International Scientific Journal
Journal of Environmental Science
http://environment.scientific-journal.com/

Design Analysis of the Courtyard Building Morphology Based on a Bioclimatic Assessment in Hot Arid Region

Marouane Samir Guedouh
Department of Architecture and Urbanism
University of Batna 1
Batna, Algeria
merouanesamir.guedouh@univ-batna.dz

Kamal Youcef
Department of Architecture
University of Biskra1
Biskra, Algeria
youcefkamal2008@gmail.com

***Abstract*—This paper aims to solve a design dilemma between a specific building's morphology and a hostile climate conditions. In hot and dry regions, courtyard building is the most building designs used to face such extreme climatic factors especially hot air temperatures. In the search of the optimum courtyard building form that can be passively adapted to extreme climate conditions, an on-site measurement campaign has been conducted, using a digital monitoring instrumentations, to record: air temperature, relative humidity, illumination levels and wind speed values in an existing courtyard buildings samples with various morphologies for both summer and winter seasons in order to extract morphological indicator values which will be used later in building's conceptual process by designers. The important findings are related to the existing of a reversed formula using extreme climatic factor values to calculate the optimum morphological indicators for the best courtyard building design in hot and dry regions.**

Keywords—Courtyard building morphology; Bioclimatic design; On-site measurement campaign; Hot and dry climate

I. INTRODUCTION

In the current context, the global energy crisis is progressively taking inevitable influences, an exhausting consumption of energy and greenhouse gas emissions, starting by the architectural conception, first point of the construction process [1]. The new challenges associated with international agreements such as the Rio Summit (1992), the Kyoto Protocol (1997) and, specifically in developed countries, the challenge to halve or minimize the energy consumption of buildings (RT 2012), as well as the goal of halving greenhouse gas emissions by 2050 [1].

Sustainable development has triggered new stock movements and considerations that affect construction throughout its life cycle. The energy consumption and the air pollution are the major obstacle of the building construction process. The observation of introverted buildings from the point of view forms and the reasoned use of technical properties, where we can extract information on the formal arrangements related to various geo-climatic data: the sun trajectory, the sky conditions, and the winds direction... etc., it is also possible to illustrate information from natural constraints adaptation [5], such as: formal responses of the building envelope, and how, it is adjusted to the climate [6]. However, the building must be integrated perfectly into its environment, taking into account all the physical and psychological factors, towards the major objective of a comfortable and energetically efficient building.

Providing comfortable indoor spaces needs to take into account climate tribulations such as: intense sun radiation, excessive heat, hot winds... etc. [8], these influence the interior spaces comfort. Our concern for building's environmental quality and energy consumption becomes important as well as the formal or functional qualities [3]. Empirical studies will be conducted for the "courtyard building" case by developing certain numbers of possible criteria that characterize such a configuration and it the impact on the adjacent thermal environment [7].

II. PRESENTATION OF CASE STUDY

The data collected from the weather station in Biskra and the National Office of Meteorology (NOM), the Biskra area is considered an arid climate zone with mild cold winters and hot dry summers. The prevailing winds are: Northwesterly (cold winds) that blow from November to May, and South and South-east (warm winds) blowing from July to September.

A. Biskra downtown

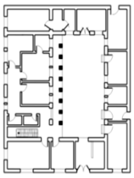
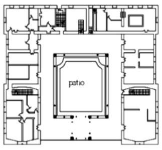
Since its promotion to the range of Wilaya in 1974, the city of Biskra becomes a regional urban center. The city's position allows it to connect the North to the South of the country. Biskra is also located in the southern foothills of the Saharan Atlas (Aures), which gives it an arid climate. These particular aspects of geo-climatic and topographic factors have played a vital role in the development of the region in general and the city in particular.

B. Courtyard buildings : Selection, presentation and choice's criteria

The courtyard buildings selected are representative of the case study architecture, with specific morphological characteristics. Each courtyard buildings represent a typical morphology of the architectural style; these styles marked the city architecture history. The following criteria were decisive in the selection of our corpus study:

- Usage: public work-office.
- Style: Morphology and architectural form.
- Bioclimatic values: degree of climate adaptation.

TABLE I. TABLE STYLES

Building 1 : Daïra office (Traditional)		
		
- R+1 - Earth bearing wall (40cm) - Solid slab floor - Glazed rapport : 22%	- Opening ratio: 31% - Total area : 490,73 m2 - Average high of the building : 7,25m	- Courtyard surface : 156,12 m2 - Glazed surfaces rapport : 25%
Building 2 : CPA office (Colonial)		
		
- One-Storey building - Earth bearing wall (50cm) - Solid slab floor - Glazed rapport : 21%	- Opening ratio: 15% - Total area : 1343 m2 - Average high of the building : 12m	- Courtyard surface : 200 m2 - Glazed surfaces rapport : 18%
Building 3 : laboratory building at Biskra university (Contemporary)		
		
- 4-Storey building - Double brick wall with air gap (30cm) - Post-beam structure - Glazed rapport : 37%	- Opening ratio 7% - Total area : 965 m2 - Average high of the building : 20m	- Courtyard surface : 67,71 m2 - Glazed surfaces rapport : 26%

a. Photography Source: Author

III. Morphological Analysis

A. *Global links analysis*

The courtyard building does not possess just one, but two vertical envelopes [9]. The outer one, separating the building from its external environment, the other internal, separates the interior spaces of the courtyard itself [2]. If we stick to a purely topological approach to the plan, we find, in any courtyard building, the three successive zones included in each other [7].

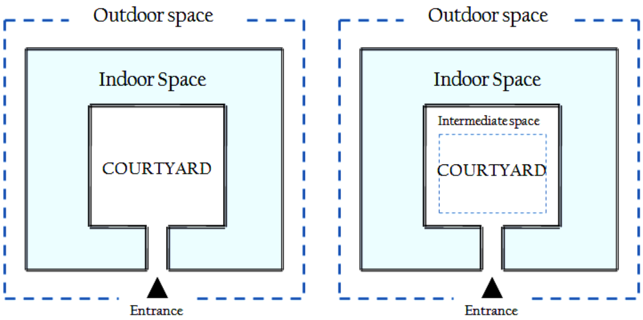


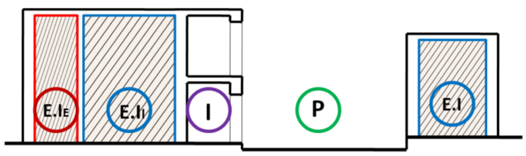
Fig. 1. The trilogy zonal of a courtyard building (courtyard/indoor space/outdoor space).

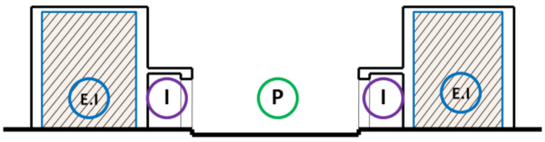
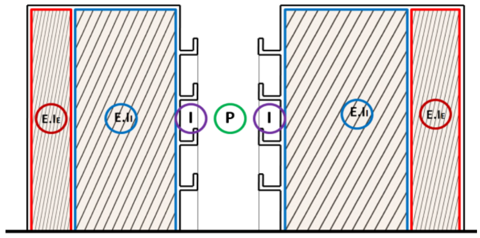
The study of the connections between the courtyard and the interior spaces are carried out: a direct connection between the internal envelopes and the courtyard throughout the piercing, or an indirect connection between the two previous ones; an intermediate space [3]. We will see that it may be galleries or small open spaces, in any case, have a situation and intermediate qualities between the courtyard and the interior spaces.

B. *Hierarchical and topological rapport*

There are several ways to approach these rapports; the first is to compare the Courtyard surface with the interior spaces area possibly presenting this report as a percentage. A second way seems better to compare not surfaces, but lengths taken along a cross section made on the building, by comparing the respective depths of the three zones: the courtyard, intermediate or transitional cover space and the indoor spaces [9].

TABLE II. TABLE STYLES

Building 1

One side of intermediate space E.I > P > I

Building 2

Courtyard domination case P > E.I > I
Building 3

Indoor spaces dominate case E.I > P > I

IV. Morphological Indicators

The morphological indicators used in this research make it possible to evaluate the thermal environment from the morphological characteristics of the building and its courtyard [9]. According to the literature review, the important ratios and morphological indicators are exclusively chosen in relation to the solar exposure.

A. Opening ratio (OR)

Then courtyard opening ratio is calculated from the rapport of the courtyard surface to the building's total plan area. This rapport allows us to know the importance of the size, exposure to solar radiation and the natural light penetrating amount of a courtyard.

B. Aspect ratio (AR)

The aspect ratio is an important consideration of the effectiveness of a courtyard as a conduit of nature, where the degree of sky-openness, is of supreme importance. The higher is the aspect ratio, the greater the exposure of the courtyard to the sky conditions. This exposure allows the warming by the sun during the day, the cooling by the cold climate at night, and some breeze penetrations [5].

C. Solar shadow index (SSI)

Conversely, the solar shadow index examines exposure to the winter sun. The higher solar shade index, the deepest is the courtyard, and less the winter sun reaches the ground, or even the north wall of the courtyard [5].

Table 3 summarizes the different ratios already quoted above of the different courtyard buildings selected.

TABLE III. Table Styles

	R.O	***R.A***	***IOS***
Buil.1	31%	29,7%	0,21
Buil.2	15%	40,9%	0,42
Buil.3	7%	10,6%	/

V. Measurement Campaign

The complexity of in situ research requires a long-term investigation to test the bioclimatic value of the samples. These buildings of different morphologies generate specific thermal conditions, which will be examined through an on-site investigation to extract the maximum of thermal passive strategies.

Objectives of measurement campaigns is to analyze and reinterpret the role of the courtyard building in a morpho-climatic vision, to seek the comfort requirements by introducing the courtyard as a thermal conditions generator in relation to the climatic conditions of an arid region [8].

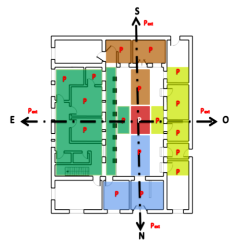
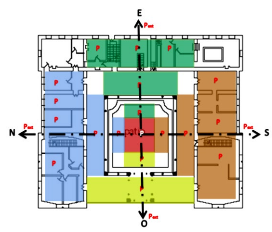
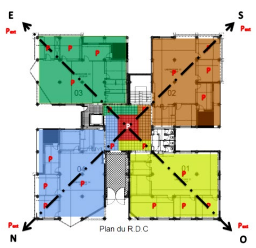
A. Measurement stations choice

The chosen days for the onsite measurement are the most representative of the extreme seasonal conditions. Measures are taken to cover all representative days:

- At 9h for the beginning of the day.
- At 11h for the midday.
- At 14h for the afternoon.
- At 17h for the end of the day.

In order to study the internal thermal environment, we proceeded to a zonal distribution according to the different orientations; to cover much area around the building for all the selected samples. The center of the courtyard as a measurement repair (Tab. 4).

TABLE IV. Zoning And Location Of The Measurement Stations

Building 1	***Building 2***
	
Building 3	***Legend***
	Courtyard (Central Zone) Northern Zone Eastern Zone Southern Zone Eastern Zone P Measurement station Orientation Axis

B. Collected data treatment

Air temperatures (°C) and relative humidity (%) Represent the most important quantitative data for thermal environment evaluation. After the achievement of the measurement campaign, we calculated the following means: air temperatures means and relative humidity means of the different zones.

VI. RESULTS ANALYSIS

A. Thermal variation analysis between the different courtyards

A first analysis validates that the different courtyards of the selected buildings generate different thermal environments. Measurement results show a large dissimilarity between one-storey, two-storey and multi-storey buildings (Fig. 2). It is clear that the courtyards of one and two storey buildings are the hottest in summer season, due to sun exposition, while multi-storey building with the deep courtyard is the coolest; this is due to the depth that has a major impact on the thermal environment in summer [11].

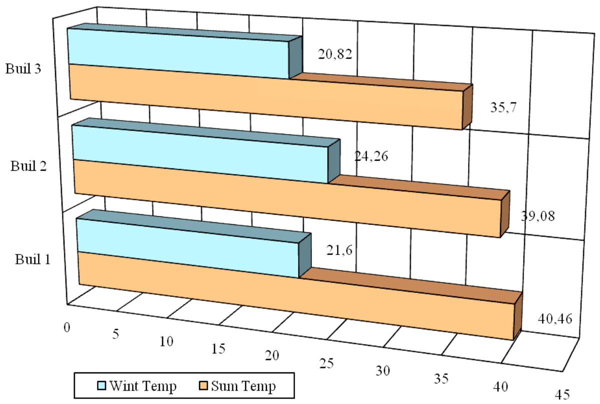
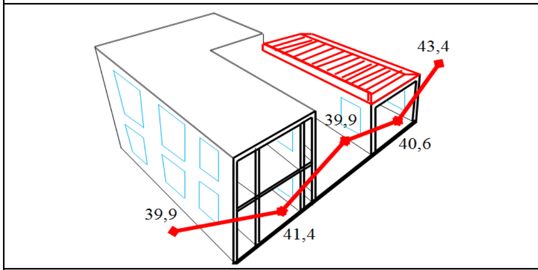
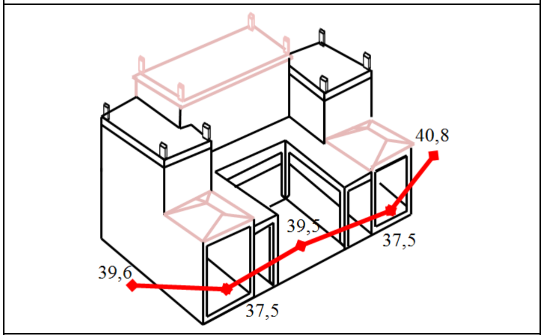
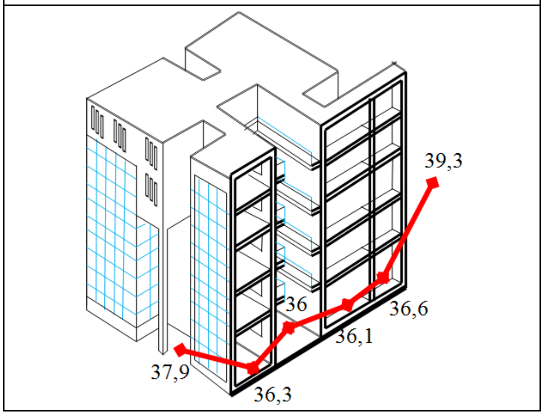


Fig. 2. Seasonal air temperature variation (All courtyards).

B. Analyse des variations thermique entre les bâtiments à patio

The analysis of air temperature variations along the North-South and East-West axes is based on the superposition of thermal variation graphs on vertical sections of buildings. This technique makes it possible to evaluate changes in temperature judiciously. From the three areas that make up a courtyard building: the exterior, the courtyard and the interior spaces. This superposition will also make it possible to make a reading of the variations with respect to the morphological characteristics of the buildings with courtyard.

TABLE V. SEASONAL AIR TEMPERATURE PROFILES IN THE SELECTED BUILDINGS

Summer air temperature Variations




In general, the difference between the air temperatures recorded outside the building and the center of the courtyard is about 3°C in the deep courtyard case. The courtyard manages to maintain pleasant indoor temperatures, as is the case with adjacent spaces, which have temperatures that approximate those of the courtyard, and this depends on the orientation [10]. The presence of the courtyard allows solar gains in winter even at the end of the day for spaces oriented North and East.

The thermal benefits of a courtyard are:

1) Better protection through intermediate spaces: galleries, arcades, awnings and corridors ... etc.

2) Multiply the choice of positions and sizes of openings and orientation.

3) The introduction of vegetation and water inside the building.

I. CONCLUSION

A significant amount of data was collected under typical meteorological conditions in the area during the investigation period. In each courtyard building studied, we clearly observed the difference between the thermal qualities. Building 3 is the most protected from overheating in summer, due to the depth and minimum courtyard opening ratio, as well as solar protection of vertical surfaces by galleries and a double skin exterior façade system for the protection of glass surfaces.

The air temperatures and relative humidity measured vary according to different conditions. The first observation, a variation observed between the different areas of the same building, where the Eastern and Western zones are the hottest. We found that there is a large phase shift in daily and annual temperatures. The morphological parameters of a courtyard building should be deeply related in proportion to the geometric composition of the courtyard, which can be designed in a combination of important morphological indicators such as: the depth of the courtyard, the various ratios and rapports. Proportions, which fundamentally control the thermal environment of the building, can be developed in a proportional approach.

REFERENCES

[1] A. Al-Dawoud, Thermal performance of courtyard buildings. Energy and Buildings, 40 (5), 906-910, 2008.

[2] A. Rapoport, The Nature of the Courtyard House: A Conceptual Analysis. Tradition Dwelling Settlements Rev, 2007.

[3] A.S., Muhaisen, and M.B. Gadi, Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate of Rome. Building and Environment 41, 245-253, 2006.

[4] B. Edwards. & Al., Courtyard Housing: past, present and future. Taylor and Francis, New York, 2006.

[5] J. Reynolds, Courtyards: Aesthetic, Social, and Thermal Delight. New York: John Wiley & Sons, Inc, 2002.

[6] K. Douglas, Courtyards: Intimate outdoor spaces. Gibbs Smith, Layton, Utah. 2005.

[7] M. Taleghani, Dwelling on Courtyards: Exploring the energy efficiency and comfort potential of courtyards for dwellings in the Netherlands. Architecture and the Built Environment N°18, Germany, 2014.

[8] M. S. Guedouh and Al., Courtyard Building a thermal and daylight regulator in hot and arid regions. A case study. International Scientific Journa, Journal of Environmental Science, Volume 6, 2017.

[9] N. Al Masri, Courtyard housing in midrise building. An environmental assessment in hot-arid climate. Master of Science in Sustainable Design of the Built Environment. Faculty of Engineering, the British University in Dubai, 2010.

[10] S. Abdulac, Maison à patio. Rapport final N°4-5, Ministère de l'Urbanisme et du Logement, France, 1982.

[11] S. Bin, Impacts of the Courtyard with Glazed Roof on HouseWinter Thermal Conditions. World Academy of Science, Engineering and Technology 76. 2011.

[12] Sh. Heidari, A deep courtyard as the best building form for desert climate, an introduction to effects of air movement. Case study: Yazd. Faculty of Architecture, University of Tehran, Tehran, Iran, 2010.