INVESTIGATING THE INFLUENCE OF EXTERNAL FACADES REFLECTIVITY ON THE INDOOR DAYLIGHT AUTONOMY IN HOT ARID CLIMATES

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ABSTRACT

Hot arid climates are characterized by clear sunny sky most of the year time. Such climates affects the urban morphology, which requires sometimes dense urban fabric. Narrow streets have significant effect on the amount of daylight permeating indoor residential zones, which may have a negative or positive effect on the overall visual performance.
This paper studies the quantitative effect of using different Façade reflectivity ratios, under different street widths, on the indoor daylight autonomy. The researcher performed a parametric analysis using DIVA for Rhino simulation tool on a hypothetical residential building unit with various window ratios facing neighbouring buildings. Four main orientations were examined under different urban contexts and wall reflectivity. This paper aims to measure daylight autonomy and address possible strategies and solutions to achieve better daylighting that can be used by architects at early design stages of housing developments in the desert climates.

INTRODUCTION

As the largest city in Africa and the Middle East, Cairo suffers from an extreme densification for several reasons, mainly due to housing crisis (Fahmi and Sutton 2008). During the last half century, population has increased four times and settlement areas have barely doubled (Harris and Wahba, 2002). The desert was the approach to build new settlements to host exceeding populations and to reduce traffic on streets and public facilities from the capital city.

In desert climates, clear sunny sky prevails most of the year, giving a good opportunity to easily provide indoor spaces with sufficient natural light most of the day time. Yet, it is crucial to manage the amount of the daylight entering the indoor zone without exceeding comfort limits. Special attention should be taken in the early decisions of design in terms of orientation, massing, opening positions and sizes (Andersen et al. 2008).

Achieving good daylighting in buildings is a challenging task; it is directly proportion with minimizing environmental impacts of a structure (US Department of Energy, 2006). It is a major impact on how the space is perceived by the different users (Lam 1986; Guzowski, 2000) as well as it has a positive impact on health (Veitch 2005; Webb 2006), wellbeing and efficiency (Cuttle 2002; Heschong-Mahone Group, Inc., 2003; Kim and Wineman, 2005).

Many Variables affect the quality of daylight in a space in an urban context, such as building heights, street widths and façade reflectivity ratios. Thus, it is the responsibility of urban planners working in the government or municipalities to tackle those variables to achieve better indoor daylighting. But, like the majority of developing countries, we are following methods and techniques that came initially from the West of the Far East, those have been ill-applied without any adaption to our climate or backgrounds (Abdel Razek R. 1998 and Weytjens et al. 2010).

Moreover, the majority of neighbourhoods do not follow legislations that consider any of those variables, rather than informal settlements. It is very important to impose possible and applicable solutions for existing conditions as retrofitting measurements.
Different Façades reflectivity or colours are usually associated with the amount of heat absorbed, sometimes it is associated with culture or traditions or it has something to do with the types of rendering materials that are available in a city. Yet, colours of building facades have a great influence on the amount of daylighting in the interior spaces of neighbouring buildings. It could be understood axiomatically that bright colours enhance the daylight availability of the interior spaces, and dark colours have an opposite influence. However, it is hard to find codes that regulate types and brightness of buildings facades in a specific urban context, except under special conditions with buildings that are conserved by the UNESCO such as in Tunisia . (UNIESCO)

This research aims to study the effect of different facades reflectivity and window ratios on the daylight autonomy under different street widths. By using a simulation tool that calculates the annual daylighting performance; quantitative results were presented and recommendations for retrofitting measures were discussed to be used by architects and those who works on urban development projects in Cairo and Egypt.

METHODOLOGY

This paper is a part of an ongoing research that aims to produce retrofitting measures on the urban scale to achieve optimized performance concerning thermal and visual comfort. The focus deals with the reflectivity of external building façades and its relation with the indoor daylight autonomy as a valid measurement.

As a first step, weather and climatic conditions were identified according to the location, which is in Cairo. The case study does not resemble a certain area or neighbourhood; it is based on a parametric analysis under different possible cases. Second Step addressed the simulation software used to perform the analysis, the metrics used for measurement. Third step describes the parameters of a hypothetical urban context based on the Egyptian unified code for construction, and in a challenging case with narrower street widths. A single case study room and occupancy schedules were calculated in the simulation. Fourth step presented the results of the simulation and discussed them, in which recommendation for better retrofitting solutions were proposed.

Weather Analysis

The area chosen for the analysis is Cairo; it lies in Latitude 30.1 and Longitude 31.4. The high temperatures in winter ranges from 19C to 29C, while at night it drops from 11C to 5C. High temperatures in summer can reach 40C by maximum, and drops to 20C at night. Extreme sun altitudes are 36.4 degrees in winter and 83.2 degrees in summer at 12:00 noon for a south façade. Difference between the weather inside the city and in the suburbs ranges from three to five degrees.

Sky Classification

We conducted a sky type analysis to convert the hourly global irradiance values, found in Cairo's weather file (EGY_Cairo.Intl.Airport_ETMY) (DOE 2014), into hourly direct and diffuse beam irradiance based on Perez All-Weather Sky Model Analysis. The sky model divides the sky clearness into eight categories and applies different coefficients for its luminous efficacy model equations (Perez et al., 1992). This combined with the iterative calculation of irradiance values allowed to classify Cairo's sky into four major categories presented in Table 1.

Table 1
Radiance simulation parameters

Sky	Overcast	Cloudy	Turbulent	Clear
Percentage	5.08%	7.83%	17.88%	71.7%

Simulation Tools and Parameters

According to the Illuminating Engineering society of North America (IESNA), Daylight Availability represents the annual amount of daylight coming from the sun and the sky at a specific location, time, and date and sky condition. Climate-based Daylight Modelling approaches (CBDM) handles long periodic analysis represented by two popular metrics; Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI). Daylight Autonomy metric was adopted in this research as it is not constrained by a minimum and maximum threshold for daylight intensity as in the UDI (100 lux – 2000 lux).

DIVA for Rhino simulation tool was used to model the case study and calculate Daylight Autonomy. DIVA works with several simulation engines that calculate Daylighting, Solar Radiation, Glare and Energy Consumption. The main two simulation engines on which the simulation was based are Radiance and Daysim. Radiance works with the ray trace backward technique for the precise daylight calculations (Ward and Shakespeare, 1998) on which most of the daylighting software tools are based (Reinhart and Fitz 2006) and it has been validated by different researches (Mardaljevic, 1995; Reinhart and Herkel, 2003). Daysim (Reinhart and Walkenhorst 2001) calculate the annual performance in the form of Daylight Autonomy that represents the percentage of work hours were daylight is sufficient to perform a given task (Reinhart et al. 2006).

Table 2
Radiance simulation parameters

Ambient bounces	Ambient divisions	Ambient sampling	Ambient accuracy	Ambient resolution
5	1500	20	0.1	300

Case Study Parameters

A hypothetical room with dimensions 4m x 5m x 3m (width, length & height) is examined under different window ratios with no shading devices. The window is double glazed with visual transmittance: 88.4%. The interior walls reflectivity is set to be 50% and ceiling 80% and the floor is 20%. The single zone lies in the first floor from the street. The room is examined under three different windows to wall ratio WWR 20%, 40% and 60%. The centre height of the window is about 5m above the street level. It is important to mention that no obstructions in front of the living room case study, such as trees and urban landscape, have been taken in consideration, which will make an effect in a real case situation.

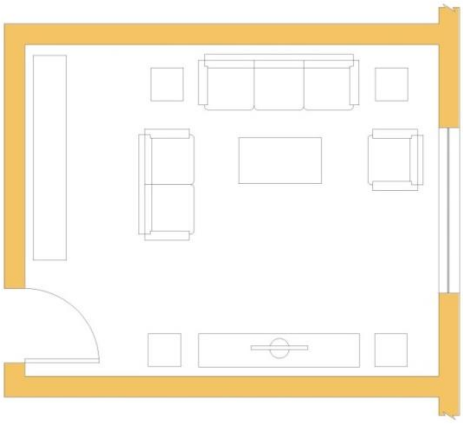

Figure 1 Hypothetical living room plan

Figure 2 Living room height from the street

Occupancy schedules were developed for the living room. It was divided into two main periods; summer (22nd of March till 23rd of September) and winter period (from 24th of September till 21st of March). Starting hours of occupancy were based on detailed schedules presented as a benchmark model of a living room in Egypt (Attia et al 2012). Last hours of occupancy were defined by the sunset for winter and summer seasons. Total occupancy hours are 3760 hours per year.

Table 3
Architectural design parameters for the tested zone

Living Room parameters			
Dimensions	4m x 5m x 3m		
Area	20 m2		
Reflectivity Ratios	Ceiling	80%	White Paint
	Walls	50%	Medium Off-White Paint
	Floor	20%	Wooden Floor
Occupancy Schedules	Summer	10:00 – 19:00	
	Winter	07:00 – 17:00	

Based on the annual metric Daylight Autonomy, the IES Daylight Metric Committee defined the daylit area boundary at the 50% daylight autonomy iso-contour line for a target illuminance. Based on the Egyptian code of Energy Efficiency in Residential Buildings (EERB), the mean target illuminance for a living room is 300 lux, on which daylight autonomy calculations were based. According to the furniture organization, it is presumed by the author that achieving Daylight Autonomy for 50% of the room area is an acceptable threshold for adaptive occupant behaviour.

Urban Context Definition

According to the unified Egyptian construction law, the minimum street width defined in the new cities is 12 m for the side roads. Yet, it is not the case in the real condition in the building sector in Cairo and Egypt overall. It is hard to find a representative urban context for the unconventional urban patterns whether used in old cities of Cairo or informal settlements. Accordingly, the research was based on two different conditions; first, according to the unified construction law with 12m street width for a five story building, and the other under an extreme condition with the same building height and a narrower street with 6m width. Such extreme conditions could be found for example in Ain Shams, Matarya, Shubra and Dar El Salam districts in Cairo.

External Facades of the surrounding buildings are examined under three different reflectivity parameters; 35%, 50% and 80%, in which they count the colour of the façade that gives the required reflectivity.

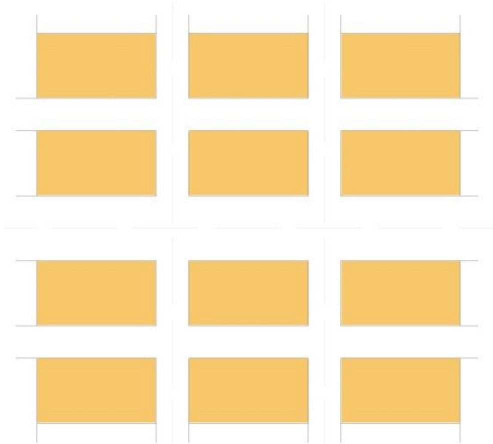

Figure 3 Hypothetical urban pattern with 12m and 6m street widths

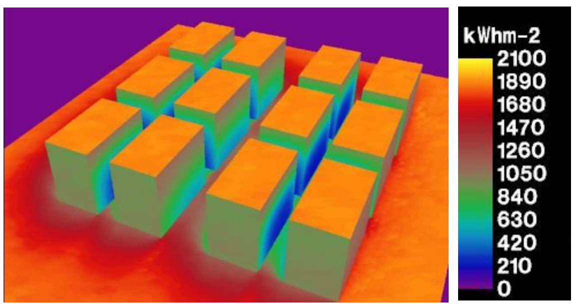

Figure 4 Solar Radiation on the modelled urban pattern

<u>RESULTS</u>

East Façade

According to furniture distribution in the room, (DA300lux[50%]) that covers 50% of the room area is presumed to be the threshold for achieving good daylighting for an adaptive occupant behaviour. By default, distribution and intensity of daylighting is increasing by the increase of reflectivity or window ratio. With 6m street widths, façades with 35% and 50% reflectivity did not reach the threshold for all window ratios, only with 80% façade reflectivity it was approached with window ratios more than 40%.

Table 4
East Façade Daylight Autonomy

	Façade Reflectivity 35%			Façade Reflectivity 50%			Façade Reflectivity 80%		
WWR	20 %	40 %	60 %	20 %	40 %	60 %	20 %	40 %	60 %
6m	8	17	25	13	25	39	35	57	80
12m	32	57	84	45	63	89	65	93	100

With 12m street widths, the results showed that almost all façade reflectivity percentages lead to reach the threshold for daylighting except in two cases; with window ratios 20% with external façade reflectivity 30% and 50%.

North Façade

The North Façade did not achieve relatively higher values than that of the Eastern Façade. With 6m street width, the final results were slightly similar to those for the northern façade, by which only with 80% façade reflectivity it was approached with window ratios more than 40%. With 12m street widths, almost all results reached the threshold except with façade reflectivity 35% with window ratio 20%. The room achieved DA 100% of floor area with 60% window ratio with façade reflectivity 50% and 80%, while it achieved DA 99% with window ratio 40% with wall reflectivity 80%.

Table 5
Northern Façade Daylight Autonomy

	Façade Reflectivity 35%			Façade Reflectivity 50%			Façade Reflectivity 80%		
WWR	20 %	40 %	60 %	20 %	40 %	60 %	20 %	40 %	60 %
6m	10	22	25	16	29	39	35	56	78
12m	33	55	81	48	70	100	73	99	100

It is a bit obvious that the results of the northern and eastern facades are similar especially under 6m street width, which is not the case in a conventional four orientations daylighting study.

South Façade

The South Façade achieved lower daylighting values than those of the eastern and northern facades especially under wider streets. With 6m street width, threshold is achieved with façade reflectivity 80% and with only window ratios 40% and 60%. With 12m street width, the possibility to reach the threshold is higher with more façade reflectivity percentage as shown in table 5.

Table 6
Southern Façade Daylight Autonomy

	Façade Reflectivity 35%			Façade Reflectivity 50%			Façade Reflectivity 80%		
WWR	20 %	40 %	60 %	20 %	40 %	60 %	20 %	40 %	60 %
6m	5	15	23	12	28	40	37	57	82
12m	31	42	63	36	57	86	63	96	100

On one hand, daylit area achieved in the southern façade is less than that of the northern façade with wider streets, while on the other hand, with narrower streets, northern façades achieves less amount of daylighting with bigger window ratios and larger amount of daylighting with smaller window ratios compared to the southern façade.

West Façade

The western façade achieved less amount of daylighting than the eastern façade. With 6m street width, the threshold was achieved with façade reflectivity 80% and window ratios more than 40%. With 12m street width, there were higher possibilities to reach the threshold with Façade reflectivity 80% with all window ratios, or with façade reflectivity 50% with window ratios larger than 40%. With window ratio more than 60% it was only possible to reach the threshold with façade reflectivity 35%.

Table 7
Western Façade Daylight Autonomy

	Façade Reflectivity 35%			Façade Reflectivity 50%			Façade Reflectivity 80%		
WWR	20 %	40 %	60 %	20 %	40 %	60 %	20 %	40 %	60 %
6m	7	15	23	12	28	40	35	58	81
12m	28	42	63	37	58	87	63	95	100

DISCUSSION

In Cairo, it is very rare to find buildings with white or bright colour facades. In the poor districts, plastering is only applied on the main façades, while the other three sides of a building are left in a redbrick appearance. Accordingly, façade designs and its relation to the overall recommendations of urban districts is the least priority of local inhabitants. Thus, this paper aimed to investigate the effect of the different neighbouring facades reflectivity ratios on the indoor daylight autonomy for a hypothetical representative residential room. Different window ratios were associated with that experiment. The results estimate possible retrofitting measures to achieve better indoor daylighting. Different street widths represented different urban contexts in this research, which resembles real case situation in high density districts in Cairo.

According to all the results, increasing wall reflectivity in narrow streets can increase the amount of daylighting from five to seven times for small window ratios, and up to four times for large window ratios. In wide streets, daylighting can be increased by two times for small window ratios, and up to 50% for larger window ratios. Thus, increasing façade reflectivity in informal and high density areas with narrower streets is more efficient than in the normal cases in Cairo.

In normal cases, urban landscaping such as trees resembles an obstruction for daylighting to enter an indoor zone. Yet, in this research, it was not included in the calculations, as the main aim was to evaluate the pure amount of daylighting caused by the reflections coming from neighbouring facades.

Thus, daylight performance was different within urban surroundings rather than in single cases. It is common that southern and western facades receive higher daylight values than those in the north and east. However, in this research on one hand, northern and eastern facades received relatively more daylighting due to the external reflections of the day and sunlight. On the other hand, south and west facades did not receive more reflections from the opposite facades that face the north and east directions.

Energy consumption associated with of artificial lighting and cooling loads were not calculated in this research; however, it will be included in further research. This study focused on daylighting in the lower floors (first floor). Upper floors are affected minimally with façade reflections; as they are affected more with building orientation and street width as mentioned in previous studies (Hegazy et al. 2013).

Moreover, Glare, Privacy and view factors can be affected naturally with the increase or decrease in window ratios, and with occupancy behaviour window operability will change the final output, knowing that, for instance, privacy factor in the Middle Eastern countries resembles a higher priority than daylighting (Hegazy 2013). Yet, it was important to in this research to mention the basic parameters and possible solutions that are important to enhance an existing condition, which are not considered yet in any given codes or building regulations in Egypt.

RECOMMENDATIONS:

Simulation results show that northern and eastern facades have nearly the same results, southern and western facades have same results as well. The tendency to achieve more daylighting through reflections is significant through the results here. In the normal cases, Southern and Western facades achieve more daylighting, but here the case is reversed, the amount of daylighting mainly comes from the reflections of the outer facades.

According to the simulation results and the predefined threshold indicator for a good daylighting in the living room, the following are the recommendations for all facades reflectivity and window ratios.

For the North and East Facades

For wide streets, WWR 40% and more achieves daylighting with any façade reflections, and WWR 20% only with reflections that exceeds 80%. For Narrow Streets, WWR 40% or more only gets sufficient daylight with high reflectivity facades.

For the South and West Facades

For wide streets: window Ratio 20% only works with façade reflectivity 80%. Window ratios 40% or more can bring sufficient daylight with façade reflectivity 50% and more. For narrow streets: with low façade reflectivity only window ratios, more than 60% would be suitable. Window ratio 40% can bring sufficient daylight with façade reflectivity more than 50%. However, with Façade reflectivity more than 80% can fit with all window ratios.

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