



THERMAL STUDIES OF RESIDENTIAL BUILDINGS IN
HOT DESERT CLIMATE IN ALGERIA

BY

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A dissertation submitted in fulfilment of the requirement for
the degree of Master of Science in Building Services
Engineering

Kulliyyah of Architecture and Environmental Design
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APRIL 2018

ABSTRACT

The traditional houses (Trad.H) in Ghardaia City in Algeria had been built using traditional construction materials and passive design strategies for the hot desert climate. These thousand year old houses are still standing and conditioning the harsh desert climate while maintaining indoor thermal comfort for its occupants. As of late, two trends of modern housing and construction were observed to have evolved in Ghardaia. Firstly, are the modern houses (Mod.H) following the international style and secondly, the eco-friendly houses (Eco.H) utilizing passive solar design. The Mod.H were observed to implement some of the traditional features but using the modern construction material. Meanwhile, the Eco.H modified closely the features of the traditional construction and materials. The intention of this study was to investigate the thermal performances of the two contemporary houses in relation to the thermal performance of the Trad.H. The argument was to determine whether the Eco.H or the Mod.H provided better indoor thermal comfort in the context of the summer season. Asserting this aim, the study investigated the thermal comfort of Eco.H and Mod.H and compared their performances with Trad.H. The quantitative method was used to measure the thermal comfort of the three types of houses. A field survey was conducted using thermal data loggers installed in three selected houses to record the air temperature and relative humidity of the outdoor and indoor spaces. Data collection was carried out in July, which was one of the hottest months. The study indicated that passive solar techniques employed in Trad.H could reduce indoor temperatures for comfortable indoor environment to the occupants. It was also observed that the indoor temperature of the Eco.H was almost similar to that of Trad.H, which is 3 to 5 °C cooler than the Mod.H. The study ascertained that designs of buildings with traditional construction and material played significant roles in moderating the indoor environment when the outside climate of the Algerian desert becomes unbearable. Inadvertently, energy for cooling was saved, creating a great impact not only on the economy both at national and global levels, but on an environmental level as well.

خلاصة البحث

تتميّز البيوت التقليدية (Trad.H) بمدينة غرداية في الجزائر باستخدام مواد بناء تقليدية، واستراتيجيات تصميم البناء البيئي المحافظ على الطاقة في المناخ الصحراوي الحار؛ هذه المنازل التي يتجاوز عمرها ألف سنة لا تزال مسكونة؛ لأنها تتلاءم مع المناخ القاسي للمنطقة، وأغلبها لا يزال محافظاً على درجة الحرارة الداخلية المريحة لسكانها. وفي الآونة الأخيرة ظهر نمطان من السكنات الحديثة في غرداية: منازل حديثة (Mod.H) وفق النمط العادي، ومنازل صديقة للبيئة (Eco.H)؛ والتي تتميز باستخدام استراتيجيات البناء البيئي المحافظ على الطاقة، وقد لوحظ أنّ (Mod.H) و (Eco.H) قد استعمل فيهما نفس مميزات التصميم الداخلي للمنزل التقليدي (Trad.H)، غير أنّ مواد البناء اختلفت؛ ففي (Mod.H) استعملت مواد البناء الحديثة، وفي (Eco.H) مزج بين مواد البناء الحديثة والتقليدية. ونظراً للاختلاف بين النمطين؛ تهدف هذه الدراسة إلى التحقق من الأداء الحراري للمنازل العصرية مقارنة بالأداء الحراري للمنازل التقليدية، ومعرفة مدى توفير النموذجين (Mod.H) و (Eco.H) للحرارة الداخلية المريحة خلال فصل الصيف في المناطق الصحراوية؛ ولتحقيق هذا الهدف فقد تمت دراسة الأداء الحراري لكل من (Mod.H) و (Eco.H) وقارنتهما بـ (Trad.H) باستخدام الطريقة الكمية لقياس الأداء الحراري للمنازل الثلاثة، وأجريت الدراسة باستخدام أجهزة تسجيل البيانات في أحد أشهر الصيف الحار وهو "يوليو" سنة 2017م، لتشير الدراسة إلى أنّ تقنيات التصميم البيئي في (Eco.H) واستعمال مواد البناء التقليدية يمكن أن يخفّضاً درجة الحرارة في الفضاءات الداخلية بما يناسب البيئة الداخلية المريحة للسكان. وقد لوحظ في هذه الدراسة أنّ درجات الحرارة الداخلية في (Eco.H) كانت مقارنة لدرجات الحرارة المسجلة في (Trad.H)؛ والتي تعتبر أخفض بثلاث إلى خمس درجات مئوية من (Mod.H). كما أكّدت الدراسة أنّ تصاميم المباني الحديثة الصديقة للبيئة (Eco.H) أدت دوراً مهماً في تلطيف الجو الداخلي للمنزل خصوصاً مع ارتفاع درجات الحرارة الخارجية للبيئة الصحراوية الجزائرية؛ مما وقرّ الطاقة المستعملة لتبريد المنازل وقلّص الكلفة الاقتصادية على المستوى الوطني والعالمي.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Building Services Engineering.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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*This Thesis is dedicated to my beloved **parents** and **siblings**
who have always been my source of inspiration, encouragement and
stamina to undertake my higher studies and face the eventualities of life
with enthusiasm and fear of **ALLAH**.*

ACKNOWLEDGEMENTS

All praise be to Allah, Lord of the Worlds, I offer Him all praise and gratitude, and seek His assistance and forgiveness. I seek refuge in Allah from the evils of our souls and the wickedness of our deeds. I thank Allah, the Exalted, for the completion of this Masters dissertation. This is another milestone in the journey of my life all along, from Allah unending strengths and blessings. - Alhamdulillah Wa shokrulillah.

First, it is my utmost pleasure to dedicate this work to my father '*Miloud Behaz*' and my mother '*Saliha Derradji*' for their unconditional love and constant d'ua. No words can describe their parental love to me. I owe a lot to them as they set me on the path of life I found myself today. Their belief in my ability to accomplish this goal. Special appreciations to my elder sister *Jalila*, who believed in me and supported me and to all my precious siblings *Rafika, Siradj, Raouf and Djihane*. Also not forgetting the kind spirit that accompanied me with all love and care during this stage of my study. In you, I find company and forget all worries. Thank you very much.

Next in the forefront of my gratitude, is my supervisor Asst. Prof. Dr. *Zuraini Denan* for her guidance and invaluable advice. Her suggestions have a significant impact in shaping this research into its final form and contributed to the success of the research. I express my sincerest appreciation for the co-supervisor Asst. Prof. Dr. *Noor Aziah Mohd Ariffin* in her role to the success of this research. I consider it my privilege to have accomplished this dissertation under their right guidance. My appreciations also go to all my lecturers during my study at the International Islamic University Malaysia from CELPAD to the Kulliyah. Thank you for your roles in my career development.

Sincere thanks to my friends especially *Sawsan*, for her moral support during my journey in Malaysia and all others for their kindness. Thanks for the friendship and memories.

Finally, I wish to express my appreciation and thanks to the families in Ghardaia city, those who welcomed me in their houses and provided their time for this project, your kindness means a lot to me.

Amira Behaz

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
DBT	Dry Bulb Temperature.
EC	Evaporative Cooling.
Eco.H	Ecological House (Modern house with passive solar design)
HMV	High Masse with nighttime Ventilation
HT	High Thermal mass
ISO	International Organization for Standardization
Mod.H	Modern House
MRT	Mean Radiant Temperature.
NVM	Natural Ventilation and Mechanical ventilation
O.P.V.M	Office of Protection and Promotion of the M'zab Valley
O.N.M	Climate parameters of Ghardaia weather station.
RH	Relative Humidity
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
PSD	Passive Solar Design
Trad.H	Traditional House.
WS	Wind Speed

LIST OF SYMBOLS

T	temperature
T_a	air temperature
T_m	mean temperature
T_o	operative temperature
T_{mrt}	mean radiant temperature
T_n	thermal neutrality
$^{\circ}C$	degrees Celsius
clo	clothing insulation unit degrees
kW	kilo watt
kWh	kilo watt hour
met	metabolic rate
m^2k/W	square meter kelvin per watt
m	meter
mm	millimeter
m/s	meter per second
W/m^2	watts per square meter

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The dissertation is a comparative study of thermal performances of houses in the hot and dry desert climate in Ghardaia city in Algeria. It presents thermal performance of an existing traditional house (Trad.H) located in *Ksar Melika*, to compare with two contemporary houses: the first, a modern house with passive solar design (Eco.H) in *Ksar Taffilelt* ; and the second, a modern house without passive solar design (Mod.H) located outside the Ksar.

A “*Ksar*” is the North African Meghrebi Arabic term for "castle", generally means a fortified village. The ‘Ksar’ (plural is Ksour) in Algeria typically consist of adjacent houses with other facilities like a masjid, bath, oven and shops. A Ksar is usually contained entirely within a single continuous wall for defense. The building material if the entire structure is normally adobe, or cut stone and adobe. Ksars form one of the main manifestations of Berber architecture of Algeria. Although built for defense the Ksar was also designed to withstand the harsh desert climate.

Thermal comfort is considered an essential and necessary aspect in the urban sector specially in the desert climate where the outdoor temperature reaches 50°C in the summer season. The role of the architects is about reducing energy, protecting human health and saving the environment. This dissertation attempts to look for an explanation of the little known “*Ksar*” traditional design and passive solar design concepts.

The following proposal will describe an overview of the thesis conducted. It includes the following aspects: background of research, problem statement, research

questions, aim and objectives of research, scope of research, methodology of research, significance of research and structure of research.

1.2 BACKGROUND OF RESEARCH

The issues of thermal comfort have become a global point of interest to many researchers around the world, apparently attributed to the realisation that people spend most of their time (more than 90%) in an indoor environment (Lee and Chang, 2000). Passive methods of reaching thermal comfort in buildings in several countries have been commonly investigated. These passive methods are the solution to provide the energy-efficient of indoor environment and healthy life style (Hegde and Ananthakrishna, 2008).

Algeria, located on the north of Africa is the largest country in Africa in terms of the area, which is estimated at 2.382million km². Only a small part in the north has warm mediterranean climate and most of the south part is significantly desert with hot and dry climate, as shown in Figure 1.1.

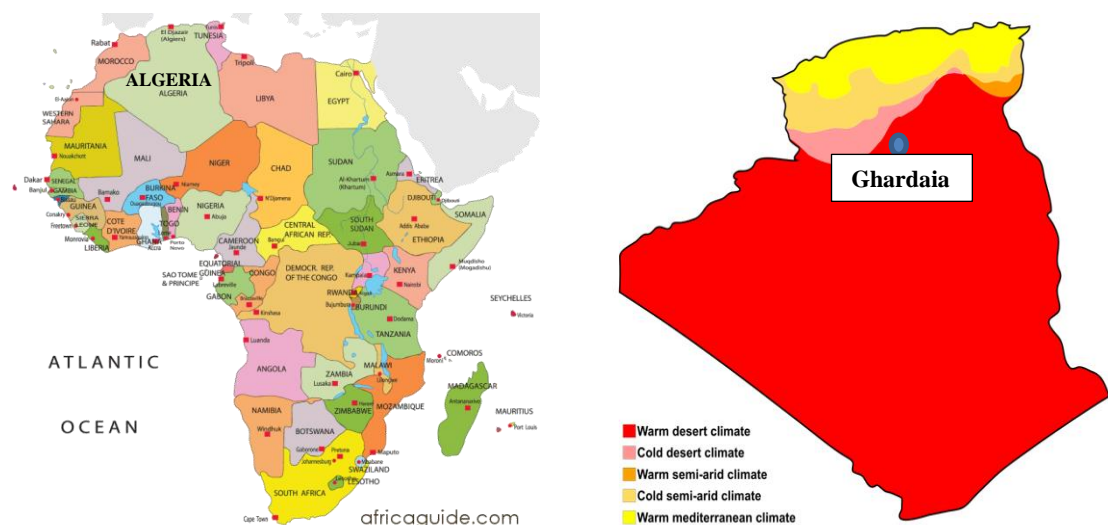


Figure 1.1: The African map and the Köppen climate classification of Algeria

Source: www.google.com/search?q=climate+classification+algeria&source

Ghardaia is an old desert city in Algeria; one of the most Algerian heritage cities due to its many ancient *Ksour* (fortified villages, singular “*Ksar*”).

There are seven (7) old ksour in Ghardaia built from the 11th until the 17th century, (Chabi and Dahli, 2014) as listed and shown in Figure 1.2:

- (1) *Ksar El Attaf* (1012).
- (2) *Ksar Bounoura* (1046).
- (3) *Ksar Ghardaia* (1053).
- (4) *Ksar Melika* (1124).
- (5) *Ksar Beni-Isguen* (1347).
- (6) *Ksar Guerrara* (1631).
- (7) *Ksar Berriane* (1679).

At present, there are two (2) new ksour which are located a few kilometres from *Ksar Beni-Isguen* as shown in Figure 1.2.

- (8) *Ksar Taffilelt* (2000).
- (9) *Ksar Tinamirin* (in the process of completion).

The Trad.H is located in *Ksar Melika*, while both the Eco.H and Mod.H are located in *Ksar Taffilelt*

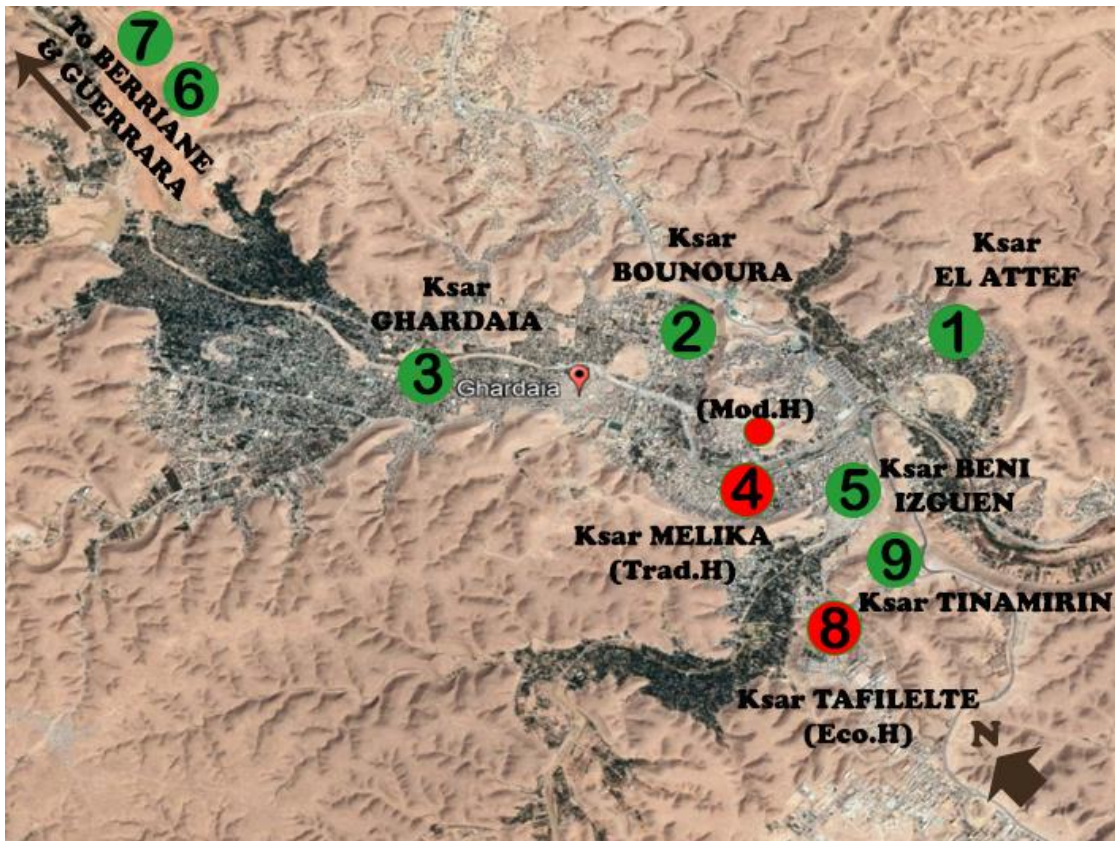


Figure 1.2: Map of Ghardaia showing the locations of the Ksour
Source: Google earth

Ghardaia city contains rich architectural and cultural heritage inscribed since 1982 on the World Heritage List of the UNESCO as a cultural site. This thousand-year-old architectural masterpiece, were built in particularly unfavourable conditions: climate and topography (Messahel, 2011). Known as the cradle of a ksourial architecture it is constituted today as a reference in the perfect harmony between the social organisation, the system of urbanisation, the architectural typology, and the ecological balance. This urbanism is resulting from customs, traditions and climatic conditions (Benyoucef, 1986).

Before the occupation of Ghardaia by the French authorities in 1882, the territory underwent little changes. The ksour of the city included some extension areas inside the ramparts, and the nucleus of the colonial city was planted between *Ksar Beni-*

Isguen and *Ksar Ghardaia*, in what was a part of *Ksar Melika*, where the Trad.H is located (Mercier, 1932). Towards the middle of the twentieth century, it was seen that linear urbanisation along the roads, between *Ksar Beni-Isguen* and *Ksar Ghardaia*, where the Mod.H is located (Messahel, 2011).

1.2.1 Principles of urbanisation of the M'zab valley

(Association of man - culture - climate)

The principle urbanisation of Ghardaia is intimately linked to the concept of *Ksar*, which is the mode of a fortified settlement built around a mosque. The installation of the *Ksar* depends directly on the availability of water resources, a condition that ensures the creation of palm groves, which influenced the microclimates that are essential for human settlement. Some literature relates that once the population growth exceeds the capacities of the mosque, it is necessary to build another *Ksar* and a new city around it. The fortified morphology of the *Ksar* reiterated the historical need to protect itself from external threats and to cope with bioclimatic conditions. They comply with urban planning rules, architectural design principles and rigorous construction techniques (O.P.V.M, 2014).

Beauty, profound harmony and unity of thought emerge from the architecture of the Ghardaia. Traditional knowledge and know-how in the face of a hostile and resource-poor environment is manifested in the development of techniques that make the best use of water and land, whether its availability is sustainable or cyclical (Chabi and Dahli, 2014).

In sedentary settlements, the search for protection against wind and sun has been extended to the design of architecture and town planning, where the technical solution to the rank of art confers on dwellings and urban fabric a particular aesthetic (Sidi

Boumediene and Veirier, 2003). In Ghardaia, the main features of the constructions are rationality and simplicity with the use of materials that harmonise perfectly with the environment, since they are extracted on site (Benyoucef, 1994).

The house is articulated to the street by an entrance called “*Squifa*”, designed to preserve the inside from foreign eyes. This house also has a distribution of spaces on two levels, with a right to sunshine, a distribution of rooms around the patio, which is called the “*Wast-eddar*”. The spaces are lit and ventilated by the door and the slot in the thick walls and by the skylight grill called the “*Chebek*”. A superposition of patios or “*wast-eddar*” have the effect of reducing the radiant heat inside the house. As for the functional terrace, it is reserved for women and was used at night to sleep. It consisted of the flat and heavy slab, allowing the reduction of heat transfer, by conduction, inside the house (Toudert et al., 2005).

Other climate integration strategies characterised Ghardaian houses starting with a south orientation to benefit in winter oblique sun rays, and the rays become vertical in summer (Toudert et al., 2005).

Finally, the stone is the most used as the building material and characterised by a high thermal capacity. The stones had the advantage of capturing solar energy and accumulating it, to restore it later and easily evacuated at night by natural ventilation effect. It is, therefore, a potential asset for bioclimatic construction (Chabi & Dahli, 2014).

1.3 PROBLEM STATEMENT

Housing in Algeria changes its styles and forms throughout its history in response to socio-economic forces as well as climatic conditions and geographic locations. In the south, the traditional architecture developed, were mainly oriented to the achievement