Atrium Daylight Penetration in Dense Apartment Blocks. A case of Roysambu Nairobi, Kenya.

Etta Madete*

[*] Department of Architecture and Building Science, School of the Built Environment, University of Nairobi

DOI: 10.29322/IJSRP.12.04.2022.p12441
http://dx.doi.org/10.29322/IJSRP.12.04.2022.p12441

Paper Received Date: 25th March 2022
Paper Acceptance Date: 10th April 2022
Paper Publication Date: 17th April 2022

Abstract- In dense urban neighbourhoods the main source of daylight to the internal spaces is the atrium, however, these are not designed, or sized to consider daylight penetration along all its floors. Adequate daylight in residential spaces has proved to have physiological and psychological benefits, improves air quality, reduces damp rising, reduces energy consuming effects of using artificial lighting during the day, reduces operational costs and improves rental value. The study looked at existing literature on atrium design for daylight penetration in dense apartment blocks to identify parameters, then used the case study research method to conduct data collection, analysis, and BIM simulation on 50 x 100 ft plots in the Roysambu neighbourhood in Kenya. The study established that the market has developed multiple solutions to atrium designs in dense apartment blocks while still trying to meet minimum regulations, maximise profit and rental income. The study identified three atrium types namely the I- shaped, O-shaped, and U-shaped atriums. Daylight penetration is most effective in U – shaped atriums shared between neighbouring plots because each development benefits from shared daylight access. This is the recommended typology for dense urban apartments. In addition, the study identified daylight obstructions namely stairs, hanging lines, vehicles (on ground floor) and opaque railing materials. As well as opportunities for daylight optimisation namely, large window sizes, light coloured wall finishes and glazed internal partitions, ensuring residential units on ground floor are replaced with commercial functions, having single banked, single space units with minimal internal partitions, and having a dedicated, and secure laundry area to prevent hanging lines in the atrium. The recommendations from the study were used to form policy and design guidelines for effective atriums for daylighting in dense apartments.

Index Terms- Atrium Design / Daylight Penetration/ Affordable Housing/ Dense Apartment Blocks

I. INTRODUCTION

According to the UN (UN Stats, 2020)[1], 1.6 billion people live in substandard housing and one billion people currently live in urban slums. This figure is projected to increase to two billion by 2050. In Kenya, the government's Vision 2030's Big Four Agenda (GOK, Big Four Agenda, 2021)[2] includes affordable housing, affordable healthcare, food security, and manufacturing as key goals. Despite this effort, the private sector is the highest provider of affordable housing in Kenya, whose dominant market solution for affordable housing has been a five to seven-storey apartment block on a 50 x 100 ft (1/8th acre). In such dense urban neighbourhoods, the main source of daylight to the internal spaces is the atrium; however, these are not designed or sized to consider adequate daylight penetration along all its floors. These impact the health and wellbeing of the residents as well as the energy use of each household due to the increased reliance on artificial lighting. Yet, Nairobi, Kenya benefits from an average of 12 hours of sunlight every day which can be harnessed (Climatedata, Accessed 2021)[3].

Currently, six-storey apartments in 50 x 100 ft plots are most of the affordable housing in Kenya. A majority of which are being provided by the private sector. The cost of construction of the project is a significant factor in affordability and developers aim to maximise the number of units permissible according to the law. This has led to high densities and congestion we see coming up in Nairobi which, as shown in figure 2, and has led to poor daylighting conditions in many of the homes. Each new building is designed to borrow light from incorrectly sized atriums, narrow street canyons, and from adjacent plots, which will inevitably get built on in the future and block the main source of daylight. In dense urban neighbourhoods such as Roysambu, shown in figure 3, the primary source of light is the atrium which are not designed or sized to consider daylight penetration along all its floors. Yet, access to adequate daylight in residential spaces has proved to have physiological and psychological benefits due to its ability to ensure a healthy circadian rhythm (sleep /wake cycles), improve mood, improve concentration, reduce eye strain, provide essential vitamin D, reduce depression, ensure hormonal balances, reduce moulding, and increase productivity (Johnsen, 2010)[4]. Natural daylight also reduces the operational costs of a building and has a positive effect on the rental value of a space. To meet both global and Kenyan climate change targets and the growing demand for affordable urban housing, whilst ensuring these are good for the users' wellbeing, it is necessary to develop realistic design guidelines for effective atrium daylight penetration in dense apartment blocks, specifically 50 x 100 ft plots.

II. THE STUDY APPROACH

1. Objectives

The study has three main objectives. The first is to establish knowledge on atrium design for daylight penetration in dense apartments; the second is to assess the existing daylight penetration from atriums of apartments in Roysambu, Nairobi. Finally, the third objective is to recommend atrium designs for adequate daylight penetration in dense apartments.

2. Scope and Limitations of the Study

The geographical scope of this study is limited to the Roysambu neighbourhood in Nairobi, Kenya. The location was chosen because of the high densities which are representative of the typical atrium walk-up apartment block in Nairobi, Kenya. As well as its population growth parameters, and neighbourhood block featuring four roads on each side and typical apartment blocks. The study takes a cross-sectional study during the year 2021 for data collection and analysis. The year of study was during the COVID- 19 pandemic, which created unique circumstances in the study region. The theoretical scope of the study is environmental science bound by the study of daylighting, which is the natural light coming directly from the sun and reflected by water and dust. The study is also theoretically bound by housing in 50 X 100 ft plots provided by the private sector because it is currently the prevalent form of housing being supplied to the market and will continue to do so, given the growing housing crises.

3. Research Methodology

This study used a mixed method of qualitative and quantitative data collection and analysis. Qualitative research is the process of collecting, analysing, and interpreting non-numerical data such as text, drawings, video, and photographs. Quantitative research methods emphasise objective measurements such as statistical, calculations, mathematical measurements, or numerical analysis of the data collected (Rukwaro, 2016)[5]. In addition, the case study area was modelled using ArchiCAD and Revit software to run daylighting simulations for comparison and corroboration with the geometric calculations. The unit of analysis in architectural research is the element that is being studied (Rukwaro, 2016)[5], which in this study is the apartment block and is defined as the block as a five to seven-storey walk-up housing without a lift, on an eighth-acre plot with 50 x 100 ft (15 M x 30 M) dimensions. The atrium design is the independent variable (cause) that is affecting daylight penetration (effect). The case studies in Roysambu will study the atrium design and its effect on daylight penetration. This study took a typical block and studied the plot size, ground coverage, plot ratio, number of floors, block design, sky view factor, relation to neighbouring buildings, relation to road, wall material, wall finish, colour, size position % of the window to floor area, distance outside open window, window blocks (i.e., curtains). Analysis of internal spatial configuration and impact on functional uses of the atrium, the section aspect ratio, plan aspect ratio and the well index.

Project sampling was done using a biased convenience sampling method in Roysambu. The biased approach and selection of Roysambu are because it is representative of the typical housing units in Nairobi for the low-income formal economy population. The researcher used a reconnaissance visit in February 2021 to determine the suitability of the case study location and apartment selection, coupled with aerial photography and mapping. Primary data was collected through unstructured participant observation of the natural environment and recorded in narrative, sketches, photographs, and measurements. Non-structured interviews were used with users of the spaces. Block measurements were additionally taken and modelled, and Building Information Model (BIM) was used to simulate the daylight factor effects in different atrium designs. Secondary data was collected and analysed from existing literature. The study used research assistants who assisted in data collection in the field, taking measurements, photography and inputting software for analysis and detail. The researcher was keen to not subject apartment occupants and participants to harm. The study prioritised respect and dignity for the apartment and occupants by obtaining consent and avoiding exaggeration and deception on the research objectives. The researcher also upheld honesty and accountability (transparency) throughout the research process.

4. Literature Review

The desk study identified key parameters to the study of daylighting atriums in dense apartment blocks. These are divided into three sections namely, the apartment building typology, atrium design, and the science of daylight in high rise buildings. Since the 10th century three to six storey multi dwelling residential blocks were used to house most of the population in large villages and towns for the purposes of affordability, shared services, and developer profit maximisation for a minimised footprint. The key properties of an apartment are that they are multi-storey, multi-dwelling, and house multi-family occupant. The plurality means that they are ideal for densification and provision of housing for rising populations, as well as creating efficiencies for common services such as water supply, wastewater treatment, electricity supply, garbage collection, infrastructure, and security. In relation to massing and design the key considerations are its location, the size of the plot, the ground coverage, plot ratio and number of floors (without necessitating the additional cost of installing a lift).

Access to adequate daylight in residential spaces has been proved to have physiological and psychological benefits due to its ability to ensure a healthy circadian rhythm (sleep/wake cycles), improve mood, improve concentration, reduce eye strain, provide essential vitamin D, reduce depression, ensure hormonal balances, and increase productivity (Boyce, 2003)[6]. Natural daylight also reduces operational costs of a building and has a positive effect on the rental value of a space. The tropics benefits from an average of 12 hours of sunlight every day. The unit of measurement for daylight penetration is daylight factor (DF) which quantifies the amount of diffuse daylight at points within a space under an overcast-sky condition. The three factors that need to be considered are the quantity of light, quality of light and distribution of light. Different spaces and their respective uses also have different lighting requirements, global green building code requirements stipulates that 50% of all spaces should have minimum daylight factor of 2%, and that 3% is better. The factors that affect daylight in a space include, fenestration types, materials, and size, the wall material and colour, as well as the rooms height, depth, and width. The arrangement of spaces with each individual apartment block also plays a key role in daylight penetration, because if the user of the space adjoining the corridor/ atrium feels they need more privacy, they often have curtain or sheers blocking the source of daylight penetration.

Atriums have been used in buildings for centuries. Their main functions were for privacy from the street, creating a common meeting space that everyone had access to, which had access to natural light, ventilation, as well as for a secure defensible open space. In modern times atriums have featured across all building typologies from educational, residential, institutional, industrial, and commercial. Their main functions are to allow natural light, natural ventilation, into a deep plan building without losing out on prime real estate. Atriums in residential spaces, unlike in offices and institutional buildings, have multiple functions often not accounted for during the design stages. These include parking, clothes hanging, outdoor cooking, social (informal meetings), extra storage, play space for children, laundry, and the circulation space (corridor and stairs). These additional functions of the atrium space affect its daylight penetration, the quality of space and the air quality. The design, sizing of atriums came from thought into the architectural, economic, and environmental factors. The key considerations for adequate daylight penetration in atriums are the roof fenestration types, atrium geometry, wall surface material and colour, window size and position, sky conditions, building regulations (plot ratio and ground coverage), and what other functions the atrium has.

In addition, the most effective calculations to determine the daylight penetration of an atrium are the plan aspect ratio (PAR), the section aspect ratio (SAR) and the combination of the two forming the Well Index. PAR= Width / Length (Closer to 1 the better). SAR= Height/Width (Lower the SAR the better). Well Index (WI)= 0.5SAR (1+PAR)- The lower the WI the higher the Daylight Factor. Sky View Factor (SVF)=cos(atan(H/0.5*W)-Closer to 1 the better)

III. FINDINGS AND DISCUSSION

1. Contextual Parameters

Roysambu is a neighbourhood in Nairobi County and a constituency in the capital. It has five wards; Roysambu, Githurai 44, Kahawa, Kahawa West and Zimmerman. The wards were Jewish coffee farms owned by Joreth, who later subdivided the land and sold it (Mwake, 2021). The population is dense at approximately 4000 people per square kilometre (GOK, 2021). It has numerous higher learning institutions, including Kenyatta University (KU) and the United States International University Africa (USIUA). The case study block is in Roysambu along Lumumba drive, which has numerous privately-owned residential units in eighth-acre plot parcels. In 18 years, the substantial development has caused the loss of green areas without daylight considerations. Residential apartments on eighth-acre plots are designed and built with key daylight from the neighbouring plots. When the neighbouring plots are developed, they block the key spaces for daylight sources.

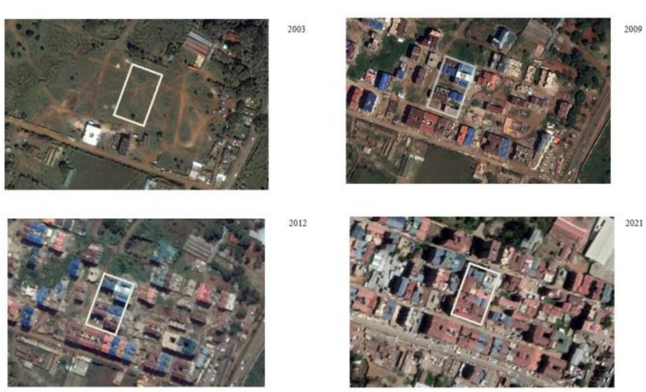


Figure 1; Chronological map view of the Roysambu block that is being studied. Source: Author adapted from google maps, 2021.

Figure 2; Roysambu buildings are built without consideration of future upcoming developments. Source; Author 2021

Roysambu is a vibrant and social community with a rapid rate of densifying, overlooking daylight access considerations in the development process. Plots were initially designed for single dwelling houses, but developers and landowners built high-rise apartments for rental revenue maximisation due to the increasing land value and demand for rentals. There is a lack of internal laundry areas throughout the neighbourhood in apartments; hence residents hang clothes in the street-facing balconies and windows or within atriums which are the main source of daylight. The protruding balconies also reduce the sky view area in the street canyon. The opaque construction material used also prevents daylight penetration. The social activity in the neighbourhoods, such as shops, people and markets, block light to the ground units while impeding privacy for the ground-floor residents, hence the norm to leave curtains closed during the day. The ground floor is thus an opportunity for commercial transformation to directly engage the streets and remove residents from spaces with inadequate daylight.

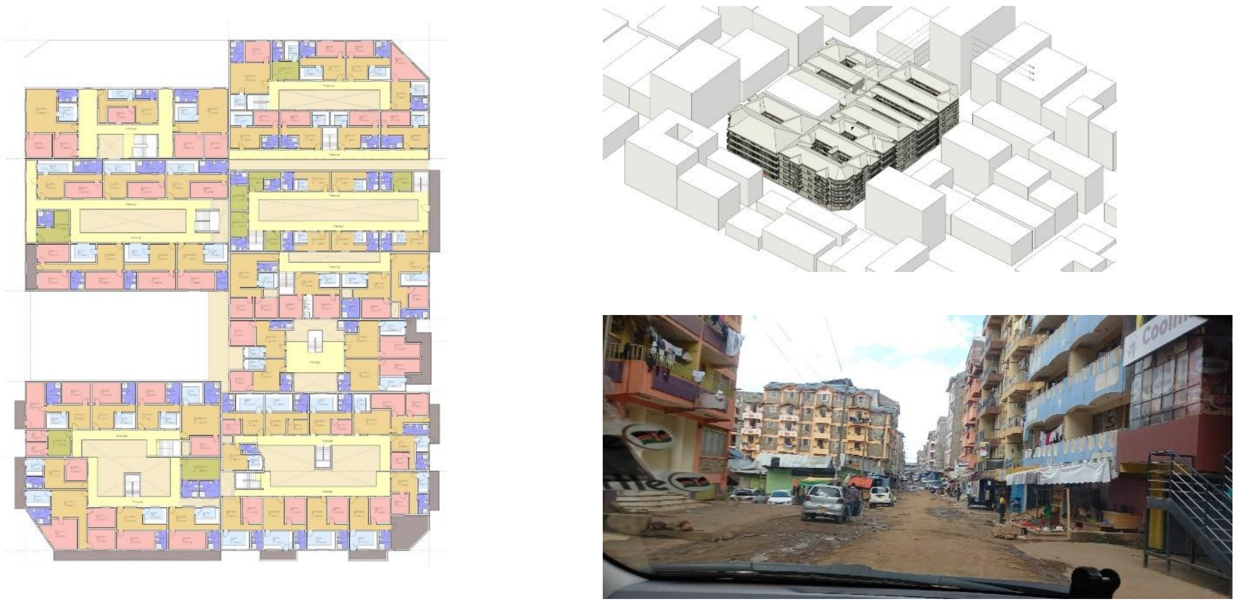


Figure 3; Roysambu case study block plans, 3D and photo. Source; Author 2021

Street orientation is also a key factor as blocks receive reduced daylight into atriums due to the blocked daylight orientation. The orientation of Roysambu 18 degrees west of the true north also affects the daylight penetration into atriums. Neighbouring apartments block each other from direct sunlight, hence behaving like wells, and the sun moving overhead only directly penetrates between 11 am and 1 pm into the lower-level atriums. The sky view of the street canyon in the case study region is reduced by protruding balconies into the street canyon. The architectural design of the balconies also plays a key part, with the use of heavy masonry, an affordable construction material in the region, too opaque to let light in and preventing direct daylight penetration. The urban street level in the case study region is very social with multiple street level activities such as shops, temporary stalls, people, markets, etc. This brings life, character, social capital, and neighbourhood social-economic support. However, they also block light to the ground level units, as well as impede privacy for ground-level residents, meaning most ground level units leave their curtains closed throughout the day. In dense urban neighbourhoods, the ground level is an opportunity for commercial businesses to engage directly with the street which adds vibrancy to the neighbourhood, but also removes vital residential spaces away from areas without good daylight penetration.

2. B. Block design, Internal layouts and BIM simulation

The case study region identified that the main types of atriums used in apartment blocks in Roysambu, Nairobi are U-shaped, I-shaped and O-shaped atriums on 50ftx 100ft plots. They are in various sizes and types with varying functional designs, which is the main factor aiding or hindering daylight penetration. The I-shaped atrium leaves only the side facing the street accessing adequate daylight when neighbouring plots are developed, because they are typically narrow. The atriums also have hanging lines which further limit daylight penetration, hence highly ineffective in dense urban neighbourhoods. The U-shaped atrium is the ideal typology as it maximises rentable space and minimises corridor spaces, while there is the benefit of shared daylight access spaces with neighbouring plots to form an effective O-shaped atrium. The O-shaped atrium is ineffective especially in small plots where it is used for other activities such as hanging lines, hence impeding daylight access to shapes. The design requires adequate sizing to account for corridor widths and provision of spaces for hanging lines. The developing plots should be regulated to enhance proper atrium and window size designs to enhance proper daylight access in Roysambu.

The most common atria were the U-shaped, as it reduces corridors, maintains access to each unit and maximises lettable units. In the corner plots, daylight penetration is effective as lighting from two streets is enhanced, including in shared atriums; hence the U-shaped is the most effective. The O-shaped central atrium in the study block is used in large and small plots, attempting to maximise rental spaces with corridors accessing each unit. The corridors, however, impede daylight penetration into spaces, especially with hanging lines. Hence, the typology is not adequately sized for corridors, stairs, and clothing lines limiting daylight access. The I-shaped atriums are thin and run across the edges of the building, leaving only the units facing the street with adequate daylight after full development. The thin atrium also has hanging lines that block daylight from getting into spaces. Therefore, the typology is unsuitable in dense urban blocks unless with efficiently sized atriums for effective daylight access. The limitation of daylighting due to the atrium designs in the dense urban neighbourhood of Roysambu remains a key area of concern especially with more developments in progress maximizing rental spaces and overlooking atrium necessity for daylight access.

Analysis of the case study blocks internal layout identified that the living and bedroom spaces are along the corridors facing the atrium, and the kitchen faces outside or into balconies. In addition, very few blocks have balconies or kitchen yards, leaving the atrium as a space for hanging lines. Furthermore, the main stairs for circulation in five apartments within the case study block are in the atriums, which block the light access to the houses. The quantitative analysis of the case study neighbourhood block revealed key correlations. The section aspect ratio (SAR) has a direct correlation with the atrium well index and hence the daylight factor. The higher the SAR the poorer the Well index. SAR is the relationship between the height of the atrium and the length of the atrium. If the height of the atrium is higher than its length, then the well index reduces, and the daylight performance improves. This is because atriums are meant to be effective across their entire depth, to provide daylight penetration to the lower levels of the building. For a five-storey building with an average floor-to-floor height of 3.0M, then the atrium heights are typically 15M. Atrium lengths of between 15M to 30M (the typical length of a plot) are ideal for effective daylight penetration.

Table 1; Field research findings of case study block in Roysambu, Nairobi, Kenya

Building No.	**Built area**	Well Index	Sky view factor	Wall finishes	Railing	Stair
Notes		0=ideal	1=ideal			
X-low yield	270.00	0.82	0.39	Light coloured	See through	Recessed/ not in atrium
X- Realistic compromise	348.0	1.02	0.38	Light coloured	See through	Recessed/ not in atrium
1	333.4	1.59	0.21			
2	302.6	1.53	0.21			
3	284.3	5.18	0.05			
4	295.1	2.48	0.11			
5	227.9	2.57	0.11			
6	254.6	2.79	0.11			
7	551.9	2.44	0.12			
8	310.5	1.55	0.29			
9	335.7	1.47	0.29			

3. *Code requirements*

The ground coverage is also a key factor in the market forces, ranging between 88% and 95%. Daylight access ranges from 7% to 29% in shared atrium design, hence the need for government to put guidelines with health and safety standards in dense areas. The studied blocks fail to comply with the open space outside windows requirement, while those with open spaces have obstructions such as hanging lines and parking areas on the ground floor, which blocks the daylight penetration. The daylight factor quantifies the diffuse daylight at the points in spaces under an overcast sky condition. Different spaces have different uses hence varying lighting requirements. Most green building and global building guidelines stipulate a minimum 2% and 3% daylight factor is better in 50% of all spaces. The studied block revealed poor daylight penetration across the depth of each atrium due to simulation averaged across all floors. Atrium corridors received 15% daylight penetration, causing heat gain and glare, while another daylight factor was less than 1% hence poor daylight due to narrow atrium widths.

IV. CONCLUSION

The study seeks to examine atrium designs in dense urban apartment blocks for effective daylight access from existing literature and establish crucial parameters. Qualitative and quantitative methods using the Roysbambu neighbourhood as a case study to examine the effect of daylight penetration in dense apartment blocks through atriums. Daylight access has been established to be crucial for psychological and physiological wellbeing.

The study identified that in dense urban neighbourhoods in Nairobi the apartment blocks are typically 5 storeys, to avoid the expensive additional cost of having an elevator above 6 stories according to building regulation. They have an average floor-to-floor height of 3.0M, then the atrium heights are typically 15.0M. Atrium lengths of between 15M to 30M (the typical length of a plot) are ideal for effective daylight penetration. The key design guidelines fro atria include using a U-shaped centralised shared atrium is an ideal typology, because it maximises lettable space, minimises corridor space and developments benefit from shared daylight access. In addition, staircases as service areas should be recessed in the main built footprint and not permitted in the atrium to prioritise daylight to living spaces. Furthermore, Atrium wall surfaces should be painted with light-coloured wall finishes to aid in reflecting daylight along the atrium, should never have an overhead covering and clothes hanging spaces should be prohibited in atriums and instead, be allocated space on the roof or within the apartment. In addition, railings in atriums should be made from transparent materials such as mild steel, aluminium, or timber because they offer better daylight penetration than opaque options such as masonry or concrete and windows facing the atrium should be above 50% of wall surface to maximise daylight penetration into the spaces. Contextually, dense urban neighbourhoods should adopt the mixed urban development typology with commercial units on ground floor because residential units on ground floor suffer from insecurity, lack of privacy, and have the lowest daylight penetration and it is also recommended to step back floor plates on higher floors to maximise sky view access to lower floors. For compliance, the county government should enforce building regulations on minimum allowable open space outside windows for the health and safety of residents, as well as to ensure effective daylight penetration and triple banked spaces should not be permitted in dense urban neighbourhoods. The study identified the ideal scenario for the 50 x 100 ft plot atrium to be the shared U-shaped atrium typology. This is because it provides the typical market rental yield, but with neighbouring properties should maximize daylight access through shared atriums. The low yield scenario below is based on reducing the building footprint below the average typical for this region. The case study region averages a built footprint of 321 SQM per plot, as such the ideal low yield scenario is not realistic and applicable to current market forces. Realistic compromise is a scenario based on U- Shaped courtyard, which maintains a market rental yield average but with optimised dimensions for an effective atrium on a 50 X 100 ft plot. The atrium as illustrated in figure below, is square in nature bringing the plot ratio (PR) as close to 1 as possible, to ensure effective daylight penetration.

Table 2; Recommendations for optimum atrium types for daylight penetration

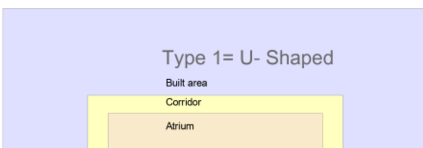
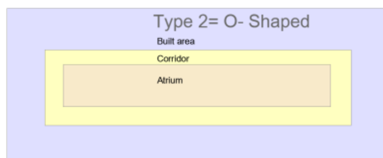
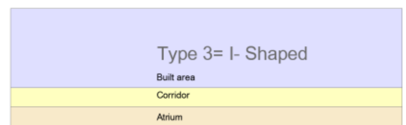
Atrium type- U-Shaped = Good	**Atrium type- O**-Shaped = Medium	**Atrium type-** I-Shaped = Poor
		
The U-shaped atria type was the most popular atria type observed due to its ability to reduce circulation / corridor, maintain access to each unit and maximise lettable space. This typology was used for both central plot within the neighbourhood block, as well as the corner plots. In the corner plots this was observed to be effective as corner plots have the benefits of lighting from two streets. In the case study neighbourhood block, the corner plots for building 1 and 2 as well as 8 and 9 had a shared atrium which both developments benefited from higher daylight penetration. The U-shaped atrium typology is the most effective in daylight penetration, especially is neighbouring developments face each other to maximise the open space.	The O-Shaped central atrium in the case study region has been adopted for both large plot and small plots and tried to maximize rental space whist ensuring corridor access to each unit. In this case the corridors around the atria impede effective daylight access to the spaces, especially if used also for clothes hanging. For this typology, the atria were not adequately sized to account for corridor widths, stairs and hanging lines to be effective for daylight provision. Minimum corridor widths around atria must be specified in the building code as a percentage of total atria space to avoid poor daylight in centralised atria.	The narrow straight block is a thin atrium running alongside one of the building long edges. Once all neighbouring building are developed, the only unit with adequate daylight is the one facing the street, causing poor daylight penetration. In addition, the thin atrium typically had clothes hanging lines blocks any daylight that did get into the spaces. Unless accompanied by an inefficiently sized atrium (see Ch 5.3), this typology for dense urban blocks is highly ineffective in daylight penetration.

Table 3; Recommendations for daylighting in dense apartment blocks

Building type	**Height**	**Built Area**	**Atrium Length**	**Atrium Width**	**Atrium Area**	**% Atrium vs built**	**Plan Aspect Ratio (PAR)=W/L**	**Section Aspect Ratio (SAR)=H/W**	**Well Index (WI)= 0.5 SAR(1+PAR)**	**Sky View Factor (SVF)= cos (atan(H/0.5*W)**

							1= ideal	0=ideal	0=ideal	1=ideal
X-low yield	15	270	30	12.00	360.0	57%	0.40	1.25	0.88	0.37
x-Ideal	15	**348**	**17**	**11.50**	**195.5**	**36%**	**0.68**	**1.30**	**1.09**	**0.36**

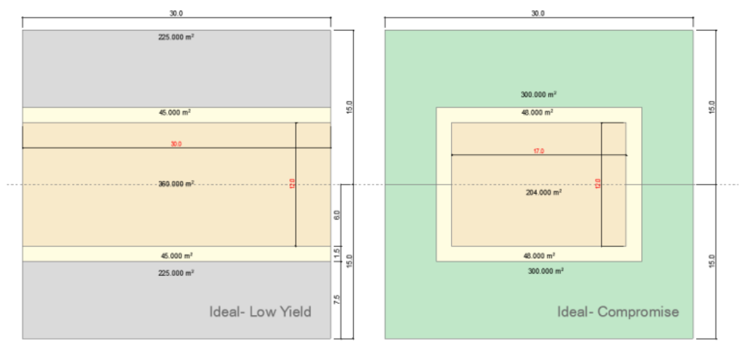


Figure 5; Ideal and low yield scenarios. Source; Author, 2021.

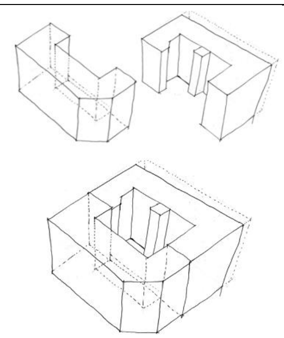


Figure 6; U shaped atrium that face each other maximise daylighting for both blocks. Source; Author, 2021.

References

[1] United Nations,(Accessed 2022), "Make cities and human settlements inclusive, safe, resilient and sustainable", Retrieved from UN Stats, https://unstats.un.org/sdgs/report/2019/goal-11/

[2] GOK. (2021). Big Four Agenda. Retrieved from https://www.president.go.ke/

[3] Climatedata. (Accessed 2021). CLIMATE NAIROBI (KENYA). Retrieved from Climate data: https://en.climate-data.org/africa/kenya/nairobi/nairobi-541/

[4] Johnsen, K., (2010). Daylight in Buildings. Hertfordshire, U.K: AECOM Ltd.

[5] Rukwaro, R. (2016). Proposal Writing in Research. Nairobi: Applied Research and Training Services Press

[6] Peter Boyce, C. h. (2003). The Benefits of Daylight through Windows. New York: Lighting Research Center.

Authors

First Author* – Etta Madete, Department of Architecture and Building Science, School of the Built Environment, University of Nairobi, ettamadete@uonbi.ac.ke/ ettamadete@gmail.com