451: Microclimatic behaviour of urban forms in hot dry regions. Towards a definition of adapted indicators.

Moussadek DJENANE[1.2], Abdallah FARHI[1], Mohamed BENZERZOUR[2], Marjorie MUSY[2],

Department of architecture. University Mohamed Kheider. Biskra. Algeria[1]
ENS Architecture de Nantes. Laboratoire CERMA. France.[2]
moussadek@gmail.com

Abstract

This research deals with the influence of urban morphology on the climatic environment constrains in hot dry regions. It is based on a comparative approach between homogeneous urban forms belonging to the same context. Basic indicators are suggested and evaluated. They correspond to two levels of both spatial and climatic scales: on the first hand the street which belongs to urban canopy and on the second, the urban tissue which represents a homogenous morphological area.

The analysis concerns these two urban space composition levels. It aims with their influence on both microclimatic conditions and urban forms. Béni-Isguen city located in the M'zab Valley, in the south east of Algeria, in full desert is the case study of this research.

The methodology applied, consists on the superposition of morphological and microclimatic analyses. We firstly present the morphological characteristics and indicators analysed and then evaluate their influence. This study uses local climatic data resulting from field measurements carried out during summer conditions.

Keywords: Urban morphology, hot dry climates, street canyon, microclimatic characterization.

1. Introduction

Old by its history, the urbanization of desert cities is new by its extent, its difficult relationship with the environment. Nowadays its forms draw their models in North more than in the Saharan culture of the ksour. This fact poses the problem of the adaptation to the rigorous climatic conditions of hot and dry desert, different from those of north. If in the past adequate answers were developed, the urban achievements of the present require a best dealt with of this phenomenon. This is why, it will be necessary to analyze the climatic behaviour of the Saharan city (urban forms, materials and occupation modes of the ground) by considering past and present cases.

This research aims to approach the interaction between the climatic constraints and the solutions adopted in terms of occupation modes of the ground and urban morphology.

Generally, researches are particularly interested to the regular plans and neglected the irregularity phenomenon in the urban forms. This is due to the fact that "the irregularity does not lend itself as much to a qualitative classification" (Frankhauser, 1994). Moreover the study of real urban forms characterised by their morphological complexity requires the adoption of quantitative measures which represent filters making it possible to extract a feature property studied structure.

By this way, there was initially the search of base forms (compacts, dispersed and in cluster) according to the temperature, the wind, dust, the orientation and the shape of the roofs (Golany, 1996). The objective was to establish the simple design rules. Then, there was the search of indicators such as compactness, occlusivity (variation of the section built according to altitude) and the directionality related to thermal potentials of natural ventilation, solar and luminous radiation of the city (Baker1995).

Among recent studies on the subject, there are researches based on the use of a geographical Information system (GIS). These researches aim to analyze the urban morphological characteristics according to there environmental phenomena. This system allows the calculation of density indicators; streets form factor, roughness (absolute and relative) and the porosity, the sinuosity relating to a direction, the occlusivity, the compactness, the adjacency and the solar access.

These parameters could permit the microclimatic characterisation of urban forms. It however misses in this work the comparison of the morphological indicators with flows. That would pass by the environmental study of a large panel of urban fabrics and the formulation of a typology.

The indicators resulting from this research and those similar require however, a real validation

which would pass by a confrontation of the results obtained with microclimatic measurements in situ (Toudert, 2004) (Johanson, 2006). This kind of research, owing to the fact that it doesn't disregard urban morphological heterogeneity and associated ambiances, makes it possible to extract differently the characteristic properties of a given structure. It represents moreover a means to measure the relevance of one or several indicators, among those already established. This approach offers us the possibility of studying the influence of the natural site, in particular its form.
The examination of researches on this topic shows the importance of street canyon. According to its shape, this space is a significant generic element of the urban form. It is also, a significant level of radiative and energy exchange. The current studies on the subject are interested to the relation between these two levels of the climatic scale strongly interdependent. The analysis carried out in this study is based on morphological parameters defining the urban street form and urban tissue. We take the M'zab Valley as a case of study.

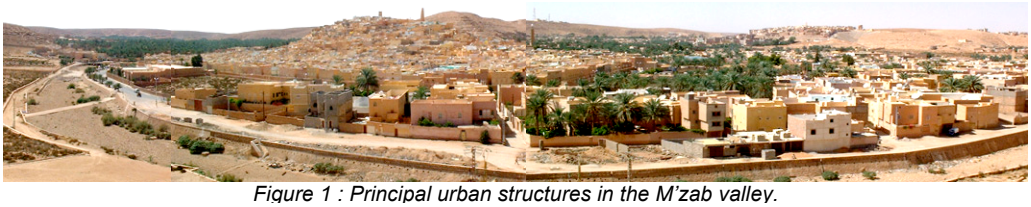


Figure 1 : Principal urban structures in the M'zab valley.

2 Study case: Beni Isguen city in the M'zab Valley

The valley of the "wadi" M'zab includes five "Ksour" (small strengthened cities), founded during more than six centuries and half (1011 until 1679), C and P. Donnadieu/H. and J-Mrs. Didillon (1986). During all this period the knowledge of the medium and constructive know-how were undoubtedly refined to contribute to an adaptation always more efficiency to the local rigorous conditions. The M'zab Valley is situated at the south east of Algeria, in full desert and belongs to a hot dry climatic zone. Renowned for its secular architecture and remarkable urban form's integration to whole conditions of the natural environment (M Roche, 1973), it has undergone today, extensive changes which had affected these exceptional characteristics. The organization of each city consists of three great classes: the ksar generally established on a piton builds overall out of traditional materials, the habitat of the palm grove, with a variation of the building density, generally very low far from Ksar and contemporary extensions with rather high densities and a horizontal spreading out. They are generally made out of concrete with little vegetation.
Located in the M'zab Valley, Béni-Isguen city is one of its five strengthened cities. It is composed of juxtaposed morphological areas which have relatively clear limits and marked differences.

2.1 Regional climate characteristics of the M'zab Valley

Prevailing winds: they are of northern and north-west direction in winter (14.53% and 10.44% respectively) and north-east in summer (12.44%). Strong, cold and relatively humid in winter, they are heat and dry in summer. The mean speed is of 3.9m/s.
Temperature and insolation: recorded average temperatures are from 10°C in January to 38°C in July. The seasonal thermal amplitude is of 20°C. The insolation is strong, and varies between 250 W/m² and 350 W/m², with the highest value recorded in July.
Humidity and pluviometry: the values of humidity, ranging between 25% and 60%, are inversely proportional to the air temperatures: maximum in winter (January – December), minimal in summer (August – July).

3 Methodology

This paper concerns an experimental study using field measurements. The sites and measurements points are not selected only considering their particular morphological characteristics but also the occupation mode of land, the topography and the establishment of each one compared to the natural site (at the bottom of the valley, on a slope or a plateau). This will enable us to study the interaction between parameters which are simplified or avoided in the majority of the similar researches.
Another significant parameter is the vegetation rate within each site. In this study case this rate evolves from one site to another, presenting clear differences. On one hand, there is the Ksar which is a completely mineral structure and on the other hand the palm grove which gathers only some constructions and presents significant wide along the "Ntissa Wadi".

3.1 Morphological selection criteria

The morphological criteria adopted for the selection of measurements sites and points relate to two characterization levels of the climatic behaviour at the urban scale:
The street which is an important element of the urban form and a significant filter of the radiative and energy exchanges between the urban canopy and atmosphere.
The urban tissue which is a kind of aggregation of streets, places, course and built forms. Being a significant level of urban composition (form and density of the layout, compartmental and geometrical configuration of the fragment), the influence of its morphology on the local climatic factors is notable.
A particular interest is given to the interdependence between these two levels of urban space strongly dependent in terms of form and also of climatic behaviour.
Related to these criteria, four sites were selected: the Ksar, the "Extra-muros extension", the palm

grove habitat and the new Ksar (see the description of measurements points bellow).
The interest of the morphological surfaces selected in this study resides in the fact that they present each one a certain morphological homogeneity and different modes of land use. Within each site represented below (Figure 2) the choice of streets is made according to the morphological characteristics of each area. The measuring stations are placed within and above a representative street of the morphological surface and located towards its center.

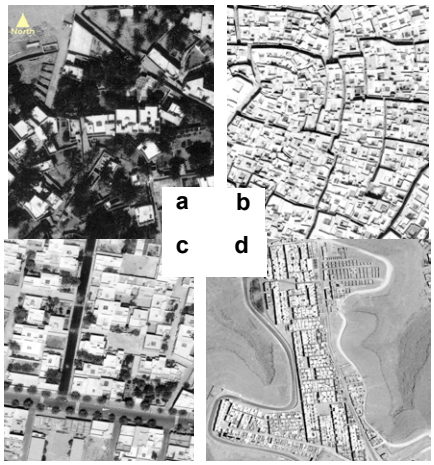


Figure 2 : Morphological area of the study: a) Palm grove habitat, b) Ksar, c) Extra-muros extension, d) New Ksar of Tafilelt.

3.2 Field measurements Description

The results presented in this paper, correspond to a field measurements carried out during the summer. We used mini automatic measuring stations which record continuously the climatic data for each point and in a simultaneous way (solar radiation, temperature and relative humidity of the air, speed and direction of the wind).
Each station is provided has a data memory where the values are recorded automatically. (Figure 3)

Figure 3 : measuring station used.

Within the street, the station is fixed on a support in consol of neutral colour, at semi depth height of the street and is placed about the middle of the street. (Figure 4)
The Second is located above the street on a terrace at a sufficiently released height of the ground (2m at least) and far from any heat source or another form of interference. The station is fixed on a tripod adequately placed.
Measurements were taken during representative days of summer conditions. This work presents only the analysis of the data corresponding to one representative day, by relatively low wind.

Six points, in addition to the reference station were selected: the first is located on a plateau which overhangs the valley and the second at the bottom, on a building located on the valley axis. These two stations permit us to measure the local climatic effect of the valley, compared with the meteorological airport regional data.
Because of its topography and the clear variation of its building density between the high and low part, the Ksar was subdivided in two parts. Two points of measurements are selected: the first is located on the top of the Ksar, in a sloping street and the second in bottom in flat site.

Figure 4 : Two examples of measuring stations localization. At left, measurements taken above the roof. At right, measurements taken within street.

4. Results analysis and discussion

The results presented and discussed in this analysis concerns two climatic parameters: air temperature and wind speed resulting from field measurements of four urban tissues.
The morphological characteristics consist on basic parameters. Firstly, those describing urban tissue in terms of building density (plot ratio), opening to the sky (site coverage) and vegetation rate. On the other hand those concerning the street. The adopted parameter is H/W ratio expressing the exposition of the street to solar radiation.
Compared to the weather data (airport station), temperatures of the various morphological areas (within streets and above roofs) are in general, higher in both summer and winter. The differences are of 2°C above roofs and 3.5°C in the streets. In summer, diurnal values are lower, compared to the airport data station (from sun rise to sun set), while nocturnal temperatures are higher.

4.1 Ksar site

The Ksar is an entirely mineral urban structure. It is characterized by a high urban density. It is a secular strengthened city, built in several stages. The high part is established on a sloped terrain. The narrow and deep streets rather sinuous are compared with those of the low part which are relatively rectilinear because established on a flat ground. Relating to built density the two parts present the difference in terms of plot ratio which is high in the low part. The streets of the low Ksar are deeper than those of the high. (Figure 5)
Reference station temperatures are lower than those of Ksar measurements points. Since sun rise, these points have a continuous increase in air temperature, which is essentially due to the important solar gains, between 9am and 3pm. During this period the high Ksar is overall hotter than the low one. The difference is sometimes about 3°C. Between 6pm and midnight air temperatures

decrease. After this, until 3pm the streets are overall hotter than the roofs in both cases. (Figure 6)

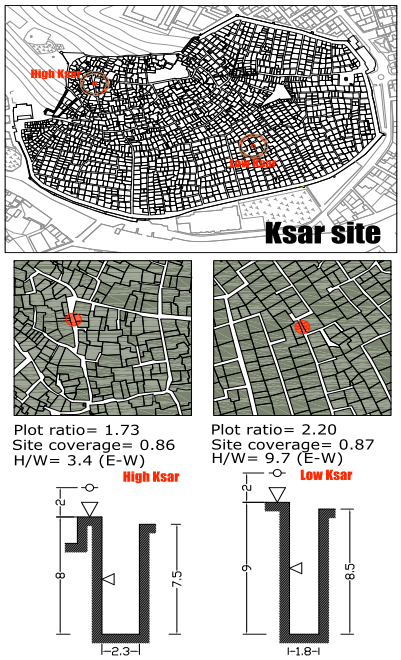


Figure 5: Ksar site and measurement points.

The results analysis shows here that the deep streets in dense urban tissue act as heat traps. Solar protection in this case has little effect because the depth of the street prevents the dissipation of the heat the night. The effect of this heat is prolonged during a large part of the day (until 3pm). This fact is confirmed on the graph expressing the wind speed in low and high Ksar where a significant reduction of wind speed between the terraces and the streets is noted (<1m/s). This cannot support the night dissipation of the heat by infrared long wave radiation.

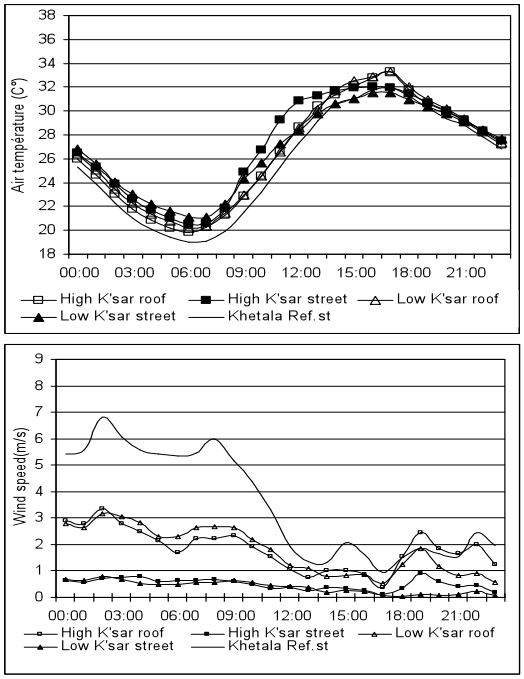


Figure 6

4.2 « Extra-muros » extension site (Figure 7)

The Ider city is the residential allotments built in the external part of the Ksar. It is characterized by a low density compared with Ksar tissue. A third of its surface is occupied by vegetation. Built on a flat site in the depth of the valley upstream of the "Ntissa wadi", it has a rectilinear layout. Its H/W ratio is about (1.6).

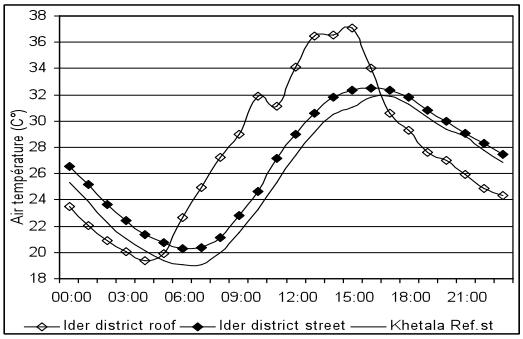
The temperatures recorded in this case show an opposite situation with the preceding one. The heating of the air above roofs is more significant during the day than within streets. This situation is reversed between sun set and sun rise.

Compared with the temperatures reached in the Ksar, those corresponding to this tissue are more significant above roofs. While within streets the values are similar.

Figure 7: "Extra muros" extension measurement point.

Measured wind speed indicates a more significant reduction above roofs. They are more significant within street, compared to the preceding case (+1m/s). The wind has not a mechanical effect in this case because low recorded speeds (< 2m/s).

In spite of low H/W ratio and site coverage, the air temperatures measured within street are close to those of the streets of the Ksar which are however deeper ensuring a better solar protection. In the same way the more significant opening of the streets in this case, seems to support diurnal and nocturnal ventilation (the wind speed of within street is about 2m/s). (Figure 8)



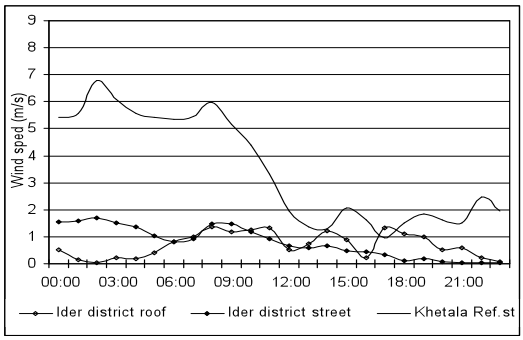


Figure 8

4.3 Palm grove site (Figure 9)
The palm grove habitat established in the depth of the valley, gathers residences of summer. Formerly scattered, the building density today tends to be more important. The vegetation occupies more than two thirds of total surface.

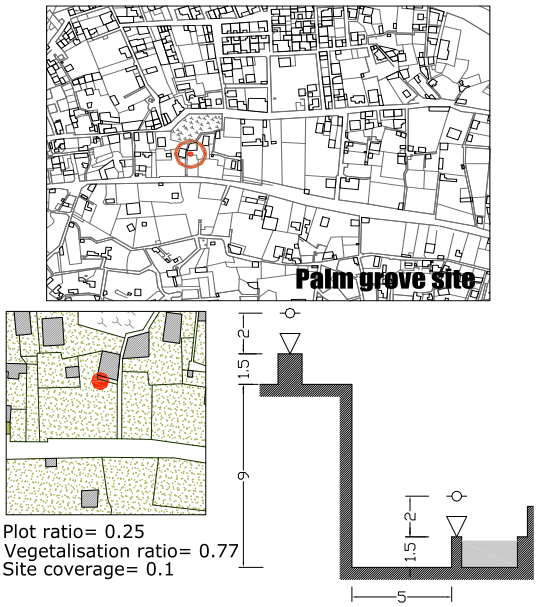


Figure 9: Palm grove measurement point.

Compared to two tissues analyzed previously, that of palm grove has low air temperatures. Those measured above roofs are slightly lower than those taken at the lower part of palm trees. After 4pm a temperature decreasing starts. The values measured above the roof are higher (+1.5°C) than those taken at the ground level (3.5m).
It is a particular effect due primarily to the important vegetation rate which ensures an efficient solar protection. The significant presence of the shade on the other hand does not prevent the relative heating of canopy. The recorded temperatures are similar to those measured above the roofs.
Compared with the Ksar and its extension, the palm grove habitat presents the characteristic of a net night cooling beyond the extreme heat period (6PM).

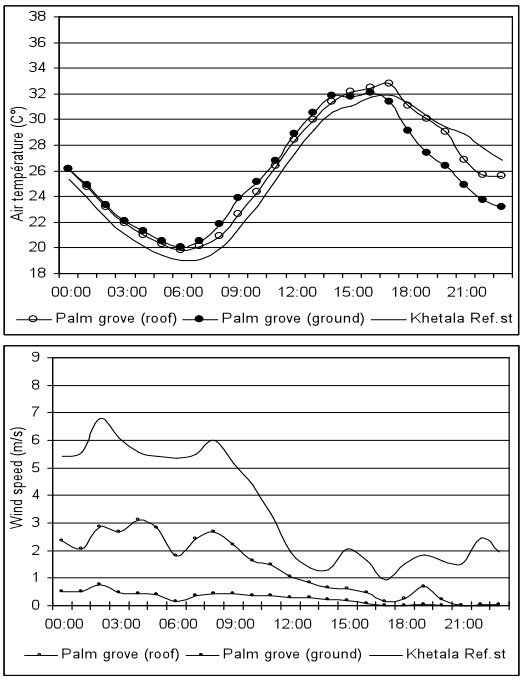


Figure 10

This temperature decreasing is recorded above the canopy and at the ground level. The effect of the palm grove is not only due to solar protection, but also to their contribution increase the relative humidity of the air and also the absorption of solar energy and its conversion to chemical energy (photosynthesis).
Wind Speeds are considerably reduced at the ground level (< 1m/s). On the other hand above the roofs these speeds reach 3m/s. (Figure 10)

4.4 New Ksar site ("New Tafilelt") (Figure 11)
Built on a plate at the same height as the reference station, the new Ksar "New Tafilelt" constitutes a reproduction tentative of the old Ksar. The similarity lies in the search for a relatively dense tissue with no large constructions spacing (5 m) and a similar architectural language with the old city. The houses are built out of stone and lime mortar. The ground coating of the streets was still out of sand. The New Ksar is also a mineral structure. Its characteristic is that it is established on a released site not undergoing the effect of the valley.

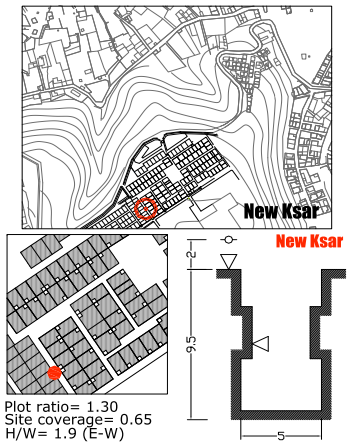


Figure 11: New Ksar measurement point.

In this case, the data relating to the roof are not available because the measuring station was damaged. The results obtained in the street will be only compared with the reference station located at the same altitude.
The air temperatures are similar to those of the reference station.
Compared with those of the high or low Ksar, the air temperatures in this case are clearly lower and tend to the reference station values. (Figure 12)
During the night these temperatures don't decrease as the precedent case. During the day the values are similar to those of reference station.
Compared with those of the Ksar (high and low) and its extension, these results make show that the heat trapping in this case does not have the same importance. The diurnal and nocturne heating of the street is less.
The wind speeds in the case in new Ksar are very low in the street, in spite of its establishment on a released site. In this case also these speeds do not exceed 1m/s. Combined with this situation the very low heating of the street seems to be less due to the dissipation of the heat by ventilation (diurnal and nocturne) than to the H/W ratio. This one is characterized by a low depth. Its opening is reduced by the projecting volumes.

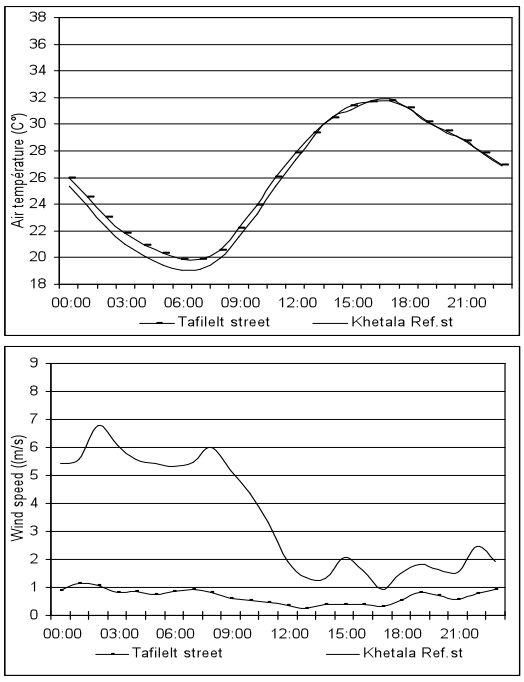


Figure 12

5 Conclusion

This research shows the importance of a climatic behaviour related to morphological characteristics of urban tissue (above roofs and within streets) in hot dry regions. Considering all patterns of urban morphology analyzed and related to natural site characteristics, the land use and the vegetation rate, it shows that the thermal behaviour of a given morphological area is the reverse of the behaviour of its wind flow patterns. The first is effective within streets more than roofs, while the second is more explicit above roof than within streets.
It also shows that the thermal behaviour in streets is concerned both with solar exposure and wind flow effect (diurnal and nocturnal periods).
The streets overheating during one day is largely influenced by heat dissipation the previous night. To ensure a good solar protection proves to be insufficient in deep streets known for their thermal efficiency.
In hot dry regions, the roof represents coolness urban islands during the summer nights, compared with the streets where a containment of heat due to their narrowness is noted. High H/W ratios (until 9.7) adopted in the desert cities allow a good solar protection of the streets during the day; however they increase its heating during the night.
The determination of the indicators in a similar research must integrate all the influential parameters, particularly the natural site characteristics. The crossing of these parameters allows the alternatives multiplicity and a better city adaptation to the climate rigour, in particular in the case of the hot and dry regions.
The emergent desert cities seem to be unaware of these facts, sometimes proposing contradictory combinations of parameters. For example, in exposed site, it is recommended to adopt ratios W/H favouring solar protection, knowing that ventilation is more significant in the case of such sites.

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