Lessons from Three Daylighting Systems used in Traditional Architecture of the United Arab Emirates

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ABSTRACT: This paper presents the results of an evaluation of three daylighting systems used in the indigenous architecture of the United Arab Emirates (UAE), located in Dubai (latitude 25°N longitude 55°E). The purpose of this research was to investigate the daylighting performance of three of the most common daylighting systems found in indigenous buildings of the UAE: Type I- Traditional double panel windows, Dreeshah; Type II- Gypsum decorative panels, Mesbah; and Type III- Wind tower, Barjeel. The lighting performance parameters examined were illuminance level, light distribution, uniformity and glare. These parameters were compared to the recommended light levels specified in IESNA and CIBSE standards. The RADIANCE program was used to evaluate the lighting performance of the three daylighting systems under clear sky conditions. On-site measurements were also conducted to validate the lighting performance generated by the simulations. The prototypes tested in this research showed different outcomes. From the results, the overall lighting performance of the gypsum decorative panel prototype outperforms the other prototypes under clear sky conditions. These prototypes carry an aesthetic and identity value to the culture of the UAE. Through the use of the derived values and conclusions, local public awareness can be increased on the importance of preserving indigenous buildings and the numerous lessons that can be learned from their study.

Keywords: daylight, windows, indigenous buildings, UAE, RADIANCE.

1. INTRODUCTION

The UAE is located in the Middle East at the tip of the Arabian Peninsula with a tropical desert climate. Traditional Arabic residential architecture was developed to protect the inhabitants from the overpowering heat of the Gulf's summer. This led to houses being built with climatic responsive architectural features. One of these unique features is the daylight opening.

Windows in the indigenous buildings of the UAE differs from windows nowadays, in that they did not have glazing and they were always open to the external environment. Due to the high temperature of the region this characteristic served well in promoting natural ventilation through the space. Therefore all openings in the indigenous buildings had a dual function of both ventilating and daylighting interior spaces. Instead of glazing people used iron bars, gypsum ornaments and wooden shutters to cover the window, for privacy, security and to control the amount of daylight entering the space.

We can find diverse types of daylight openings in the indigenous buildings of the UAE ranging from regular sidelight windows (the most common daylight system) to wind towers (Barjeel). The purpose of this research is to evaluate the daylighting performance of three of the most common types of daylighting systems found in the indigenous buildings of the UAE. Type I- Traditional double panel windows, Dreeshah (Fig.1), usually it is bigger than a standard window size. It is covered by iron rails from the outside for security purposes, and closes from the inside with wooden shutters. These shutters divide the window into half, allowing some flexibility to either have it completely open or partly closed.

Figure 1: Window Type I, Dreeshah.

Type II- Gypsum decorative panels, Mesbah (Fig. 2) are mainly located on the upper part of the wall, and they are smaller than the usual size of window. This type of window opening is either covered by gypsum ornamentation or iron bars. The window size varies depending on the room area and location.

Figure 2: Window Type II, Mesbah.
Type III- Wind tower, Barjeel (Fig. 3) is the most distinctive architectural element of indigenous buildings. It consists of four open sides, each of which is hollowed into a concave V-shape that deflects the wind down to cool the rooms below. In addition to its ventilation purpose, the Barjeel acts as a skylight in bedroom spaces. In general, bedrooms have few windows for privacy. Daylight is admitted through the upper part of the Barjeel down to the rooms.

2. CONTEXT

2.1 Location

Dubai is located in the north east of the UAE. It lies on latitude 25°N and longitude 55°E overlooking the Arabian Gulf and extends for a distance of 72 km along the coastline (Figure 4).

Dubai has a sub-tropical climate with mild temperate winters and very hot summers. In summer (April to September), the temperature in Dubai varies between 32-40°C (90-104°F) in the daytime while at night it varies between 20-30°C (68-86°F) with high humidity levels (see Figure 5). Light rainfall and fog are characteristics of the winter season. In winter (October to March), the days are sunny and pleasant with an average of 26°C (79°F), while nights are cool with an average of 15°C (59°F). The mean maximum humidity ranges between 75% and 82%, while the mean minimum varies between 28% and 45% (Fig. 6.) There is very little rainfall, even in the winter months.

2.2 Site Information

Al-Bastakia is located in Dubai, UAE. It represents one of the historic landmarks of Dubai. Its construction dates back to around 1890. It extends along the creek for a distance of three hundred meters (Fig. 7), with the width of nearly two hundred meters to the south and a total area of 38,000 m² [2]. It includes traditional residential buildings of one and two floors with historical value, rich with traditional architectural elements such as wind-towers, air-pullers, columns, wooden and gypsum ornaments.

Plot 143 is one of the restored historical buildings in Al-Bastakia District. It dates back to early 1920s. It is a two-story residential building, with a central courtyard with a loggia overlooking it from two sides, several rooms and a Majlis (sitting room) with its separate entry. Three different spaces in Plot 143
were selected for this study. These spaces were chosen because each one includes only one daylighting systems. Fig. 8 shows the selected three spaces. Room A represents window Type I which faces East. It has a window wall ratio (WWR) of 1 to 8.5, and window to floor ratio (WFR) of 1 to 6.9. Room B includes window Type II which faces North; it has a WWR of 1 to 8.1, and WFR of 1 to 10. Room C includes window Type III, with WFR of 1 to 2.

3. METHODOLOGY

The lighting performance evaluation of the three daylighting systems consisted of on-site lighting measurements and Desktop Radiance 2.0 Beta (DR) computer simulations. The on-site measurements were done to compare these values with the outputs from DR and to estimate the differences with the DR simulations. DR was used for its accurate and detailed lighting calculations and scene rendering.

The on-site measurements and DR simulations were conducted under clear sky conditions, which is the predominantly sky type in Dubai, UAE.

Simulations in DR were performed on June 21, March 21, September 21 and December 21 at 9:00 am, 12:00 pm, and 3:00 pm. The dates were chosen to evaluate the variation of daylighting at extreme sun angles.

3.1 On-site Measurements

In this study each prototype was examined in its actual surroundings. The measurements were conducted on the tenth of June, July and August starting at 12:00 pm, 2:00 pm, and 4:00 pm, with 15 minutes interval between the different spaces.

Three illuminance meters were used for the daylight measurements. Two TES light meters were used for interior measurements. Horizontal illuminance levels were taken at the center point of each space, at the workplane height of 60 cm. Another illuminance meter was used for measuring the total horizontal exterior illuminance level. A Konica Minolta LS-110 luminance meter was used along with Kodak Gray Cards to take the luminance measurement of the surfaces inside the space.

3.2 Computer Simulation

DR [3] was chosen for its ability to model a geometrically complex environment and simulate light behaviour with precise numerical results and refined rendered images. It has been tested for its validity under real sky conditions and it is able to calculate interior light levels with a high degree of accuracy.

This study used DR to calculate the interior illuminance level and to generate images for each prototype at the specified times in the previous section. The systems were modelled in DR with no glazing (using the special illum material with 100% visible transmittance).

Each daylighting system was tested for visual performance by comparing DR with the on-site measurements. The luminance meter and the Kodak gray and white cards were used to calculate the reflectance of the building materials during the on-site visits (Table 1.). These reflectance values were later used in the DR simulations.

Table 1: Reflectance values

<table>
<thead>
<tr>
<th>Material Name</th>
<th>Reflectance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>target</td>
<td>18</td>
</tr>
<tr>
<td>Brown-gray</td>
<td>17.63</td>
</tr>
<tr>
<td>Yellow, Driftwood (proto)</td>
<td>88.3</td>
</tr>
<tr>
<td>Local Paint (Benoil)</td>
<td>85.5</td>
</tr>
<tr>
<td>Larch Wood</td>
<td>54</td>
</tr>
<tr>
<td>Brushed Aluminum</td>
<td>70</td>
</tr>
</tbody>
</table>

The daylighting metrics used in this study were:

1. **Illuminance level (lux).** Illuminance level is the visible energy (light) incident on a surface, measured in lux. IESNA [4] has made recommendations for the illuminance level for various tasks and building types.

2. **Light distribution and uniformity.** The light distribution and uniformity can be described as the relative illuminance at different points in space. In this study we measured the uniformity and diversity of illuminance parameters to compare the performance of each system. CIBSE guidelines defines uniformity of illuminance as the ratio of the minimum illuminance to the average illuminance of the space, and this ratio should not be less than 0.7 [5]. The diversity of illuminance is defined as the ratio of the maximum to the minimum illuminance level of the space. This ratio should not exceed 5 to 1.

3. **Visual Comfort.** Glare is caused by the light within the field of vision that is brighter than other objects to which the eyes are adapted. It can be caused by looking directly at a bright light source, or surfaces reflecting bright areas into the field of view. Luminance ratios were used to assess visually the spaces. These ratios were measured between the task and background, and should not exceed 1 to 10 values. For general tasks, ratios of 20 to 1 for fenestration and adjacent surfaces and of 40 to 1 for anywhere within the field of view are acceptable.

Sensors were located in reference points in each space where typical visual tasks were used to be
performed. Each reference point taken on-site was compared to the DR runs. Two tests were done in each space.

The first one compared on-site measurements with DR simulations. A single sensor placed at the center of each space at the height of 60 cm was used (Fig. 9). DR simulations were done at the same exact location. The results were then compared for discrepancies.

Figure 9: Sensor location for test one.

The second test calculated the illuminance level and uniformity over a rectangular reference grid in the three spaces. Each space had a number of sensors based on its floor area. The sensors were placed at two heights: one at 60 cm, representing how the space was used in old days; and the other at 90 cm, representing a contemporary work plane height (Fig. 10).

Figure 10: Sensor location for test two; (a) Room A, (b) Room B and (c) Room C.

4. RESULTS AND ANALYSIS

4.1 On-site Measurements and DR Simulations

Comparisons between on-site measurements and DR simulations of the three daylighting systems showed that, under clear sky conditions, the illuminance values were fairly similar. The DR simulations were slightly higher than the on-site illuminance values at most times. The overall discrepancy is about 10%. Only in the afternoons of the summer months DR overestimate illuminance levels as much as 49%, even though the exterior horizontal illuminance of the actual clear sky of UAE is higher than the one modelled by DR. Some possible reasons for this discrepancy are:

- The spaces were modelled in DR without the furniture of the real spaces.
- On-site measurements were done under Dubai clear sky conditions, while DR used CIE clear skies.
- The materials defined in DR have slightly different reflectance values than that found on-site.
- The last calibration dates of the three light meters and the luminance meter used for the on-site measurements are unknown.

4.2 Window Type I: Double Panel Window Analysis

4.2.1 Illuminance Level

The illuminance level across the Room A does not vary much seasonally in the space with the double panel window, but it changes notoriously throughout the day. Because the window faces east, the illuminance in the morning hours can reach up to 2,000 lux at the height of 60 cm and 90 cm on June 21 at 9:00am, while in the afternoon values remain in 880 lux on June 21 at 3:00pm (see Figs. 11 and 12).

Figure 11: Daylight variation at solstices and equinoxes of Type I- east-facing double panel window.

Figure 12: Plan view of illuminance iso-contours in Room A with Type I- double panel window, at 9:00am, 12:00pm and 3:00pm on September 21.
4.2.2 Illuminance Distribution and Uniformity

The illuminance gradient (or diversity of illuminance defined by CIBSE [5]) and uniformity of illuminance parameters were used to analyze the light uniformity in the spaces. The illuminance gradient is defined as the ratio of maximum to minimum illuminance; CIBSE recommends a maximum ratio of 5:1. The uniformity of illuminance is defined as the ratio of minimum to average illuminance; CIBSE recommends that this ratio should not fall below 0.7.

The room with the double panel window does not meet CIBSE criteria of uniformity (Tables 2 and 3). The range of illuminance gradient is between 6 and 13. These values almost double CIBSE maximum recommended illuminance gradient of 5. The highest uniformity of illuminance value of the space is 0.48, which is lower than the 0.7 recommended by CIBSE. The illuminance levels measured at 90 cm is more uniform than the ones measured at 60 cm, this is due to its proximity to the daylight source.

4.2.3 Visual Comfort

CIBSE recommendation for achieving a visually comfortable space is to maintain the luminance ratios within the field of view below 10:1. Since the space with the double panel window is facing east the luminance ratios were higher reaching 16:1 at 9:00 on June 21. Fig. 13 shows different DR images illustrating the highly variable illumination in the space.

4.3 Window Type II: Gypsum Decorative Panels Analysis

4.3.1. Illuminance Level

Room B with the gypsum decorative panels does not show high illuminance levels variations by season or time of day mainly because the window faces north (see Fig. 14).
4.3.3 Visual Comfort

Even though Room B faces north, the luminance ratio 17:1 (on June 21 at 12:00pm) is over CIBSE recommended ratio of 10:1 (Fig. 16).

4.4 Window Type III: Wind Tower Analysis

4.4.1 Illuminance Level

As observed in Fig. 17, the illuminance level across Room C and under the wind tower does not show high variations by season or time of day; except for the west wall that is washed by morning light and the east wall in the afternoon hours.
4.4.3 Visual Comfort

The overall luminance ratio in the Room C shows values as high as 391:1, which exceeds the 10:1 recommended by CIBSE. But if we consider the luminance ratios only under the wind tower or in the adjacent area, these ratios will be lower and within acceptable ranges for visual comfort (Fig. 19).

5. DISCUSSION AND CONCLUSIONS

The window systems analyzed in this study provided different outcomes. The overall lighting performance of the Type II- Gypsum decorative panels in Room B provides better quality light with more uniform light distributed throughout the space, though with lower illuminance level (see Tables 8 and 9). This can be improved by increasing the window size. The illuminance levels measured at 60 cm or 90 cm did not change the overall illuminance gradient or the uniformity of illuminance in Room B.

Even though the Type I- Double panel window yields higher illuminance levels into the Room A during the morning hours most part of the year, it has poor lighting performance in terms of glare, light distribution and uniformity. This condition can be improved by adding screen or diffusing material to the window opening.
The Type III- Wind tower performed well mainly in the area underneath the wind tower; light levels in this area are fairly high and uniform. Adding another window to the space will yield an increase in illuminance levels throughout the space, resulting in a more uniform space with lower illuminance gradient and higher uniformity of illuminance.

Indigenous buildings, as the presented in this study, have many sustainable features built into their structures. These buildings were built to use daylighting, natural ventilation, thermal mass of masonry and efficient heating. It is important to understand how these systems worked and how they were used in the past. The windows examined in this study may be judged by today's standards as daylighting systems that perform poorly, but we need to understand that these windows served dual functions, for ventilating and daylighting the room. These windows interacted with wooden shutters, iron bars and gypsum ornaments to provide privacy, security and control of daylighting for occupant's comfort. It was the occupant who decided which panel from the double panel window to close or open based on the external environment and occupant's needs. The gypsum decorative panels filtered daylight to adequate levels through an intricate array of small openings. There is a cultural value in these historical structures that need to be preserved for future generations to come.

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