Daylight Efficiency Prediction of Courtyard vs. Conventional Building Models Using Simulation Tool under Specific Climate Conditions

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Abstract—The major goal of the present research is to investigate in daylighting efficiency of different building typologies under specific climate conditions of hot and arid regions. It has been demonstrated in previous research that courtyards in buildings offer the ability to regulate various environments of the indoor spaces. However, in hot and arid regions lighting and protecting the building is always problematic. To estimate the degree of correlation between morphological characteristics and illuminance levels, the monitoring under clear sky during different seasons to test building models daylight efficiency using a simulation tool (DesignBuilder). The results are then used to establish the optimal design solutions. The simulation testing with geometric modifications has proved essential in carrying out a comparative analysis between the courtyard type and other Architectural morphologies such as mono block type. The courtyard type performs well in terms of daylighting. The comparative analysis determined the optimal architectural configuration, and parameters such as: courtyard opening ratio, depth, and orientation, can provide the most appropriate building typology for daylight in hot and dry areas.

Keywords—Building Typology; Daylight; Indoor Space; Simulation; Arid Zone

I. Introduction

Nowadays, The concern about global warming and the need to reduce high emissions of greenhouse gasses, increasing energy consumption continually, suggest the need for the use of indoor climate modification strategies for a comfortable indoor environment [4]. Energy efficiency is a key dimension of sustainable building design. Human comfort is a complicated issue and depends on different indicators such as light, sound, temperature… etc. The building is considered a major contributor to the total national energy consumption [6]. It is intended that energy consumption in the construction will continue to increase in the coming years. There will be a spectacular increase of the quantity of energy consumption caused by an excess use of devices (such as air conditioners) in hot climate areas.

In hot and dry regions, building design always faced a dilemma between lighting and protecting buildings from sunlight. In hostile climate, the bioclimatic architecture provides passive strategies and takes into account the local climate factors during the design process. The traditional architecture supplied models of bioclimatic architecture, in which the courtyard building remains a typical morphology of these Saharan regions. However, to make choices and effective decisions, the tools of investigation in situ and in vitro become indispensable. In this work, a digital simulation tool will be used for the prediction of an optimal building configuration.

II. Literature Review

A number of researches show interest in the courtyard building typology, especially bioclimatic dimension. Givoni (1994) analyze a number of specific issues related to adjacent outdoor spaces such as yards and internal courtyards [4]. With some details, courtyards can provide a pleasant outdoor environment and also improve the thermal conditions inside the spaces around [3]. Reynolds (2002) studied all courtyard dimensions: aesthetic, social and thermal [7]. In their book "Courtyard Housing" Brian Edwards and Al. (2006), have gathered some researches which treated the past, present, and future of courtyard houses [1]. Many researchers studied the environmental dimension of courtyard building e.g. (Brown & DeKay 2001; Heidari 2002, Aldawoud 2008…etc.), but the morphological aspects rarely studied, which limits the application of architectural strategies in this type of building.

The buildings have been recognized as major energy consumers [4]. The courtyard - as an important architectural space - affects the lighting, heating, and cooling, and has a positive impact on the energy consumption of the building. This research aims to study the light environment of the indoor spaces in divers building typologies to provide valuable information to designers, professionals and academics in particular with regard to the building’s daylighting and energy performance.
III. Basic Models

The modelization basic is an open central courtyard building surrounded by adjacent spaces, which was modeled in the graphical interface of “DesignBuilder” software. The building is a two-storey rectangular form of 300m² (20m/15m), the internal organization of four indoor areas and all the building has been completely separated from the outside environment by a double wall brick wall of 15cm and 10cm with an air gap in the middle. Two types of windows used: in the exterior facades: windows of (1.80m/2.00m), while the courtyard interior windows are of dimensions (2.50m/2.00m). These characteristics have been maintained for the rest of the models derived from this basic model (Tab. 1).

<table>
<thead>
<tr>
<th>Building models</th>
<th>Typology 1</th>
<th>Typology 2</th>
<th>Typology 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior wall components</td>
<td>Exterior window type</td>
<td>Courtyard interior window type</td>
<td></td>
</tr>
<tr>
<td>EXTERIOR</td>
<td>BRICK WALL 1 (15cm)</td>
<td>AIR GAP (5cm)</td>
<td>BRICK WALL 2 (10cm)</td>
</tr>
<tr>
<td>2.00m/1.80m</td>
<td>2.50m/2.00m</td>
<td></td>
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</table>

In order to analyze the influence of arid climate on daylight performance of the models, we have selected the city of Biskra as one of the hottest arid region in the Algerian desert. Under clear sky condition, simulations were running for the same types of glazing: single glazed for both summer and winter seasons.

IV. Model Morphological Variations

As the research associated with hot and arid regions, the modelization of models intends to take into consideration morphological variations between the configurations of a courtyard building and other morphologies, such as the mono block. The building typologies choice is essentially based on morphological variations including intrinsic and extrinsic varieties in the same model; whose objective is to compare conventional buildings vs. courtyard building using digital simulation tool; the simulation calculates illuminance levels and daylight factor (DF), in order to test daylight efficiency between those buildings. Parameters, such as: building orientation, window types and opening ratio, zoning, and total building area were maintained all along tests.

<table>
<thead>
<tr>
<th>TABLE II. THE TESTED BUILDING MODELS</th>
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<tbody>
<tr>
<td>Model 1: courtyard building (2 storey)</td>
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<tr>
<td><img src="image1" alt="Model 1" /></td>
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<tr>
<td>Model 3: conventional 2 (2 storey)</td>
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<tr>
<td><img src="image3" alt="Model 3" /></td>
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<tr>
<td>Model 5: courtyard building/wide opening (1 storey)</td>
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<tr>
<td><img src="image5" alt="Model 5" /></td>
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</tbody>
</table>

Six (6) models carried out: one, two and multi-storey single-building to test their daylight environment and effectiveness in terms of energy consumption accords to their morphological characteristics already mentioned in (Tab. 2).

V. Simulation Protocol

After the achievement of all the models modelization in the graphical interface of DesignBuilder trial version (v4.6.0.015) [8], a neutral and passive simulation was conducted under open indoor space of an office building consideration, where all the mechanical and electrical systems were deactivated: air conditioning, heating, artificial lighting and mechanical ventilation, and the occupation. The
simulation is based on comparing the effects of depth, storey number, the courtyard opening ratio and orientation on the daylighting performance between conventional and courtyard building models.

VI. Analysis of Results

A. Courtyard Building vs. Conventional Building

According to the comparative analysis of three types of buildings of the same level, we clearly observe that the courtyard building is more efficient in daylighting the building’s indoor space. The impact of the courtyard configuration on the luminous environment is superior to the others typologies. The illuminance levels are beyond the minimum required of 500Lux in courtyard adjacent spaces (Fig. 1).

In Addition, bilateral lighting in courtyard building allows a uniform distribution in most of the indoor space surfaces, also qualified as homogeneous with less contrasted zones; therefore, the courtyard has a better quantitative and qualitative impact on the luminous environment. On the other hand, conventional models contain a large central dark zone that requires an artificial lighting system; the extroverted form doesn’t solve and increase daylight quantities.

B. Relative to Depth

Muhaisen & Gadi (2005) have already highlighted that deep courtyard performs better in winter [6]. Heidari has also put in evidence that the deepest forms require less energy for summer cooling [5]. In the same 6-storey courtyard model we noticed that the depth effects negatively the luminous environment, as the illuminance levels of the inferior indoor spaces are decreasing significantly between the first and last storey (Fig. 2).

C. Relative to Courtyard Opening Ratio

The winter simulation tests the courtyard building’s winter behavior and verifies if it is as effective as in summer. The tested models are based on the courtyard opening ratio, the
models of various opening ratio (0.25, 0.50 and 0.66) show a variation in illumination levels (Fig. 3).

Fig. 3. The relationship between courtyard opening and illumination levels/DF in a winter day (model 1, 4 and 5)

Model 1 (21 December)
OR: 0.5

Model 4 (21 December)
OR: 0.25

Model 5 (21 December)
OR: 0.66

More the courtyard opening ratio is bigger it allows more natural daylight penetration, courtyard with (0.66) opening ratio is the most illuminated while the building with a (0.25) opening ratio is the less lightened model with lots dark zones. The courtyard building also lighted efficiency with an average opening ratio, especially in winter. Considering the opening ratio of the models (1, 4 and 5), the illumination levels result proportionally to opening ratio. But there may be risks of dazzling caused by illumination levels, which reach 1000Lux to 2000Lux in the extreme model.

D. Relative to the Orientation

The effect of orientation has a major importance [2], the daylight simulation of courtyard model 1 in different temporalities of a summer day showed the orientation effect in interior diverse zones, the results obtained and presented in table 4 below.

TABLE IV. ILLUMINATION LEVELS IN A SUMMER DAY (21 JUNE) (MODEL 1).

<table>
<thead>
<tr>
<th>21 June at 9h</th>
<th>21 June at 12h</th>
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</thead>
<tbody>
<tr>
<td>21 June at 15h</td>
<td>21 June at 18h</td>
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</table>

The illumination simulation in a summer day shows that the East and West zones benefit of a natural light more than those facing North and South sides (Tab. 4). There is a disagreement between the thermal and the luminous environments due to the dilemma between lighting and protecting the building from direct solar radiation in hot summer season; the courtyard building has solved this problem by offering more possibilities of the natural lighting.

VII. Conclusion

Relative to its configuration, the courtyard building offers enormous potential for natural lighting, it has been demonstrated that courtyards regulate natural lighting. the control of the courtyard opening ratio helps to reach the annual illuminance levels desired, but the deep courtyard loses this privilege, more the courtyard is deep, less the interior spaces are illuminated. The results show a slight improvement of the luminous conditions of indoor spaces in conventional typologies. It remains to note that introducing of a courtyard in building removes the dark central zone in conventional building and produces better daylighting efficiencies under specific climatic conditions of hot and dry areas.

References

[5] 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.


[8] Site web DesignBuilder: http://www.designbuilder.co.uk