Daylighting optimization for informal settlements in Cairo, Egypt

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Abstract

In developing countries, the phenomenon of informal settlements has increased significantly. For instance, Cairo is considered to have four out of the thirty biggest "mega-slums" in the world, with a total of 11.8 million inhabitants. These settlements occupy 62% of the Greater Cairo area. Sustainable development is urgently needed to ensure better quality of life for now and the following generations. One of the characteristics of informal settlements is having narrow streets and dense urban fabric. Thus, only a small amount of natural lighting enters indoor spaces, which has adverse effects on the physical and psychological health of the inhabitants.

This paper aims to identify the most reasonable window ratios in relatively narrow street widths (4, 6 and 8 meters) based on the amount of light reaching the ground floor levels. This paper utilizes brute force procedure based on daylighting performance criterion. The parametric daylighting simulations were conducted using the Diva-for-Rhino, a plug-in for Rhinoceros 3D modeling software, which is used to interface Radiance and Daysim daylighting simulation engines. For the parametric tool, Grasshopper was used to generate the parametric urban model based on a generic case study taken in Cairo, Egypt.

This paper presents quantitative results and measurements aiming to help decision makers address development strategies for informal settlements and to provide essential data for setting regulations for newly built urban spaces.

1. Introduction

Informal settlements are characterized by being illegal residential settlements that are not committed to any urban regulations and codes (Von Rabenau, 1995). Informal housing is an unauthorized development that occurs around and in city master plan causing undesired adverse impacts. Land and natural green area around cities are been chewed up by new roads, residential and commercial buildings. On one hand, informal areas have been a standardized lifestyle for large populations in developing countries (Srinivas, 1991), and eventually they provide affordable living standards and a steady job market.

On the other hand, informal settlements have many opposing effects on both local inhabitants and the whole society. They cause a significant threat to the housing market and urban development in the country, in addition to other problems concerning sanitation, health, environmental facilities and services.

Informal areas in Cairo have taken an epidemic toll in the last three years, especially after the revolution of 25 January. That was simply a direct result of the official neglect of the fast spatial expansion of the city as shown in Fig. 1.

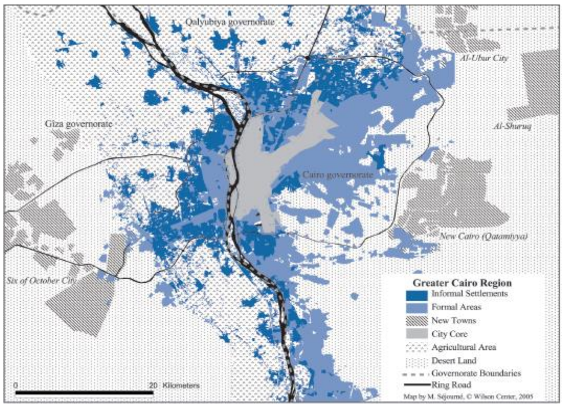

Fig. 1 – Distribution of the formal and Informal Settlements in Cairo

The unorganized expansion has extended over serial agricultural areas around the city. Immigration from villages and other governorates has exponentially risen which has led to an

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Baratieri, M., Corrado, V., Gasparella, A. & Patuzzi, F. (Eds.). 2015.
Building simulation applications BSA 2015. bu,press.
https://doi.org/10.13124/9788860460745

enormous increase in population in the big cities forming unorganized vertical expansion with very dense urban fabric. These densities in some areas have reached 350,000 inhabitants per square kilometer which is beyond the standard limits (Sejourne, 2002).

2. Informal settlements features

Three key features are common to all informal areas around the world: social, physical and legal features (Sirinivas, 1991). First, physical features are represented by a lack of services, inadequate housing, degrading environmental conditions, insufficient lighting, ventilation and air quality. In addition, there is a scarcity of infrastructure and services such as a clean water supply, public sewer network, public transportation, efficient streets, schools, policing and fire fighting.

Regarding social features, informal settlement inhabitants usually have the lowest income, they work in temporary and informal jobs, and they are also the poor and acquire no or little education. Lastly, legal features are evident through illegally occupying land plots that belong to the government or even individuals.

It is possible to see buildings on agricultural lands, which are built without the permission of the local authorities and are not committed to urban planning codes or regulations as shown in Fig. 2 and 3.

Fig. 2 – A typology of Informal Settlements in Cairo

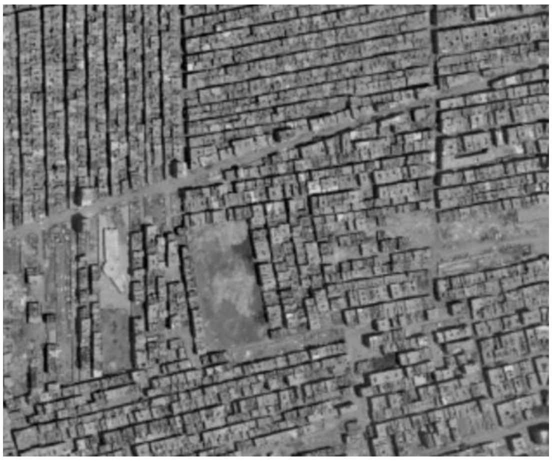

Fig. 3 – Another typology of Informal Settlements in Cairo on agricultural lands

3. Urban Daylighting

Many researchers have investigated the influence of urban morphology on daylighting and daylighting planning tools. Previous work identified an empirical relationship between street widths and daylighting for interior zones, aiming to identify city forms that consider daylighting requirements (DeKay, 2010). Lately, urban daylighting has been granted an extensive interest from the research community. A new tool for assessing daylighting on the urban scale has been developed by MIT sustainable lab (Dogan et al., 2012). Moreover, this tool is capable of calculating other aspects, such as walkability and energy consumption (Reinhart et al., 2013).

Some contributions from Egypt tried to provide some solutions to enhance daylighting in the informal settlements. Changing window ratios and external façade reflections can provide daylighting with more than 50% than the original cases (Hegazy and Attia, 2014). Others have developed a device that is attached to the top of the buildings that provides diffuse daylighting on the opposite buildings' facades (Nassar et al., 2014).

It is hard to unify settings for informal settlements; thus there is a need to generate a set of solutions based on the random variations that are given in any informal area. The aim is to identify most reasonable window sizes according to narrow street widths (4, 6 and 8 meters) based on the amount of daylight that reaches indoor spaces on the ground floor levels. However, due to time and efforts constraints, only the south façade was examined. In the end, this research provides decision makers with informative data, which helps in determining the recommended building heights and window ratios based on the road width.

4. Methodology

A broad investigation has been conducted on the conditions and conventional ways of dealing with informal settlements. In addition, a review of previous literature helped to find solutions for narrow street designs. A hypothetical model for an extreme urban context was modeled and parametrically simulated with a set of multiple variables. Optimum solutions were sorted based on the predefined urban dimensions limits. The Grasshopper for Rhinoceros 3D modeling tool was used in this research work (Wagdy, A. 2013). A typical living room is modeled on the ground floor in the defined context. The daylighting was assessed based on the approved method IES Spatial Daylight Autonomy ($sDA_{300/50\%}$) and Annual Sunlight Exposure ($ASE_{1000/250hr}$) (IES, 2012). The results show possible solutions under different configurations for increasing the Daylit area in residential zones.

4.1 Experimentation approach

It is barely possible to extract a fixed building regulation; the case study does not represent a particular informal area in Cairo. The context was modeled considering extreme urban conditions for building heights and street widths in a very dense urban fabric. In this context, a dwelling living room was modeled oriented to the south; it is located on the ground level in order to represent the zone with the least amount of daylight.

Table 1 – Living room configuration

Living Room Configurations			
Floor Level		Ground Level	
Dimensions		6m x 4m x 3m	
Area		24 m2	
Reflectivity Ratios	Ceiling	80%	White
	Walls	50%	Off- White
	Floor	20%	Wooden
Window orientation		South	
Occupancy Schedules		08:00 – 18:00	

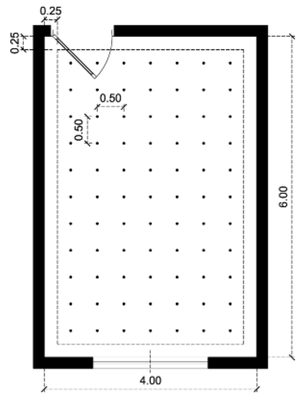

Fig. 4 – Room dimensions

Radiance parameters of the simulation model are set to meet the minimum requirements for LEED v4 for a valid simulation results. Namely, Spatial Daylight Autonomy (sDA300/50%) Metric followed Annual Sunlight Exposure (ASE1000/250hr) is shown in Table 2. (IES, 2012 & Elghazi et al., 2014).

Table 2 – shows radiance simulation parameters for [sDA and ASE Metrics respectively].

Ambient bounces	Ambient divisions	Ambient sampling	Ambient accuracy	Ambient resolution
6	1000	20	0.1	300
0	1000	20	0.1	300

The analysis runs through three primary variables. The first variable is window ratio, which ranges from 20% to 90% as shown in (Fig. 5). Consequently, window ratios represent the possible solution that can be done by any inhabitant individually.

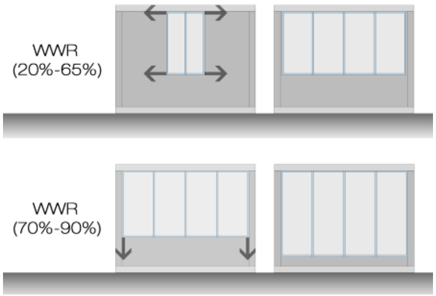

Fig. 5 – Window sizes and positions.

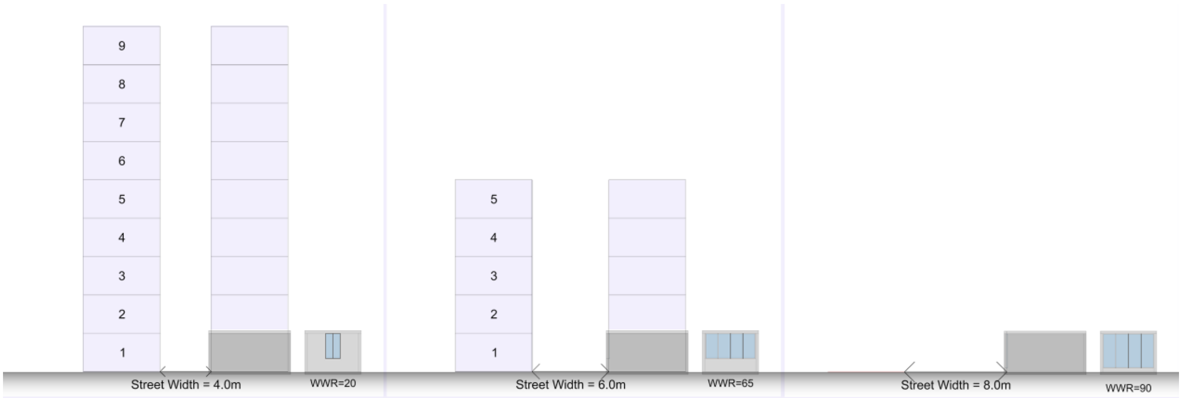

Fig. 6 – Street widths range from 4 to 8 meters and the building heights range from zero to 9 floors.

The second variable is the height of the opposing building, which varies from no neighboring buildings till nine storeys for extremely densely populated areas. The third and last variable is street width; the street width is set to start from 4, 6 and 8 meters for a relatively wide street in an informal area as shown in Fig. 6. The tested room is simulated attached to multi adjacent buildings representing the dense urban fabric of informal areas, and to increase the accuracy of the assessment that should be based on the opposite buildings' heights only. In Table 3, the three variables are summarized so that parametric iterations took place representing all possible combinations of the different variables resulting 450 different situations.

Table 3 – Variables and parameters of the simulation model.

Parametric Parameters	
WWR	20% - 90% (5% Increment)
Street Width	4 - 6 - 8 (2 meter Increment)
Number of floors	0 - 9 (1-floor Increment)

5. Results

The results are generated parametrically based on brute force technique to create 450 different cases. This research explores the influence of urban configurations on the daylighting performance in the interior zones of the opposite buildings. This evaluation is necessary to understand the daylight performance according to building height, street width, and window size, considering constant values for the weather condition, schedules for occupancy and no shading devices. The results of this exhaustive search are divided into three sections, according to street widths, with 150 results each explaining the effect of each variable on daylight performance, by which optimum solutions are identified.

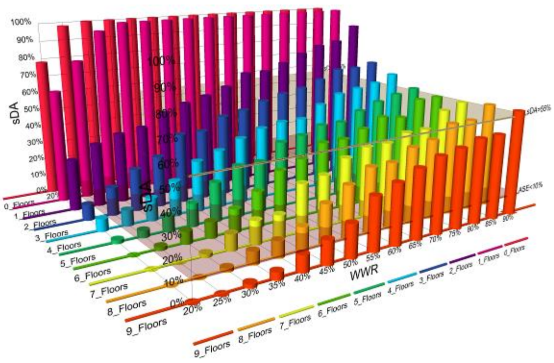

Fig. 7 – sDA results of different window ratios according to the various heights of the opposite building for a 4 meters street width.

The narrowest street width of 4 meters in Fig. 7, and the results of daylighting performance for 150 cases are shown. The cutting edge for the successful cases lies on the 55% sDA. All the cases with a 90% WWR reached or exceeded the threshold. With 85% WWR the results reached the threshold only when the opposite building height was reduced to six and five floors. Then, more results were accepted when facing a building with three floors above the ground level. The accepted range of WWR percentages increases with lower height of the surrounding buildings, which allow more sunlight into the indoor spaces. However, the values of Annual Sunlight Exposure (ASE) increases as well. The ASE analysis illustrated in Fig. 8 shows a constant value of 0% when the space faces a building with a height of 3 storeys or more. Thus, high buildings in narrow streets entirely block sunbeams from entering indoor spaces. However, only the case changes when building heights are reduced to two floors allowing more sunlight, which may overheat the space in that case.

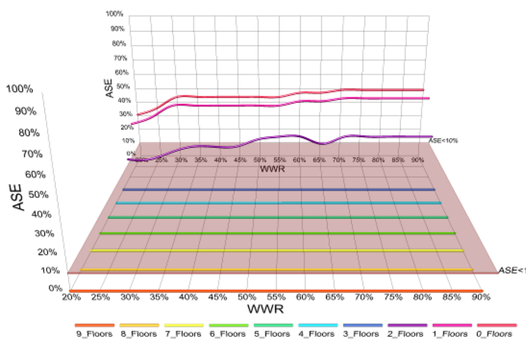

Fig. 8 – ASE performance of each WWR based number of floors for 4 meters street width.

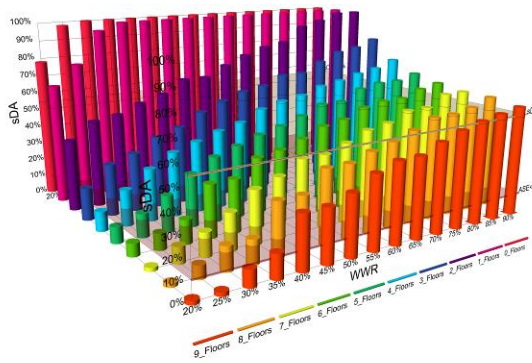

Fig. 9 – sDA performance of each WWR based number of floors for 6 meters street width.

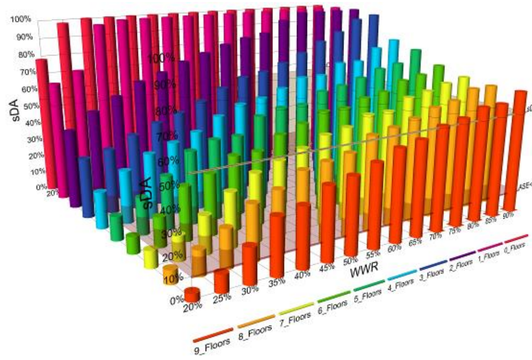

Fig. 10 – sDA performance of each WWR based number of floors for 8 meters street width.

The cases with wider streets have correspondingly better performance. The analysis shows larger range of accepted window ratios especially when the analyzed zone faces mid-height to high building 3 to 9 floors as shown in shown in Fig. 9 & 10.

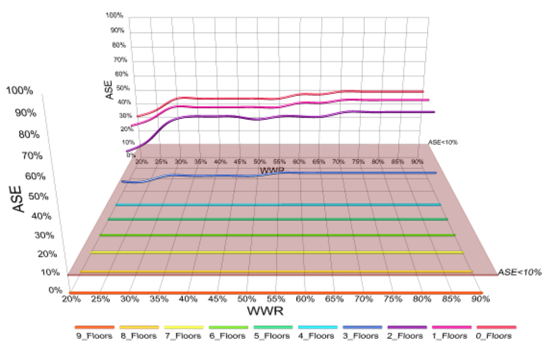

Fig. 11 – ASE performance of each WWR based number of floors for 6 meters street width.

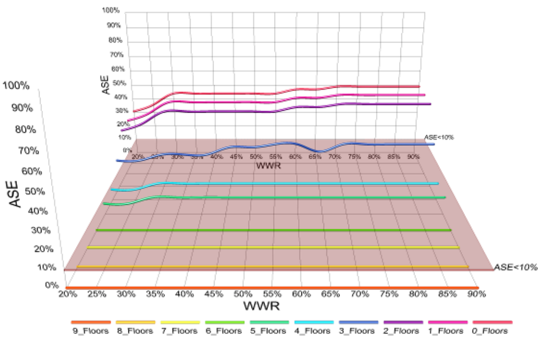

Fig. 12 – ASE performance of each WWR based number of floors for 8 meters street width.

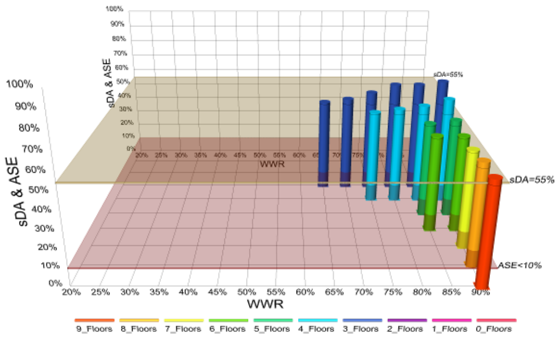

Fig. 13 – sDA and ASE performance of the accepted WWR based on the number of floors for 4 meters street width.

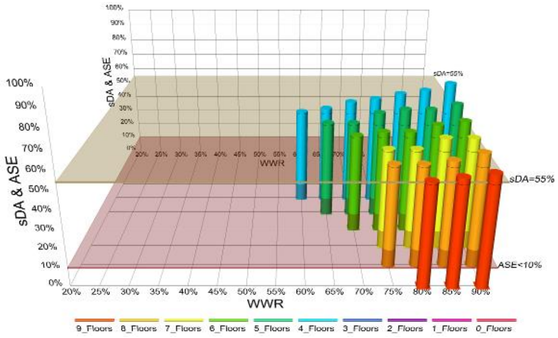

Fig. 14 – sDA and ASE performance of the accepted WWR based on the number of floors for 6 meters street width.

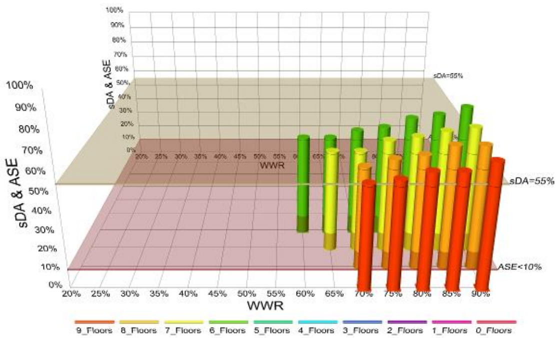

Fig. 15 – sDA and ASE performance of the accepted WWR based on the number of floors for 8 meters street width.

Nevertheless, according to the IES and LEED v4, the quality of daylighting is not assessed with only the amount of daylighting inside the zone. Direct sunlight counts as well as a discomfort factor when it reaches more than 10% of the room area, due to the excess heat that is accompanied by direct sunlight or potential for discomfort glare. The ASE values increase with the rise of street widths or the decrease of the heights of the opposite buildings as shown in Fig. 11 & 12.

Drawing conclusions from the results above would help decision makers set strategies and regulations that consider daylighting qualities in the informal settlements. As shown in Figs 13, 14 and 15 only accepted window ratios are presented according to the number of floors in the opposite building for each street width.

In a street of 4 meters in width, only larger WWRs reach the threshold when building heights reach up to 9 storeys. In a street of 6 meters in width, WWRs starts from 80% and achieve a proper amount of daylighting with a maximum building height of nine storeys. The results are limited to a lower number of storeys due to the increasing annual sunlight exposure. Lastly in a street of 9 meters in width, accepted window ratios are more limited with lower building heights. It starts to achieve adequate amount of daylighting from 70% WWR with 8 or 9 storeys, while it drops to 65% and 60% with 7 and 8 storeys.

Table 4 – sDA and ASE performance based on the number of floors for 6 meters street width at 65% WWR.

Street Width	6 meters		Building Height	9 Floors			WWR=65%		
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	3	4	2	0	0	0	0	0	0
7	17	17	18	7	0	0	0	0	0
29	45	46	44	30	0	0	0	0	0
54	61	65	62	56	0	0	0	0	0
70	76	77	75	70	0	0	0	0	0
81	83	83	83	80	0	0	0	0	0
88	87	87	88	90	131	131	0	123	123
sDA= 44%					ASE= 0%				
Street Width	6 meters		Building Height	5 Floors			WWR=65%		
0	1	2	1	0	0	0	0	0	0
3	4	7	5	2	0	0	0	0	0
10	19	18	16	11	0	0	0	0	0
24	33	37	33	24	0	0	0	0	0
50	59	64	58	54	0	0	0	0	0
69	74	74	71	67	0	0	0	0	0
79	83	83	83	79	0	0	0	0	0
87	89	90	89	88	0	0	0	0	0
93	94	94	94	94	131	131	0	123	123
sDA= 56%					ASE= 0%				
Street Width	6 meters		Building Height	1 Floors			WWR=65%		
90	91	92	91	91	0	0	0	0	0
91	92	92	92	92	0	0	0	0	0
93	93	93	93	93	0	0	0	0	0
94	94	94	94	94	0	0	0	0	0
94	94	95	95	95	277	185	0	158	224
95	95	96	96	96	495	576	568	526	449
96	96	96	96	96	598	695	934	709	554
96	97	97	97	97	926	1083	1195	1066	908
97	97	97	97	97	1457	1711	1629	1666	1431
sDA= 100%					ASE= 47%				
100% Daylit 50% Partially – daylit 0%					ASE > 250 Hours		ASE < 250 Hours		

In Table 4, a comparison is illustrated showing the difference between the daylight performance of one window ratio on the same street width but with different heights of opposite buildings; nine, five and one storey buildings. It explains the phenomenon of increasing the amount of sunlight exposure when decreasing the number of the opposite storeys, while the decline of sDA with higher storeys. The same also happens with bigger and smaller window ratios.

6. Conclusion

The results of this study are compiled in the above table to make it easier to read and for decision makers to choose the right strategy for development shown in table 5. The blue rectangle colors represent the results with low daylight performance, while the red represents the performance with high sunlight exposure. The right-ticked rectangles represent the recommended configuration for window ratio or building height for a constant street width. One observation was extracted from the simulation process; it was found that ground reflectivity has a minor effect on the overall indoor daylighting performance. This finding gives the table another way to be read, by which the recommended height of the opposite building can be given starting from the level of the storey where the daylighting performance will be assessed.

Table 5 – Shows the accepted window size based on the opposing building height and street width.

WWR	20% - 55 %			60%			65%			70%			75%			80%			85%			90%		
Street Width / Height of the opposing building	4 meters	6 meters	8 meters	4 meters	6 meters	8 meters	4 meters	6 meters	8 meters	4 meters	6 meters	8 meters	4 meters	6 meters	8 meters	4 meters	6 meters	8 meters	4 meters	6 meters	8 meters	4 meters	6 meters	8 meters
9												✓			✓		✓	✓		✓	✓	✓	✓	✓
8												✓		✓	✓		✓	✓		✓	✓	✓	✓	✓
7									✓			✓		✓	✓		✓	✓		✓	✓	✓	✓	✓
6						✓			✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
5								✓			✓			✓			✓		✓	✓		✓	✓	
4					✓			✓			✓		✓	✓		✓	✓		✓	✓		✓	✓	
3							✓			✓			✓			✓			✓			✓		
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7. Discussion

In this research, it is important to mention that the results have been extracted without considering any shading device, curtains or occupancy behavior. These aspects are important to ensure privacy, which will affect the overall performance of the daylighting. However, the primary aim is to provide minimum bare configurations of an urban context and window ratios. It provides the primarily accepted amount of daylighting indoor spaces. Moreover, it presents a fast track measuring tool for decision makers, knowing that the simulation process for each case requires experts, which is not an applicable process in real life. On the governmental side, one of the greatest challenges is to deal with informal areas and to limit the physically deteriorated conditions of buildings and provide better building configurations and dimensions.

Many policies were initially considered by the government such as land clearance, rehabilitation, and the upgrading of informal settlements. However, the key element in choosing a suitable strategy is the financial conditions and the value of the selected informal area. This concerns both the buildings and land since most of the new informal urban extensions have occurred in high land value on a large scale, which makes the land clearance policy not applicable most of the time. Therefore, a way to find retrofitting measures turns out to be more applicable and affordable at the moment. Thus, solutions including either changing window sizes or demolishing a couple of floors at the top of the building can be applicable.

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