The internal courtyard of mixed use buildings, a device of thermal and luminous comfort

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Laboratoire CERMA, UMR CNRS 1563, Ecole d'Architecture de Nantes
Rue Massenet, 44300, Nantes, France.
Email: roula.ntefeh@cerma.archi.fr

ABSTRACT: The historical patio-courtyard is an outdoor area largely or entirely surrounded by buildings or walls. Generally, the courtyards are useful to sunlighting because their open spaces preserve the solar access of the adjoining buildings. They allow sunlight to reach the facades so that side-lighting strategies can be used. In urban fabric of the Mediterranean countries, we observe a new generation of big patios with mixed-use buildings (housing, trade, offices). This may be a return to the traditional form of the patio, which allows a passive regulation of built environment, multi-use activities, and security of the inhabitants. This new interpretation of a traditional passive device suggests more problems of illumination on lower levels. It becomes necessary to assess the performances of different courtyard shapes that behave as shafts. This paper presents the influence of the courtyard shape and orientation, on sunlighting duration and illumination levels of ground and facades. The results enable to propose changes of the distribution of the uses through the facades, vertically or horizontally, according to the orientation preferred and the illumination for each use.

Keywords: Courtyard- Patio, Mixed use buildings, Natural Light, Sunlight

1. INTRODUCTION

The Mediterranean region is found between 30 and 40 degrees north of the equator, in south Europe, Middle East and North Africa. This region is characterized mainly by high summer daytime temperature, large diurnal temperature range and high solar radiation. For such difficult conditions, the urban design should achieve the following objectives: providing shade in summer in open spaces and courtyards, providing solar access in winter for the interior building, enabling good ventilation potential in evening, minimizing the dust level [1].

In traditional urban fabric, the great majority of houses incorporate courtyards, which are in two high storeys, but the functions and use of courtyard is also an important factor for determining its size [2].

Currently, with new urban fabric of mediterranean countries, buildings are separated. In this case, it is essential to ensure greater ratio between the built volume and the envelope design. This implies vast residences surfaces and a great number of storeys. That also supposes many families or communities within one building [3].

In fact, in some Mediterranean countries, like Spain, Italy, and some Arab regions, we find a new generation of residential buildings whith big courtyard. They are mixed-use buildings: habitat, trade and office. The flexibility of this new type is due to the introduction of several uses into the building (see Figure1).

This new type of mixed-use building with a large interior courtyard might achieve the objectives of sustainable development; use the renewable energy, reduce the electricity consumption, combine much function in one building, and so on.

However, this generation of building with interior courtyard is introduced into a new context. The space of courtyard has undergone some changes: the physical changes and the heat exchange between the envelope design and the exterior environment. These modifications are due to the absence of dense fabric of traditional cities characterized by narrow streets. Additionally, in a big courtyard, the direct daylight never reaches the lower parts of walls.

In this paper we discuss the solar and luminous interior environment in courtyard, by investigating the effects of five different courtyard configurations. The used configurations present a simplification of existing models with big courtyard of mid-rise building in mediterranean climate.

We achieve solar simulations in order to study the effect of its height and shape on the interior courtyard environment from luminous and thermal point of view. For that, we evaluate the sunlighting and the illumination on façades for each level, and in courtyard center. We consider the arriving of light through the courtyard as a principal daylight source for adjacent spaces and courtyards ground.

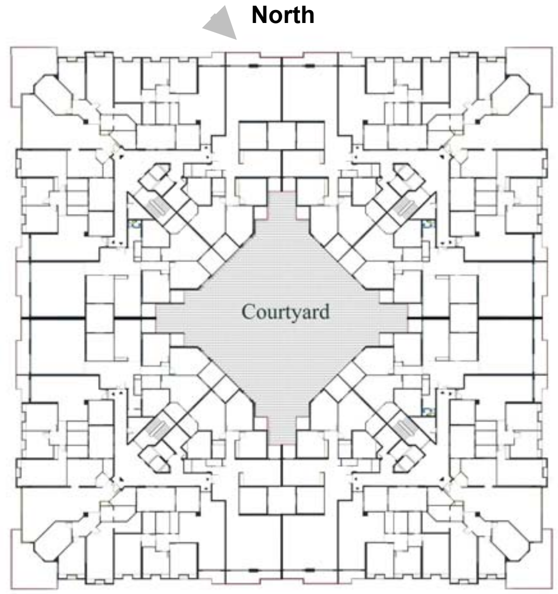

Figure1 Fourssan Housing, Architect: Architectural and urban design studies, El-Mously Group& Hossam Eldien, Cairo, 1998. Typical housing floor plan and view of the building mass.

2. METHOD

The methodology adopted is based on simulation produced by SOLENE model developed by CERMA laboratory. This model uses the geometrical procedures for the calculation of sunshine duration, and the radiosity method for the daylight reflected calculation [4].

The choice of shapes studied is based on a group of existing real examples found in mediterranean countries. The regular forms, square, rectangle, triangle and circle are mainly used, according to several orientations.

In fact, large patios are heated more quickly than traditional small ones, because of the higher exposure to the sky in the day and the overheating radiation diffused by the upper parts of walls at night. The degree of openness to the sky is given by the following relation, proposed by J. S. Reynolds, between floor area and square of average height of surrounding walls (aspect ratio used in daylighting design is found in Baker, Franchiotti and Steemers 1993) [5]:

$$\text{Aspect ratio} = \frac{\text{Area of the courtyard floor}}{(\text{Average height of surrounding walls})^2}$$

The greater aspect ratio, the more exposure is the courtyard to the sky. This exposure allows heating by the sun by day, cooling by radiation to the cold sky at night, some entry to the wind and vice versa. For that, with big courtyards in mediterranean climate, the choice of courtyard scales is made in order to decrease the ratio between area and square height. In this study we use the ratio 1:3 which is detailed later.

In this case, we suggest the nocturnal ventilation, which appears the best with climatic condition such as the hot-dry climate, and that supports the chimney effect with the higher depth of courtyard. This has been studied in case of the residential buildings [6].

2.1 Geometric parameters

We classify the outdoor area courtyard in terms of configuration and orientation, scale, and finally proportion.

Configuration and orientation: The forms suggested are: square, rectangle ratio1:2, rectangle ratio1:3, isosceles triangle and circle, the ratio is considered here between width and length (see figure.2). Each configuration has a ground plane and many adjoining façades. Solar access and luminous energy are evaluated for several configurations

Scale: The building's type is the typical mid-rise building; number of the storeys is 8. With a height of 24m, the patio surface is approximately 200 m^2, and finally, the position of courtyard is central.

Proportion: the geometrical shape is a vertical shaft, which provides the solar protection. In order to facilitate the comparison between different patios, we will fix the ratio (between surface and square of average height), which is approximately about 1:3, and the plan surface is a little over 200 m^2 which corresponds to a large courtyard of a residential multifamily building.

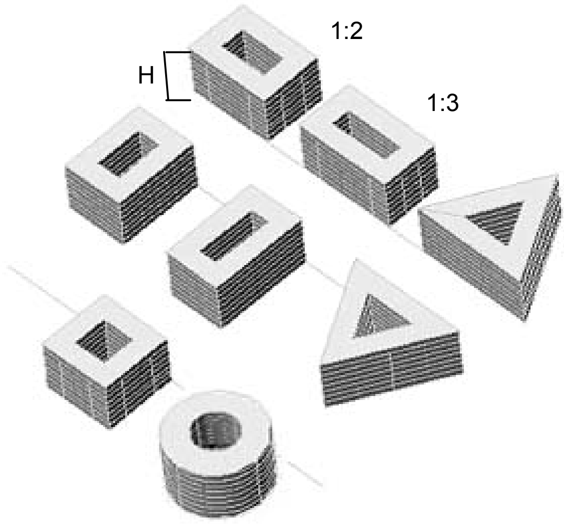

Figure 2: The configurations of enclosed courtyards

2.2 Simulations

Our analysis addressed the following parameters: the effects of geometry and orientation may be observed by using the internal shading of surfaces to indicate the degree of shading and sunlighting. We will consider the percentage of shade on vertical surface area and the percentage of ground area in shade.

The examined dates are June 21 (summer solstice) and December 21 (winter solstice). The interval of time between two calculations is one hour for the latitude 35°N which corresponds to the average latitude of the Mediterranean region.

For the heat gain recommended during winter months, we considered that the threshold of sunlighting is limited to two hours minimum.

On the other hand on summer, if the facades receive more than four hours of sun, the overheating is probable; this is due to the inertia of the built masses, the solar energy received and absorbed by the walls of the patio, which will be diffused later towards the interior by heat convection [7].

As a measured of daylight distribution we have chosen the daylight factor DF%. Notice that the factor is obtained after reflexion. Values were computed on the centre of courtyard ground and at the middle level of each story (height 3 m). The model of sky used for simulation is the standard CIE overcast sky. The choice of this condition is to investigate the illumination distribution with the more undesirable climatic conditions. Values have been normalised in a similar manner to the sky component of the daylight factor % (ratio of the local illuminance to the simultaneous outdoor horizontal illuminance due to an unobstructed sky) [8]. The simulation was conducted on December 21, it was considered a ground and building façade reflectance of 0.8. The models were studied at different hours of the day; here we only show the results for 12:00h, where direct sunlight access is vertical and doesn't enter the interiors surrounding buildings.

Rotations are considered in order to present the effect of orientation on the courtyard geometry. We have carried out simulation every 15°ccw. In the interest of brevity, only simulations for eight shapes are presented in this paper.

3. DISCUSSION OF RESULTS

3.1. Summer monitoring (June 21)

The simulation on the square shows, that square form supports solar protection in summer, the percentage of protected surfaces is equal to 53,1% in initial position (see Figure 3).

Simulation carried out on the rectangle (ratio1:2 elongated east-west) shows, that it seems to be not powerful in term of solar protection on summer. A greater part of the north, east, and west courtyard façades is exposed to direct solar access more than four hours in the day. The increased insolation minimizes the thermal comfort in adjacent spaces. On the contrary, the rectangle (ratio 2:1) elongated north-south appears more efficient than the horizontal one; the percentage of shading on interiors façades is 60%. Moreover, during the day, the upper part of north façade reaches at minimum four hours of sun.

The rectangular courtyard (ratio1:3) elongated vertically is most efficient compared to the horizontal one. The vertical position ensures more protection on its long edges. Nevertheless, the two higher levels reach more than four hours, on north, east, and west courtyard façades.

On the other hand, it is found that isosceles triangle in initial position has less effect compared with second rotation. We noted that the results of the triangular form are similar to the results of the rectangle ratio 1:2. Also the rotation angle 60°ccw improves the solar protection.

Finally, for the circle, the percentage of the protected facades is approximately 30% and on the courtyard ground is 50%

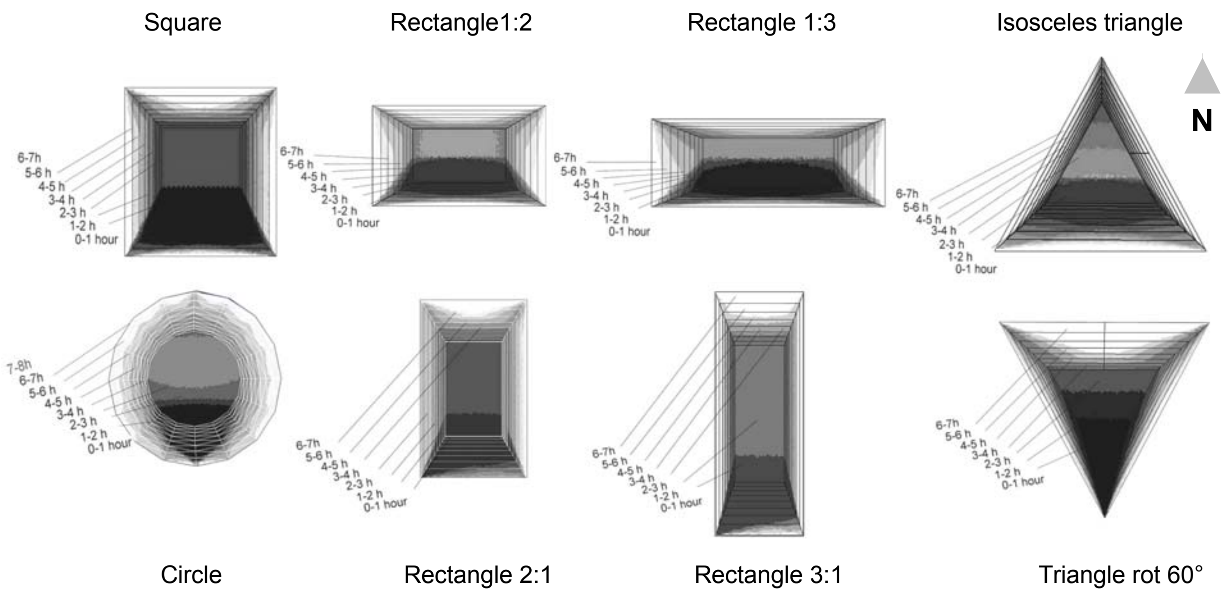

Figure 3: simulation results for sunshine duration in June 21.

3.2. Winter monitoring (December 21)

First of all, we search the surfaces, that receive a heat gain more than two hours by day.

The simulation results carried out on the square form, show that the percentage of vertical surfaces, which receive sun less than two hours on winter, is 18,75% max (see figure 4).

The vertical position of rectangular form (ratio1: 2) is better than the horizontal one. The percentage of the surfaces shown upon on winter is approximately 23% at vertical position, and fall down to 13% in horizontal position.

Similarly, rectangle elongated East-West (ratio 1:3) presents a lack of sunlighting. This is remarkable for both cases studied; the percentage of the internal facades, which reach the minimal hours recommended in winter, doesn't exceed 10% in initial position. Contrary to the vertical position the values reach to 18% on the interior façades.

The triangular shape doesn't optimise the heat gain on winter without rotation; the percentage of the facades, which reached the threshold, is 16% and decrease to 11% with 60° rotation angle.

For the cylindrical shape, the percentage of interiors façades in sun is about 25% of total vertical faces.

For all studied cases, the ground plane never has any direct sunlight on winter. The improvement of sunshine duration is remarkable with rotation angle 90° for the rectangular forms (see figure.5)

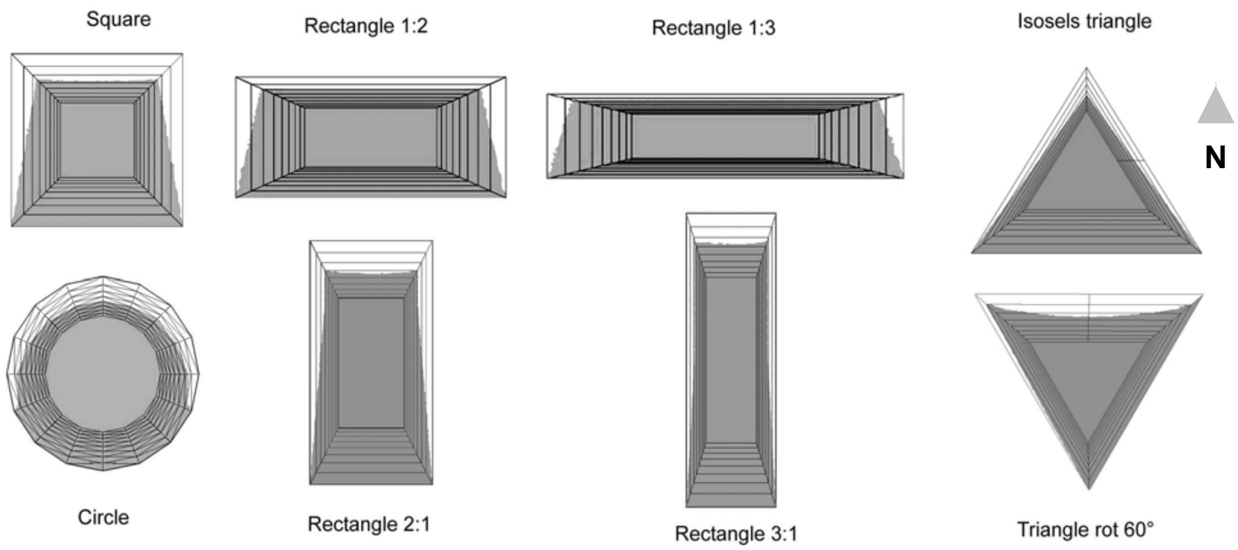

Figure 4: solar simulations; in grey the surfaces receive less than two hours on winter from axonometric view

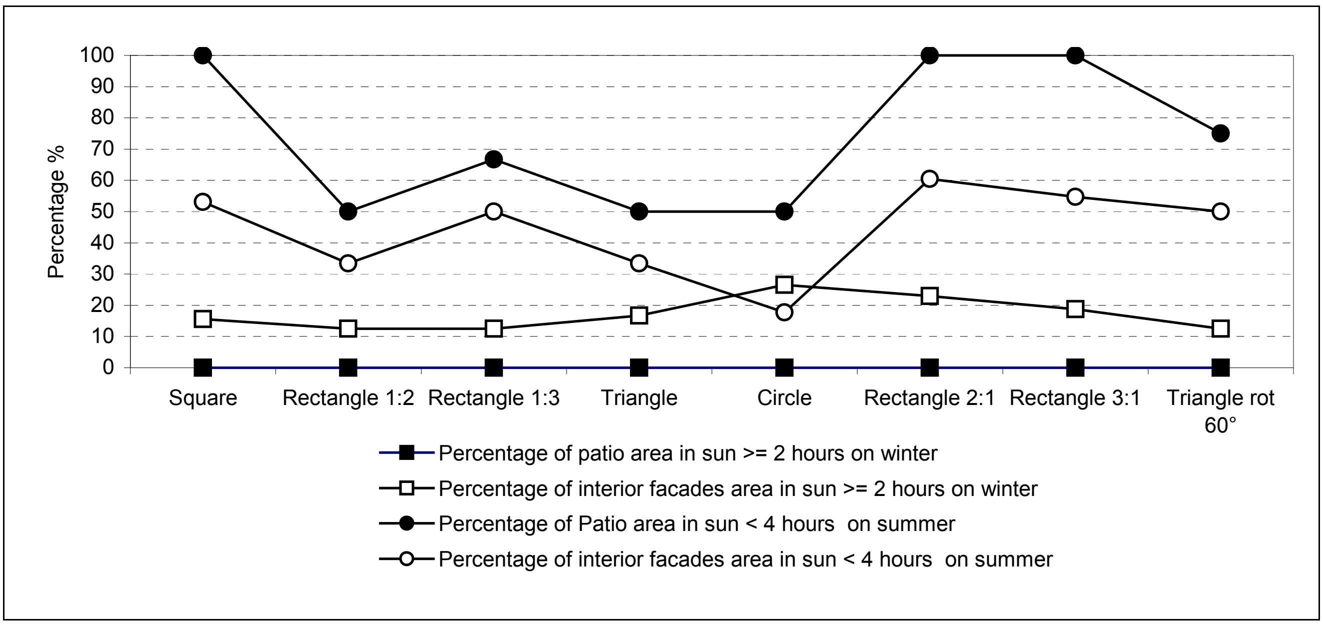

Figure 5: comparison between different shapes of the patio

3.3. Daylight in courtyard

Study of the various forms shows that the circle, the rectangle (1:2), the square, and the triangle rotated 60°ccw optimise illumination on the patio ground. The daylight factor reaches to 16.5%, 9.87%, 9.5%9.45% respectively. (See table I).

However, the minor values are monitored in the rectangle ratio 1:3 (DF: 9.2%), the same result for rectangle ratio 3:1, rectangle ratio 2:1 (DF: 9,32%), and triangular form (DF: 9.41%)

On the other hand, analysis of illumination on the façade shows that the light decreases gradually from top to bottom. By using the average daylight factor to indicate the best form, we found the following results. The rotation angle 90°ccw doesn't improves the average daylight factor in both rectangle ratio (2:1) and rectangle (3:1).

Besides, the rotation angle 60°ccw applied on the triangle, gives a value more than the initial orientation one. Also for all rotations angle 90° and 60°ccw, the difference between results is slight (see figure 6).

Also, the square shape provides good illumination on the patio ground. The average value reaches to 12.81% while the maximum value obtained is in the circular form with 18.82%.

We noted that in all cases studied the upper levels receive sufficient amount of light, the values rise to 35.35% at least in rectangle 1:2 and reaches to 33.18% in the triangle rotation 60°ccw.

The daylight factor measured on the façades can clarify the influence of the patio shapes on the illumination of surrounding walls, while these calculations are not sufficient in order to evaluate the interior illumination quality and the visual comfort.

Height on façade (m)	Square	Rectangle 1:2	Rectangle 1:3	Isosceles Triangle	circle	Rectangle 2:1	Rectangle 3:1	Triangle rot60°
Patio 0	9,5	9,87	9,2	9,41	16,5	9,32	9,2	9,45
1,5m	2,81	2,57	2,06	2,39	6,58	2,53	2,09	2,45
4,5m	3,81	3,47	2,83	3,21	8,33	3,42	3,84	3,22
7,5m	5,33	4,81	3,91	4,47	10,8	4,76	3,9	4,47
10,5m	7,55	6,85	5,61	6,34	14,16	6,83	5,65	6,35
13,5m	11,04	10,11	8,45	9,2	18,51	9,96	8,45	9,21
16,5m	16,18	15,14	13,26	13,68	24,11	14,99	13,23	13,69
19,5m	23,75	23,08	21,61	20,77	31,02	22,8	21,29	20,78
22,5m	35,36	35,35	34,64	33,16	39,45	34,79	34,52	33,18

Table I: Daylight factor % on interiors façades and in courtyard

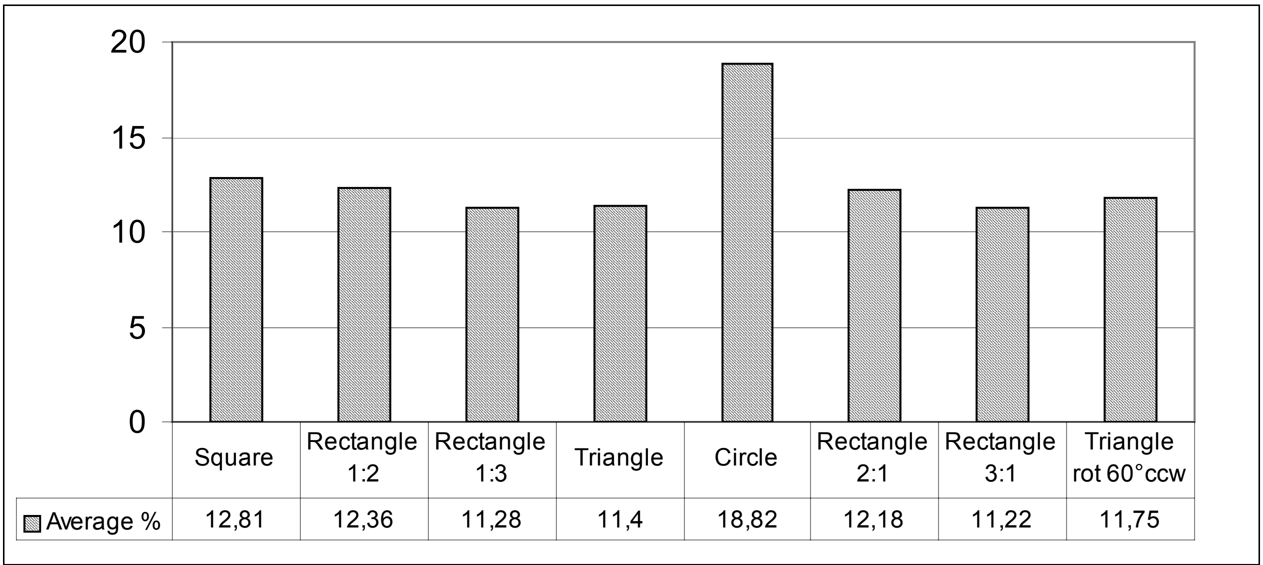

Figure 6: average daylight factor% on façades from ground floor to upper level

4. CONCLUSION

By comparing the various studied forms, the results of solar simulations show that the rectangle ratio (2:1) presents the highest values in terms of solar protection on summer and heat gain on winter. As the square form and the rectangle ratio (3:1), it appears more adequate compared to the others. Additionally, the square shows a good illumination in both façades and courtyard itself. The rotation angle 90°ccw gives an improvement in terms of solar protection and heat gain on winter, as well as the rotation angle 60° applied to the triangle. The results obtained in this case are more powerful compared to triangular one.

On the contrary, the results of the circle, are contradictory. This form presents a highest level of illumination and heat gain in winter, and the lowest level of solar protection in summer. We noted that its presence in urban fabric of Mediterranean cities is seldom excluding the court of the small urban islands.

On the other hand, the different studied forms show an insufficiency of the solar gain in winter; the patio ground doesn't receive enough sun.

Moreover, on the summer, the percentage of surfaces, which receive less than four hours, is to 50% at minimum, while the ground is approximately protected.

Nevertheless, in this Shaft form of patio, the uppers level are almost exposed to the sun, and the four lower floors can't receive sufficient light and heat gain in winter. It seems that the obstruction of the sky, due to the higher number of level, has not provided the best solution for the thermal comfort and human use in habitat, specially in terms of heat gain on winter. The degree of the openness to the sky is more important for illumination and improving heat gain on winter.

By considering the requirements of the sunlighting recommended in winter, it seems that the apartments should be placed in the sunny part of building, in upper levels or on the western, eastern, and the southern façades. This implies a solar protection in summer especially on the last proposition

On the other hand, the offices can be sited on the north façade which receive a minimum of sun compared to the other ones.

Also, the problem of luminosity on the first floors has to be solved. It seems that the combination between trim materials and the colors could ensure the improvement of lighting on winter and minimizes the risk of discomfort glare on the interior on summer time.

The trades which are normally placed on the lower floors in order to facilitate their access. They are well protected from the direct solar access, however, they cannot benefit from natural daylight. A bilateral lighting can improve the illumination in this part.

This study aims at clarifying the influence of geometry and orientation on the courtyards environment. We will carry out, later, an analysis of luminous and thermal aspects inside the interior parts of buildings. This future step is in order to distribute the functions according to obtained results. The objective of studies examines the new shapes of big patios, which exists in an urban Mediterranean context. This new type of mixed-use building with the large interior courtyard might achieve the objectives of sustainable development.

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