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Evaluating the Performance of Daylighting Inside Interior Spaces of Historic and Ancient Buildings for Identifying Strategies of Designing Facade Openings of Future Buildings

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Abstract*: *This paper aims to evaluate the performance daylighting, using a validated simulation tool, during the day time based on reading the daylight factor of a specific room, oriented south, in three of the most distinguished buildings in AL Baha region namely, Thee Ain village, Bin Rogosh Palace and Al Dhafeer Village. Each room has been adopted sampling points along the center of the window above a working plane to predict the daylight factor. The average daylight factor of the points was evaluated versus the required daylight factor for the interior space living room, 1%, and an office space, 2%. The conservation of heritage and historic buildings can proceed beyond the its objective and progress to insight designer and engineers to reflect their values on the future and modern structures. Discussing façade criteria of these buildings can have a great effect in formalizing the identity and codes when achieving acceptable visual levels from proper daylighting performance from the aspects of space activities, weather conditions and openings sizing and specifications. The assessment revealed that for a given future building of Al Baha region, the identification of its daylight criteria must be obtained from optimization of the interior space for an average room area of 20m^2 and starting WWR 3.5% with an interval of 0.4% for consecutive iterations until the space is well-lit with an acceptable level for its occupants. Due to the lack of obtaining past weather profile that can be concomitant with these structures, a most updated weather profile has been applied and revealed informative results for contemporary buildings. Thus, comfortable indoor environment can be maintained. This paper fulfils a strategy need to study how brand-supportive behavior can be enabled.

Keywords: Insights, Daylighting, Historic, Façade, Visual comfort.

I. INTRODUCTION

The consideration of daylighting and its effect had been addressed properly for heritage and historical structures locating in Al Baha region since artificial lighting, that was invented in the mid-1930s (Richard 2009), had no applications in their means of occupants comfort in the past.

That's implies those buildings were reliant on daylighting as the only fundamental design element to provide visual comfort, satisfied illumination level, and thermally acceptable interior. Therefore, effective use of sustainable energy had always been involved into their design strategy.

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When developing design codes for window openings for contemporary and future building façades that inherited their criterion from old structures, the effect of daylighting must be analyzed on the energy performance at an early stage of the design process, thereby enabling architects, builders and specialist planners to construct energy-efficient buildings. Thus, they will be able to determine lighting conditions in buildings with artificial lighting, determine daylighting and temperature conditions, evaluate visual and thermal comfort, determine the impact of daylighting on lighting in general, determine the effects of different strategies on heating and air conditioning and evaluate economic and lighting aspects of many diverse daylighting and energy systems. Daylight can further afford building occupants an interaction with the outside environment. Despite, daylighting concepts of heritage and historic structures represent past climate conditions and cultural needs, and due to the complexity of contemporary buildings that requires achieving different functions, daylight must be adhered to computational techniques, modeling and investigation, to redefine the relationship between a building envelope and its interior space for future buildings according to today's needs, culture and the city's stipulations.

The importance of acquiring natural light into the inside environment stands for Psychological, physiological, aesthetical, social, environmental, economic and technological aspects such as healthy and comfortable interior space, heritage design theme, minimizing electricity consumption, energy saving and new definition of control systems (Darula 2018). For example, the first recognition of daylighting was on 1832 in the United Kingdom in a Prescription Act named Act Right of Light (Legislation 1832) as an important step to standardize natural light resources. In addition the revolution of European manufacturing in the 19th century has urged to environmental considerations that imposed impacts on architects, Le Corbusier and his peers, thoughts to change the quality and the significance of indoor natural light (Darula 2018). Since then, the design theme has embraced techniques for transparency and daylighting availability as fundamental elements of architectural work (Corbusier and Eardley 1973). Hall (2008) and Lechner (2014) revealed that typical energy consumption of electric lighting in buildings is about 40% where slight saving can be attributed to daylighting availability. Architectural design manuals, such as the Architects' Data or the CIBSE SLL Lighting Handbook confirm that a floor plan's pattern and a building orientation should be concomitant to the sun movement (Neufert 2012, CIBSE 2018).

Historic museum structures have been the aim of several studies (Pinilla, Moliní et al. 2016, Ahmad, Ahmad et al. 2017, Al-Sallal, AbouElhamd et al. 2018, Al-Sallal, AbouElhamd et al. 2018, Brembilla, Hopfe et al. 2018, Kaya and Afacan 2018, Sharif-Askari and Abu-Hijleh 2018) with regards to the design characterization and daylighting strategies. Ahmad, Ahmad et al. (2017) assessed the ceiling geometry contribution for daylighting of a historic museum gallery through a computer simulation modelling from each cardinal direction; North, East, South and West. In addition, roof openings played a great role in the systematic and statistical studies of (Mahdavi and Orehounig 2008, Morales-Segura 2009, Sibley and Sibley 2013, El Habashi, Moujoud et al. 2016, Tsikaloudaki, Coecen et al. 2016, Sibley 2018) that provided benchmarks of vernacular daylight in several heritage and historic public bathhouses in Europe, Turkey and North Africa. The studies specified the tacit rules underlying the number, location and configuration of circular roof opening of the hammams. However, façades were the aspect of investigation when Iommi (2019) highlighted a new and inedited daylighting analysis for multiple residential buildings designed by Le Corbusier exploring some design criteria related to the accessibility of daylight. The author investigated the daylighting with regards to illumination, luminance, daylight autonomy and daylighting factor revealing a quantitative description of natural light. Furthermore, a reduction of 4–29% in visual discomfort can be attributed to adjusted orientation of the facades in modern houses (Abdulkareem, Al-Maiyah et al. 2018). Despite that widespread research and manuals (Kerr 1865, Pollio 1914, Hopkinson 1963, Love 1992, Enarun and Littlefair 1995, Ravitch 1995, Wu and Ng 2003, Tuaycharoen and Tregenza 2007, Tregenza and Loe 2013, Tregenza and Wilson 2013, Jacobs 2014, Mardaljevic 2015, Mardaljevic, Janes et al. 2015, Blades, Lithgow et al. 2017, McNeil, Lee et al. 2017, Brembilla, Hopfe et al. 2018) investigated the requirements for daylighting codes and guidelines considering regulations and modelling, there are still scarce data to define exclusive criteria for façade's openings and specific climate and culture. Even though, a study carried out by Vaisi and Kharvari (2019) that investigated the daylight for a specific rejoin, it was only for assessing identified regulation for contemporary built up areas.

Hence and in line with the Saudi Arabia move towards sustainability and architecture conservation (MOEP 2005, MOEP 2010, Al-Jasser 2013, Aljoufie and Tiwari 2015, Kyriazis, Balasis et al. 2018, Daye 2019) has urged to step forward and contribute through façade design criteria for the city of Al Baha as part of urban governance and sustainable urban development and most important of all the new Vision 2030 plan (Khan 2016, Daye 2019). This could be relevant to what was concluded by Aina, Wafer et al. (2019) that traditional business mode is dominating the legislative framework and the administrative procedures for sustainable urban development. Thus, to ensure proper sustainable institutionalized urban development, they must subject to updated framework of stipulations and administrative approaches.

This paper aims to put forward the recommendation of study carried out by Haredy (2019) that quoted architectural façade elements from three distinguished heritage and historical structures locating in Al Baha region, namely Thee Ain Ancient Village, Bin Rogosh Historical Palace, and Al Dhafeer Historical Village in order to formulate a newly specified criterion–façade imageability- and demonstrates its potential value as a guide for Al Baha region new and retrofitted buildings. The study recommended that the daylight factor of the traditional façade with regards to window to wall ratio, since it is a critical criteria for specifying a preferred window size for daylighting (Tregenza and Wilson 2013), of each floor must be identified.

II. METHODOLOGY

The building modelling software Insights 360, a developed and regenerated software of ECOTECT (Autodesk 2016), as its outputs have been reliable and were validated by (Autodesk 2014, Haredy 2016), and can provide predictions for illuminance levels and daylight factors with slight computational efforts. The tool was implemented to examine the performance of daylighting of the window opening about their dimensions of each mentioned historic and heritage structure. Daylight factor will be calculated, due to its ability of expressing the percentage amount of daylight at a particular point in a space under the effect of overcast sky at any time of the year or day (CIBSE 1999), and investigated upon the availability of each opening and its direction. Moreover, under the impact of overcast skies, the daylight factor can resist the changes of internal and external illumination for any given design (Lechner 2014). It was assumed that during the simulation the windows were only apertures, so they were constantly open during the daytime of the city due to the heritage specifications of the windows as wooden texture patterns.

III. AL BAHA CULTURE, LOCATION AND CLIMATE

The region of Al Baha is in the southern part of the Kingdom of Saudi Arabia and constitute two sides, terrain and valleys. The first area has a hot desert climate (CLIMATE-DATA.ORG 2016), however, due to its location that is tremendously high above the sea level, it is cold in winter and mild in the summer while the valley areas have hot climatic conditions in the summer and warm in the winter. The culture of Al Baha heritage and historical structures from the aspect of design and configuration represent mainly the tribal culture that is themed with rural life. As such, buildings were, dating back to the end of the 10thcentury AH/8th century CE (UNESCO 2015), functioning naturally as far to water, lighting and power resources. Indeed, it can be noticed from their design that the first floors left solid without openings for daylighting to store goods and carps. However, the higher floors constitute spacious rooms with more than one opening to ensure natural light during the day.

Buildings played multiple roles in the history such as fortifications, social hubs and dwellings. Therefore, daylighting strategies were characterized for different use of the buildings.

IV. CASE STUDY OF HERITAGE AND HISTORICAL BUILDINGS

Three distinguished heritage and historical houses of Al Baha region located in different sites, the first one in the valley side and the other two in the mountainous part, were selected as case studies for the investigation of daylighting which are within Thee Ain Ancient Village, Bin Rogosh Historical Palace, and Al Dhafeer Historical Village. The reasons for selecting these buildings comes from their exceptions to the region and international outstanding classification. Thee Ain village has been listed in the World Heritage list of the United Nations Educational, Scientific and Cultural Organization (UNESCO) as an outstanding universal village (UNESCO 2015); Bin Rogosh Palace is the oldest historical palace in Al Baha region and several governmental efforts have been dedicated to preserve and rehabilitate its structures spending more than SAR 8m ; and Al Dhafeer village contains governmental buildings that helped the inhabitants of Al Baha city to gather and run the city.

For the daylighting investigation, the south facing façade has been considered since it is most optimal orientation of consistent sunlight throughout the day and the year (Obrecht, Premrov et al. 2019). Each of these buildings were specified a room in a higher floor, in which higher windows are advantageous for cherished daylighting (Gibberd 2020), of its floor plan for simulating the daylight performance. In addition, south façades were illustrated for each building and the window openings were highlighted with their walls as shown in Fig. 1, Fig. 2 and Fig. 3. The three buildings represent varied geometric characteristics and slightly similar culture due to their occupancy with different hierarchies.

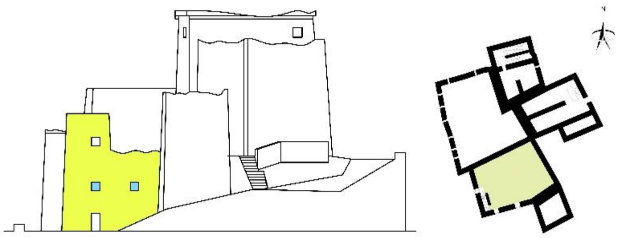

Fig. 1. Floor plan and south oriented facade of Thee Ain Village building. Source: The author

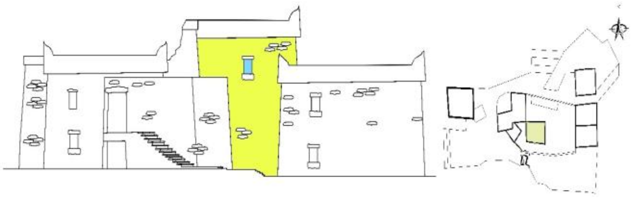

Fig. 2. Floor plan and south facade of Bin Rogosh Historical Palace building. Source: The author

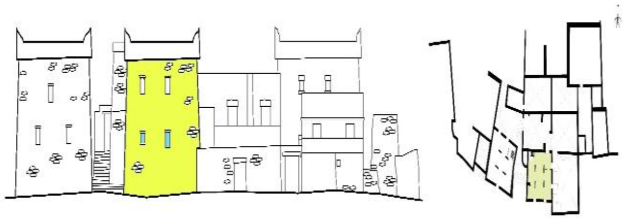

Fig. 3. Floor plan and south facade of Al Dhafeer Historical Village building. Source: The author

V. INVESTIGATION APPROACH

Insights 360 visualized the daylight factor for each selected room in each given building based on the geometry of the space and the dimensions of the openings, Fig. 4, within various points inside the room. Predictions were then illustrated into contours of daylight factors for the interior. Each space was assessed according to the typical minimum daylight factor required for living room, 1%, and an office space, 2% (CIBSE 1999) as these two types of spaces are the most occupied rooms in the selected buildings during the day time. Furthermore, office will represent the classical example of commercial buildings and so do the living room for residentials. The daylight factor can be calculated at a particular point on the room as follows (Lechner 2014):

$$DF = (Ei/Eo)\ 100 \qquad (1)$$

Where DF is daylight factor (%), Ei is illuminance due to daylight at a reference point on the indoors working plane (lux); Eo is simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky (lux).

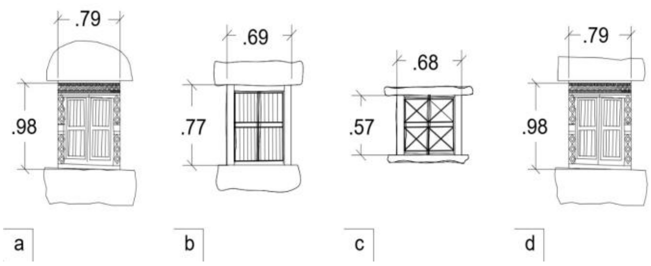

Fig. 4. Window shapes and dimensions, a and b for Al Dhafeer rooms, c for Thee Ain room and d for Bin Rogosh room. Source: The author

The overall information on the model characteristics were identified in the Table 1,

Table 2 and Table 3 as follows:

Table 1. Insights 360 module characteristics for Thee Ain Village building

Configuration	Description
Space	Living or office room
Height	2.8m
Occupancy Schedule	From 5:00a.m. to 7:00p.m.
Wall Thickness	600mm
Room area	$24m^2$
Room Height	3.1m
Opening area **1&2**	$0.8m^2$
Opening Height	570mm
Opening width	680mm

Window to wall ratio	2.3% of wall area
Sky condition	Overcast

Table 2. Insights 360 module characteristics for Bin Rogosh Historical Palace building

Configuration	Description
Space	Living or office room
Height	2.8m
Occupancy Schedule	From 5:00a.m. to 7:00p.m.
Wall Thickness	600mm
Room area	$25m^2$
Room Height	3.2m
Opening area	$0.52m^2$
Opening Height	980mm
Opening width	790mm
Window to wall ratio	3.5% of wall area
Sky condition	Overcast

Table 3. Insights 360 module characteristics for Al Dhafeer Historical Village building

Configuration	Description
Space	Living or office room
Height	2.8m
Occupancy Schedule	From 5:00a.m. to 7:00p.m.
Wall Thickness	600mm
Room area	$16.7m^2$
Room Height	3.6m
Opening area **1**	$0.8m^2$
Opening Height	770mm
Opening width	690mm
Opening area **2**	$0.52m^2$
Opening Height	770mm
Opening width	690mm
Window to wall ratio	2.7% of wall area
Sky condition	Overcast

For each simulation model the effect of the room's depth on daylighting was verified, by assigning reference points with consistent intervals to the room depths aligned with the center of the windows, Fig. 5, Fig. 6 and Fig. 7, starting at number one at the center of each window. The daylight factor (DF) was then calculated for each point inside each interior and represented by an average value. The average daylight factor required can be calculated as follows:

$$D = 0.1\ P \quad (2)$$

where:
D = Daylight factor
P = Percentage glazing to floor area
The work surface heights were slightly varied between the rooms in an average of 3.3m. The models have white walls and ceilings with a reflectance of 0.85 and a beige floor with a reflectance of 0.6.

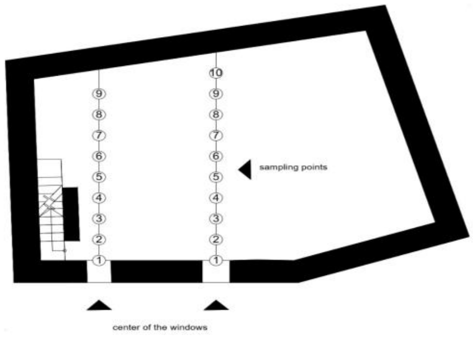

Fig. 5. Thee Ain room sampling points

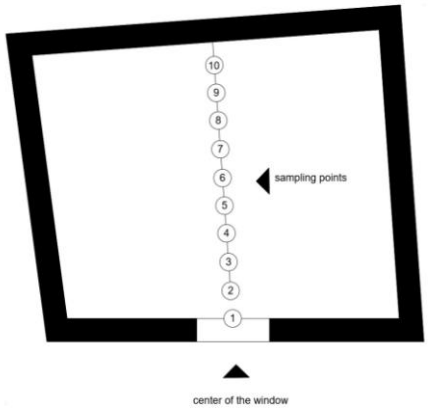

Fig. 6. Bin Rogosh room sampling points

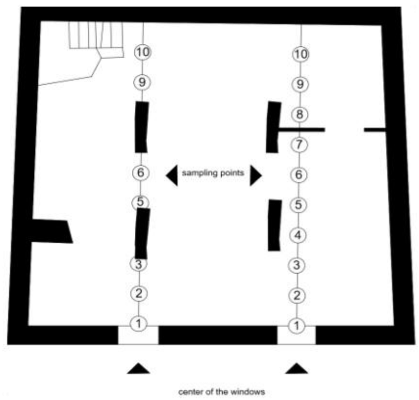

Fig. 7. Al Dhafeer room sampling points

VI. DAYLIGHT FACTOR ANALYSIS

The values of daylight factor were predicted for each room of the historic and heritage buildings. Fig. 8 illustrates the ratio of the light level inside Thee Ain room on a working plane raising above the floor to the window level. It can be noticed that the interior space is very dark, represented as zero per cent of daylight factor dominating the space, to the light level of the outside the room. That would be attributed to the small size of the window opening that are in the one side of the structure. Furthermore, the criteria of the space size and its apertures are not suitable to be adopted for modern buildings whether as an office nor living area. However, from the cultural point of view, these criteria might be acceptable in the history due to the different activities that had been happening. Moreover, each sampling point inside the room produced zero per cent value of the daylight factor from the center of the window to the back of the room with an average of zero per cent, Table 4, value that represent a dark space below the required level of daylighting.

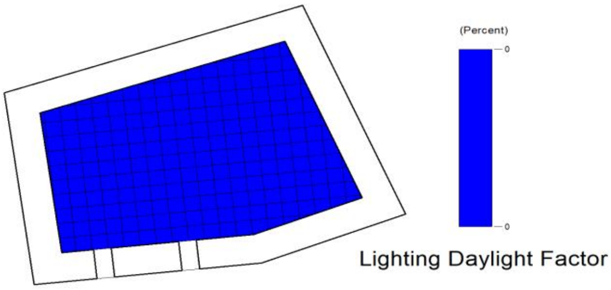

Fig. 8. Images of Daylight Factors on working plane in Thee Ain room.

In contrary, the measured daylight factor of Bin Rogosh room as represented in the working plane in Fig. 9 reflects well-lit interior space for the window surrounding as far as 4 sampling point from the center of the window where the daylight factor value reach up to eight per cent. In which be construed as suitable window opening for the room. In contrast, modern buildings are not capable to satisfy the required daylighting level for their occupants due to the domination of dark area of the room, around 70% of its area. However, the average daylight factor value of the sampling points is appearing to be acceptable with two per cent ranging from 8 to zero per cent from the center of the window to back of the room, Table 4.

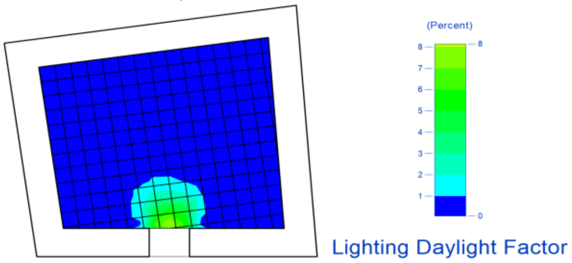

Fig. 9. Images of Daylight Factors on working plane in Bin Rogosh room.

Similarly, the illustration of the daylight factor of Al Dhafeer room, Fig. 10, that were allowed from two different size window openings shows high daylight level, ranging daylight factor values from seven to two per cent, for the close part of the room around the windows with a dark domination of the middle and back of the room plummeting down to zero per cent value of daylight factor. Despite the average value of the daylight factors for the sampling points along the center of each window is 2%, Table 4, the room criteria will not be proper to be consider in contemporary buildings since the interior space is still dark for most of its part.

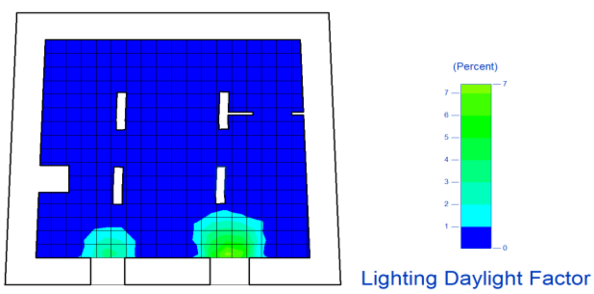

Fig. 10. Images of Daylight Factors on working plane in Al Dhafeer room.

Table 4. The values of daylight factors for each sampling points in each room.

Sampling Points	Thee Ain room	Bin Rogosh Room	AL Dhafeer room
1	0.00	8	7
2	0.00	7	6
3	0.00	4	4
4	0.00	1	1
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
Daylight factor average (%)	0.00	2	2

VII. CONCLUSION

Providing quality daylight strategy and criteria for the modern and contemporary buildings in AL Baha depending on its heritage and historic structures is critical. Those former buildings can play a major role in characterizing the openings identity of the future city buildings facades since they represent the city culture of the occupants, weather interaction and the architectural components forms and materials. Even though, those factors have been undergone slight changes due to the great time intervals, future buildings are still needed to inherit their criteria from these structures. The study reported here attempted to evaluate the daylight performance of the window openings when allowing daylight during the daytime inside the heritage and historic buildings of AL Baha region namely, Thee Ain village, Bin Rogosh Palace and Al Dhafeer Village. The room of each building were expected to be visually comfortable due its characteristics (south orientation and window sizing) since they had been adhered to a period of no energy was applied. However, Thee Ain room presented dark interior space with a daylight factor level below two per cent (for $24m^2$ room area, $0.52m^2$ opening area and WWR 2.3%) which can be construed as a different occupants' activity pertaining to that time inside this building.

On the other hand, the other rooms of Bin Rogosh (for 25m2 room area, $0.52m^2$ opening area and WWR 3.5%) and Al Dhafeer (for $16.7m^2$ room area, $1.32m^2$ opening area and WWR 2.7%) buildings showed acceptable visual level of daylighting with an average daylight factor of two per cent even though most of their areas across the rooms were dark. Despite that the current weather profile applied into the software does not represent the actual weather conditions of the former buildings were inhabited, the evaluation of their daylight performance according to a contemporary weather data can direct to a thought-provoking informative analysis that insight to modern design strategy for daylighting of future buildings.

In conclusion, identifying accurate daylighting design strategies for Al Baha region future buildings, must be defined from optimization of the daylight f performance of a future building rooms considering the average room area of 22 m2 and increasing WWR from 3.5% with an interval increase of 0.4% for each iteration until the required level of a proper daylighting factor is achieved.

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