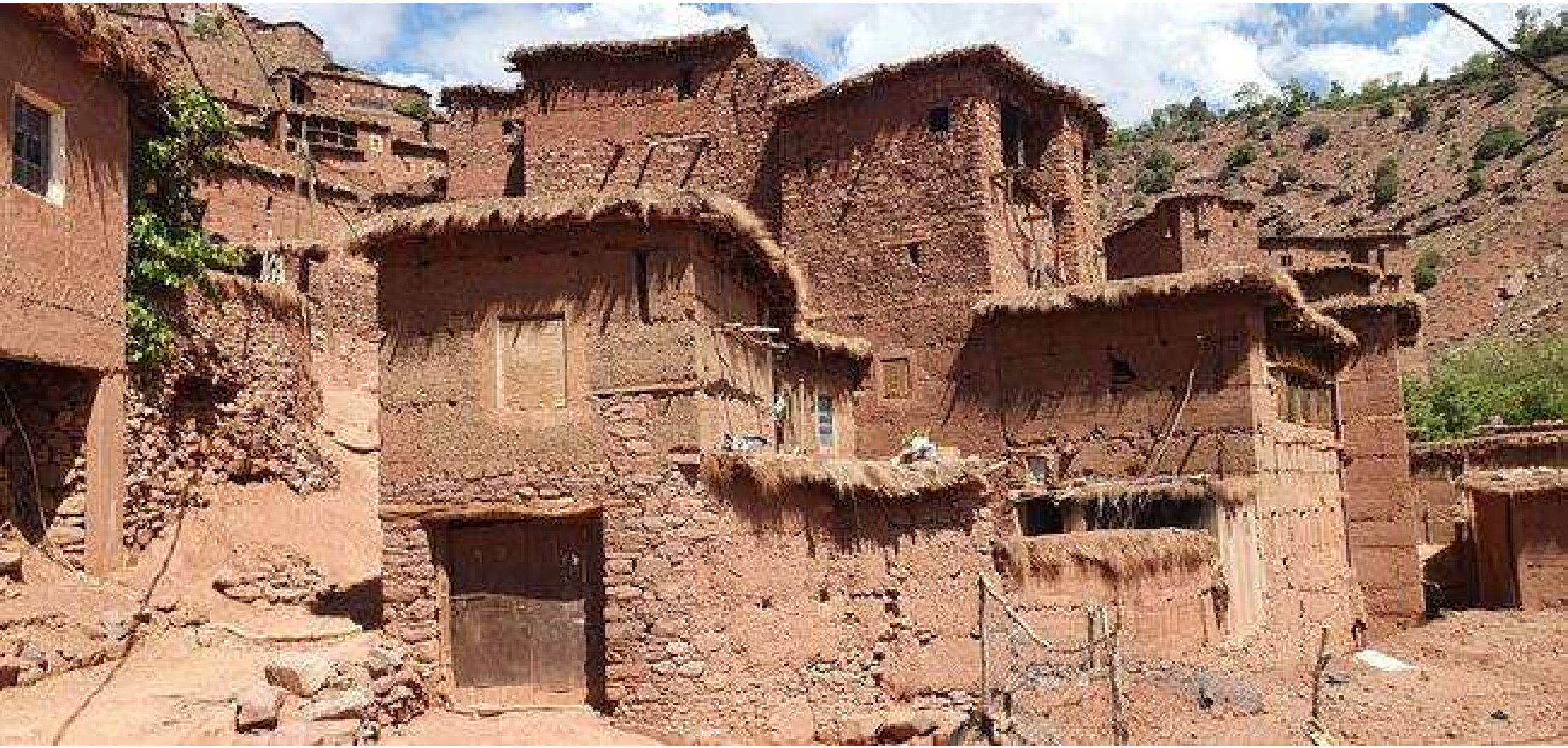
Source: Charte architecturale du Haut Atlas Central, Agence Urbaine de Béni Mellal

Architectural Typologies And Construction Materials



Architectural & Material Vernacular Construction Systems

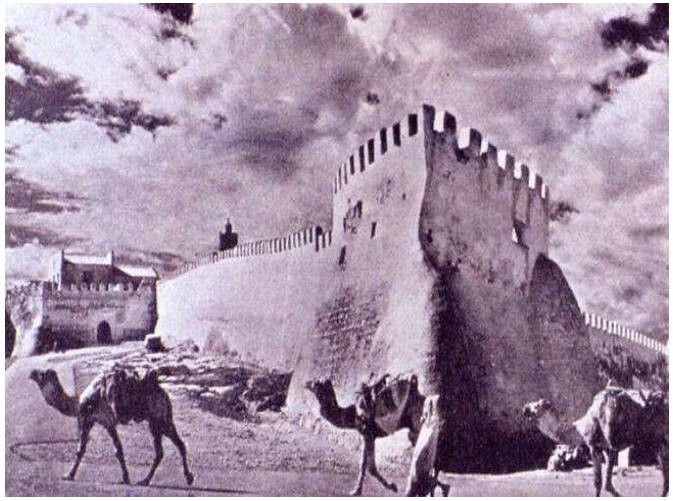
Architectural & Material Vernacular Construction in Villages



Architectural & Material Vernacular Construction Systems

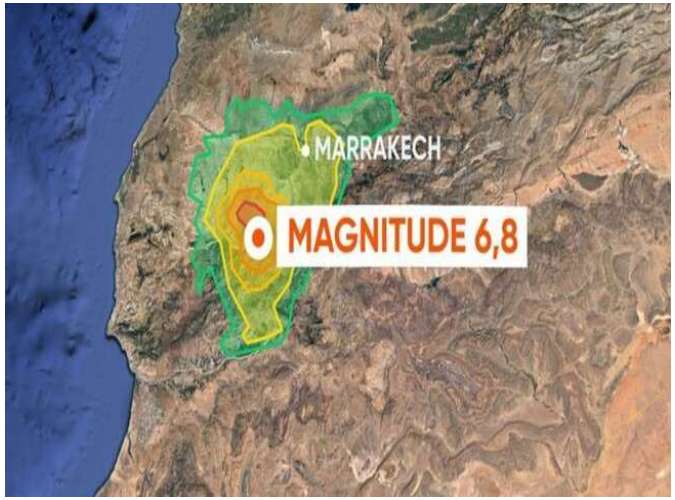
SEISMIC VULNERABILITY OF EARTH AND STONE ARCHITECTURE

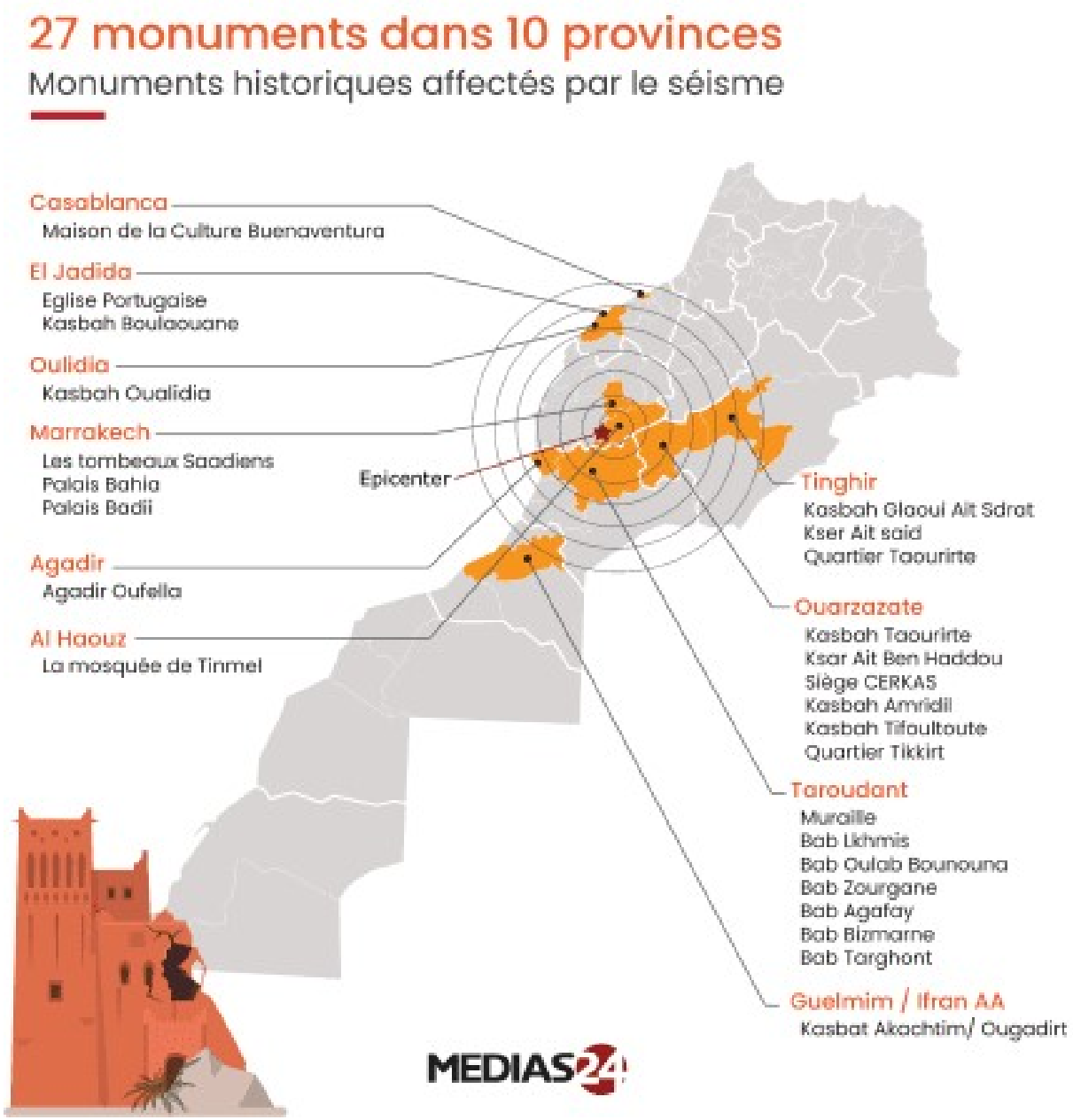
Agadir Earthquake, 1960



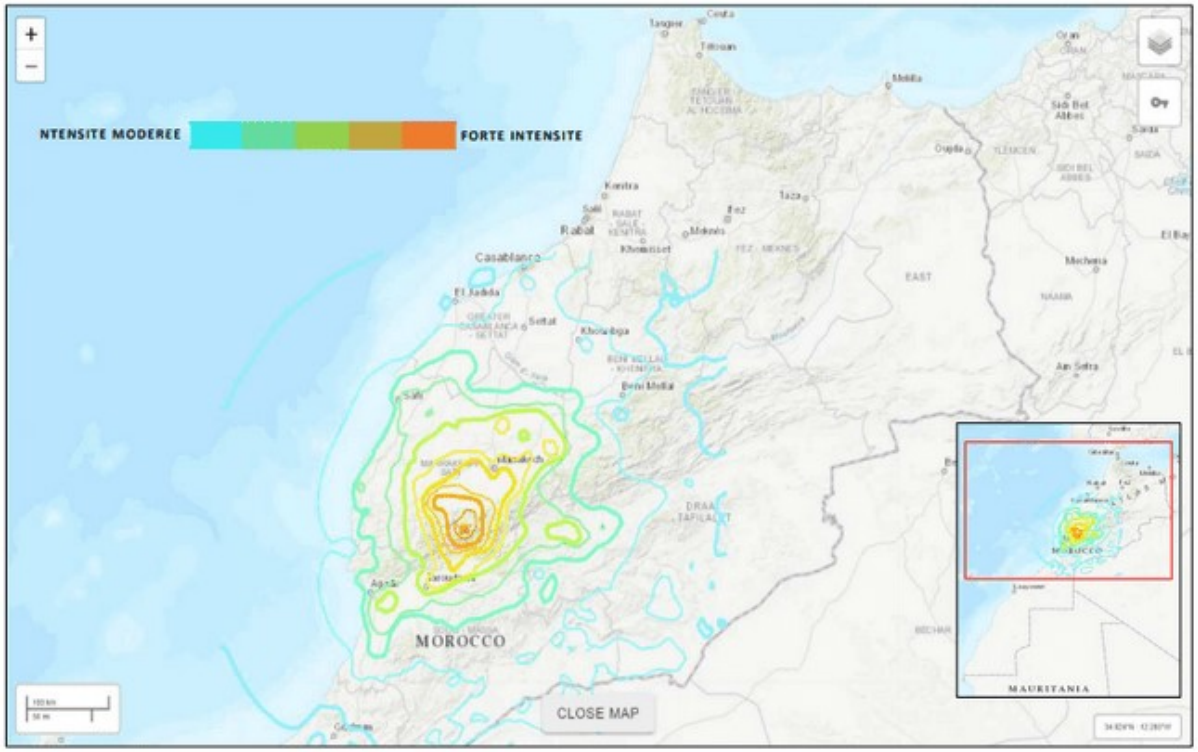
Before and After Earthquake

Al Haouz Earthquake, 2023

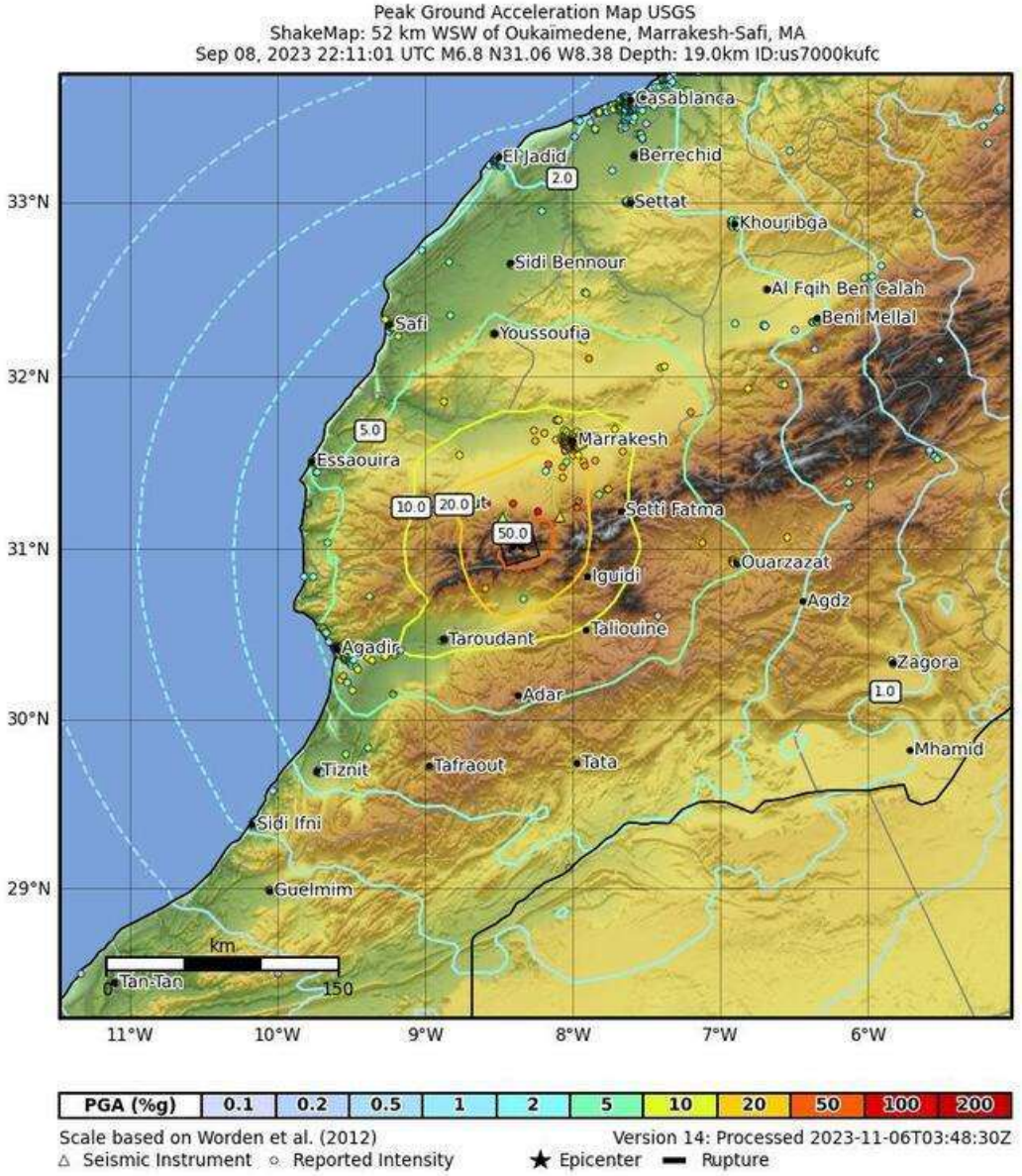




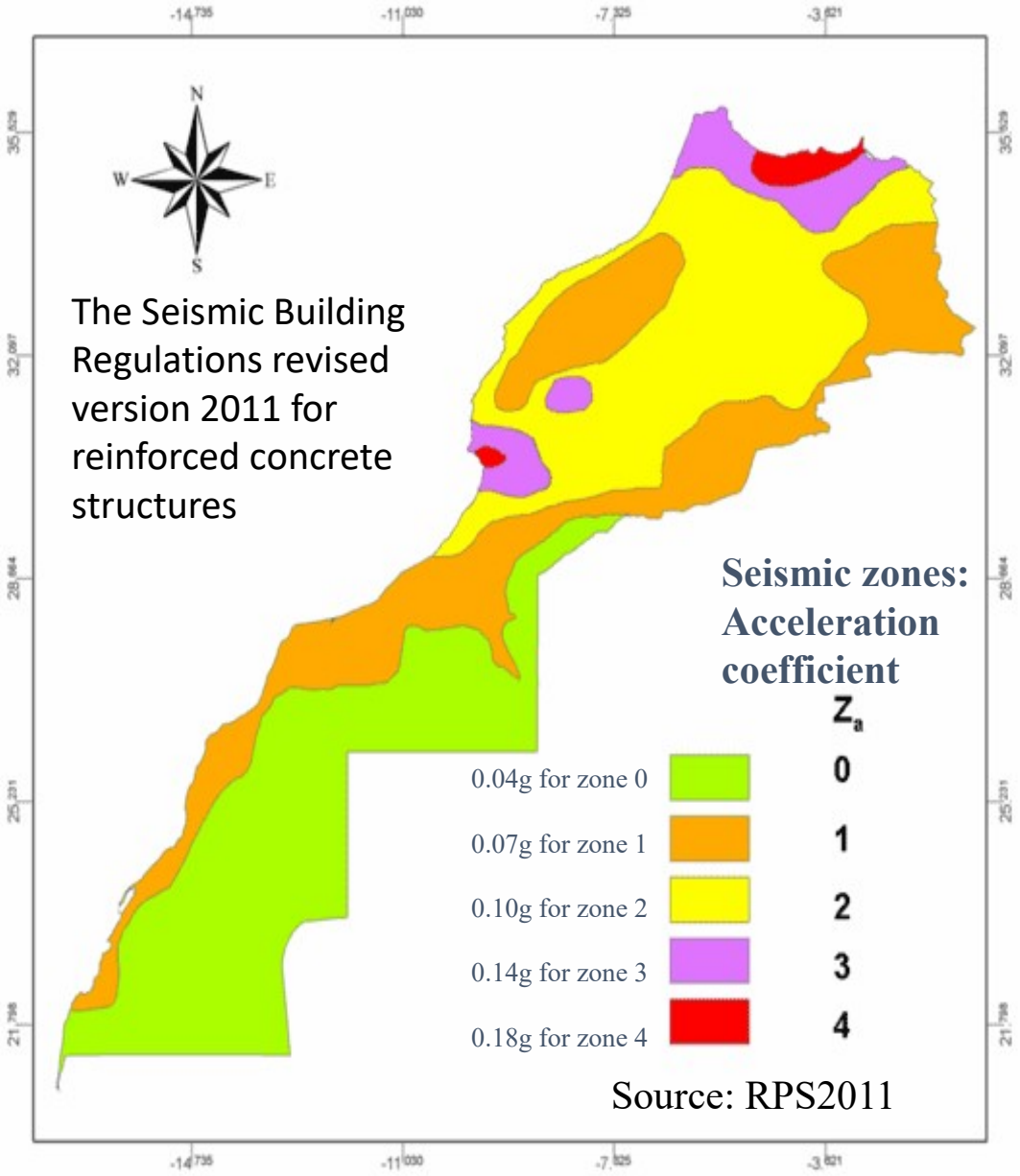
The location of 27 historical Monuments in 10 Provinces, affected by the earthquake (Source: Medias24, 2023, in French)



Intensity of the earthquake felt according to the Mercalli scale (according to USGS)

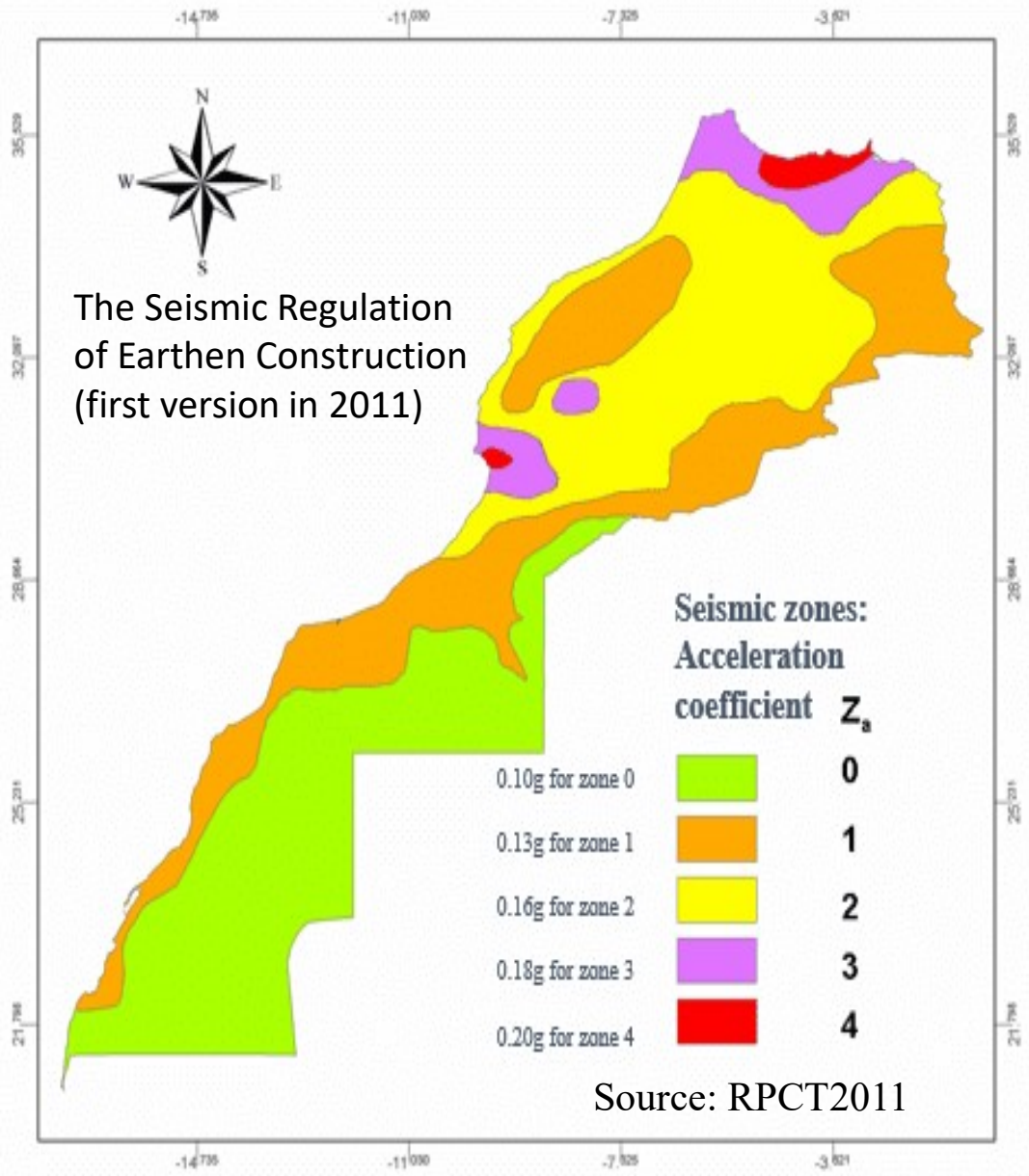


Peak Ground Acceleration-PGA Map, Al Haouz, Morocco earthquake of September 8, 2023, (Source: USGS)



The Seismic Building Regulations revised version 2011 for reinforced concrete structures

Source: RPS2011



The Seismic Regulation of Earthen Construction (first version in 2011)

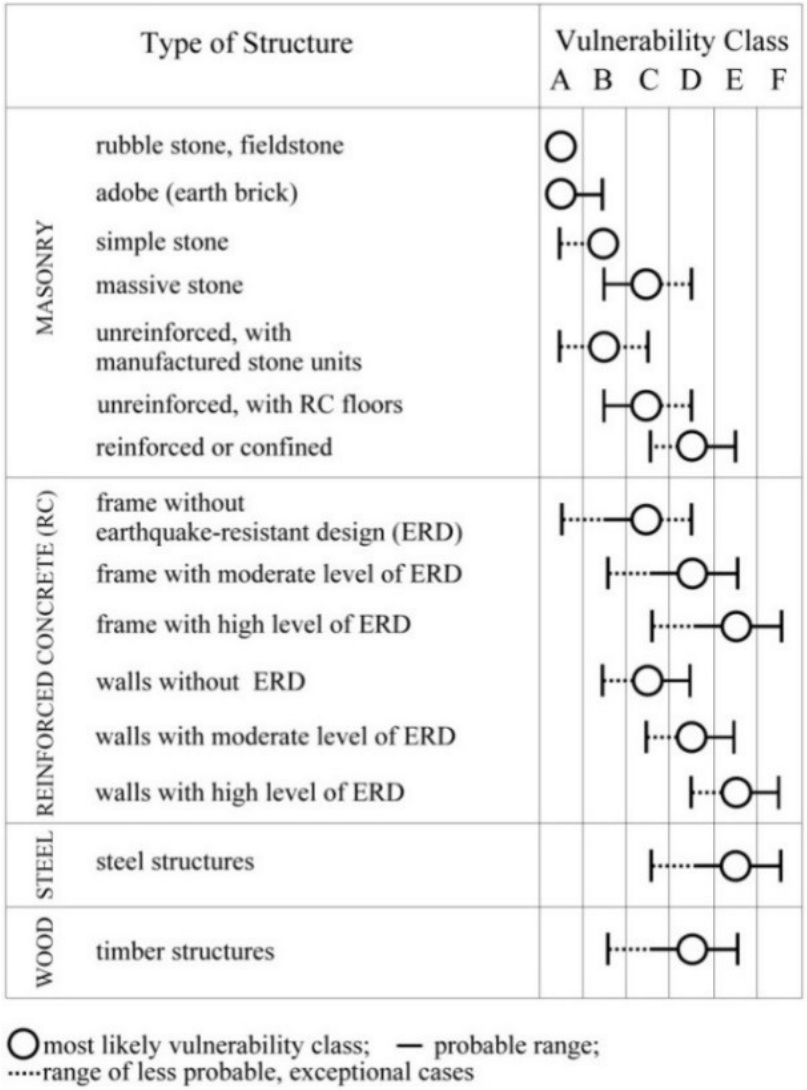
Source: RPCT2011

Decisions taken at the Meeting of the National Committee for Earthquake Engineering and the National Committee for Earth Construction on the reconsideration of the seismic zoning of the areas affected by the earthquake of September 8, 2023

-Validation, unanimously, of the proposed reconsideration of the seismic zoning of the disaster areas in anticipation of the general revision of the earthquake regulations;

- An integrated response must accompany the reconsideration of the seismic zoning, particularly on communication, monitoring and training components. Simple means of communication relating to the minimum construction provisions are to be respected and training sessions for the workforce will be put in place to contribute to the proper implementation.

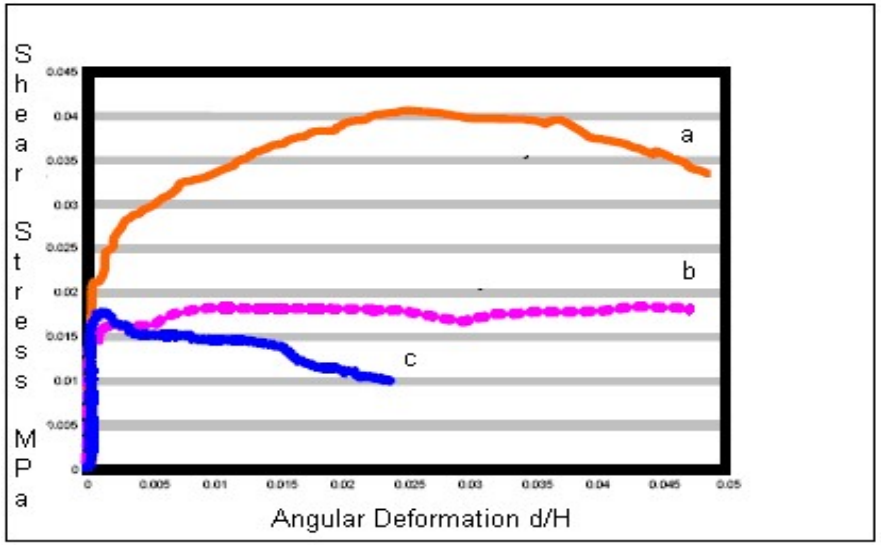
Seismic vulnerability of built heritage



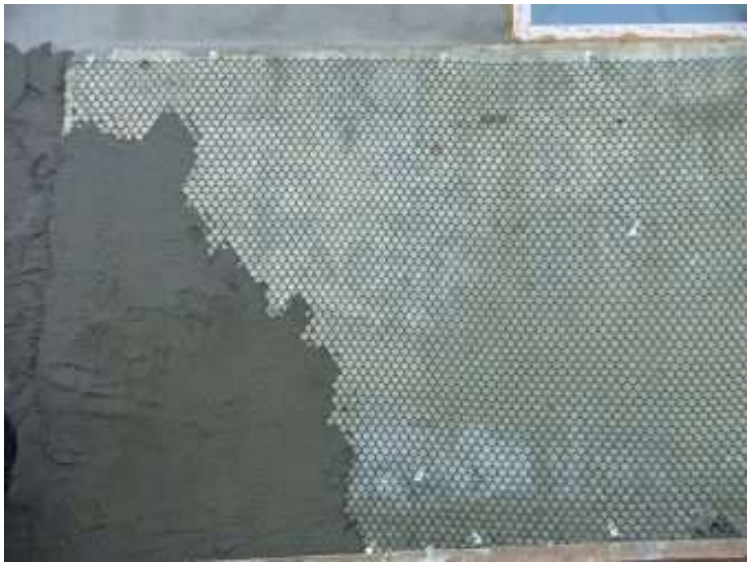
The seismic vulnerability of a building refers to the likelihood of experiencing damage. A higher vulnerability indicates a greater potential for significant damage and harm.

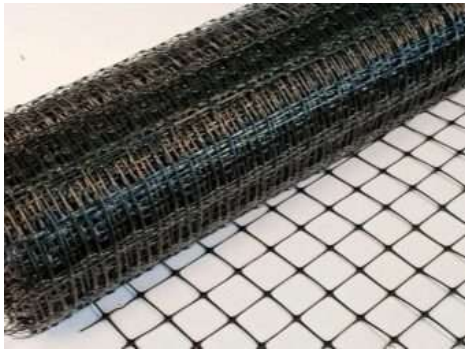
Vulnerability classes according to EMS-98 European Macroseismic Scale 1998

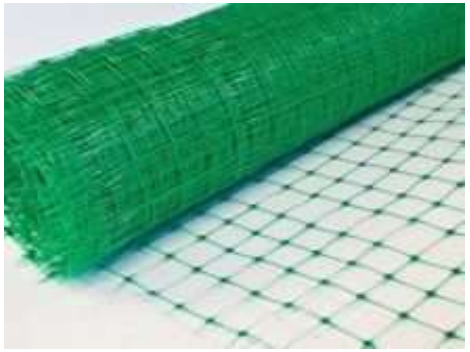
Adobe test-house reinforced with polymer mesh and partially plastered.



Comparison between compressive strength (Y-axis) and Angular distortion (X-axis) of:
c) Adobe wall without polymer mesh – Blue line,
b) Adobe wall without plastering- Pink line,
and a) Adobe wall with polymer mesh reinforcement- Orange line.
(Torrealva 2009)







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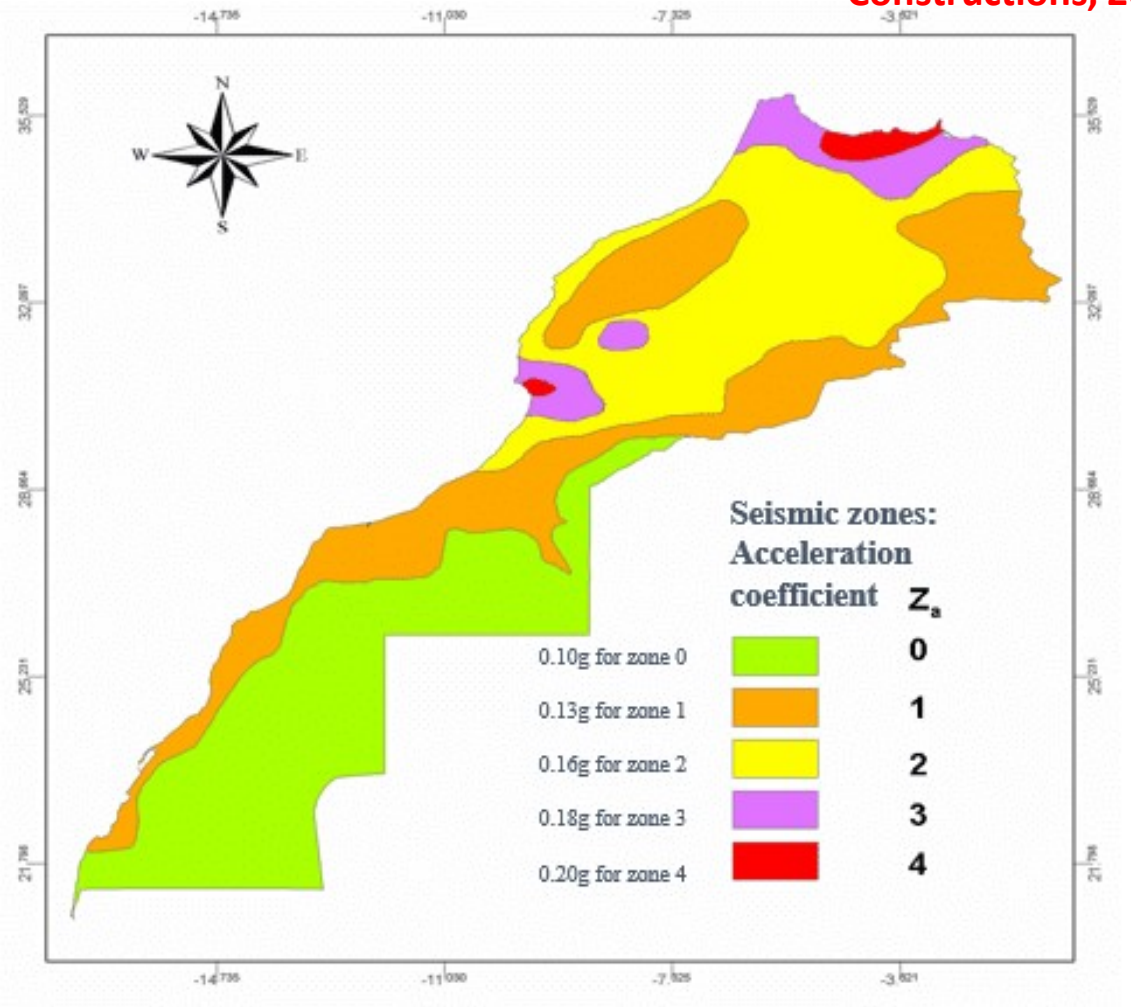
ENA de Rabat

BC architects

Décret n° 2-12-666 du 17 rejeb 1434 (28 mai 2013) approuvant le règlement parasismique pour les constructions en terre et instituant le Comité national des constructions en terre.

Decree No. 2-12-666 Approving the Paraseismic Regulation for Earth Constructions and Establishing the NC for Earth Constructions, 2013



TITRE PREMIER

DU REGLEMENT PARASISMIQUE DES CONSTRUCTIONS EN TERRE

ARTICLE PREMIER. – Est approuvé tel qu'il est annexé au présent décret le règlement parasismique pour les constructions en terre.

Self-construction and earth construction with architect

Ce règlement est divisé en deux sections :

Section première. – **Le règlement parasismique pour l'auto - construction en terre, dénommé «RPACTerre 2011»**

Section 2. – **Le règlement parasismique des constructions en Terre fixant les règles parasismiques auxquelles doivent satisfaire les constructions aux fins de garantir la sécurité , dénommé «RPCTerre 2011»**

Ces deux règlements sont applicables aux bâtiments conçus selon les techniques locales traditionnelles et dont la structure porteuse utilise essentiellement la terre, la paille, le bois, le palmier, les roseaux ou des matériaux similaires.

Les matériaux couverts par ces règlements sont l'adobe, l'adobe stabilisé, le bloc de terre comprimé, le pisé, le torchis, la bauge et le mortier de terre.

The Earthquake-Resistant Regulations for Earth Constructions apply to:

Earth constructions subject to the obligation to use an architect and a design office to obtain a building permit. The main load-bearing elements are adobe, rammed earth, cob, or stone rubble walls with earth mortar. The earth material may be stabilized or not.

Constructions are limited to one level in maximum acceleration zones (from 18%g to 20%g) and to two levels in maximum acceleration zones (from 10%g to 16%g).

Earth constructions of vital importance such as hospitals, clinics, civil protection establishments, police stations, and administrative buildings of decision-making centers in the event of an earthquake, are limited to a single level in all zones.

Earth constructions intended for the general public such as schools, universities, libraries, museums, large places of worship, shopping centers, etc., are limited to a single level in maximum acceleration zones (from 18%g to 20%g). The maximum height of earth load-bearing walls is 4m for a single-level construction and 6.5m for a two-level construction.

Sites for earthen construction installation:

-It is necessary to ensure that the site where the new construction is to be built is not crossed by a fault that is recognized as active (differential movements on the surface). If a fault is recognized as active, it is not permitted to build on the fault or in a strip 200 m wide on either side of its path.

-It is not permitted to build on a slope presenting a risk of instability due to sliding.

-Earthen constructions are recommended on sites with maximum slopes of 35% (inclination less than 20°) that do not present a significant topographic amplification effect.

-Earthen constructions built on sites with slopes greater than 35% must be made of blocks arranged in terraces. Constructions on a sloping site, made in a single block with foundations located at different levels are not tolerated in seismic zones 4, 3, and 2.

-Earth construction must not be founded on sandy and loose soil, soft or expansive clayey soils, loose or poorly compacted soils, marshy and unstable soils

-Earth constructions must not be on sites exposed to flooding, landslides or geologically unstable soils.

Walls and openings:

-Minimum thickness of load-bearing walls: 0.4 m

-Minimum thickness of partition walls: 20 cm

-The width of an opening must not be greater than 1.2 m (window or door)

-The distance between an external angle and an opening will not be less than 1.2 m

-The total sum of the widths of the openings of a wall must not exceed 40% of the total length of the wall in seismic zone 1

-The support length of the lintels (lintel anchoring) on each side of the opening must not be less than 50 cm

-The length of the wall between two successive walls that are orthogonal to it must not be greater than 10 times the thickness of the wall nor greater than $64t^2/h$, with h is the height, t is the thickness of the wall.

CLIMATE VULNERABILITY & ADAPTATION

Thermal Construction Regulations in Morocco (RTCM)

Cent-troisième année – N° 6306 — 12 moharrem 1436 (6 novembre 2014)

ISSN 0851 - 1217

ROYAUME DU MAROC

BULLETIN OFFICIEL

EDITION DE TRADUCTION OFFICIELLE

Décret n° 2-13-874 du 20 hija 1435 (15 octobre 2014) approuvant le règlement général de construction fixant les règles de performance énergétique des constructions et instituant le comité national de l'efficacité énergétique dans le bâtiment. 4256

Publication of the decree in the Official Bulletin:
Decree 2-13-874, relating to the General Construction Regulation setting the Energy Efficiency Rules for construction, November 6, 2014

extraits du décret…

REGLEMENT GENERAL DE CONSTRUCTION
FIXANT LES REGLES DE PERFORMANCE ENERGETIQUE DE CONSTRUCTIONS

Objet

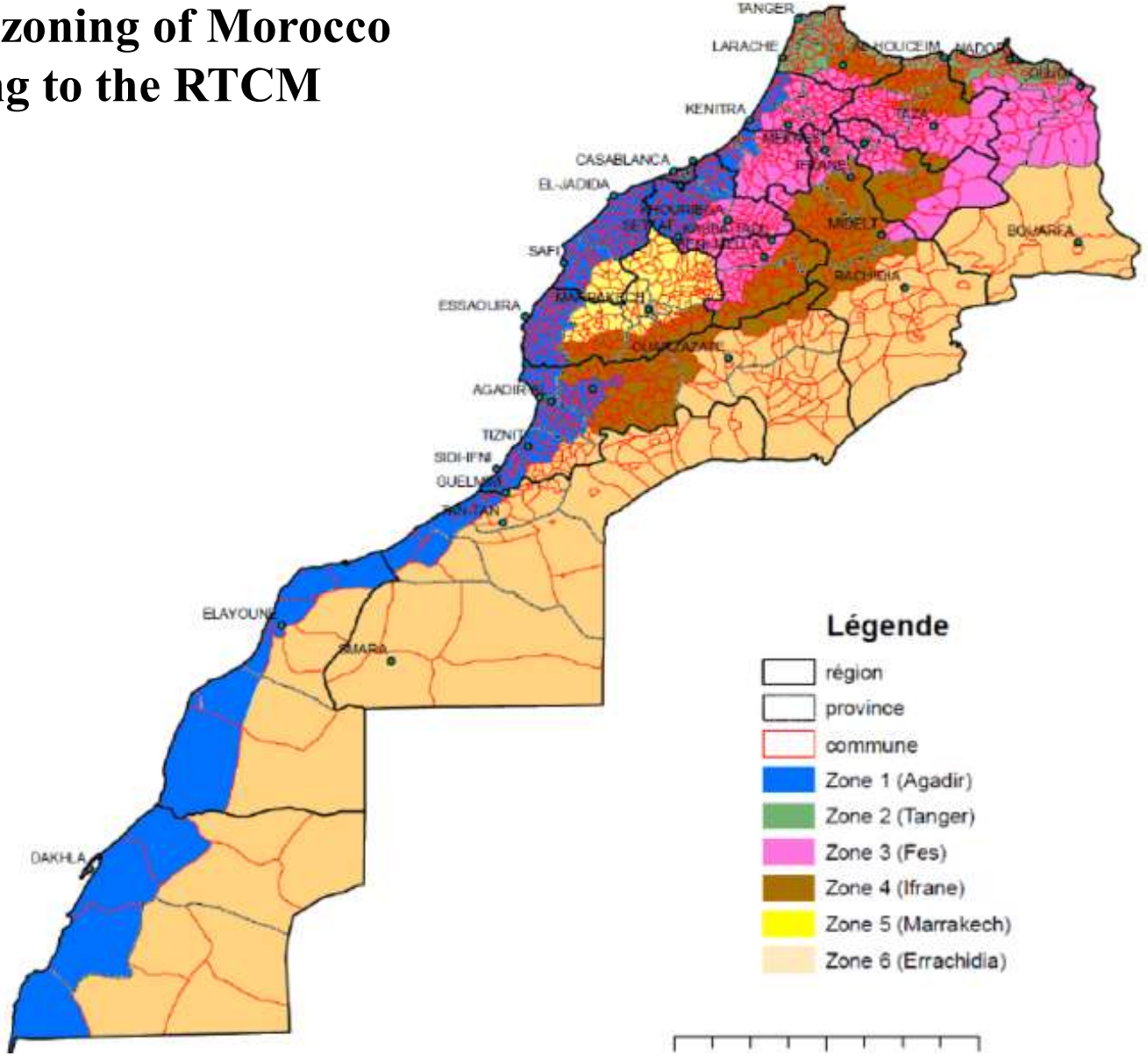
Le Règlement général de construction fixant les règles de performance énergétique des constructions a pour objet de fixer les caractéristiques thermiques que doivent respecter les bâtiments par zone climatique, afin d'atteindre les résultats suivants:

- réduire les besoins en chauffage et en climatisation des bâtiments ;
- améliorer le confort thermique au sein des bâtiments ;
- participer à la baisse de la facture énergétique nationale ;
- réduire les émissions de gaz à effet de serre.

-Reduce heating and cooling needs of buildings
-Improve thermal comfort inside buildings

Ledit règlement s'appliquera aux bâtiments résidentiels et tertiaires à édifier, à l'exception de l'habitat individuel rural, et permettra de produire une nouvelle génération de constructions plus respectueuses de l'environnement, avec une meilleure utilisation des techniques de l'efficacité énergétique dans le bâtiment.

Climate zoning of Morocco according to the RTCM



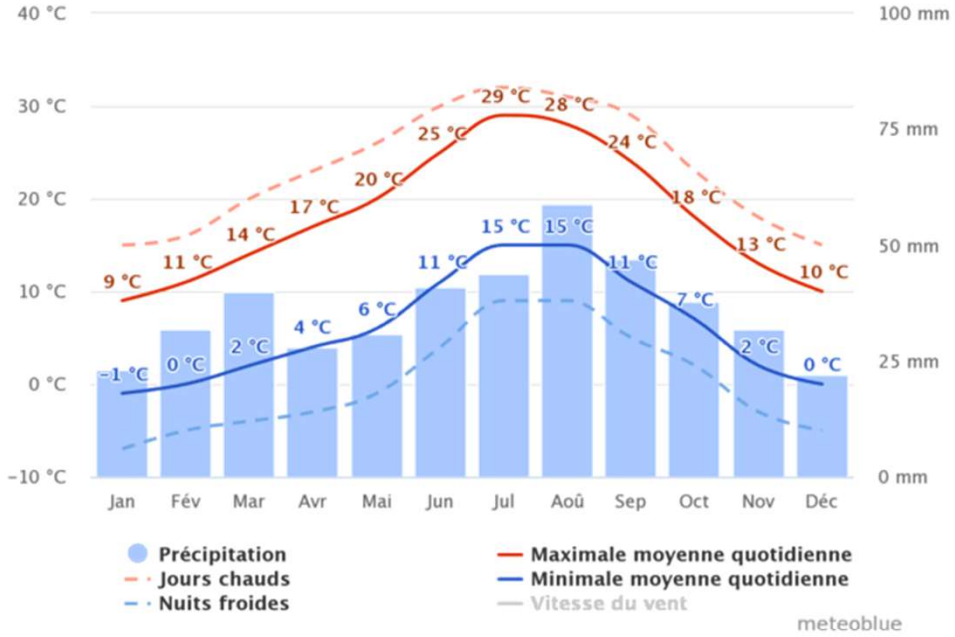
Bioclimatic Analysis and EE of Stone and Earth Housing in High Atlas

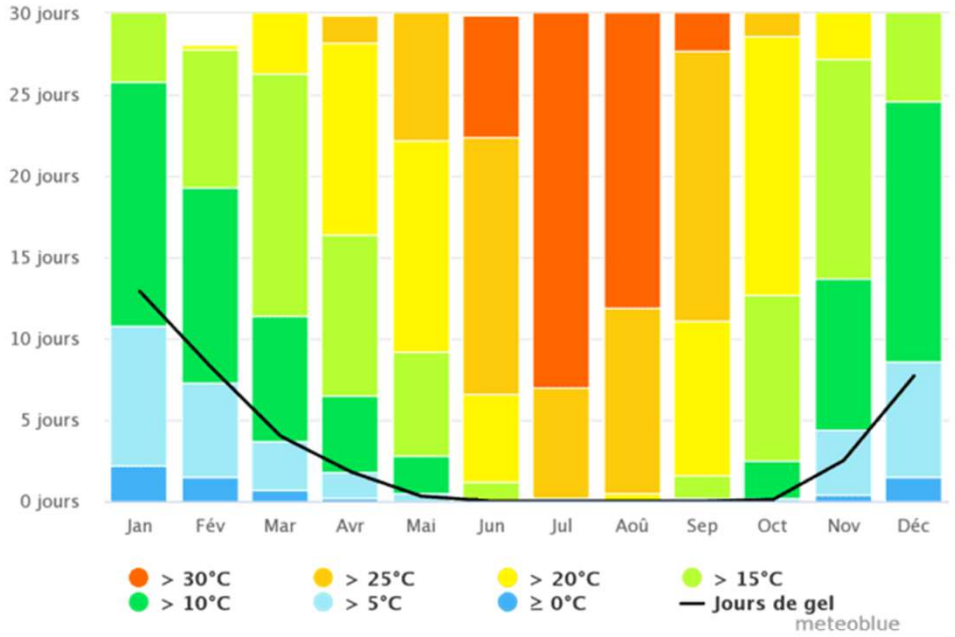
Bioclimatic analysis using Szokolay/Givoni psychrometer and Mahoney's tables

- Szokolay/Givoni bio climatic diagram and Mahoney's tables have been used. There are still useful tools to give general considerations of the comfort zone with some recommendations for the design of the building.

- According to the Szokolay/Givoni climatic diagram, there is a possibility to extend the comfort zone for the cold months by internal gains and in some severe cases by heating.
  - Based on a diagnosis of some climatic indicators, the Mahoney tables give the performance specifications and the design recommendation for buildings in the Haut Atlas in order to have the best indoor climate:

-Layout: orientation north and south (long axis east-west);
-Spacing: compact layout of estates;
-Air movement: No air movement requirement;
-Openings: small openings (15-25 %) to medium openings, 25-40 %;
-Walls and floors: heavy, over 8h time-lag;
-Roofs: heavy, over 8h time-lag.

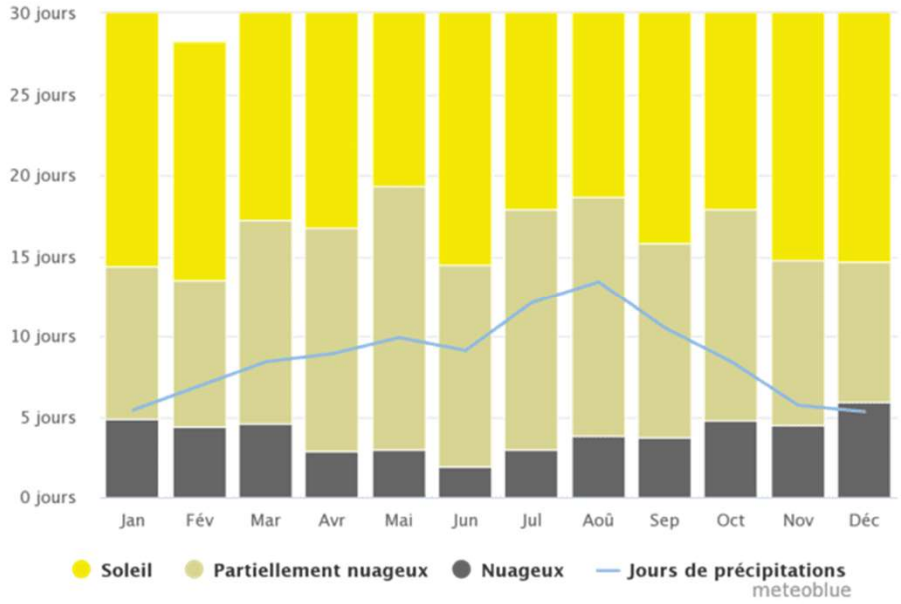




Average temperatures and precipitation

Maximum temperatures

Cold zone



Cloudy, sunny, and rainy days

Source: https://www.meteoblue.com/

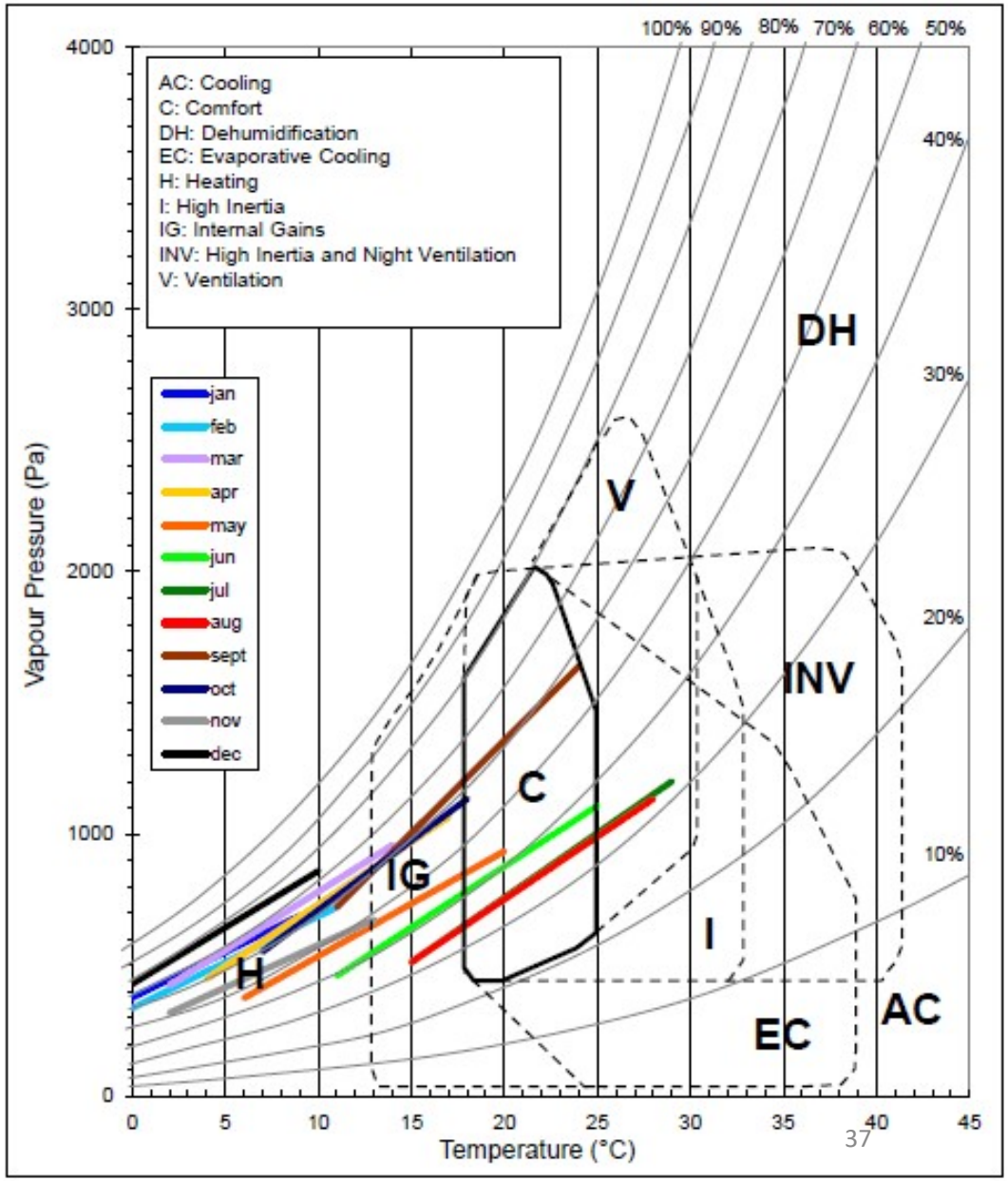
Mahoney Tables:
General Recommendations
Haut Atlas
Latitude 31°N

Layout	
X	Orientation north and south (long axis east–west)
	Compact courtyard planning
Spacing	
	Open spacing for breeze penetration
	As above, but protection from hot and cold wind
X	Compact layout of estates
Air movement	
	Rooms single banked, permanent provision for air movement
	Rooms double banked, temporary provision for air movement
X	No air movement requirement
Openings	
	Large openings, 40–80%
	Very small openings, 10–20%
X	Medium openings, 20–40%
Walls	
	Light walls, short time-lag
X	Heavy external and internal walls
Roofs	
	Light, insulatted roofs
X	Heavy roofs, over 8h time-lag
Outdoor sleeping	
	Space for outdoor sleeping required
Rain protection	
	Protection from heavy rain necessary

Bioclimatic Diagram (Givoni)

Location	**Haut Atlas**
Longitude (°)	7
Latitude (°)	31
Altitude (m)	2200

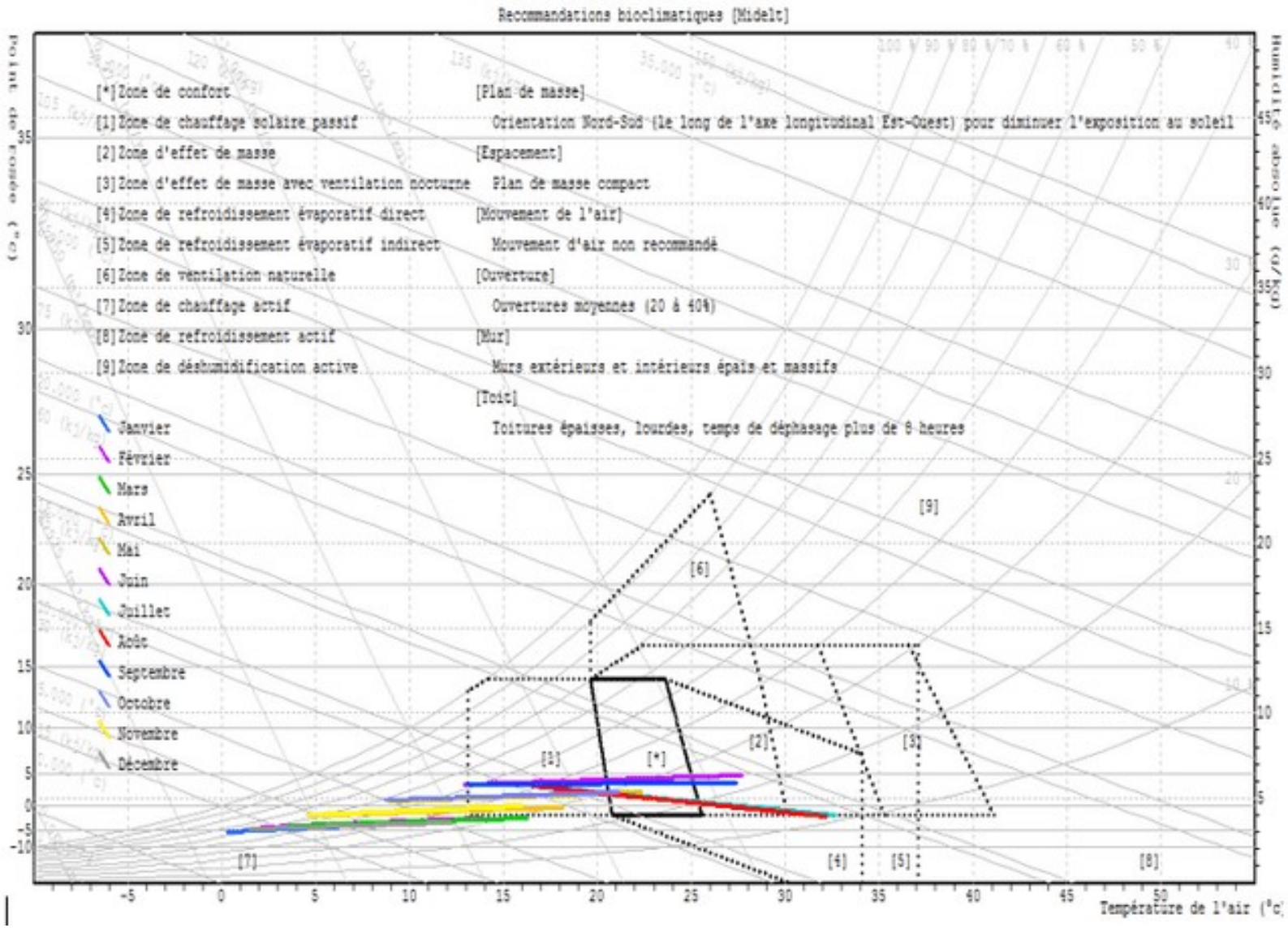
Cold zone



Cold zone

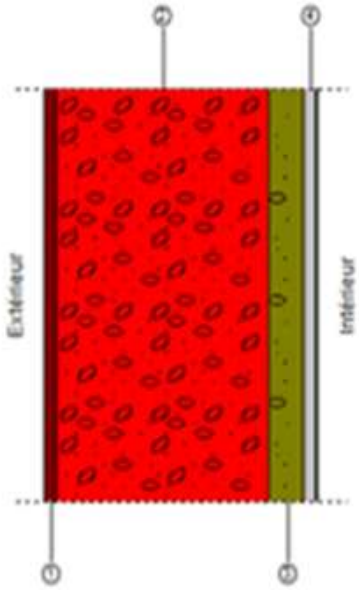
Szokolay bioclimatic Chart

The average comfort limits between 19.5°C and 25.5°C with an average of 40% relative humidity



Szokolay bioclimatic chart for Midelt (Source: Awrash)

Cold zone



Wall

Couches
1 - Enduit mortier de terre: 2 cm
2 - Pierre locale: 35 cm
3 - Isolant TH panneau laine minérale: 6 cm
4 - Enduit plâtre: 2 cm
Épaisseur totale: 45.0 cm
Caractérisation thermique
Coefficient de transmission thermique: 0.54 W/(m² K)

Référence	Coefficient de transmission thermique	Conforme
Mur Ext	0.55 W/m²K	✓

Valeur limite réglementaire	
Zone climatique	Zone 4
Usage du bâtiment	Résidentiel
Taux global des baies vitrées (%)	19.0
Coefficient de transmission thermique (W/m²K)	**0.60**

Roof

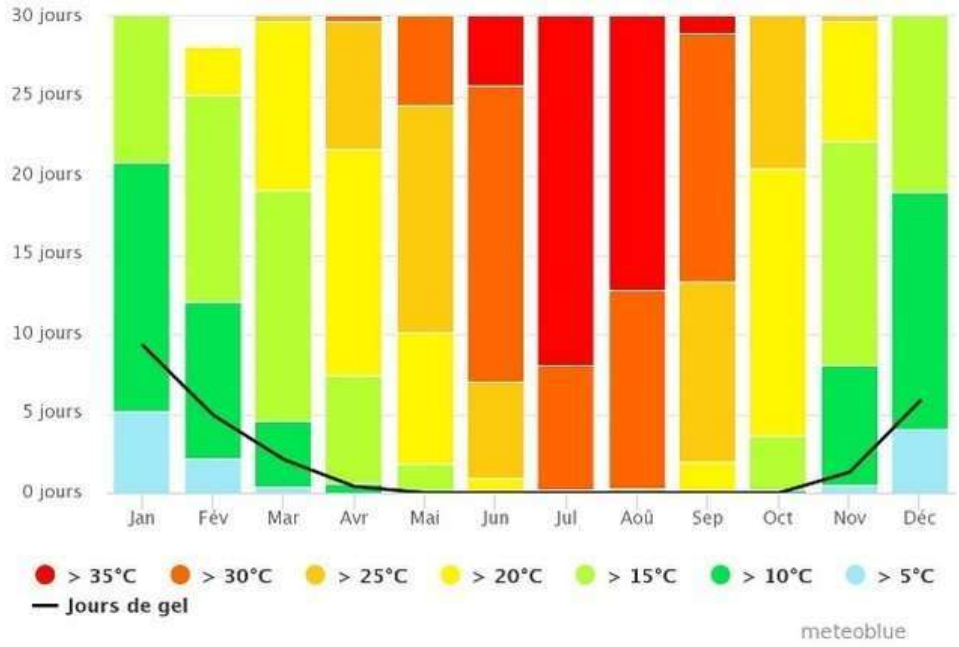
Couches
1 - Dess 1 Barbotine de chaux: 3 cm
2 - Dess 2 Enduit de finition Sable Chaux: 2 cm
3 - Dess 3 Forme de pente en terre battue: 5 cm
4 - Couche de terre Argile ou Limon: 10 cm
5 - Lit de roseaux: 2 cm
6 - Solives en bois: 8 cm
7 - Poutres maîtresses en bois: 15 cm
Épaisseur totale: 45.0 cm
Caractérisation thermique
Coefficient de transmission thermique: 0.42 W/(m² K)

U value for Walls and Roof

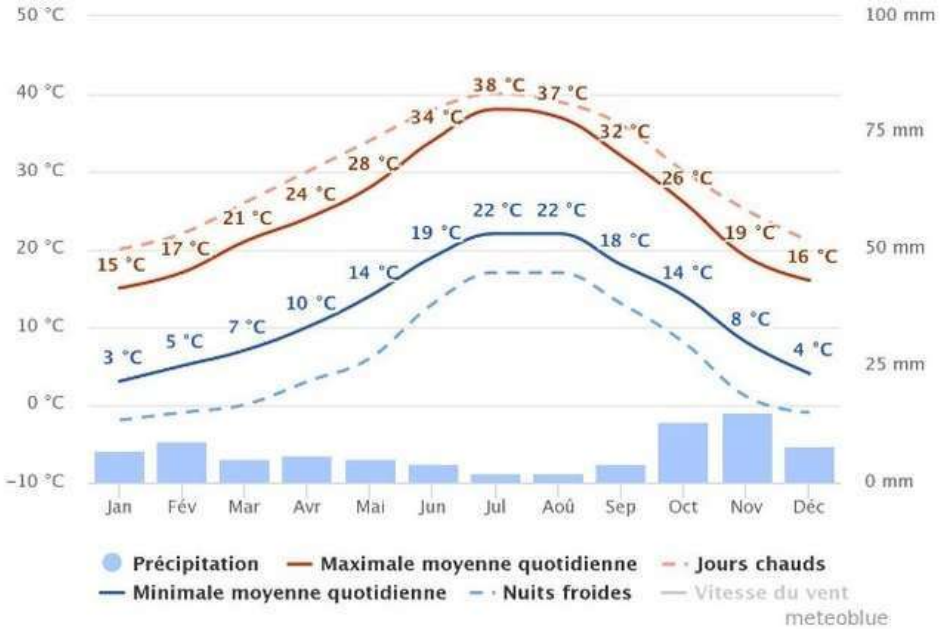
Référence	Coefficient de transmission thermique	Conforme
Toiture terrasse	0.42 W/m²K	✓

Valeur limite réglementaire	
Zone climatique	Zone 4
Usage du bâtiment	Résidentiel
Taux global des baies vitrées (%)	19.0
Coefficient de transmission thermique (W/m²K)	**0.55**

Hot zone



Maximum temperatures



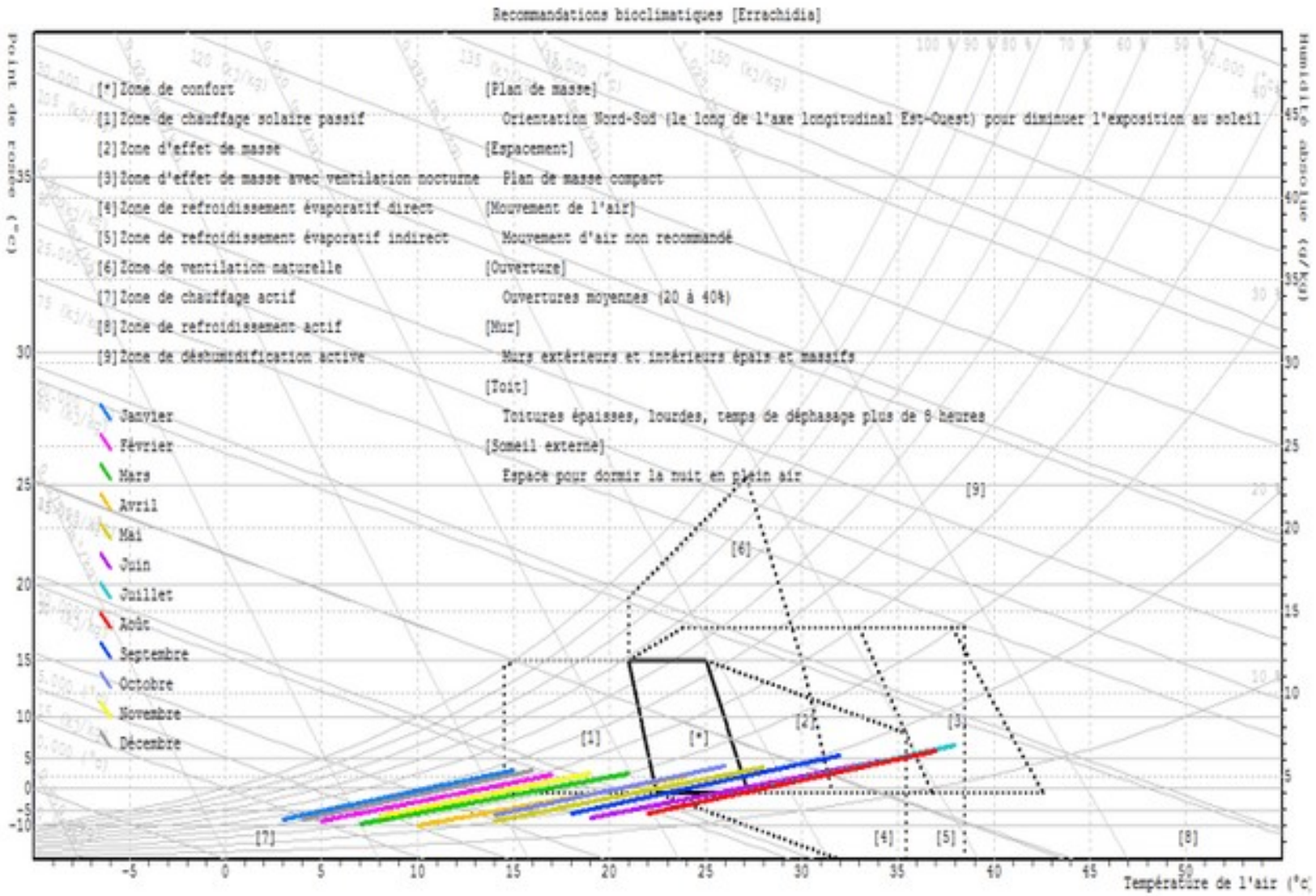
Average temperatures and precipitation

Climatic data in Errachidia, Temperatures (www.meteoblue.com)

Hot zone

Szokolay bioclimatic Chart

The average comfort limits between 21°C and 27°C with an average of 35% relative humidity

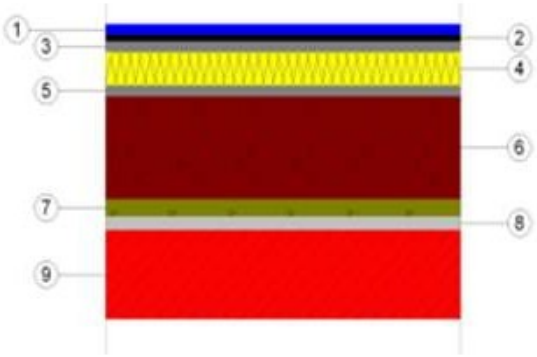


Szokolay bioclimatic chart for Errachidia (Source: Awrash)

Thermal performance of construction elements:

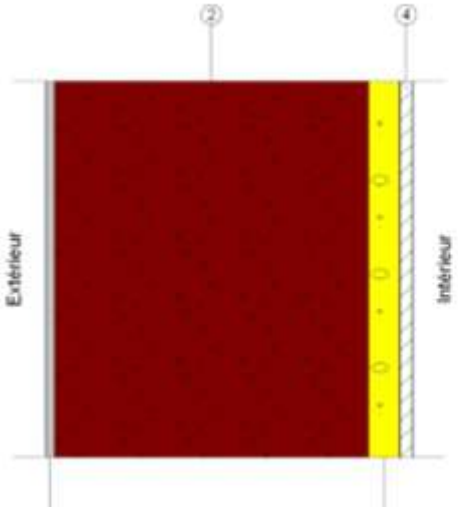
The U value

Hot zone



Roof terrace layers
1- Ceramic/porcelain: 1.5 cm
2- Asphalt: 1cm
3- Cement mortar: 1.5 cm
4- Glass wool: 5 cm
5- Cement mortar: 1.5 cm
6- Clay or silt: 15 cm
7- Sand and gravel: 2.5 cm
8- Lime coating: 2 cm
9- Heavy softwoods: 13 cm
Total thickness: 43.0 cm
U-value: 0.49 W/m²K

Roof



Wall layers
1- Lime coating: 1.5 cm
2- Pise, cob, stabilized earth concrete, compressed earth blocks: 50 cm
3- Wood fiber panels: 5 cm
4- Current plaster for interior coating: 2 cm
Total thickness: 58.5 cm
U-value: 0.51 W/m²K

Wall

Cold zone
Hot zone

U value

- **Poor thermal quality: U > 1.5 W/m² °C**
- **Average thermal quality: 1 < U < 1.5 W/m² °C**
- **Fairly good thermal quality: 0.8 < U < 1. W/m² °C**
- **Good thermal quality: 0.5 < U < 0.8 W/m² °C**
- **Outstanding thermal quality: 0.3 < U < 0.5. W/m² °C**
- **Excellent thermal quality: U < 0.3 W/m² °C**

	U_{wall} (W/m² °C)	U_{roof} (W/m² °C)	R_{ground} (m² °C/W)
Climate Zone 4 (Midelt) Glazing rate			
16-25%	≤0,60	≤0,55	≥1,25
26-35%	≤0,60	≤0,55	≥1,25
36-45%	≤0,55	≤0,49	≥1,25
Calculated U-value of traditional buildings in Midelt or Errachidia	**0.51**	**0.49**	**1,34**
Climate Zone 6 (Errachidia) Glazing rate			
16-25%	≤0,70	≤0,65	≥1,00
26-35%	≤0,60	≤0,55	≥1,00
36-45%	≤0,55	≤0,49	≥1,00

Conclusions

The High Atlas Agdal = natural, social and cultural heritage.
Its preservation is essential in the face of the challenges posed by CC.
Its resilience and that of its population depend on the collective capacity to support sustainable practices and to value the cultural and natural wealth of this ecosystem.

Heritage sites of earth and stone architecture can be better equipped to face the challenges posed by CC and continue to play their cultural, social and economic roles for future generations:

-By integrating climate considerations into heritage conservation efforts,
-By involving local communities,
-By promoting research and innovation on materials combining traditional properties and increased durability,
-By advocating for favorable policies to strengthen resilience to climate and seismic shocks as well as the overall capacity of socio-ecological systems.