Energy efficient Design for thermally comforted dwelling units in hot arid zones: Case of vernacular buildings in Jordan

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Abstract

This paper examines the effect of building design parameters on energy consumption in Jordan. Different building configurations were tested through the study to test the effect on energy consumption for cooling and heating. The study compared the traditional buildings with the modern buildings in Jordan. Eighty vernacular buildings were studied in different climatic regions in Jordan classified according to four major building variables; form, orientation, materials, and used shading devices. An energy simulation program for building (DEROB-LTH) was used to analyze the parametric design elements on energy consumption incorporated with thermal comfort in architectural space. The study developed a model for applying different design criteria in different climatic regions in Jordan that highly prioritizes energy consumption in buildings with great consideration of building forms.

1. Introduction

The development of human living standards worldwide requires careful thinking in building design strategies for heating and cooling in architectural spaces to achieve high level of thermal comfort with least amount of energy consumption. As known, high portion of energy consumptions in buildings goes for heating and cooling. A very significant part of the consumed energy is attributed to the lack of proper environmental design. It is estimated that buildings consume around 50% of energy production in the world for heating, cooling, lighting and other building construction operations (Gaitani, ,Mihalakakou, & Santamouris, 2005).

During the last two decades, building and construction sector in Jordan has highly accelerated; the construction volume in Jordan is approximately 7 million m^2 /year (RSS, 2006). Jordan is poor in terms of natural resources, including energy, compared to neighboring Arab countries. Its renewable energy is the major energy resource that is available today. The annual daily average solar irradiance (average insulation intensity on horizontal surface) ranges between 5-7 kWh/ m2 .(JNGC, 1984)

The energy consumption in residential buildings in Jordan is approximately 22% of the total energy consumption in other sectors (RSS, 2007). The cost of energy for heating in this sector is 1,059 JD/year. On the other hand, the cost of energy consumption for cooling is 526 JD/year for a typical house of $150m^2$ (RSS, 2007).

Up to now, building technology in Jordan pays little attention to the climatic and thermal design; which causes many problems in residential buildings leading to unsatisfactorily comfort levels for their occupants. In addition, the energy consumption is increased due to the lack of attention to the climatic and thermal design. Building design in most cases in modern buildings in Jordan doesn’t fit with local climatic conditions. Compared to vernacular buildings, contemporary buildings consume more heating and cooling energy. This problem is attributed to the fact that vernacular buildings meet the requirements of climatic conditions better than the modern buildings.

In fact, there is a need to think of environmental design in architectural spaces to find solutions for energy consumption and human thermal comfort in spaces. On the other hand, vernacular architecture can be utilized to serve the concept of bioclimatic environmental architecture. Hence; there are vernacular buildings in Jordan scattered all over the kingdom and classified as environmentally friendly buildings that set as an important element of investigation. However, climatic design and bioclimatic architecture worldwide are receiving high attention despite the years of ignoring traditional building.

Accordingly, this study investigates design strategies for vernacular buildings in order to create database for residential building strategies in Jordan. It sets basic guidelines for architects, builders, decision makers, and engineers for a better environmentally responsive design in residential buildings in Jordan.

Based on the aforementioned facts, this research investigates the performance of vernacular buildings in terms of location, building types, building envelope, and used materials. It also aims to examine the effect of building parameters in vernacular architecture in Jordan on energy consumption for heating and cooling. The study also assesses thermal performance of contemporary building facades in Jordan in different climatic regions and links it with the global energy consumptions in buildings.

2. Conceptual Framework and Literature Review

The effect of climate on human environment led to witnessing new technologies to solve any negative effect on human comfort in spaces. Climate has major role in building principles and the problems of climate control have to be solved. The term *bioclimatic* is derived from *bioclimatology*, a science introduced by Koppen at the beginning of the century with the purpose of explaining the distribution of vegetation on the planet as a consequence of the relations between the climatic conditions and the chances of life (Magliocco &Giachetta, 1999). However, bioclimatic architecture means a building system where the climatic control inside spaces causes a high quality of life for the inhabitants.

Vernacular architecture is the traditional and natural way by which communities house themselves. It is a continuous process including necessary changes and continuous adaptation as response to social and environmental constrains. It can be realized from the definition above that the form grow out firstly, for the needs of inhabitants and constrains of climate and region. It is noticed in all vernacular examples the existence of the relationship between site form, climate and building.

Vernacular architecture in Jordan is architecture that formed in different locations in the country in a form of several stages of development of dwellings in the region, where architecture and construction developed through thousands of years by trial and error to meet climatic and society needs (Khammash, A.,1986) . The era when traditional architecture took place started mainly in the 19^{th} century, where the agricultural prosperity begun in Jordan. As a result many villages with traditional dwellings appeared in that era, after the decline of the agricultural products coming from the Balkans lead the Ottoman government to take some measures to encourage agricultural production in the Levant (Al-Nammari F., 2003). The elements of passive technologies used in vernacular buildings in Jordan are: Compact form to reduce the sun light in the summer and thermal loss in winter, thick roofs and walls, high roofs, wind catchers, high tiny windows and the design of the courtyard house. Other traditional ways to achieve the thermal comfort in vernacular buildings include; orientation, building materials, night ventilation, shading devices, and opening design.

The architectural style of buildings changed from traditional peasant houses to modern styles using new material, from local to international in the last one hundred years. The concept of village and its development was before the date-1866, the peasant house appeared with the use of local materials. Then, the initial expansion took place in a form of more sophistication in construction and the architecture become more urban in its character. After that, there was a rapid growth and more complexity, new material appeared, and this era was called the Boom years. Thirty years later and the establishment of Amman as the capital, the influences become more European. In 1930 the international modern architectural influences took place, therefore a lot of traditional ways and elements of climatic design were loosed (RSS, 1990).

Several studies were conducted to investigate how bioclimatic architecture that was expressed through vernacular practices and appeared as a new solution to control climate. Canas ,Martin (2004) stated that popular architecture is the origin of the bioclimatic architecture , he defined bioclimatic architecture as a well adapted to the dominant climate of its surrounding by means of the method of trial and error (Canas I. & Martin S., 2004). Bioclimatic architecture concerns with climate; it is a perception of climate as a major contextual generator by using minimal energy as its target (23) (http://www.msa.ac.uk/colleges/bioclimatic). In the same context, Silva Guedes clarified that the prefix “bio” is used precisely to demonstrate that the adaptation to the climate conditions occurs by natural processes and with minor negative impacts on nature (Silva G., & Guedes M.C. 2006). Matzarakis, on the other hand, stated that the task of the bioclimatological research is to evaluate the thermal environment of human beings, since it determines the energy balance of the body and consequently its comfort sensation nevertheless, it can provide important data for planning and constructing urban surface structures and their environment, which is relevant not only for human comfort aspects (Gulya A., Unger J., & Matzarakis A. 2005).

Bioclimatic charts are good representation for analyzing climatic characteristics of any location from the standpoint of human comfort. Basically, these charts have a combination between temperature and humidity at any given time. However, the primary aim of the bioclimatic building design charts is to give architects and engineers a quick overview of the appropriate design strategies during the initial design stage where different conceptual building schemes are being considered (Lam C.J.; & Yung L.; Liu J. 2005). However, all bioclimatic charts refer to comfort zone, which is the range of climatic conditions within which the majority feels thermally comfortable. In general, there are three different means to improve the comfort sensation, which are presented in the charts by different zones; Comfort zone (CZ), where the person is comfortable in the shade at certain clothing and activity level. Wind needed zone (V), where a person needs a fresh breeze. And radiation needed zone: Where sunlight is needed to feel comfortable.

There are a lot of forms of bioclimatic charts showing the relation of various climatic elements to each other. Sayigh, Marafia (1998) in their study compared several bioclimatic charts, in order to adopt building bioclimatic chart concepts to determine the most appropriate building design strategy (Sayigh A. ,& Marfia H. 1998). In China Lam, Yang, Liu (2005) assessed the potential use of passive design strategies such as solar heating, natural ventilation, thermal mass with/without night ventilation and evaporative cooling by using bioclimatic charts, in which the comfort zone and 12 monthly climatic lines were determined and plotted on the psychometric chart for each city (Lam C.J.; & Yung L.; Liu J. 2005).

However, there four major bioclimatic charts and tables deal with human thermal comfort; Olgyay's bioclimatic chart, Giovani's bioclimatic charts, Szokoly's bioclimatic charts, and Mahoney tables.

Olgyay's bioclimatic chart is one of the first versions of bioclimatic chart which was developed in 1950. This type of charts identifies the comfort zone in relation to ambient temperature, humidity, mean radiant temperature, wind speed, solar radiation and evaporative cooling (Olgyay V. (1963). Giovani's chart was developed to identify the comfort zone between temperature amplitude and vapor pressure of the outdoor air. In this chart the proper passive cooling strategies are defined according to the climatic conditions outside the building envelope (Giovani B., 1976). Szokolay also used the Index of Thermal Stress and thermal Neutrality equation to develop his chart in 1986. He developed the concept depending on location and people. In this chart, there are two comfort zones working on thermal neutrality that is correlated to the outdoor mean temperature (SzokolayS.V.,1986). Mahoney tables are also used to analyze the climate characteristics to end with design indicators. These indicators give a primary design, orientation, shape and structure of building. These tables can be grouped in eight subjects: Layout, Space, Air movement, Openings, Walls ,Roof ,Outdoor space, and Rain protection. Most of bioclimatic studies utilized the above-mentioned tables and charts as useful tools to understand the effect of local climate conditions considering different design strategies for achieving thermal comfort conditions (Capeluto G.I.,2004).

In the same context, Oktay (2001) evaluated the housing settlements in Northern Cyprus where the vernacular urban and architectural patterns provide useful hints for designing more sustainable environments. (Oktay 2001). He introduced the courtyard design, which has good utility for hot climate regions as Northern Cyprus as a design tool for the new developments. Oktay concluded that the hot climate of the island Cyprus brings the possibility for open and semi-open spaces to be used for 9 months of the year.(Oktay 2001)

Engin, Vural, and Sumerkan (Engin N., Vural N., & Sumerkan M.R., 2005) examined the interaction between building and the natural environment. They tested the effect of climatic elements such as rain, wind, humidity and sun on the vernacular house elements in Eastern Black Sea region which are plan, external walls, roof and exterior of buildings. Compared to the vernacular architecture, contemporary buildings have less control on their environment without the use of mechanical systems. (Kim 2005) examined the methods used to control environment in Korean architecture, and compared between traditional architecture and contemporary architecture in Korea. The results of Kim study are that Korean traditional architecture coexists with nature. Natural phenomena were accepted and used. Therefore, the architectural environment manages the differences in climate. In contrast, Korean contemporary architecture ignores the natural surroundings and relies on mechanical systems, which consumes a great deal of energy. On the contrary, environmental problems are increased with increasing energy (Coch H. 1998).

3. Climate in Jordan

Jordan is located in a desert climatic zone in the subtropical region; it lies between longitude 35° to 38.5° east and latitude 29° to 32° north. It has a range of geographical features, starting from the Jordan rift valley in the west ending with the desert plateau in the east, with a series of small hills. It has the lowest point in the world, the Dead Sea, with altitude of - 408 meters (-1338.6 feet) below sea level.

The climate in Jordan is predominantly a Mediterranean type; a hot dry summer and cold winter with two short transitional periods in between. It is classified into four different climatic sub-regions http: //met.jometeo.gov.jo.

1. Desert Sub region: The desert is characterized by its clear sky during most of the year, it has very hot dry summer and the average daily maximum in August ranges between 34°C and 37°C. A temperature as high as 46.6 °C was recorded in summer and very cold winter and nights, the average daily min is 2.9°C but a temperature as low as –12.0°C was recorded. This region represents more than 70% of the total area of the country.

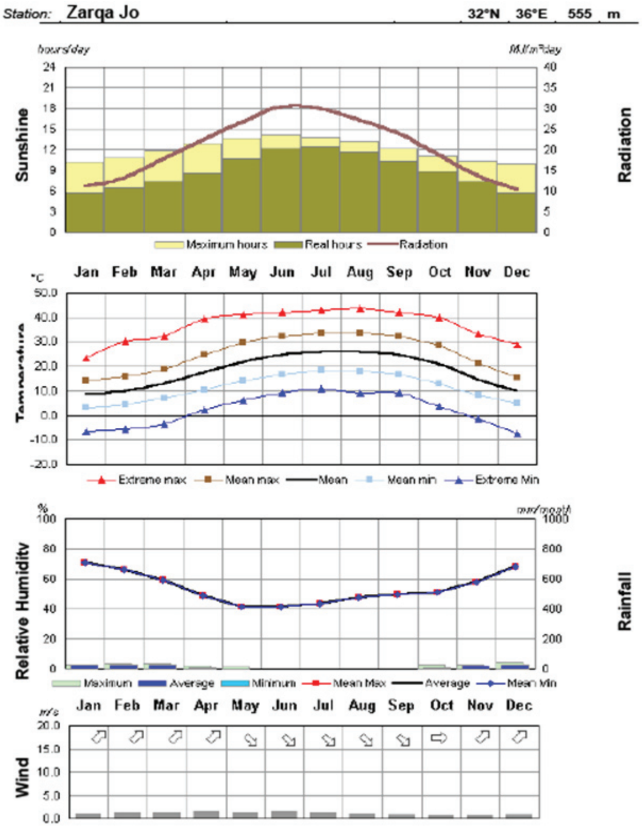

Figure 1: Weather Profile for one station in the Desert region.

2. Jordan valley sub-region **(**The Ghor): this region has altitude below the sea level and warm climate in winter and hot in summer. The Ghor area is very similar to the sub-tropical regions, it is extremely hot in summer and the temperature is rather high with average daily mean of about 31C° and average daily maximum of 39 C°, the highest observed temperature in the country is 51.2C° that was recorded in this area near the Dead Sea (http ://met.jometeo.gov.jo).

3. Aqaba bay sub-region: is considered as a tropical resort, extend between latitude 29 °N to 31° and between longitude 35° to 36°E. Aqaba climate is warm in winter, very hot in summer with northern prevailing wind. The average yearly temperature is 24.2 °C, with the highest temperature of 39.3 °C in July and the lowest of 8.9 °C in January. The average humidity is from 34.8 % in June to about 58.8% in December (http ://met.jometeo.gov.jo).

4. Mountain and heights sub-region, the climate of this sub-region is cold

and rainy in winter, while it is hot and dry in summer. The hilly regions are characterized by their pleasant climate, and the majority of the population of Jordan lives in these regions. In winter these regions experience cold weather and in January the temperature is rather low and the average daily mean is 7.9C°. In summer during August, the hottest month of the year, the average daily mean of temperature is 25.4C°(http ://met.jometeo.gov.jo).

4. Research Methodology

To determine building variables that point out thermal comfort and energy consumption in buildings, a collection of the documented vernacular buildings was studied to create a model of bioclimatic architecture in Jordan. A comprehensive survey was conducted in order to collect as much as possible of the documented vernacular buildings in Jordan. This survey focused on residential buildings in several locations in Jordan.

Eighty-two residential buildings from different regions in Jordan were investigated in terms of time of construction, location, geometry, building form, building envelope, wall thickness and availability of shading elements.

The main focus of this study was analyzing the collected data about the targeted residential vernacular buildings in Jordan. This help make a typological classification according to building layout, envelope, unit size, orientation, and shading devices. Based on the above mentioned steps, this study build up a specific model depending on vernacular buildings and validate it according to its thermal comfort and energy consumption, through building *simulation computer programs*.

To generalize the findings, this research analyzed the results of the energy load and thermal comfort conditions generated from the building simulation and concluded statistical relationships, comparisons and similarities for the best models for desert region.

4.1. Stages of the Methodology:

Stage (1): ***Typological Classification:***

The survey was carried out for the vernacular buildings. In this stage building data were collected ;(date of building, location, area, number of stories, envelope, and form). Then a typological classification was assessed according to the followings:

1-Building layout (form): type of traditional buildings (*courtyard, rectangular, compact, L-shape, and U -shape)*

2-Building envelope: includes *materials* used in building floors, walls and roofs, and *thickness* of every layer.

3-Building size: Includes *area* and *height* of the building

4-Building shading devices and openings: Includes the *percentage of the* openings in the elevation, glass characteristics and shading devices. As shown on Table 1.

Table 1: Parametric modeling procedure

	Bld . Form	Orientation	Floor material	Roof material	Wall material	Shading device	...
Base case	reqtangular	S	marble	concrete	stone	no	...
Case 1	courtyard	S	marble	concrete	stone	no	...
Case 2	L-shape	S	marble	concrete	stone	no	...
Case 3	reqtangular	E	marble	concrete	stone	no	...
Case 4	reqtangular	N	marble	concrete	stone	no	...
Case 5	reqtangular	W	marble	concrete	stone	no	...
Case 6	reqtangular	s	Ceramic tile	concrete	stone	no	...
Case 7	reqtangular	S	marble	mud	stone	no	...
Case 8	reqtangular	S	marble	concrete	concrete	no	...
Case 9	reqtangular	S	marble	concrete	mud	no	...
Case 10	reqtangular	S	marble	concrete	stone	yes	
...	...	...	...	...	...	no	?

Stage (2): ***Climatic Data Analysis:***

Climatic analysis was conducted based on climatic data for desert region in Jordan, which includes air temperature, relative humidity, and wind speed. Initial recommendations for climatic strategies were built according to bioclimatic charts.

Stage (3): ***Alternatives Modeling and Building Simulation***

Parametric modeling procedure for building elements is a probabilistic approach of all of the elements of the building, which affect thermal comfort and energy consumption in the building. These elements are building envelope, building material, building orientation and shading devices. **DEROB- LTH**(6)**,** Dynamic Energy Response of buildings software was used to simulate classified buildings. The outcome included: Heating and cooling peak loads, Monthly / annual heating and cooling loads, temperatures, and thermal comfort.

Stage (4): ***Statistical Analysis:***

In the final stage the results of simulation were analyzed through statistical analysis, according to qualitative assessment.

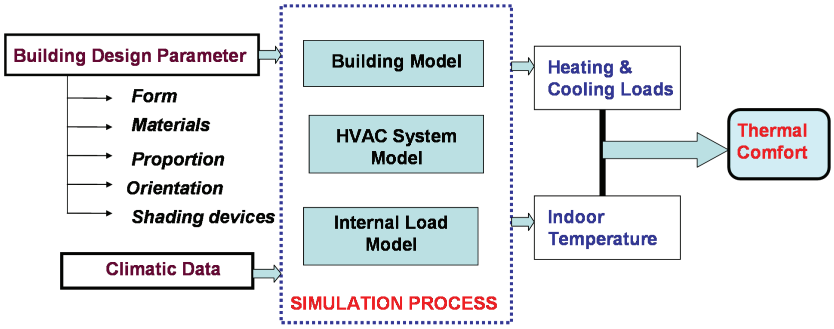

Figure 2 Major elements of building energy simulation

5. Result and Analysis

The number of traditional buildings, which were collected, is (82) traditional building. Full details about this survey are shown in table 2.

5.1. Typological Classification of Traditional Buildings

Bioclimatic design considerations depend on building characteristics and elements. Building form, building envelope, wall thickness, orientation and shading devises.

Table 2: Traditional building survey from different locations in Jordan

No.	Residential Building	Location	Era	Area	N. of storeys	Materials	Bld. Form	Wall thickness	shading devices	Height
1	Abd-eljawad dwelling	Irbid	1950	225 m.sq.	1 storey	stone,Bazelt stone ,mud ,concrete	rectangular	30cm	yes	3.75
2	Al-Nabulsi dwelling	Irbid	1950	245 m.sq.	2 storeyes	stone,Bazelt stone ,concrete,steel	U-shape	40cm	yes	5.25
3	Al-Sabagh dwelling	Irbid	1920	500 m.sq.	2 storeyes	stone ,concrete,steel	rectangular	40cm	yes	_
4	Arar dwelling	Irbid	1925	150m.sq	1 storey	stone ,mud,wood	L-shape	40cm		4.25
5	Saraya	Irbid	_	700m.sq	2 storeyes	stone,mud,wood	courtyard	40cm	yes	5.25
6	Sharaira dwelling	Irbid	1908	220 m.sq.	2 storeyes	stone,mud ,concrete,steel	rectangular	40cm		4.25
7	Abu-Rje>a dwelling	Irbid	1930	250 m.sq.	2 storeyes	stone ,concrete	rectangular	30cm	yes	3.75
8	M. Joma>a dwelling	Irbid	1935	250 m.sq.	3 storeyes	stone,mud ,concrete,steel	compact form(square)	2040- cm	yes	4.85
9	Irshedat dwelling	Irbid	_	125m.sq	1 storey	stone ,concrete	rectangular	50cm		4.25
10	N. Bataine dwelling	Irbid	1800	225 m.sq.	1 storey	stone ,mud	cvourtyard	40cm		5
11	M. Bataine dwelling	Irbid	1800	100 m.sq.	1 storey	stone ,concrete,steel	rectangular	40cm		4.25
12	Al-Akhras dwelling	Jerash	1900	125m.sq	2 storeyes	stone ,mud,concrete	rectangular	90cm	yes	5
13	Saba el-Esh dwelling	Jerash	1895	_	2 storeyes	stone ,mud,wood,reed	rectangular	90cm		_
14	Frehat dwelling	Jerash	1900	100m.sq	1 storey	stone ,mud,wood,reed	L-shape	60cm	yes	4.75
15	Demolished dwelling	Jerash	1900	40m.sq	1 storey	stone ,mud,wood,reed	rectangular	60cm		4

No.	Residential Building	Location	Era	Area	N. of storeys	Materials	Bld. Form	Wall thickness	shading devices	Height
16	Mirza dwelling	Jerash	1960	65m.sq	3 storeyes	stone,concrete	rectangular	25cm		6
17	M.Laban dwellimg	Jerash	1890	15m.sq	1 storey	stone ,mud,wood,reed	rectangular	70cm		3.5
18	Commercial building	Jerash	1900	20m.sq	1 storey	stone ,mud,steel	rectangular	70cm		3.75
19	A.Laban dwelling	Jerash	1880	100m.sq	2 storeyes	stone ,mud,wood,reed	compact form(square)	25cm	yes	4.5
20	AL-Hayek dwelling	Jerash	1890	65m.sq	1 storey	stone ,mud,steel	L-shape	25cm		4
21	Al-Smadi dwelling	Jerash	1890	200m.sq	2 storeyes	stone ,mud,wood,reed	compact form(square)	25cm		3
22	Ewedat dwelling	Jerash	1890	100m.sq	1 storey	stone ,mud,steel	courtyard	60cm	yes	6
23	Abu-Jaber dwelling	Salt	1887-1906	420m.sq	3 storeyes	stone , plaster,red tyle,wood	rectangular	60100-cm, 30cm	yes	6
24	Tukan dwelling	Salt	_	300m.sq	2 storeyes	stone ,concrete	rectangular	80100-cm	yes	5
25	Mu>asher dwelling	Salt	1893-1910	250m.sq	2 storeyes	stone	compact form(square)	60100-cm		4
26	Sukar dwelling	Salt	1879-1884	200m.sq	4 storeyes	stone,mud ,wood	compact form(square)	60100-cm ,25cm		5
27	Saket dwelling	Salt	1890	275m.sq	4 storeyes	stone	rectangular	60-100cm,30cm		5
28	Khatib complex dwelling	Salt	1860	600m.sq	4 storeyes	stone	rectangular	40120-cm		5
29	Mehaier dwelling	Salt	1890	300m.sq	2 storeyes	stone	courtyard	75 cm		7
30	Nabulsi dwelling	Salt	1880	250m.sq	2 storeyes	stone	rectangular	50 cm	yes	8
31	Qaqish dwelling	Salt	1878	300m.sq	3 storeyes	stone ,mud ,wood	courtyard	50 cm		6
32	Falahi dwelling	Salt	1860	100m.sq	1 storey	stone ,mud,wood,reed	compact form(square)	80cm		5
33	Sawalhe dwelling	Madaba	1913	55m.sq	2 storeyes	stone ,hay,wood,reed,mud	rectangular	100cm		4.25
34	S.Halase dwelling	Madaba	1913	300m.sq	1 storey	stone ,hay,wood,reed,mud	L-shape	75cm	yes	7
35	Farah dwelling	Madaba	1904-1908	600m.sq	2 storeyes	stone ,cement plaster	rectangular	75100-cm	yes	6.25
36	H.Halase dwelling	Madaba	1932	200m.sq	2 storeyes	stone,concrete	rectangular	4080-cm		5
37	Hamarneh dwelling	Madaba	1904	253m.sq	1 storey	stone	compact form(square)	100-120cm		7.5
38	Jomei>an dwelling	Madaba	1905	108m.sq	2 storeyes	stone	rectangular	70100-cm	yes	4.25
39	S.Hamarneh	Madaba	1904	80m.sq	2 storeyes	stone	rectangular	2070-cm	yes	4.25
40	Al-Aref dwelling	Amman	1923	200m.sq	2 storeyes	stone ,concrete	compact form(square)	3050-cm		5
41	Al-murtada dwelling	Amman	1925	225m.sq	1 storey	stone ,concrete	compact form(square)	5070-cm		4.25
42	Al-Taji dwelling	Amman	1927	300m.sq	1 storey	stone ,concrete	compact form(square)	2040-cm		5
43	Ghanma dwelling	Amman	1927	195m.sq	1 storey	stone ,concrete	rectangular	3060- cm		4.25
44	Farrah dwelling	Amman	1928	300m.sq	1 storey	stone ,concrete	compact form(square)	50cm		4.25

No.	Residential Building	Location	Era	Area	N. of storeys	Materials	Bld. Form	Wall thickness	shading devices	Height
45	Sharif Shaker dwelling	Amman	1928	200m.sq	2 storeyes	stone ,concrete	courtyard	3060-cm		4.5
46	Qsus dwelling	Amman	1929	210m.sq	1 storey	stone ,concrete	compact form(square)	2040-cm		4.25
47	Freh dwelling	Amman	1935	225m.sq	2 storeyes	stone ,concrete	rectangular	2040-cm		4.5
48	Sabagh dwelling	Amman	1935	200m.sq	1 storey	stone ,concrete	compact form(square)	2040-cm		4.25
49	Al-she>er dwelling	Amman	1920	200m.sq	2 storeyes	stone ,concrete	compact form(square)	3050-cm	yes	_
50	King Talal dwelling	Amman	1920	235m.sq	2 storeyes	concete	rectangular	50cm	yes	4
51	Al-Nabulsi dwelling	Bardun(S-Ghor)	_	105m.sq	2 storeyes	stone ,hay,wood,reed,mud	L-shape	50cm		4.25
52	Plot (1) dwelling	Souf	late 19th	65m.sq	1 storey	stone ,concrete	compact form(square)	80cm		5.5
53	Plot (2) dwelling	Souf	late 19th	65m.sq	1 storey	stone ,hay,wood,reed,mud	rectangular	80cm		4.5
54	Plot (3) dwelling	Souf	late 19th	120m.sq	1 storey	stone	rectangular	80cm		4.5
55	Plot (4) dwelling	Souf	late 19th	120m.sq	1 storey	stone ,wood,mud	compact form(square)	60cm		5
56	Plot (5) dwelling	Souf	late 19th	200m.sq	1 storey	stone ,concrete	compact form(square)	30cm		4
57	Plot (6) dwelling	Souf	late 19th	260m.sq	1 storey	stone ,concrete	L-shape	2050-cm		3
58	Plot (7) dwelling	Souf	late 19th	350m.sq	1 storey	stone ,concrete	L-shape	3080-cm		5
59	A-Kayed dwelling	Souf	late 19th	300m.sq	2 storeyes	stone	courtyard	3050-cm		3
60	Majali(1) dwelling	Kerak	1910	145m.sq	2 storeyes	stone ,hay,wood,reed,mud	U-shape	60cm	yes	3.5
61	Qsus dwelling	Kerak	1938	125m.sq	1 storey	stone	L-shape	2060-cm	yes	3
62	Sana>a dwelling	Kerak	1327	180m.sq	2 storeyes	stone ,mud	L-shape	50-100cm ,30cm	yes	3.85
63	Majali(2) dwelling	Kerak	_	150m.sq	2 storeyes	stone ,mud	compact form(square)	3080- cm	yes	3.5
64	Majali(3) dwelling	Kerak	_	135m.sq	2 storeyes	stone ,mud	compact form(square)	7085- cm		4
65	Majali (4) dwelling	Kerak	_	50m.sq	2 storeyes	stone ,mud	compact form(square)	70 cm		3.5
66	Majali (5) dwelling	Kerak	_	500m.sq	2 storeyes	stone ,mud	rectangular	85 cm	yes	2.65
67	Craft center (new)	Kerak	_	400m.sq	2 storeyes	stone ,mud	U-shape	80-150cm		3
68	Cafeteria (new)	Kerak	_	300m.sq	1 storey	stone ,mud	compact form(square)	100cm	yes	3
69	Museum (new)	Kerak	_	475m.sq	2 storey	stone ,mud	rectangular	280		3
70	Mawafi dwelling	Kerak	1926	114m.sq	2 storeyes	stone ,mud	rectangular	120	yes	5.25
71	Tarawneh dwelling	Kerak	1325	350m.sq	1 storey	stone ,mud	rectangular	60100-cm		3.75
72	Omari dwelling	Umm Qays	1922	80m.sq	1 storey	stone	L-shape	75cm		5

No.	Residential Building	Location	Era	Area	N. of storeys	Materials	Bld. Form	Wall thickness	shading devices	Height
73	Malkawi dwelling	Umm Qays	_	900m.sq	2 storeyes	stone	L-shape	75cm	yes	5
74	F.Russan dwelling	Umm Qays	_	700m.sq	2 storeyes	stone	courtyard	75cm	yes	5
75	Village school	Umm Qays	20th	75m.sq	1 storey	stone	U-shape	50cm	yes	5
76	Sawayti dwelling	Umm Qays	20th	160m.sq	1 storey	stone	courtyard	75cm	yes	4.5
77	Hawatmeh dwelling	Umm Qays	20th	200m.sq	1 storey	stone	courtyard	75cm	yes	4.25
78	Shana>a dwelling	Umm Qays	20th	75m.sq	1 storey	stone	rectangular	75cm	yes	3.75
79	Al-Hosban dwelling	Umm Qays	20th	75m.sq	1 storey	stone	compact form(square)	75cm		5
80	Al-Masri dwelling	Umm Qays	20th	125m.sq	1 storey	stone	rectangular	75cm	yes	5
81	Al-Shareef dwelling	Umm Qays	20th	225m.sq	1 storey	stone	courtyard	75cm		3.75
82	Omari Hosh dwelling	Umm Qays	20st	200m.sq	1 storey	stone	L-shape	75cm		4.25

A- Building Form Classification

Building form (type) is an important factor in studying climatic design, because there is an appropriate building form for every climatic region.. Knowing the best form for any climatic region is the purpose of this research. Suggesting best solutions are useful to improve thermal quality inside spaces.

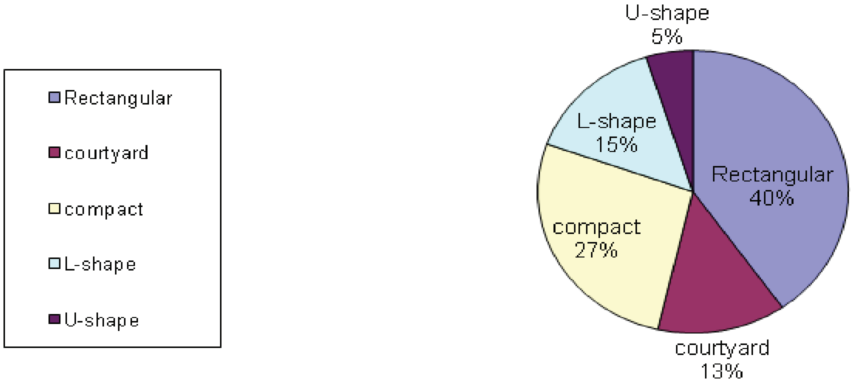

Figure 3 Outline of building forms percentages

B. Buildings Envelope Classification

Building envelope materials affect the climatic design of the building, through the thermal property of each material.

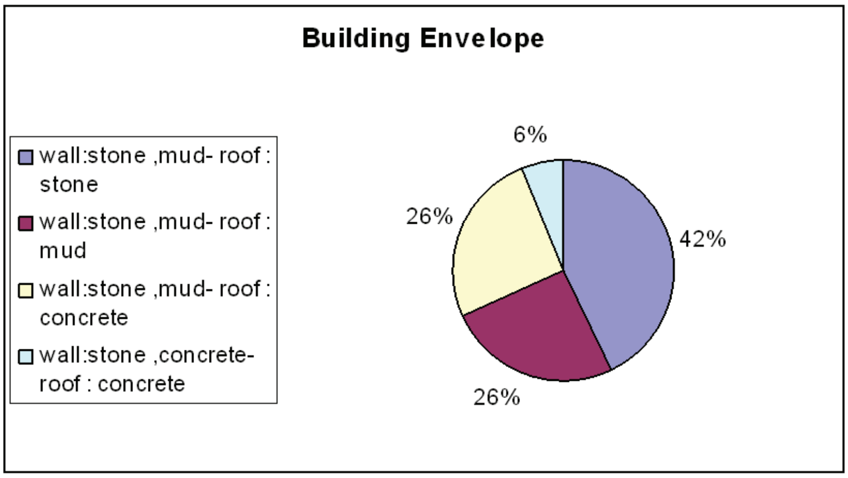

Figure 4: Outline of building envelope percentages

C. Wall thickness classification

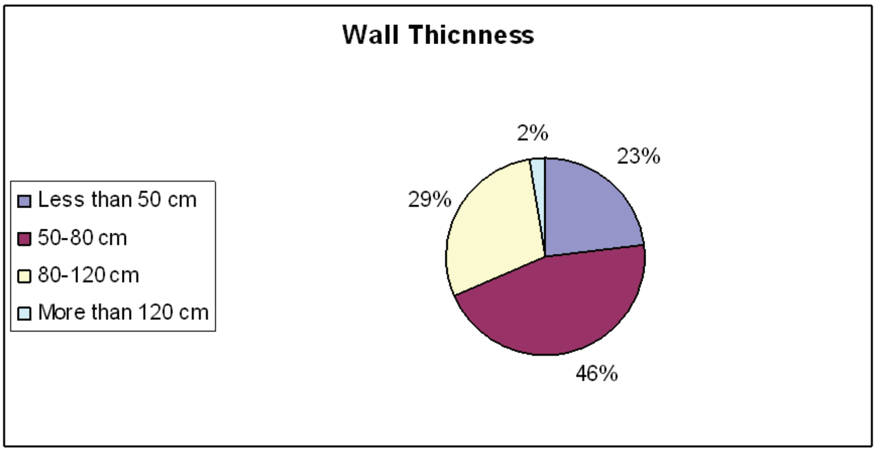

Figure 5. Wall thickness

D- Shading Devices

It is an important factor to determine the contribution to the heating and cooling loads in desert zone. Sixty one percent of the surveyed buildings do not have shading devices, while 39% of them use devices for thermal protection. There is a relation between the usage of shading devices and wall thickness. For building with thick wall there is no need of such devices because walls protect sun and the wall itself acts as shading element. Moreover, shading systems are much correlated with the orientation of buildings, for example, north sided walls do not need such devices.

E- Building orientation

Four orientation classifications were considered in this study and were used in the simulation process to come up with best and ideal building settings.

5.2. Building Simulation Process

Simulations have been conducted to obtain information about the behavior of building elements considering parameters as: geometry, used materials for walls, floors, roofs, orientation, and shading devices.

The selected buildings were simulated using DEROB-LTH software for thermal analyses. The simulation was done for the selected buildings running several cases applied to the five selected buildings types; rectangular, compact, courtyard, L-shape and U-shape. Figure 6 is shows the hierarchical classification of one type of building layout (rectangular form).

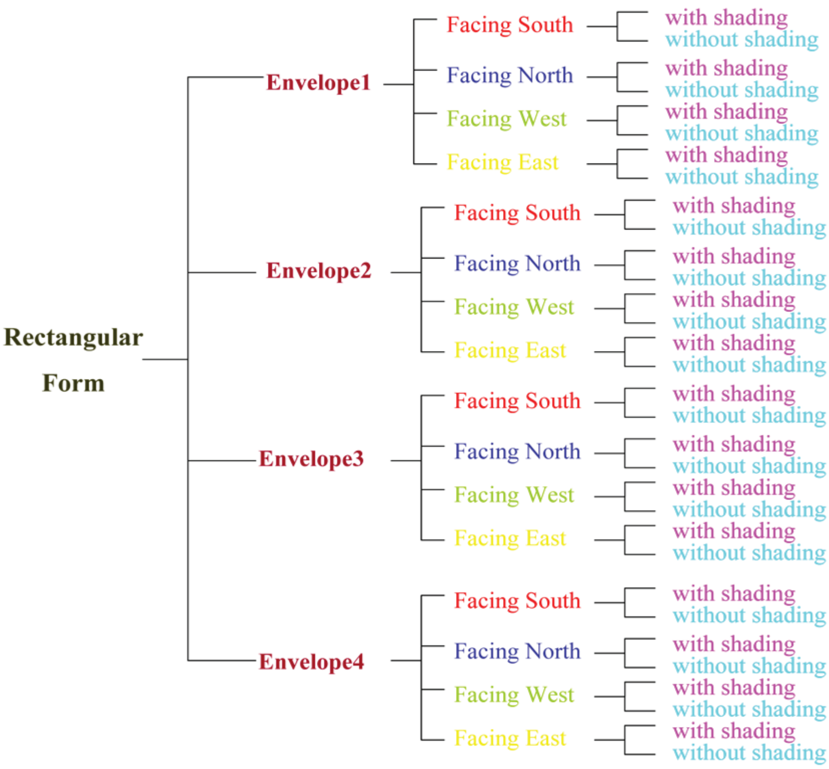

Figure 6. Building elements configuration for rectangular form

In the simulation process there was a limitation in drawing curves, as DEROB-LTH simulation program does not support drawing curve lines, therefore all openings were assumed to be rectangular.

There is constant data input for all the cases, which are:

1- The simulation was made for all the year, for the four seasons.

2- The ground reflectivity was 20%, and the soil resistance 1.87 m2, k/w.

3- The floor materials was constant for all the cases which was in order; earth (100cm), gravel jeer (50cm), base coarse stone (10cm), sand (50cm), cement mortar (30cm) and ceramic tiles (20cm).

Table 3. Materials property for floors

Floors

Materials	Thickness (cm)	Conductivity	Sp.Heat	Density
Earth	100	1.4	0.22	1300
Gravel jeer	50	0.37	0.23	1400
Base coarse stone	10	1.5	0.23	2000
Sand	50	0.4	0.24	1700
Cement mortar	30	0.93	0.29	1800
Ceramic tiles	20	1.2	0.24	2000

4-The windows were single glassed windows type. The door material is high wood density.

5-The Absorbance factor of all walls, floors, and roofs, is 70%, while the Emittance is 87%.

6-A family of five persons lives in these buildings in all of the cases.

7- Heating is used only in winter, the normal comfort temperature is required is(18°C).

8-The normal comfort temperature in summer is (25°C).

9- The internal loads for all volumes in all cases are constant, building equipment. Used are TV, refrigerator and other appliances used in kitchen.

10- The color of the inside surface is white.

Table 4. Materials property for doors and windows

Doors

Materials	Thickness (cm)	Conductivity	Sp.Heat	Density
high wood density	5	0.37	0.13	1000

Windows

Materials	U-value	G-value	Tsol
Single glass	5.88	0.636	0.45

5.3. Selected Buildings Description

1- Rectangular Form Simulation (Old dwelling reused as a museum, located in Kerak)

This building is two-story building, with area of 425m^2, and the ground story is underground with 80 cm wall thickness, while the first storey is 60cm wall thickness. Building height is 3.0m.This building has no shading devices. The construction material is natural stone and mud, for walls and ceilings.

2- Compact Form Simulation (Al-Murtada dwelling in Amman)

This building is one storey building, its area is approximately (225m2), and wall thickness is 60 cm. Building height is 4.25m .This building has no shading devices. The construction material is Jordan stone for walls and concrete for ceilings.

3- Courtyard Form Simulation (Eweidat dwelling in Jerash)

This building is one storey building, its area is approximately (100m2), and wall thickness is 60 cm. Building height reaches to 6.00m .This building has shading devices. The construction material is stone for walls and mud for ceilings which is carried on (I) beams made from steel.

4- L-shape Form Simulation (S-Halase dwelling in Madaba)

This building is one story building, its area is approximately (300m^2), and wall thickness is 75 cm. Building height is 7.0m. This building has shading devices. The construction material is stone for walls and mud for ceilings which is carried on wood beams.

5-U-shape Form Simulation (Al-Nabelsi dwelling in Irbid)

This building is two-story building, its area is approximately (360m2), and wall thickness is 40 cm. Building height is 5.25m. This building has shading devices. The construction material is stone, concrete for walls and concrete for ceilings which is carried on (I) beams of steel.

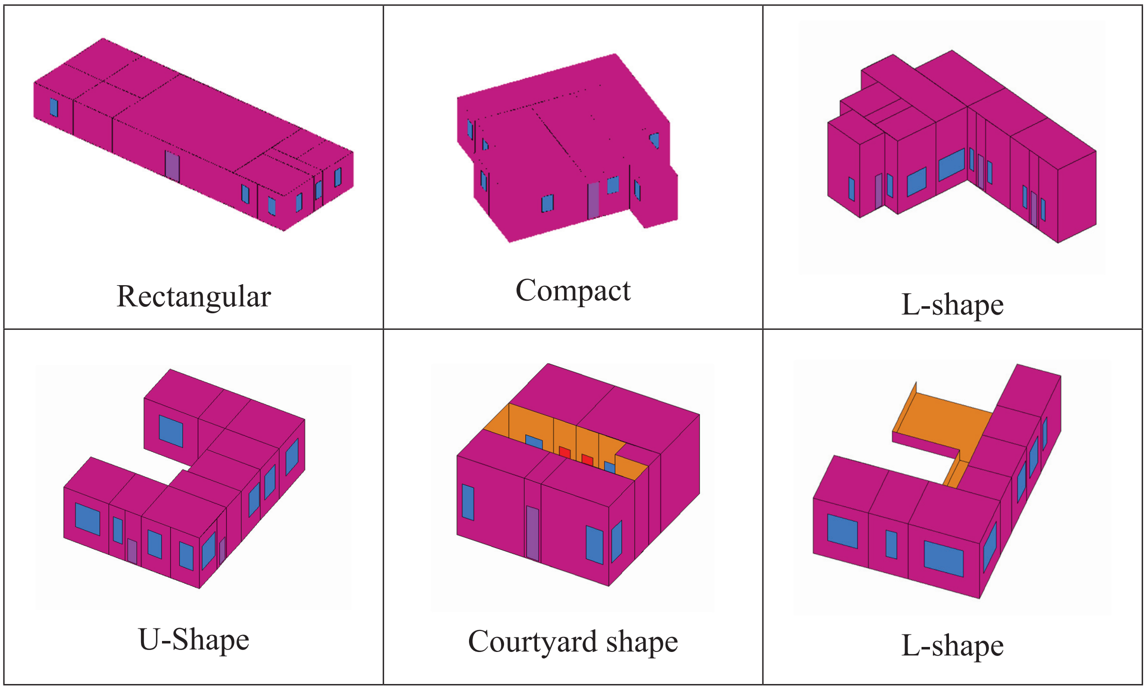

Figure 7. Several buildings layouts used as prototypes of vernacular buildings in desert region in Jordan.

5.4. Building Simulation Results

Once the different building forms were simulated, several results were generated showing heating and cooling loads, indoor minimum and maximum temperatures, and thermal comfort.

5.4.1. Heating and Cooling Loads Results

The yearly heating and cooling loads were calculated for the above mentioned cases in the badia region as follows: The rectangular form samples scored the minimum yearly heating and cooling for, located in the North-east desert climatic region is in the case were the material was 25 cm stone, 10 cm mud, 25 cm stone for walls, and 25 cm stone for roof, facing south and without shading devices for heating, while the minimum cooling is in the case were the material

25 cm stone, 10 cm mud, 25 cm stone for walls, and 25 cm mud for roof, facing south, with shading devices. For the compact form; the minimum heating is in the case were the material was 35 cm stone, 25 cm mud, for walls, and 25 cm mud for roof, facing south and without shading devices, The minimum cooling was in the case were the material was 35 cm stone, 25 cm mud, for walls, and 25 cm concrete for roof, facing north, with using shading devices. Courtyard form consumption was minimum in the cases the material was 25 cm stone, 10 cm mud, 25 cm stone for walls, and 25 cm stone for roof, facing north and without shading devices for heating demand, while the minimum cooling was in the same case were the material was 35 cm stone, 25 concrete for walls, and 25 cm stone for roof, but facing south, also without shading. The case was the material was stone, 30 cm mud, for walls, and 25 cm mud for roof. Facing west and without shading devices was the minimum heating for L-shape form, and the case using stone, 30 cm mud, for walls, and 25 cm stone for roof, facing south, with shading devices was the minimum cooling for L-shape form. The U-shape energy consumption results were in the case uses 15 cm stone, 10 cm mud, 15 cm stone for walls, and 25 cm mud for roof. Facing south and without shading devices for heating demand , and the case uses 15 cm stone, 10 cm concrete, 15 cm stone for walls, and 25 cm mud for roof , facing west with shading for cooling demand.

Table 5: Minimum heating and cooling loads of different building forms in Northeast desert climate

Bld. Form	Heating (kWh)/m2	Cooling (kWh)/m2
1-Rectangular Form	4.91	4.23
2-Compact Form	3.39	6.33
3-Courtyard Form	9.32	24.71
4-L-shape Form	8.2	5.54
5-U-shape Form	5.35	8.55

It can be noticed that the best form for heating demand is the compact form. Then the rectangular form, U-shape, L-shape, and courtyard form in order. The courtyard form is the worst in both heating and cooling demand. This is because, the exposed areas of the single detached houses are high compared with other building layouts. For cooling demand the minimum consuming energy form is rectangular and L-shape form, in the other hand, the maximum one is the courtyard form. It can be seen that both cooling and heating consumption are high in the desert region, were there is need for cooling through the day also the heating need through the night. It is recommended both rectangular and compact form for desert regions, to minimize energy consumption, because the heating demand is high as the cooling one.

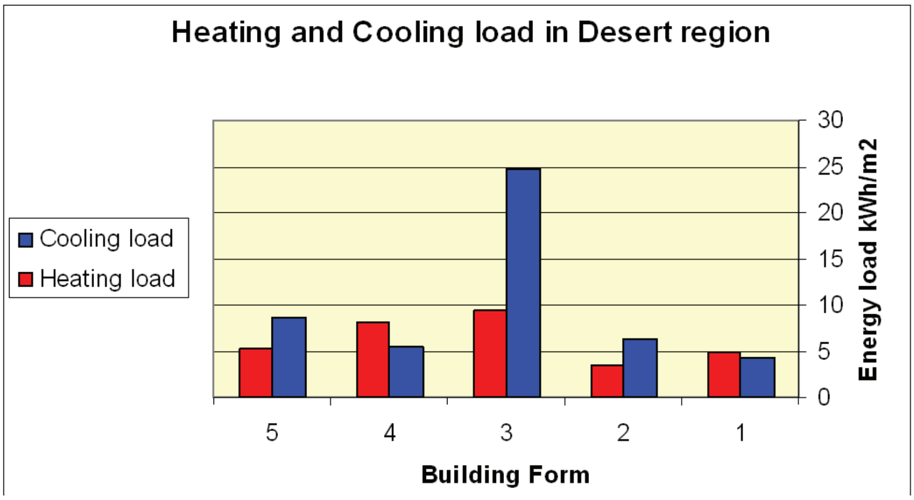

Figure 8: Heating and cooling loads of different building forms in North-east desert climate

5.4.2. Indoor Temperature results

The indoor temperature results or the operative temperature can be an indication of the thermal comfort. For the purpose of this study comfort temperatures were taken from Mahoney tables for the three climatic regions.

Jordan valley indoor temperature of the five forms are as follows ; rectangular form in the Jordan valley is comfortable all the days in summer and winter, while in the night, it is just comfortable in the summer. The compact form is comfortable all the time in summer and winter. The courtyard form is not comfortable at all in the summer days. While the L-shape type is not comfortable in the summer days. U-shape form has no comfort in the summer days, but it is comfortable all other times. It can be noticed from the above graphs that the best comfortable forms is the compact form then comes the rectangular form. All of the open forms have no comfort especially in the summer days.

Rectangular and compact forms in the Desert climate have thermal comfort all the time in summer and winter. There is no comfort in the courtyard form from May to September. In the other hand, the L-shape Form has comfort all the time expect in the summer nights. U-shape has no comfort in the nights of summer and winter, and in summer days. That means U-shape form is not a comfortable form in the desert climate region. The following table shows heating and cooling loads and indoor temperature results of all cases.

“Best Fit “Building models once the building forms model had been calibrated, the results of 480 cases have been calculated and the effect of the different design parameter has been analyzed. The best building form configuration will be discussed for desert region.

The minimum heating and cooling of the best building configuration was figured out from (32) cases for the same building form in desert region. The best configurations of every building form, rectangular, compact, courtyard, L-shape and U-shape forms were compared to each other to reach the “Best Fit “ form for desert regions as shown in table 7.

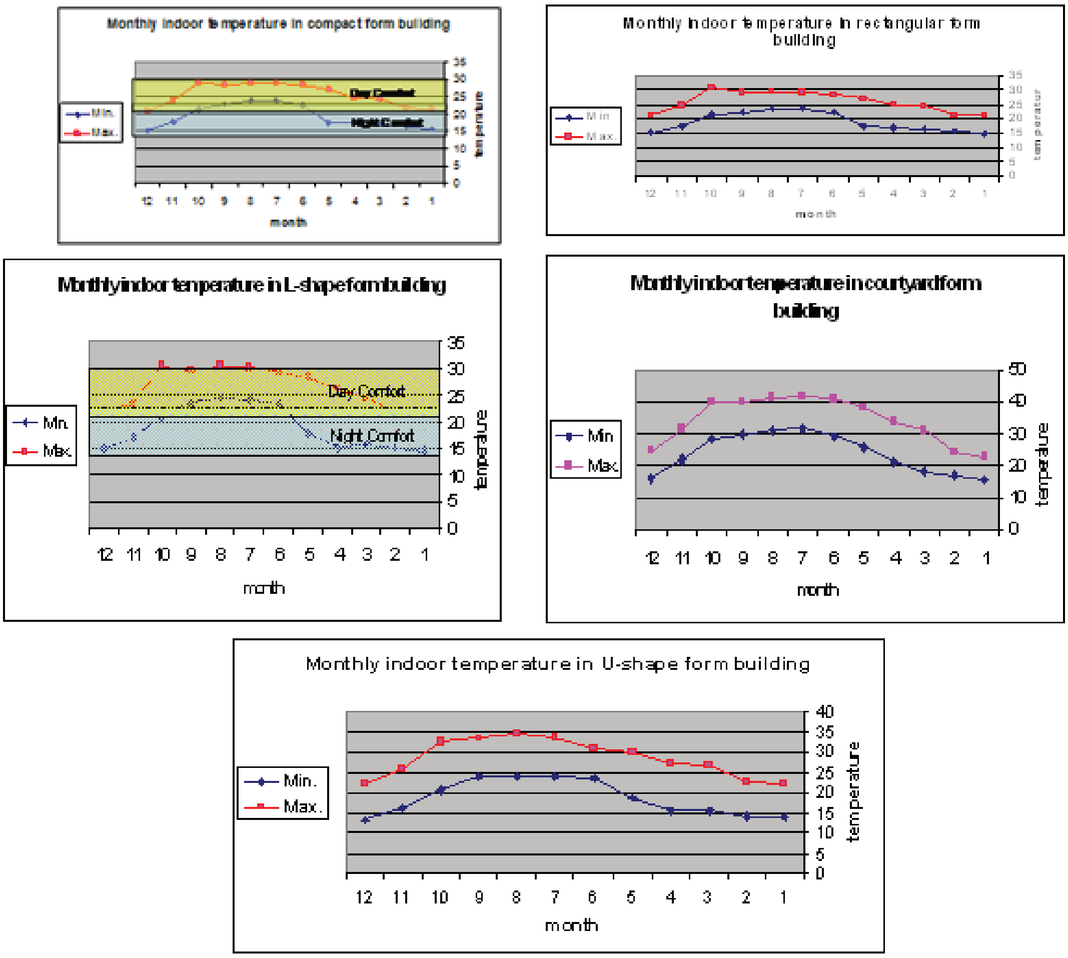

Figure 9. Monthly indoor temperature of different building forms in the desert region in Jordan

Table 6 : Building configurations and minimum energy consumption of the studied buildings.

North-east Desert Regions							
Energy ConsumptionkWh/m2		Building Form	Walls Materials	Roof Materials	Orientation	Shading Devices	Total Energy
Heating	4.91	Rectangular	stone-mud	stone	north	with shading	
Cooling	4.23	Rectangular	stone-mud	mud	south	with shading	280.597
Heating	3.39	Compact	stone-mud	mud	south	without shading	
Cooling	6.33	Compact	stone-mud	concrete	south	with shading	272.398
Heating	9.32	Courtyard	stone-mud	stone	north	without shading	
Cooling	24.71	Courtyard	stone-concrete	stone	south	without shading	691.599
Heating	8.2	L-shape	stone-mud	mud	south	without shading	
Cooling	5.54	L-shape	stone-mud	stone	west	with shading	339.301
Heating	5.35	U-shape	stone-mud	mud	west	without shading	
Cooling	8.33	U-shape	stone-mud	mud	south	with shading	391.484

Table 7. Optimized building parameter in desert region.

Region/design parameter	Building form	Building envelope/ walls	Building envelope/ ceiling	Long elevation facing	Shading devices
North-east desert/ Heating	Compact	Stone, mud	25cm mud	South	No shading devices
North-east desert/Cooling	Rectangular	Stone, mud	25cm mud	South	With shading devices

5.4.3. Optimized Design for Badiaclimatic region

This study concluded optimized design elements for desert region in Jordan. The building parameters should be taken into consideration in the pre–construction phase in the design process. Architectural designers, engineers, and decision makers should consider the optimized situation in setting the thermal comfort codes in building construction taking into account the climatic conditions for every case.

In Badia region, rectangular and compact forms are most preferable for minimizing heating and cooling energy consumption. Stone and mud act positively in minimizing energy consumption because they have lower U-value compared to that of concrete. It is noticed that the effect of roof on the heating and cooling loads is much less than that of walls. In most cases, the best orientation from the standpoint of energy consumption was south-facing facades. However, in south facades, there was a need for shading devices for the purpose of minimizing cooling loads.

According to vernacular buildings survey, it was noticed that rectangular-form buildings are 40% of the vernacular buildings sample. The compact-form sample represents 27 % of the vernacular buildings using stone, mud for walls, and mud for roof.

The best way to test the performance of vernacular buildings is to compare it with modern contemporary buildings. Comparing the energy consumption of the simulated vernacular buildings to contemporary building showed that approximately all the simulated vernacular buildings perform better than any contemporary building.

The following figure presents the final configuration of all building design parameters handled in this research, giving the minimum heating and cooling loads associated with higher thermal comfort.

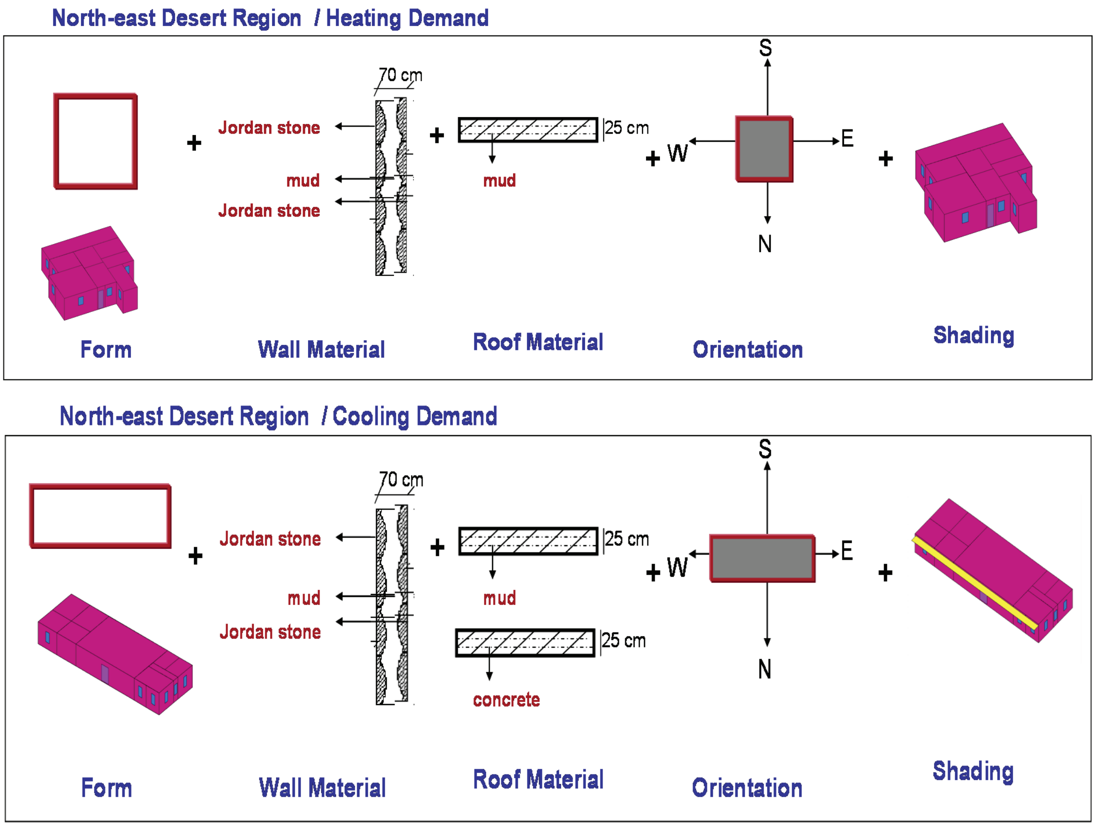

Figure 10 : Final Configuration of the best building design parameters for badia region in Jordan

6. Conclusions and Recommendations

Energy efficiency and thermal comfort in the building sector in Jordan using passive techniques has both short and long-term benefits. The short-term benefits are skipping the cost of applying heating and cooling mechanical systems, and low cost construction where we use local materials and simple forms. The long-term benefit is apparent in reducing energy consumption in the long run of building lifecycle.

In addition, this research showed that thermal comfort in the indoor environment and the current techniques for energy conservation of the modern contemporary buildings of Jordan has to be improved. This was clear in comparing heating and cooling loads resulted from the vernacular buildings simulation and the energy consumption of modern contemporary buildings in Jordan. Good bioclimatic design techniques exist in vernacular architecture and can be applied to the modern buildings using advanced technologies. This leads to acceptable human comfort in indoor environment of buildings with minimum energy consumption, and guide designers to create a better response to the environment.

The study recommends different combinations of building layout, building materials, and orientation, which fulfill the requirements of minimizing energy consumption in buildings and achieve high thermal comfort. The following parameters influence the thermal comfort and energy consumption in a bioclimatic passive building:

First: *Building Form*

Compact forms are preferable to achieve thermal comfort and minimize heating and cooling loads for all climatic regions in Jordan, specifically, compact form is preferable for desert region in winter while rectangular form is better in summer.

Second*: Building envelope / materials*

Materials with relatively high time lag and density will improve the house climatic behavior in Jordan. Less U-value will improve insulation, so that a combination of mud material with stone, local materials used in vernacular buildings, has lower U-value and works very efficiently in Jordan.. This reduction of the U-values of the building elements was the main reason for the advantages effects on the indoor climate especially in winter. Insulated roof will make a big difference in the indoor temperature. It was seen that the use of asphalt insulation in the concrete slab roof, work perfectly and give low energy loads results.

Third: *Building Orientation*

South and west orientations for windows are best in the desert climatic region in Jordan for minimizing both heating and cooling demands in order to increase solar gain in winter.

Fourth: *Building shading devices*

Shading devices is a must in regions such as Jordan valley where cooling and ventilation is much needed. .however, it must be limited to the summer season for desert regions using vertical movable shading devices .

Based on the above mentioned information the study recommends the followings:

First; comprehensive researches of building design parameters must be conducted during design process using advanced simulation process for particular cases, changing building parameters to reach to the best design where thermal comfort is achieved with minimum heating and cooling energy consumption.

Second; it is good to let architectural designers aware of the concepts of energy conservation in building construction, where the energy consumption is highly increased. It will be useful to make specific bioclimatic codes and regulations with a comprehensive framework in building construction code to reach to thermal comfort.

Third; it is recommended to make a previous study of the climatological conditions in order to apply the most appropriate techniques, materials and technologies of modern construction to obtain buildings with high quality of bioclimatic design.

Fourth; developing codes, regulations and legislations to respect the climatic factors and make them major influential factors in the design process.

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التصميم المعماري الفعال لاستخدامات الطاقة في المساكن المحققة للارتياح الحراري في المناطق الحارة-الجافة- حالة دراسية للابنية التراثية في الاردن

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الملخص:

يهـدف هـذا البحث الى دراســة تاثير عناصر التصميم المعمــاري على استهلاك الطاقة في المبــاني السكنية في الاردن. تمت دراسة مجموعة خصائص الابنية التراثية من خلال تفحص استهلاك الطاقة لاستخدامات التبريد والتدفئة، وتمت مقارنة هذه الخصائص مع الابنية الحديثة. ثمانون مبنى تمت دراستها في عدة اقليم مناخية في الاردن، وتم تصنيفها بناء على اربعة متغيرات اساسية هي: شكل المبنى، توجيه المبنى، مادة البناء واستخدام المظلات للفتحات. تم استخدام برنامج المحاكاة المشهور (دي روب) لتحليل عناصر التصميم وعلاقتها باستهلاك الطاقة في هذه المباني لتحقيق المستوى المقبول من الارتياح الحراري.

خرج البحث بنماذج ومعايير للتصميم المعماري الحديث مستندا الى خصائص الابنية التراثية لاستخدامها وللحصول على افضل الحلول المعمارية لتحقيق الحد الادنى من الطاقة مع توفير الراحة الحرارية للمستخدمين.