THE UNIVERSITY OF NAIROBI

DEPARTMENT OF ARCHITECTURE AND BUILDING SCIENCE

SCHOOL OF THE BUILT ENVIRONMENT

EXTERNAL SHADING FOR PASSIVE THERMAL AND DAYLIGHTING DESIGN

A Case of Small Learning Spaces in tropic upland climate of Nairobi.

A research thesis presented to the Department of Architecture in partial fulfilment of the requirement of

Masters of Architecture, Environmental design

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B52/33952/2019

DECLARATION

This thesis report is my original work and to the best of my knowledge has not been presented for the award of a degree in any other institution.

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Signature ______________________ Date 10TH NOV, 2021

A thesis report submitted in partial fulfilment of the examination requirement for award of the of Masters of Architecture degree;

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DEDICATION

"To whom I am most indebted"

TOPIC: EXTERNAL SHADING FOR PASSIVE THERMAL AND DAYLIGHTING DESIGN

A Case of Small Learning Spaces in tropic upland climate of Nairobi

ABSTRACT

In a tropic climate, cooling dominates the highest energy consumption for buildings (UN-Habitat, 2014). Approximately 50% of these cooling loads occur through the building envelope, mainly due to the building form and architectural shading devices. Buildings in Nairobi have not survived the vice either, despite the fact that the climate of Nairobi presents an opportunity for passive design (Kimeu, 2014). With good design, there is no need for either heating or cooling in buildings. Despite this advantage, the demand for thermal cooling and visual comfort remains an important issue in learning spaces in the City of Nairobi. Most buildings are marked as high-spenders on artificial lighting and thermal cooling (Moraa, 2019).

This phenomenon is directly related to the design of the building envelope, in which external architectural shading elements fall. This study, therefore, explored and presented an external shading device as a contributor to the indoor thermal and lighting environment. The study aimed to find an optimal trade-off between visual comfort and thermal comfort using a shading device.

The study adopted a case study approach and computer simulation to explore the performance of vertical, horizontal, and egg-crate types of external shading devices for thermal control and daylighting within small learning spaces. It was established, through literature and actual simulation, that the egg crate is the best performing external shade in the indoor lighting and thermal environment, while vertical shading was the least performing external shade. In addition, the sizing, shape, location and the material of the devices played a significant role in influencing the indoor lighting and thermal environment.

The study is concluded by recommending the optimal trade-off between indoor lighting and thermal environment when designing an external shading device appropriated for the studied cases and other similar spaces within the city of Nairobi.

Key word. Shading devices, Thermal environment, daylighting, small learning spaces, shading type, effectiveness, potentiality

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1 CHAPTER ONE

1.1 Background information

In the tropic climate, cooling dominates the highest energy consumption for buildings. Approximately 50% of these cooling loads occur through the envelope of a building (UN-Habitat, 2014). In addition, 50% of the heat in buildings is generated by solar radiation, while the rest is due to anthropogenic activities (Minseok, et al., 2015). Whereas attempts to suppress overheating have taken tremendous steps, more often than not, the application of shading devices has always inconvenienced daylighting. It is within scope for architects and designers to sufficiently design for solar radiation control at the building envelope without limiting the admission of daylight.

An external shading device, an element of the building envelope, presents one of the tools that a designer can use to control indoor thermal and lighting environments. Therefore, the design of shading devices in learning spaces can and should be used to significantly reduce cooling loads while increasing penetration of light into the spaces (Kim, et al., 2012). However, this is not always the cause. Exposure to glare or lack of adequate light is evident in many learning spaces in local universities. Poor shading or lack of shading for thermal control can be attributed to this phenomenon. **(Figure 1-1 and Figure 1-2)**

Figure 1-1: Evident glare in shaded classroom in a local university. Source: Author

Figure 1-2: Learning environment in a non-shaded classroom in a local university. Source: Author

Figure 1-3 Application of shading in devices in local university building. Source: Author

An external sun shading device is considered the most effective technique of minimizing solar heat gain. However, in conventional designs of school buildings, fixed shading systems are widely adopted for a thermally comfortable indoor environment. Most often, this has significantly reduced the admission of daylight into buildings due to obstructions created by these systems. Conversely, devices such as light shelves direct some of the radiant heat into spaces, contributing to heat build-up (Kumar, et al., 2005). In Nairobi's tropical climate, the phenomenon is very common in many buildings. The school building and its associated learning spaces were destroyed by Vice. A tour into various learning spaces reveals the following conditions which can be attributed to the design of shading devices:

1. Direct sunlight in learning spaces, which is a key contributor to glare and heat stress in learning spaces without external shading devices,
2. Under lit spaces or under heated spaces, especially in the coldest months where over shading is executed.

Over time, passive designers have been working on providing an optimal visual environment within acceptable thermal comfort levels across the globe (Le Hong & Lucelia, 2013). However, there still exists a gap between what is considered the best trade-off between daylighting and thermal comfort in school buildings. Research by UN-Habitat on Adequate Shading: Sizing Overhangs and Fins has given more attention to office spaces, theatres, galleries and exhibitions in East Africa (UN-Habitat, 2014). However, very little attention is directed towards classrooms, making the situation worse in the Nairobi city context, despite the large number of schools in this region. Little effort has been dedicated to passive daylighting and thermal design, making many school buildings marked as high energy spenders. Many learning spaces rely on artificial lighting even where adequate daylight is available outside the classroom, as is the case with the ADD building at the University of Nairobi.

In a review of a light shelf as a horizontal solar shading device, Antoni Kontadakis describes this device as a system that can be easily modified in depth, spacing, and texture to address daylighting issues such as redirection of daylight and protection from glare (Kontadakis, et al., 2018). Hence, it supports the concept that a building envelope can play a selective role as an environmental filter by keeping out unwanted heat or cold, letting in ventilation and light, while providing views out and still maintaining privacy.

Potentially, a shading device is a tool to provide a visually and thermally comfortable indoor environment. While this may be the case, the potential contained within it has remained unexploited. Indoor environmental quality and artificial lighting simultaneously contribute to the biggest energy spenders in most institutional buildings, despite growing attention to indoor environmental quality.

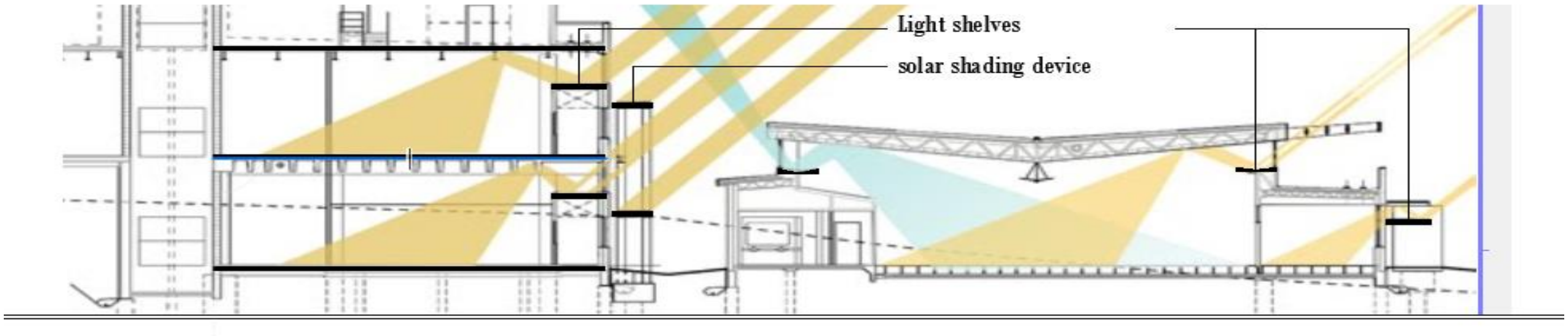


Figure 1-4:illustration on the Potential of shading devices as a tool to provide a visually and thermally comfortable indoor environment

There is far less attention to the visual and thermal comfort aspects within schools in the city of Nairobi, as is the case with the Technical University of Kenya and the University of Nairobi. Worse, the developers of private universities are more concerned with providing a place for students to sit rather than with the students' well-being.

1.2 Problem statement

One of the great benefits of the Nairobi climate is that, with good design, there is no need to provide active means of heating and cooling in buildings (Kimeu, 2014). This is a great bonus for designing a building that aims to be energy neutral by avoiding air conditioning and central heating, both of which are huge consumers of energy.

However, over the years, the design of building envelopes and shading devices in Nairobi tropic buildings has heavily focused on very extreme cases of managing indoor overheating risks. Most offered solutions are based on solar radiation control. Non-shaded glazed parts have almost been considered a vice in achieving thermal comfort (Rabah & Mito, 2003). Formulas for calculating vertical and horizontal shading are already developed, but there is no denial that the challenge of the trade between thermal comforts for daylighting is very real.

To obtain high-quality outcomes for the existing problem, the research tested the existing design at The Technical University of Kenya with an accurate pilot study.

1.2.1 The scope and context pilot study

The pilot study was performed to reflect all the procedural variables relating to air temperature using temperature data loggers and lux meters on horizontal overhangs and louvered shading. Its selection is based on the representation of shading devices. The study purposely targets learning spaces in the Nairobi tropic climate.

As is the objective of this study, the pilot study limits the city's use of classrooms as a basic unit in a learning institution. However, it acknowledges its existence as part of a larger building, hence studies the influence of the building envelope shading typology as a contributing factor to the problematization process of the study. The pilot study further informs the selection of the case study classrooms at The Technical University of Kenya, which is significant in de-familiarization with the common problem and a more scientific approach in the study.

The study was carried out using hobo temperature data loggers and a lux meter to record classroom air temperatures and lighting levels, respectively. Recording was carried out in the month of January, a month prior to the actual data collection in the main study.

1.2.2 Findings of the pilot study

The results demonstrated that despite the ambient luminance levels of about 18000lux in Nairobi at latitude 1.2S, between 1600-1800 metres above sea level, very little light finds its way into the interior of spaces without overheating, as illustrated in the piloted studies below (Figure 1-5).

The assessessment of the problem covers the inclusion and exclusion criteria of randomized classroom groups, shading type characteristics and appropriate shading, later identified in the literature review as either vertical, horizontal or Eggcrate, based on the researcher's plans and understanding of randomization of the case study in a purposive approach.[1]

The phenomenon presents a designer with a number of difficulties; one of those is achieving an optimum balance between passively achieved visual and thermal performance of spaces which may be in conflict with each other in terms of both energy consumption and internal comfort. Most of the time, better thermal performance leads to worse light performance and vice-versa, as illustrated in Figure 1-5 Classrooms with shading devices recorded the greatest number of hours within thermal comfort levels but failed to meet the least illumination levels required for a learning space. Depending on the context and the buildings' function, the designer may give priority to visual or thermal performance. However, small changes in parameters such as shading devices, orientation, room geometry, or even window size might significantly affect the indoor environment, contributing to a considerable consumption of energy for cooling or lighting.

[1] The pilot study is designed to test the existence of the problem under investigation. In addition, it tests aspects of the methods planned for the larger study with the recording tools and variables to provide a more confirmatory approach to the existence of the problem.

Figure 1-5. Graphical illustration of the current indoor environment of various shaded and non-shaded building in learning spaces in a local university. Source: Author

Figure 1-6: A pictorial representation of a shaded classroom selected to pilot the study. Source Author 2021

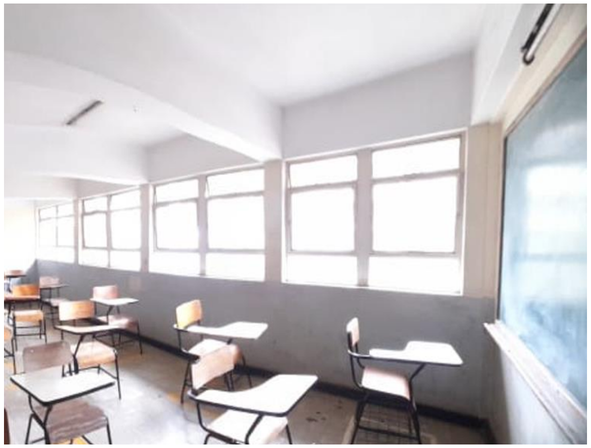


Figure 1-7: A non-shaded classroom piloting this study

Source: Author

Liveable spaces in Nairobi's tropic upland climate have not survived this vice. An illustration of the current indoor environment of various shaded and non-shaded buildings in learning spaces in a local university shows that the indoor environment in this climate contains three major difficulties:

1. Extremely high fluctuation of daylighting,
2. Difficulties in optimization of daylighting in heat protection, and
3. Lack of specific architectural design guidelines.

(**Figure 1-5, Figure 1-6, Figure 1-7)**

Key notes from the pilot study show that at low solar azimuth angle, 9:00am in the morning, a space on the east facades using a single horizontal shading device receives direct sunlight, which contributes to a drastic rise in air temperature. The situation is worse at 3:00pm for a space in the west. This results in overheating. At the same time, the cases present a record-high lighting level, which contributes to a large glare index.

Overcoming daylighting and heating challenges is therefore a domicile issue. Where attempts to suppress overheating are made, it has inconvenienced daylighting and vice versa, as evident in the N/S block pilot study (Figure 1-5), characterized by horizontal louvers across the window. The space in N/S has maximum temperatures of 26.7^0, only 1.7 degrees above the comfort zone for about 6 hours during the hot January season.

However, the lighting levels are dominantly below 200 lux, making it very expensive to run the class of artificial lighting.

It is supposed that natural light strongly impacts the health, well-being and academic performance of learners. It boosts attitude, alertness, concentration and vitality levels. Further, studies indicate that exposure to natural daylight improves learners test scores, audience attendance and conduct (Santiago, 2020). Unfortunately, artificial lighting is optimized only for visual tasks and disregards the biological impacts of natural light, which is the case with many of the most piloted learning spaces in Nairobi.

With this finding, the conflict between shading for thermal control and daylight is very rampant. It should be investigated in detail to cover the gap and recommend the best trade-off between the two environments.

In addition, designers of learning spaces in Kenya rely on the Ministry of education's guidelines. The guidelines emphasis on spatial organisation, adequate facilities and resolution of structure. Barely any effort is dedicated towards environmental design. This absence of clear strategies that combine thermal and lighting design for learning space has significantly contributed to the current building status of learning institutions within the city of Nairobi. As a result, it is very important to address the issue in the context of rising energy crises in the global market, ensuring that designers have a reference as to what a suitable shading device must be.[2]

1.3 Research questions

The research seek to answer three main questions which includes:

1. What are the various types of external shading devices in use and in the selected case studies of learning spaces in Nairobi?

[2] The increasing world energy demands is already raising huge concerns over current and future supply difficulties, depletion of energy resources, increased environmental impacts due to anthropogenic activities, rapid population growth and urbanisation, increased construction activities and enhancement of building services have been raising building energy consumption to over 40% of the world energy demand, the levels of comparing to transport and industrial production process. (Lombard, et al., 2007)

2. What is the effectiveness of the identified shading devices towards passive thermal and lighting design environments of learning spaces in these selected learning spaces?
3. What is the potential of external shading devices in improving passive indoor thermal and visual environments of selected cases and other built forms of learning spaces in Nairobi's tropical climate?

1.4 Research objectives

The objective of this study is to:

1. Explore and document the various architectural shading devices used over time by designers and in selected learning spaces, as part of a case study in Nairobi.
2. Determine the effectiveness of the identified shading devices towards passive thermal and daylighting design environments in the selected learning spaces in Nairobi by actual recording of room temperatures and lighting lux levels?
3. Through descriptive, comparative, and parametric analysis, we identify the potential of external shading devices in providing optimal passive thermal and visual comfort in learning spaces of selected cases, and how the lessons learned can be applied to Nairobi's built forms to provide optimum design in learning institutions.

1.5 Hypothesis

The indoor lighting and thermal environment of buildings in Nairobi learning spaces fluctuates with the change of geometry, orientation and properties of shading devices. A change in the shape, size, orientation or spacing of shading devices will have a resultant impact on indoor air temperature and illumination levels.[3]

1.6 Significance and contribution

In Nairobi, where the sky provides an ample lighting environment of approximately 18000lux, over emphasis on lighting design may lead to a ‘no day light benefit’. This may occur in instances where the benefit from daylight is less than the resultant combination of solar gains in a space, leading to high cooling loads. It’s prevalent where high glazing ratios cause temperatures to rise, undermining thermal comfort. Hence, the study of types of shading devices, their effectiveness, and potential in the design of passive thermal and lighting environments will contribute to a significant reduction in energy demand in school buildings amidst the rising energy crisis in the international market.

Thermal comfort, the state of a human mind that expresses the extent of satisfaction per the thermal environment in a spaces, receives great significance in building performance as the main cause of energy consumption. Additionally, Room thermal comfort directly affects occupants' health, well-being, and productivity in educational buildings (Santiago, 2020). Establishing a good trade-off between the types of external shading devices, their effectiveness, and potential in the two environments through this study would therefore contribute to better learning outputs in school in addition to energy-saving benefits.

[3] It is essential to be able to identify that optimal shading system is one of the most instrumental design parameters to realize ‘good’ indoor climatic conditions, to let in excellence natural light but exclude undesired glare and control contrast relations with minimal energy consumption.

Similarly, Adopting daylighting as a strategy is considered a valuable approach for energy savings in buildings. Elsewhere, beyond energy savings, intentional and careful design with daylighting has significant contributions to occupier well-being and productivity. Architects, designers and engineers should therefore be encouraged to advance the application of daylighting strategies offered by external shading devices for building design solutions. This is a timely study to recommend solutions.

Providing thermal and visual comfort in classrooms is therefore a palpable necessity. Students devote up to one-third of the day in school. Elevated air temperature is a common problem in most school classrooms as identified in the problem statement in Nairobi's tropic climate, especially during the hot season of January and February. This problem is exacerbated when buildings gain a lot of heat. The connection between indoor environmental conditions and student success in a test is well established. However, the specific trade of role of thermal and visual comfort is not well understood (Zhang, et al., 2017). This study is, therefore, timely to explore the best trade and contributions offered by an external shading device to improve indoor thermal and visual environments for stakeholders in learning spaces.

1.7 Research scope and limitations

This study covers Learning spaces in Nairobi tropic climate. It seeks to understand the types of external shading devices and their regulation of interior thermal and lighting environments. It will therefore, limit to exhibiting the resultant indoor temperatures compared to human thermal comfort range and lighting levels against recommended limits for thermal comfort range and analyze energy saving potential as a result of using external shading elements

A thorough understanding, limiting the study to this Tropic upland climate of Nairobi is important in providing optimal solution to the case study and other similar facilities within the city context. The study randomized on classrooms in selected learning institution in Nairobi, Kenya- The Technical University of Kenya

As a result, the situation in which the research is carried out has limited means such as environmental labs to test models and to provide adequate knowledge in the intended direction. The author acknowledges this as a constrain, however, this will not limit the quality of the study as scientific methods will be applied to correct data and anchor it on existing literature

There is reasonably a number of issues outside the architectural possibility such as occupant behaviour, age, diminished psychological well-being and irritability among many others that has a lot of influence on human thermal comfort and visual comfort. This research will not examine these realms, it will mainly pay attention to evidence based architectural elements. This approach might pose a research limitation. However, to reduce of such errors that may be influenced by personal behaviours the scope is limited to learning spaces of high education projecting that most students are within the same age group.

This study in limited to a period of one year. However, adequate understanding of environment may demand more time than is required of this study. Time to visit and document all the selected case studies in all seasons of the year is a possible research constraint.

1.8 Research structure

Chapter one: Introduction: This chapter introduces the shading device as the face of a building that is an important environmental regulator of indoor thermal and visual conditions. It briefly illustrates how the Nairobi climate has a lot of potential in passive design. In addition, it emphasizes the challenges that a shading device presents to the two environments studied, highlighting the constraints, significance, and justifications of this study to the body of environmental design.

The chapter raises questions of study and draws key objectives from them as the main core of the research thesis. The questions and objectives are then used to set the study hypothesis, scope, and outline the research structure and design.

Chapter Two: Literature Review: The chapter reviews previous studies with the aim of identifying the types of shading devices, their global application as an important element of design, and regulating indoor environments. It also investigates building overheating, under lighting, and the factors to consider when designing shading. To contextualise the study, the climate study of Nairobi and its influence on buildings is similarly included in this chapter.

Thermal and visual comfort being the backbone of the study, its parameters relating to shading devices have been studied deeply.

At the end of this chapter, precedent studies and literature reviewed are summarized into measurable valuables to form a conceptual framework for use in this study.

Chapter Three (3): Research Methodology: The chapter focuses on how the research methodology and design will be carried out. It demonstrates qualitative and quantitative process approaches.

Chapter Four (4): Data Collection and Analysis: This chapter highlights the analysis of parametric studies and observation findings. This is done by limiting the types of shading, their effectiveness, and the potential for optimum thermal and lighting environments within them.

Chapter Five: Conclusions and Recommendations: The final chapter entails conclusions arrived at the previous chapter guided by the types of shading device, the effectiveness and the optimization of the same. It also provides a set of recommendations and highlights on issues that require further research.

This study adopts an exploratory case study of small leaning spaces at the Technical University of Kenya to investigate the influence of geometry, shape, size, orientation, material, and spacing of shading devices on the indoor thermal environment and lighting.

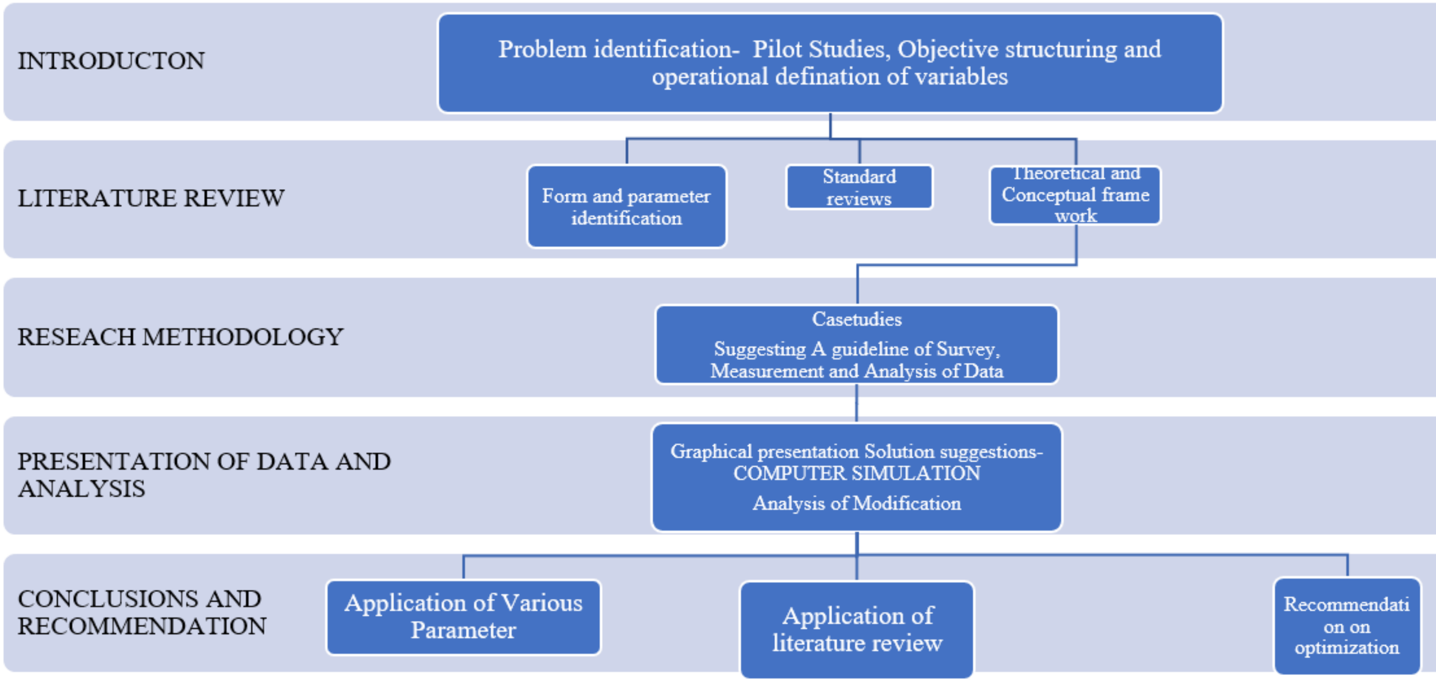


Figure 1-8: Research structure source: author created 2021.

2 LITERATURE REVIEW

2.1 Background

'The sun shading device must be on the outside of the glazing in a building. It can be an element of the Façade and building architecture. And since this device is so vital as measure of our open architectural design, it may develop into as characteristic form as a Doric column.'

Breuer Marcel, Sun and Shadow

Sun shading designs have transformed overtime, notably in the modernist period, where great advances in study have been made. They have been seen as part of the building skin. Like human skin, which plays a major role in internal body regulation, with sensors that sense environmental changes and trigger responses, e.g., the rise of hair follicles to trap air for thermal regulation when it's cold, vasodilation and vasoconstriction, sweating and air exchange, architectural façade elements and designs in form, and sun shading devices are a result of responses to the environment.

This chapter focuses on the types, strategies, and performance of external shading devices towards indoor lighting and thermal comfort. The discussion is aimed at summing up the attributes of external shading devices in the indoor lighting and thermal environment without ruling out other contributing factors such as ventilation, thermal mass of materials, form, and window to wall ratio. It also engages in a reading and documentation of the architectural design strategies, the climatic condition in Nairobi and relevant standards from the existing knowledge on the safety and comfort of the students in the built lighting and thermal environment.

Table 2-1: A table comparing the research objective to the literature review objectives. Source: author, 2021

Research objectives	Literature review objectives
1. To explore and document the various architectural shading devices in selected case studies in Nairobi.	1. Explore and document the types of architectural shading devices that have developed over history.

2. To determine the effectiveness of the identified shading devices towards thermal and daylighting environments in these selected cases,	1. Determine architectural design parameters that have been used over time to evaluate the performance of indoor thermal and lighting environments. 2. Examine Nairobi's climate in relation to thermal and daylight design parameters. 3. Document, using the horizontal and vertical shadow angles, the appropriate sizing of shading devices for Nairobi's latitude of 1.2 degrees south. 4. Explore various strategies in which a shading device has been used to improve indoor lighting and thermal environments.
3. To identify and document the potential of a shading device in providing optimal thermal and visual comfort in learning spaces, selected cases, and how the lessons learned can be applied to Nairobi's built forms in learning institutions,	1. Position the research within a global context, highlighting the gaps that exist in the design of shading devices for thermal and lighting environments. 2. Create a conceptual and theoretical framework for identifying the potential of a shading device to provide optimal thermal and visual comfort in learning environments.

2.2 Types of shading

2.2.1 A shading device as a Moderator of Indoor Environment

An external shading device forms part of the building envelope. Over time, the building form and associated architectural shading devices have had a significant role in thermal and lighting regulation. They have always served a dual purpose: they allow advantageous exchanges from inside to outside the building and vice versa. As a result, they are referred to as moderators as shown in the table below (World Building Design Guide, 2020).

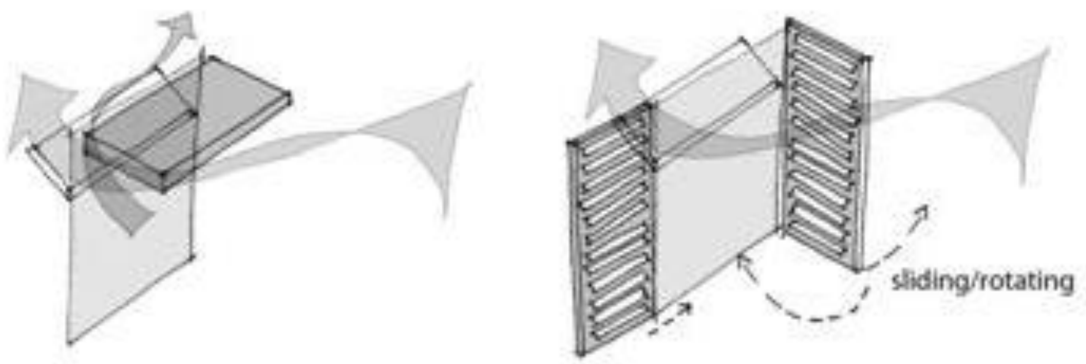


Figure 2-1: illustration of various external shading devices as environmental filters

(Lechner, 2015)

Table 2-2: Fundamental strategies for the control of heat, air, and solar radiation in the design of shading device.

Source: extracted by Author from, (Givoni, 1969) and World building Design Guideline 2014

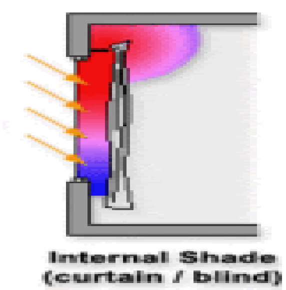
CONTROL FUCTION	PHYSICAL MECHANISM	CONROL STRATEGY
• Solar Radiation	• Heating	• Increasing or decreasing Shading the co-efficient on the window through shading type, size and geometry

		• Thermal Resistance of the device (transmittance, absorption, reflective and diffusive properties.
	• Visible Light	• Orientation • Glazing optical properties • Light shelves and shading
• Heat transfer	• Conduction	• Thermal insulation (transmittance, absorption,)
	• convection	• Air barrier systems in a shading device
	• Radiation	• Radiation barriers

2.2.2 Types of shading devices

Shading Devices are classified according to their position and geometry in the building envelope. They are either internal or external

2.2.2.1 Internal shading devices



Internal shading devices are located on the inner side of a window or glazing. They are considered less effective at reducing solar heat gain, due to the greenhouse effect, that is, solar radiation has already be transmitted through the glass. Internal shading devices, such as curtains and blinds can be a useful only when the sun penetrates for only a short time and heat build-up in the space is not b a major problem, or when it is required to reduce glare on a working plane. The performance of internal shading in tropical buildings is very insignificant in reducing solar gain. For this reason, a lot of attention will be given to external devices, as discussed below.

Figure 2-2: illustration of internal shading informs of a blind; Source kamal, 2011

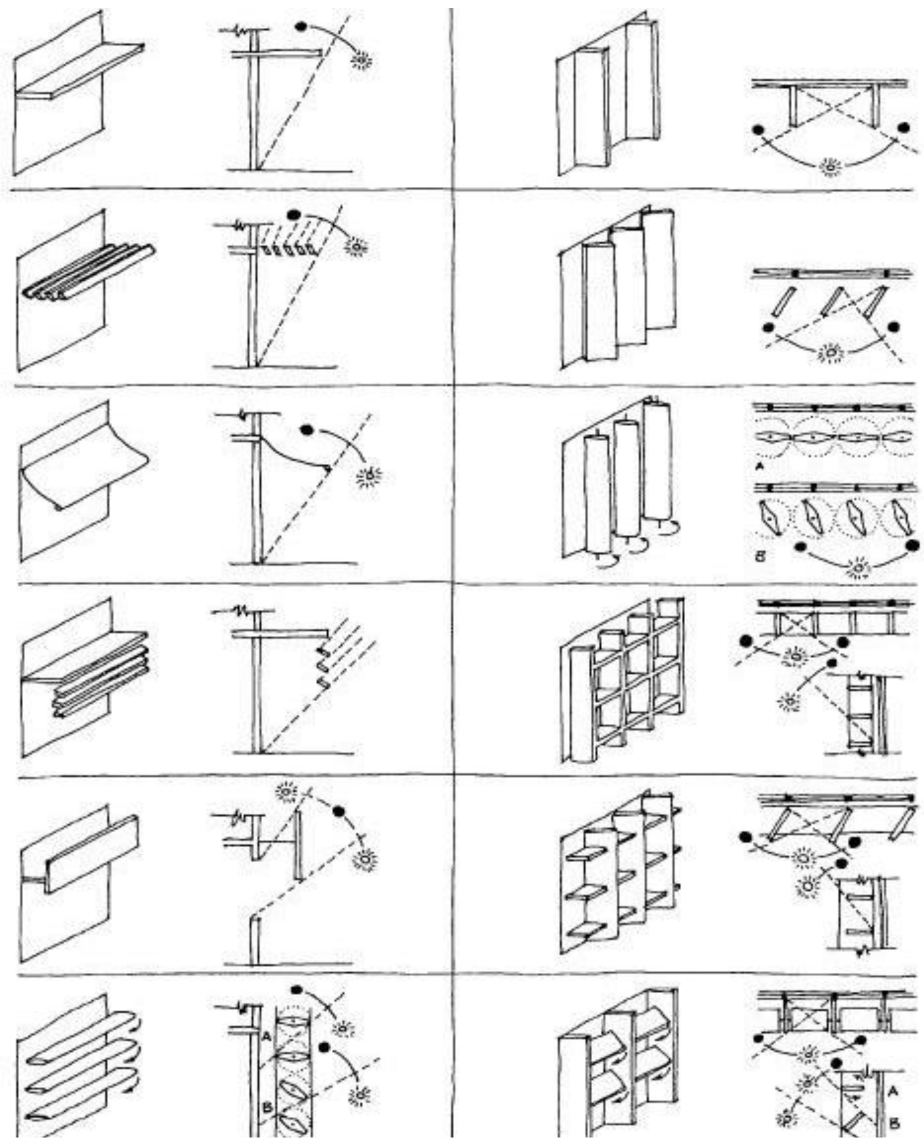


Figure 2-3: Illustration of various types of external shading. Source: Mohamed kamal 2011 Aligarh

External shading prevents solar access before it gets into a space. They are considered the most effective shading devices in the tropics due to heat build-up (Manzan & Francesco, 2009). Examples include Eaves, awnings, screens, shutters, louvres, verandas and pergolas. Whichever the option, it's essential that each device is designed taking to account the sun's path at the site and the different shadow angles for the most critical time of the year. In addition, to make it more effective, the design of external shading must considered other passive design features such as site location, orientation and layout, window geometry and placement, and thermal properties of its material.

External Shading devices are further classified into three:

1. Vertical Shading
2. Horizontal shading
3. Egg crate/ Horizontal and vertical shading

(Kamal, 2011)

2.2.2.2 Horizontal shading devices

Horizontal sun shading devices are ordinarily in the form of building canopies, verandas, horizontal louvre blades, or roof overhangs. Their performance towards shading is measured by the vertical shadow angle as demonstrated below:

2.2.2.3 Sizing Horizontal Shading Devices

The following steps are used to decide on the appropriate size of a horizontal shading devices for as glazed window in Nairobi- latitude 1.2 degree south: (UN-Habitat, 2014)

1. Determine the overheated period for the various facades, that is, the dates and times when shading a window on a given façade will experience the highest solar radiation. A west, south and north window experiences the highest radiation at 3:00pm while east facing window experience the highest radiation at 9:00am

2. Use the applicable solar chart diagram, suitable for the location, Nairobi-1.2S hence use 0-degree chart, to obtain the azimuth and altitude of the sun at each time of the cut-off periods in 1 above.

3. using the solar shading protractor determine the VSA for each facade. They can also be established using equations 1 and 2 below.

- HSA = AZI - ORIENTATION (eq.1) ORI=0/360,90,180 OR 270
- VSA= Arc tan (Tan altitude/cos HAS) (eq.2)

4. Design the actual horizontal shading device that will satisfy the performance specifications.

In reference, the design of horizontal shading devices in Nairobi (1.2921° S, 36.8219° E) for the pick overheating periods will be 1.6m deep, 1.3m deep, 0.6m deep and 0.6m for the west, east, north and south orientations, respectively (Figure 2-4).[4]

[4] The calculation arrived in are used to determine the effectiveness of vertical shadow components in the types of shading devices in the case study against actual recorded air temperature and luminous levels

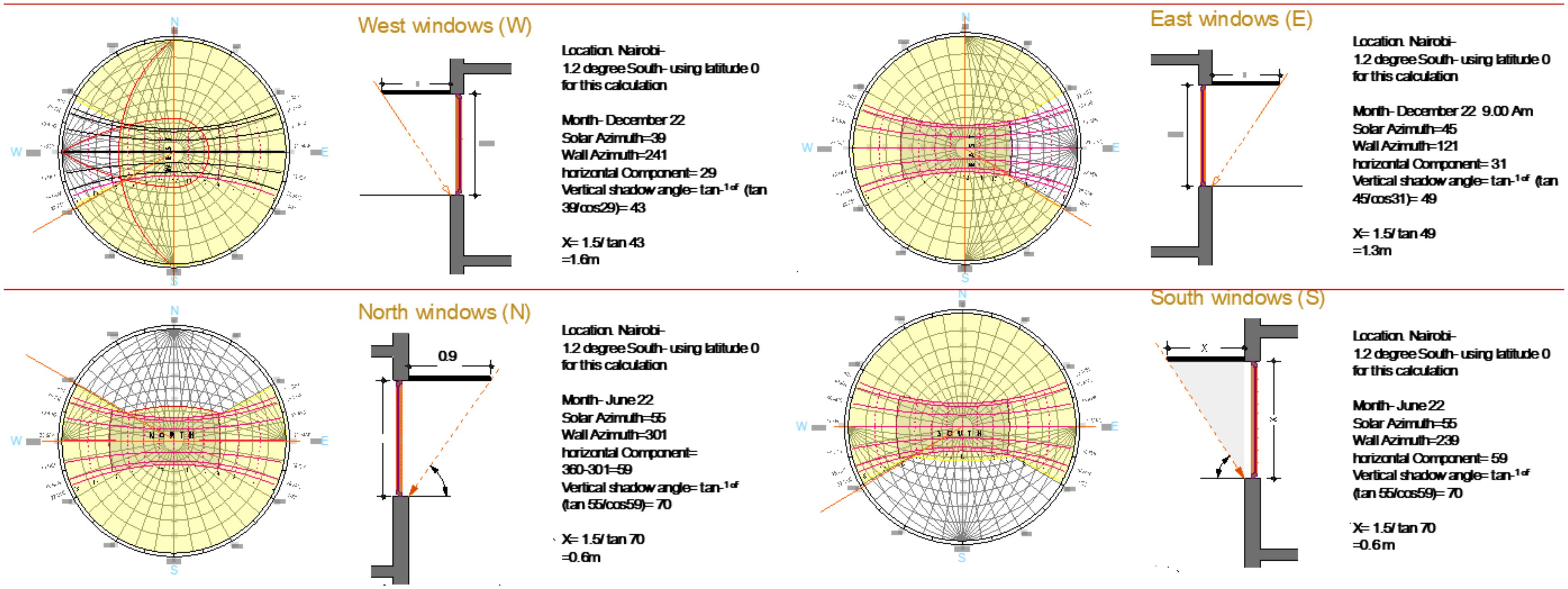


Figure 2-4: Illustrated horizontal shading device calculation for Nairobi Modified by author 2021from (UN-Habitat, 2014)

Figure 2-5:illustrations of horizontal shading devices in use, Source: Archdaily2020: Facades and solar control, Brise Soleil Systems for residential, commercial, corporate, hospitality

2.2.2.4 Vertical shading devices

Vertical sun shading devices are in the form of pilasters, vertical louvre blades and projecting fins in a vertical position. Their performance towards shading is measured by the horizontal shadow angle (HAS).

Figure 2-6:illustrations of vertical shading devices in use, Source: Arch daily 2020: Facades and solar control, Brise Soleil Systems for residential, commercial, corporate, hospitality

2.2.2.5 Sizing Vertical Shading Devices

The following steps are used to determine and design the appropriate size of the vertical shading devices for as glazed window in Nairobi- latitude 1.2 degree south: (UN-Habitat, 2014)

1. Determine the overheated period for the various facades, that is, the dates and times when shading a window on a given façade will experience the highest solar radiation. A west, South and North window experiences the highest radiation at 3:00pm while east facing window experience the highest radiation at 9:00am

2. Use the appropriate solar chart diagram (suitable for the location Nairobi-1.2S hence use 0-degree chart) obtain the solar azimuth and altitude angles for each time of the cut-off periods in 1 above.

3. Use the solar shading protractor read the HSA for each facade. Alternative use equations 1 below to calculate the HSA.

4. HSA = AZI - ORIENTATION (eq.1) ORI=0/360,90,180 OR 270

5. Design the vertical sun shading device to satisfy the performance stipulations. The section (Figure 2-7), demonstrates the recommended size of vertical fin to completely shade an opening 0f 1.5m with during the periods in Nairobi. i.e., 2.7 M for the West window, 2.4m for an East one and 0.9M for North and South respectively

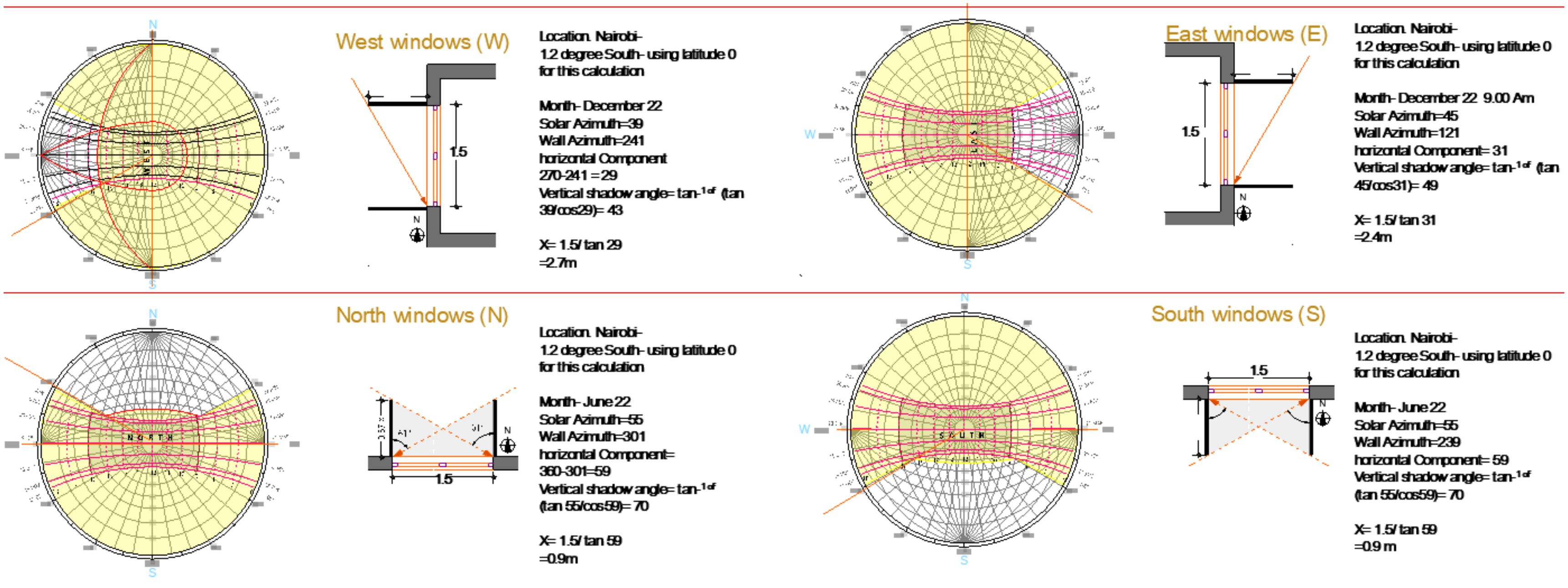


Figure 2-7: Illustrated vertical shading device calculation for Nairobi Modified by author 2021from (UN-Habitat, 2014)

2.2.2.6 Egg- crate

An egg crate is a combination of vertical and horizontal sun shading devices. They are designed in form of, sized grill blocks or decorative solar screens. Their shading performance is determined by both the horizontal (HSA) and vertical shadow angles (VSA). (Miguel, 2008)

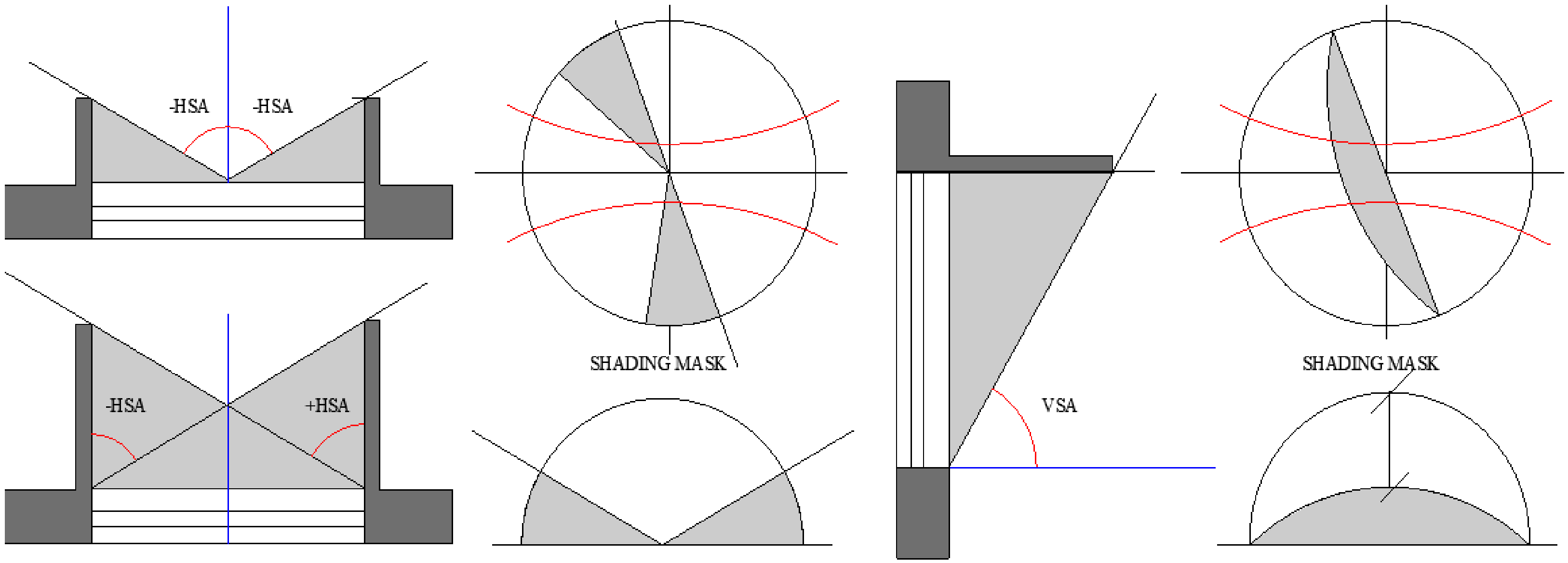


Figure 2-8: The contribution of horizontal and vertical shading in making of egg crate shading systems

Figure 2-9:Illustrations egg crate shading devices in use, from left: University of Nairobi hyssop building, University of Nairobi Kabete campus and The Technical university of Kenya main building. Source: UN-habitat. Source 2: Author 2021

2.3 Evolution of shading in the tropical architecture.

2.3.1 Development of traditional Forms and shading

The scramble for colonial territories and the Nazi era of Adolf Hilter in Germany pushed architects out of Europe into different fragments of the world. The migration of architects influenced the spread of "Tropical Modern architecture" into Africa, Asia, and the Caribbean, among other tropical climates (Mumbi, 2016).The common strand of all Tropical Modern design is the acknowledgement that the sun is hot and the luminous levels are high.

This climate-sensitive architectural style called "Tropical Modern architecture" has been explored since the early 1950s and identified a shading device as a hallmark feature of Tropical Modern architecture. Creating protective shade is important. Deep porches, extra-wide eaves, verandas, covered walks, lanais and canopies are integrated to offset the heat. Shelter from the sun also means shelter from wind-driven rain.

Figure 2-10: Edouard 'Le Corbusier' Jeanerette, Chandigarh the city of Sun, Space and Verdure" that is meant to fulfil basic functions of a working, living and care of body Characterised by massive concrete.

AD Classics: Master Plan for Chandigarh / Le Corbusier; Source Archdaily retrieved 2018

The exploration of Corbusier's work: the creation of Chandigarh as a city of "Sun, Space, and Verdure" meant to fulfil basic purposes of working, living, and caring for the body and spirit is evident in shading elements and massive concrete (Figure 2-10). Further, it is expanded in the Ministry of Public Health Building in Brazil.

Singling on a shading device and the window in understanding the application of external shading devices in indoor thermal lighting design. For a tropical building to stand out as a climate-responsive design, it features certain characteristics as noted below:

1. glazed areas are externally shaded to protect excessive heat gains
2. Small window opening (recommended in the North and South façade) are used on the façade to limit heat gains
3. Windows on North and south façade, must too be shaded.

(Mumbi, 2016)

In a different context, traditional Japanese sudare consists of horizontal bamboo strips woven together with hemp or silk, forming screens, hung on hooks at the edge of roof eaves or a tie beam (‘nageshi’) between columns. They play a role in filtering the hot sun, preventing solar glare, and providing privacy and aesthetics. The aesthetic form of Sudare is referred to as "misu" and is commonly used in shrines, temples, palaces, and aristocratic schools (Locher , 2015).

Japanese Sudare attempted to strike a balance between providing adequate daylight levels and solar protection. However, they are limited in their inability to adapt to the variations in external conditions as well as their ability to block the view to the outside. During the hot sun, the occupants could roll down the elements to cut out the sun. At the same time, it becomes relatively difficult to admit daylight and have a view outside.

Furthermore, Brise-Soleil, a French word meaning "sun breaker," has been commonly used as an external solar shading device for windows. The Le Corbusier concept of 1926 still remains influential to date with the use of permanent architectural structures that serve as sun-shielding elements (Kamal, 2013).

2.3.2 Development of Modern Forms and shading

Figure 2-11: Ludwing van der Rohe IIT campus illustrating simplicity and transparency. Source: Chicago architecture centre architecture.org

Modern development has seen the introduction of 'Simplicity and transparency', pioneered by Architect Mies van der Rohe with the extensive use of glass on façades. His form of architecture in buildings is labelled as "skins and bones" due to his use of steel and glass. With a minimalistic approach labelled "less is more" that associates concrete floors with glass facades to enhance "purity and renewal" glass has been extensively used on façades all over the world.

Notably, at Illinois Institute of Technology's (IIT) College of Architecture's crown hall, extensive use of glass with sandblasted lower windows screens to distract students from outside views, while the upper glass window freely admit light and external views of the surrounding plants and sky. However, glass offers transparency of heat, absorbs heat and acts as a greenhouse, hence it is not suitable for hot climates. Glare is also one of the most problematic things about glass façade buildings.

Recently, Francis Keere's work, especially in Gando School, illustrates a modern approach to "simple opaque" characterised by large overhangs to provide shading beyond fenestration. Solid surfaces are shaded from direct sun to delay heat build-up in the hot climate of Burkina Faso.

Figure 2-12:Gando school, Aga Khan Award winning design for Architecture 2004 and Global Award for Sustainable Architecture 2009; Source: https://www.kerearchitecture.com/work/building/gando-primary-school-3

Closer to home, in the capital of Nairobi, the learning and resource centre at Catholic University (CUEA) uses external sun-shading devices to prevent glare and also reduce the intensity of solar radiation.

Most windows in the LRC centre are on the North and South facades of the buildings, with the exception of windows to the wet areas, kitchenettes, stores, and fire escape stairs. All glazed parts are shaded regardless of their position. (Figure 2-13)

Figure 2-13: The Learning Resource Centre at Catholic University of Eastern Africa. Source Musau kimeu. Retrieved by Author 2019: 2-14Architect Issue 2 2013 by The Architect Magazine – issue

2.4 Tropic climate daylighting and thermal design parameters

2.4.1 Tropical Daylighting Design Parameters.

Significant daylighting is influenced by certain façade parameters. According to Gagnel & Andersen, **the type of geometry, reflective properties, and the size of shading devices, window to wall ratio (WWR), window position, and glazing transmissivity** have a high to very high impact on daylighting (Gagnel & Andersen, 2010).

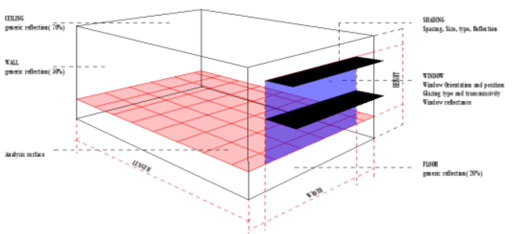
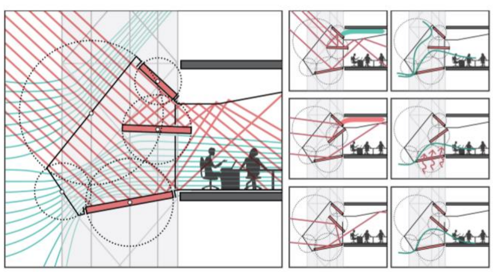
In 2007, Torres and Sakamoto selected the same parameters as Gagnel and Anderson, but added the reflection of the room and the reflection of façade elements to study daylighting. They emphasised the impact of reflection on a light shelf as a focus parameter. The two researchers agree with Rodrique, Winterbottom and Samani that daylighting systems, such as light shelves, are a highly operational parameter in daylighting. (Samani, 2012); (Le Hong & Lucelia, 2013); (Wymelenberg, 2012) and (Winterbottom & Wilkins, 2009)

Designing with this parameter, where a light shelf is optimised to direct an adequate amount of light into a space, can significantly reduce overreliance on artificial lighting, which, subsequently, has a reduction in lighting loads. In addition to energy saving benefits, lighting and shading control improve visual comforts.

In summary, the tropical day lighting environment is affected by external shading devices. The parameters within an external shading device that affects this environment can be concluded as:

1. Shading type, either horizontal, vertical or egg crate system
2. The geometry, positioning, and the size
3. Reflective properties of the external shading device

Table 2-3: Comparison of various research and design parameter performances against environmental comforts and energy efficiency.

Simulation model	Research Purpose	Findings and Conclusion
 Figure 2-15:illustration of basic simulation model for lighting design	Multi-objective study on facade optimization for daylighting project using a genetic algorithm presented in fourth National Symposium of IBPSA-USA Sim Build 2010, 11-13 August 2010, New York, USA. (Gagnel & Andersen, 2012)	When designing high-performance façades, pairs of environmental design criteria, such as daylighting adequacy, thermal comfort, and energy efficiency, frequently clash. Façade optimization can also be utilized to explore building massing orientation, structure, and building systems such as shading devices when facing conflicting criteria such as human comfort and energy consumption.
 Figure 2-16:Effect of small changes of the façade on luminous environment Source: (Le Hong & Lucelia, 2013)	Passive visual and thermal performance in building Façade Design (Le Hong & Lucelia, 2013)	Rooms with the same use of materials, the same dimensions, and fenestration, in the same conditions, present similar thermal performance. However, small changes to the façade lead to significant changes in the luminous environment and the lighting energy consumption fluctuates dramatically.

2.4.2 Indoor thermal Design Parameters.

Indoor thermal comfort in learning space is affected by six fundamental variables: four environmental variables of air temperature, air movements, mean radiant temperature and humidity combine with two personal factors, the level of clothing of an individual and the activity levels (Fanger, 1972). Personal factors are purely physiological thermoregulation and behavioural adjustment and can only be determined by observation. However, environmental factors are measurable parameters and can accurately be attributed to the building envelope.

Building envelopes have a vital impact on thermal comfort, satisfaction of occupants, and energy savings. Buildings in hot climates with shading devices have higher comfort levels than non-shaded building facades (Minagi, 2019). In his study, underpinned by **Effective Temperature,** which combines air temperature and humidity into a single index, he utilises the constraints of the shading device to determine thermal comfort. **The size, shape, location, spacing, texture,** and **material** of the shading device have high utilisation. Fittingly, it gives the whole building a bioclimatic use directed toward ambient air temperature. However, over-utilisation of the devices significantly reduces the acquisition of natural light in space by reducing the sky component on a working plane.

(Handbook 2019 A.S.H.R.A.E.® , 2019)

In a similar finding, on optimization of daylight and thermal performance studies of educational buildings grounded on a multi-objective genetic algorithm in classrooms of cold climate of China, **the building shape, WWR (window to wall ratio), orientation,** and **depth contribute** to a range from minimum to maximum energy demand depending on the designer's specification (Zhang, et al., 2017). The building envelope has high correlation to a shading device, while orientation influences the sizing and geometry of the device. When the window-to-wall ratio and room depth are kept consistent, they can support constant air movement. This provides an opportunity to study varying shading devices relative to air temperature.

Further, **solar heat gain co-efficient (SHGC)**, which the most common metric for illustrating the amount of solar heat gain that penetrates into a building through a component, depend on shading. An external shade, like an overhang, reduces the quantity of solar radiation that reaches a window glazing. Sun shading will therefore element affects both the direct radiation from the sun and the diffuse radiation from the atmosphere component, depending on the **shading geometry.** Further, it will affect the sum of reflected and diffused radiation that a glazed facade receives from the ground (Kohler, et al., 2017).

According to Christian etl, the **solar heat gain co-efficient (SHGC)** is given as a fraction of the amount of radiation transmitted through a window to the total amount of radiation transmitted through the same window without a shading component.

SHGC (Solar Heat Gain Coefficient) = Q shaded/Q unshaded

Where **Q shaded** is the amount of solar energy pass on through the glazed window due to the incident solar radiation without a shade. Q unshaded is the total quantity of solar radiation that is instance on the window without the presence of any external shade.

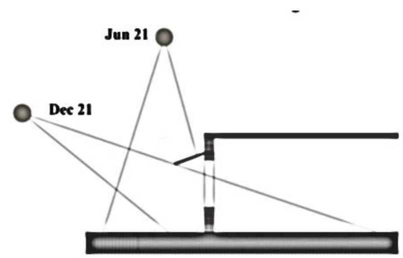


Figure 2-17: Effect of an awning on solar shading at different angles

Of note, the lower the co-efficient, where zero is the least and one is on the higher end, the higher the shading effect. However, the application is very static for a specific time. Its trend is only important to inform possible outcomes. The annual SHGC of a window due to the shading component cannot be calculated. This is due to the statistic that the solar energy transmitted through an opening, be it indirect, direct or diffuse radiation, and the inward-heatflow fraction of the absorbed energy, interrelates with the surfaces inside the building and must not be separated out.

In summary, Tropical indoor thermal environment is affected by external shading devices. The parameters within an external shading device that affects this environment can be concluded as:

1. Shading Size, shape, location,
2. spacing texture and material,

3. solar heat gains co-efficient
4. Shading type, either horizontal, vertical or egg crate system

2.5 Review on lighting Design and associated standards

2.5.1 Lighting design standards for schools

During the day, there are a numeral of different visual tasks in a classroom. In order, for designers to make good lighting concept, knowledge of the specific tasks lighting in classrooms is important. Each task necessities its own light conditions, but at the same time, energy efficiency should not be neglected. The standards reviewed here will include:

1. Building bulletin Lighting design for schools (Loe, et al., 1990)
2. The European norm which gives requirements for the luminance in learning institution (Professional Led&Lamps;, n.d.)

2.5.1.1 Lighting design standards for schools

The best school environments give an impression of aliveness, with attractive space and a general pleasantness. The environment should be appropriate for particular tasks to enable students and staff to carry out various activities easily and comfortably without compromising the aspects of architectural integration, efficiency, cost, maintenance, and visual amenities. The CIBSE-Chartered Institution of Building Services Engineers-codes for interior lighting in 1994, section 2.6.4.4, public and educational buildings, provide the standards as tabulated below: [5]

[5] Task lighting is very specific to the nature of activity such as reading. It is not a subject of regional or any climatic condition. The lighting Standards reviewed are absolutely critical in the design process of specific learning environments universally. Although the standard is set and developed in the template climate, their understanding provide many benefits in the tropic, such as uniformity reference that makes the design process efficient and safe for the protection of people in the lighting environment regardless of regionalism.

2.5.1.2 The CIBSE- Chartered Institution of Building Services Engineers lighting standards

Table 2-4: Standard Illuminance, Uniformity Ratio and Limiting Glare Index in classroom for schools buildings. An abstract from CIBSE- Chartered Institution of Building Services Engineers

Space	Standard Maintained Illuminance	Uniformity Ratio	Limiting Glare Index
General teaching involving reading and writing in classrooms	Illumination of 300 lux	0.8	19
Teaching space, studios with close and detailed work such as drafting.	500 lux	0.8	19
General Circulation Spaces: corridors, entrance halls, stairs, lobbies &waiting areas reception areas	80 - 120 lux 175 - 250 lux 250 – 350 lux	Not Defined Not Defined Not Defined	19 19 19
Atria	400 lux		19

Source: (McLaughlin, 2009)

2.5.1.3 The European norm EN 12464-1 classroom requirements for the Illuminance in learning institution.

Table 5: The European norm EN 12464-1s

Task	The teacher-Activities	The student- Activities	Illuminance	
			In classroom	In general,

1	Writing on a board in a classroom	Reading on board in a classroom	500lux (vertical)	200lux
2	Talking and listen to the students	Paying attention to the teacher	300lux	300lux
3	Showing a visual presentation (slides, PowerPoint, television.)	Looking on the display screen	300lux	10lux
4	Paying attention to working students	Students writing and reading drawing on a plane	300lux	300lux
5	Tutoring using computer activities	Looking to the monitor screen and the paper	50lux	300 lux above the computer
6	Preparing lessons materials on a paper	Not present	300lux	50lux

2.5.1.4 Lighting in teaching spaces for students with special education needs

Classrooms intended for use by deaf students are most critical when designing the lighting environment. The co-ordination of a person will heavily rely on the associated built environment. It is therefore important to avoid:

1. All aspects of contributing glare in space
2. Any strong lighting contrasts within the visual field
3. Direct sunlight into learning spaces
4. Avoid highly reflective finishes on the wall and floor.

To ensure visual comfort at all times. Deaf visual design can therefore be an important aspect of universal visual design. Letting some natural light filter in from the windows can be great for students. The threshold must not be less than 250 lux and not more than 300 lux. The light levels must be uniformly distributed in a space in a ratio not exceeding 0.8 for two points within the visual angle and a limiting glare index of 19. The importance of good lighting in classrooms and other educational centres hinges on the fact that light doesn't only affect us visually, but also has an impact on different physical and emotional attributes.

2.6 Thermal Comfort and Thermal Comfort standards for schools

Thermal comfort, which has been defined as the condition of mind that expresses satisfaction with the thermal environment (Szokolay, 2014). There is a large variation, both physiologically and psychologically, from person to person, hence it is difficult to satisfy everyone in a space. A number of factors identified in this study as thermal parameters are determinants influencing occupant comfort. This includes metabolic rate and clothing insulation. Air temperature, radiant temperature, air speed, and humidity (Fanger, 1972). This factor can be further classified into environmental, personal and contributing factors as illustrated below. Architects and designers might only have control over the environmental conditions to achieve comfort that can be accepted by a specified percentage of occupants of a space.

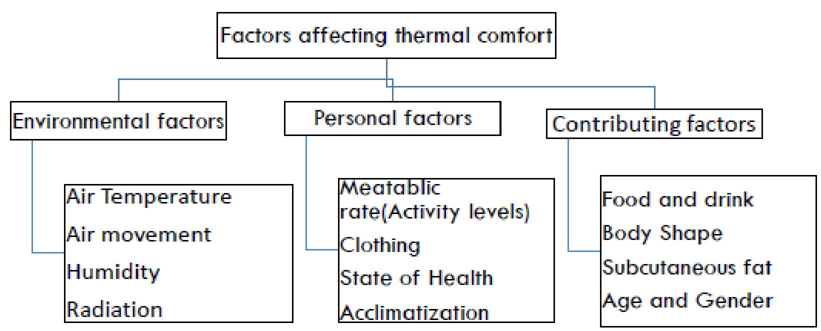


Figure 2-18: Factors Affecting Thermal Comfort

Thermal comfort prediction methods, thermal sensation, and the degree of occupant comfort or discomfort of people exposed to moderate thermal environments are analytically determined and interpreted by the use of thermal indices that include Predicted Mean

Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) and local thermal comfort models. This gives generally acceptable thermal comfort as well as highlights local discomfort levels.

2.6.1 The Predicted Mean Vote (PMV)

ANSI/ASHRAE Standard 55, 2010 recommends a thermal comfort range of between-0.5 and 0.5 on the predicted mean vote sensation scale. The predicted mean vote background formulae combine all physiological, activity, clothing, habits, convective heat transfer, and environmental variables. The PMV was developed by Fanger and was later adopted as part of ISO standard 7730. It involved a large number of people who selected their thermal sensation from the scale after being subjected to different conditions.

2.6.2 Predicted Percentage of Dissatisfied

This predicts the percentage of people who are dissatisfied with thermal conditions. It's an applied function of the PMV. This provides the percentage of people feeling too warm or too cold in a given scenario. It can be extracted from the PMV. Thermal comfort is achieved when at least 80% of the people in the building feel thermally satisfied.

Going by the information by Ole Fanger and various climatic charts developed for the climate of Nairobi, 20^0C to 25^0C forms the basis of thermal comfort.

2.7 The climate of Nairobi

Good architecture must be responsive to the climate in which it sits. Thermal and lighting environments are just two of the many arms of climate-responsive architecture. To present a good prototype of a learning space in the Nairobi tropic climate, a deep understanding of the region and its climate is necessary. Given the given recommendation towards thermal and lighting design, it must be understood in parallel with the climate. This part explores different climatic recommendations, but the study is open to further interrogation as most of these charts have studied the parameters independently. The aim of the study is to find the best trade-off between the two environments.

Nairobi's climate is classified under the Köppen classification as Cfb, which averages 190C. However, weather data at various stations suggests a variation. That is, Dagoretti, Wilson, and JKIA demonstrate that the microclimate within this classification has been created by various urban factors. A microclimate is created when a small amount of water and heat is trapped or expelled near the surface by influences created by changes in anthropogenic activities, solar exposure, and wind speeds due to morphological differences. Climate policy watcher claims that this has an impact on the resulting temperature and humidity levels.

Designers in the tropical climate classify Nairobi as a tropical upland climate. From 1985 to 2015, the average maximum temperature reached 27^{0} C for the hottest month and 22^{0} C for the coldest month. It records 16^{0} C and 12^{0} C minimum temperatures for the hottest and coldest months, respectively. With a diurnal temperature range of about 100 C and an annual temperature range of about 150 C,

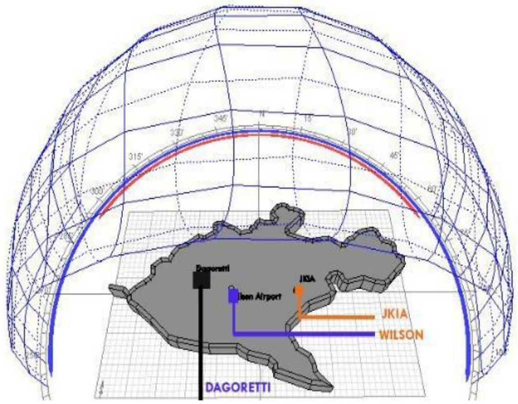


Figure 2-19: Nairobi region weather data collecting centres.

From the East Dagoretti is to a height of 1798m above. Sea level Wilson at 1769m above. Sea level and JKIA at 1624m above. Sea level

Source: Kenya Meteorological Data, 2017

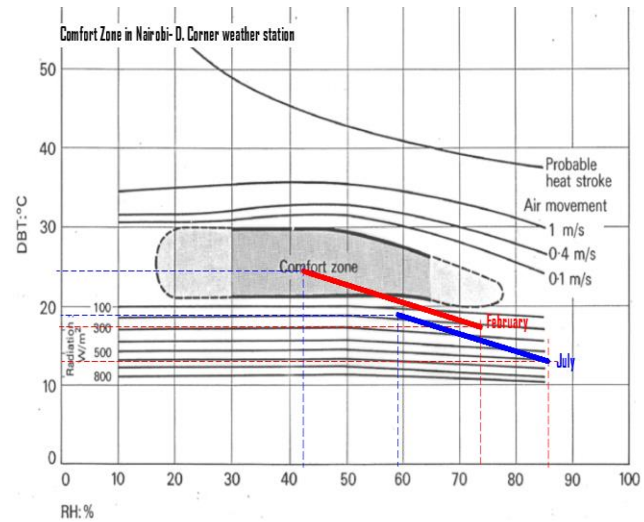


Figure 2-20 bio climatic chart plotted for Nairobi

The luminance levels in the area averaged about 18000lux in Nairobi at latitude 1.2S, between 1700-1800 metres above sea level. It therefore presents a climate for passive thermal and lighting design with a big opportunity for energy saving. However, despite this, many buildings in the city are marked as high energy spenders on thermal cooling and admission of ambient light (UN-Habitat, 2014). Building bio-climatic charts, the "comfort zone" for the City of Nairobi, recommends appropriate design goals for Nairobi. External architectural shading devices should be seen as an appropriate tool to achieve thermal comfort for people in their thermal environment.

Thermal comfort is a key player in the determination of strategies to use for thermal comfort. Nairobi's temperatures are moderate, with high temperatures being experienced from January to March, April and September towards October. This period also coincides with high altitude solar angles. The hottest month is February, with highs of 280C, while the coldest is July, with highs of 22^{0}C. Temperatures fluctuate between JKIA, Wilson, and Dagoretti, respectively.

Table 2-6: Nairobi climate Mahoney table design guideline for the case of Dagoretti, Wilson and JKIA

NAIROBI CLIMATIC DESIGN RECOMMENDATION							
	H	A		D	W	J	Recommendation
Dagoretti	H1(0)H2(8) H3(0)	A1(3) A2(0) A3(0)					
Wilson	H1(0)H2(6) H3(1)	A1(5) A2(0) A3(0)					
JKIA	H1(1)H2(6) H3(1)	A1(6) A2(0) A3(0)					
LAYOUT		A1(0-10)	a1	x	x	x	**Long axis east- west**
		A1(11-12) + A3(5-12)					
		A1(11-12) +A3(0-4)	a2				Compact courtyard planning
SPACING	H1(11-12)		b1				Open space for breeze penetration
	H1(2-10)		b2				Open spacing, protect from winds
	H1(0-1)		b3	x	x	x	Compact Planning
AIR MOVEMENT	H1(3-12)		c1				Single banking and permanent ventilation
	H1(1-2)	A1(0-5)	c2				Double banking and temporary ventilation
	H1(1-2)	A1(6-12)				x	
	H1(0)/ H2(0-1)						No air movement required
SIZE OF OPENING		A1(0-1)/A3(0)	d1				Large. 40-80% of wall area
		A1(0-1) +A3(1-12)	d2				**Medium 25-40% of wall area**
		A1(2-5)		x	x		
		A1(11-12) +A3(4-12)					
		A1(6-10)	d3			x	Composite. 20-35% of wall area
		A1(11-12) +A3(0-3)	d4				Small, 15-25% of wall area
POSITION OF OPENING	H1(3-12)		e1				In North and south wall height
	H1(1-2)	A1(0-5)					
	H1(1-2)	A1(6-12)	e2			x	**In North and south wall height also in internal wall**
	H1(0) + H2(2-12)			x	x		

PROTECTION OF OPENING	H3(0-2)	A3(3-12)	f1				No special protection necessary
	H3(0-2)	A3(0-2)	f2	x	x	x	**Exclude direct sunlight**
	H3(3-12)	A3(0-2)	f3				Protection from rain and direct sunlight
	H3(3-12)	A3(3-12)	f4				Protection from rain
WALLSAND FLOORS		A1(0-2)	g1				Light, low heat capacity
		A1(3-12)	g2	x	x	x	**Heavy over 8 hours' time lag**
ROOFS	H1(10-12)	A1(0-2)	h1				Light, reflective surface and cavity
	H1(10-12)	A1(3-12)	h2				**Light and well insulated**
	H1(0-9)	A1(0-5)		x	x		
	H1(0-9)	A1(6-12)	h3			x	Heavy over 8 hours' time lag
OUTDOOR SLEEPING		A2(0)	i1	x	x	x	No provision for outdoor sleeping
		A2(1-12)	i2				Provision for outdoor sleeping
RAIN PROTECTION	H3(1-2)		j1		x	x	Provide adequate rainwater drainage
	H3(3-12)		j2				Protection from heavy rain needed
	H3(0)		j3	x			No Protection from heavy rain needed

As per the tables, the building's longer axis should lie in the East-West direction. This minimizes heat gains and solar glare during low solar angles, usually in the morning and afternoon. Indoor heat buildup will result from low angle and high direct solar radiation. Daily average air temperatures are comfortable. Indoor discomfort arises through heat build-up caused by solar radiation and indoor activities**.** Daily hourly temperature peaks are attained in the afternoon, whereas very cold nights are attained in the months of June and July. As shown in the Nairobi sun chart, shading devices should be used in the afternoons to avoid excess heating.

Average humidity extends from 62% in February to a maximum of 70% in mid-year April, July, November and December. High humidity levels are seen to concede with rainy seasons and low sun hours, as a result of the effect of sky openness caused by clouds. The high sun hours are also associated with the sun's position at different times of the year. Months with high solar hours are also associated with high temperatures and high temperatures.

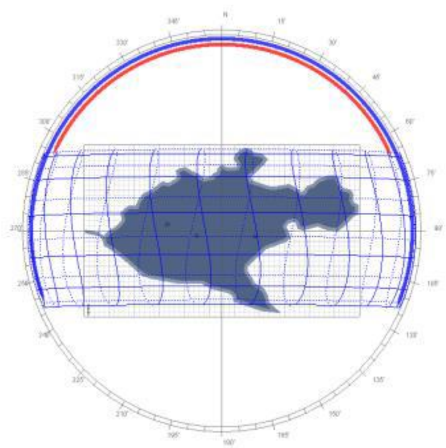


Figure 2-21: Nairobi Solar Geometry.

Source; Author 2021

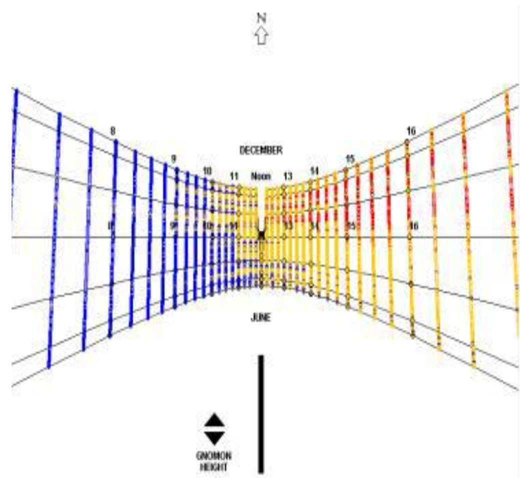


Figure 2-22: Application of Shading to avoid excess heating plotted against Sun path Diagram for Nairobi

Source: Mukinda 2017

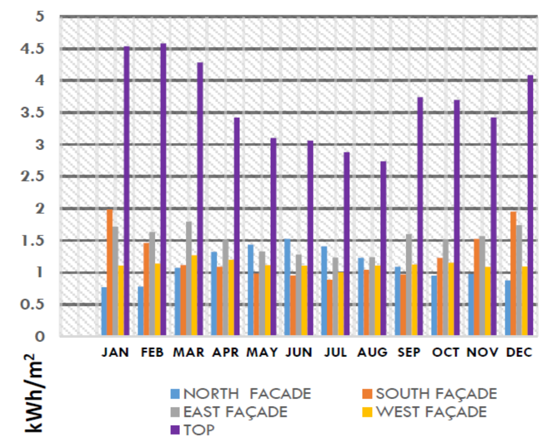


Figure 2-23: heat build-up caused by solar radiation in Nairobi on various facades

Source: Mukinda 2017

Solar radiation at any surface is dependent on geographic location, slope, orientation, and weather conditions. Hence, this is a vital determinant in any shading device design. Solar radiation reaching the building envelope can either be direct or diffuse. Direct irradiation comes directly from the sun, with more energy received as the striking angle nears 900. Diffuse irradiation is indirect and comes from all sides of the atmosphere and the amount received depends on exposure of the surface to the sky dome.

Daily average air temperatures are comfortable. Indoor discomfort arises through heat build-up caused by solar radiation and indoor activities. Daily hourly temperature peaks are attained in the afternoon, whereas very cold nights are attained in the months of June and July. Shading devices on a window should be used in the morning and afternoons to avoid excess heating as shown in the Nairobi sun chart and its subsequent application.

2.8 Theoretical Framework

Conflicts between thermal and daylighting are ever evolving, with major contradictions arising when the window size needs to be optimized, small window sizes for cooling energy, and visual comfort optimisation large window sizes. The literature finds common parameters that can be attributed to the thermal and lighting environment.

Table 7: A table of summary on design parameters associated with the shading devices

No.	Environment	Parameters
1	Lighting environment	**Shading type, geometry, positioning, reflective properties and the size**
2	Thermal Environment	Shading **Size, shape, location, spacing texture** and **material, solar heat gain co-efficient**

Source: Author created 2021

By combining the two, three main characteristics of a shading device can be attributed to the thermal and lighting environment in school buildings.

1. **Sun shading geometry**- It will include the size, shape, and position/location.
2. **Shading Properties** (the material shading co-efficient (SHGC) - absorption, transmittance, reflectivity)
3. **Orientation of window-** calculating required shading size depending on different exposure to the sun position.

Studying each parameter independent of the others may prove to be difficult. Holding some constant can give a result with a smaller margin of error that directly attributes the outcome to the truth given by the study parameter. For example, to understand the role of a shading device's size and shape, factors relating to material, glazing ratio, orientation, and shading geometry can be held constant. By varying the shading size and shape, different results can be achieved to help in the study.

Space air temperature and Lux levels on a working plan have over time been used to study indoor thermal and luminous environments, respectively. This study will therefore pick this variable to drive an argument that can be believed to be true and scientific.

2.9 Conceptual Framework

The specific basis of arguments in the studied theories drives the key conceptual framework of this study. It is generally accepted in theoretical work that the level of exposure of a tropic building due to the presence or absence of shading devices on glazed parts has a direct impact on the room air temperature. Similarly, a shading device has significant influence on the sky component, external and internal reflection of light which the summation gives the total flux reaching a point on a working surface.

In terms of environmental reporting, these theories serve as the foundation for both the creation of new reports and practices that can be combined to create a shading device that performs optimally in thermal and lighting environments, as well as the evaluation of existing ones with the goal of recommending improvements. This reporting and evaluation will be purely studied using existing knowledge, Energy plus and velux daylight visualizer computer simulation models and case studies respectively.

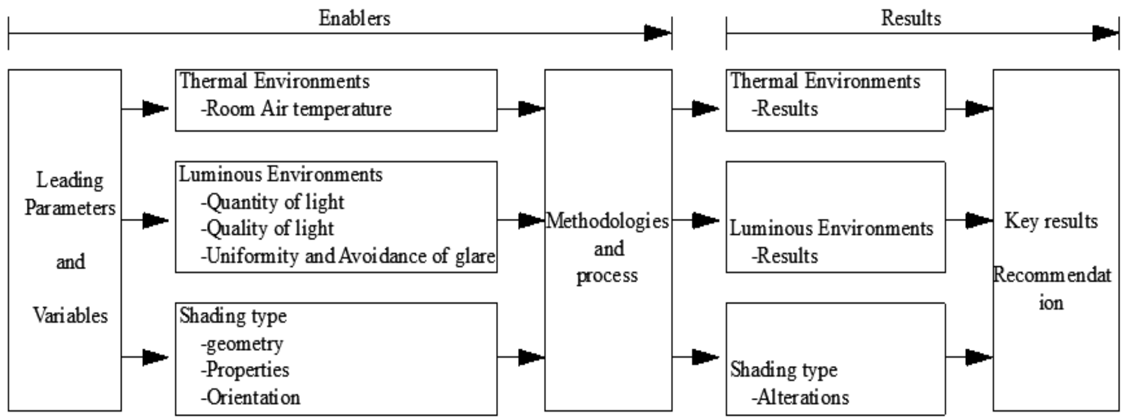


Figure 2-24: Conceptual Framework of potentiality of shading devices for optimum thermal and daylighting design

The literature forms the underpinning knowledge on the theoretical basis for determining which of the **shading geometry, shading properties, and orientation** of a device should be accounted for in resultant thermal and lighting environmental conditions, how they should be measured, and how they should be traded to achieve an optimum indoor environment.

3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the various means and ways undertaken to achieve the aims and objectives of the research. It describes the process used to select the case study based on its objectives while explaining the research operational framework that was adopted in the piloting and identification of the problem. Furthermore, it expands on the analysis and evaluation process involved in the study, as illustrated in the table below.

Table 3-1: A comparative review of the research objectives against methodology objectives

Research objectives	**Research methodology objectives**	**Specific research Approach**
To explore and document the various architectural shading devices in selected case studies in Nairobi.	1. Explain how literature was covered and used to develop a theoretical background adopted to identify the types of shading devices and develop a guideline to investigate the case study. 2. Identify and explain the data correction, analysis, and presentation techniques that will showcase the types of shading devices identified in the case study.	1. Theoretical analysis 2. Observation and Test
To determine the effectiveness of the identified shading devices towards thermal and daylighting environments in these selected cases,	1. Determine comparative techniques that will evaluate the performance of indoor thermal and lighting environments. 2. Explain how the data is documented to indicate the effectiveness of external shading devices in the case study selected.	3. Observation and Test 4. Explanatory data analysis on response rate

		5. Confirmation or rejection
To identify and document the potential of a shading device in providing optimal thermal and visual comfort in learning spaces, selected cases, and how the lessons learned can be applied to Nairobi's built forms in learning institutions,	1. Explain the application of modification and analysis techniques from the **conceptual and theoretical framework** in the optimization of shading devices to provide optimal thermal and visual comfort in learning spaces.	6. Confirmation or rejection 7. Structured equation modelling

Source Author.

3.2 Research design

This study is designed in such a way that it is an exploratory case study. Exploratory research is conducted to study a problem that has not been studied more clearly. It establishes its own priorities, develops operational definitions, and improves the final research design by emphasizing discovery and understanding of ideas and insights (Shields & Rangarajan, 2013). The study explores the effectiveness of shading devices in the selected case under a guiding criterion of availability, geographical location, and climatic location, and more importantly, a case that has not been studied in the past. Furthermore, it explores the possibility of optimization of existing devices for thermal and lighting design in the learning spaces.

Energy plus simulation, Autodesk Ecotect analysis, and Velux daylight visualizer Computer simulation is further used to explore the effects of modification of shading devices based on the calculation of horizontal and vertical shadow angle components highlighted in the literature review in this study.

This research identifies thermal design parameters and lighting design parameters relating to a shading device with a view to comparing the performance in both environments. It is based on a case study of selected shading devices within the Technical University of Kenya to evaluate their performance in indoor thermal and visual environments.

This mode of research will involve **searching for more evidence** concerning this phenomenon, **assembling and organizing** that evidence, **evaluating** it, and **constructing** a narrative from the evidence that is holistic and believable **based on the selected case study.**

Figure 3-1: A photography illustration of the selected area of study (From left Horizontal concrete vents on N Block, Eastern balcony on U block, non-shaded façade and combined Eggcrate and aluminium louvers on C block).

Source: author 2021

The Technical University of Kenya, with its various shading devices, (Figure 3-1), presents a suitable case due to its location within the study climate and provides the best access to information. Despite its varsity in design, the case is not adequately studied in this area. It is therefore an opportunity to inject new knowledge into the topic of thermal and visual environment design.

Emphasis will be placed on the variables of air temperature and illumination, in relation to the type of shading device as classified in the literature review and how their effect contributes to the comfort levels. As built models are subjected to computer simulation, enabling comparison between recorded data and simulation, Furthermore, this guides the research to explore the parameters of energy, air temperature, and lighting by modifying various parameters of geometry, orientation, and material properties of the shading device.

3.3 Research strategy

The research methodology adopted a three-step approach.

3.3.1 Finding out what exists in the field:

1. Find out the type of shading devices that are used in the selected cases at the Technical University of Kenya. This will be classified as either horizontal, vertical or eggcrate shading as identified in chapter two shading.
2. Establishing the indoor thermal and lighting conditions in the selected case studies and the extent to which the type of shading device has been used.
3. Using identified standards of thermal comfort and lighting levels for classrooms, determine the effectiveness of the various types of shading adopted and what influences they present on the resultant indoor thermal and lighting performance in the learning space.
4. Criticize the design of the shading devices vis-a-vis their performance towards comfort.

3.3.2 Finding out what is needed:

Determining the architectural interventions on the form, geometry, orientation, and material properties of the shading devices that can be made to improve the existing situation in the selected cases. Purely, the variables of shading geometry, shading properties and shading orientation will be simulated in a computer model and read against the variables of temperature and illuminance.

3.3.3 Making Appropriate Recommendations:

After a careful study and analysis of the topic, appropriate recommendations will be made. These proposals will offer design guidelines for professionals in the building industry and stakeholders in what would be an optimal form of a shading device in a learning space.

3.4 Sample design

The method of sampling used is purposive sampling. According to (Crossman, 2017), a purposive sample is a non-probabilistic sample that is selected based on the **characteristic of a population** and the main objective of the study is to get specific variables, in this case types of shading devices guided towards selection of the case. The selection not influenced by the size of the population other by the objectives of the study, type of shading. Hence, the selection of Technical University of Kenya learning spaces due to the variety of shading presented. (Figure 3-1)

The selection of Technical University of Kenya is used to reach to a target sample of horizontal, vertical and egg crate devices quickly, however proportionality is not a main concern as the research focus more on the typology of external shading device. The case study selecting rationale is such that they are picked after insightful analysis of their relevance in effectively representing the subject matter and their suitability within the given environmental design context, which is tropic upland climate of Nairobi.

Further a classroom in the educational institutions under consideration is selected such that it provides a space where learning can take place. This research limits a classroom to a space within 8:10 length to width ratio. The room must be side lit and characterised by an external shading device unless stated in the course as non-shade.

3.4.1 Criterion for choice of and case study.

Small learning spaces, previously defined as a space within a length to width ratio of 8:10, in the local Nairobi tropical climate are selected since they present a suitable environment for studying indoor thermal and lighting environments. The technical university is located in the Nairobi Central Business District.

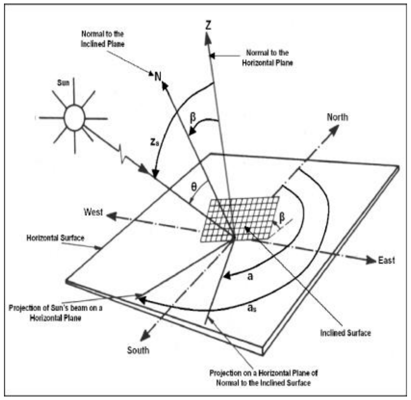
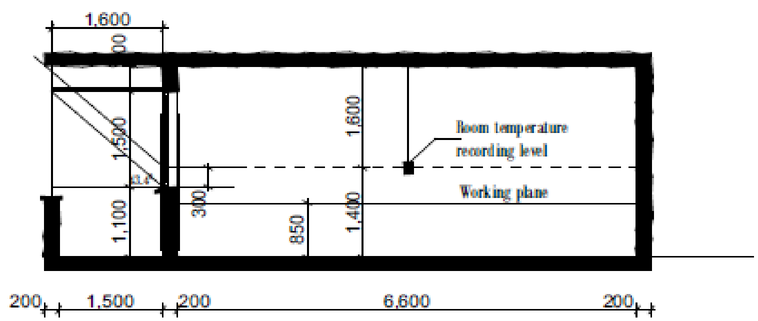
In addition, the following criteria are used for precedent and case study selection:

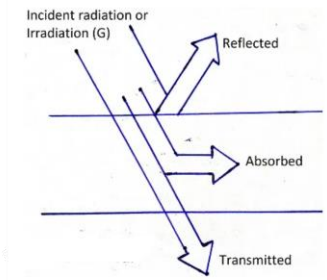
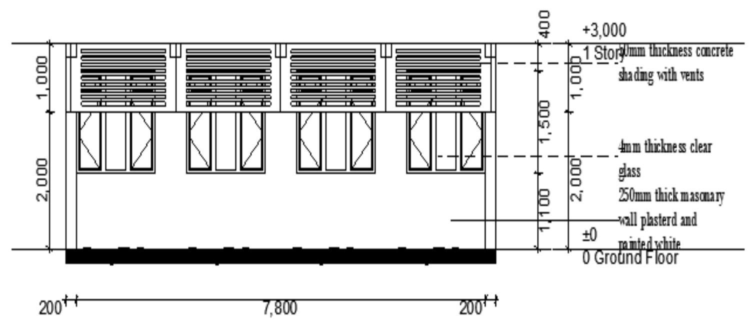
1. The institution that has an adequate presentation of the types of shading devices documented in chapter two and information that is accessible for this study.

2. The institution that demonstrates a strong image and successful integration of various types of shading devices within the same microclimate.

3. The institution is not widely studied in the research area. The aim is to increase the body of knowledge by providing new case study information.

Table 2: Summary of selected cases based on Criterion for choice of case study

Variable	classroom	External Shading type and description
Shading Geometry  Figure 3-2: summary of block orientation and its influence on shading deriving basic research criterion	U 1 and U 2	1.6-meter-deep single horizontal device inform of a walk way  Figure 3-3: section illustrating the balcony as a shading device: source: author 2021
	N1, N2 and N3	Louvered concrete shading fins with vertical interventions-
	F1	Louvered aluminium shading fins- Horizontal shading
	R1	Not Shaded- classroom used to derive the impact of various shading in a space. It forms the nominal model of comparison
Shading Properties	U 1 and U 2	1.6-meter-deep single horizontal concrete device

 Figure 3-4: illustration of the impact of shading upon receiving light or heat wave	N1, N2 and N3	200 mm thickness reinforced concrete with cement sand screed above. Plastered and painted white underneath
	F1	Aluminium-Aluminum has high reflectivity properties which make it an efficient material for light management while in shading devices, due to high conductivity when used exterior, it can reduce solar heat gain on the main envelope.
	R1	Not shaded- glass as the only shading element
Orientation	U 1 and U 2	30 degrees to the west off the North. U1 face north east while U2 overlooks the south west
	N1, N2 and N3	Figure 3-5: elevation illustrating shading on block  N
	R1	Not shaded. Window at 30 degrees of the north and south facade

Source: Author 2021

Further, the case study presented almost identical classroom size and volume, giving a reasonably standard unit of adopting a similar parametric model to study various types of shading in a computer simulation model. The nominal class, defined as the parametric model, defines measurable factors, forming a set that helps understand the influence of different geometric or physical parameters of the shading, such as sizing, material, and reflectivity towards the thermal and lighting environments.

3.5 Data collection method

Figure 3-6: A tape measure (top) used to measure size of indoor space, size of external shading elements on the windows

The recording was carried out in the month of February 2021. February is the hottest month in Nairobi with an average temperature of 20.5°. This is to provide an in-depth study for thermal design control. These recordings are linked to the physical architectural characteristics of shading devices in the associated building with a bias towards finding the contribution of the shading towards visual and thermal comfort.

The data was collected with the aim of illuminating the set parameters of a shading device which mainly influence its performance towards daylighting and thermal regulation. The shape, size, position, and space of the device will be attributed to the resultant indoor air temperature and luminous levels. As such, data will be collected through the methods:

3.5.1 Actual measurements

This method involves air temperature logging. HOBO data loggers will be used to record the resultant air temperature and humidity levels. To investigate the effectiveness of the shading device, a comparative analysis will be applied. The daylight factor (DF) calculation for available interior daylight and the glazing factor(GF) calculation for available interior daylight will be used to investigate light as an architectural design element and how a shading device influences the indoor levels. A light meter, lux meter, was used to record luminance levels in identified spaces. The results obtained are compared and rated against the Chartered Institute of Building Service Engineers and European norms on lighting design for classrooms as established in chapter two.

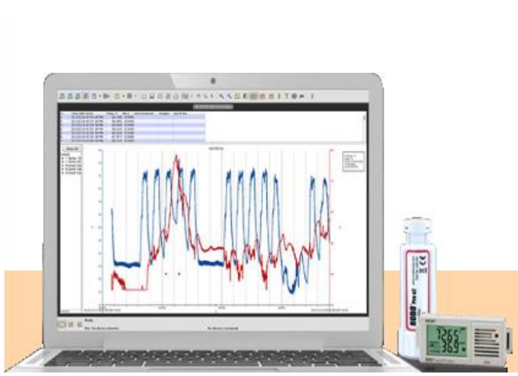


Figure 3-7: Hobo data logger mounted in a computer to record air temperature and Air humidity during the study

3.5.2 Observation

The observation method is illuminating the discrepancies between beliefs and casual conversations. The primary data collection method included is observations. The study articulates this through use of sketches, photographs and measured drawings as is in the data collection method.

The major strength of direct observation in this study observation is such that it is not obtrusive and does not require direct interaction with participants, the researcher makes judgement based of recorded evidence (Adler and Adler 1994) as this would dilute scientific data recorded. However, the room occupants are significantly important in this study. To account for their influence on recorded data, their number is consistently recorded and observed against the environmental graphs for any resultant impact of their presence.

The research will employ both structured and unstructured observation techniques. The structured observation method will ensure that the study is able to respond to its research questions. Unstructured observation will ensure that any other relevant information identified in the fieldwork is not left out just because it was not concealed in the predefined observation list.

3.5.3 Sketches, Measured drawings and Photographs

In this study, sketches and measured drawings played a significant role in documenting findings and observations made during fieldwork and analysis. They offer an extensive variety and flexibility in presenting findings of the research. Architectural, Floor plans, sectional elevations, and 3D drawings are used to present identified typologies of shading.

Physical measurements by the use of tape measures enabled precise dimensioning and derivation of precise parameters that were crucial inputs in the data analysis stage, especially in CAD simulations.

The **effectiveness** of the shading type towards lighting is shown using daylight contours on the plan drawing and the 3d Velux daylight visualizer. Using the output data, glare and uniformity ratios are accessed to describe the quality of light in a space.

Photography was used to capture almost all the issues of the study. The pictures are analysed in sketches and computer-generated models. This tool is major observation element in capturing the existing condition in the area of study. Picture photos of both the exterior and interior, the context of the typology's devices are taken to give a clear understanding of the studied lighting and thermal environments. Later, they used to support principles in literature and authors informed analysis of the information obtained from the field.

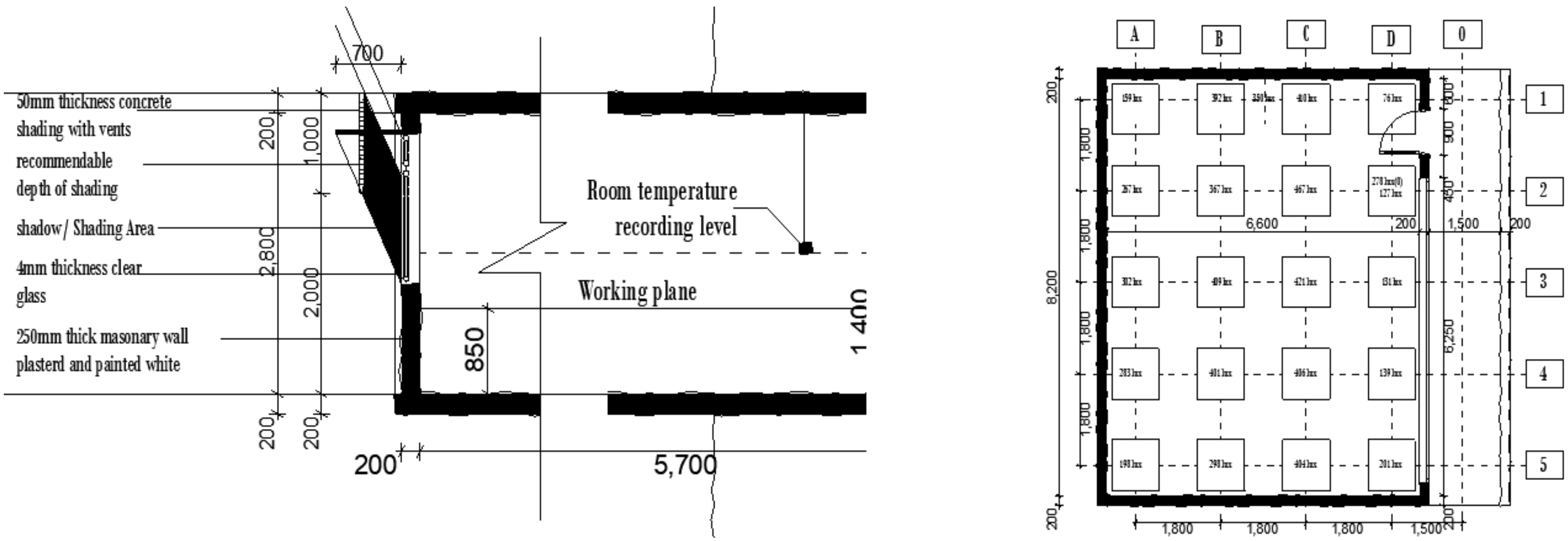


Figure 3-8: Sample sectional and Plans used to illustrate spaces

3.5.4 Computer Simulation

The effect of any modification of the external sun shading elements on indoor thermal and visual quality is guided by the following computer-aided design tool. Energy plus simulation, Autodesk Ecotect analysis, and Velux daylight visualizer

Different external shading methods used in selected case studies are simulated to compare their effectiveness in reducing indoor temperature, lighting, and energy savings. They include horizontal overhangs, vertical fins and egg crate systems. Validation of the applications is carried out using a parametric class model similar to the one used in the pilot study. The various applications represented

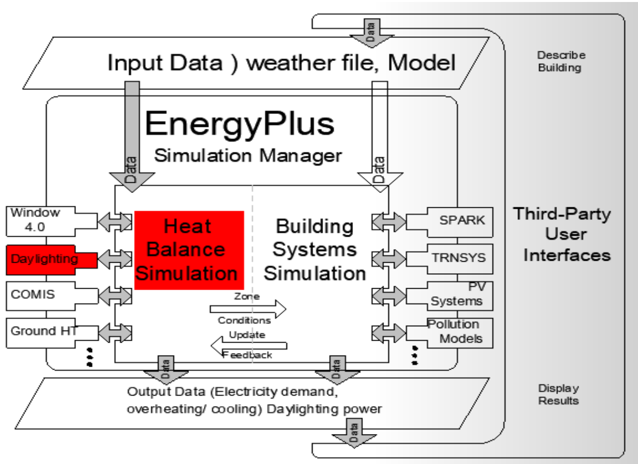


Figure 3-9: Graphic illustration of Energy plus input and output data for heat balance, overheating and electricity requirement due to under lighting in a product.

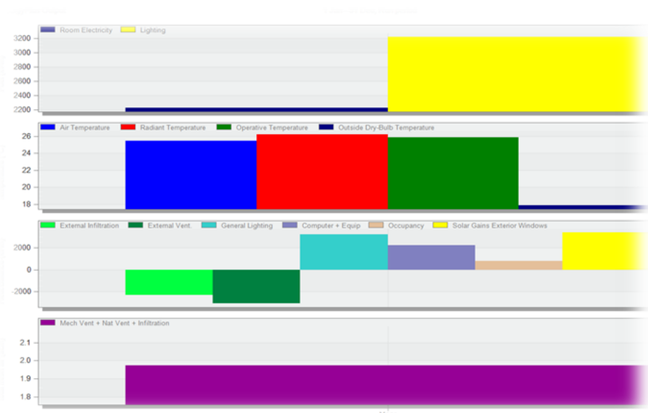


Figure 3-10: Output data graph for heat balance, overheating and electricity requirement

identical graphics and behaviours with minimal variance, where the software presented a perfect graph as opposed to actual recordings, which presented variance due to human activities in the recording space, among other minor influencing environmental factors.

Overhangs and vertical fin effectiveness will first be tested by increasing the devices at selected intervals. Their effectiveness on different façades will be investigated to show their thermal and lighting comfort and energy savings potential.

3.5.4.1 Energy plus simulation validated

Energy Plus building performance simulation program is mainly used due to its ability to combines features on heat balance, overheating and electricity requirement due to under lighting in an architectural product. The program

Structure relay on input data to give output response.

(Figure 3-10).

The comfort zone is set at 20^0-25^0C. If the temperature falls below 20^0C, the thermostat in the AC system initiates heating until the lowest comfort level is reached. When indoor temperatures are beyond 25^0 C, it initiates cooling until the upper limit is attained. These heating loads are measured in kWh.

When passive methods of design are employed to maintain temperatures at comfort level, the foregone cooling and heating energy becomes energy savings.

3.5.4.2 Autodesk Ecotect analysis

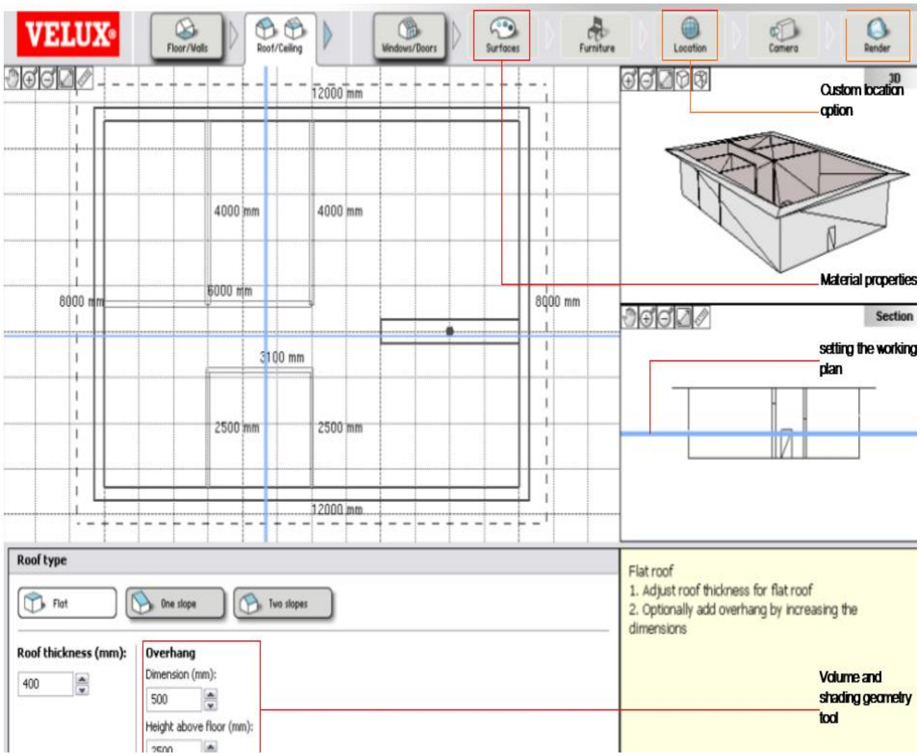
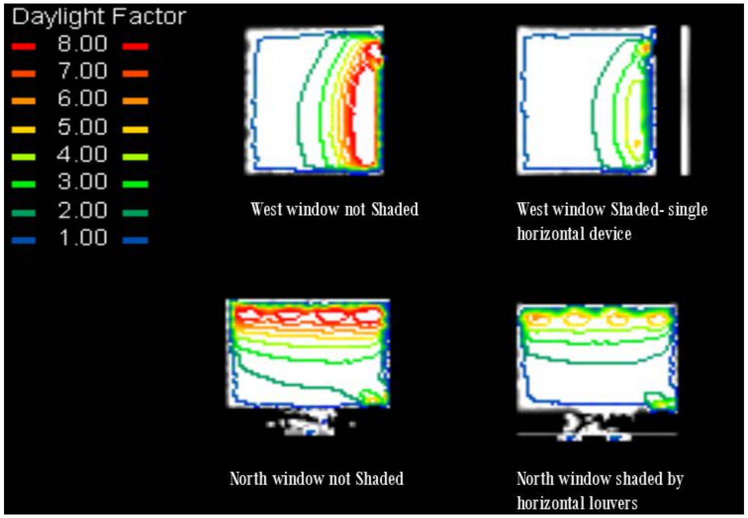


Figure 3-11: Graphic illustration of velux daylight simulation tools for input data

The simulation software used for thermal simulation is Autodesk Ecotect Analysis 2011. The software validation has been conducted in previous research by Yahya Lavafpour and Steve Sharples in July 2015. In their study, they sought to establish the potential of façade geometry in the southern façade of Passivhaus dwellings to reduce overheating discomfort in Islington, UK. (Lavafpour & Sharples, 2017)

The parametric models in this research resemble a Passivhaus dwelling. The shading component of the wall is varied while the room geometry and opening size are maintained. The minimum indoor comfort level was set at 200C and the upper limit at 250C. Like in Passivhaus by Yahya. A mechanical ventilation HVAC system with an 87% heat recovery efficiency manages the indoor thermal conditions. The models are based on the current weather in 2011, with an urban background. (Lavafpour & Sharples, 2015)

3.5.4.3 Velux daylight visualizer



Velux Daylight Visualizer software is a daylighting simulation instrument for the analysis of daylight factor (DF) conditions in buildings. Over time, it has been intended to encourage the use of daylight design strategies to aid environmental designers in predicting and documenting illumination in building proposals prior to realization of the actual building design.

Figure 3-12: Daylight factor data output file illustrated by velux

This study adopts the DAYLIGHT FACTOR. Due to variations in illumination from the sky, specific illumination values could not be used in simulation design standards for interiors. Instead, a ratio known as the Daylight factor (DF) is used. It is the ratio of illumination at a point indoors E_I recorded using the data logger to that received simultaneously by an unobstructed point outdoors E_O. Recorded data is used to validate computer simulations and set up for this study.

Thus, DF = E_I/E_O x 100%.

Composition: DF is composed of the three following components.

SC – direct/diffused light from the sky dome/hemisphere

Externally reflected component (ERC) – reflected from other buildings' or the ground's external surfaces

Internally Reflected Component ERC-reflected from internal surfaces of the room

DF = SC + ERC + IRC.

Velux daylight visualizer validated

Velux has gotten approved all of the CIE 171:2006 assessment cases dedicated to natural lighting by simulates the facets of natural light transmission, Luminous flux conservation and measure of its perceived power, directional transmittance of light by clear glass and light reflection on a diffusing surfaces with an average error lower than 1.29 %.

3.6 Data presentation method

3.6.1 Tabulation and Graphs

Tables are used to present collected data on air temperature, humidity levels, and daylight factors in order to compare the cases studied. Tables give an overview of the qualities and quantises of the variables within the learning spaces. In addition, the objectives of the research are tabulated against various sub objectives to maintain the flow and relevance of the study within a scope limited to the identified problem.

Graphs are mainly used to compare scientific data, air temperature, associated humidity levels and daylight factors against the variable of time, collected in the selected case studies. This involves plotting Illuminance and air temperature against each other at various times of the day. Graphs help to simplify the data towards making it presentable and easy to interpret and compare cases with each other.

3.6.2 Photographs

Photography is the most and extensively used mode of graphical communication in this study to capture and aid in documenting parameters of the research such as the type of building form, location of shading and types of shading elements. In addition, through photographs, it is easy to capture the performance of a shading device by observing and comparing shadow patterns. Each element studied will have its variables corresponding to the standard parameters recorded, which includes: shading geometry, orientation and properties such as material composition. Image Visualization and modified 3-Dimensional images

This method of presentation will be used to present the computer-generated models of the cases in order to analyse the form and layout of the learning unit planning. The author uses these models with additional software, i.e., Autodesk and Velux, towards simulating building performance with regard to daylighting and thermal regulation.

3.6.3 Sketches and Architectural Drawings

Measured replicated sketches, including plans, sections, and elevations, are used to present the findings of the study to ensure easy interpretation of the findings found in each area of the study. The plans show the location and orientation of the buildings and provide an analysis of their form and window ratio for daylighting.

3.7 Data analysis

Quantitative and qualitative data collected will be analysed, interpreted and presented using various research tools discussed. As posited by Yin (2003), case descriptions, rival explanations, and theoretical propositions are the general analytical strategies for which priorities for what to analyse and the basis for analysis will be employed. The data analysis technique is carried out through contextual, descriptive and comparative analysis.

3.7.1 Contextual analysis

Analysis of the context in which the selected classroom in a learning institution forms part of the historical setting that contributes to recorded data on the thermal and visual environment. The location, site conditions, and general orientation are analysed. The aim of this analysis will be to gain insights as to the impact of site conditions on the expression of the built environment. This will be illustrated through the use of site plans, photographs, descriptions and satellite maps

3.7.2 Descriptive analysis

A descriptive study of each classroom is focused on the architectural design guidelines for shading devices. The parameters, which include: lighting levels, temperature ranges, shading geometry, orientation, and properties of shading materials, are described based on theories to create a scientific analogy that can be believed to be true.

3.7.3 Comparative analysis.

The aim of the comparative study is to demonstrate the way in which architectural design guidelines of shading devices have been expressed in different selected case studies.

3.7.4 Parametric analysis

The study adopts the nominal class as defined by standard size and volume as a parameter to define measurable factors, forming a set that defines the standard conditions of simulation operation. It helps understand the influence of different geometric or physical parameters of the shading, such as sizing, material, and reflectivity on the thermal and lighting environments.

Parametric analysis is an important tool in this study for design exploration, for instance, to examine the influence of the sizing shading on the resultant indoor thermal and lighting environment. The user-defined solving scenarios in this case hence become a standard size of classroom and window while varying the shading type.

3.8 Summary of the methodology

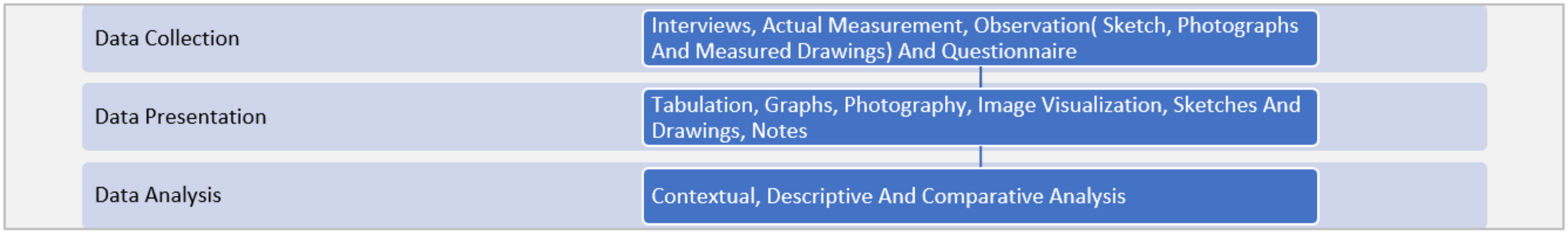


Figure 3-13: Summary of the research methodologies guided identified variables

4 DATA COLLECTION AND ANALYSIS

4.1 Introduction

This chapter discusses the data collected and analyses the data as explained in the methodology. It begins by presenting the existing types of shading devices for the selected cases at the Technical University of Kenya. In addition, the effectiveness and performance against the lighting and thermal environment are presented in the form of recorded data.

The recording was carried out in the month of February 2021. February is the hottest month in Nairobi with an average temperature of 20.5°. This is to provide an in-depth study for thermal design control. These recordings are linked to the physical architectural characteristics of shading devices in the associated building with a bias towards finding the contribution of the shading towards visual and thermal comfort.

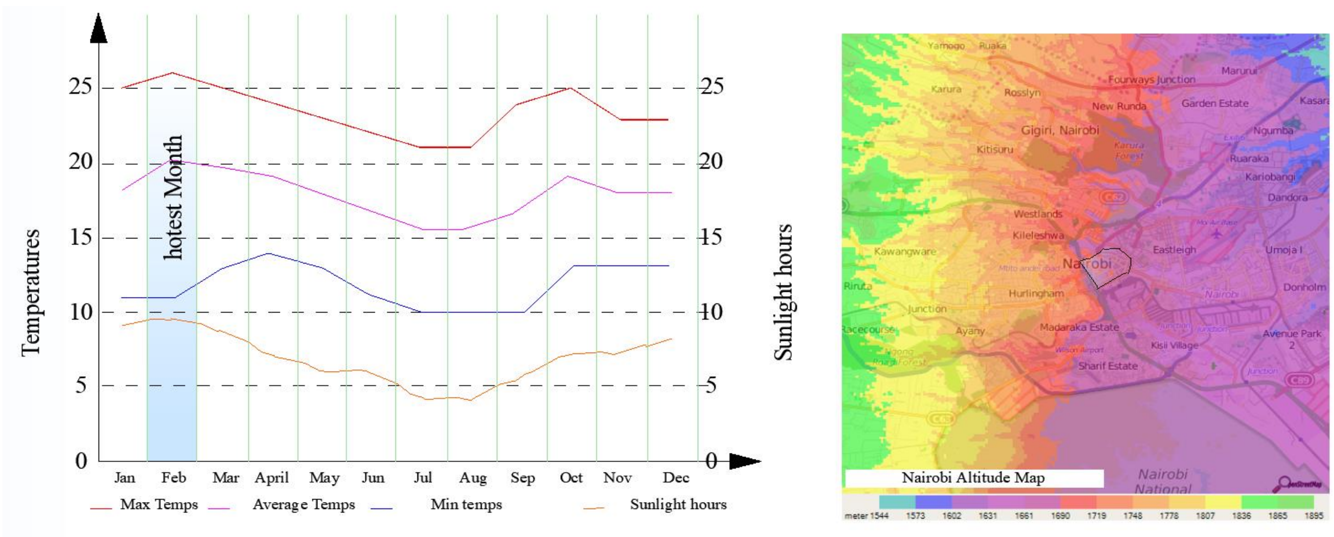


Figure 4-1: Graphical illustration of annual temperature in Nairobi- February is the hottest month in Nairobi with an average temperature of 20.5°C: Source. Dagoretti- https://meteostat.net/en/station/63741, Flood Map

This chapter goes ahead and examines for optimization various typologies of shading devices using computer models. I.e., horizontal, vertical and egg-crate. For each typology, the performance in thermal and visual comfort was validated against actual recorded data for the month of February, then proceeded to annual simulations. Further, modification of shading is carried out in size, depth, spacing and overall geometry. The best performance in ambient lighting and thermal design is then considered the most optimum.

Table 3: A table comparing the research objective to the data analysis objectives. Source: author, 2021

Research objectives	**Data analysis objectives**
To explore and document the various architectural shading devices in selected case studies in Nairobi.	1. Identify and document the types of external shading devices at The Technical University of Kenya, detailing their respective sizes, positioning, and material properties.
To determine the effectiveness of the identified shading devices towards thermal and daylighting environments in these selected cases,	2. Record environmental data relating to the thermal and daylight environment, present and compare the data with intentions to attribute it to the external shading device in the selected cases. 3. Explain how the data is a key performance indicator on the effectiveness of shading devices for the case study.
To identify and document the potential of a shading device in providing optimal thermal and visual comfort in learning spaces, selected cases, and how the lessons learned can be applied to Nairobi's built forms in learning institutions,	4. Explore further modifications to external shading devices and analyze output data as a key performance indicator on the effectiveness of shading devices for the case study with the aim of recommending improvements.

4.2 Contextual area of Study- Cases of classroom at The Technical University of Kenya

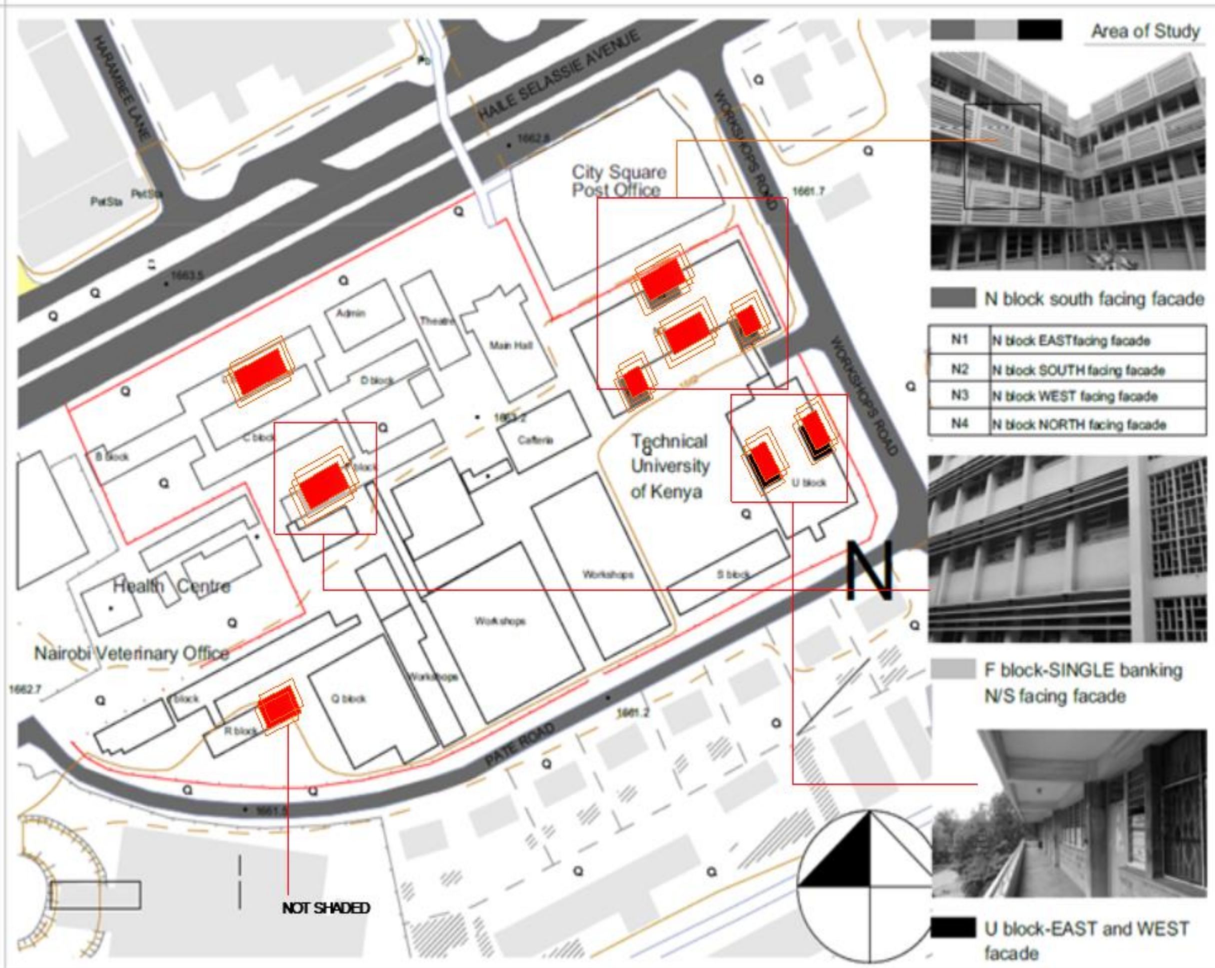


Figure 4-2: Location of selected classroom for study as identified on the master plan of technical university of Kenya. Source: JACA, author modified 2020

External shading Devices were studied at the Technical University of Kenya. Spaces were randomized from a population of four buildings that best presented the types of external shading.

Types of external shading identified were classified into two broad categories

1. Horizontal shading Devices.
2. Eggcrate shading Devices.

Horizontal shading is further subdivided as follows:

1. Corridors and balconies are examples of overhangs.
2. perforated concrete elements and layered aluminium louvres
3. egg crate devices mainly sized concrete components

4.3 Types of shading Devices Studied

Table 4-4: table comparing the various types of shading devices identified in the study area at the technical University of Kenya

 Figure 4-3: horizontal overhangs in form of balconies in U block	 Figure 4-4: Perforated concrete shading devices in N block where 4 classes were studied on all orientation	 Figure 4-5: layered aluminium devices used to form shading on F block
 Figure 4-6: An external environment on the corridor of U block	 Figure 4-7: Eggcrate shading studied in C block	 Figure 4-8: A non-shaded classroom on r block studied to pilot the shaded classrooms

Source: Author 2021

4.4 Case study analysis

4.4.1 Classroom U1 East with Single Horizontal Shading Device

4.4.1.1 Description of U1 East

Classroom U1, on the eastern facade of the U block, presents a room glazed and shaded to the east. The classroom has a total floor area of 54SQM and an equal ceiling, a 90SQM wall area and a total glazed area of 9SQM, which is 16.67% window to floor ratio and 10% window to total wall ratio. Since only one wall has grazing, it presents a 36% window to wall ratio on the specific eastern wall.

In addition, 1.8SQM of the window is exposed to direct sunlight at 9:00am, eastern sun, resulting in 20% exposure of the glazed part. Luminous recordings show that the working surface receives the highest illumination of up to 600 lux at 9:00am due to direct sunlight in parts of the classroom. However, this is not uniformly distributed on the entire working surface, with edges receiving as little as 100 lux, which contributes to glare in the space. Since direct sun light cannot be achieved on the entire working plane, avoiding venturing into sky lighting probably presents a better option. On the other hand, the air temperature increases through the morning hours to mid-afternoon at 3:00pm and takes a steady, stable curve at 26 degrees Celsius.

4.4.1.2 Finding from Classroom U1 East

The indoor air temperature graph on the recorded day of the year shows about 3 hours (12:30pm–3:30pm) are required for cooling in U-1 to achieve the upper comfort limit and not for heating. Using energy plus the energy output given to create a heat balance is attributed to this phenomenon. Important to note, 1.8SQM of the window is exposed to direct sunlight at 9:00am, eastern sun, resulting in 20% exposure of the glazed window, which must be contributing to this heat build-up in the early afternoon. (Figure 4-10, Table 5)

The light levels bar shows that the classroom requires supplementary lighting throughout the day, apart from 9:00am, when a portion of the class receives direct sunlight. However, this contributes to glare and heat build-up. Daylight Factors (DF) were calculated using the formula

EI/EO x 100% = DF

Where: E_I is illumination indoors and E_O is illumination at an unobstructed point outdoors, and the composition of DF is the summation of Sky light Component (SC), Externally Reflected light Component from adjacent facilities (ERC), and Internally Reflected light Component ERC.

DF = SC + ERC + IRC (Yuniarono, et al., 2020)

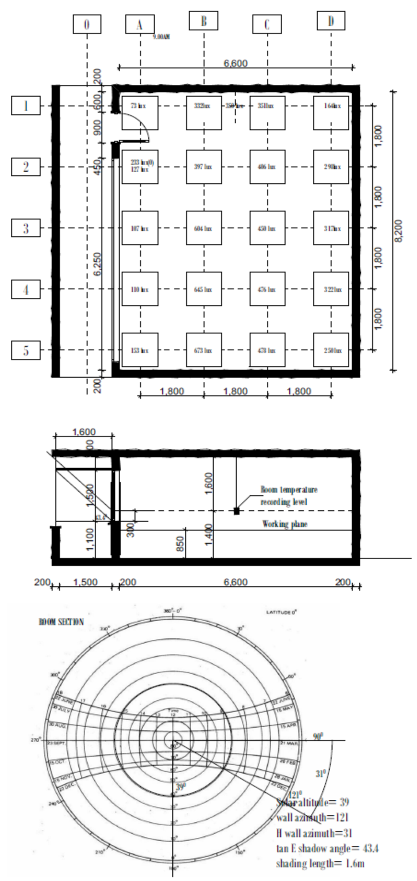
Table 5: Calculated DF from recorded lux levels in U classroom.

U BLOCK Lighting levels Classroom U 1 East							
08:00AM				11:30AM			
Point	Ei in lux	Eo in Lux	DF	P	Ei in lux	Eo in Lux	DF
A1	**73**	**3456**	**2.112**	**A1**	**76**	**3867**	**1.97**
A2	233	3456	**6.742**	A2	278	3867	**7.19**
A3	107	3456	**3.096**	A3	131	3867	**3.39**
A4	110	3456	**3.183**	A4	139	3867	**3.59**
A5	153	3456	**4.427**	A5	201	3867	**5.20**
B1	332	3456	**9.606**	B1	241	3867	**6.23**
B2	297	3456	**8.594**	B2	233	3867	**6.03**
B3	350	3456	**10.127**	B3	227	3867	**5.87**
B4	645	3456	**18.663**	B4	265	3867	**6.85**
B5	673	3456	**19.473**	B5	250	3867	**6.46**
C1	256	3456	**7.407**	C1	247	3867	**6.39**
C2	243	3456	**7.031**	C2	367	3867	**9.49**
C3	213	3456	**6.163**	C3	409	3867	**10.58**
C4	198	3456	**5.729**	C4	401	3867	**10.37**
C5	204	3456	**5.903**	C5	298	3867	**7.71**
D1	168	3456	**4.861**	D1	159	3867	**4.11**
D2	298	3456	**8.623**	D2	267	3867	**6.90**
D3	286	3456	**8.275**	D3	254	3867	**6.57**
D4	265	3456	**7.668**	D4	243	3867	**6.28**
D5	225	3456	**6.510**	D5	198	3867	**5.12**
Average			7.710				6.31

Source: Author

The average daily light factor calculated above is further used to set the parameters in simulation modelling and is repeated in all cases.

Figure 4-9: Illustration of lighting levels and room air temperature recorded in class U 1- U block between 7.00am and 6.00pm



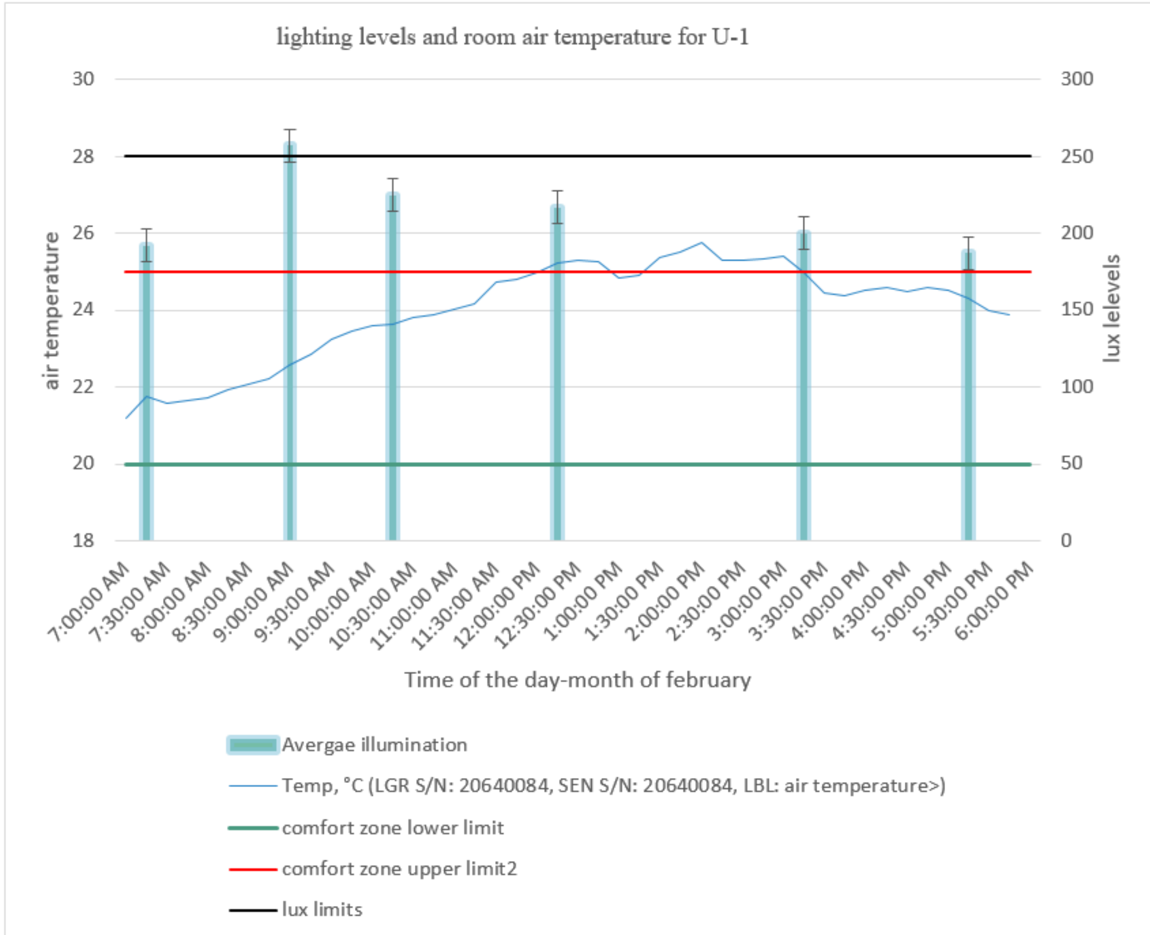


Figure 4-10: Lux and air temperature data recorded and plotted against the comfort limits

Source: Author 2021

Based on Equations 1 and 2 in the literature review, where HSA = AZI-ORIENTATION (eq.1) ORI=0/360, 90,180 OR 270, VSA= Arc tan (Tan altitude/cos HAS) (eq.2), and the window height is given as 1.5 (Figure 410), implying that the recommended shading depth (x) for this classroom, U, is 1.3 metres.

x=1.5/tan 45=1.5 (PROCEDURE)[6]

Given that the east façade should be considered for shading in the morning hours with the critical time at 9:00am on 22 December (UN-Habitat, 2014),

Where: Solar azimuth angle =45^0, wall azimuth=131^0, horizontal shadow angle component=31^0

And the vertical shadow angle component is equal to the arc tan of (tan/cos 31) = 49^0

The shading device provides a 1.6M depth, but it has an upward displacement (Figure 4-10) of 450 mm due to the beam depth, which exposes a ribbon of 300mm throughout the entire window, contributing direct sunlight at 9:00am. Over lighting is measured similarly at points B3-5 in (Table 5: Calculated DF from recorded lux levels in U classroom.)

Velux daylight simulation for a single fully shaded horizontal device in the same classroom shows evident glare on the same points, further providing evidence to continue adopting the simulation in other cases in the study (Figure 4-19).

[6] The following steps are used to calculate the appropriate size of the horizontal Sun shading devices

1. Determine what is the overheated period for the various facades, that is, the dates and times when shading a window on a given façade will experience the highest solar radiation. A west, south and north window experiences the highest radiation at 3:00pm while east facing window experience the highest radiation at 9:00am 2. Use the appropriate sun chart diagram (as suitable for the location Nairobi-1.2S hence use 0-degree chart) to obtain the azimuth and altitude of the sun at each time of the cut-off periods in 1 above. 3. Use the solar protractor determine the Vertical Angle for each facade. (HSA = AZI - ORIENTATION (eq.1) ORI=0/360, 90, 180 OR 270, VSA= Arc tan (Tan altitude/cos HAS) (eq.2) 4. Design the correct sized horizontal shading device to satisfy the performance specifications.

4.4.1.3 Parametric Analysis of U1 East Classroom

U1 Nominal- Shaded with Single Horizontal Device	U1 Not-shaded
	
Figure 4-11: Classroom U-1energy simulation graph as existing with shading device	Figure 4-12: Classroom U-1 energy simulation graph without shading

Simulated annual maximum temperature of 25.60 degrees Celsius. This is a reflection of the one-day upper limit recorded in the month of February (Figure 4-9**,** Figure 4-10). Lighting electricity is significantly high at above 32600Kw throughout the year.

The non-shaded model shows an increase in room air temperature to 28^{0}C and a reduction in lighting power to 32300kw to present a significant increase in cooling load from 3100kwh to 5750kwh as illustrated above (Figure 4-11**,** Figure 4-12). This statistic represents an 85% saving in cooling energy.

There is an increase in the total energy required to retain the room temperature within the thermal comfort zone. This is attributed to increased hours off the comfort range in a no shaded model above showing a substantial increase in cooling load energy. The exposed nature of the window increases solar heat gains.

4.4.2 Classroom U1 West with Single Horizontal Shading Device

4.4.2.1 Description of U2 Western Classroom

Classroom U2, on the western facade of the U block. It presents a room glazed with shade to the west. The classroom has a total floor area of 54SQM, a 90SQM wall area, and a total glazed area of 9SQM, which is 16.67% window to floor ratio and 10% window to total wall ratio. Since only one wall has grazing, it presents a 36% window to wall ratio on the specific eastern wall.

At 3:00pm, the room is most exposed to solar heat gain due to direct heating and sunlight. The temperature in the room rises steadily throughout the morning and afternoon, reaching 27.7 degrees Celsius at 6 p.m.

4.4.2.2 Finding from Classroom U2 West

The indoor air temperature graph shows over 5 hours (12:30pm-6:00pm) of recording period required cooling in U-2 on the recording day to suppress temperature levels to the least upper comfort. These account for over 50 more in time when cooling is required compared to U-1 in the east, despite the two cases adopting identical shading devices. Important to note, like U-1, U-2 has a 1.8SQM window that is exposed to direct sunlight at 3:00pm, Western sun, resulting in 20% exposure of the glazed window, which contributes to further heat build-up in the late afternoon.

The light levels bar shows that the classroom requires supplementary lighting throughout the morning up to 3:00pm. Therefore, the average illumination is above the limit, but the classroom receives direct sunlight after 3:00pm for over two hours. This greatly contributes to glare and heat build-up.

The configuration and a graphical presentation of recorded data for classroom U-2 against recommended comfort limits is illustrated below

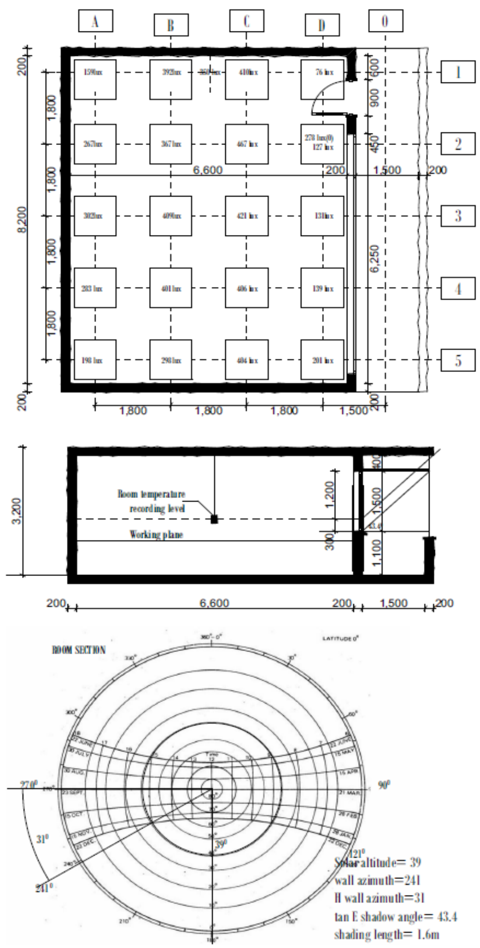


Figure 4-14: Configuration of classroom U-2, showing the position of recording device and the findings

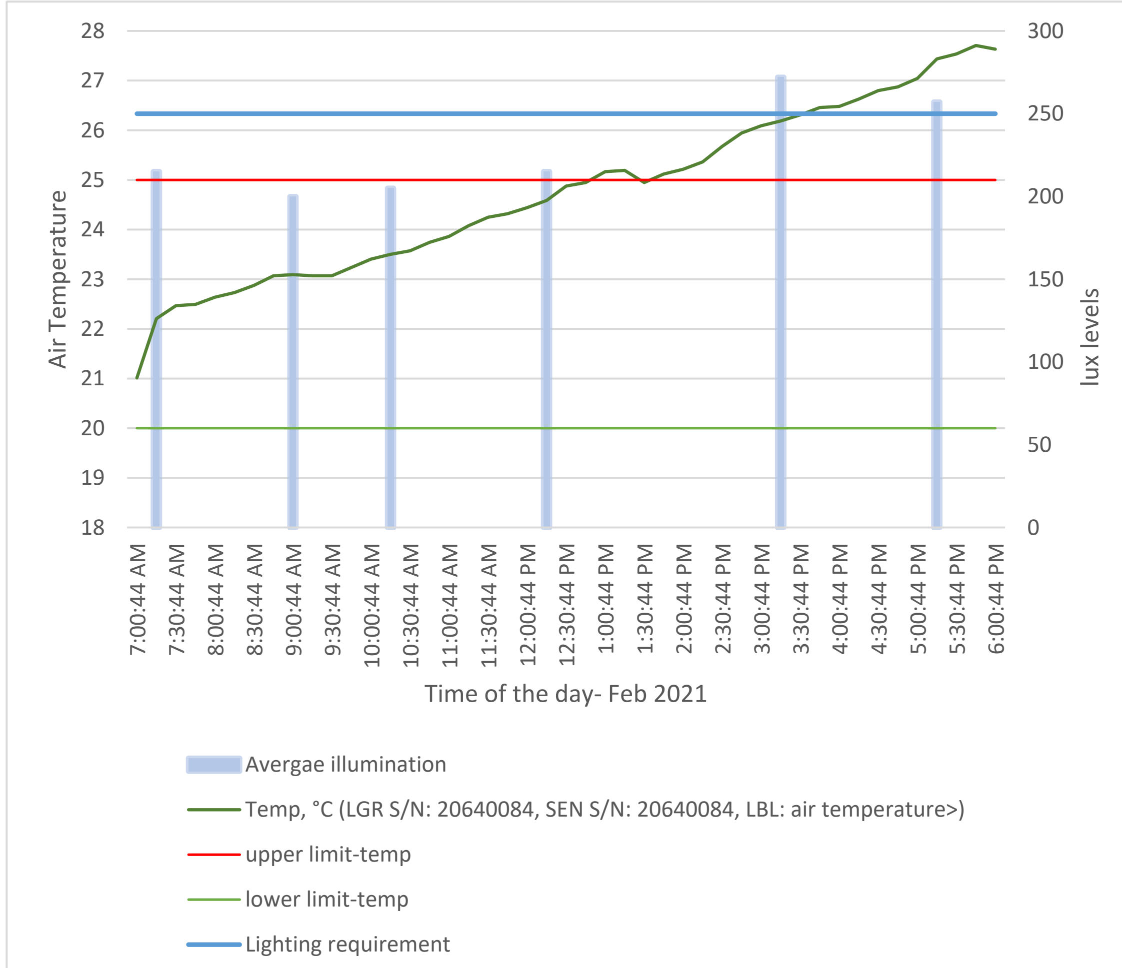


Figure 4-13: A graphical presentation of recorded data for classroom U-2 against recommended comfort limits

4.4.2.3 Parametric Analysis of U2 West Classroom

U1 Nominal- Shaded (West)

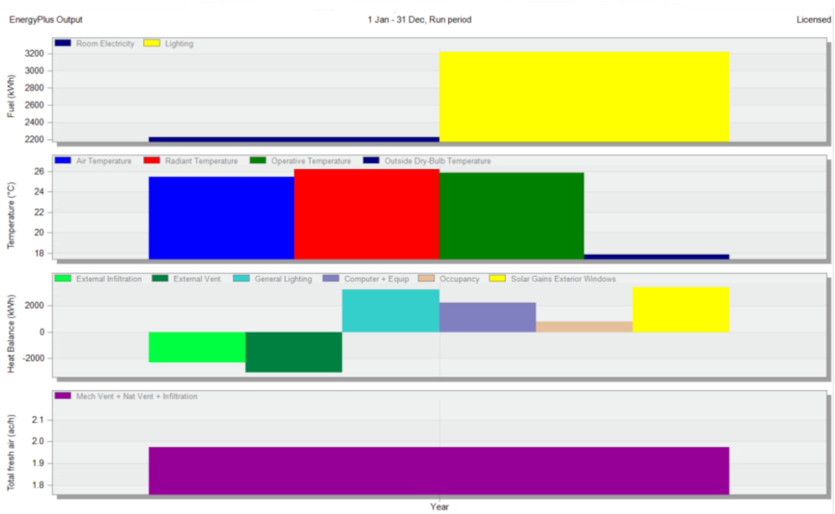


Figure 4-15:Classroom U-2 energy simulation graph as existing with shading device

U1 Not-shaded (West)

Figure 4-16:Classroom U-2energy simulation graph without shading device

There is a significant and notable change in cooling energy requirements to cover 3800Kwh for shaded windows as opposed to 6500Kwh in the non-shaded windows on the west façade (presenting a 71% energy saving). The overhangs have high potential for shading with outflanking effects. The solar heat gain presented in the graph above shows the advantage of using overhangs.

Comparing East and West, 85% against 71% energy saving, a shaded window in the east is potentially better than a western window regardless. However, it is worth noting that in the tropics, east or west windows are highly discouraged due to solar exposure.

Figure 417 and Figure 418 present an identical class as U-1 and U-2, oriented such that the window faces south. The cooling energy requirements read at 2550 Kwh for a shaded window as opposed to 4500Kwh in a non-shaded model, which contributes to 76%.

U-1’ Nominal- Shaded (South)	U-1’ Not-shaded (South)
 Figure 4-17:Classroom U-1' an arbitrary class U-1 energy simulation with shading similar to U-1 and U-2	 Figure 4-18:Classroom U-1' an arbitrary class U-1 energy simulation without shading similar to U-1 and U-2

Table 6: Illustration of the western window with the highest energy demand followed by the eastern one while southern window has the least demand.

Model Orientation		Cooling Demand	Lighting Demand	Comments
Model U-1 East	Shaded	3100kwh	*Equivalent of 36000*	Either shaded or not, a western window has the highest energy demand followed by the eastern one while southern window has the least demand. A south window has 154% energy shaving potential over western window. i.e. ((6500-2550)/2550*100) =154%
	No-shade	5750kwh	*Equivalent of 32000*	
Model U-2 West	Shaded	3800kwh	*Equivalent of 36000*	
	No-shade	6500kwh	*Equivalent of 32000*	
Model U-1” South	Shaded	2550kwh	*Equivalent of 36000*	
	No-shade	4500kwh	*Equivalent of 32000*	

4.4.3 Effect Modification on Horizontal Shading Devices in U block

Table 7: A comparative table illustrating the various modification on shading device with the resultant thermal and lighting environments

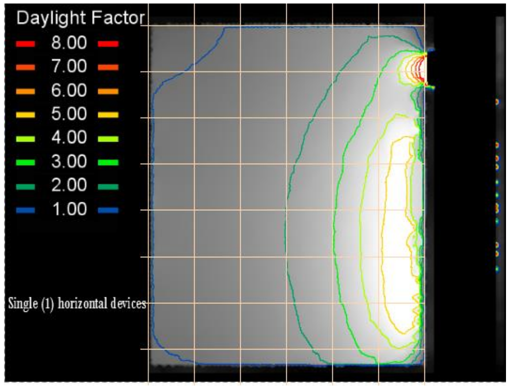


Figure 4-19: Velux daylight simulation for a single fully shading horizontal device

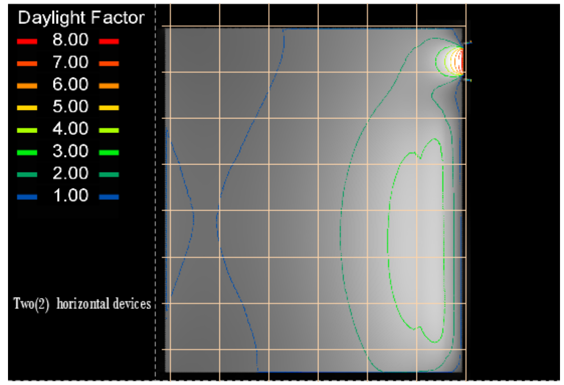


Figure 4-20:Velux Daylight Simulation for double horizontal Shading devices

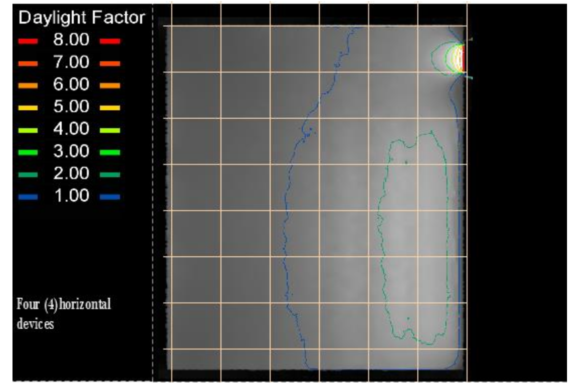


Figure 4-21: Velux Daylight Simulation for four horizontal Shading device

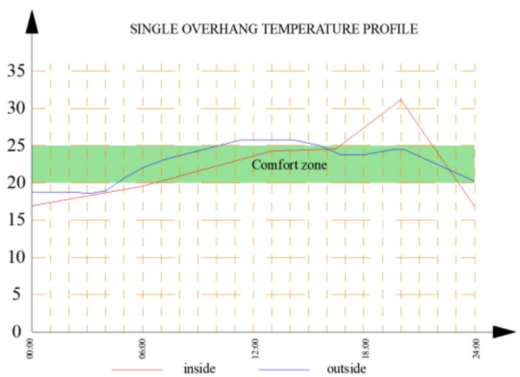


Figure 4-22: Air temperature graph for U1-single horizontal shading

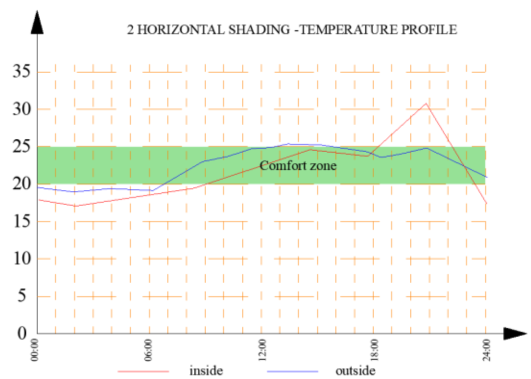


Figure 4-23: Air temperature for graph U1-double horizontal shading devices

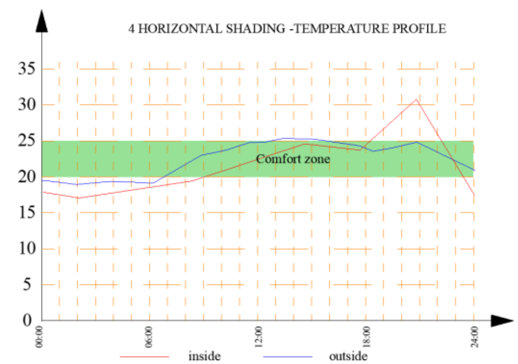


Figure 4-24: Air temperature for graph U1-4 horizontal shading

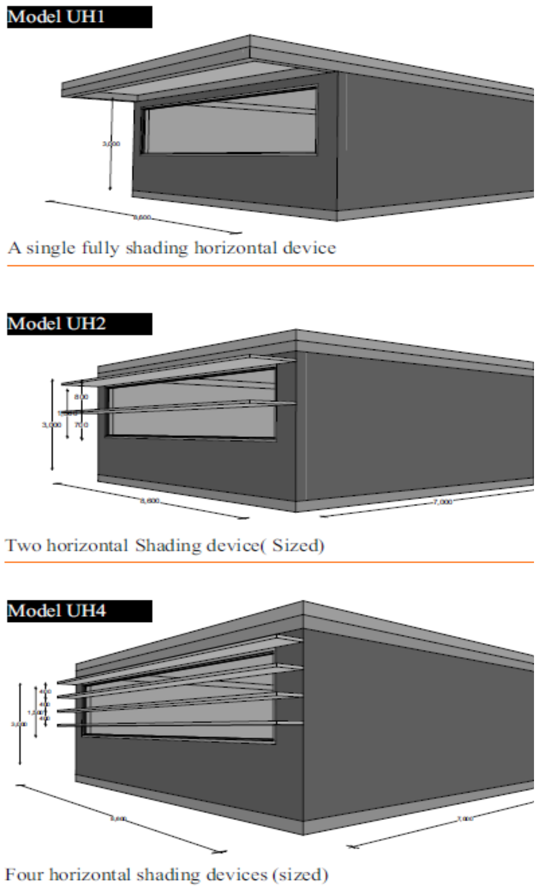


Figure 4-25: illustration of UH1-UH3 simulated in for optimum lighting

A single fixed horizontal overhang shading the entire glazed area in a west or east facade is as effective as double or four-sided overhangs on the same facades at shading the same size of a window.

UH1, consisting of a single horizontal shading device positioned on the upper edge of the window, presents eight contours in a span of 6.6 metres, which is the room depth. This is a daylight factor range of 0-8 within the space. The drastic change is an indication of low uniformity ratio and contribution to glare, as shown in Figure 4-19-Compromise on the quality of light despite admitting a high quantity of light.

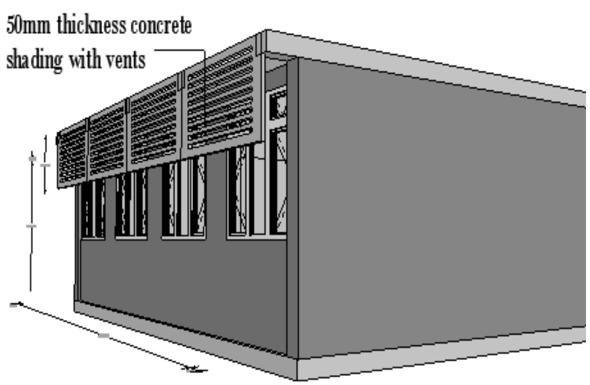
UH2, distinguished by two horizontal shading devices, admits less light than UH1, but projects it deeper into the room to achieve a better uniformity ratio and reduce glare. This can be attributed to the lower shading device which acts as a light shelf to enhance further light penetration despite less admission (Figure 4-20).

Model UH3, with 4 horizontal shading devices at equal intervals, presents the least amount of daylight admission as in Figure 4-21. It has the best uniformity ratio; however, this might be the least helpful due to the smallest number of admissions.

Considering that all the models are fully shaded and present identical thermal heat gain curves, **the best lighting design model will be the UH2.**

Therefore, when using horizontal shading devices, it is best to consider a window in the South or North. The device must be designed such that there are more than one to provide a light shelf and they are not less than 500mm apart to avoid blocking a substantial amount of daylight. That is, a ratio of 1:1 in UH1 showed evident glare while 1: 4 produced multiple shadows. The UH2 reflected a lot of light onto the ceiling, making it the most useful device size.

4.4.4 N block classrooms- Classroom N1 with Horizontal louvres



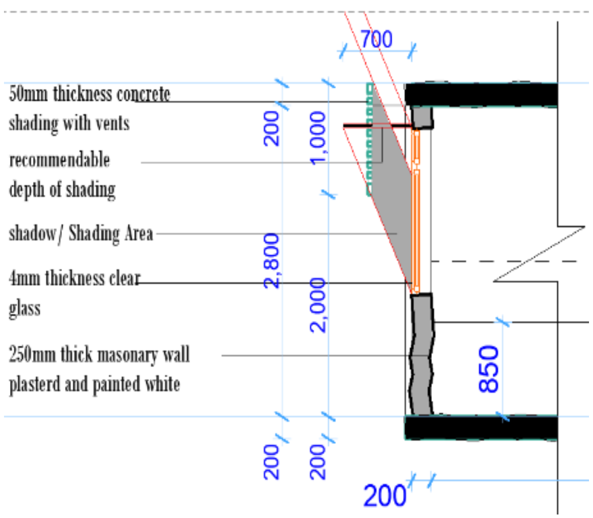


Figure 4-26: Descriptive drawings of classroom N1

4.4.4.1 Description of N1 Southern Classroom

Classroom N1, like U1 and U2, is a single-sided lit space. The window faces south in the N block. It presents a room with a glass roof and a shaded south-facing window. The classroom has a total floor area of 54SQM, a 90SQM wall area and a total glazed area of 9SQM, which is 16.67% window to floor ratio.

The shading is placed 450 mm away from the window with an upward deviation of the same, making the entire window shaded at the critical time, which is projected to be 3:00pm. This is the only identified case where the window is fully shaded.

4.4.4.2 Finding from Classroom N1 Classroom

The indoor air temperature graph shows over 3 hours (1:30pm-4:00pm) of recording period required cooling on the recording day of February to suppress temperature levels to the least upper comfort levels. This accounts for over 50% less time when cooling is required compared to U-2 on the west, despite the fact that this is the only classroom recording the highest number of occupants in the afternoon at 14 students between 2pm and 3:30pm.

It is important to note that, unlike U-1 and U-2, the window is not exposed to direct sunlight at any time of the day, with the most critical time being 3:00pm, covered by the western sun. The light levels bar shows that the classroom requires supplementary lighting throughout the day from 7am to 6pm (Figure 4-27, Figure 4-28).

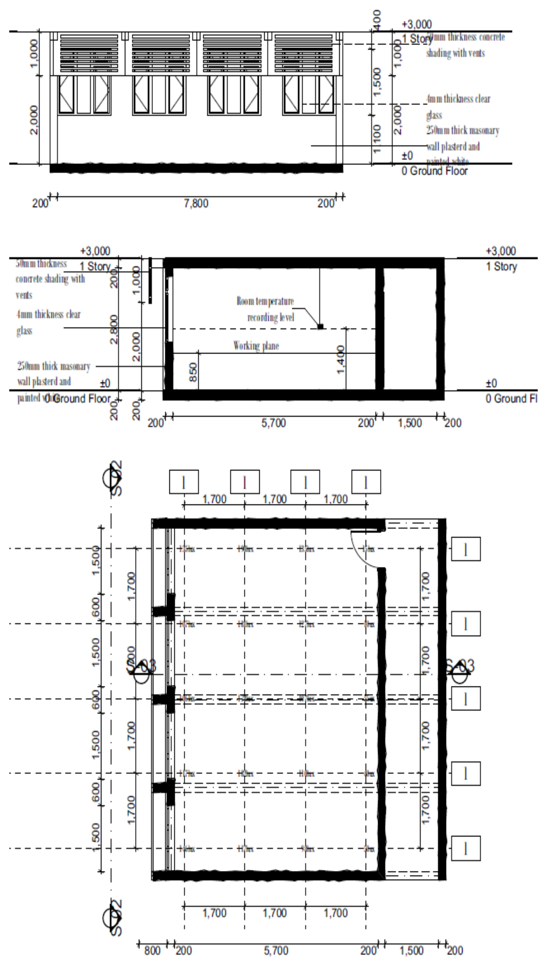


Figure 4-27: Configuration of classroom N-1, showing the position of recording device and the findings

Figure 4-28:A graphical presentation of recorded data for classroom N-1 against recommended comfort limits

4.4.4.3 Parametric Analysis of N1

A high-performance shading device will generally reduce cooling loads without negatively impacting the admission of daylight. The effectiveness of the shading in N1 can be defined from first principle by simulating the same class without the shading. The findings are presented in Figure 4-29 **and** Figure 4-30**,** where the absence of shading presents a reduction in general lighting and a significant increase in solar gains. For example, the shaded model has a 3500Kwh solar gain exterior window, whereas the no-shading model has a 15% increase in gains to 4500kwh.

Table 8: Comparative analysis of N1 shaded and N1' not shaded

<table>
<tr><td>N1 Nominal- Shaded (Louvered North/South)</td><td>N1 Not-shaded (north/South)</td></tr>
<tr><td>

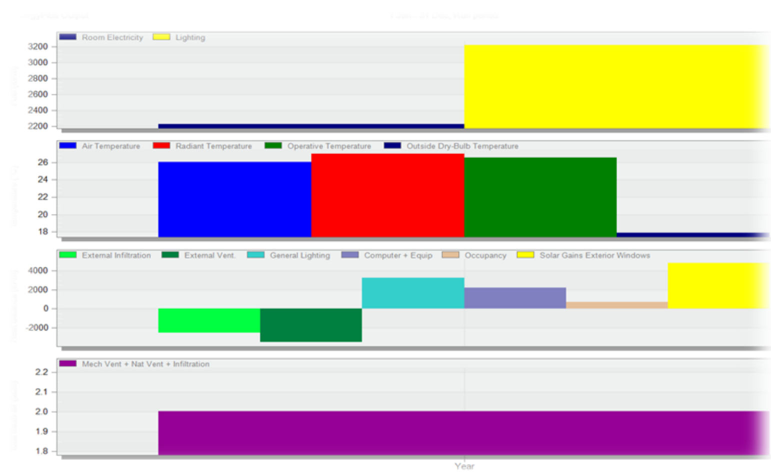

Figure 4-29:Classroom N-1 energy simulation graph as existing with shading device</td><td>


Figure 4-30:Classroom N-1 energy simulation graph without shading device</td></tr>
</table>

Source: Author, 2021

In this case, lower solar radiation levels have a proportionate advantage in the decline of the thermal loads in the classroom that would otherwise be resolved by mechanical ventilation systems, as an outcome of the heat energy transmission through the exposed glazed window portion. This is especially important in the months of January and February. Although the reduction of solar radiation in the month of July has the opposite effect, it should be noted that energy savings from air-conditioning systems would be positive in corrective terms as simulated in the annual reports (Figure 4-29), especially when considering forthcoming prospects of rising global temperatures due to happening climate change.

4.4.5 Analysis of Eggcrate Shading in C block classroom

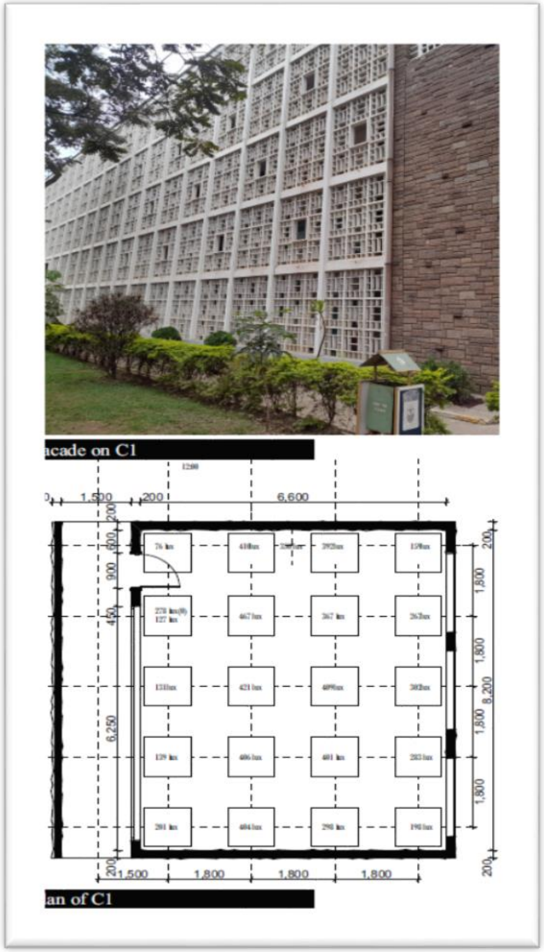


Figure 4-31: Configuration of classroom C1

4.4.5.1 Description of C BLOCK Classroom

Classroom C1, like U1, U2, and N1, is within the length with an 8:10 ratio. I measures 6.6 by 8.2 metres. Its windows face north, towards a veranda that is fully shaded using Eggcrate devices. Unlike the classroom, it has a ribbon window on the southern façade. The class has a total floor area of 54SQM, a 90SQM wall area and a total glazed area of 12SQM, which is 22.67% window to floor ratio.

The shading is placed 1500 mm away from the window, making the entire window shaded at the critical time, which is projected to be 3:00pm. The space between the window and shading forms a critical transitional space.

(Figure 4-31: Configuration of classroom C1)

4.4.5.2 Finding from Classroom C1 Classroom

The indoor air temperature graph shows less than an hour's (4:30pm-5:30pm) of recording period required cooling on the recording day to suppress temperature levels to the least upper comfort levels. These account for the least time when cooling is required compared to U1 3 hours, U2, 5 hours, and N1 3 hours. It is important to note that, unlike U-1 and U-2, the window is not exposed to direct sunlight at any time of the day, with the most critical time, 3:00pm, covered by the north-western sun. The light levels bar shows that the classroom requires supplementary lighting only past 6pm.

Figure 4-32: Graphical illustration of indoor thermal and lighting environments in Classroom C1

The eggcrate shading devices are the most effective of all the shading devices studied in supressing air temperatures within the comfort zone. Coincidentally, it has the best light levels recorded. (Figure 4-32)

This is most appropriate by

1. The concrete lattice design avoids most of the direct solar radiation but at the same time enhancing more diffused light, due to the numerous specular reflections that take place in its structure. This improving on the uniformity of indoor illumination levels. However, it is also important to note that this classroom has the highest window to wall ratio at 22% compared to 16% in another classroom.

2. The adoption of this type of shading element decreases glare, contributing to a lessening in the use of single blocks of light entering a space.

4.4.5.3 Comparative Analysis on sizing and Modification of Egg crate shading

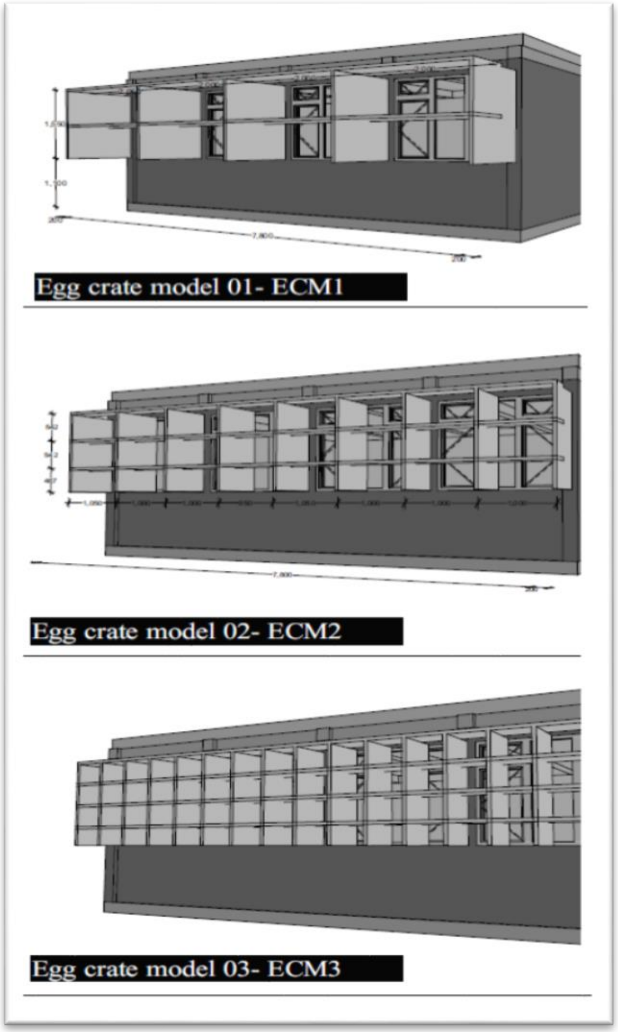


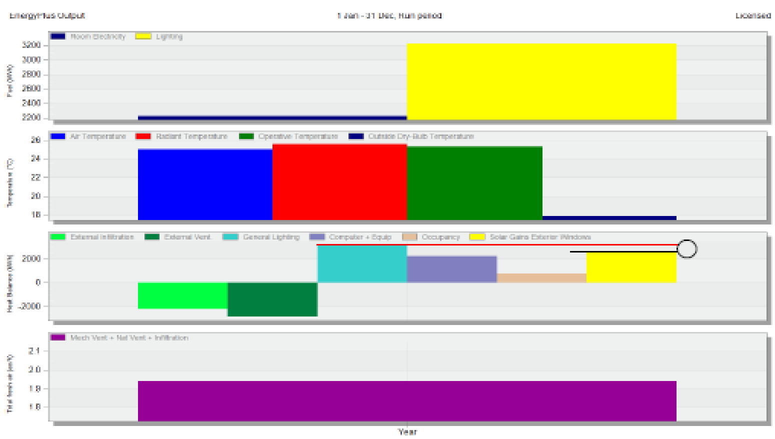
Figure 4-33Variance of modification simulated for effectiveness

The modification is carried out such that there is a proportionate increase in the number of shading devices. I.e., 1:2:3:4. For every increase in the number of shades, the depth reduces based on HVA and VSA for vertical and horizontal sizing of the devices.

Figure 4-34: Energy simulation graph for ECM1 model

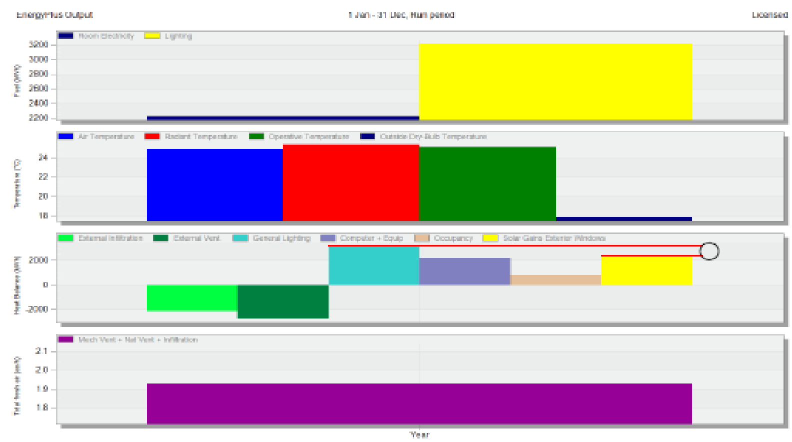
ECM1, an egg crate model comprised of 2:2, horizontal to vertical devices, exhibits a heat balance due to general lighting and solar heat gain in the same range, while also keeping air temperatures within the comfort limit Figure 4-33 ECM2 with a ratio 3:3 presents a decrease in energy demand due to solar heat gain with an increase in general lighting. The phenomenon explodes even more in ECM3 with a 4:4 ratio.

Table 9: Energy simulation models on ECM02 and ECM03



Egg crate model 02- ECM2

Figure 4-35:illustration in graph of energy simulation for models ECM2



Egg crate model 03- ECM3

Figure 4-36:illustration in graph of energy simulation for models ECM3

Table 10: Daylight factor graph for a Combined HSA and Single VSA device

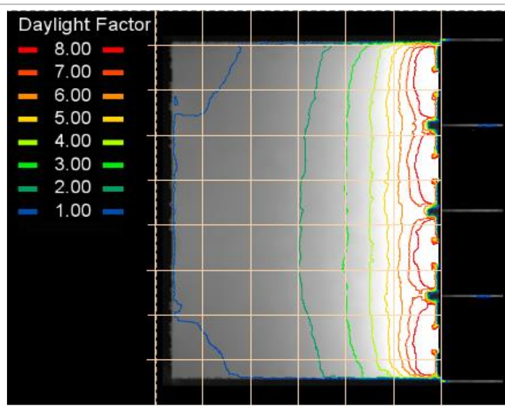


Figure 4-37: Daylight factor graph for a Combined single HSA and Single VSA device

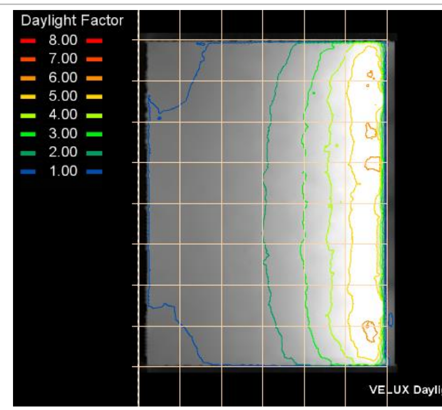


Figure 4-38: Daylight factor graph for Combined two HSA and Two VSA device

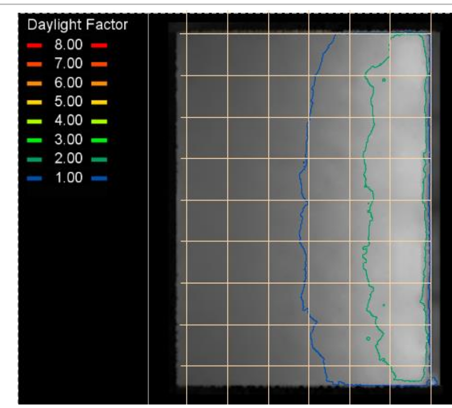


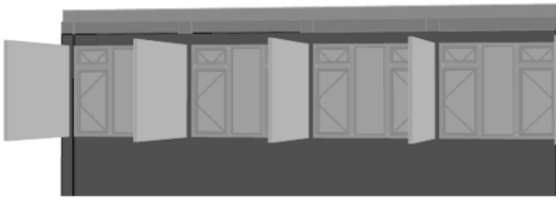
Figure 4-39: Daylight factor graph for Combined four HSA and four VSA device

More light is not always better; the superiority of light quality, which is defined by the uniformity ratio and the absence of glare, is equally important.ECM1 has the maximum admission of light of the 3 models (Figure 4-37**)**

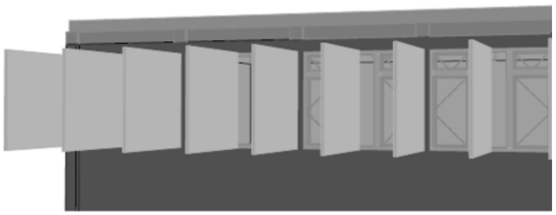
ECM2 has the best quality of light compared to the other two models. It presents a shading system that reduces glare and excess contrast on the work plane. It has high potential to reduce solar heat gain and electric lighting demand compared to ECM1 and ECM3.

The use of the egg-crate shading device has been confirmed to decrease yearly electrical lighting from 3300kwh to 3000kwh in consumption, which by approximation is about 10%. Furthermore, in terms of carbon dioxide emissions, this is a savings. According to a study conducted in a hospital environment in Spain, by Rodrigues and friends proper shading represents an equivalent of approximately 12.98kgCO2/kWh of electric energy generated.

(Leion-Rodrigues, et al., 2018)



Two vertical device on 1.5m width window



Three vertical device on 1.5m width window(spacing at 750 centre to centre

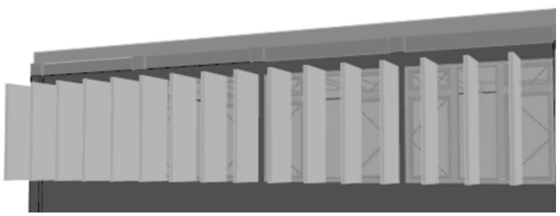


Figure 4-40: illustration of simulated models with different spacing and size of vertical shading devices

4.4.6 Analysis Vertical shading analysis

From the literature, it requires a shading device of at least 2.7m [7] in depth to fully shade a 1.5m height window with a horizontal shadow angle of 29^0 on the west façade. The modification in this case is carried out such that the HAS is maintained at 29^0

Where,

The solar azimuth angle =39^0

Wall azimuth angle=241^0

Horizontal shadow angle component=29^0

Vertical shadow angle= arc tan (tan 39/cos 29) =43^0.

(UN-Habitat, 2014)

Preliminary simulation studies at 0 degrees (vertical device on target to the window) indicate that vertical shading reduces visual performance due to glare when compared to horizontal devices previously studied, An increase in the angle to 30 degrees, but

[7] The following steps are helpful to determine the most appropriate size of the vertical shading devices for as glazed window in Nairobi- latitude 1.2 degree south

1. Determine the overheated period for the various facades, that is, the dates and times when shading a window on a given façade will experience the highest solar radiation. A west, South and North window experiences the highest radiation at 3:00pm while east facing window experience the highest radiation at 9:00am
2. Use the recommendable sun path chart, (suitable for the location Nairobi-1.2S hence use 0-degree chart) obtain the sun azimuth and altitude of the sun at each critical time of the cut-off periods in 1 above.

maintaining the HSA has a reducing effect on the depth of the shading with increased thermal performance. However, there is increased loss in harvesting of beneficial daylight.

To be more specific, a vertical device at 0 degrees will most likely be oriented at 90 degrees to air movement currents, reducing the convective cooling on the surface of the shading. Some of the heat radiated by the shading device may find itself in space, contributing to heat build-up. Increasing the number of shading devices by reducing the depth of each element creates multiple areas of glare as opposed to fewer but longer devices which render an over lit space.

Table 11: annual energy reports for various modification on vertical fines

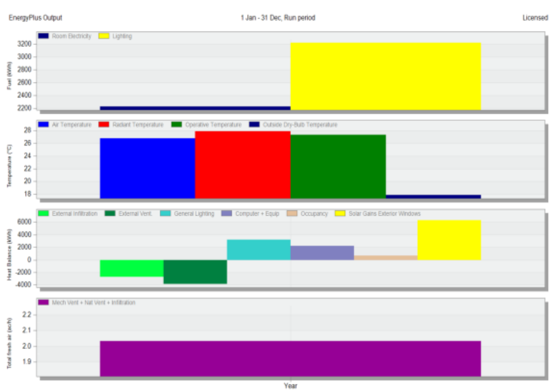


Figure 4-41:Two(2) Vertical Fins on either end of the window annual energy report

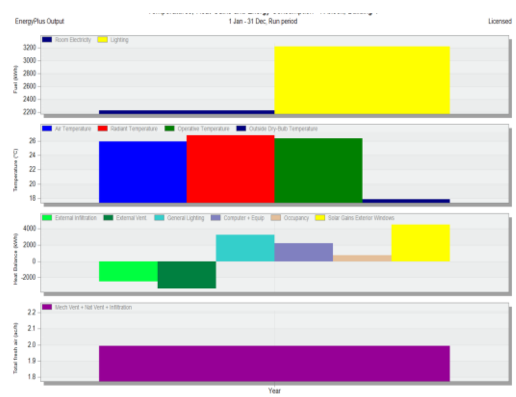


Figure 4-42: Three vertical devices/Vertical Fins on either end and at the centre of the window annual energy report

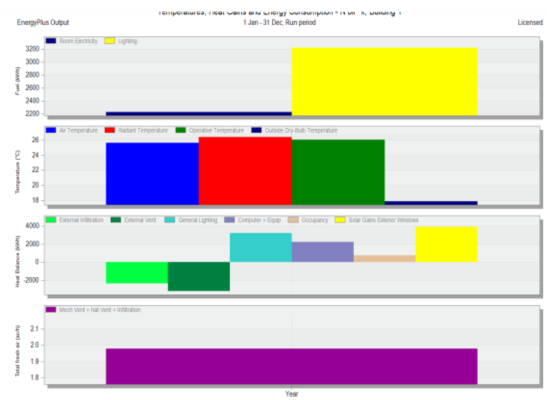


Figure 4-43: Four vertical fins on either end and two at the centre of the window annual energy report

Source Author, 2021

3. Use the standard solar protractor determine the Horizontal Shadow Angle for each facade. Alternative, use the established equations 1 below.
4. HSA = AZI - ORIENTATION (eq.1) ORI=0/360,90,180 OR 270
5. Calculate and design the actual vertical sun shading device to meet the window performance specifications foe indoor comfort.

Table 12: A table illustrating the various result on lighting and room air temperature on various modified model

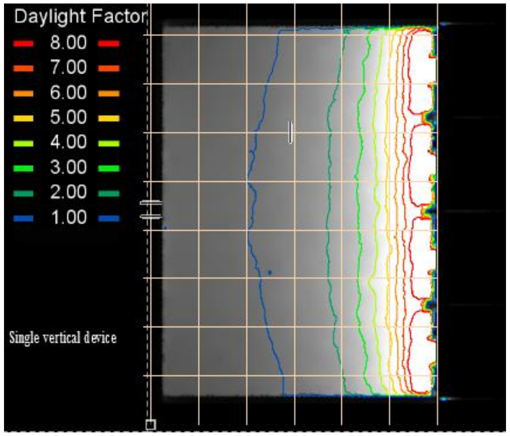


Figure 4-44: Effect of two vertical Shading on daylight distribution in a Classroom.

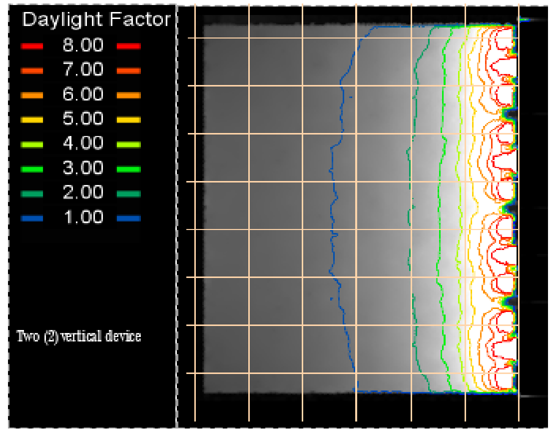


Figure 4-45: Effect of Three vertical Shading on daylight distribution in a Classroom.

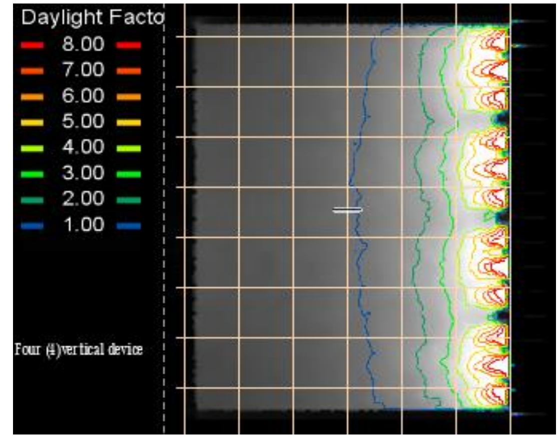


Figure 4-46: Effect of four vertical Shading on daylight distribution in a Classroom.

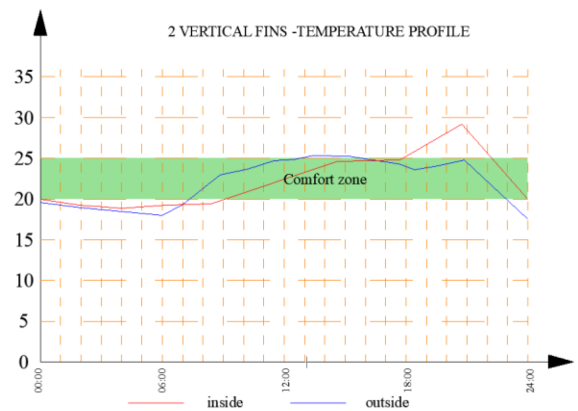


Figure 4-47: Two(2) Vertical Fins on either end of the window, Temperature profile during Hottest Day Peak

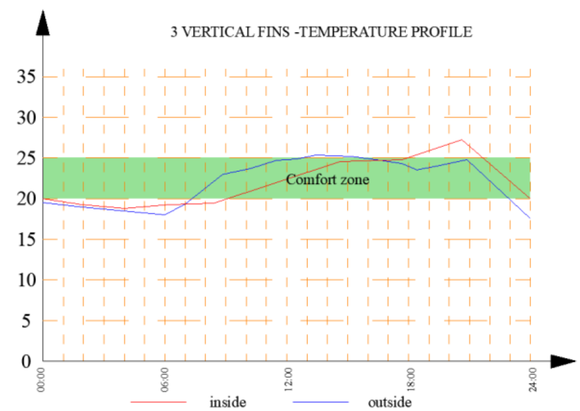


Figure 4-48:Three equally spaced Vertical Fins Model, Temperature Profile During Hottest Day Peak

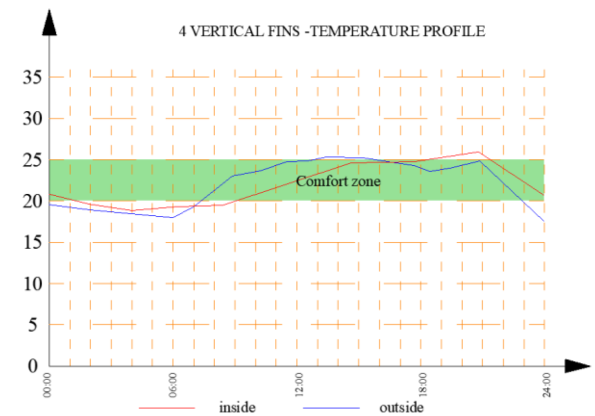
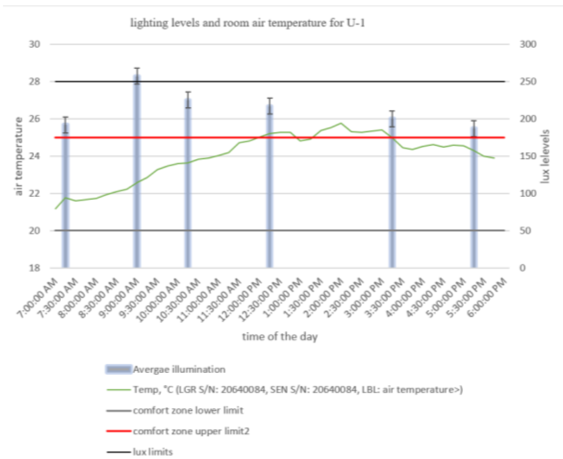
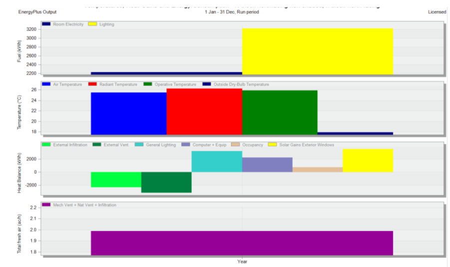
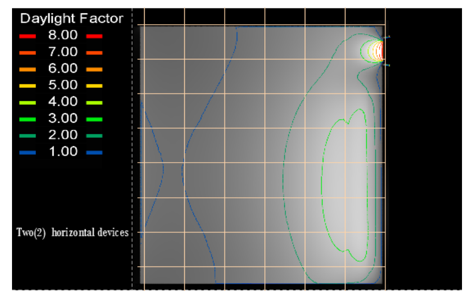


Figure 4-49: Four Equally Spaced Vertical Fins Model, Temperature Profile During Hottest Day Peak

4.5 Comparative Analysis of various type of Shading.

Table 13: Summary on the Effectiveness of shading Devices in the case studies at the Technical University of Kenya

Type of shading	Effectiveness in Thermal Control and daylighting	Simulated output on Modification of horizontal shading	Comments on potentiality
1. Single horizontal device (East).  Figure 4-50: Existing thermal and lighting conditions in U1 with Single horizontal Shading	The indoor air temperature is displayed 3 hours (12:30pm–3:30pm) are required for cooling in U-1 to achieve the upper comfort limit. The classroom requires supplementary lighting throughout the day, apart from 9:00am, when a portion of the class receives direct sunlight. However, this contributes to glare.	  Figure 4-51: optimisation of horizontal shading for least energy consumption simulated	Introducing a light shelf would help in increasing the amount of light penetrating into the space, as was tested with models UH1, UH2 and UH3.

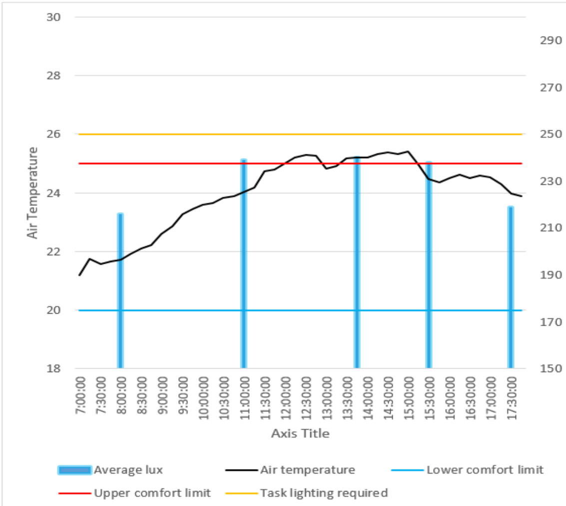
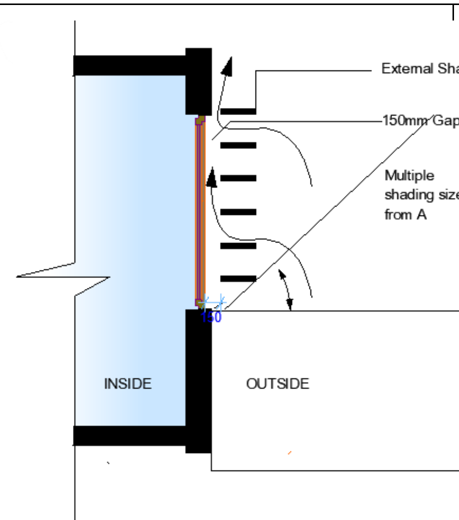
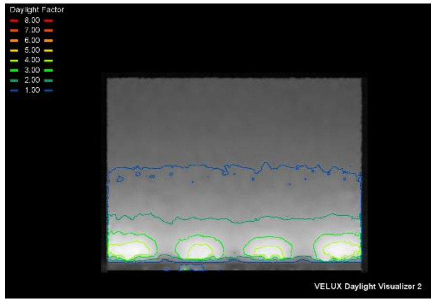
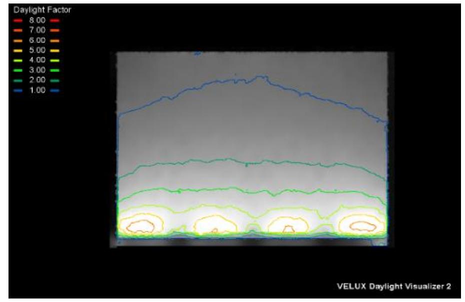
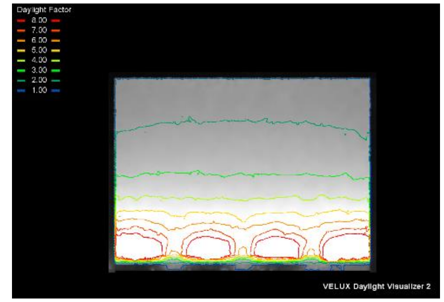
<table>
<tr>
<td>2. Horizontal Vented concrete shading.

</td>
<td>Indoor air temperature shows 3 hours (1:30pm-4:00pm) are required for cooling to achieve the upper comfort limit, but this classroom recorded 14 occupants between 2pm and 3:30pm during the recording time. The occupants might have influenced the recording as the lights were put on and the anthropogenic heat contributed to high recording as well.</td>
<td>

Figure 4-52: Modification for convective cooling to optimize cooling used in simulation</td>
<td>Air flow though the shading system helps in getting rid of trapped heated air through convective cooling.</td>
</tr>
<tr>
<td>3. Egg crates in form of perforated concrete blocks.

</td>
<td>Indoor air temperature records the least time of overheating due to delayed heat transfer (less than one hour) compared to aluminium, wherein indoor air temperature increases shortly after exposure of the shading to the sun and reduces drastically on non-exposure.</td>
<td>The light levels bar shows that the classroom requires supplementary lighting between 7-8am and after 5 pm, while the case aluminum shading shows that the classroom does not require supplementary lighting until past 6pm.</td>
<td>The egg crate lattice avoids most of the direct solar radiation while enhancing multiple specular reflections, hence improving the uniformity of indoor illumination levels.</td>
</tr>
</table>

4.5.1 Effect of Modification on Shading Devices (Material properties)

Table 14: Effective of material reflectivity on N1 shading device- As Existing.

Material	Reflectivity at 25%	Reflectivity at 50%	Reflectivity at 75%
 Figure 4-53: Existing facade on N1	 Figure 4-54: Daylight factor contour graph at 25% reflectivity	 Figure 4-55:Daylight factor contour graph at 50% reflectivity	 Figure 4-56:Daylight factor contour graph at 75% reflectivity

The reflectivity of a shading device on light has a direct influence on light quality. The higher the reflection, the more light is directed into the space. Over reflection contributes to glare, especially if the penetration is not deep inside a space. (Compare Figure 4-54**,** Figure 4-55**,** Figure 4-56**)** Where 25% reflectivity is present, the darkest space in over half of the classroom receives a daylight factor of less than 1, on a scale of 1 to 8.

The reflectivity of a shading device is greatly influenced by the material used and the colour properties. Light and shading materials are mutually reliant on on each other. Materials, surface reflection, absorption and transmission potentials are important to understanding after incident light properties in architecture for they directly affect the direction, quantity and the quality of the light. Studied simulation give emphasis on two qualities of sun shading materials, their surface finish and their colour, to drive the argument discussed in this regard.

Specular materials, such as glossy finishes, reflect light as a mirror does, which can result in reflected images of the light source being visible on the surface of shading device will lead to glare in space. Matte surfaces, such as natural stone, wood, and plaster, reflect light diffusely and equally in all directions, creating a relative light uniformity in a space.

Colour Hue, its value, and intensity determines how plentiful light is absorbed and what quantity is reflected. A bright white wall reflects nearly 82% of its incidental light while a light-yellow wall surface range in about 78%, and a shady green or dark blue wall has about 7%. Coloured surfaces advance some of their own hue to light that is reflected from them.

Table 15: reflectivity properties of common materials and colours

Reflectivity	Materials in the limit
0-25 %	Concrete finish, dark plaster, red bricks, oak timber
25-50%	Sand stone finish, medium grey plaster, granite, plywood,
50-75%	Nickel, light yellow plaster, mantle, marble, enamel, Aluminium
75% and above	Polished aluminium, silvered mirror, mirrors, pure white, chrome, white plaster

A change in the materials of a shading device can alter the level of illumination in the space. The cheapest way to enhance the amount of light in a gloomy room from a shading device's point is to coat the internal surfaces bright.

Table 16: Effective of material reflectivity on Horizontal shading device From Model UH2

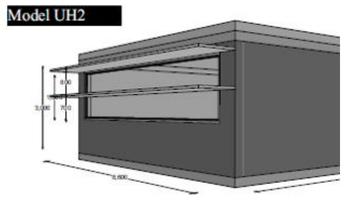
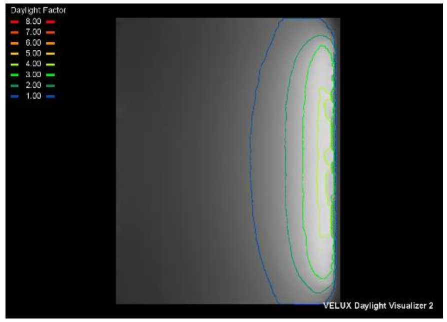
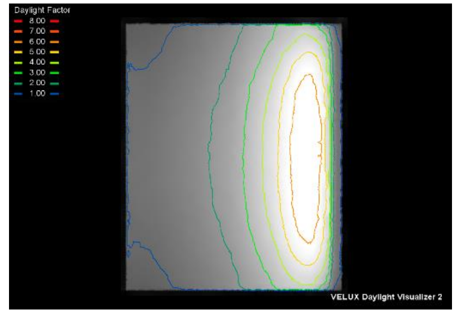
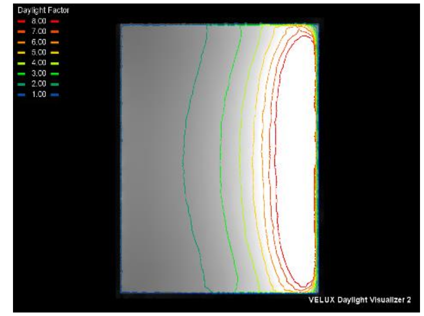
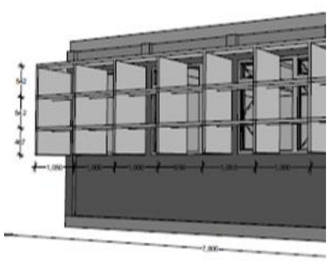
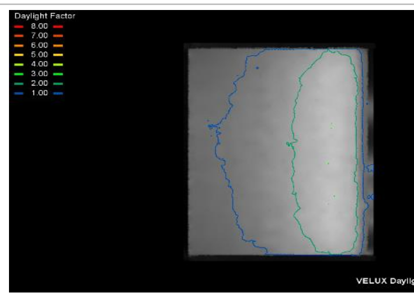
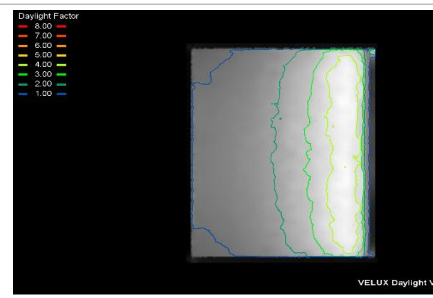
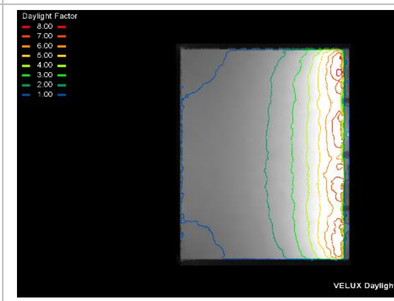
Material	Reflectivity at 25%	Reflectivity at 50%	Reflectivity at 75%
Two horizontal devices-Model UH2)  Two horizontal Shading device(Sized)	 Figure 4-57: Daylight factor map on UH2 at 25 % reflectivity	 Figure 4-58:Daylight factor map on UH2 at 50 % reflectivity	 Figure 4-59Daylight factor map on UH2 at 75 % reflectivity

Table 17: Effective of material reflectivity on Eggcrate device From Model ECM2

Material	Reflectivity at 25%	Reflectivity at 50%	Reflectivity at 75%
 Egg crate model 02- ECM2	 Figure 4-60:Daylight factor map on ECM2 at 25 % reflectivity	 Figure 4-61:Daylight factor map on ECM2 at 50 % reflectivity	 Figure 4-62:Daylight factor map on ECM2 at 75 % reflectivity

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This section of the study gives suggestions on ways to improve in these cases or for new projects. The section focuses on recommendations that should be adopted while designing shading for learning in the built environment.

5.2 Conclusions from literature review

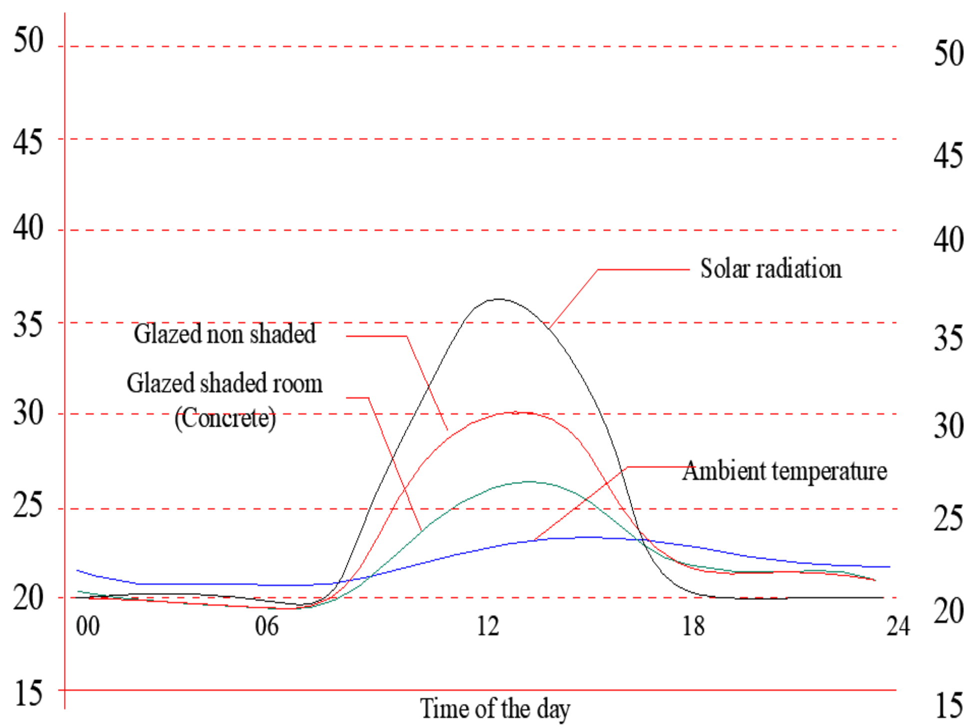


Figure 5-1: Temperature profile for shaded and non-shaded room

Source: velux Group https://www.velux.com/what-we-do/research-and-knowledge/deic-basic-book/thermal-comfort/thermal-comfort-with-roof-windows-and-solar-shading

Studied literature generally classified External Shading devices into three:

1. Egg crate/ Horizontal and vertical shading
2. Vertical Shading
3. Horizontal shading

In Nairobi, overhangs, louvers, vertical fins and egg crates should be encouraged as architectural elements to protect building envelopes and occupants from solar radiation in classrooms.

Further, a building surface exposed to the sun admits heat leading to a surge in the primary amount of energy needed for thermal cooling purposes. To avoid such heat gains, be it direct solar or indirect, the facade on which the sun's beams fall must be protected

(Shaded). Emphasis must be given to external shading devices mentioned above.

Glazed, non-shaded windows are the main building components that allow the highest penetration of incoming solar heat, consequently escalate the risk of indoor overheating (Schittich, et al., 2001). In this regard, shading must appropriately directed towards glazed parts of classrooms

A shading with a high Solar Heat Gain Co-efficient (SHGC) grade is more operative at collecting solar heat, while a design product with a less SHGC rating is effective at decreasing cooling loads during the summertime by blocking heat gain from the sun. On the other hand, a material with high reflectivity of light will direct more light into a space. It is likely to aid in deep penetration and may as well contribute to glare. The orientation, geometry, and material of external shading help determine the ideal SHGC for a particular glazing on a wall in admitting heat and light into a space.

External shading systems must be designed with a gap between them and the walling component on the main façade. In such a case, heat loss and dissipation may be affected by air flow. Air flow through the shading system helps in getting rid of trapped heated air. e.g., perforated overhangs that enable smooth air flow and reduce heat gain by contact walls. Therefore, the shading system should be spaced from the main enclosing envelope or fenestration to allow air flow for cooling.

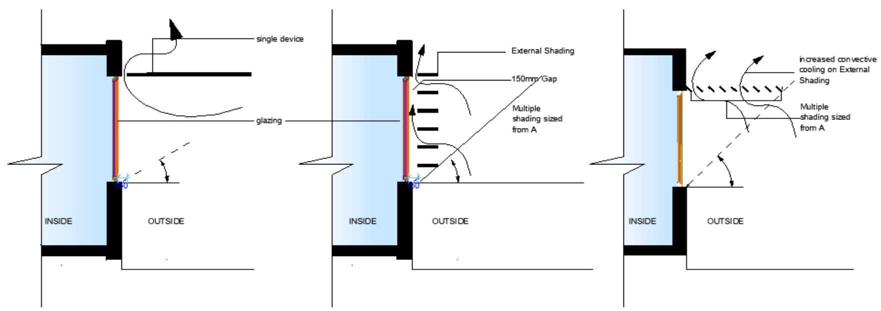


Figure 5-2: Illustration of convective cooling on shading devices by creating gaps to enhance air flow and minimise trapping warm air on the glazed surface Source: Author Modified 2021. Retrieved from UN habitant 2014

Shading must not only concentrate on the prevention of heat gains but also daylighting. Quantitative and qualitative daylighting need increased understanding of the causes and effects of shading device design and daylight transmission (Stefan, 2010).

Eggcrate shading presents the best performance in controlling solar heat gains, preceded by horizontal and then vertical. Longer shading projection is required for a longer window, while a vertical window with a bigger height can never be satisfactorily shaded by a horizontal device.

The orientation of a window relative to the sun path should be used to define the size of a shading element for that specific window. An effective horizontal shading device should take into consideration the vertical shadow angle and vice versa. The designers have the freedom to further size a device into smaller segments as long as the HAS and VSA are maintained for each piece relative to the window being shaded (Figure 5-2, Figure 5-3). A single fixed horizontal overhang shading the entire glazed area in a west or east facade, for example, is very effective at shading the same amount as four sized overhangs on the same facades, but the sizing into segments has a high to low impact on the lighting levels in a room.

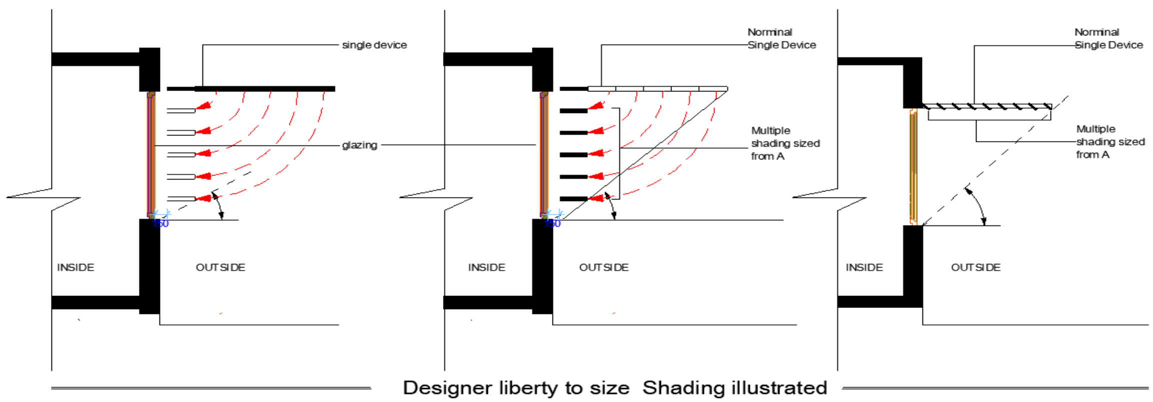


Figure 5-3: Illustration of shadow angles and the designer's liberty to size shading in the form making process

Author Modified 2021. Retrieved from UN habitant 2014

Shading proficiency is significantly dependent on window geometry: longer, horizontal windows on northern façades that are satisfactorily shaded by small depth egg crates perform better than similar windows facing south, east, and west, which rank last with the highest depth. Therefore, shading effectiveness gradually reduces with increase in the window azimuth angle from the north or south in Nairobi's tropical climate.

5.3 Conclusions from case studies

5.3.1 Types of shading Devices

Selected shading devices at the Technical University of Kenya can be broadly classified into three: horizontal shading devices, eggcrate, and horizontal devices are further classified as:

1. Single horizontal device informs of balcony. (Figure 5-4)
2. Louvered concrete shading. (Figure 5-5)
3. Louvered Aluminium shading. (Figure 5-6)

Table 18: types of shading devices identified in the case study area

			
Figure 5-4: horizontal shading on U block: Source: author	Figure 5-5:horizontal vented concrete shading on N block: Source: author	Figure 5-6:Aluminium louvers shading on F block	Figure 5-7: Eggcrate shading on C block: Source: Author 2021

Source: Author 2021

The case study presented one form of Eggcrate shading

1. Perforated concrete blocks. (Figure 5-7)

5.3.2 Effectiveness of shading Devices in the case studies

5.3.2.1 Single horizontal shading on U1, U2

Horizontal shading devices on the north facade are more effective than on the south, east, and west façades. The northern facade presented the least number of hours outside the comfort zone and the least sizing as well, which attracted less cost. I.e., to completely shade a 1.5m high window on the northern façade, one requires a depth of 0.6m as opposed to 1.3m and 1.6m on the east and west façades, respectively. The western façade attracted the longest shading device (representing the highest cost) and the greatest number of hours outside the comfort zone. Southern shading performed better than the east, which rated slightly better than the west, but a bit poorer compared to the north.

5.3.2.2 Comparison between Concrete and Louvered aluminium horizontal shading on N1, N2

Classrooms with aluminium shading recorded high lux levels compared to concrete shading. However, they heated more dramatically. Concrete shading provided a longer time lag and delayed heat build-up in the spaces. However, the heat build-up was realized late in the afternoon, especially in the western classrooms.

Aluminium is known for having high reflectivity than concrete, which is explained by its shiny appearance. Since the reflectance of light by aluminium is high, a lot of light is directed into the spaces, making the classroom well lit. In addition, aluminium has high lattice vibrations and excites electrons to higher energy levels. When heated for a longer time, it contributes to a drastic heat build-up in the space. When using aluminium as a shading device, it should be used as narrow plates to allow for convective cooling.

5.3.2.3 Effectiveness of Egg crate shading on C block

Egg crate shading devices are the most effective devices for suppressing air temperatures within the comfort zone. Coincidentally, it has the best diffused light compared to classrooms U1, U2, N1, N2 U block and N block, respectively.

Although throughout the research there was no clear performance pattern, energy plus and velux daylight visualizer confirmed that the average interior illuminance intensities due to natural illumination are greater in the area with egg-crate devices. This is most appropriate for two reasons:

1. The lattice in eggcrate eludes most of the direct heat, while improving diffused light thanks to the many specular reflections that dominates in its structure. As a result eggcrate improve the uniformity ratio of indoor illuminance levels;
2. The use of this type of element decreases glare, contributing to a reduction in the use of single blocks of light entering a space.

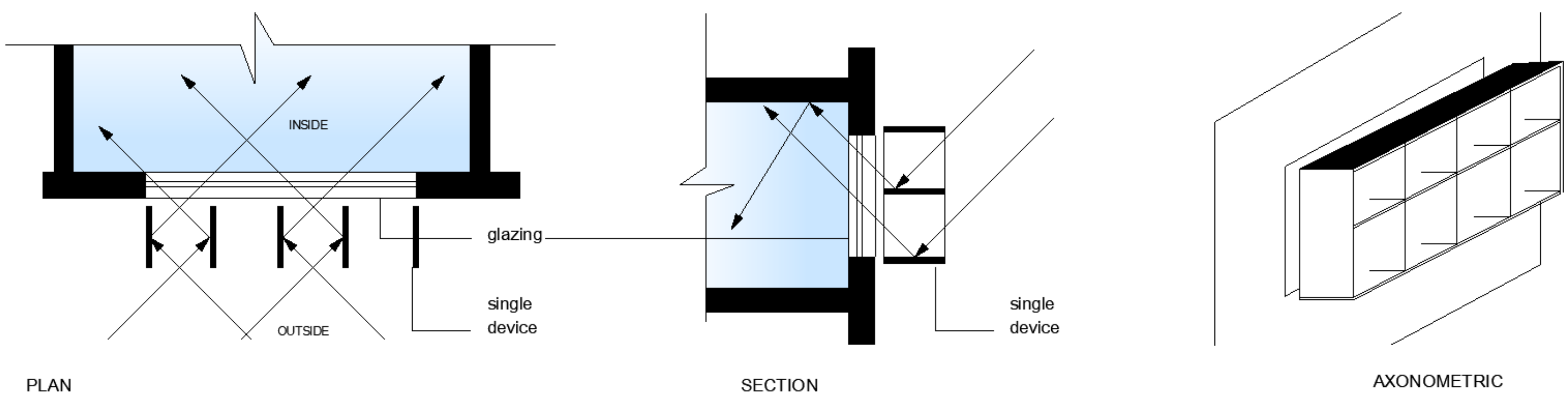


Figure 5-8: Multiple specular reflections on eggcrate enhancing lighting Author Modified 2021. Retrieved from UN habitant 2014

5.4 Conclusions potential of shading devices

Concrete as an external shading device appears to be a reliable material to be applied since it prevents heat gain into the room due to its high heat storage. When solar radiation falls on a concrete shading device, it slowly absorbs the heat and deliberately transfers the heat at a slow rate, preventing rapid heat gains. However, the study established that aluminum produced a better lighting environment due to its reflectivity.

Based on the findings of the research, it is appropriate to make the following recommendation: when using concrete as an external shading for classrooms, it should be finished with brighter colours to achieve high reflectivity. This increases light penetration and enhances the performance of external shading devices in thermal comfort and lighting environments.

External shading devices in the form of horizontal overhangs of aluminium material have better lighting performance than concrete. Aluminium is known for devising high reflectivity due to its shiny surface appearance. Since the reflectance by aluminium is higher, a lot of light is directed into the spaces, making the classroom well lit. In addition, aluminium has high lattice vibrations and excites electrons to higher energy levels. When heated for a longer time, it contributes to a drastic heat build-up in the space. When using aluminium as an external shading device, it should therefore be used as narrow plates to allow for convective cooling.

Shading devices in either north, south, east or west facade rooms have a weighty impact on improving in-house thermal conditions. In addition, egg-crate strategies are the best in decreasing indoor air temperature and reducing the number of discomfort range because of their arrangement (i.e., combination of horizontal overhangs and vertical fins devices to cover both horizontal and vertical shadow angles), which avoids solar radiation from varied sun angles.

Consequently, comparing the rooms U1, U2, N1, N2 and C1 shaded on the west with those between U1 and C1 shaded on the north, the improvement in the total number of comfortable hours (i.e., less than 25^{0}C) was establish to be 154%. The key contributing factor to better performance is directly related to the external shading device in the following ways.

1. Locating the window on the northern façade

2. Providing an egg-crate shading system that maintained a depth to length ratio of 150: 200: 300 (where 150 is the death of shading, 200 is the spacing between vertical fins, and 300 between horizontal louvres)

In this application, to design a good external shading device for optimum thermal and lighting environments in classroom environments, it is appropriate to adopt the following strategies.

1. It is most appropriate to position windows on a north or south façade in Nairobi, as shading in such cases will require the least shading depth due to less solar exposure. Smaller depth invites more light penetration.
2. To be able to improve the lighting environment, external shading should reflect light up to the ceiling in a classroom. The upper surface of the light shelf should be matte white or diffusely specular. It does not need to be shiny or reflective.
3. A depth to spacing ratio between 1:2 and 1:3 enhanced light penetration. Multiple reflection of light within a shading device contributes to light intensity loss, hence should be limited.

5.5 Area for Further research

Considering all these facts in the study which suggest that the egg crate is the best device for thermal and lighting design, future studies and research in analysis of egg crates is desirable to adequately guide in their influence on indoor daylighting and thermal design alongside other design parameters such as window to wall ratio, ventilation system, and obstruction due to context. This will help a step further in complementing passive design and the results of this paper.

Furthermore, this paper did not dwell on the economic cost of various shading devices during design, construction, and building operations. Further studies should be carried out to complement the findings and conclusions reached in this study.

6 REFERENCES

Alison Smithson, Peter Smithson, 1955. *Collective Housing in Morocco 'The works of ATBAT-AFRIQUE by Bodiansky, Candilis and Woods.* Rabat, Architectural Design (january 1955).

Crossman, A., 2020. *An Overview of Qualitative Research Methods.* [Online]
Available at: thoughtco.com/qualitative-research-methods-3026555.

Fanger, P. O., 1972. *Thermal comfort. Analysis and applications in environmental engineering..* s.l.:Copenhagen: Danish Technical Press..

Gagnel, J. M. & Andersen, M., 2010. *Multi-Objective Façade Optimization for Daylighting Design Using a Genetic Algorithm.* New York, USA, 4th National Conference of IBPSA-USA SimBuild 2010, 11-13 August 2010.

Gagnel, J. M. L. & Andersen, . M., 2012. A Generative Façade Design Method Based on Daylighting Performance Goals. *Journal of Building Performance Simulation,* 5(3).

Givoni, 1969. *Man, Climate and Architecture..* Amsterdam: Elseveir Publishing Company..

Givoni, B., 1969. *Man, Climate and Architecture..* 2nd 1982 ed. Amsterdam ; London ; New York :: Elsevier Publishing Company Limited, 1969..

Handbook 2019 A.S.H.R.A.E.® , 2019. *Heating, Ventilating, and Air-Conditioning Applications.* S-I ed. s.l.:Elsevier.

Kamal, M. A., 2011. Shading: A Simple Technique For Passive Cooling And Energy Conservation In Buildings. *ARCHITECTURE - Time Space & People*.

Kamal, M. A., 2013. Le Corbusier’s Solar Shading Strategy for Tropical Environment: A Sustainable Approach. *Journal of Architectural and Planning Research,* Volume 10 No. 1 (2013).

Kim. G, G. et al., 2012. Comparative advantage of an exterior shading device in thermal performance for residential buildings.. *Energy and Buildings*, Issue 46.

Kimeu, M., 2014. *Passive Building Design Principles.* Apollo Centre in Westlands, Nairobi., UON.

Koeningsberger, O., 1975. *Manual of Tropical housing and building climatic design*, Bangalore: First Orient blackswam press.

Kohler, C., Shukla, Y. & Rawal, R., 2017. *Calculating the Effect of External Shading on the Solar Heat Gain Coefficient of Window*, Ahmedabad, India: Lawrence Berkeley National Laboratory, CEPT University.

Kontadakis, A., Tsangrassoulis, . A., Doulos, L. & Zerefos., S., 2018. A Review of Light Shelf Designs for Daylit Environments. *Sustainability*, 10(71).

Kumar, R., Garg, S. & Kaushik , S., 2005. "Performance Evaluation of Multi-passive Solar Applications of a non-Air-conditioned Building.". *Int. J. Environmental Technology and Management,*, Volume 5 , pp. No.1, pp. 60-75..

Lavafpour, Y. & Sharples, S., 2015. Summer thermal comfort and self-shading geometries in Passivhaus dwellings: a pilot study using future UK climates. *Energy and Buildings*, Volume 5, pp. 964-984.

Lavafpour, Y. & Sharples, . S., 2017. *The Influence of façade design on the optimum window to wall ratio and overheating rate in UK Passivhaus dwellings for current and future climates: A Parametric Design Method.* s.l., Conference: PLEA 2017.

Le Hong, M. D. & Lucelia, R., 2013. *Visual and Thermal Performance in Façade Design.* Munich, Germany, PLEA2013 - 29th Conference, Sustainable Architecture for a Renewable Future.

Lechner, N., 2015. *Heating, cooling, lighting : sustainable design methods for architects.* Fourth edition ed. s.l.:Hoboken, New Jersey : John Wiley & Sons, Inc., [2015].

Leion-Rodrigues, A. L., Calama-Gonzalez, m. C. & Suarez, R., 2018. Daylighting and Energy Performance Evaluation Daylighting and Energy Performance Evaluation Daylighting and Energy Performance Evaluation. *Sustainability,* 10((8), 2714;).

Locher , M., 2015. *Japanese Architecture: An Exploration of Elements & Forms.* Periplus Edition ed. s.l.:Tuttle Publishing, Airport Business Park,364 Innovation Drive,North Clarendon, VT 05759-9436.

Loe, D. et al., 1990. *Building bulletin 90_lighting_design_for_schools- Building Bulletin 90,* s.l.: HMSO Publications Centre, P.O. Box 276, London, Educational Environment; Educational Facilities Design.

Luis Pe´rez-Lombard, Jose´ Ortiz, Christine Pout, 2007. *A review on buildings energy consumption information*, s.l.: Energy and Buildings 40 (2008) 394–398.

Manzan, M. & Francesco, P., 2009. *Genetic Optimization of external Shading Devices.* Trieste, Italy, Bulding Simulation.

McLaughlin, M., 2009. Code for lighting. In: L. U. Adam Smith Institute, ed. *Energy efficiency in buildings. CIBSE Guide.* s.l.:Chartered Institution of Building Services Engineers. Delta House,222 Balham High Road, London SW12 9BS. UK.

Miguel, A. F., 2008. Constructal design of solar energy-based systems for buildings, Energy and Buildings. *Energy and Buildings,* 40(Issue 6, 2008, Pages 1020-1030).

Minagi, F. S., 2019. *Effect of shading on thermal performance of Dormitory Building on Hot Climate*, s.l.: International Journal of Interdisciplinary Research and Innovations.

Minseok, K., Leigh, S.-B., Taeyeon, K. & Sooyoun, C., 2015. A Study on External Shading Devices for Reducing Cooling Loads and Improving Daylighting in Office buildings. *Journal of Asian Architecture and Building Engineering,* Volume 14.

Moraa, V. . N., 2019. *Climate Responsive Institutional Buildings In Nairobi,* Nairobi: UoN.

Mumbi, M., 2016. *Tropical modern architecture- climate responsive Modern architecture in East Africa between 1940 and 1980,* Nairobi kenya: UON.

Nedhel, A.-T. A., Sharifah, F. & Syed, F., 2011. The potential of shading devices for temperature reduction in highrise residential buildings in the tropics. *Procedia Engineering,* Volume 21.

Olgyay, A. & Olgyay, V., 1957. *Solar Control and Shading Devices.* First Paperback Edition (February 21, 1977) ed. s.l.:Princeton: Princeton University Press..

Professional Led&Lamps;, n.d. *The European standard NEN 12464-1 in a few key points | Any-lamp,* s.l.: s.n.

Rabah, V. K. & Mito, C., 2003. Pre-design guidelines for passive solar architectural buildings in Kenya. *International Journal of Sustainable Energy,* 23(3)(83-119.).

Samani, S. A., 2012. The impact of indoor lighting on students' learning performance in learning environments: a knowledge internalization perspective.. *International Journal of Business and Social Science,* 3(No. 24 [Special Issue – December 2012]).

Santiago, P. A., 2020. Natural Light Influence on Intellectual Performance-A Case Study on University Students. *Sustainability,* 12((10):4167).

Schittich, C., Werner, L. & Krippner, R., 2001. *Building Skins: Concepts, Layers, Materials..* New ed. s.l.:Basel: Birkhäuser..

Shields, P. M. & Rangarajan, N., 2013. *A Playbook for Research Methods: Integrating Conceptual Frameworks and Project Management.* 10-1-58107-247-3 ed. s.l.:New Forums Press, Stillwater.

Stefan, b., 2010. *High-performance facades for commercial buildings.,* (USA).: M.S.S.D. Thesis, UTSOA Center for Sustainable Development.

Szokolay, S., 2014. *Introduction to Architectural Science.* 3rd ed. s.l.:Taylor and Francis.

UN-Habitat, 2014. *Sun Shading Catalogue. Adequate Shading: Sizing Overhangs and Fins | UN-Habitat,* First published in Nairobi in August 2014 by UN-Habitat.: www.unhabitat.org.

Winterbottom, M. & Wilkins, A., 2009. Lighting and discomfort in the classroom.. *Journal of Environmental Psychology,* 29(1, March 2009,), pp. 63-75.

World Building Design Guide, 2020. *Sustainable | WBDG - Whole Building Design Guide,* s.l.: Extracted by author.

Wymelenberg, K. V. D., 2012. Patterns of occupant interaction with window blinds: A literature review.. *Energy and Buildings,* Volume 51, p. 165–176.

Yuniarono, M., Rizal, Y. & Robandi , I., 2020. Daylight Factors Distribution OptimizationBased on Sky Component for window Opening. *International Journal of Innovative, Computing, Information and Control,* Volume 16, Number 1.

Zhang, A. et al., 2017. Optimization of thermal and daylight performance of school buildingsbased on a multi-objective genetic algorithm in the cold climate of China. *Energy and Buildings,* 139(15), pp. 371-384.

7 APPENDICES

7.1 Identified areas of Study on the masterplan of technical university of Kenya

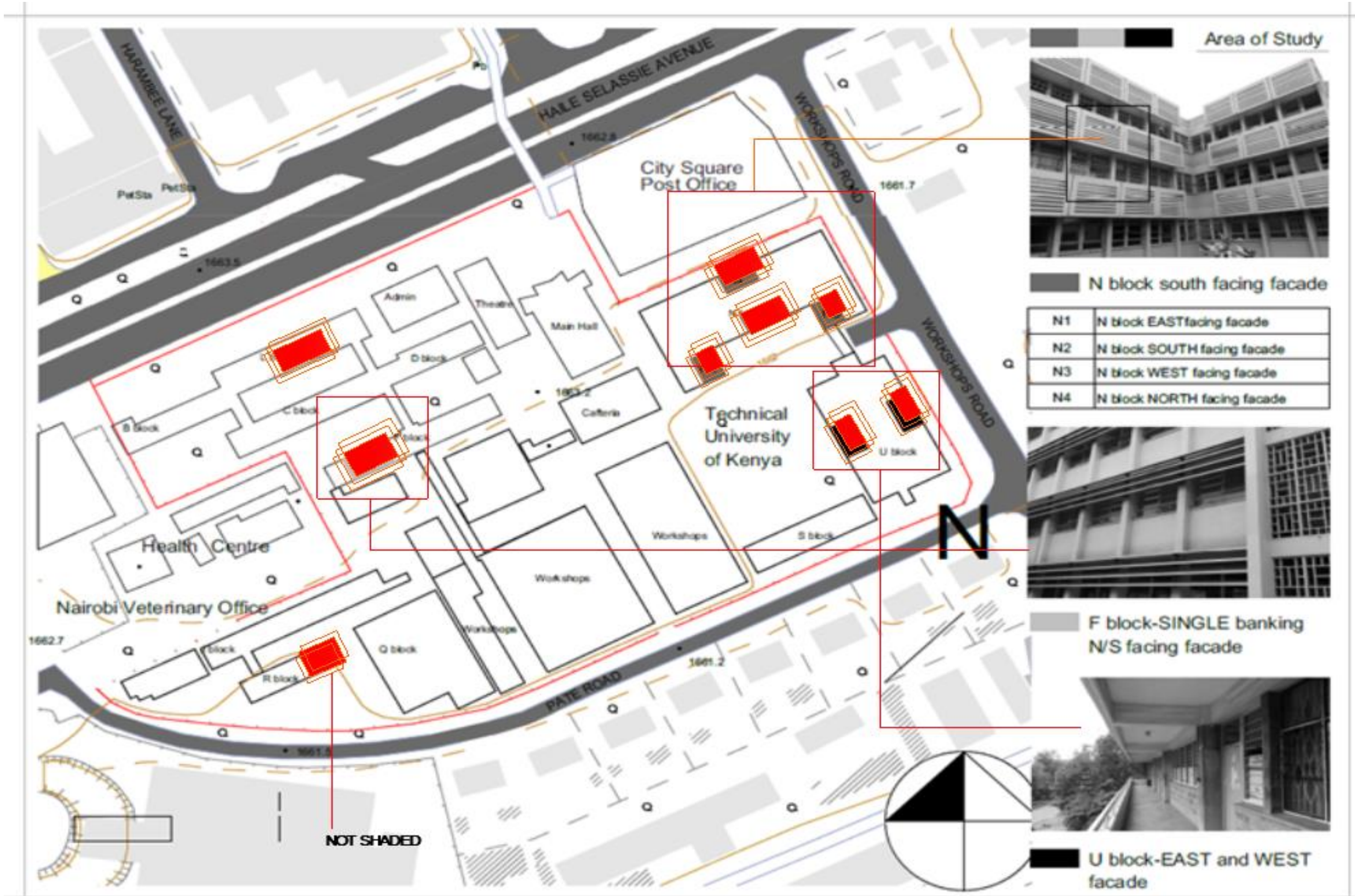


Figure 7-1: A map of the technical university of Kenya showing the study areas and location of various classrooms as studied

7.2 Temperature and Lighting level Records

Table 19: Air temperature and Lighting level recording for U1 and U2

Eastern Window- shading Data						Western Window- shading Data					
Column1	**Temp, °C (LGR S/N: 20640084, SEN S/N: 20640084, LBL:**	**RH, % (LGR S/N: 20640084,**	**Average illumination**	**zone limit**	**lux limits**	**TIME**	**Temp, °C (LGR S/N: 20640084, SEN S/N: 20640084, LBL:**	**upper limit-**	**lower limit-temp**	**Average illumination**	**Lighting requirement**
7:00:44 am	**21.179**	**65.5**		**25**	**250**	7:00:44 am	**21.012**	**25**	**20**		**250**
7:15:44 am	**21.752**	**63.838**	**192**	**25**	**250**	7:15:44 am	**22.206**	**25**	**20**	**215**	**250**
7:30:44 am	**21.584**	**64.956**		**25**	**250**	7:30:44 am	**22.469**	**25**	**20**		**250**
7:45:44 am	**21.656**	**64.966**		**25**	**250**	7:45:44 am	**22.493**	**25**	**20**		**250**
8:00:44 am	**21.728**	**64.112**		**25**	**250**	8:00:44 am	**22.637**	**25**	**20**		**250**
8:15:44 am	**21.919**	**63.325**		**25**	**250**	8:15:44 am	**22.733**	**25**	**20**		**250**
8:30:44 am	**22.086**	**63.376**		**25**	**250**	8:30:44 am	**22.877**	**25**	**20**		**250**
8:45:44 am	**22.206**	**62.117**		**25**	**250**	8:45:44 am	**23.069**	**25**	**20**		**250**
9:00:44 am	**22.589**	**62.173**	**257**	**25**	**250**	9:00:44 am	**23.093**	**25**	**20**	**200**	**250**
9:15:44 am	**22.853**	**61.589**		**25**	**250**	9:15:44 am	**23.069**	**25**	**20**		**250**
9:30:44 am	**23.261**	**60.252**		**25**	**250**	9:30:44 am	**23.069**	**25**	**20**		**250**
9:45:44 am	**23.453**	**60.332**		**25**	**250**	9:45:44 am	**23.237**	**25**	**20**		**250**
10:00:44 am	**23.597**	**60.264**		**25**	**250**	10:00:44 am	**23.405**	**25**	**20**		**250**
10:15:44 am	**23.645**	**60.095**	**225**	**25**	**250**	10:15:44 am	**23.501**	**25**	**20**	**205**	**250**
10:30:44 am	**23.814**	**59.796**		**25**	**250**	10:30:44 am	**23.573**	**25**	**20**		**250**
10:45:44 am	**23.886**	**58.61**		**25**	**250**	10:45:44 am	**23.742**	**25**	**20**		**250**
11:00:44 am	**24.031**	**58.403**		**25**	**250**	11:00:44 am	**23.862**	**25**	**20**		**250**
11:15:44 am	**24.175**	**57.343**		**25**	**250**	11:15:44 am	**24.079**	**25**	**20**		**250**
11:30:44 am	**24.731**	**54.913**		**25**	**250**	11:30:44 am	**24.248**	**25**	**20**		**250**
11:45:44 am	**24.803**	**52.772**		**25**	**250**	11:45:44 am	**24.32**	**25**	**20**		**250**
12:00:44 pm	**24.997**	**53.626**		**25**	**250**	12:00:44 pm	**24.441**	**25**	**20**		**250**
12:15:44 pm	**25.215**	**54.356**	**217**	**25**	**250**	12:15:44 pm	**24.586**	**25**	**20**	**215**	**250**
12:30:44 pm	**25.288**	**53**		**25**	**250**	12:30:44 pm	**24.876**	**25**	**20**		**250**
12:45:44 pm	**25.264**	**52.194**		**25**	**250**	12:45:44 pm	**24.948**	**25**	**20**		**250**
1:00:44 pm	**24.827**	**51.575**		**25**	**250**	1:00:44 pm	**25.167**	**25**	**20**		**250**
1:15:44 pm	**24.9**	**50.83**		**25**	**250**	1:15:44 pm	**25.191**	**25**	**20**		**250**

1:30:44 pm	**25.385**	**50.668**		**25**	**250**	1:30:44 pm	**24.948**	**25**	**20**		**250**
1:45:44 pm	**25.531**	**49.049**		**25**	**250**	1:45:44 pm	**25.118**	**25**	**20**		**250**
2:00:44 pm	**25.774**	**48.836**		**25**	**250**	2:00:44 pm	**25.215**	**25**	**20**		**250**
2:15:44 pm	**25.312**	**48.774**		**25**	**250**	2:15:44 pm	**25.361**	**25**	**20**		**250**
2:30:44 pm	**25.288**	**48.998**		**25**	**250**	2:30:44 pm	**25.676**	**25**	**20**		**250**
2:45:44 pm	**25.336**	**49.603**		**25**	**250**	2:45:44 pm	**25.944**	**25**	**20**		**250**
3:00:44 pm	**25.409**	**49.064**		**25**	**250**	3:00:44 pm	**26.09**	**25**	**20**		**250**
3:15:44 pm	**24.973**	**49.536**	**200**	**25**	**250**	3:15:44 pm	**26.188**	**25**	**20**	**272**	**250**
3:30:44 pm	**24.465**	**50.461**		**25**	**250**	3:30:44 pm	**26.31**	**25**	**20**		**250**
3:45:44 pm	**24.368**	**51.323**		**25**	**250**	3:45:44 pm	**26.456**	**25**	**20**		**250**
4:00:44 pm	**24.513**	**51.004**		**25**	**250**	4:00:44 pm	**26.481**	**25**	**20**		**250**
4:15:44 pm	**24.61**	**51.501**		**25**	**250**	4:15:44 pm	**26.628**	**25**	**20**		**250**
4:30:44 pm	**24.489**	**52.294**		**25**	**250**	4:30:44 pm	**26.799**	**25**	**20**		**250**
4:45:44 pm	**24.586**	**52.077**		**25**	**250**	4:45:44 pm	**26.872**	**25**	**20**		**250**
5:00:44 pm	**24.537**	**52.143**		**25**	**250**	5:00:44 pm	**27.044**	**25**	**20**		**250**
5:15:44 pm	**24.296**	**52.009**	**187**	**25**	**250**	5:15:44 pm	**27.437**	**25**	**20**	**257**	**250**
5:30:44 pm	**23.982**	**52.924**		**25**	**250**	5:30:44 pm	**27.536**	**25**	**20**		**250**
5:45:44 pm	**23.886**	**55.079**		**25**	**250**	5:45:44 pm	**27.708**	**25**	**20**		**250**
6:00:44 pm				**25**	**250**	6:00:44 pm	**27.634**	**25**	**20**		**250**

7.3 Temperature and Lighting level Records for Non- shaded classroom

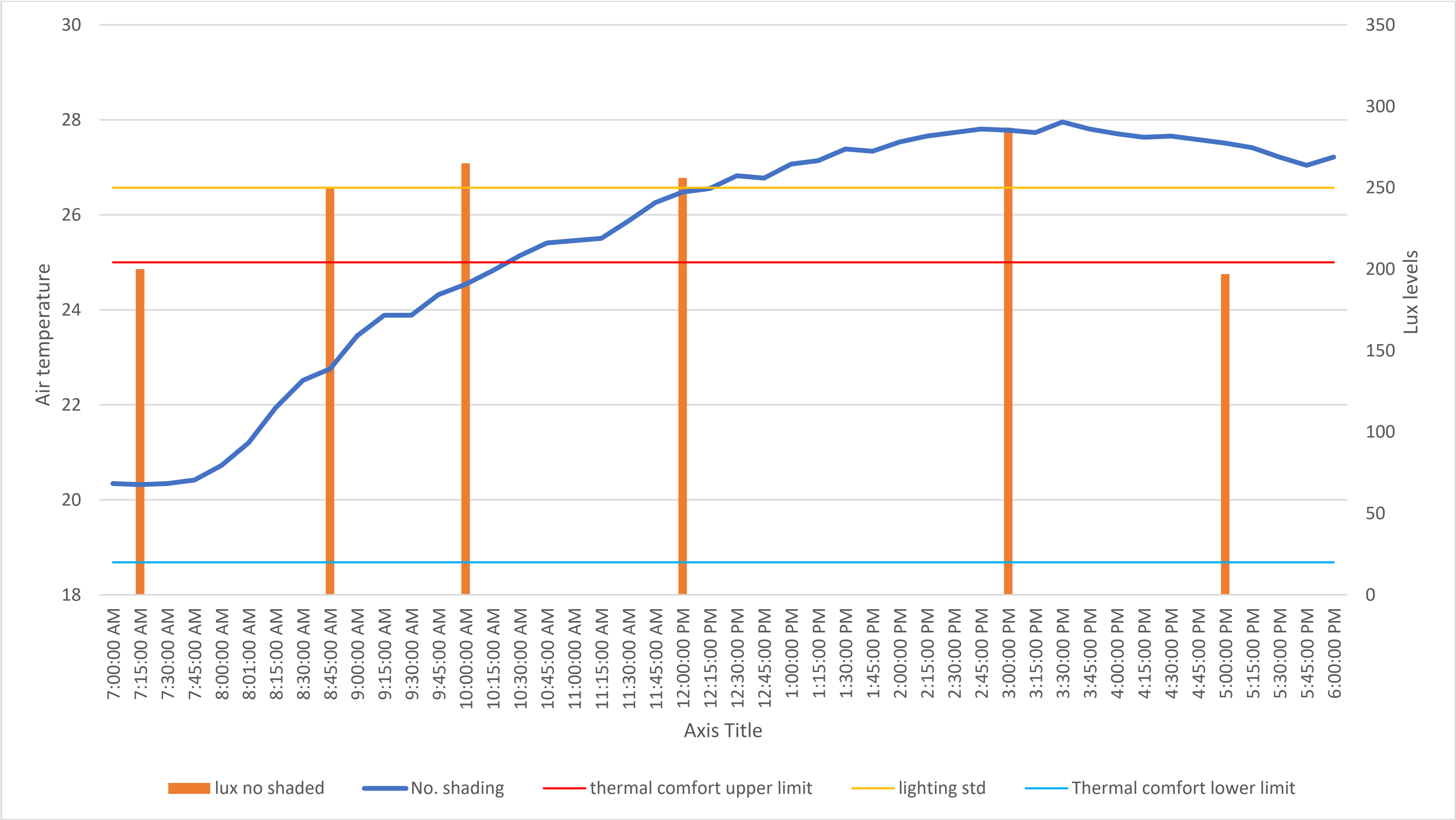


Figure 7-2: A graphical illustration of indoor environment is Classroom R21- used to pilot the study

7.4 Problem piloting graphs in Sample classroom in a local university

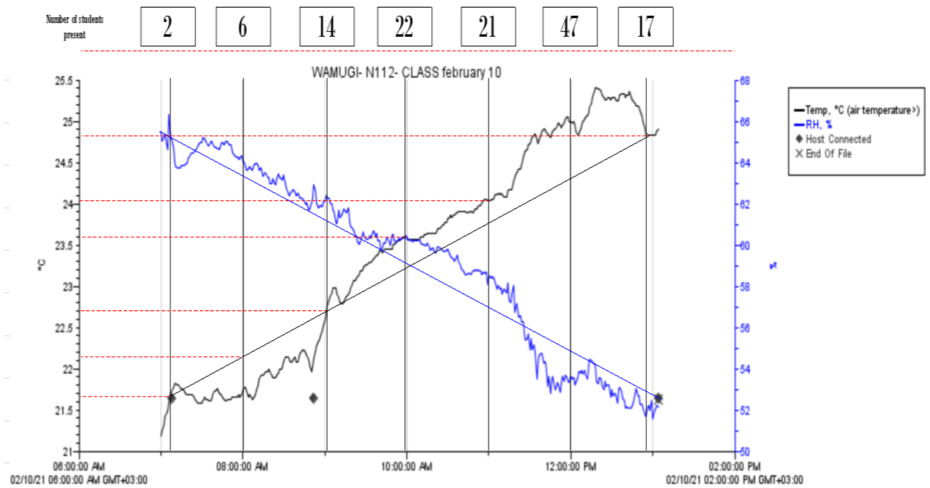


Figure 7-3: Recording of air temperature in the morning hours in N block classroom

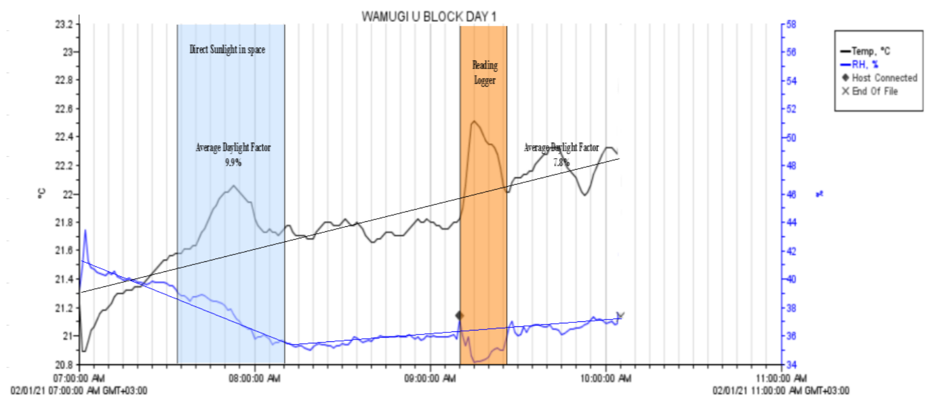


Figure 7-4: the challenge of direct sunlight on temperature in a small learning space of a local university.

7.5 Worked Daylight Factor in Studied classrooms

Table 20: Lighting levels in C Classroom with egg crates and calculated daylight factors

C BLOCK Lighting levels Classroom C							
08:00AM				11:30AM			
Point	Ei in lux	Eo in Lux	DF	P	Ei in lux	Eo in Lux	DF
A1	73	3456	2.1122685	A1	76	3867	1.965347815
A2	233	3456	6.7418981	A2	278	3867	7.189035428
A3	107	3456	3.0960648	A3	131	3867	3.387638997
A4	110	3456	3.1828704	A4	139	3867	3.594517714
A5	153	3456	4.4270833	A5	201	3867	5.197827773
B1	332	3456	9.6064815	B1	410	3867	10.60253426
B2	397	3456	11.487269	B2	467	3867	12.07654513
B3	604	3456	17.476852	B3	421	3867	10.8869925
B4	645	3456	18.663194	B4	406	3867	10.49909491
B5	673	3456	19.47338	B5	404	3867	10.44737523
C1	351	3456	10.15625	C1	392	3867	10.13705715
C2	406	3456	11.747685	C2	367	3867	9.490561159
C3	450	3456	13.020833	C3	409	3867	10.57667442
C4	476	3456	13.773148	C4	401	3867	10.36979571
C5	478	3456	13.831019	C5	298	3867	7.706232221
D1	168	3456	4.8611111	D1	159	3867	4.111714507
D2	298	3456	8.6226852	D2	267	3867	6.904577192
D3	317	3456	9.1724537	D3	302	3867	7.80967158
D4	322	3456	9.3171296	D4	283	3867	7.318334626
D5	250	3456	7.2337963	D5	198	3867	5.120248254
			9.9001736				7.769588829
N BLOCK Lighting levels N.S CLASSROOM							
Point	Ei in lux	Eo in Lux	DF		Ei in lux	Eo in Lux	DF
N1	15	3456	0.434027778	N1	27	3867	0.698215671
N2	10	3456	0.289351852	N2	32	3867	0.827514869
N3	55	3456	1.591435185	N3	65	3867	1.680889578
N4	40	3456	1.157407407	N4	60	3867	1.55159038

N5	50	3456	1.446759259	N5	66	3867	1.706749418
N6	135	3456	3.90625	N6	140	3867	3.620377554
N7	127	3456	3.674768519	N7	137	3867	3.542798035
N8	107	3456	3.096064815	N8	154	3867	3.982415309
N9	110	3456	3.18287037	N9	110	3867	2.844582364
N10	98	3456	2.835648148	N10	112	3867	2.896302043
N11	190	3456	5.497685185	N11	221	3867	5.715024567
N12	181	3456	5.237268519	N12	216	3867	5.585725369
N13	178	3456	5.150462963	N13	200	3867	5.171967934
N14	182	3456	5.266203704	N14	199	3867	5.146108094
N15	117	3456	3.385416667	N15	117	3867	3.025601241
N16	135	3456	3.90625	N16	276	3867	7.137315749
N17	107	3456	3.096064815	N17	219	3867	5.663304888
N18	106	3456	3.06712963		254	3867	6.568399276
N19	117	3456	3.385416667		250	3867	6.464959917
N20	146	3456	4.224537037		241	3867	6.23222136