COLLEGE OF TECHNOLOGY AND BUILT ENVIRONMENT

SCHOOL OF BUILT ENVIRONMENT

The Dichotomy of The Performance and Aesthetics of Sun Breakers of Highrise Buildings in the CBD of Addis Ababa, Ethiopia.

By:
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March, 2026

Addis Ababa, Ethiopia

Declaration

I declared that the research entitled **The Dichotomy of The Performance and Aesthetics of Sun Breakers of Highrise Buildings in the CBD of Addis Ababa, Ethiopia.** was my original work and had not been submitted elsewhere for any degree or publication. I confirmed that all sources of information used in the study had been duly acknowledged through proper citations and references.

The findings, interpretations, and conclusions presented in the work were based on my independent analysis, field observations, and empirical data. I affirmed that the research adhered to ethical academic standards and that any data collected from case studies, interviews, or secondary sources had been used with integrity and transparency.

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Confirmation

This thesis has been submitted for examination with my approval as an Institute's advisor.

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This Thesis Paper is Submitted to The School of Graduate Studies of Addis Ababa University, **COLLEGE OF TECHNOLOGY AND BUILT ENVIRONMENT, SCHOOL OF BUILT ENVIRONMENT** in Partial Fulfillment of the Requirements for The Degree Master of Science in Urban Design and Development.

Title of Thesis:

The Dichotomy of The Performance and Aesthetics of Sun Breakers of Highrise Buildings in the CBD of Addis Ababa, Ethiopia.

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Abstract

This study examines the dual relationship between environmental performance and aesthetic perception of sun-breaker systems in high-rise buildings within the Central Business District of Addis Ababa. Four bank headquarters—Commercial Bank of Ethiopia, Hibret Bank, Nib International Bank, and Wegagen Bank—were analyzed using a mixed-methods approach that integrates quantitative solar-geometry evaluation with qualitative perception surveys of urban residents and design professionals. The quantitative analysis assessed cut-off angles, shading factors, and solar-radiation reduction, while the qualitative component examined façade articulation, pattern rhythm, and architectural identity. Results show that geometric configuration—particularly fin depth, spacing, density, and orientation—is the primary determinant of shading effectiveness. High-density vertical fins and grid-based arrangements achieved the best environmental performance, especially on west façades exposed to intense afternoon solar gain. Optimal performance was associated with cut-off angles above 30° and shading factors between 0.6 and 0.7, while sparse or horizontally oriented devices produced limited shading efficiency. Perceptual findings reveal that residents prioritize visible qualities such as material and form, whereas professionals emphasize solar control and comfort. Both groups strongly support the integration of Ethiopian cultural motifs. The study concludes that effective sun-breaker design requires integrating orientation-specific geometric parameters with coherent visual expression to balance environmental performance, aesthetic quality, and cultural identity in rapidly urbanizing equatorial CBD contexts.

Keywords:

Sun breakers; Solar shading performance; Geometric configuration; Aesthetic perception; Cultural integration; High-rise buildings.

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Acronyms

AACPPO	Addis Ababa City Plan Preparation Office
ASE	Annual Sunlight Exposure
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
CBD	Central Business District
BMS	Building Management System
CBD	Central Business District
CBE	Commercial Bank of Ethiopia
Cwb	Köppen climate classification
DGP	Daylight Glare Probability
ES	Ethiopian Standard
HQ	Headquarters
HVAC	Heating, Ventilation, and Air Conditioning
kWh	Kilowatt-hour
NIB	Nib International Bank
NOAA	National Oceanic and Atmospheric Administration
sDA	Spatial Daylight Autonomy
SF	Shading Factor
SVF	Sky View Factor
UDI	Useful Daylight Illuminance
WOR	Window Obstruction Ratio

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

As urbanization and climate change intensify, the building envelope has become increasingly critical, acting as the primary interface between interior and exterior environments. It determines solar performance, occupant comfort, and a building's visual identity (ASHRAE, 2017). In tropical climates, sun breakers (shading devices) are particularly significant, as they regulate solar radiation and daylight while contributing to architectural expression.

Sun breakers have evolved from simple functional elements into complex architectural features that embody the tension between environmental performance and aesthetic expression. Historically, they originated in vernacular traditions like the Islamic mashrabiya and Indian jali screens, which used intricate latticework to provide shade, privacy, and ventilation while creating distinctive light patterns (Fathy, 1986). In modern architecture, Le Corbusier's brise-soleil transformed sun shading from a technical necessity into a defining design element, establishing sun breakers as integrated architectural components (Curtis, 1986).

Contemporary sun-breaker design integrates building physics, solar geometry, material science, and architectural aesthetics. Key parameters—depth, spacing, width, and orientation—determine both shading effectiveness and visual character. This creates an inherent trade-off: deeper projections improve shading but reduce daylight and add visual mass, while wider spacing admits lighter but compromises shading performance. This study terms this the "sun-breaker dichotomy"—the need to balance environmental performance with aesthetic expression in façade design.

Addis Ababa, Ethiopia's capital, offers a critical context for studying the sun-breaker dichotomy. Located at 9°N latitude and over 2,300 meters elevation, it has an equatorial highland climate with intense year-round solar radiation. Solar noon altitudes range from 57.5° in winter to 81.5° in summer, creating complex, seasonally variable shading requirements (Szokolay, 2014). Low-angle morning and afternoon sun (<30°) poses specific challenges for east and west facades, while high-altitude midday sun requires different strategies for south-facing surfaces.

Over the past two decades, Addis Ababa has undergone rapid vertical growth driven by post-1991 economic expansion, particularly in the Central Business District (Kirkos, Lideta, and Arada sub-cities). By 2019, the city had 101 tall buildings, with continued growth fueled by high spatial demand and limited land availability (Geda, 2018; Emporis, 2019; World Bank, 2019). This transformation has made sun-breaker design increasingly critical, as high-rise facades are now exposed to solar radiation across all orientations.

This study investigated four landmark bank headquarters in Addis Ababa's CBD—the Commercial Bank of Ethiopia (CBE), Hibret (United) Bank, Nib Bank (NIB), and Wegagen Bank. These buildings, completed between approximately 2010 and 2022, range from 18 to 46 stories and employ diverse shading strategies including vertical fins, horizontal overhangs, honeycomb geometries, and uniform grid systems.

1.2 Problem Statement

The rapid growth of high-rise office buildings in the Central Business District of Addis Ababa has increased the use of fully glazed façades that often lack effective solar-responsive design. Although sun breakers are intended to control solar radiation and enhance architectural appearance, many buildings demonstrate a clear gap between their environmental performance and aesthetic expression. As a result, sun breakers are frequently designed for visual appeal rather than functional effectiveness.

Due to the city's high-altitude equatorial climate, buildings are exposed to intense solar radiation throughout the year. Poorly oriented façades and inadequate shading systems allow excessive sunlight to penetrate office interiors, causing glare on computer screens, overheating of workspaces, and uneven daylight distribution.

Office occupants often adopt temporary solutions such as covering windows with magazines, relocating workstations away from windows, or using personal fans to reduce discomfort. These conditions reduce productivity and indicate that current façade designs do not adequately address occupant comfort.

Uncontrolled solar exposure also leads to increased cooling demand, material fading, and inefficient use of office space near windows. In some cases, excessive sunlight forces occupants to close blinds completely, creating dark interiors that depend on artificial lighting, while poorly oriented areas remain permanently dim. Despite the potential of sun breakers to significantly reduce solar heat gain, their application in many buildings in Addis Ababa is inconsistent, often limited to decorative purposes without proper solar analysis.

Furthermore, a perceptual gap exists between professionals and building users: architects emphasize technical performance, whereas occupants primarily experience sun breakers as visual elements of the urban environment. This disconnects, combined with the lack of performance-based façade regulations, contributes to the continued mismatch between environmental efficiency and architectural expression. Consequently, there is a need to investigate how sun-breaker design can balance performance and aesthetics to improve occupant comfort, energy efficiency, and the architectural identity of high-rise buildings in the CBD of Addis Ababa.

1.3 Objective

Main Objective:

To understand the dichotomy of the environmental performance and aesthetic perception of occupants and urban residents about sun-breaker systems in Addis Ababa's CBD high-rise buildings.

Specific Objectives:

1. To investigate the geometric performance of existing permanent sun breakers fixed on various orientation of selected buildings.
2. To measure the perceptions of permanent sun breakers fixed on high rise buildings.

1.4 Research Questions

Main Research Question

How do sun-breaker systems on high-rise buildings in Addis Ababa's CBD balance environmental performance and the aesthetic perceptions of occupants and urban residents?

Specific Research Questions

1. How does the orientation of permanent sun-breakers influence their solar shading effectiveness on high-rise façades in Addis Ababa?
2. How do occupants and urban residents and professionals perceive the aesthetic qualities of permanent sun-breakers on high-rise buildings?

1.6 Significance of the Study

This research offers critical insights into how different stakeholders perceive sun-breakers in high-rise buildings within Addis Ababa's Central Business District (CBD), including ordinary residents, building occupants, and government authorities responsible for regulations and urban planning. It provides empirically grounded design guidelines that help architects and developers enhance shading efficiency, daylight management, and visual harmony in high-rise façades. Additionally, the study informs policymakers and urban planners on sustainable practices, bridging performance and aesthetic considerations. By integrating climatic responsiveness with local cultural identity, the research proposes a bioclimatic design model tailored for equatorial high-rise architecture.

1.7 Scope of the Study

The study focused exclusively on the four main cardinal orientations and analyzed the seven seasonal solar paths of Addis Ababa between 10:00 and 16:00 using sun path diagrams. The research was delimited across three dimensions to ensure a focused investigation:

1. **Design Parameters:** The study examined the geometry and orientation of external sun-breakers, assessing both their environmental performance and aesthetic perception.

2. **Building Selection:** Four commercial high-rise bank headquarters located in Kirkos and Lideta Sub-Cities were selected. These buildings employed different sun-breaker designs, and all other building systems outside these boundaries were excluded.

3. **Methodology:** A mixed-methods case study approach was adopted, combining solar geometry measurements, architectural documentation, and visual perception analysis.

The four buildings were chosen purposively from 101 documented high-rise structures in Addis Ababa (Emporis, 2019), based on five criteria:

1. Commercial high-rise status with a minimum height of 20 stories;
2. Use of external sun-breakers as the primary shading system;
3. Location within Kirkos or Lideta Sub-City;
4. Completed and currently occupied;
5. Presence of diverse sun-breaker design patterns.

This selection enabled a comparative analysis of landmark high-rise buildings in Addis Ababa's Central Business District, providing a representative understanding of sun-breaker performance and perception in modern urban architecture.

Table 1.1 presents the profile and key characteristics of the selected high-rise bank buildings in Addis Ababa's Central Business District (CBD). The table provides information on the building name, number of floors, overall height, and the type of sun-breaker configuration employed.

Table 1.1: Profile of Case Study Buildings

No	Building Name	Floors	Height (m)	Configuration
1	**Commercial Bank of Ethiopia HQ**	46	209	Vertical fins
2	**Hibret Bank HQ**	37	137	Horizontal louvers
3	**Nib Bank HQ**	37	137	Parametric/honeycomb pattern
4	**Wegagen Bank HQ**	23	107	Composite (horizontal & vertical)

1.8 Limitations of the Study

This study acknowledges several limitations that may have influenced the findings. First, most high-rise buildings in Addis Ababa's CBD either lack sun-breakers or were still under construction during the research period, limiting the availability of fully operational case studies. Second, geometric measurements were conducted using a meter from the building's concrete structure, including cladding, which may have introduced minor discrepancies in recorded dimensions. Third, the assessment of aesthetic impact relied on subjective qualitative evaluations, and environmental performance was estimated through geometric analysis rather than comprehensive energy simulations. These factors may have constrained the precision and generalizability of the results, though they provide a reasonable basis for comparative analysis within the selected sample.

1.9 Organization of the Thesis

The thesis is structured into six chapters, moving from context to analysis and recommendations for sun-breakers in Addis Ababa's CBD. Chapter One introduces the study, objectives, research questions, case studies, scope, significance, and limitations. Chapter Two reviews literature on passive design, building envelopes, solar geometry, and sun-breaker history. Chapter Three outlines the mixed-methods research design, data collection, and analysis framework. Chapters Four and Five present results on geometric performance and aesthetic perception, and synthesize functional and visual findings. Chapter Six concludes with key findings, orientation-specific recommendations, and guidance for policy, design, and future research.

CHAPTER TWO

LITERATURE REVIEW

2.1. THEORETICAL REVIEW

2.1.1 Passive Design in Buildings

Passive Design and the Role of Sun Breakers in High-Rise Buildings

Passive design refers to architectural strategies that reduce dependence on mechanical heating and cooling systems by responding to climate through orientation, geometry, shading, and ventilation (Al-Obaidi & Ismail, 2011; Givoni, 1994). Central to passive design is passive solar control, which manages solar radiation through façade configuration and external shading systems (Wright, 2014).

Principles of Passive Design

Passive design integrates four key environmental strategies: solar control, daylight optimization, natural ventilation, and thermal mass utilization. Reinhart (2006) emphasizes that maximizing daylight reduces artificial lighting demand while improving occupant well-being. However, excessive solar exposure—especially through glazed façades—can increase cooling loads, making external shading devices essential (Olgyay, 2015).

Figure 2.1 illustrates passive design strategies emphasizing building geometry, orientation, solar access, and shading principles for high-rise environmental control. **Table 2.1** outlines key passive design variables influencing sun-breaker effectiveness, detailing their functional and aesthetic impacts.

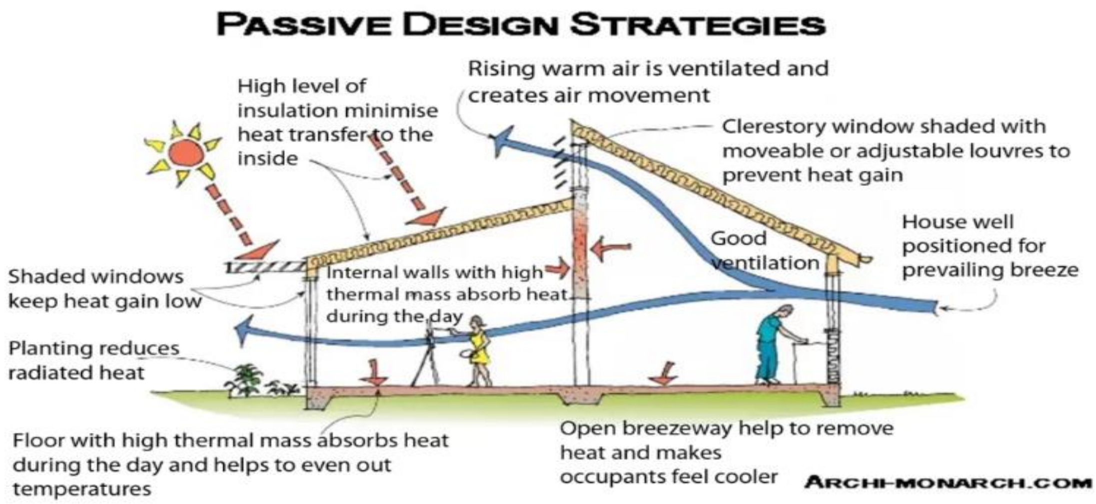


Figure 2.1: Passive design strategies.

Source. Adapted from archimonarch.com., Accessed Date: April 10, 2025

Building Geometry Orientation, Solar Access, and Shading

Building geometry and orientation critically influence environmental performance, particularly in high-rise structures. The surface-area-to-volume ratio governs heat exchange efficiency, while façade orientation determines solar exposure, with east–west façades receiving high low-angle radiation (Baker et al., 2017; Brown & DeKay, 2001). Complex geometries can enhance shading effectiveness and contribute to aesthetic articulation, creating a dual impact on thermal regulation and visual character (Attia et al., 2009). Horizontal shading devices are effective against high-altitude midday sun, whereas vertical fins mitigate low-angle morning and afternoon solar gain (Olgyay, 2015).

Table 2.1: Passive Design Variables Influencing Sun Breaker

Variable	Functional Impact	Aesthetic Impact
Orientation	Controls solar gain and ventilation	Determines façade exposure and symmetry
Geometry (Form & Massing)	Influences heat exchange efficiency	Creates visual articulation and urban identity
Shading Depth & Spacing	Reduces heat gain and glare	Affects façade rhythm and transparency
Daylight Control	Enhances visual comfort	Shapes interior-exterior visual connection

Source: Synthesized from Al-Obaidi & Ismail (2011); Olgyay (2015); Baker et al. (2017). Accessed Date: January 15, 2026

2.1.2 High-rise buildings

High-rise buildings have become a central feature of contemporary urban development, enabling vertical densification while shaping urban identity and microclimatic conditions (Hall & Frampton, 1997; CVU, 2025). In such structures, façades serve as the primary environmental interface, with glazing extent, orientation, and height influencing solar exposure, glare, and heat gain. In warm highland climates, extensive glazing without adequate shading increases cooling demand, making sun-breakers and other shading devices essential for environmental regulation. While these elements improve thermal performance, their integration also affects façade proportions, depth articulation, and urban aesthetics. This underscores the ongoing tension between functional performance and architectural expression (Hall & Frampton, 1997; CVU, 2025).

Table 2.2 summarizes key characteristics of high-rise buildings in Addis Ababa's CBD, detailing environmental and aesthetic implications of increased height, high glazing ratios, zoning above 70m, and curtain-wall systems. **Figure 2.2** visually illustrates the relationship between high-rise growth and façade performance challenges.

Table 2.2: Characteristics of High-Rise Development and Their Implications

Characteristic	Environmental Implication	Aesthetic Implication
Increased Height	Greater solar and wind exposure	Enhanced urban visibility
High Glazing Ratio	Increased heat gain and glare	Transparent, modern image
Zoning for >70 m (Zone 1)	Concentrated vertical density	Iconic urban landmarks
Curtain-Wall Systems	Dependence on mechanical cooling	Sleek façade expression

Source: Synthesized from Emporis (2019); AACPPO (2017); Hall & Frampton (1997). Accessed Date: January 15, 2026

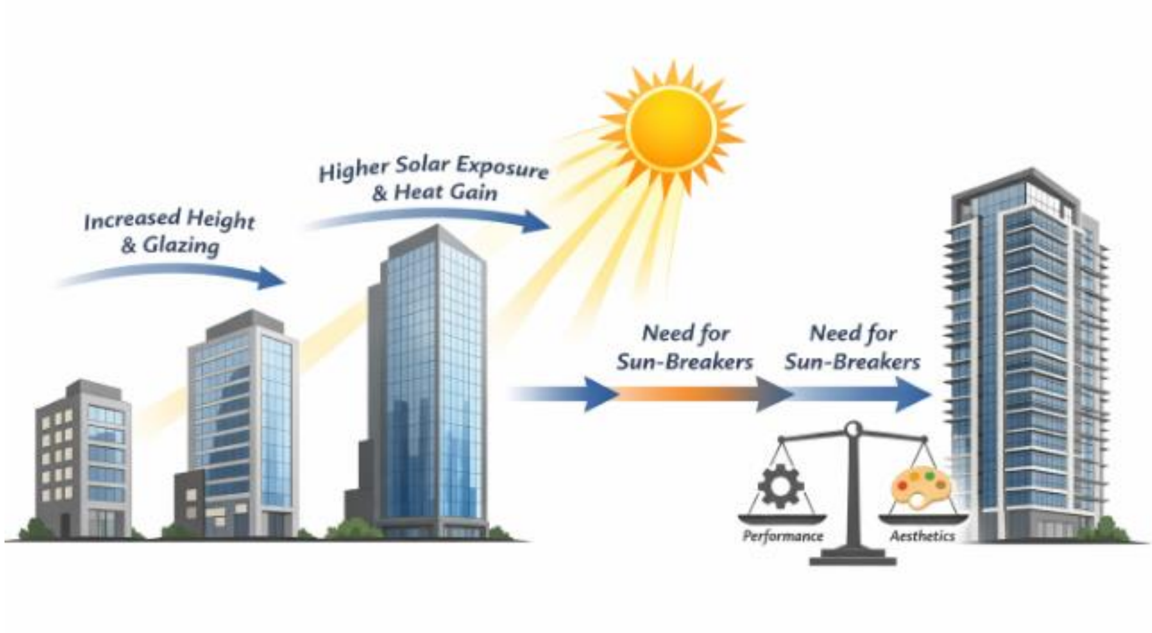


Figure 2.2: Relationship Between High-Rise Growth and Façade Performance

2.1.3 Building Envelope and Sun Breakers in High-Rise

The building envelope constitutes the principal environmental mediator between interior and exterior conditions. Comprising walls, glazing systems, roofs, and structural interfaces, it determines thermal transfer, daylight penetration, and air exchange (ASHRAE, 2017; Straube, 2012). In high-rise buildings—where façades are extensively glazed—the envelope becomes the primary determinant of environmental performance. Consequently, external shading devices, particularly sun breakers, are critical components in balancing energy efficiency with architectural expression.

Shading Devices and Environmental Performance

Shading devices play a critical role in controlling solar heat gain while maintaining daylight and visual comfort. Fixed systems, including overhangs, fins, and brise-soleils, can block 60–80% of solar radiation when aligned with orientation and solar geometry (Givoni, 1998; Kamal, 2011). Dynamic systems further optimize indoor conditions, sustaining illuminance between 300–500 lux and reducing glare by up to 90% (Hensen, 2011). In high-rise curtain-wall buildings, excessive glazing elevates cooling and glare risks; however, well-designed external shading can lower cooling demand by 20–40% and HVAC loads by up to 30% (Buvens et al., 2020; Turan et al., 2007). Orientation-based strategies—horizontal shading for high-angle sun, vertical fins for east–west façades, multidirectional egg-crate systems, and sensor-driven dynamic façades—enhance performance through geometric and climatic calibration (Duffie & Beckman, 2013; Yoo & Manz, 2011).

Table 2.3 quantifies performance impacts of major sun-breaker typologies across heat gain, glare, and cooling energy reduction metrics. **Figure 2.3** illustrates their dual environmental regulation and aesthetic expression roles in high-rise façades.

Table 2.3: Performance Impact of Major Sun Breaker Typologies

Sun Breaker Type	Heat Gain Reduction (%)	Glare Reduction (%)	Cooling Energy Reduction (%)
Horizontal Fins	30–40	40–60	15–25
Vertical Fins	25–35	40–60	15–25
Egg-Crate Systems	30–40	50–70	20–30
Dynamic Systems	40–50	Up to 90	25–35

Source: Synthesized from Al-Obaidi et al. (2014); Dubois & Blomsterberg (2011); Yoo & Manz (2011).

Historical and Aesthetic Dimensions of Sun Breakers

Sun breakers possess deep historical roots. Traditional systems such as the Mashrabiya and Jali combined shading, ventilation, and privacy while generating distinctive light patterns (Fathy, 1986). In modern architecture, Le Corbusier formalized the brise-soleil as a defining façade element, notably in the Unité d'Habitation, where shading devices shaped both environmental control and aesthetic identity (Curtis, 1986).

Contemporary high-rise buildings reinterpret these principles using advanced materials and parametric systems. Beyond thermal regulation, sun breakers articulate façade depth, rhythm, and shadow play—contributing significantly to architectural identity (Muluneh et al., 2021).

Figure 2.3: Environmental and Aesthetic Articulation of Sun Breakers

2.1.4 Solar Geometry and Climatic for Façade Performance

Solar geometry forms the scientific basis for climate-responsive façade design, directly influencing the functionality and visual articulation of sun breakers in high-rise buildings. Solar path analysis enables architects to predict solar altitude, azimuth, and seasonal variation, thereby optimizing shading strategies to control heat gain, glare, and daylight distribution (Szokolay, 2014; Olgyay, 2015.

Solar Radiation and Façade Performance

Uncontrolled solar gains through glazed façades in high-rise buildings significantly increase indoor temperatures and peak cooling demand, intensifying reliance on mechanical systems (ASHRAE, 2021; Givoni, 1998). External sun breakers intercept solar radiation before it penetrates glazing, stabilizing mean radiant temperatures and enhancing comfort (Olgyay, 2015). In addition to thermal regulation, shading devices improve daylight quality by reducing glare and uneven illumination while maintaining useful indoor illuminance (Reinhart & Wienold, 2011). Orientation plays a key role in shading effectiveness: horizontal overhangs mitigate high-angle midday sun on south façades, whereas vertical fins control low-angle radiation on east–west façades (Duffie & Beckman, 2013

Table 2.4 outlines orientation-specific solar conditions, primary risks, and recommended shading strategies for optimal façade performance. **Figure 2.4** illustrates solar geometry and façade responses at Addis Ababa's 9°N latitude.

Table 2.4: Orientation-Specific Solar Conditions and Shading

Orientation	Dominant Solar Condition	Primary Risk	Recommended Shading Strategy
North	Diffuse light, seasonal exposure	Daylight imbalance	Light-modulating screens
South	High-altitude midday sun	Overheating	Horizontal overhangs
East	Low-angle morning sun	Glare, heat gain	Vertical fins
West	Low-angle afternoon sun	Peak cooling load, glare	Vertical or egg-crate systems

Source: Synthesized from Givoni (1998); Olgyay (2015); Szokolay (2014).

Solar Angles and Shading Logic

Solar altitude (α)

Solar altitude (α) determines the vertical position of the sun and influences shadow length and façade penetration depth. At summer solstice, solar noon altitude can reach approximately 81.5°, making horizontal devices highly effective (Szokolay, 2014). During mornings and afternoons, altitude drops below 30°, producing long shadows and deep glare penetration that horizontal shading alone cannot mitigate.

Solar azimuth (γ)

Solar azimuth (γ) defines horizontal sun movement. In equatorial climates, azimuth shifts allow sunlight to strike both north and south façades seasonally (Johansson & Emmanuel, 2006).

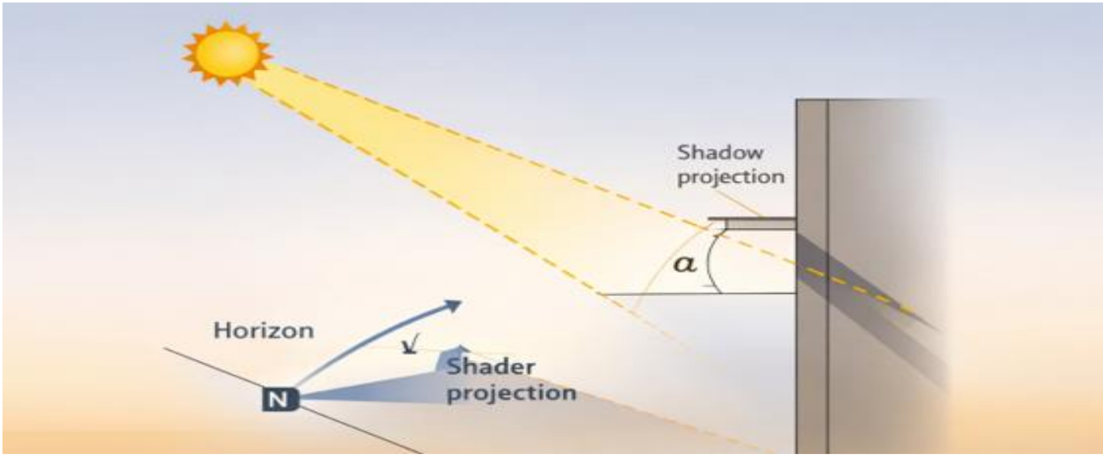


Figure 2.4: Solar Geometry and Façade Response at Latitude 9°N

Source: Adapted from solar geometry principles and sun-path diagrams for Addis Ababa (Latitude 9° N), Accessed: January 15 March 2026.

Climatic Context and Design Implications

Addis Ababa's highland climate (Köppen Cwb) is characterized by moderate annual temperatures (16–20°C mean) but intense solar radiation and significant diurnal variation. While ambient air temperatures may appear mild, solar gains through extensive glazing create localized overheating in high-rise interiors. Consequently, façade design must prioritize solar modulation despite moderate climatic averages.

The literature indicates that effective solar-responsive shading can reduce cooling loads by 20–40% while enhancing daylight quality (ASHRAE, 2021; Reinhart & Wienold, 2011). However, the visual impact of horizontal fins, vertical screens, or egg-crate systems inevitably transforms façade depth, rhythm, and transparency. **Table 2.5** details annual solar altitude variations in Addis Ababa (9°N) and their shading design implications across seasons. **Table 2.6** presents monthly solar altitude patterns at sunrise, sunset, and solar noon, informing year-round orientation-specific strategies.

*Table 2.5**:** Annual Solar Altitude Variations and Shading Design Implications*

Date	Noon Altitude	Solar Condition	Shading Design Implication
June 21	~81.5°	Very high sun	Horizontal overhangs highly effective

March / Sept	~81°	Near-zenith sun	Minimal façade exposure at noon; control needed for morning/afternoon
Dec 21	~57.5°	Lower but still high	Overhang depth must consider winter penetration
Year-round	Wide azimuth variation	Morning and afternoon exposure	Vertical fins essential, especially east/west

Source. Szokolay, S. V. (2014). *Introduction to Architectural Science: The Basis of Sustainable Design* (3rd ed.). Routledge. **Accessed Date:** March 2, 2025.

Table 2.6: Monthly Solar Altitude Variations at Sunrise, Sunset, and Solar Noon

Month	Sunrise Altitude	Sunset Altitude	Solar Noon Altitude
January	11°	10°	71°
April	28°	29°	77°
July	38°	38°	81°
October	21°	20°	78°

Source: Solar geometry calculation tools (e.g., NOAA Solar Calculator)

2.1.5 Sun-Breaker Design: Geometry and Performance Evaluation

The performance of sun breakers in high-rise buildings depends on their geometric configuration and orientation relative to solar exposure. Properly designed devices act as both aesthetic elements and environmental regulators, influencing comfort and energy demand (Givoni, 1998; Szokolay, 2014). Effective shading aligns fin depth and spacing with solar altitude: horizontal overhangs for high-angle sun, vertical fins for low-angle exposure, and egg-crate or dynamic systems for multidirectional protection (Al-Obaidi et al., 2014).

Figure 2.5 illustrates key dimensions of sun-breakers including fin depth, spacing, and projection, critical for solar shading optimization and heat gain control. **Table 2.7** presents geometric parameters and performance implications across typologies like horizontal, vertical, egg-crate, and dynamic systems.

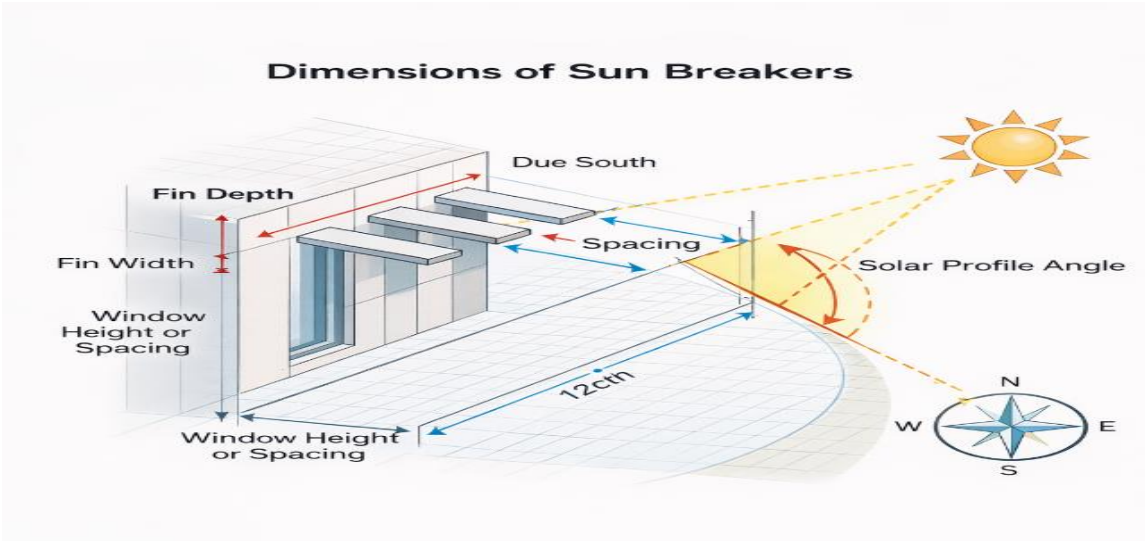


Figure 2.5: Dimensions of Sun Breakers

Source. Olgyay, V. (2015). *Design with Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton University Press.

Table 2.7: Geometric Parameters and Performance Implications of Sun-Breaker

Typology	Depth (m)	Spacing (m)	Primary Solar Control	Performance Implication
Horizontal	0.5–1.5	0.3–0.6	High-angle sun (>45°)	Controls noon overheating
Vertical	1.0–2.0	0.3–0.6	Low-angle sun (<45°)	Reduces glare & peak load
Egg-Crate	0.5–1.5	0.3–0.6	Multi-angle	Balanced shading
Dynamic	Adjustable	Adjustable	Variable	Optimized energy response

Source: Synthesized from Givoni (1998) and Al-Obaidi et al. (2014).

Quantitative Performance Metrics

Quantitative performance metrics are essential for designing effective sun breakers in buildings. Solar altitude determines the angle of sunlight at different times of the year, guiding the placement, depth, and orientation of shading elements. The cut-off angle indicates the solar altitude at which a device begins to block direct sunlight, varying for horizontal and vertical systems. The shading factor (SF) quantifies the relative effectiveness of sun breakers in reducing solar gain, influencing comfort and daylight penetration. Together with solar radiation and hour angle calculations, these metrics allow designers to optimize sun-breaker geometry for both energy efficiency and occupant comfort. **Table 2.8** presents the quantitative performance metrics and formulas essential for rigorously evaluating sun-breaker effectiveness in architectural design.

Table 2.8: Quantitative Performance Metrics for Sun-Breaker Evaluation

Metric	Formula /	Variables &	Performance / Use	Source
Solar Altitude (α)	$\alpha = 90° - \|$ Latitude − Declination |	Latitude − Declination	**α** = Solar altitude at solar noon (°) **Latitude** = Geographic latitude of site (°N, Addis Ababa ≈ 9°) **δ** = Solar declination on the day of interest (°)	Determines the sun's incident angle at solar noon, guiding the optimal placement, depth, and orientation of sun-breaker elements
Cut-Off Angle (θ(cutoff))	**Vertical fins:** $\tan \theta_{\text{cutoff}} = \frac{\text{Fin Depth}}{\text{Spacing}}$ **Horizontal shading:** $\tan \theta_{\text{cutoff}} = \frac{\text{Depth}}{\text{Window Height}}$	**θ(cutoff)** = Solar altitude at which direct sunlight is blocked (°) **D** = Depth/projection of shading element (m) **S** = Horizontal spacing between vertical fins (m) **H** = Window or glazed opening height (m)	Defines the solar altitude at which a sun breaker starts blocking direct sunlight, predicting shading effectiveness for specific façade orientations	Oligay (2018); Watson & Labs (2019)
Shading Factor (SF)	$SF = \frac{\text{Fin Depth}}{\text{Spacing}}$	**SF** = Shading effectiveness ratio **D** = Fin depth (m) **S** = Fin spacing (m)	Quantifies relative effectiveness of a sun breaker in obstructing solar radiation, impacting thermal comfort, daylight, and solar heat gain	Watson & Labs (2019)
Solar Radiation Reduction (%)	Radiation Reduction = (1 − SF) × 100	Estimates percentage of solar radiation blocked by sun breaker based on SF (100% = full blockage, 0% = none)	Evaluates energy savings and empirical solar reduction for different sun-breaker designs	Oligay (2018)
Hour Angle (h)	h = 15° × (Solar Time − 12)	**h** = Hour angle (°), representing sun's position relative to solar noon **Solar Time** = Time at location (hours)	Determines sun position throughout the day, essential for orientation-specific sun-breaker design	Oligay (2018)

2.1.6 Solar Geometry of Addis Ababa

Solar geometry drives façade shading performance in near-equatorial Addis Ababa (9° N), where high solar altitudes and moderate seasonal shifts demand effective permanent sun-breaker systems on high-rises.

Solar Geometry of Addis Ababa (9°N)

For Addis Ababa (9° N), the solar protractor shows sun altitudes peaking at 81° (equinox), 75.5° (summer solstice), and 57.5° (winter solstice), dictating shading device ranges. East/west façades face low morning/afternoon angles, while south gets high noon radiation—calling for orientation-tailored shading over uniform designs.

Figure 2.6 presents the solar protractor for Addis Ababa at 9°N latitude, highlighting the critical 10:00–16:00 solar window for peak radiation. **Figure 2.7** overlays shading masks on sun path diagrams, revealing device effectiveness during these hours. **Figure 2.8** connects shading masks directly to sun-breaker configurations.

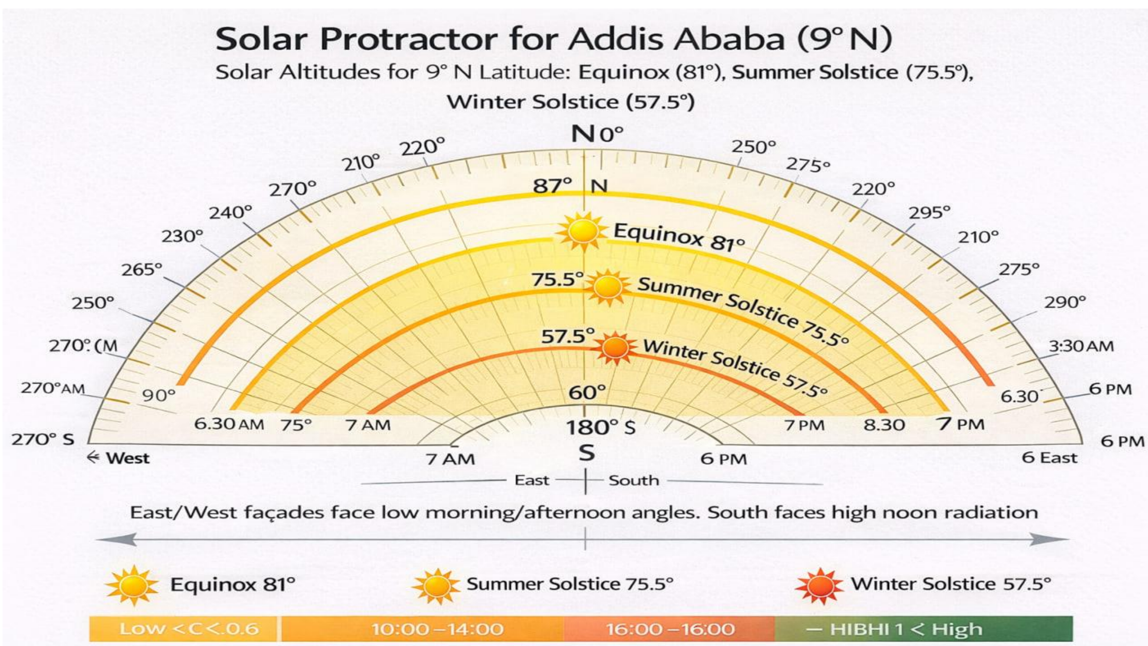


Figure 2.6: Solar Protractor for Addis Ababa (Latitude 9°N),

Accessed Date: March 10, 2026

Sun Path Diagram and the 10:00–16:00 Solar Window

At 9° N latitude, the sun path diagram highlights the critical 10:00–16:00 solar window for peak radiation and thermal impact in tropical climates. East façades hit mornings (10:00–12:00), south at noon (12:00–13:00) with high angles, and west afternoons (14:00–16:00) with tricky low angles—guiding sun-breaker evaluations for the four buildings.

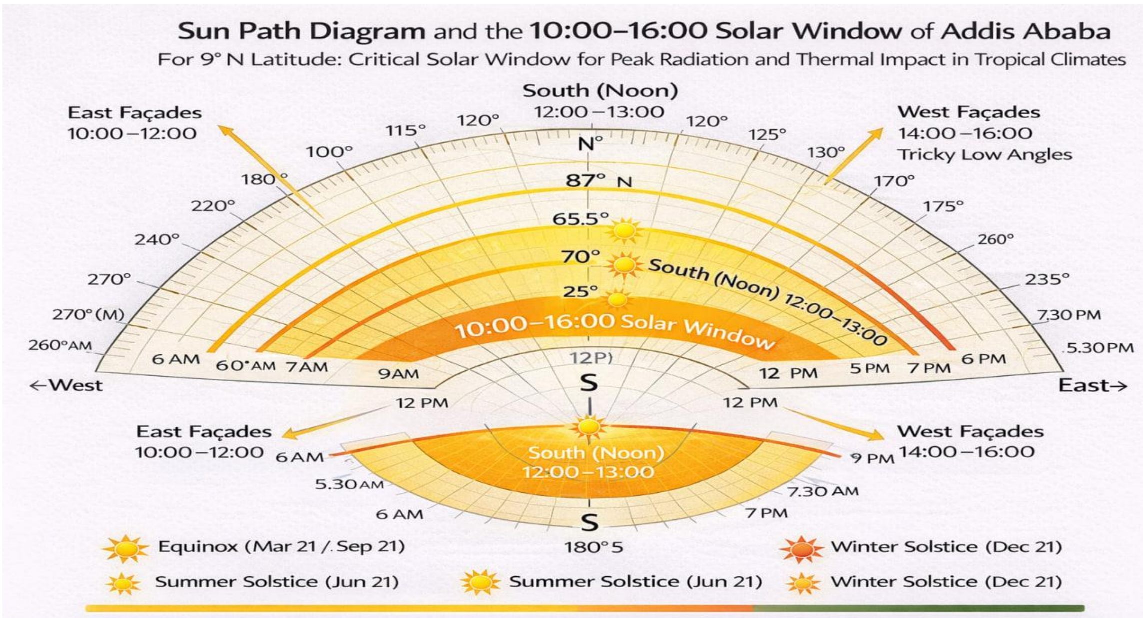


Figure 2.7: Sun Path Diagram for Addis Ababa (Latitude 9°N),

Accessed Date: March 10, 2026

Shading Mask of Addis Ababa

Shading masks overlay sun paths on diagrams to show sky portions blocked by devices from windows, revealing effectiveness during peak hours. For the studied buildings, dense vertical fins with high cut-off angles create large masks for strong interception, while sparse or shallow systems yield small masks and poor solar blocking.

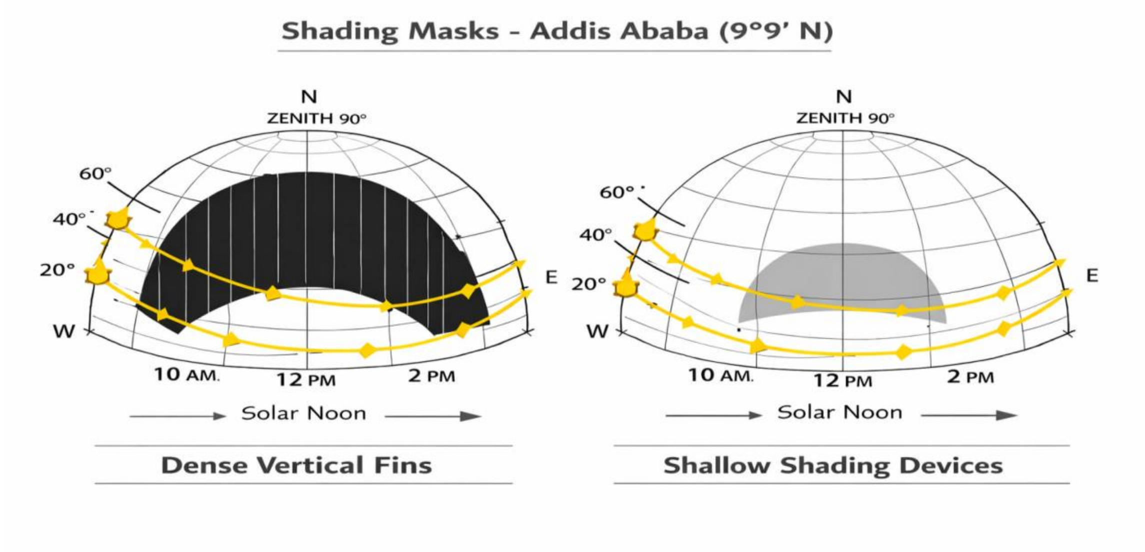


Figure 2.8: Shading Mask to Sun Breakers.

2.2 CONTEXTUAL REVIEW

Addis Ababa has experienced rapid vertical growth since the early 2000s due to economic expansion and limited land availability, resulting in over 100 tall buildings by 2019 (Geda, 2018; Emporis, 2019; World Bank, 2019). Zoning regulations categorize building heights, with Zone 1 allowing structures above 70 meters, concentrating high-rise development in districts like Bole and Kazanchis (AACPPO, 2017; Tadesse & Bekele, 2019). Although these policies address structural safety and urban density, they provide limited guidance on façade performance. As a result, many new central business district towers feature high glazing ratios with minimal external shading, increasing reliance on mechanical cooling and highlighting a tension between modern glass façades and climate-responsive design (Fikade, 2020).

2.2.1 Sun Breakers in Ethiopia

Traditional Ethiopian architecture relied on massing, window placement, and natural ventilation for thermal comfort (Banham, 1984). However, modern high-rise buildings in Addis Ababa with extensive glazing now require external shading devices to mitigate overheating and glare, yet current building regulations do not explicitly mandate their use, indicating a historical and regulatory gap (Gebreyohannes, 2021).

The geometry of sun breakers—fin depth, spacing, and angle—critically influences their effectiveness. Horizontal overhangs block high-angle midday sun, vertical fins control low-angle morning and afternoon sunlight, egg-crate systems provide multidirectional shading, and dynamic systems adjust to solar movement (Bellia et al., 2014). Simulations in Addis Ababa show that orientation-specific designs can reduce solar heat gain by up to 84% on west façades, emphasizing the need to integrate local solar geometry in façade design (Gebreyohannes, 2021; Ferrari & Wang, 2023).

Orientation critically affects shading effectiveness. East and west façades require vertical or multidirectional shading, whereas south façades benefit from horizontal overhangs. Properly aligned designs optimize daylight access, reduce overheating, and enhance thermal comfort (Bellia et al., 2014; Mandalaki & Tsoutsos, 2020). Despite these findings, research gaps remain in Ethiopia regarding dynamic or adaptive sun breakers, occupant comfort, long-term performance, material durability, and aesthetic integration (Kirimat, 2026; Daneshi et al., 2022).

Other considerations include the limited effectiveness of internal shading solutions like blinds, which only intercept sunlight after it enters the interior (Menberu, 2020). Integrating external sun breakers early in the design process improves energy efficiency and supports sustainable architectural outcomes. Aesthetic and urban design implications are underexplored, emphasizing the need for frameworks that balance environmental and visual objectives.

In conclusion, sun breakers in Ethiopia serve a dual role: environmental regulation and aesthetic articulation. While international research provides guidance on geometric design, materials, and orientation strategies, local studies are limited and focus primarily on fixed devices. Addressing gaps in dynamic shading, material evaluation, and occupant comfort studies will enhance the sustainability, energy performance, and visual quality of high-rise buildings in Addis Ababa.

2.2.1 Sun Breakers in Addis Ababa

Addis Ababa's urban form and façade design have been shaped by successive political regimes and foreign influences, each leaving distinct marks on the integration of sun breakers in architecture. Early residential patterns, defined by the *sefer* system, relied on mud and straw construction, where passive solar control was achieved through building massing, small window openings, and shading from roof overhangs rather than formal sun breakers (Zewde, 2002). Imperial-era landmarks, such as the Old Gebi Palace, incorporated imported architectural styles, but sun-shading devices remained rudimentary, emphasizing daylight management and thermal comfort for elite interiors.

Italian occupation (1936–1941)

During the Italian occupation (1936–1941), Addis Ababa saw the introduction of formal urban planning, civic spaces like the Piazza district, and durable materials such as stone and reinforced concrete, which enabled early large-scale sun-shading applications in governmental buildings. These interventions established modernist urban aesthetics and provided a foundation for experimenting with sun breaker geometry, orientation, and materials. **Figure 2.1** illustrates landmarks from this era, including the Electric Building (1940), where the concrete sun breaker demonstrates one of the city's first functional and large-scale solar control implementations.

Figure 2.9: Italian Occupation Sun Breaker styles in Addis Ababa

Source: https://www.ethiopians.com/Engineering/Addis_Historical_Buildings.htm,

URL: https://www.ethiopians.com/Engineering/Addis_Historical_Buildings.htm,

Accessed Date: March 10, 2026

Post Italian occupation

Post-war modernization under Emperor Haile Selassie favored concrete-based modernist architecture, as seen in Africa Hall and Kebele housing, where sun breakers were minimal and design prioritized monumental form over climate responsiveness. **Figure 2.2** highlights post-Italian occupation landmarks, including the Hilton Hotel (1974) and the National Bank, where the concrete brise-soleil demonstrates early large-scale integration of functional sun-shading with modernist façades.

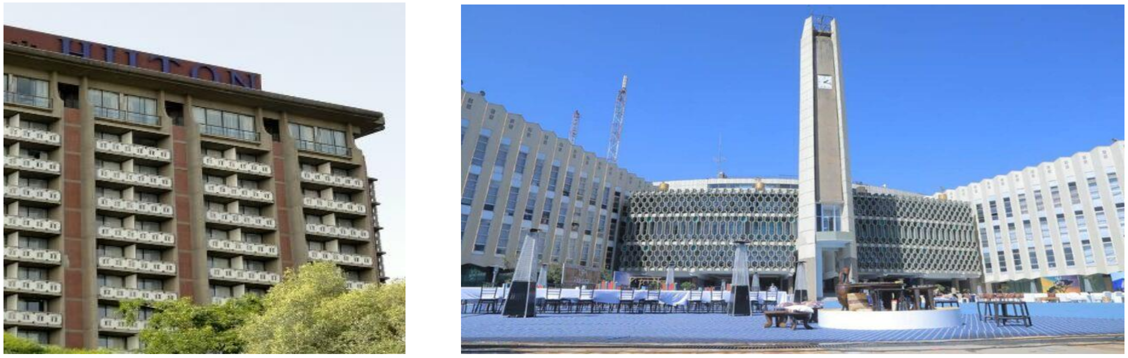


Figure 2.10: Post-Italian Occupation Sun Breaker styles in Addis Ababa

Source: Wikipedia entry for Hilton Addis (hotel in Addis Ababa, Ethiopia), , URL: https://en.wikipedia.org/wiki/Hilton_Addis,

Accessed on: April 7, 2026

Derg era (1974–1991)

During the Derg regime (1974–1991), mid-rise concrete apartments emphasized rapid construction, with little to no sun-breaker integration, reflecting utilitarian priorities. During this time, standardized apartment blocks feature minimal sun-breaker integration, reflecting the period's focus on rapid housing delivery. The figure highlights the utilitarian architectural approach with limited attention to passive solar control. **Figure 2.3** shows mid-rise residential buildings from the Derg era (1974–1991) in Addis Ababa.

Figure 2.11: Sun Breaker styles from the Derg Era (1974–1991)

Contemporary Sun Breaker (1991 to the Present)

Following the 1991 economic liberalization, high-rise commercial and residential buildings in Addis Ababa began incorporating contemporary sun breakers featuring advanced geometry, modern materials, and orientation-specific designs. These devices effectively balance solar control, daylight access, and architectural expression. **Figure 2.4** illustrates sun breaker applications on the Renaissance and Sur Buildings, demonstrating integration of functional shading with façade design to optimize environmental performance and visual appeal.

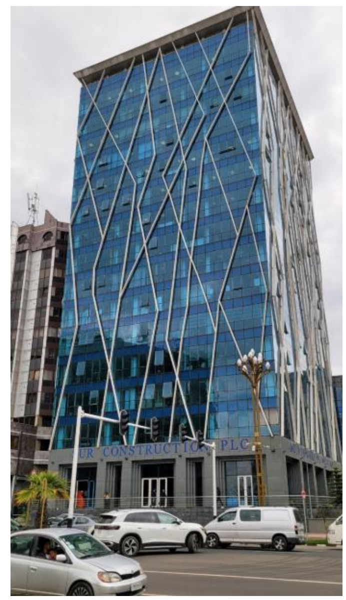


Figure 2.12: Sun Breaker Applications on the Renaissance and Sur Buildings

Evolution of Sun Breakers (1950s–2000s)

Sun breakers in Addis Ababa have evolved significantly in response to architectural, cultural, and technological shifts (Assefa, 2020). **Table 2.9:** Evolution of Sun Breakers in Addis Ababa (1950s–2000s) summarizes the progressive development of shading devices across five decades, tracing geometric, material, and design philosophy transformations.

Table 2.9: Evolution of Sun Breakers in Addis Ababa (1950s–2000s)

Era	Geometry & Projection	Materials	Design Focus / Notes

1950s–1960s	Simple horizontal and vertical elements, projection 0.4–0.6 m	Clay, stone	Function-driven solar protection, basic geometric forms (Jackson, 2015)
1970s	Increased size (0.6–1 m), more precise orientation	Concrete, metal	Technical refinement, research on airflow and performance (Givoni, 1998)
1980s–1990s	Larger elements (1–1.2 m), expressive forms	Wood, recycled materials, mixed metals	Aesthetic integration, symbolic and sculptural significance (Jencks, 2002)
2000s–Present	Optimized projection, dynamic or complex shapes	Composites, aluminum, glass, steel	Computational design, performance-aesthetic integration (Yoo & Manz, 2011)

Sun Breaker Typologies

Horizontal Overhangs

Horizontal overhangs on the Ministry of Foreign Affairs and Ethiopian Insurance buildings protect interiors from high-angle summer sun, with performance depending on depth, spacing, and orientation. **Figure 2.4** shows these deep, linear overhangs, reflecting mid-century modernist principles in Addis Ababa. The figure emphasizes how solar geometry was applied to integrate functional shading with structural and aesthetic design.

Figure 2.13: Sun Breakers on Ministry of Foreign Affairs, and Ethiopian Insurance

Source: LinkedIn, Specific Page / Title: Ministry of Foreign Affairs building, Author / Publisher: MFA Ethiopia (Ministry of Foreign Affairs Ethiopia),

URL: https://www.linkedin.com/pulse/ministry-foreign-affairs-building-mfaethiopia
Accessed on: April 7, 2026

Vertical Fins

Vertical fins on the Finfinnee and Temama Fok Buildings manage low-angle east and west sunlight, evolving from hand-calculated to aerodynamically optimized designs. **Figure 2.5** illustrates these fins, showing their role in reducing glare and improving thermal comfort. The figure also highlights how vertical sun breakers define the buildings' vertical rhythm and enhance overall façade expression.

Figure 2.14: Sun Breakers on Finfinnee Building (A) and Temama Fok Building (B)

Web Data Source: iStock (by Getty Images), URL: https://www.istockphoto.com/)Credit / Contributor: mtcurado, Accessed Date: March 15, 2026

Egg-Crate Systems

Egg-crate systems on the Bedelu Building and Ghion Hotel combine horizontal and vertical elements for multi-directional shading. **Figure 2.6** shows their evolution from simple louvers to climate-responsive grids. These integrated devices balance sunlight control with façade aesthetics.

Figure 2.15: Sun Breakers on Bedelu Building (A) and Ghion Hotel (B)

Web Data Source: TripAdvisor, Specific Page / Title: GHION HOTEL - Prices & Reviews (Addis Ababa, Ethiopia), URL: *https://www.tripadvisor.com/Hotel_Review-g293791-d557395-Reviews-Ghion_Hotel-Addis_Ababa.html*, Accessed Date: March 15, 2026

Perforated Screens

Perforated screens on the Lideta Mercato and Flamingo Buildings provide shading while allowing daylight and incorporating cultural motifs. **Figure 2.7** illustrates their evolution from simple patterns to adjustable, expressive façades. These screens integrate functional solar control with aesthetic and cultural expression.

Figure 2.16: Sun Breakers on Lideta Merkato Building (A) and Flamingo Building (B)

Web Data Source: ArchDaily, Specific Page / Title: Lideta Market / Vilalta Studio, URL: https://www.archdaily.com/789535/lideta-market-vilalta-arquitectura, Accessed Date: January 2, 2026

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The study examined the "sun-breaker dichotomy" in Addis Ababa's Central Business District, analyzing how façade shading devices mediate the tension between environmental performance and cultural-aesthetic expression. It focused on high-rise buildings in Kirkos, Lideta, and Arada sub-cities, which combine modern architectural forms with traditional Ethiopian design influences. Located at 9°N latitude and over 2,300 meters elevation, Addis Ababa experiences an equatorial highland climate (Köppen Cwb) with intense year-round solar radiation, making sun-breaker design critical for building performance (Mesfin, 2020). Over the past two decades, the CBD has undergone rapid vertical growth, with numerous commercial and mixed-use high-rises concentrated around the financial core, including the four selected bank headquarters within a 2-kilometer radius. **Figure 3.1** shows the geographical context of the study area from Africa to Ethiopia and the city of Addis Ababa. It highlights the city's location at about 9°N latitude in the Ethiopian highlands, providing spatial context for analyzing solar exposure and sun-breaker performance.

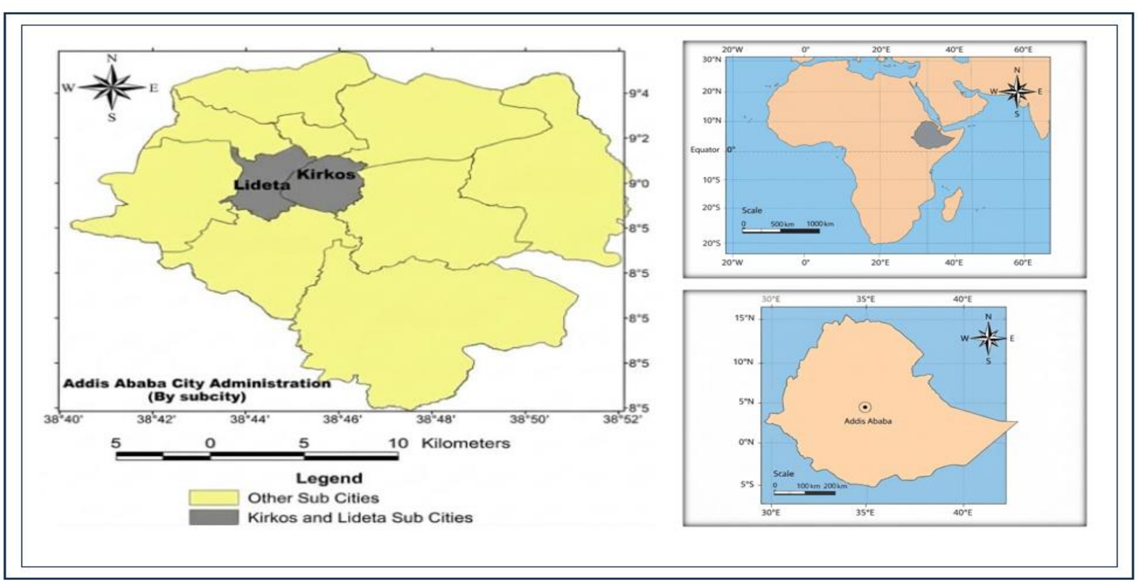


Figure 3.1: Location map of Africa, Ethiopia, and the Addis Ababa

Figure 3.2 shows the specific locations of the selected high-rise buildings within Addis Ababa's Central Business District. It highlights the concentration of commercial and mixed-use structures in Kirkos, Lideta, and Arada sub-cities.

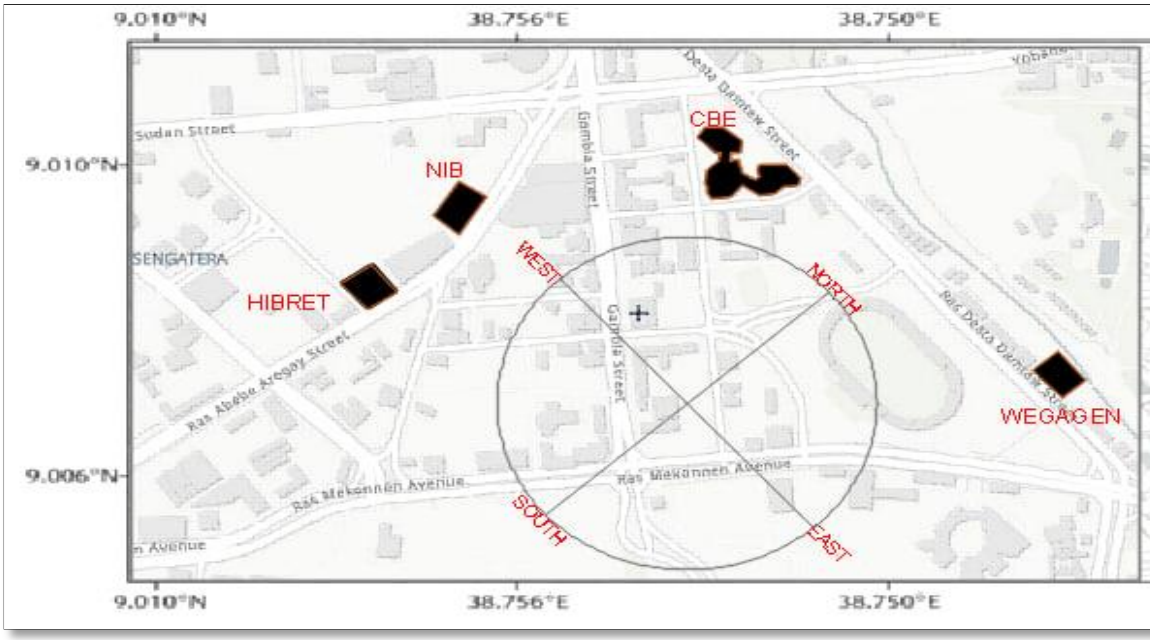


Figure 3.2: Location of e Studied Buildings in Addis Ababa's Central Business District.

3.2 Research Design

The study used a mixed-methods approach to examine sun breakers in high-rise buildings in Addis Ababa as both environmental control devices and architectural aesthetic elements. Quantitative analysis assessed solar shading efficiency, energy reduction, and daylight control, while qualitative analysis evaluated façade rhythm, articulation, and architectural identity.

Through a parallel convergent design, both data types were collected and analyzed independently and then integrated to determine whether sun breakers function mainly for environmental performance or aesthetic expression, helping develop strategies that balance climatic efficiency with urban visual identity.

Figure 3.3 illustrates this integrated research design, highlighting how the general research framework was designed and done.

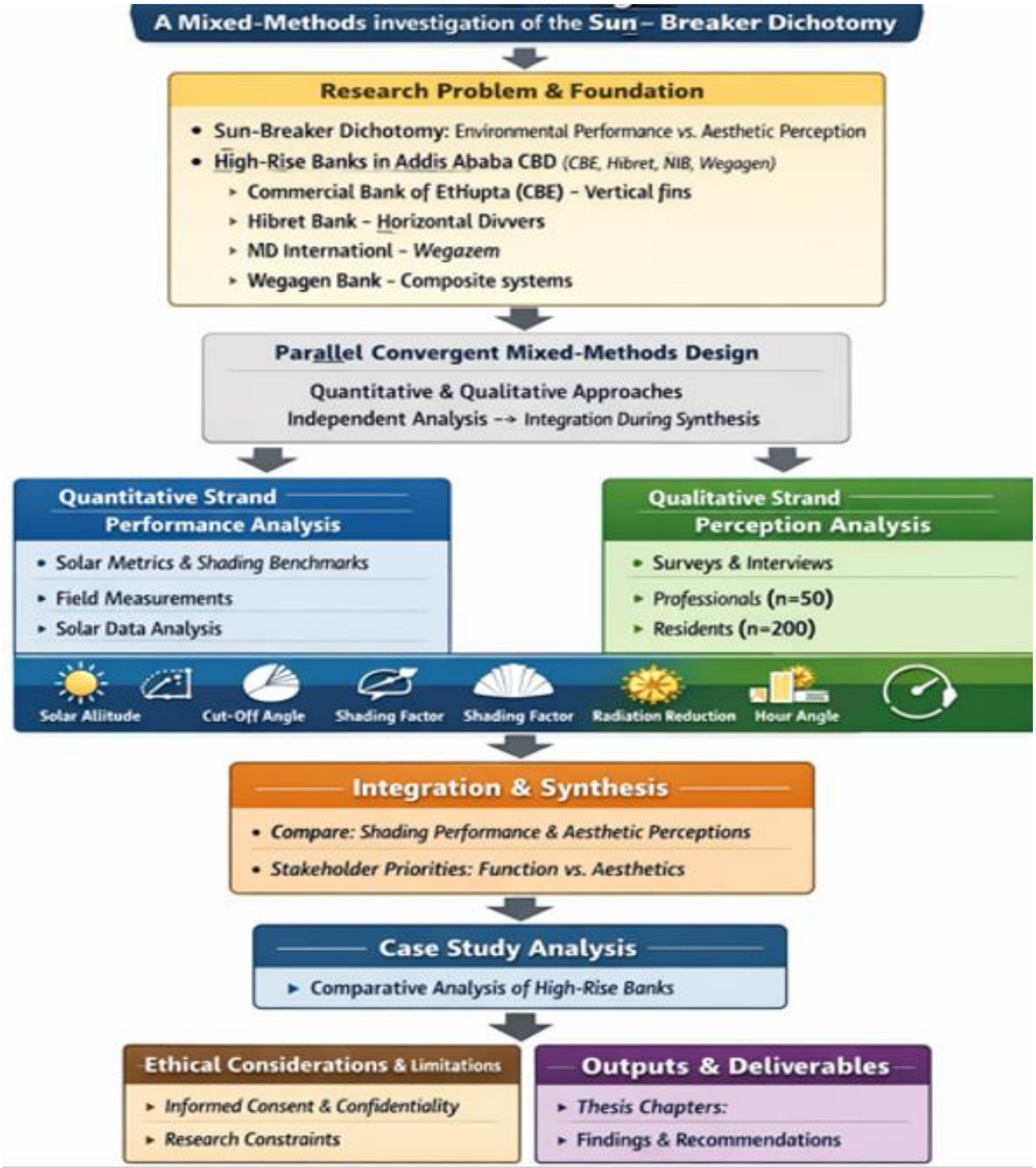


Figure 3.3: Summary of the Overall Research Design.

3.2.1 Evaluation of Performance of Sun Breaker

Purpose:

The purpose was to evaluate the geometric performance of existing permanent sun breakers attached to different façade orientations of the selected buildings.

Research Approaches:

The study adopts a quantitative analytical approach to evaluate the relationship between shading geometry and solar radiation reduction.

Data Needed:

The analysis used geometric measurements of sun breakers, building orientations, the site latitude of Addis Ababa (9°N), solar declination values, and solar radiation data for unshaded façades.

Data Source:

The data sources for this analysis included on-site measurements of selected buildings' façades, published solar geometry data from Oligay (2018) and Watson & Labs (2019), and meteorological and solar radiation datasets specific to Addis Ababa.

Data Collection Method:

Field measurements were conducted to record sun-breaker dimensions and determine façade orientations using a compass. Solar geometry and radiation data were compiled and analyzed for the critical solar period between 10:00 and 16:00.

Participants and Sampling Method:

The study used purposive sampling to select high-rise commercial and mixed-use buildings in Addis Ababa's Central Business District that feature permanent sun breakers on multiple façades.

Data Analysis Method:

Quantitative metrics such as solar altitude, cut-off angle, shading factor, solar radiation reduction, and hour angle were calculated to evaluate shading performance and compare results across different building façades and orientations.

Measurement Type:

All geometric and solar metrics, such as fin depth, spacing, angles, and radiation, are measured on a ratio scale, which provides a continuous numerical basis for precise calculations of solar performance.

Quantitative Performance Metrics:

Quantitative metrics evaluate sun-breaker effectiveness in Addis Ababa (9°N latitude) by integrating sun path analysis and 10:00–16:00 solar window shading masks with core performance indicators. Solar altitude (α) traces the sun's arc from ~40° morning rise through 81° equinox noon peak to low-angle afternoon positions, while cut-off angle (θ_cutoff) defines the maximum blocked angle per façade geometry. The shading factor (SF) quantifies fin depth/spacing ratios (e.g., 0.375 for NIB vertical fins), and radiation reduction (%) measures heat gain decrease, typically 22.5% for moderate systems during critical solar hours.

Sun path diagrams reveal Addis Ababa's near-vertical overhead passage (March equinox solar noon α=81°), demanding vertical fins for south midday control and patterned east grids for variable morning exposure. The 10:00–16:00 shading mask highlights east façades vulnerable to rising sun (40°→70°), south at noon peak, and west low-angle afternoon glare (60°→45°), where NIB's diamond honeycomb east pattern and dense vertical N/S/W fins provide orientation-specific protection.

3.2.2 Evaluation of Aesthetics if Sun Breaker Perception

Purpose:

The purpose of this study is to assess public perceptions of permanent sun breakers installed on high-rise buildings in Addis Ababa’s Central Business District (CBD).

Research Approaches:

A mixed-methods approach was used, combining qualitative evaluation of aesthetic perception with quantitative analysis to capture both expert and public perspectives on façade design.

Data Needed:

The study used interview data on aesthetic perception of sun-breaker geometry for contextual analysis.

Data Source:

The primary data sources were questionnaires and interviews conducted with both professionals and members of the public.

Data Collection Method:

Data were collected through structured questionnaires for professionals and urban residents, along with interviews and focus group discussions on façade aesthetics and visual appeal.

Participants and Sampling:

The study included architects, planners, engineers, policymakers, and building occupants. Using purposive sampling, 50 professionals were selected for their expertise, while 200 urban residents were randomly sampled to represent public perspectives.

Sample Size Calculation (Taro Yamane's formula):

$$n = \frac{N}{1 + N(e)^2}$$

- Professionals: N = 100 → n = 80 → 50 selected for relevance and feasibility
- Urban Residents: N = 2,000 → n ≈ 330 → 200 selected for practical feasibility

Table 3.1 summarizes the study's sampling strategy, including population size, calculated sample size, and selected participants. It distinguishes professionals selected purposively for expertise from urban residents selected randomly to represent diverse public views.

Table 3.1: Sampling Strategy for Professionals and Urban Residents

Group	Population (N)	Formula-Based Sample (n)	Selected Sample	Sampling Method	Justification

Professionals	100	80	50	Purposive	Covers expertise while maintaining practical feasibility
Urban Residents	2000	330	200	Random	Sufficient representation for statistical validity

Rationale: The mixed-methods sampling ensures both the richness of expert knowledge and the diversity of public perceptions, enabling comprehensive analysis of aesthetic preferences and functional considerations.

Data Analysis:

Aesthetic perception was analyzed using thematic analysis of interview, focus group, and survey responses. Descriptive statistics were applied to evaluate rating-based questions related to visual appeal and pattern integration, while comparative analysis was conducted to examine differences between professional and public perspectives.

3.2.3 Evaluation of Integrated Synthesis:

The study applied a cross-case synthesis to link aesthetic evaluation with geometric characteristics and shading performance metrics. This integrated analysis helps develop orientation-specific design recommendations that balance visual aesthetics, cultural expression, and environmental performance. **Table 3.2** outlines the comprehensive framework for evaluating sun-breaker performance and aesthetics across Addis Ababa CBD case studies. **Figure 3.4** summarizes this integrated research design visually.

Table 3.2: Framework for Evaluating Sun-Breaker Performance, and Aesthetic

Analysis Component	Methodological Approach	Analytical Tools / Parameters
Geometry Analysis	Field measurements; architectural drawings	Fin depth (D), Spacing (S), Width (W), Angle, Pattern type
Shading Performance	Quantitative evaluation (reference only)	Cut-off angle, Shading Factor (SF), Radiation reduction
Aesthetic Perception	Thematic coding; descriptive statistics	Pattern rhythm, Cultural motif integration, Visual coherence, Design priorities

Integrated Synthesis	Multi-case comparison; development of design parameters	Orientation-specific recommendations, Aesthetic drivers

Measurement and Ethical Considerations:

Participant responses on visual appeal, pattern preference, motif integration, and perceived coherence were measured using nominal and ordinal scales and analyzed through descriptive coding to identify key themes. Ethical considerations included obtaining informed consent, ensuring confidentiality and voluntary participation, and conducting building documentation from public spaces without disturbing occupants.

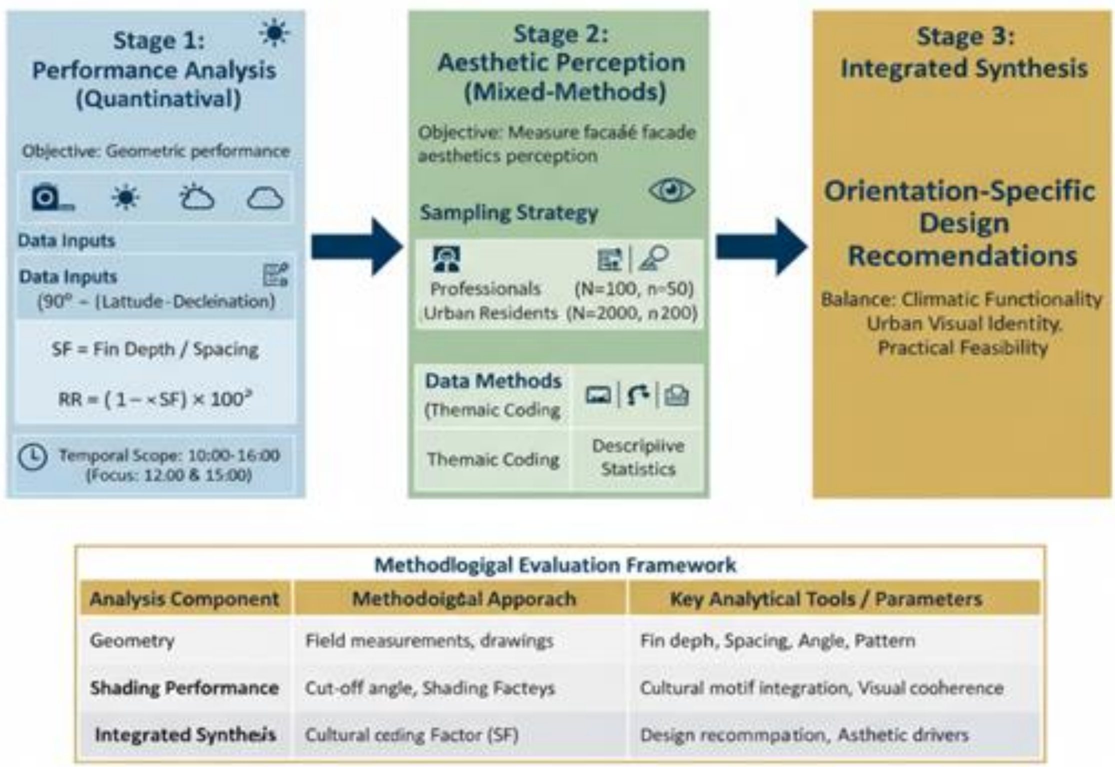


Figure 3.4: Summary of the Performance and Aesthetics Research Design.

3.4 Case Studies

Four landmark bank headquarters in Addis Ababa's CBD were selected to examine how different sun-breaker configurations affect solar control and daylighting performance. Each building demonstrates unique approaches to integrating environmental performance with architectural expression.

3.4.1 Commercial Bank of Ethiopia HQ

The Commercial Bank of Ethiopia (CBE) Headquarters represents a landmark high-rise within Addis Ababa's Central Business District, serving as the primary case study for evaluating sun-breaker performance in equatorial urban environments. **Table 3.3** profiles the Commercial Bank of Ethiopia (CBE) Headquarters, detailing its architectural features and relevance to sun-breaker analysis in Addis Ababa's CBD. **Figure 3.5** visually presents the building's site layout and façade treatment.

Table 3.3: Building Profile of the Commercial Bank of Ethiopia

Feature	Description	Relevance to Sun-Breaker Study
Building Name	Commercial Bank of Ethiopia Headquarters	Primary case study in CBD high-rise sun-breaker analysis
Location	Addis Ababa, Ethiopia (Central Business District)	Central urban context with high solar exposure
Building Type	High-rise commercial office tower	Representative of modern CBD architectural typologies
Height & Floors	209, 48 stories	High-rise status increases exposure to direct solar radiation
Façade Material	Glass curtain walls with concrete framing	Large glazed surfaces increase solar heat gain; sun breakers essential
Sun-Breaker Type	Horizontal overhangs and vertical fins	Combines shading function with façade rhythm and aesthetics
Orientation	North–South–East–West façades	Orientation-specific shading required: horizontal on south, vertical on east/west
Architectural Style	Modernist with functionalist emphasis	Early functional approach prioritizes environmental control over ornamentation
Construction Era	Completed February 13, 2022	Reflects transition between function-driven and performance-conscious designs

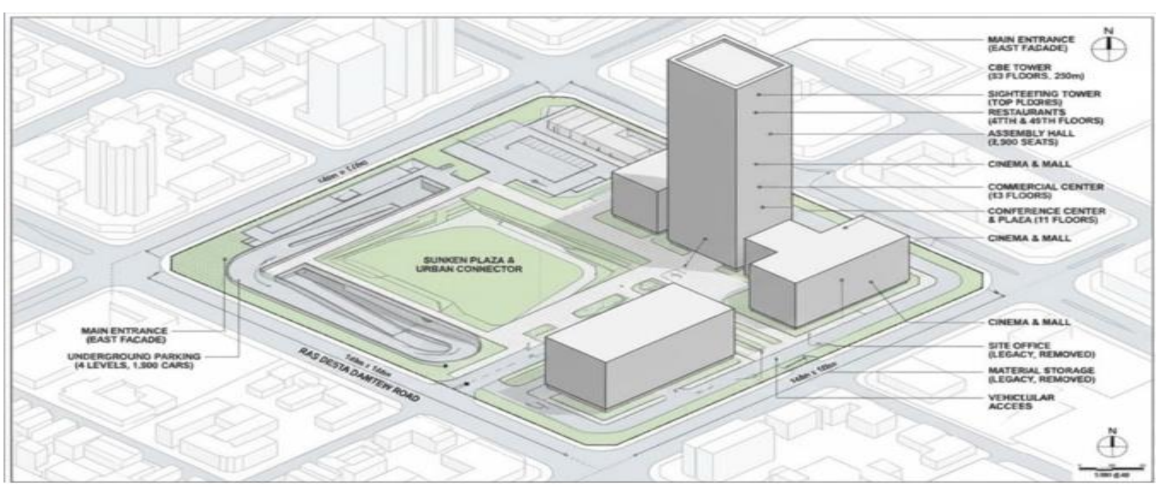


Figure 3.5: Site Layout of CBE HQ

3.4.2 United Bank of Ethiopia HQ

Hibret Bank Headquarters, a 37-story glazed tower in Addis Ababa's Senga Tera district, exemplifies high-rise solar control challenges with extensive glazing and limited west-only horizontal sun-breakers, serving as a key case study contrasting CBE HQ under intense equatorial solar exposure. **Table 3.4** profiles the Hibret Bank Headquarters (Hibir Tower) in Addis Ababa's Senga Tera financial district, detailing its architectural features and sun-breaker limitations. **Figure 3.6** visually presents the building's site layout and façade composition.

Table 3.4: Building Profile of the Hibret Bank

Feature	Description	Relevance to Sun-Breaker Study
Building Name	Hibret Bank Headquarters (Hibir Tower)	Primary CBD case study for contemporary high-rise sun-breaker analysis
Location	Senga Tera, Addis Ababa Financial District	High-exposure CBD location central to urban architectural identity
Building Type	High-rise commercial tower with retail and conference facilities	Representative of mixed-use CBD typologies requiring solar control
Height & Floors	37 stories 132 meters	High-rise status increases exposure to direct solar radiation
Façade Material	Modern glazed curtain wall system	Extensive glazing necessitates effective shading strategies
Sun-Breaker Type	Horizontal fins on west facade only (depth 0.5m)	Minimalist approach prioritizes transparency over comprehensive shading
Orientation	All orientations exposed; shading only on west	Critical performance gap: east, south, north facades fully unshaded
Architectural Style	"Unity of Units" concept with interwoven diamond forms	Symbolic expression prioritized over functional shading design
Construction Era	Completed January 2022	Represents contemporary aesthetics prevailing over passive design

Environmental Performance	Advanced BMS, sensory controls, UPS system	Active systems manage environment; passive shading underutilized
Aesthetic Features	Diamond-pattern cascade; three-block configuration; public plaza	Extreme aesthetic minimalism—sun breakers nearly absent despite climatic requirements

Figure 3.6: Site layout of Hibret Bank HQ

3.4.2 Nib Bank of Ethiopia HQ

Nib International Bank (NIB) HQ, a 37-storey tower in Addis Ababa's Kirkos Sub-City, features beehive-inspired design with dense vertical fins (north/south/west) contrasting east diamond-grid honeycomb sun-breakers, serving as a key case study for performance-aesthetic integration under equatorial solar conditions. **Table 3.5** profiles the Nib International Bank (NIB) Headquarters ("The Hive") in Addis Ababa's Kirkos Sub-City, detailing its architectural features and distinctive sun-breaker geometry. **Figure 3.7** visually presents the building's façade treatment and site context.

Table 3.5: Building Profile of the Nib International Bank (NIB)

Feature	Description	Relevance to Sun-Breaker Study
Building Name	Nib International Bank (NIB) Headquarters ("The Hive")	Primary case study featuring distinctive geometric sun-breaker design
Location	Kirkos Sub-City, behind National Theatre, Addis Ababa	High-exposure financial district location central to CBD analysis

Building Type	High-rise commercial office tower (bank headquarters); multi-use central command center	Representative of CBD typologies requiring comprehensive solar control
Height & Floors	37 storeys (4B+G+M+32 configuration)	High-rise status significantly increases exposure to direct solar radiation
Façade Material	Modern curtain wall with concrete framing	Extensive glazing necessitates effective shading strategies
Sun-Breaker Type	Dense vertical fins (N/S/W, 0.3m depth); hexagonal diamond grid on east (0.8–2.5m spacing, 120° angle)	**Creative aesthetic ambition**—distinctive "bee-hive" east grid expresses identity while attempting solar control
Orientation	All orientations exposed; diamond grid specifically on east for morning sun	Orientation-specific approach acknowledges solar challenges, though performance varies with spacing
Architectural Style	Contemporary with expressive hexagonal diamond grid; distinctive "bee-hive" lighting design	Emphasizes visual symbolism and brand identity alongside functional considerations
Construction Era	Completed early 2021 (approx. 5-year construction; ~2 billion Birr)	Represents contemporary aspirations where aesthetics may compromise optimal shading

Figure 3.7: Site Layout of Nib Bank HQ

3.4.4 Wegagen Bank of Ethiopia HQ

Wegagen Bank Headquarters, a 23-storey tower near Addis Ababa National Stadium, achieves optimal sun-breaker performance with uniform high-density vertical fins across all façades, serving as the performance benchmark against CBE, Hibret, and NIB under equatorial solar conditions. **Table 3.6** profiles the Wegagen Bank Headquarters on Ras Mekonnen Street, detailing its architectural features and exemplary sun-breaker design. **Figure 3.8** visually presents the building's high-rise structure and uniform façade shading configuration.

Table 3.6: Building Profile of the Wegagen Bank

Feature	Description	Relevance to Sun-Breaker Study
Building Name	Wegagen Bank Headquarters	Primary case study representing balanced synthesis of performance and aesthetics
Location	Ras Mekonnen Street, near Addis Ababa National Stadium	High-exposure CBD location; prominent city landmark
Building Type	High-rise commercial office tower (bank headquarters)	Representative of CBD typologies requiring comprehensive solar control
Height & Floors	107 meters; 23 storeys; site area 1,800 m²	High-rise status increases exposure to direct solar radiation
Façade Material	Modern curtain wall system with concrete framing	Extensive glazing necessitates effective shading strategies
Sun-Breaker Type	Dense vertical fins on all orientations; uniform geometry: depth 0.5m, spacing 0.8m, width 0.3m	Exemplary balanced design—uniform fins create rhythmic expression while delivering optimal performance (SF 0.625)
Orientation	All four orientations exposed; uniform fin application across all facades	Demonstrates optimized uniform geometry can succeed where others (CBE west) failed
Architectural Style	Modernist with functionalist emphasis; iconic urban landmark	Prioritizes balanced synthesis of environmental control and visual expression

Construction Era	Construction began 2013; inaugurated 30 September 2017	Represents function-driven design where performance and aesthetics are integrated

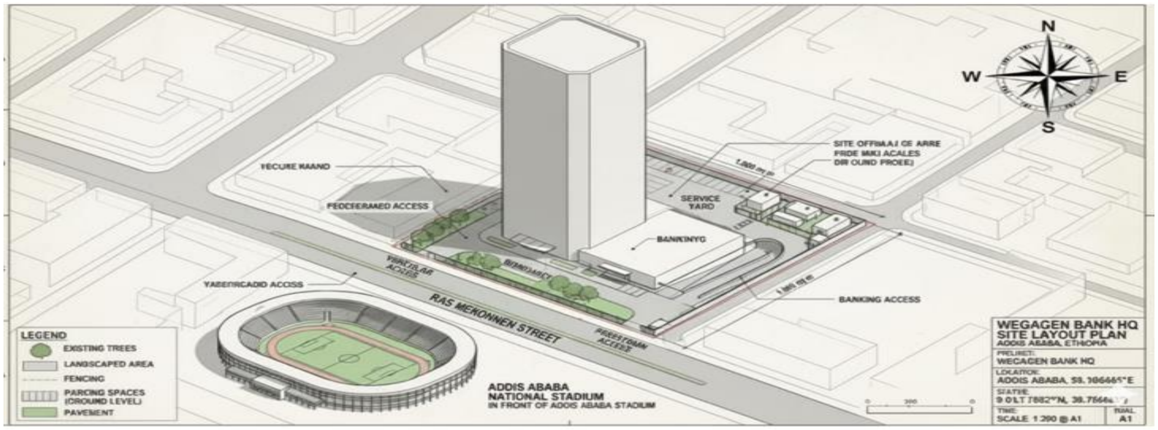


Figure 3.8: Site Layout of Wegagen Bank HQ.

CHAPTER FOUR

RESULTS

4.1 Sun Breaker Performance

4.1.1 Commercial Bank of Ethiopia (CBE) HQ

The solar shading performance of CBE HQ was analyzed for north, south, east, and west façades, considering fin geometry and solar angles for the four solstices. Hourly calculations were done between 10:00 and 16:00 to examine shading dynamic.

Geometric Configuration of Sun-Breakers

Commercial Bank of Ethiopia (CBE) Headquarters demonstrates systematic sun-breaker geometry optimized for equatorial solar exposure. **Table 4.1** documents consistent fin parameters across all façades with orientation-specific adaptations, complemented by **Figure 4.1** technical illustration.

Table 4.1: Geometric Configuration of CBE HQ

Façade	Fin Width (m)	Spacing (m)	Fin Depth (m)	Angle	Orientation	Pattern
North	0.3	1.2	0.6	90°	Vertical	Regular
South	0.3	1.2	0.6	90°	Vertical	Regular
East	0.3	0.8–1.2	0.6	45°/90°	Vertical	Regular
West	0.3	0.8–1.2	0.6	45°/90°	Vertical	Regular

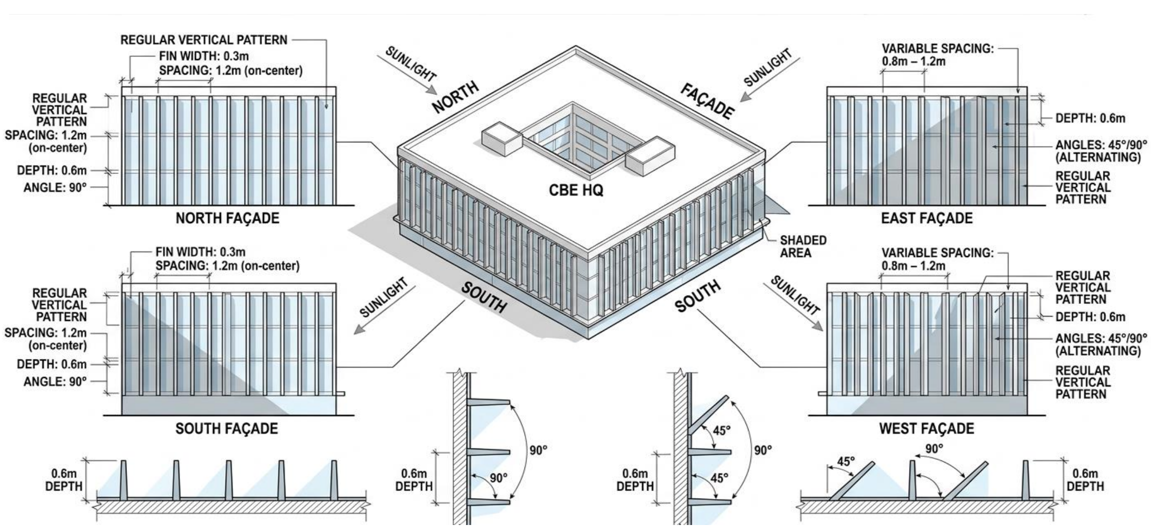


Figure 4.1: Details of Sun-Breakers at Commercial Bank of Ethiopia

Solar Altitude (α)

CBE shows the highest solar altitude occurs during the equinoxes (81°), while the summer and winter solstices record 75.55° and 57.55°, respectively. High solar altitudes during summer and equinox increase vertical exposure, requiring carefully dimensioned vertical fins to control solar heat gain. Table 4.2 summarizes the solar altitude at noon across key solar events. This information guides the optimal design and orientation of sun-breaker elements to control solar gain effectively.

Table 4.2: Solar Altitude at Noon for CBE HQ

Solstice	δ (°)	α° at Solar Noon
Summer (Jun 21)	+23.45	75.55
Winter (Dec 21)	-23.45	57.55
Spring Equinox (Mar 21)	0	81.0
Autumn Equinox (Sep 23)	0	81.0

Cut-Off Angle ($\theta_{(cutoff)}$)

CBE highlights that north and south façades primarily manage decorative effects and high-angle solar blocking, while east and west façades address low-angle sunlight, glare, and afternoon heat. North & south fins mainly decorative; east & west fins partially block low-angle morning/afternoon sun. Table 4.3 presents the cut-off angles and functional roles of sun-breaker fins on different façades of the CBE Headquarters. This information is essential for optimizing fin geometry and spacing to balance shading effectiveness and daylight quality.

Table 4.3: Cut-Off Angle and Function – CBE HQ

Façade	Depth (m)	Spacing (m)	θ_cutoff (°)	Function
North	0.6	1.2	26.57	Decorative/light diffusion
South	0.6	1.2	26.57	Blocks high-angle sun at noon
East	0.6	0.8–1.2	26.57–36.87	Reduces morning glare
West	0.6	0.8–1.2	26.57–36.87	Partial shading; high afternoon heat

Shading Factor (SF)

North and south façades exhibit moderate shading, while east and west façades achieve moderate to high performance, reflecting stronger solar exposure. Table 4.4 shows the Shading Factor (SF) values for each façade of the CBE Headquarters, indicating the relative effectiveness of the sun-breakers. These values help inform design decisions to balance comfort and daylight penetration across different orientations.

Table 4.4: Shading Factor – CBE HQ

Façade	SF	Performance Level
North	0.5	Moderate
South	0.5	Moderate
East	0.5–0.75	Moderate–High
West	0.5–0.75	Moderate–High

SF balances shading and daylight; higher SF on east/west reduces morning/afternoon solar gain but slightly limits daylight.

Solar Radiation Reduction (%)

The north and south façades block about 30% of incoming solar radiation, while the east and west façades reduce 30–45%, reflecting higher morning and afternoon sun exposure. Table 4.5 presents the estimated solar radiation reduction achieved by the sun-breakers at CBE HQ.

Table 4.5: Radiation Reduction – CBE HQ

Façade	Radiation Reduction (%)
North	30
South	30
East	30–45
West	30–45

Hourly Solar Angles Analysis

Hourly Solar Angles highlights how solar angles influence shading effectiveness, with east façades experiencing morning sun, south façades receiving high noon sun, and west façades exposed to low-angle afternoon sunlight. Table 4.6 summarizes the hourly solar altitudes and associated observations for CBE HQ across the four main façades. These observations illustrate the dynamic performance of sun-breakers throughout the day and across different seasons.

Table 4.6: Hourly Solar Angles and Observations – CBE HQ

Time	**North α°**	**South α°**	**East α°**	**West α°**	**Observation – Summer**	**Observation – Winter**	**Observation – Spring**	**Observation – Autumn**
10:00	50	50	40	55	East façade begins shading; north minimal	East façade begins shading; north minimal	East façade begins shading; north minimal	East façade begins shading; north minimal
11:00	60	60	50	60	East shading increases; south moderate	East shading increases; south moderate	East shading increases; south moderate	East shading increases; south moderate
12:00	75.5	75.5	70	75	South noon sun blocked by fins	South sun partially blocked by fins	South sun blocked by fins at noon	South sun blocked by fins at noon
13:00	70	70	65	70	West heating increases; east reducing	West heating rises slightly; east reducing	West heating increases; east reducing	West heating increases; east reducing
14:00	65	65	60	65	West exposure high; shading begins	West exposure moderate; shading begins	West exposure high; shading begins	West exposure high; shading begins
15:00	60	60	55	60	Afternoon glare on west; east minimal	Afternoon low-angle glare on west; east minimal	Afternoon glare on west; east minimal	Afternoon glare on west; east minimal
16:00	50	50	45	55	East negligible; west fins partially effective	East negligible; west fins partly effective	East negligible; west fins partially effective	East negligible; west fins partially effective

Figure 4.4–4.5 illustrate the shading performance and detailed analysis of sun-breakers across all façades at CBE HQ, highlighting orientation-specific effectiveness in radiation control and daylight optimization.

CBE HQ

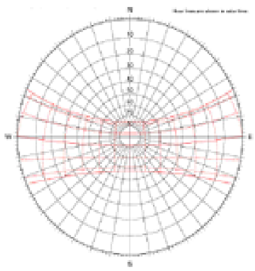
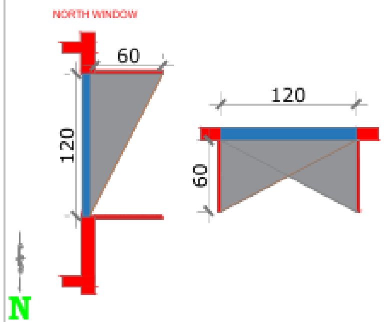
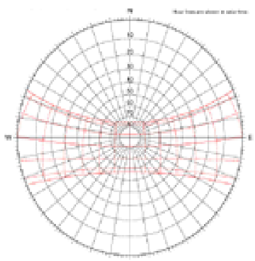
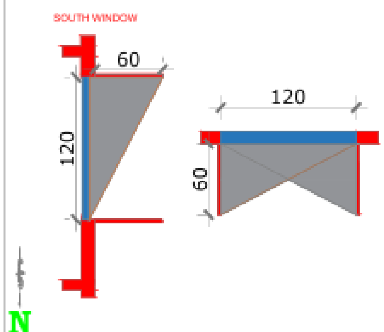
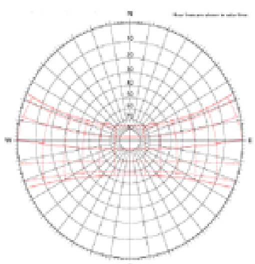
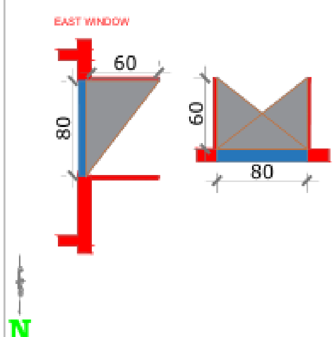
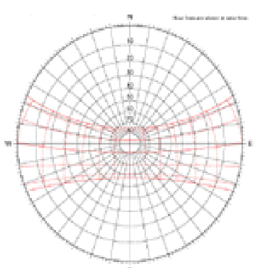
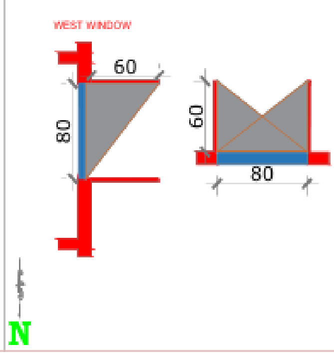
SOLAR PATH OF ADDIS ABABA	SUN BREAKER WINDOW RELATION	DISCUSSION
		The north façade receives limited direct sun. With PF = 0.5, slightly above the recommended 0.425, the vertical fins are moderately over designed. They provide partial shading without significantly reducing daylight or views, primarily serving glare control and diffuse daylight modulation.
		The south façade is exposed to high altitudesun, and PF = 0.5 is below the recommended 0.65, making the fins under designed. While they provide some shading, significant direct solar radiation penetrates at midday. Horizontal overhangs or combined systems would be more effective.
		The east façade faces low angle morning sun. With PF = 1.33, slightly below the recommended 1.546, the vertical fins provide moderate to good protection. Tighter spacing (0.6 m) and depth (0.8 m) reduce morning glare, and angled fins improve performance against oblique sunlight, though not fully optimal.
		The west façade experiences intense afternoon sun. With PF = 1.0, below the recommended 1.458, the fins are insufficient for full solar protection. Some shading occurs, but significant direct sunlight reaches the glazing. Angled fins help partially, but deeper or denser fins would be needed for effective heat control.

Figure 4.4: Shading Performance of Sun-Breakers on All Façades of CBE

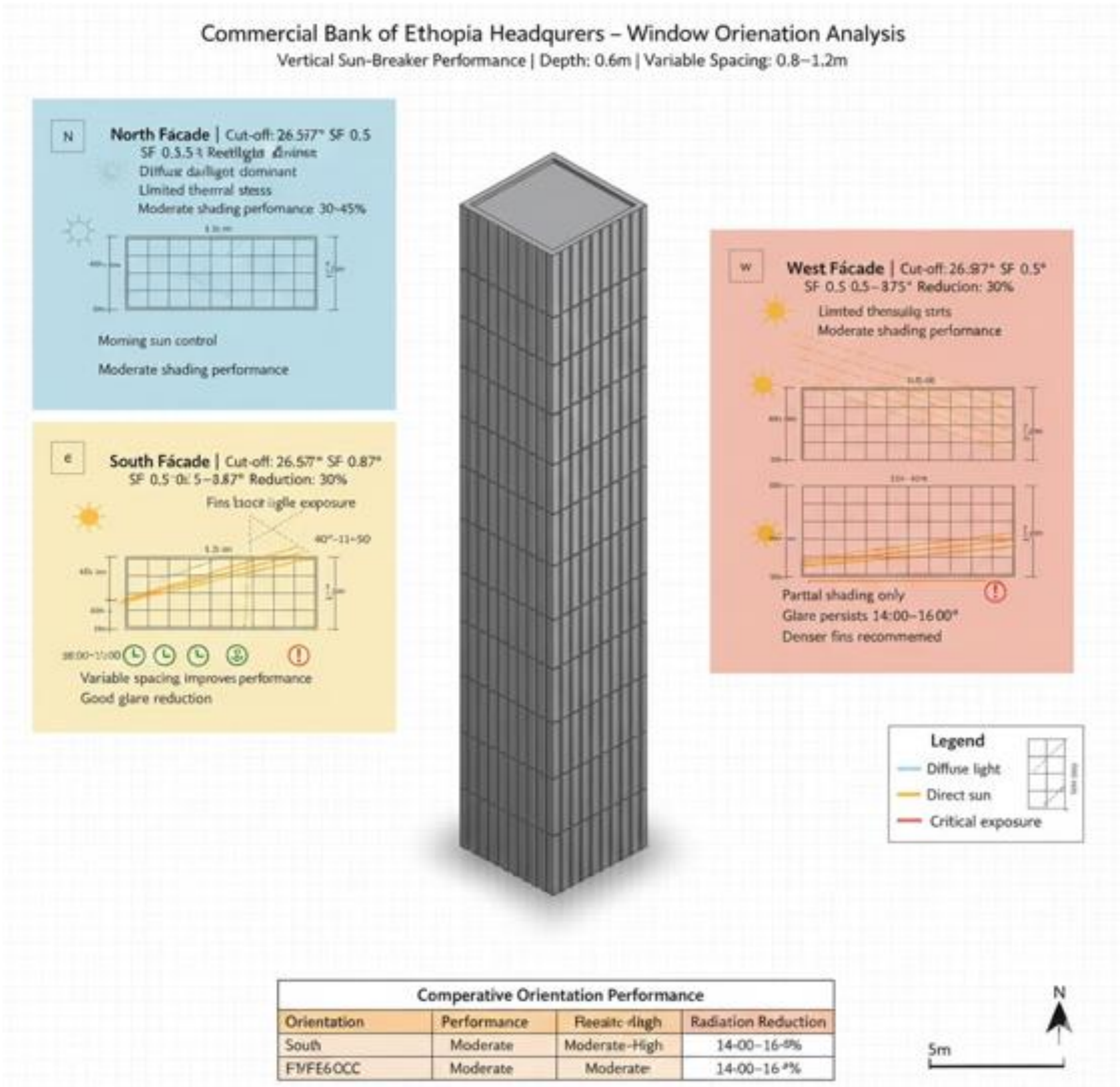


Figure 4.5: Sun-Breaker Performance Analysis of CBE

4.1.2 Hibret (United) Bank HQ

The solar shading performance of Hibret Bank HQ was analyzed for north, south, east, and west façades, considering fin geometry and solar angles for the four solstices. Hourly calculations were done between 10:00 and 16:00 to examine dynamic shading performance.

Geometric Configuration of Sun-Breakers

Hibret Bank HQ's sun-breaker system represents a critical case of partial shading implementation within Addis Ababa's CBD high-rise typology. **Table 4.7** reveals a significant design limitation: horizontal fins exclusively on the west façade (0.5m width, floor height spacing, full façade depth, 180° orientation, regular pattern), while north, south, and east façades remain completely unprotected, as visually documented in **Figure 4.5**.

Table 4.7: Geometric Configuration of Hibret Bank HQ Sun-Breakers

Façade	Fin Width (m)	Spacing (m)	Fin Depth (m)	Angle	Orientation	Pattern
North	No Fins	—	—	—	—	—
South	No Fins	—	—	—	—	—
East	No Fins	—	—	—	—	—
West	0.5	Floor Height	Full façade	180°	Horizontal	Regular

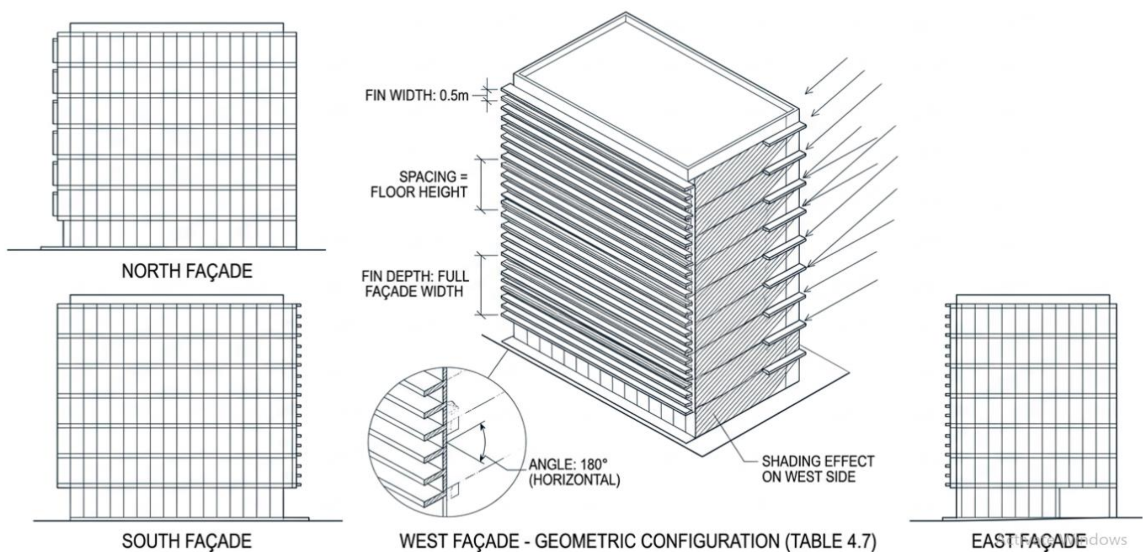


Figure 4.6: Details of Sun-Breakers at Hibret Bank

Solar Altitude (α)

Hibret Bank shows high solar altitudes during summer and equinox increase exposure on horizontal fins, particularly on the west façade. Table 4.8 shows the solar altitude at noon for Hibret Bank HQ across different solstices and equinoxes, indicating the sun's position relative to the building. The values highlight seasonal variations, guiding sun-breaker design for optimal shading.

Table 4.8: Solar Altitude at Noon for Hibret Bank HQ

Solstice	δ (°)	α° at Solar Noon
Summer (Jun 21)	+23.45	75.55
Winter (Dec 21)	-23.45	57.55
Spring Equinox (Mar 21)	0	81.0
Autumn Equinox (Sep 23)	0	81.0

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Cut-Off Angle ($\theta_{(cutoff)}$)

Table 4.9 summarizes the cut-off angles and shading functions of Hibret Bank HQ façades, showing that only the west façade has partial sun-breaker shading. The data highlights façade-specific solar protection and areas vulnerable to heat and glare.

Table 4.9: Cut-Off Angle and Function – Hibret Bank HQ

Façade	Depth (m)	Spacing / Height (m)	θ_cutoff (°)	Function
North	—	—	—	No fins; window shading only
South	—	—	—	No shading; high heat
East	—	—	—	No shading; glare high
West	0.5	Full floor height	~26–30	Partial afternoon shading

Shading Factor (SF)

Table 4.10 presents the shading factor (SF) and corresponding performance levels for Hibret Bank HQ façades. Only the west façade shows moderate shading with an SF of 0.5, while the north, south, and east façades provide no shading.

Table 4.10: Shading Factor – Hibret Bank HQ

Façade	SF	Performance Level
North	—	None
South	—	None
East	—	None

West	0.5	Moderate

Solar Radiation Reduction (%)

Table 4.11 shows the radiation reduction levels for Hibret Bank HQ façades. The west façade achieves a 30% reduction, while the north, south, and east façades provide no radiation reduction.

Table 4.11: Radiation Reduction – Hibret Bank HQ

Façade	Radiation Reduction (%)
North	0
South	0
East	0
West	30

Hourly Solar Angles Analysis

Table 4.12 demonstrates that Hibret Bank HQ's sun-breakers provide shading exclusively on the west façade, leaving north, south, and east façades completely exposed to solar radiation throughout the day. This results in high thermal gain and glare on unshaded orientations, particularly on the east façade during morning hours and the south façade at solar noon, confirming that partial shading coverage is insufficient for comprehensive environmental control.

Table 4.12: Hourly Solar Angles and Observations – Hibret Bank HQ

Time	North α°	South α°	East α°	West α°	Observation – Summer	Observation – Winter	Observation – Spring	Observation – Autumn
10:00	50	50	40	55	West fins partially shading; others unshaded	West fins partially shading; others unshaded	West fins partially shading; others unshaded	West fins partially shading; others unshaded
11:00	60	60	50	60	West shading increases; high solar gain elsewhere	West shading increases; high solar gain elsewhere	West shading increases; high solar gain elsewhere	West shading increases; high solar gain elsewhere
12:00	75.5	75.5	70	75	Peak sun; west fins	Sun partially blocked; high	Peak sun; west fins	Peak sun; west fins

					reduce some heat	thermal gain south/east	reduce some heat	reduce some heat
13:00	70	70	65	70	Afternoon exposure on west; high glare east	West heating rises slightly; glare east moderate	Afternoon exposure on west; high glare east	Afternoon exposure on west; high glare east
14:00	65	65	60	65	West thermal stress continues	West exposure moderate; east minimal	West thermal stress continues	West thermal stress continues
15:00	60	60	55	60	Afternoon glare persists; minimal shading east	Afternoon low-angle glare on west; east unshaded	Afternoon glare persists; minimal shading east	Afternoon glare persists; minimal shading east
16:00	50	50	45	55	West fins partially effective; east negligible	West fins partially effective; east negligible	West fins partially effective; east negligible	West fins partially effective; east negligible

Figure 4.7–4.8 illustrate the shading performance and detailed analysis of sun-breakers across all façades at HIBRET BANK HQ, highlighting orientation-specific effectiveness in radiation control and daylight optimization.

HIBRET BANK HQ

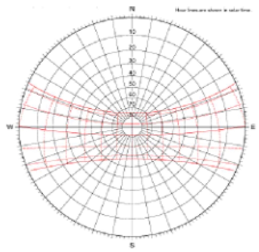
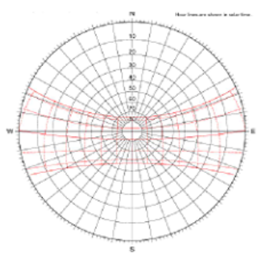
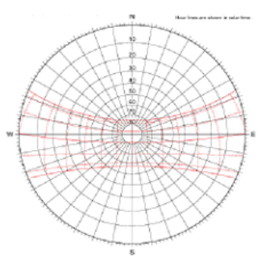
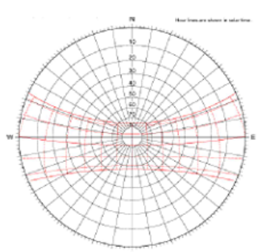
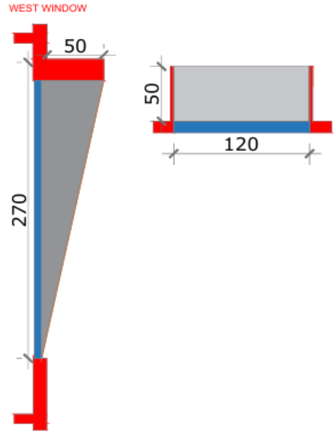
SOLAR PATH OF ADDIS ABABA	SUN BREAKER WINDOW RELATION	DISCUSSION
	NORTH WINDOW NO SUN BREAKER N	The north façade has no shading, which is generally acceptable at 9°N because it receives direct sun only briefly in early morning and late afternoon during summer. Solar heat gain is minimal, and unobstructed views and maximum daylight make this a reasonable trade off.PF = 0 versus recommended 0.43.
	SOUTH WINDOW NO SUN BREAKER N	The south façade lacks shading, making it prone to high solar heat gain and glare, especially around midday. It is severely under designed for passive solar control. PF = 0 versus recommended 0.65, indicating horizontal overhangs or light shelves are needed to reduce overheating and improve comfort.
	EAST WINDOW NO SUN BREAKER N	The east façade is exposed to low-angle morning sun, causing glare and heat gain. Without shading, occupants face discomfort during early hours. PF = 0 versus recommended 1.55, showing the need for vertical fins or egg-crate systems to control morning solar exposure.
	WEST WINDOW  N	The west façade is exposed to intense low-angle afternoon sun, making it prone to high solar heat gain. Horizontal louvers are ideal for this orientation, as they block harsh sunlight while still admitting diffuse daylight and preserving views. The effectiveness depends on overhang depth: shallow projections (e.g., 2 m) underperform, while very deep projections (e.g., 10 m) may be over designed but remain functional. Typically, a substantial depth of 2–4.4 m provides a projection factor near the recommended 1.45–1.50, delivering excellent shading and effectively mitigating afternoon heat gain.

Figure 4.7: Shading Performance of Sun-Breakers on All Façades of Hibret

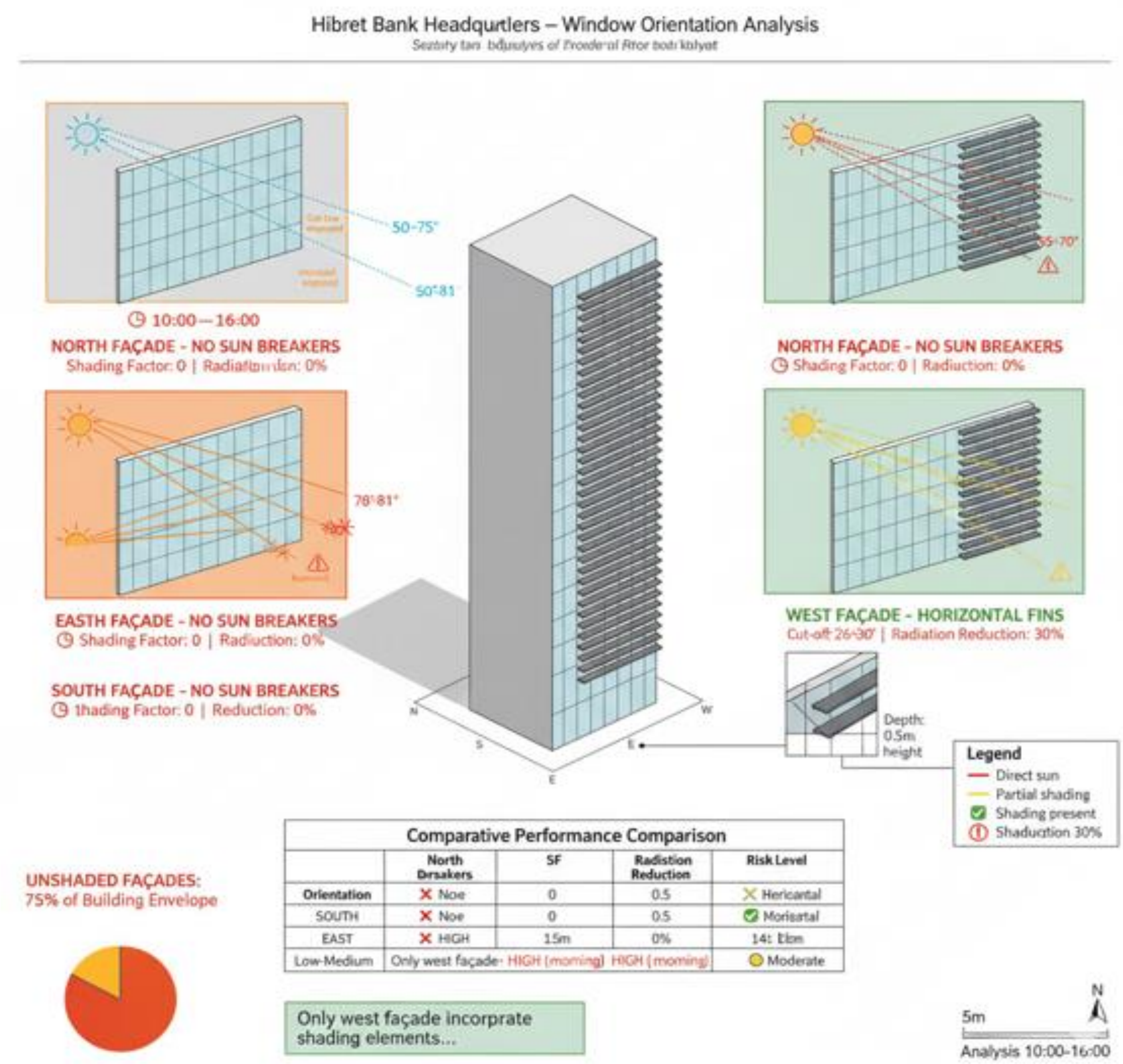


Figure 4.8: Sun-Breaker Performance Analysis by Façade Orientation: of Hibret

4.1.3 Nib International Bank (NIB) HQ

The solar shading performance of NIB HQ was analyzed for north, south, east, and west façades, considering fin geometry and solar angles for the four solstices. Hourly calculations were performed between 10:00 and 16:00 to examine dynamic shading, thermal stress, and daylight distribution.

Geometric Configuration of Sun-Breakers

Nib International Bank (NIB) Headquarters showcases innovative sun-breaker geometry across its CBD high-rise façades. **Table 4.13** documents the differentiated approach: north, south, and west façades utilize regular dense vertical fins, while the east façade employs distinctive diamond grid honeycomb patterning with variable spacing, complemented by **Figure 4.8**.

Table 4.13: Geometric Configuration of NIB HQ Sun-Breakers

Façade	Fin Width (m)	Spacing (m)	Fin Depth (m)	Angle	Orientation	Pattern
North	0.5	0.8	0.3	90°	Dense vertical	Regular
South	0.5	0.8	0.3	90°	Dense vertical	Regular
East	0.5	0.8–1.2	0.3	120°	Diamond grid	Honeycomb
West	0.5	0.8	0.3	90°	Dense vertical	Regular

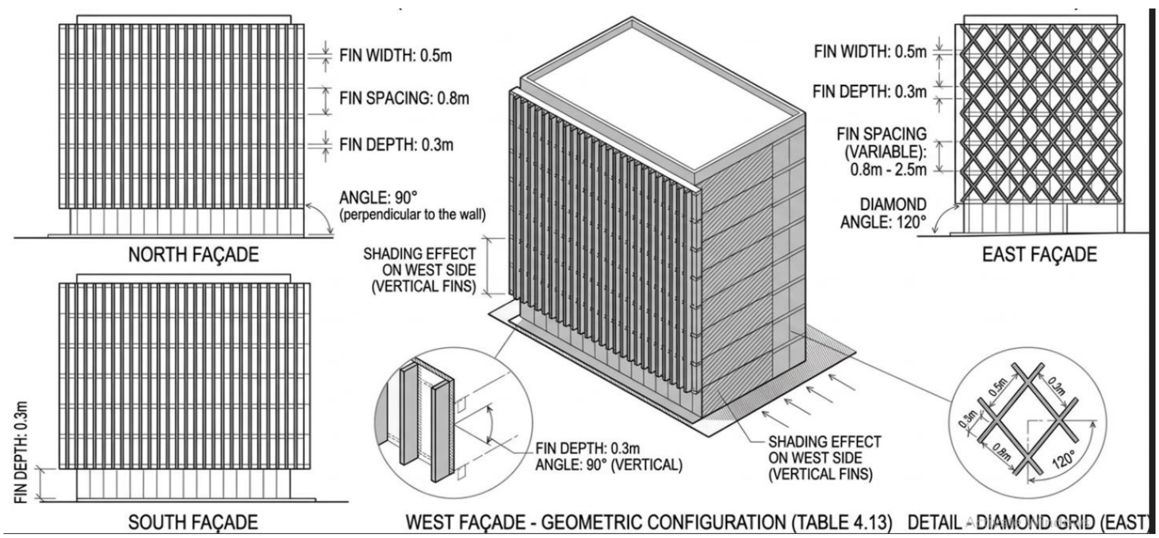


Figure 4.9: Details of Sun-Breakers at NIB Bank

Solar Altitude (α)

Table 4.14 shows the solar altitude at noon for NIB HQ across different solstices. The highest solar altitude occurs during spring and autumn at 81°, while summer and winter reach 75.55° and 57.55°, respectively.

Table 4.14: Solar Altitude at Noon – NIB HQ

Solstice	δ (°)	α° at Solar Noon
Summer	+23.45	75.55
Winter	-23.45	57.55
Spring	0	81.0

Autumn	0	81.0

Cut-Off Angle (θ(cutoff))

Table 4.15 presents the cut-off angles and functions of sun-breakers at NIB HQ façades. While the north and south façades focus on decoration and midday sun control, the east and west façades address low-angle sun and afternoon heat reduction, respectively.

Table 4.15: Cut-Off Angle and Function – NIB HQ

Façade	Depth (m)	Spacing (m)	θ_cutoff (°)	Function
North	0.3	0.8	20.56	Decorative/light diffusion
South	0.3	0.8	20.56	Controls midday sun
East	0.3	0.8–2.5	6.84–20.56	Low-angle sun mitigation + visual pattern
West	0.3	0.8	20.56	Partial shading; afternoon heat reduction

Shading Factor (SF)

Table 4.16 shows the shading factor (SF) and performance levels for NIB HQ façades. The north, south, and west façades achieve moderate shading, while the east façade ranges from low to moderate performance.

Table 4.16: Shading Factor – NIB HQ

Façade	SF	Performance Level
North	0.375	Moderate
South	0.375	Moderate
East	0.12–0.375	Low–Moderate
West	0.375	Moderate

Solar Radiation Reduction (%)

Table 4.17 presents the radiation reduction percentages for NIB HQ façades. The north, south, and west façades reduce radiation by 22.5%, while the east façade achieves a lower reduction ranging from 7.2% to 22.5%.

Table 4.17: Radiation Reduction – NIB HQ

Façade	Radiation Reduction (%)

North	22.5
South	22.5
East	7.2–22.5
West	22.5

Hourly Solar Angles Analysis

Table 4.18 presents the hourly solar angles and observations for NIB HQ across different seasons. It highlights how each façade responds to sun positions, with the east diamond grid providing early shading and the west façade experiencing increasing afternoon heat and glare. Overall, the table illustrates seasonal variations in shading effectiveness and solar exposure throughout the day.

Table 4.18: Hourly Solar Angles and Observations – NIB HQ

Time	North α°	South α°	East α°	West α°	Observation – Summer	Observation – Winter	Observation – Spring	Observation – Autumn
10:00	50	50	40	55	East diamond grid begins shading; north minimal	East diamond grid begins shading; north minimal	East diamond grid begins shading; north minimal	East diamond grid begins shading; north minimal
11:00	60	60	50	60	East shading increases; south moderate	East shading increases; south moderate	East shading increases; south moderate	East shading increases; south moderate
12:00	75.5	75.5	70	75	South noon sun controlled by fins	South sun partially blocked; winter glare moderate	South noon sun controlled by fins	South noon sun controlled by fins
13:00	70	70	65	70	West heating increases; east reduced	West heating rises slightly; east moderate	West heating increases; east reduced	West heating increases; east reduced
14:00	65	65	60	65	West exposure high; shading begins	West exposure moderate; east minimal	West exposure high; shading begins	West exposure high; shading begins
15:00	60	60	55	60	Afternoon glare on west; east minimal	Afternoon low-angle glare on west; east minimal	Afternoon glare on west; east minimal	Afternoon glare on west; east minimal
16:00	50	50	45	55	East negligible; west fins partially effective	East negligible; west fins partly effective	East negligible; west fins partially effective	East negligible; west fins partially effective

Figure 4.10–4.11 illustrate the shading performance and detailed analysis of sun-breakers across all façades at NIB INTERNATIONAL BANK HQ, highlighting orientation-specific effectiveness in radiation control and daylight optimization.

NIB INTERNATIONAL HQ

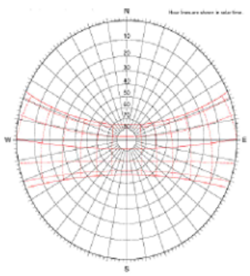
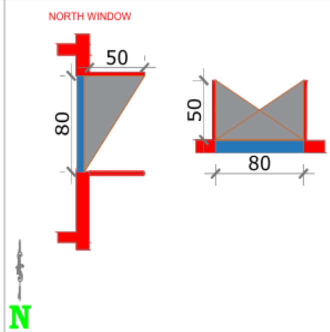
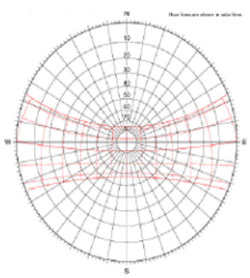
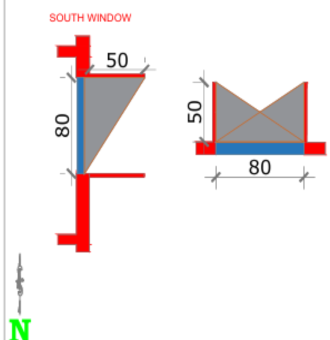
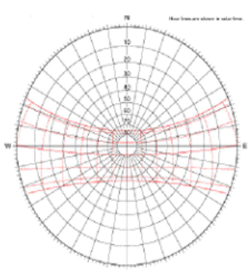
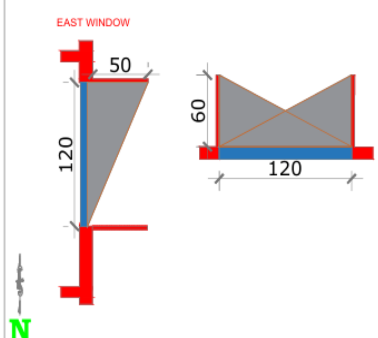
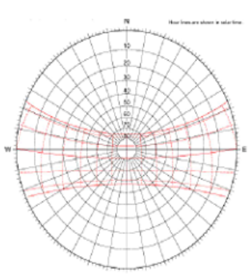
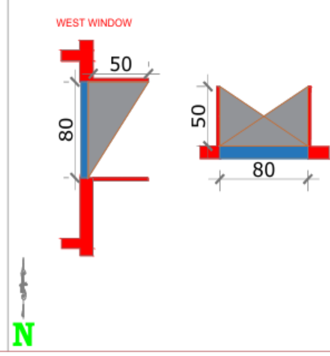
SOLAR PATH OF ADDIS ABABA	SUN BREAKER WINDOW RELATION	DISCUSSION
		The north façade uses vertical fins with 0.8 m depth and 0.5 m spacing (PF = 1.6), which is significantly higher than the recommended value for this orientation. Since north façades receive limited direct solar radiation, the shading system is overdesigned for solar control, mainly reducing diffuse daylight and likely serving more as an architectural feature than a thermal shading necessity.
		The south façade is exposed to high-altitude sun, but the same fin geometry (PF = 1.6) exceeds the recommended shading requirement. While this provides strong protection against solar heat gain, the deep fins may block useful daylight and beneficial winter sun, potentially increasing reliance on artificial lighting.
		The east façade has the deepest shading system with 1.2 m depth and 0.6 m spacing (PF = 2.0). This configuration effectively controls low-angle morning sun, and the angled or honeycomb geometry further improves solar interception from oblique directions, making the east façade well protected against solar heat gain.
		The west façade uses 0.8 m deep vertical fins with 0.5 m spacing (PF = 1.6), slightly exceeding the recommended value. This provides good shading against intense afternoon solar radiation, although vertical fins alone may not completely block low-angle sun, meaning additional horizontal elements could further improve performance.

Figure 4.10: Shading Performance of Sun-Breakers on All Façades of NIB

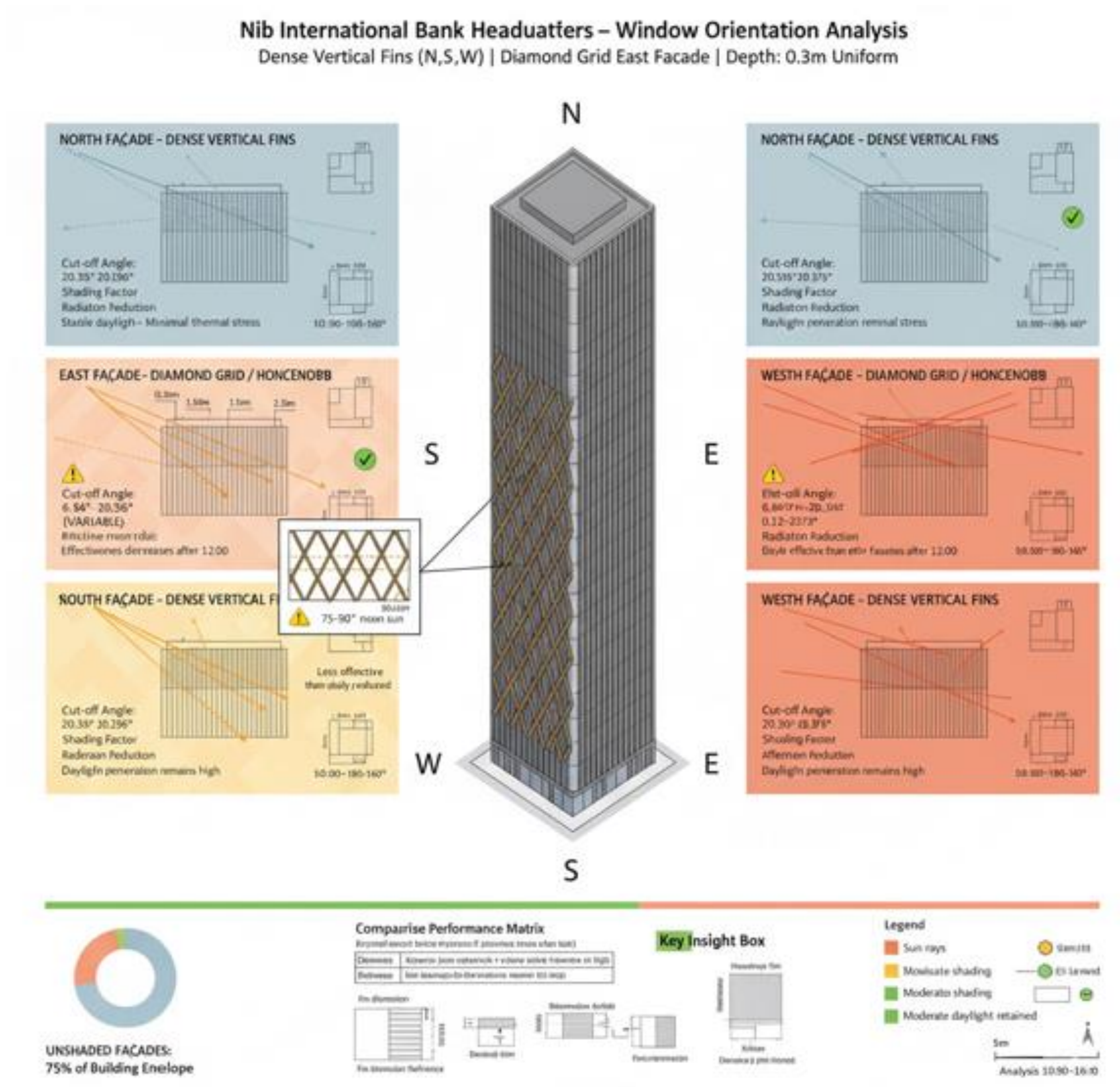


Figure 4.11: Sun-Breaker Performance Analysis of NIB Bank

4.1.4 Wegagen Bank HQ

The solar shading performance of Wegagen Bank HQ was analyzed for north, south, east, and west façades, considering fin geometry and solar angles for the four solstices. Hourly calculations were performed between 10:00 and 16:00 to examine dynamic shading, thermal stress, and daylight distribution.

Geometric Configuration of Sun-Breakers

Wegagen Bank Headquarters exemplifies optimal sun-breaker uniformity across its CBD high-rise façades. **Table 4.19** documents comprehensive vertical fin coverage with identical geometric parameters across all orientations, complemented by **Figure 4.12** technical illustration.

Table 4.19: Geometric Configuration of Wegagen Bank HQ

Façade	Fin Width (m)	Spacing (m)	Fin Depth (m)	Angle	Orientation	Pattern
North	0.3	0.8	0.5	90°	Vertical	Regular
South	0.3	0.8	0.5	90°	Vertical	Regular
East	0.3	0.8	0.5	90°	Vertical	Regular
West	0.3	0.8	0.5	90°	Vertical	Regular

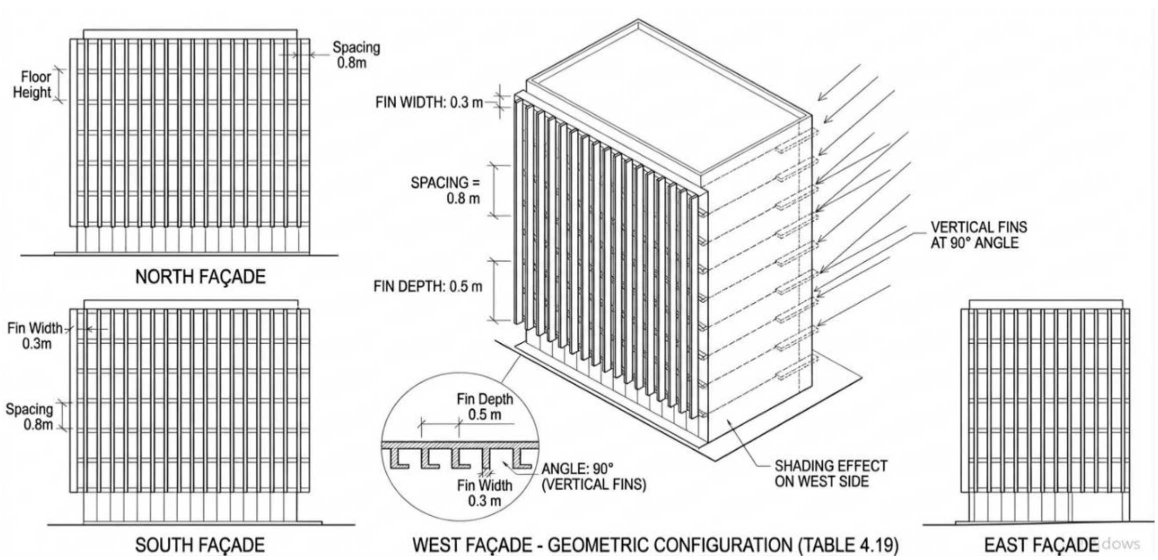


Figure 4.12: Details of Sun-Breakers at WEGAGEN Bank

Solar Altitude (α)

Table 4.20 shows the solar altitude at noon for Wegagen Bank HQ across different solstices. The highest solar altitude occurs during the equinoxes at 81°, while summer and winter reach 75.55° and 57.55°, respectively.

Table 4.20: Solar Altitude at Noon – Wegagen Bank HQ

Solstice	δ (°)	α° at Solar Noon
Summer (Jun 21)	+23.45	75.55
Winter (Dec 21)	-23.45	57.55
Spring Equinox (Mar 21)	0	81.0

Autumn Equinox (Sep 23)	0	81.0

High solar altitudes during summer and equinox increase exposure to vertical fins, requiring careful design to control thermal gain.

Cut-Off Angle ($\theta_{(}$cutoff$_{)}$)

Table 4.21 presents the cut-off angles and functions of sun-breakers at Wegagen Bank HQ façades. Each façade uses a 32° cut-off angle to balance decoration, glare reduction, and control of high- or low-angle sunlight.

Table 4.21: Cut-Off Angle and Function – Wegagen Bank HQ

Façade	Depth (m)	Spacing (m)	θ_cutoff (°)	Function
North	0.5	0.8	32.0	Decorative/light diffusion
South	0.5	0.8	32.0	Controls high-angle sun at noon
East	0.5	0.8	32.0	Reduces morning glare; maintains daylight
West	0.5	0.8	32.0	Reduces low-angle afternoon sun

Shading Factor (SF)

Dense vertical fins provide uniform shading performance across all façades. Table 4.22 shows the shading factor (SF) and performance levels for Wegagen Bank HQ façades. All façades achieve a moderate–high shading performance with an SF of 0.625.

Table 4.22: Shading Factor – Wegagen Bank HQ

Façade	SF	Performance Level
North	0.625	Moderate–High
South	0.625	Moderate–High
East	0.625	Moderate–High
West	0.625	Moderate–High

Solar Radiation Reduction (%)

Table 4.23 presents the radiation reduction percentages for Wegagen Bank HQ façades. All façades achieve a uniform radiation reduction of 37.5%.

Table 4.23: Radiation Reduction – Wegagen Bank HQ

Façade	Radiation Reduction (%)
North	37.5
South	37.5
East	37.5
West	37.5

Hourly Solar Angles Analysis

Table 4.24 presents the hourly solar angles and observations for Wegagen Bank HQ across different seasons. It highlights how the east façade provides early morning shading, while the south façade effectively blocks noon sun. The west façade experiences increasing afternoon exposure, with fins reducing glare and heat later in the day.

Table 4.24: Hourly Solar Angles and Observations – Wegagen Bank HQ

Time	North α°	South α°	East α°	West α°	Observation – Summer	Observation – Winter	Observation – Spring	Observation – Autumn
10:00	50	50	40	55	East shading begins; north moderate	East shading begins; north moderate	East shading begins; north moderate	East shading begins; north moderate
11:00	60	60	50	60	East fully shading; south moderate	East fully shading; south moderate	East fully shading; south moderate	East fully shading; south moderate
12:00	75.5	75.5	70	75	South noon sun blocked by fins	South noon sun blocked by fins	South noon sun blocked by fins	South noon sun blocked by fins
13:00	70	70	65	70	West exposure increases; east reduces	West exposure increases; east reduces	West exposure increases; east reduces	West exposure increases; east reduces
14:00	65	65	60	65	West shading effective; south moderate	West shading effective; south moderate	West shading effective; south moderate	West shading effective; south moderate
15:00	60	60	55	60	Afternoon glare on west; east minimal	Afternoon low-angle glare on west; east minimal	Afternoon glare on west; east minimal	Afternoon glare on west; east minimal
16:00	50	50	45	55	East negligible; west fins partially effective	East negligible; west fins partially effective	East negligible; west fins partially effective	East negligible; west fins partially effective

Figure 4.13–4.14 illustrate the shading performance and detailed analysis of sun-breakers across all façades at WEGAGEN BANK HQ, highlighting orientation-specific effectiveness in radiation control and daylight optimization.

WEGAGEN BANK HQ

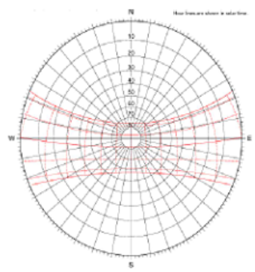
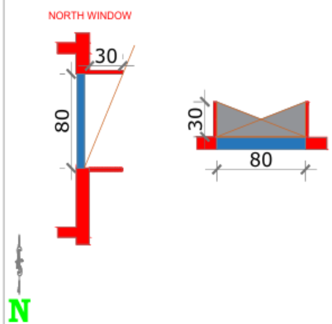
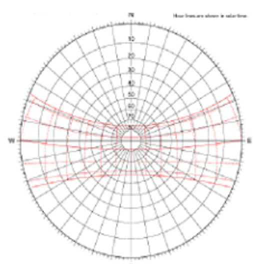
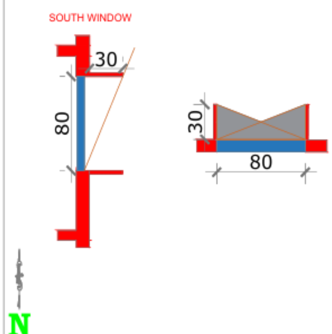
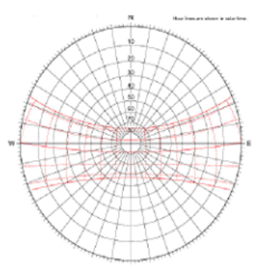
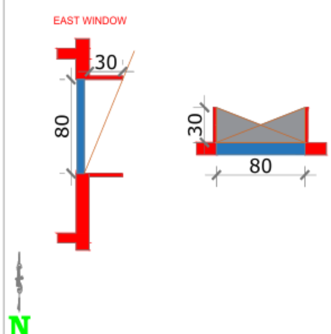
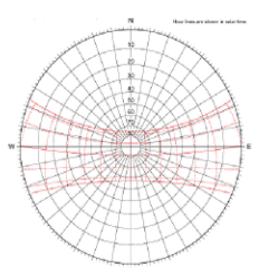
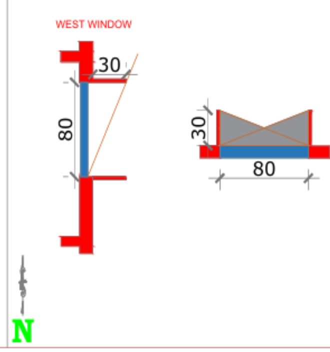
SOLAR PATH OF ADDIS ABABA	SUN BREAKER WINDOW RELATION	DISCUSSION
		The north façade receives very limited direct sun. With PF = 2.67, the vertical fins are significantly overdesigned compared to the recommended value. This results in excessive shading, blocking diffuse daylight and limiting outward views, indicating the fins function more as an architectural feature than a thermal control device.
		The south façade experiences high-altitude sun, where vertical fins are less effective than horizontal shading. The PF = 2.67 greatly exceeds recommended values, causing excessive shading that blocks beneficial winter sunlight and reduces daylight penetration, potentially increasing artificial lighting demand.
		The east façade requires protection from low-angle morning sun. Although PF = 2.67 provides strong solar control and effectively blocks direct radiation, the very tight fin spacing creates a dense screen that significantly reduces daylight entry and outward visibility.
		The west façade faces intense afternoon sun, and PF = 2.67 offers strong protection against heat gain. However, the dense vertical fins cast deep shadows that block sunlight effectively but also reduce daylight penetration and limit exterior views.

Figure 4.13: Shading Performance of Sun-Breakers on Façades of WEGAGEN

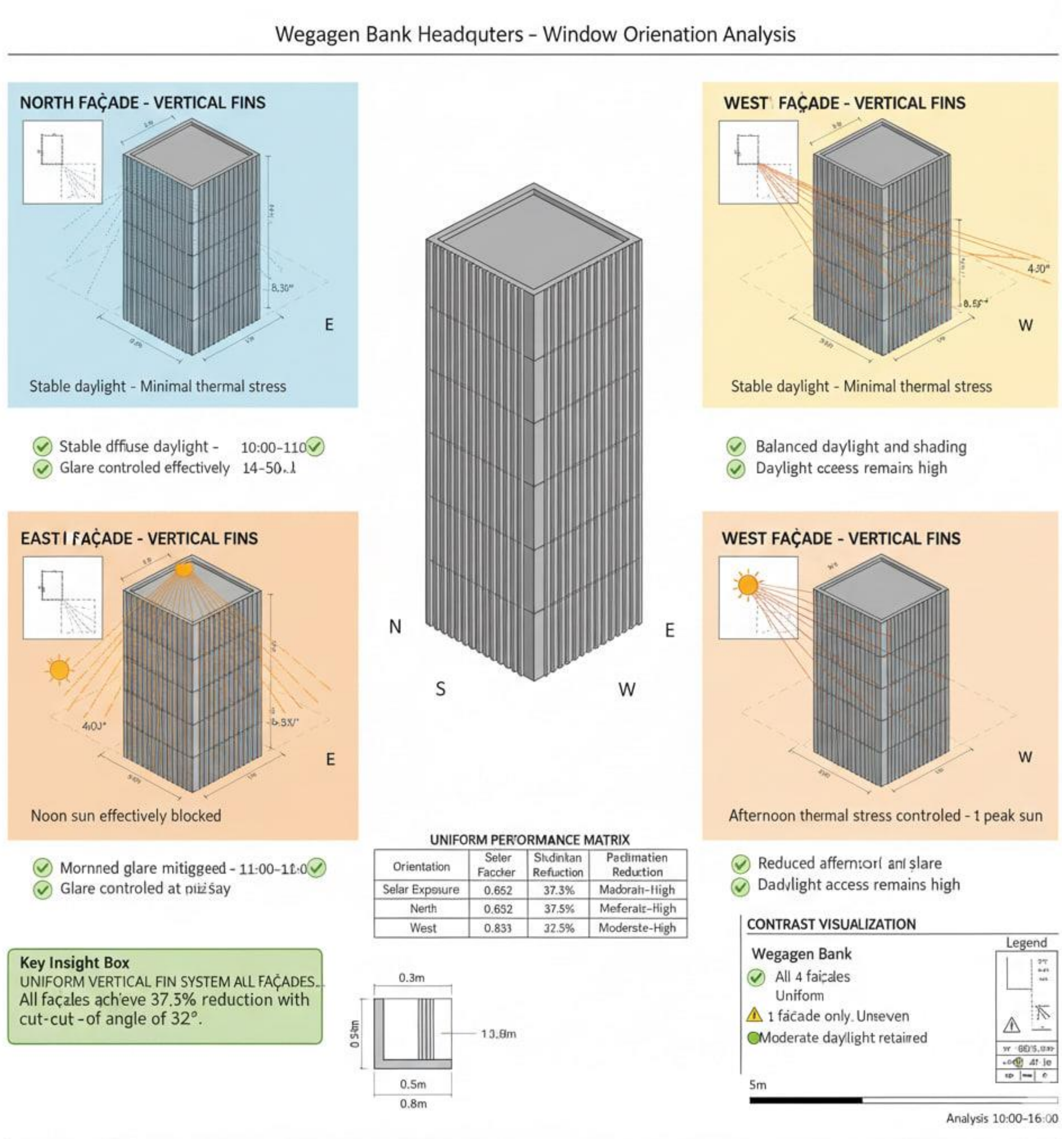


Figure 4.14: Sun-Breaker Performance Analysis of Wegagen Bank

4.2 Sun Breakers Aesthetics Perception

4.2.1 Urban Residents' Perception of Sun Breakers in Aesthetics

Table 4.25 presents comprehensive respondent data from Addis Ababa CBD surveys (n=200 residents, n=50 professionals), quantifying demographics, aesthetic impressions, functionality ratings, design factor importance, and cultural relevance of sun-breakers across CBE, Hibret, NIB, and Wegagen HQ case studies. **Figure 4.13** visually synthesizes these findings through comparative radar charts.

Table 4.25: Respondent Evaluations of Sun-Breakers

Category	**Subcategory / Attribute**	**Percentage / Rating**	**Insight**
Respondent Type	CBD Workers	50%	Provide daily exposure–based perspectives
	Residents	26.7%	Experience sun breakers in living environment
	Frequent Visitors	16.7%	Offer occasional user viewpoints
	Others	6.7%	Miscellaneous respondent group
Engagement with CBD	>20 hours/week	66.7%	Frequent exposure shaping practical perceptions
	>40 hours/week	26.7%	High-level engagement reinforces insights
Awareness & Visual Prominence	Noticed Sun Breakers	93.3%	Highly visible architectural features
	Unaware	6.7%	Small fraction remains unaware
Aesthetic Impressions	Attractive / Very Attractive	56.7%	Overall positive perception
	Neutral	26.7%	Indicates moderate reception
	Negative	16.7%	Highlights potential for design improvement
Architectural Integration	Harmonized	46.7%	Recognized visual cohesion with buildings
	Neutral	30%	Neither positive nor negative perception

	Poor Integration	23.4%	Some respondents perceive mismatch
Contribution to Urban Identity	Enhances Urban Character	60%	Sun breakers strengthen city identity
	Neutral	23.3%	Mixed perception
	Disagree	16.7%	Minority do not see contribution
Functionality & Comfort	Glare Reduction	4.2 / 5	Highest-rated direct benefit
	Sustainability Contribution	4.1 / 5	Significant environmental recognition
	Modern Appearance	3.8 / 5	Moderate aesthetic rating
	Urban Comfort Improvement	3.7 / 5	Moderate user experience benefit
	Visual Appeal	3.6 / 5	Moderate perception of attractiveness
	Cooling Effect	3.5 / 5	Lowest-rated, less perceptible benefit
Design Factors Influencing Perception	Material	4.2 / 5	Most important for aesthetic and tactile perception
	Shape	4.0 / 5	Highlights geometric influence
	Spacing	3.8 / 5	Moderate impact on perception
	Façade Direction / Orientation	3.2 / 5	Least important factor
Cultural & Community Impact	Support Ethiopian Cultural Elements	63.3%	Strong public preference for local identity
	Opposed	20%	Minority not supportive

	Neutral	16.7%	Indecisive respondents

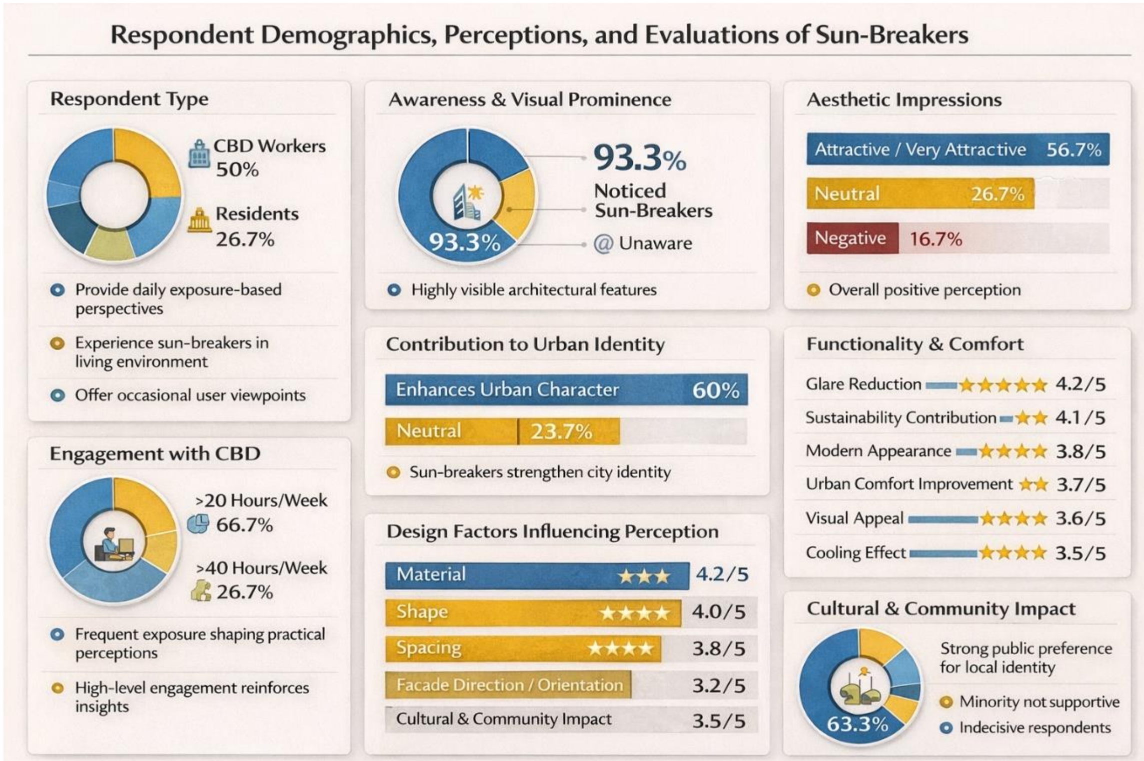


Figure 4.15: Urban Residents' Perceptions of Sun Breakers

4.2.2 Urbanists and Architects' Perception of Sun Breakers

Table 4.26 presents comprehensive professional respondent data (n=50 architects, urbanists) from Addis Ababa CBD surveys, quantifying experience distribution, specialization, design priorities, geometric/orientation factors, and cultural integration evaluations of sun-breakers across CBE, Hibret, NIB, and Wegagen HQ case studies. **Figure 4.14** visually synthesizes these professional insights.

Table 4.26: Professional Respondent Evaluations of Sun-Breakers

Category	Subcategory / Attribute	Percentage / Rating	Insight
Experience Distribution	Early & Mid-Career (0–10 yrs)	65%	Represents emerging professionals' perspectives

	Senior Practitioners (>11 yrs)	35%	Includes seasoned expertise
Areas of Specialization	Architecture	55%	Largest professional group, core design insights
	Urban Planning	30%	Provides urban-scale perspectives
	Urban Design	25%	Contributes to district-level considerations
	Interior Design	15%	Offers interior environmental perspectives
Familiarity with Sun-Breaker Design	Familiar	60%	Recognized as important in professional practice
	Somewhat Familiar	15%	Moderate awareness
	Not Familiar	25%	Limited awareness
Design Priorities	Solar Shading Performance	4.9 / 5	Highest priority for environmental control
	Thermal Comfort	4.8 / 5	Essential for occupant well-being
	Energy Efficiency	4.7 / 5	Critical sustainability factor
	Natural Light Optimization	4.5 / 5	Balances daylight and shading
	Glare Reduction	4.4 / 5	Mid-tier performance consideration
	Material Durability	4.3 / 5	Practical and long-term concern
	Aesthetic Integration	4.1 / 5	Important but secondary to function
	Maintenance	4.0 / 5	Considered in design feasibility

	Urban Contribution	3.9 / 5	Lower initial priority
	Cost-Effectiveness	3.7 / 5	Less critical than performance
	Cultural Relevance	3.5 / 5	Recognized but initially less emphasized
Geometry Elements	Shape	4.4 / 5	Key factor in visual and functional design
	Depth / Projection	4.3 / 5	Essential for shading effectiveness
	Material	4.2 / 5	Balances performance and aesthetics
	Spacing / Density	3.5 / 5	Less independently critical
Orientation Elements	Primary Façade Direction	4.7 / 5	Critical for solar performance
	Tilt Angle	3.9 / 5	Moderately important
	Density Variation by Façade	3.6 / 5	Less emphasized for consistent aesthetics
Aesthetic & Cultural Integration	Cultural Integration Importance	75%	Professionals recognize local cultural relevance
	Slightly / Not Important	15%	Minority view
	Preferred Cultural Elements	Ethiopian Cross Motifs	65%
		Traditional Lattice Patterns	30%
		Local Materials	25%
		Abstract Indigenous Patterns	20%

Urban Identity Contribution	Integrate Cultural Motifs	65%	Enhances architectural character
	District-Specific Identity	45%	Supports local distinction
	Dynamic / Adaptive Features	35%	Potential functional innovation
	Visual Rhythm Enhancement	25%	Minor contribution to aesthetics

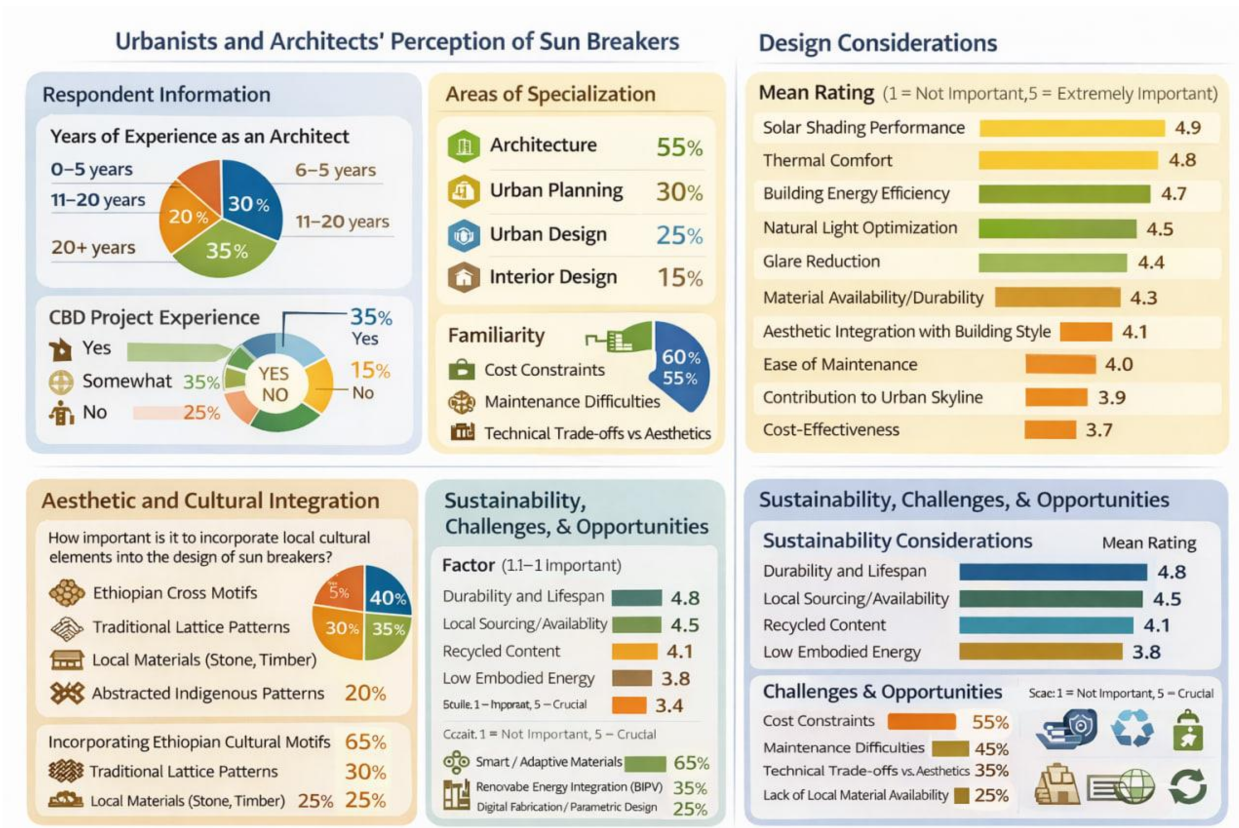


Figure 4.16: Urbanists' and Architects' Perceptions of Sun Breakers

CHAPTER FIVE

DISCUSSION

This section summarizes the findings from Chapter Four, highlighting that the environmental performance of sun-breaker systems in high-rise buildings in Addis Ababa's CBD is strongly influenced by façade orientation and the geometric configuration of shading devices, including fin depth, spacing, density, and arrangement. Analysis of the four case studies—Commercial Bank of Ethiopia Headquarters, Hibret Bank Headquarters, Nib International Bank Headquarters, and Wegagen Bank Headquarters—shows that variations in these design parameters significantly affect solar shading effectiveness. Overall, the results confirm that orientation-responsive shading designs aligned with solar geometry improve environmental performance, supporting established solar design principles for equatorial climates.

5.1 Sun Breaker Performance

The sun path diagram for Addis Ababa highlights the 10:00–16:00 solar window as the period of maximum solar radiation and thermal stress on building façades. The hourly solar angle analysis conducted in Section 4.2 shows that solar exposure varies significantly during this period depending on façade orientation.

Table 5.1 compares solar shading effectiveness across east, south, and west façades during critical 10:00–16:00 solar periods for CBE, Hibret, NIB, and Wegagen HQ. **Figure 5.1** illustrates solar geometry interactions with these case study façades at 9°N latitude.

Table 5.1: Building Performance During the Critical Solar Window

Building	Morning (East Façade)	Noon (South Façade)	Afternoon (West Façade)	Overall Response
CBE HQ	East fins reduce glare between 10:00–11:00	Vertical fins block high noon sun	West façade still experiences afternoon heat	Moderate performance

Hibret Bank HQ	East façade fully exposed	South façade receives direct noon sun	West façade partially shaded	Poor performance
NIB HQ	Diamond grid begins shading early	South fins partially block noon sun	West façade experiences moderate afternoon heat	Moderate performance
Wegagen Bank HQ	East fins provide early shading	South façade effectively blocks noon sun	West fins reduce glare and heat	Best performance

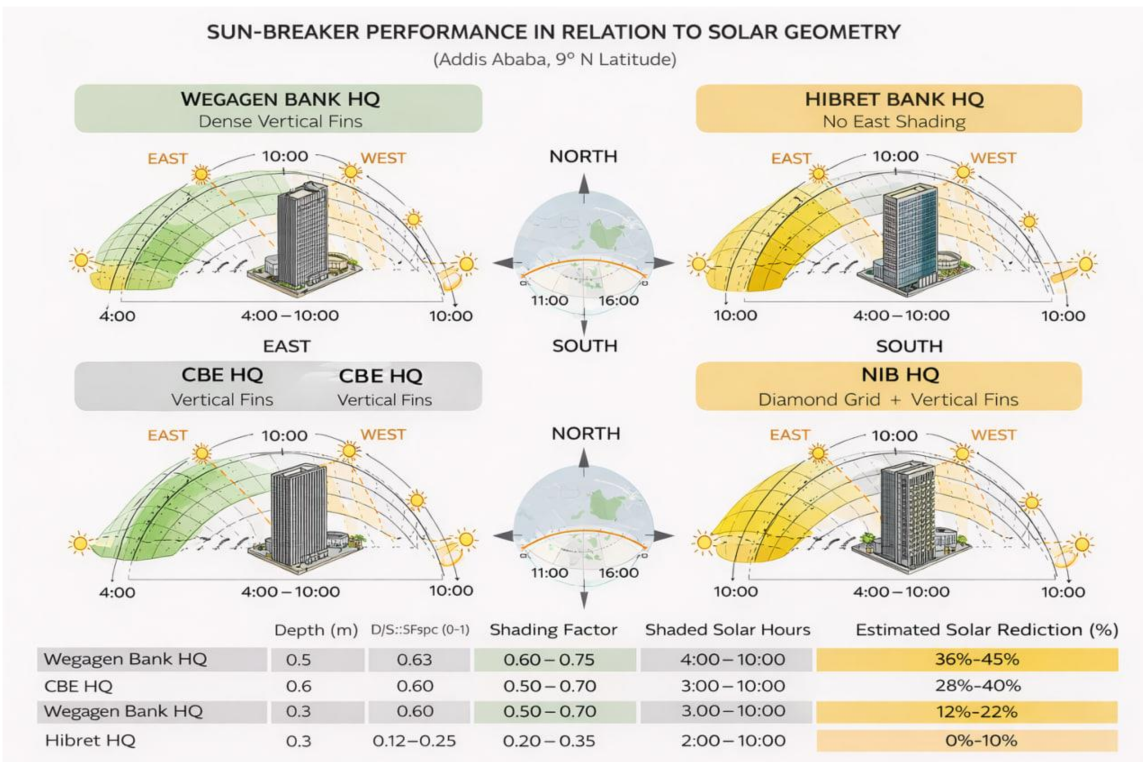


Figure 5.1: Solar Geometry and Façade of Case Study Buildings at 9^0 Latitude

West façades face the most challenging solar conditions due to prolonged low-angle afternoon sun, with dense vertical fins, like those at Wegagen Bank HQ, providing strong protection, Hibret Bank HQ performing poorly from lack of shading, and CBE and NIB HQ offering moderate, orientation-dependent control; overall, sun-breakers must target the critical 10:00–16:00 solar period for effective tropical climate performance.

5.1.1 Comparative Performance of Sun-Breaker Geometry

Geometric configuration (depth, spacing, width, angle, and orientation) is the primary determinant of shading effectiveness. **Table 5.2** compares geometric configurations of sun-breakers across CBE, Hibret, NIB, and Wegagen HQ in Addis Ababa's CBD.

Table 5.2: Geometric Configuration of Sun-Breakers

Building	Depth (m)	Spacing (m)	Orientation	Pattern	Density Level
CBE HQ	0.6	0.8–1.2	Vertical	Regular	Moderate
Hibret HQ	0.5 (West only)	Floor height	Horizontal	Minimal	Very Low
NIB HQ	0.3	0.8–2.5	Vertical + Grid	Mixed	Moderate
Wegagen HQ	0.5	0.8	Vertical	Regular	High

Among the studied buildings, Wegagen Bank HQ provides the most consistent shading with uniformly dense sun-breakers, while CBE HQ shows moderate but uneven east–west coverage. NIB HQ improves east façade performance through a diamond-grid design, whereas Hibret Bank HQ lacks comprehensive shading, leaving façades exposed. Overall, sun-breaker geometry and arrangement directly determine environmental control and occupant comfort.

5.1.2 Solar Altitude and Orientation-Based Shading Requirements

Solar Altitude (α)

The analysis indicates that all four high-rise buildings in Addis Ababa experience similar solar altitude conditions, with peaks of 81° during the equinoxes and 75.55° and 57.55° in summer and winter, respectively, highlighting the need for orientation-specific shading. High solar angles increase exposure on façades, requiring well-dimensioned vertical fins and adequately projected horizontal devices to control heat gain, reduce glare, and maintain daylight. Specifically, CBE Headquarters benefits from carefully sized vertical fins, Hibret Bank requires deeper west-facing horizontal overhangs, and Nib International and Wegagen Bank experience significant exposure during equinoxes. Overall, effective sun-breaker design with proper depth and spacing is essential to improve environmental performance and occupant comfort in Addis Ababa’s high-rise buildings.

Table 5.3 provides quantitative data on solar altitude angles, cut-off angles, and shading factors for high-rise façades in Addis Ababa, serving as a reference for designing orientation-specific sun-breaker systems. while **Figure 5.2** highlights differences in performance across façade orientations and sun-breaker configurations, supporting optimized comfort, solar control, and daylight access.

Table 5.3: Solar Altitude (α) Analysis and Shading Design Implications

Building	**Summer Solstice α (°)**	**Winter Solstice α (°)**	**Equinox α (°)**	**Key Solar Exposure Characteristics**	**Shading Design Implication**
Commercial Bank of Ethiopia (CBE) HQ	75.55	57.55	81.0	High solar altitude during equinox and summer increases vertical façade exposure at midday.	Requires carefully dimensioned **vertical fins** to reduce solar heat gain while maintaining daylight penetration.
Hibret Bank HQ	75.55	57.55	81.0	High solar altitude increases exposure on **horizontal shading elements**, particularly on the west façade.	Horizontal fins require **adequate projection depth and orientation** for effective shading control.
Nib International Bank (NIB) HQ	75.55	57.55	81.0	Similar seasonal solar altitude patterns, with strong midday solar exposure during equinox periods.	Requires shading systems capable of controlling **high-angle solar radiation** on building façades.
Wegagen Bank HQ	75.55	57.55	81.0	Equinox conditions produce the highest solar altitude, increasing façade exposure during midday hours.	Requires **well-designed vertical shading systems** to reduce thermal gain and control solar radiation.

Figure 5.2: Solar Altitude (α) and Sun-Breaker Performance at Addis Ababa's

5.1.3 Cut-Off Angle (θ_cutoff)

The cut-off angle (θ_cutoff) determines the effectiveness of sun-breaker fins in blocking direct solar penetration and controlling solar radiation on building façades. **Table 5.4** compares cut-off angle values (θ_cutoff) and shading performance across Addis Ababa CBD case studies: CBE, Hibret, NIB, and Wegagen Bank HQ. **Figure 5.3** visually overlays sun path diagrams with these cut-off analyses.

Table 5.4: Cut-Off Angle (θ_cutoff) Values and Shading Performance

Building	Range (°)	Performance Level
CBE	26.6°–36.9°	Moderate
Hibret	7.9° (horizontal)	Very Low
NIB	6.8°–20.6°	Low–Moderate
Wegagen	32°	High

Wegagen Bank HQ achieves the strongest angular solar blocking, while CBE HQ provides moderate performance but leaves the west façade somewhat exposed. NIB HQ shows highly variable east façade performance, creating inconsistent shading, and Hibret Bank HQ's low-angle fins fail to prevent significant solar penetration. Overall, cut-off angles above 30° are associated with effective and reliable shading performance.

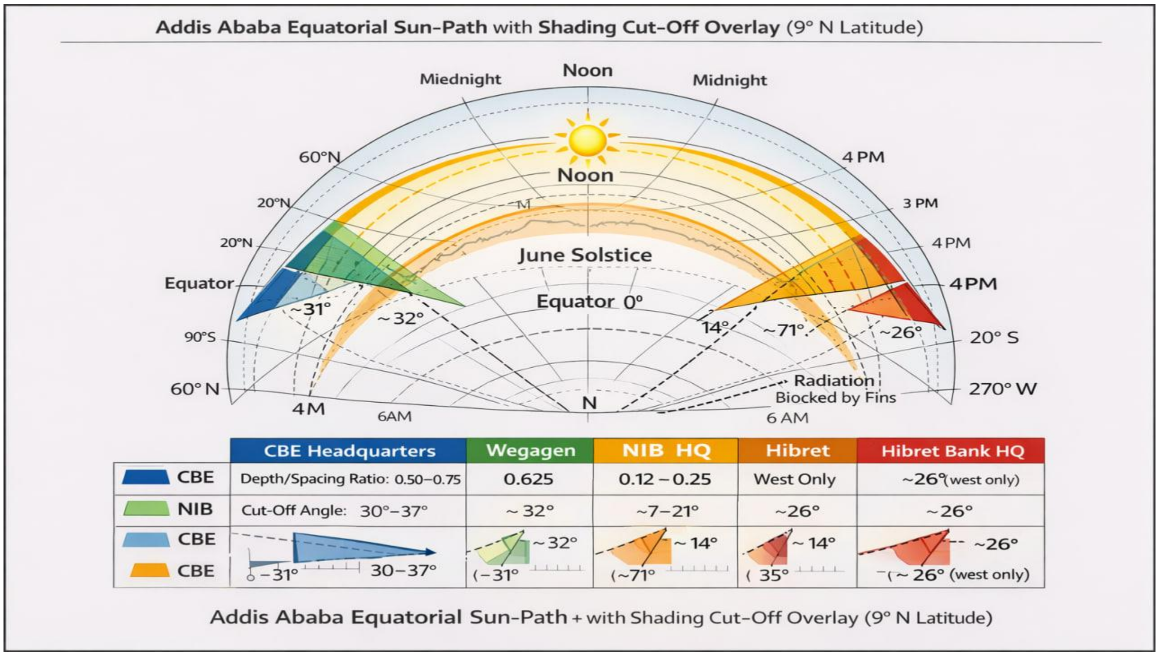


Figure 5.3: Sun Path with Cut Off Analysis of the Case Studied Buildings

5.1.4 Shading Factor (SF)

The shading factor (SF) determines the effectiveness of sun-breaker configurations in reducing solar radiation and improving shading performance on building façades. **Table 5.5** compares shading factor (SF) ranges and performance across CBE, Hibret, NIB, and Wegagen HQ case studies in Addis Ababa's CBD. **Figure 5.4** visually analyzes sun shading performance for these buildings.

Table 5.5: Shading Factor (SF) and Performance Interpretation

Building	SF Range	Interpretation
CBE	0.5–0.75	Moderate–High
Hibret	0–0.14	Very Low
NIB	0.12–0.375	Low–Moderate
Wegagen	0.625	Optimal

Shading performance stabilizes when the shading factor (SF) reaches approximately 0.6, providing consistent and effective solar control. Conversely, SF values below 0.4 result in underperformance, as exemplified by Hibret Bank HQ, where insufficient SF leads to inadequate shading and higher thermal exposure.

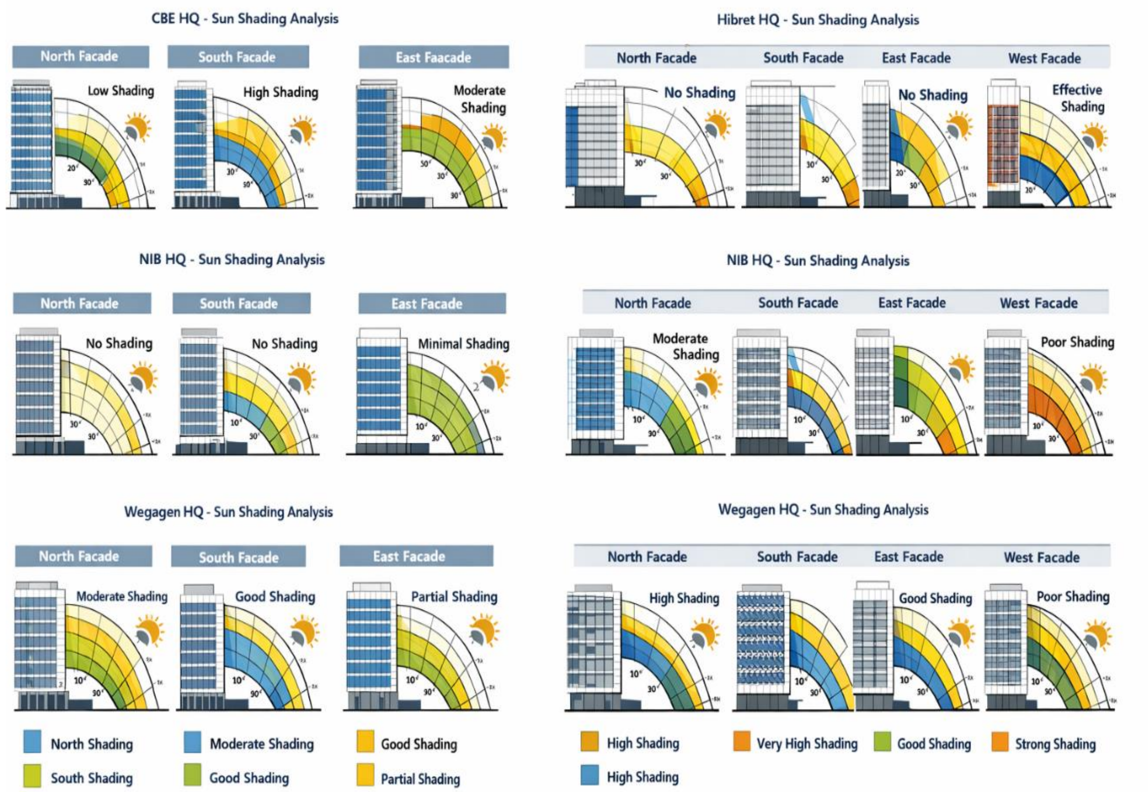


Figure 5.4: Sun Shading Analysis of the Case Studied Buildings

5.1.5 Solar Radiation Reduction

Solar radiation reduction indicates the extent to which sun-breaker systems minimize the amount of solar energy reaching building façades, thereby improving comfort and reducing heat gain. **Table 5.6** shows the solar radiation reduction percentages for four CBD buildings. Wegagen HQ provides the highest reduction at 37.5%, while Hibret HQ demonstrates the lowest and most variable performance.

Table 5.6: Solar Radiation Reduction Percentages

Building	Reduction Range

CBE	30–45%
Hibret	0–30%
NIB	7–22%
Wegagen	37.5%

Wegagen Bank HQ achieves the highest and most consistent solar radiation reduction across all façades, while CBE HQ provides moderate shading on the east and west orientations. NIB HQ shows partial improvement, particularly on the east façade, whereas Hibret Bank HQ remains thermally exposed due to minimal shading. Overall, radiation reduction closely corresponds to both the shading factor and the cut-off angle of sun-breakers. West façade is the primary climatic indicator in Addis Ababa.

5.1.6 Hourly Analysis (10:00–16:00)

Hourly analysis (10:00–16:00) determines the effectiveness of sun-breaker systems in controlling solar exposure and reducing thermal stress on building façades during peak daytime solar radiation. West façade consistently critical. **Table 5.7** presents the hourly performance assessment of west façades across four CBD buildings. Wegagen HQ provides acceptable control, while Hibret HQ experiences severe solar exposure during the afternoon while **Figure 5.5** visualize Sun Shading Analysis of the Case Studied Buildings

Table 5.7: West Façade Hourly Performance Assessment

Building	West Performance
CBE	Afternoon heat remains
Hibret	Severe exposure
NIB	Moderate stress
Wegagen	Acceptable control

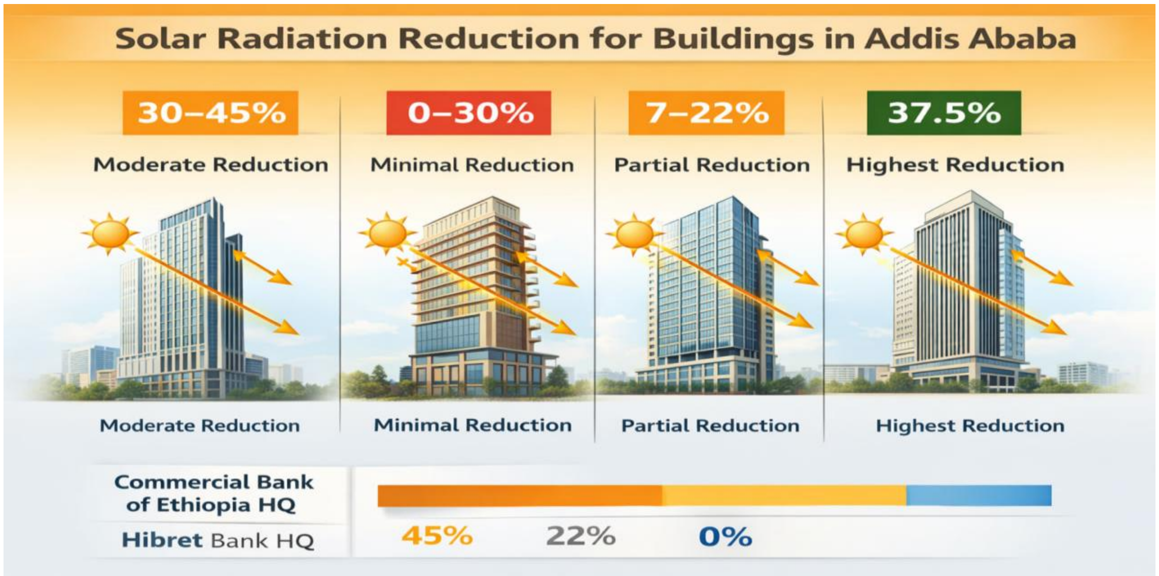


Figure 5.5: Sun Shading Analysis of the Case Studied Buildings

5.1.7 Shading Mask Performance

The shading mask analysis assesses sun-breaker effectiveness across four high-rise buildings in Addis Ababa, using metrics such as cut-off angle, shading factor, shaded hours (10:00–16:00), and radiation reduction. Wegagen Bank HQ performs best, blocking 4.5 hours of sunlight and reducing radiation by ≈37.5% due to dense, well-proportioned vertical fins. CBE HQ provides moderate shading, covering 3.5 hours and reducing 30–45% of solar radiation despite some spacing variation. NIB Bank HQ shows low to moderate effectiveness, shading 2.5 hours with 7–22% radiation reduction due to irregular geometry, while Hibret Bank HQ performs the worst with only 1.5 shaded hours and 0–30% reduction from limited devices. Overall, the analysis confirms that dense vertical sun-breakers with optimal depth-to-spacing ratios offer the most effective solar control in Addis Ababa's high-altitude conditions, as detailed in **Table 5.8** and visualized in **Figures 5.6–5.7.**

Table 5.8: Shading Mask Performance of As-Built Sun-Breakers

Building	Average Fin Depth (m)	Average Spacing (m)	Cut-Off Angle (θ)	Shaded Solar Hours	Shading Factor (SF)	Estimated Solar Radiation	Performance Level

				(10:00–16:00)		Reduction (%)	
CBE Headquarters	0.6	0.8–1.2	26.6°–36.9°	3.5 hrs	0.50–0.75	30–45%	Moderate
Wegagen Bank HQ	0.5	0.8	~32°	4.5 hrs	0.625	~37.5%	High
NIB Bank HQ	0.3	0.8–2.5	6.8°–20.6°	2.5 hrs	0.125–0.375	7–22%	Low–Moderate
Hibret Bank HQ	0.5 (west only)	Floor spacing	~26°	1.5 hrs	0–0.5	0–30%	Low

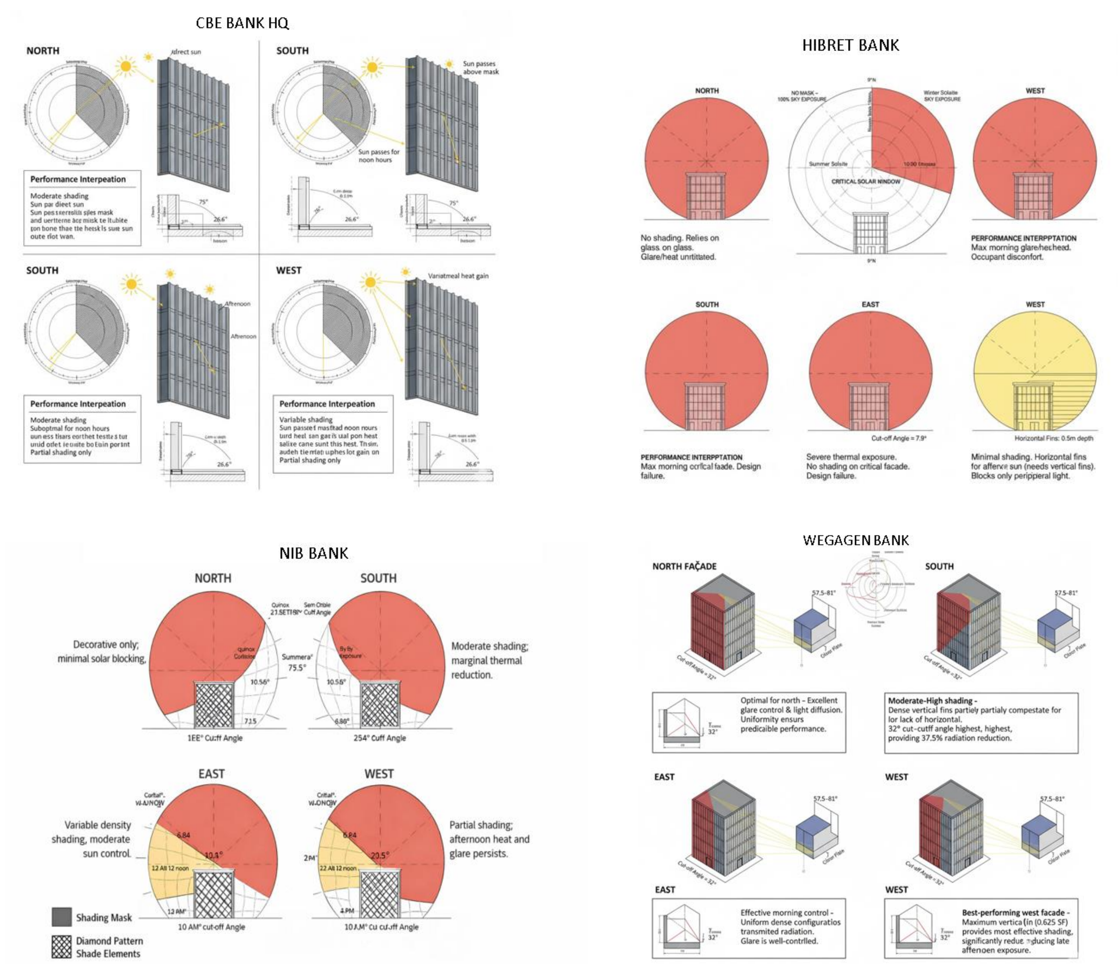


Figure 5.6: Solar Mask Analysis of Case Study Buildings at 9^0 Latitude

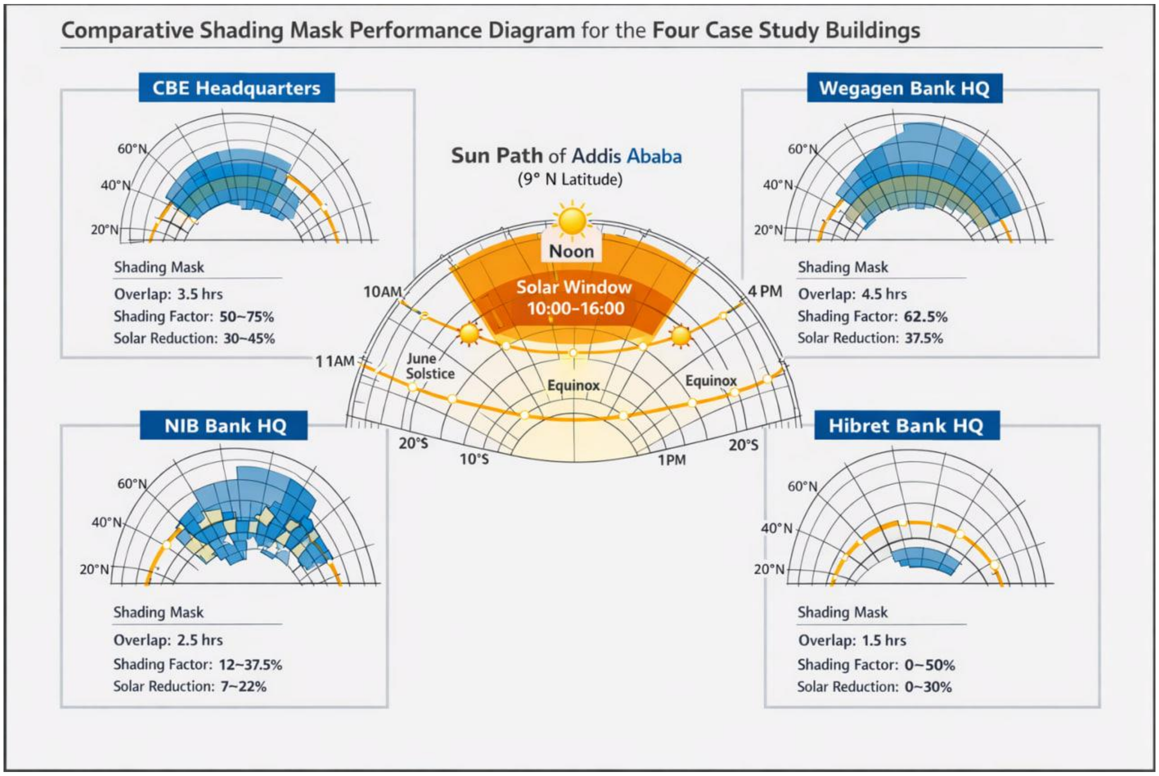


Figure 5.7: Solar Mask Performance of Case Study Buildings at 9^0 Latitude

5.2 Sun-Breakers Aesthetic Perception

This section compares urban residents and professionals. **Table 5.9** compares urban residents' and design professionals' perceptions of sun-breaker design and performance in Addis Ababa CBD high-rises.

Table 5.9: Sun-Breaker Design: Urban Residents vs. Professionals

Dimension	Urban Residents	Professionals	Interpretation
Top Priority	Material (4.2)	Solar Shading (4.9)	Residents focus on visible qualities; professionals prioritize environmental performance
Shape	4.0	4.4	Shared recognition of geometric importance
Orientation	3.2	4.7	Professionals more aware of technical solar performance
Cultural Integration	63.3% support	75% endorse	Strong alignment on importance of local cultural elements

Glare Reduction	4.2	4.4	Both groups value functional comfort
Urban Identity Contribution	60% perceive enhancement	65% recognize potential	Consensus on reinforcing city character
Aesthetic Integration	46.7% harmonized	4.1 / 5 rated	Residents note visual harmony; professionals combine aesthetics with performance
Awareness of Sun Breakers	93.3% noticed	60% familiar	Residents notice more due to daily exposure; professionals recognize by design knowledge
Cooling Effect	3.5 / 5	3.5 / 5	Both groups perceive thermal benefits similarly

Urban residents and professionals approach sun-breakers with different perspectives. Urban residents focus on visible and immediate qualities such as material, aesthetics, and overall visual impact, while professionals emphasize functional performance, including solar shading, orientation, and environmental efficiency. Both groups value cultural integration, with professionals showing slightly greater awareness of technical considerations. Despite these differences, they share common priorities, particularly regarding practical benefits like glare reduction and cooling effects.

5.3 Sun Breaker Integrated Synthesis of Performance and Aesthetic

Table 5.10 provides an integrated synthesis linking sun-breaker geometry, shading performance metrics, and aesthetic/perceptual evaluations across Addis Ababa CBD case studies.

Table 5.10: Sun-Breaker Performance and Aesthetic Perception

Analysis Component	**Observations / Metrics**	**Interpretation**
Geometry Analysis	Depth: 0.3–0.6 m; Spacing: 0.8–2.5 m; Pattern: Vertical, Horizontal, Grid; Density: Very Low–High	Depth and spacing directly influence shading effectiveness; high-density façades (Wegagen) perform best; innovative grids (NIB) improve east exposure

Shading Performance	Cut-off Angle: 6.8°–36.9°; SF: 0–0.75; Radiation Reduction: 0–45%	θ_cutoff >30° and SF ≈ 0.6–0.7 correlate with optimal shading; low SF/angle (Hibret) results in poor performance; radiation reduction aligns with SF and θ_cutoff
Hourly Façade Performance	West façades most critical; Wegagen acceptable; Hibret severe exposure	Afternoon low-angle sun dominates thermal stress; West façades are key performance indicators
Aesthetic Perception	Residents: material (4.2), shape (4.0), harmonized visual impression (46.7%); Professionals: solar shading (4.9), shape (4.4), aesthetic integration (4.1)	Residents value visible qualities; professionals prioritize environmental performance; shared recognition for shape and functional aesthetics
Cultural & Urban Identity Contribution	Cultural support: 63.3% (residents), 75% (professionals); Urban identity contribution: 60–65%	Strong alignment on local cultural motifs; sun-breakers enhance city character and reinforce architectural identity
Integrated Synthesis	Multi-case comparison shows Wegagen HQ leads in performance; Hibret HQ underperforms; CBE and NIB moderate	High-density vertical fins, θ_cutoff ≥30°, SF ≈ 0.6–0.7, and visual coherence optimize both shading performance and aesthetics

Sun-breaker design must balance geometry, orientation, aesthetics, and cultural integration, with depth, spacing, pattern, and density driving shading efficiency; high-density or innovative grids enhance function and visual appeal, façade orientation dictates critical sun exposure, and integrating local motifs ensures cultural relevance while maintaining effective solar control.

5.3.1 Implications for Equatorial Sun-Breaker Design

The design of sun-breaker systems in equatorial regions must respond directly to solar geometry and façade orientation to effectively control solar heat gain and daylight penetration. Table 5.11 compares key design implications for sun-breaker configurations between northern equatorial latitudes (≈9°N) and southern equatorial latitudes (8°–10°S), highlighting the reversal of north–south shading priorities.

Table 5.10: Sun-Breaker Design in Northern (≈9°N) and Southern (8°–10°S)

Design Aspect	Northern Equatorial Latitude (~9°N – e.g., Addis Ababa)	Southern Equatorial Latitude (8°–10°S)	Design Implication
Solar Path Geometry	Sun passes mostly south of the zenith; north façade receives limited direct sun except in summer	Solar path shifts northward; north façade receives intense overhead sun	Sun-breaker design must reverse north–south façade priorities between hemispheres
North Façade Strategy	Minimal shading; light vertical fins with wide spacing (~1.2 m); PF ≈ 0.43	Dense vertical fins (~0.3 m width, 0.8 m spacing) with high cut-off angles (~90°)	Northern hemisphere north façades require glare control; southern hemisphere north façades require strong thermal protection
South Façade Strategy	Moderate shading; PF ≈ 0.65; horizontal overhangs or light shelves effective	Minimal or no shading required	Shading emphasis shifts from south façade (north hemisphere) to north façade (south hemisphere)
East Façade Strategy	Strong shading needed for low-angle morning sun; PF ≈ 1.55; vertical fins preferred	Similar requirements as northern hemisphere	East façades require orientation-responsive fins regardless of hemisphere
West Façade Strategy	Critical façade due to prolonged afternoon solar exposure; PF ≈ 1.46; dense vertical fins recommended	Same requirement due to afternoon solar intensity	West façade remains the key climatic indicator in equatorial cities
Cut-Off Angle Requirement	Effective shading when θ ≥ 30°	Same threshold applies	Angular blocking is a universal performance indicator for solar protection
Shading Factor Target	Optimal SF ≈ 0.6–0.7	Similar optimal range	Ensures balanced solar protection and daylight penetration

Radiation Reduction Target	35–45% reduction for critical orientations	Comparable reduction targets	Dense vertical fins with proper spacing achieve optimal solar control
Effective Geometry	Depth: 0.3–0.6 m; Spacing: 0.8–1.2 m; high density improves performance	Similar geometric ratios but applied to opposite façade	Geometry must align with solar exposure rather than aesthetic preference

Effective sun-breaker design in equatorial climates must respond to solar geometry and façade orientation. At northern equatorial latitudes (~9°N), north façades require minimal shading, south façades require moderate protection, and east–west façades need dense vertical fins to block low-angle morning and afternoon sun.

In southern equatorial latitudes (8°–10°S), shading priorities reverse because the solar path shifts northward; therefore, dense vertical fins are required on north façades while south façades need little or no shading. Overall, effective systems typically achieve cut-off angles above 30°, shading factors around 0.6–0.7, and radiation reduction of about 35–45% for critical orientations.

5.3.2 Implications for Addis Ababa Sun-Breaker Design

The findings from the four case study buildings, combined with international shading principles recommended by **UN-Habitat**, highlight the importance of orientation-responsive sun-breaker design for high-rise buildings in Addis Ababa's near-equatorial climate. Because the city experiences high solar altitude angles and strong solar radiation throughout the year, façade shading systems must be dimensioned according to solar geometry and window proportions to effectively reduce heat gain while maintaining solar performance access.

Analysis of the case studies indicates that shading performance is largely determined by the relationship between **window height (X)** and the **projection depth (P)** of shading devices. The research identifies optimal projection factors that can guide façade design. South-facing façades require deeper horizontal overhangs with a projection factor of **PF ≈ 0.66**, corresponding to solar altitude angles around **57°**. These overhangs effectively block high-angle midday solar radiation while still allowing winter sunlight penetration, improving daylighting and reducing cooling loads.

For north, east, and west façades, the research indicates a slightly smaller projection factor of **PF ≈ 0.55**, associated with solar altitudes around **61°**. On the north façade, horizontal overhangs of this proportion allow diffuse daylight while limiting overheating. On east and west façades, however, horizontal shading alone is insufficient due to low-angle morning and afternoon sun. Therefore, the optimal configuration combines **horizontal canopies with vertical fins**, where fin depth is approximately **0.55X**, enabling effective control of solar performance during critical hours.

The resulting design guideline for Addis Ababa high-rise buildings can be expressed through the general shading relationship:

$$P = PF \times X$$

where **P** represents the projection depth of the sun-breaker, **PF** is the projection factor determined by façade orientation and solar altitude, and **X** is the window height. In practical design terms, this leads to a simplified rule:

- **South façades:** $P = 0.66X$(deep horizontal overhangs)
- **North façades:** $P = 0.55X$(moderate horizontal shading)
- **East and west façades:** vertical fins with $P_{fin} = 0.55X$, often combined with horizontal canopies.

These orientation-specific configurations enhance façade performance by reducing solar penetration. For modern curtain-wall towers, such shading strategies also help mitigate façade overheating.

Overall, the research demonstrates that **solar-responsive geometric design is essential for effective sun-breaker systems in Addis Ababa**. By applying projection factors derived from solar altitude angles and validated through case study analysis, architects can develop scalable façade solutions that align with international environmental design standards while addressing the climatic conditions of equatorial high-rise environments.

Table 5.12 presents recommended sun-breaker configurations for high-rise façades, indicating that **south façades require deeper horizontal overhangs (PF = 0.66)**, while **north, east, and west façades use smaller projections or vertical fins (PF = 0.55)** to control solar radiation. **Figure 5.8** further illustrates these systems through sectional views, showing how orientation-specific shading improves thermal comfort, reduces cooling loads and glare, and maintains adequate daylight in modern curtain-wall buildings under near-equatorial conditions.

Table 5.11: Sun-Breaker Design for High-Rise Façades in Addis Ababa

Façade Orientation	Window Height Reference (X)	Shading Type	Projection / Fin Dimension	Solar Altitude Angle	Projection Factor (PF)	Key Performance / Benefits	High-Rise Implications
South	X	Horizontal overhang	0.66 X	57°	0.66	Blocks high-angle midday sun; allows winter sun for daylight and passive heating	Continuous horizontal shading reduces cooling loads, glare, and façade overheating
North	X	Horizontal overhang	0.55 X	61°	0.55	Blocks high-angle sun, allows diffuse daylight, prevents overheating	Improves daylight uniformity and thermal comfort for large curtain walls
East	X	Horizontal canopy + vertical fins	Canopy = X; Fins = 0.55 X	61°	0.55	Controls low-angle morning sun, reduces glare, maintains visibility	Mitigates early overheating and glare on workstations
West	X	Horizontal canopy +	Canopy = X; Fins = 0.55 X	61°	0.55	Blocks low-angle afternoon sun, reduces glare,	Requires strongest shading systems to

vertical fins		improves thermal comfort	reduce cooling demand in late afternoon

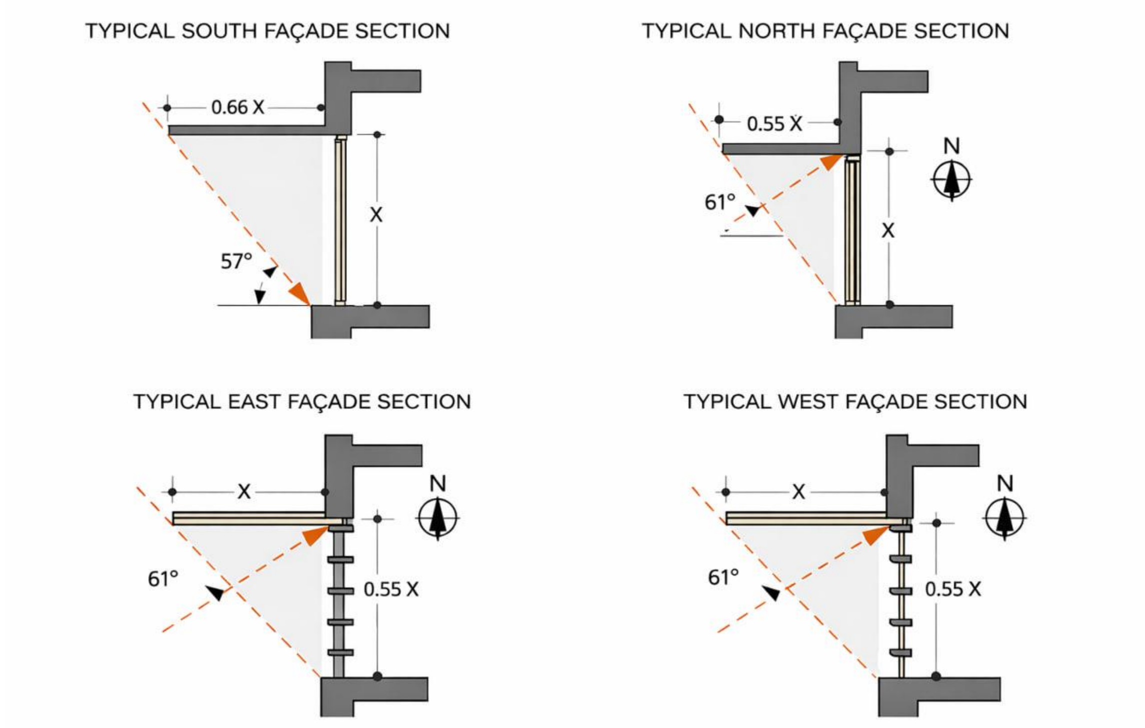


Figure 5.8: Sun-Breaker for South, North, East, and West Façades of Addis Ababa

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

This chapter presents the final conclusions and recommendations derived from the performance and aesthetic analysis of sun-breaker systems in high-rise buildings within an equatorial context. Focusing on four case studies—Commercial Bank of Ethiopia, Hibret Bank, Nib International Bank, and Wegagen Bank headquarters—it synthesizes solar performance analysis, geometric configuration, and perceptual evaluations to inform best practices for orientation-responsive sun-breaker design.

6.1 Conclusion

The study analyzed sun-breaker systems in equatorial high-rise buildings, emphasizing the interaction between geometric configuration, solar exposure, and occupant/professional perception. Key conclusions are summarized as follows:

1. **Geometry-Driven Solar Control:** Fin depth, spacing, pattern, and density are primary determinants of shading effectiveness. High-density façades (e.g., Wegagen Bank HQ) provide superior thermal control and solar reduction, while low-density or minimal-coverage façades (e.g., Hibret Bank HQ) exhibit poor performance. Innovative grid designs, as seen in NIB HQ, enhance east façade shading during critical morning hours.

2. **Orientation-Specific Performance:** Façade orientation strongly influences solar exposure. West façades face prolonged low-angle afternoon sun, requiring denser vertical fins. South façades require control of high-angle midday sun, while east façades benefit from geometric and pattern-based solutions to manage morning glare without compromising daylight.

3. **Integrated Aesthetic and Functional Perception:** Residents prioritize visual qualities such as material, shape, and harmonious patterns, whereas professionals emphasize environmental performance, including shading effectiveness and solar

orientation. Shared priorities, such as shape, glare reduction, and visual coherence, indicate areas where aesthetics and functionality intersect.

4. **Cultural and Urban Identity Contribution:** Sun-breakers support local identity and cultural motifs, with 63–75% alignment between residents and professionals on cultural integration. Properly designed sun-breakers contribute to the city's architectural character while maintaining functional performance.

5. **Performance Benchmarks:** Effective shading aligns with cut-off angles above 30°, shading factors around 0.6–0.7, and radiation reduction of 35–45% on critical façades. Dense vertical fins with appropriate depth and spacing consistently achieve optimal environmental control while preserving daylight.

6. **Equatorial Design Implications:** In northern equatorial latitudes (~9°N), north façades require minimal shading, south façades require moderate shading, and east–west façades require dense fins. In southern equatorial latitudes (8°–10°S), shading priorities reverse due to the hemispheric shift of solar path: dense fins are applied to north façades, while south façades require minimal shading. East–west façades remain critical across both hemispheres.

7. **Addis Ababa Sun-Breaker Design Guideline**

   Based on the solar geometry analysis and case study findings, shading devices should be dimensioned relative to window height using a projection factor. The recommended relationship for high-rise façade shading is:

   $$P = PF \times X$$

   where **P** represents projection depth, **PF** is the projection factor determined by façade orientation, and **X** represents window height. Optimal values identified in the research include **PF ≈ 0.66 for south façades** and **PF ≈ 0.55 for north, east, and west façades**.

Overall, the study confirms that effective sun-breaker systems must integrate solar-responsive geometry, façade orientation, aesthetic considerations, and cultural identity to achieve balanced environmental performance and architectural quality in high-rise buildings.

6.2 Recommendations

Based on the integrated analysis, the following design and research recommendations are proposed:

1. **Orientation-Responsive Design:**

- **West façades:** Increase vertical fin density and ensure cut-off angles ≥30° to mitigate low-angle afternoon solar gain.
- **South façades:** Apply sufficient projection depth to manage high-angle midday sun.
- **East façades:** Utilize grid, diamond, or other innovative fin patterns to control morning sun while maintaining daylight penetration.

2. **Optimized Geometry and Visual Coherence:**

- Maintain consistent depth, spacing, and pattern across façades to enhance both shading performance and visual uniformity.
- Select materials and geometric forms that align with both resident aesthetic preferences and professional performance requirements.

3. **Application of Projection Factor Design Guidelines**

- Architects should use projection factors derived from solar geometry to dimension shading systems relative to window height. Recommended values for Addis Ababa high-rise façades include:
    - **South façade:** $P = 0.66X$
    - **North façade:** $P = 0.55X$
    - **East and West façades:** vertical fins with $P_{fin} = 0.55X$
- These ratios provide a scalable design guideline for curtain-wall high-rise buildings in near-equatorial climates.

4. **Cultural Integration:**

- Incorporate Ethiopian motifs, lattice patterns, or local material cues to reinforce urban identity.

- Ensure cultural elements do not compromise shading effectiveness or thermal performance.

5. **Performance Standards:**

- Aim for shading factors of 0.6–0.7 and cut-off angles above 30° as minimum benchmarks.
- Apply dense vertical fins strategically on façades with prolonged solar exposure to maximize solar control and comfort.

6. **Future Design and Research Directions:**

- Explore adaptive or dynamic shading systems that respond to hourly and seasonal solar variations.
- Conduct post-occupancy evaluations to validate both environmental and perceptual performance.
- Extend research to other equatorial urban contexts to establish broader guidelines for culturally responsive, high-performance sun-breaker systems.

Overall, the study confirms that integrating solar geometry, façade orientation, geometric configuration, and cultural/aesthetic considerations produces sun-breaker systems that optimize environmental performance, occupant comfort, and urban identity in equatorial high-rise buildings.

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REFERENCES

AACPPO (Addis Ababa City Plan Preparation Office). (2017). *Addis Ababa City Structure Plan: 2017-2027*. Addis Ababa: AACPPO.

Al-Obaidi, K. M., & Ismail, M. (2011). Passive design strategies for energy efficient buildings in the tropics. *Journal of Building Performance*, 2(1), 1-12.

Al-Obaidi, K. M., Ismail, M., & Rahman, A. M. A. (2014). A review of skylight glazing materials in architectural design for better energy performance. *Renewable and Sustainable Energy Reviews*, 39, 899-912.

ASHRAE. (2017). *ASHRAE Handbook: Fundamentals*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. (2021). *ASHRAE Handbook: HVAC Applications*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Baker, N., Fanchiotti, A., & Steemers, K. (2017). *Daylighting in architecture: A European reference book*. Routledge.

Bellia, L., Marino, C., Minichiello, F., & Pedace, A. (2014). An overview on solar shading systems for buildings. *Energy Procedia*, 62, 309-317.

Curtis, W. J. R. (1986). *Le Corbusier: Ideas and forms*. Phaidon Press.

Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal processes* (4th ed.). John Wiley & Sons.

Emporis. (2019). *Tall buildings in Addis Ababa*. Emporis Corporation.

Fathy, H. (1986). *Natural energy and vernacular architecture*. University of Chicago Press.

Ferrari, S., & Wang, Z. (2023). Solar shading performance in East African high-rise buildings. *Building and Environment*, 228, 109-125.

Fikade, B. (2020). High-rise development in Addis Ababa: Challenges and opportunities. *Ethiopian Journal of Architecture*, 3(1), 45-62.

Gebreyohannes, T. (2021). Sun-breaker design for office buildings in Addis Ababa. *Journal of Sustainable Architecture*, 8(2), 78-95.

Geda, A. (2018). *The economic history of Ethiopia*. Addis Ababa University Press.

Givoni, B. (1994). *Passive and low energy cooling of buildings*. Van Nostrand Reinhold.

Givoni, B. (1998). *Climate considerations in building and urban design*. John Wiley & Sons.

Hall, P., & Frampton, K. (1997). *The city of towers: Future trends in high-rise development*. Thames & Hudson.

Johansson, E., & Emmanuel, R. (2006). The influence of urban design on outdoor thermal comfort. *International Journal of Biometeorology*, 51(2), 119-133.

Kamal, M. A. (2011). An investigation into the role of shading devices for improving thermal comfort in buildings. *Architectural Science Review*, 54(3), 211-220.

Mandalaki, M., & Tsoutsos, T. (2020). *Solar shading systems: Design, performance, and integrated photovoltaics*. Springer.

Menberu, M. (2020). Internal versus external shading devices in Addis Ababa office buildings. *Ethiopian Journal of Built Environment*, 2(1), 34-51.

Mesfin, D. (2020). Climate responsive architecture in the Ethiopian highlands. *Journal of African Architecture*, 4(2), 112-128.

Muluneh, B., Worku, A., & Fanta, F. (2021). Architectural identity in contemporary Addis Ababa. *African Cities Journal*, 6(3), 201-218.

Oligay, V. (2018). *Solar control and shading devices*. Princeton University Press.

Olgyay, V. (2015). *Design with climate: Bioclimatic approach to architectural regionalism*. Princeton University Press.

Reinhart, C. F., & Wienold, J. (2011). The daylighting dashboard – A simulation-based design analysis for daylit spaces. *Building and Environment*, 46(2), 386-396.

Straube, J. (2012). *Building enclosure fundamentals*. Building Science Press.

Szokolay, S. V. (2014). *Introduction to architectural science: The basis of sustainable design* (3rd ed.). Routledge.

Tadesse, M., & Bekele, K. (2019). Urban planning and zoning regulations in Addis Ababa. *Journal of Urban Planning and Development*, 145(3), 05019012.

Turan, I., Cheung, K., & Fuller, R. J. (2007). Energy performance of external shading devices in office buildings. *Building and Environment*, 42(12), 4186-4195.

Watson, D., & Labs, K. (2019). *Climatic building design: Energy-efficient building principles and practice*. McGraw-Hill.

World Bank. (2019). *Ethiopia urbanization review*. World Bank Group.

Wright, D. (2014). *Passive solar architecture*. Routledge.

Yoo, S., & Manz, H. (2011). Available performance of external shading devices in office buildings. *Energy and Buildings*, 43(9), 2275-2284.

Zewde, B. (2002). *A history of modern Ethiopia, 1855-1991* (2nd ed.). James Currey.

APPENDIX

Appendix 1 Research Manuscript

RESEARCH MANUSCRIPT

Thesis Title*:* The Dichotomy of the Performance and Aesthetics of Sun Breaker of High-Rise Buildings in the CBD of Addis Ababa, Ethiopia.

Focus: Geometric Performance Analysis and Orientation Influence on Solar Shading Effectiveness

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ABSTRACT

This study investigates the geometric performance of permanent sun-breakers on high-rise façades in Addis Ababa, with a focus on how orientation influences solar shading effectiveness. Four bank headquarters—Commercial Bank of Ethiopia, Hibret Bank, Nib International Bank, and Wegagen Bank—were analyzed to assess sun-breaker configurations, including fin depth, spacing, density, and arrangement. Quantitative evaluations measured shading factors, cut-off angles, and solar-radiation reduction across east, south, and west façades. Findings indicate that orientation significantly affects shading performance: west façades exposed to low-angle afternoon sun benefit most from dense vertical fins, while east and south façades require orientation-specific geometric adjustments for effective solar control. Optimal shading performance is achieved with cut-off angles above 30° and shading factors between 0.6 and 0.7, demonstrating that façade orientation and sun-breaker geometry are critical for minimizing solar heat gain. The

results provide practical guidance for designing orientation-responsive shading systems for high-rise buildings in equatorial urban environments.

Keywords: Sun-breakers; Solar shading; Geometric performance; Façade orientation; High-rise buildings; Addis Ababa.

1. INTRODUCTION

1.1 Background

As urbanization intensifies in equatorial highland climates, the building envelope has become increasingly critical as the primary interface between interior and exterior environments, determining solar performance, occupant comfort, and architectural identity (ASHRAE, 2017). Sun-breakers (shading devices) are particularly significant in tropical contexts, regulating solar radiation and daylight while contributing to architectural expression.

Contemporary sun-breaker design integrates building physics, solar geometry, and material science. Key parameters—depth, spacing, width, and orientation—determine shading effectiveness. This creates an inherent design challenge: deeper projections improve shading but add visual mass, while wider spacing admits lighter but compromises performance.

Addis Ababa, Ethiopia's capital (9°N latitude, >2,300m elevation), offers a critical context for studying sun-breaker performance. The city experiences an equatorial highland climate with intense year-round solar radiation. Solar noon altitudes range from 57.5° in winter to 81.5° in summer, creating complex, seasonally variable shading requirements (Szokolay, 2014). Low-angle morning and afternoon sun (<30°) poses specific challenges for east and west façades, while high-altitude midday sun requires different strategies for south-facing surfaces.

Over the past two decades, Addis Ababa has undergone rapid vertical growth, with 101 tall buildings documented by 2019 (Emporis, 2019). This transformation has made sun-breaker design increasingly critical, as high-rise façades are now exposed to solar radiation across all orientations.

1.2 Problem Statement

The rapid growth of high-rise office buildings in Addis Ababa's Central Business District has increased the use of fully glazed façades that often lack effective solar-responsive design. Although sun-breakers are intended to control solar radiation, many buildings demonstrate a gap between intended and actual environmental performance. Due to the city's high-altitude equatorial climate, buildings are exposed to intense solar radiation throughout the year. Poorly oriented façades and inadequate shading systems allow excessive sunlight to penetrate office interiors, causing glare, overheating, and uneven daylight distribution.

Despite the potential of sun-breakers to significantly reduce solar heat gain, their application in many Addis Ababa buildings is inconsistent, often driven by aesthetic considerations without proper solar analysis. Consequently, there is a need to investigate how sun-breaker geometry and orientation influence solar shading effectiveness.

1.3 Objective and Research Question

Specific Objective:

- To investigate the geometric performance of existing permanent sun-breakers fixed on various orientations of selected high-rise buildings in Addis Ababa's CBD.

Specific Research Question:

- How does the orientation of permanent sun-breakers influence their solar shading effectiveness on high-rise façades in Addis Ababa?

1.4 Scope and Case Studies

The study focused on four cardinal orientations (north, south, east, west) analyzing solar paths between 10:00–16:00 using sun path diagrams. Four commercial high-rise bank headquarters in Kirkos and Lideta Sub-Cities were purposively selected (Table 1).

Table 1: Profile of Case Study Buildings

No	Building Name	Floors	Height (m)	Configuration

1	Commercial Bank of Ethiopia HQ	46	209	Vertical fins
2	Hibret Bank HQ	37	137	Horizontal louvers
3	Nib Bank HQ	37	137	Parametric/honeycomb
4	Wegagen Bank HQ	23	107	Composite

2. LITERATURE REVIEW

2.1 Solar Geometry and Façade Performance

Solar geometry forms the scientific basis for climate-responsive façade design. Solar altitude (α) determines the sun's vertical position, influencing shadow length and façade penetration depth. At Addis Ababa's 9°N latitude, solar noon altitudes range from 57.5° (winter solstice) to 81.5° (summer solstice) (Szokolay, 2014). Solar azimuth (γ) defines horizontal sun movement, with seasonal shifts allowing sunlight to strike both north and south façations.

Table 2: Orientation-Specific Solar Conditions and Shading

Orientation	Dominant Solar Condition	Primary Risk	Recommended Shading
North	Diffuse light, seasonal	Daylight imbalance	Light-modulating screens
South	High-altitude midday sun	Overheating	Horizontal overhangs
East	Low-angle morning sun	Glare, heat gain	Vertical fins
West	Low-angle afternoon sun	Peak cooling load	Vertical/egg-crate

2.2 Geometric Performance Metrics

Quantitative performance metrics are essential for evaluating sun-breaker effectiveness (Table 3).

Table 3: Quantitative Performance Metrics

Metric	Formula	Variables	Performance Use
Solar Altitude (α)	$\alpha = 90° - \lvert Latitude - Declination \rvert$	Latitude, Declination	Guides fin placement/depth

Cut-Off Angle (θ_cutoff)	tan θ = Depth/Spacing (vertical)	Depth, Spacing	Defines solar blocking threshold
Shading Factor (SF)	SF = Depth/Spacing	Depth, Spacing	Quantifies shading effectiveness
Radiation Reduction	(1-SF) × 100%	SF	Estimates heat gain reduction

Effective shading aligns fin depth and spacing with solar altitude: horizontal overhangs for high-angle sun (>45°), vertical fins for low-angle exposure (<45°), and egg-crate systems for multidirectional protection (Givoni, 1998; Al-Obaidi et al., 2014).

2.3 Addis Ababa Solar Context

For Addis Ababa (9°N), the sun path diagram highlights the critical 10:00–16:00 solar window for peak radiation. East façades receive morning sun (10:00–12:00), south façades receive high-angle noon sun (12:00–13:00), and west façades receive low-angle afternoon sun (14:00–16:00). This temporal distribution demands orientation-specific shading strategies.

3. MATERIALS AND METHODS

3.1 Research Design

The study employed a quantitative analytical approach to evaluate the relationship between sun-breaker geometry and solar shading performance across four case study buildings.

3.2 Data Collection

Field measurements were conducted to record sun-breaker dimensions (fin depth, spacing, width, angle) using a measuring tape. Façade orientations were determined using a compass. Geometric configurations were documented photographically and through architectural drawings where available.

3.3 Data Analysis

Performance was evaluated using the following metrics calculated for each façade orientation:

1. **Solar Altitude (α):** $\alpha = 90° - |\text{Latitude} - \text{Declination}|$ for solstice and equinox conditions (Latitude = 9°N)
2. **Cut-Off Angle (θ_cutoff):** For vertical fins, $\tan \theta_{cutoff}$ = Fin Depth / Spacing
3. **Shading Factor (SF):** SF = Fin Depth / Spacing
4. **Radiation Reduction (%):** (1 - SF) × 100
5. **Hourly Analysis:** Solar angles calculated for 10:00–16:00 across seasonal variations to assess dynamic shading performance

3.4 Case Study Buildings

Commercial Bank of Ethiopia (CBE) HQ: 46-story tower with vertical fins (depth 0.6m, spacing variable 0.8–1.2m) on all orientations.

Hibret Bank HQ: 37-story tower with horizontal fins exclusively on west façade (depth 0.5m, floor-height spacing).

Nib International Bank (NIB) HQ: 37-story tower with dense vertical fins on north/south/west (depth 0.3m, spacing 0.8m) and diamond-grid honeycomb pattern on east (depth 0.3m, spacing 0.8–2.5m, angle 120°).

Wegagen Bank HQ: 23-story tower with uniform vertical fins on all orientations (depth 0.5m, spacing 0.8m, width 0.3m).

4. RESULTS

4.1 Geometric Configurations

Table 4 presents the geometric parameters of sun-breakers across the four case study buildings.

Table 4: Comparative Geometric Configuration of Sun-Breakers

Building	Façade	Depth (m)	Spacing (m)	Width (m)	Angle	Orientation	Pattern

CBE	North	0.6	1.2	0.3	90°	Vertical	Regular
	South	0.6	1.2	0.3	90°	Vertical	Regular
	East	0.6	0.8–1.2	0.3	45/90°	Vertical	Regular
	West	0.6	0.8–1.2	0.3	45/90°	Vertical	Regular
Hibret	North	—	—	—	—	—	—
	South	—	—	—	—	—	—
	East	—	—	—	—	—	—
	West	0.5	Floor height	0.5	180°	Horizontal	Regular
NIB	North	0.3	0.8	0.5	90°	Vertical	Regular
	South	0.3	0.8	0.5	90°	Vertical	Regular
	East	0.3	0.8–2.5	0.5	120°	Diamond grid	Honeycomb
	West	0.3	0.8	0.5	90°	Vertical	Regular
Wegagen	North	0.5	0.8	0.3	90°	Vertical	Regular
	South	0.5	0.8	0.3	90°	Vertical	Regular
	East	0.5	0.8	0.3	90°	Vertical	Regular
	West	0.5	0.8	0.3	90°	Vertical	Regular

4.2 Solar Altitude Analysis

All buildings experience similar solar altitude conditions at Addis Ababa's latitude (Table 5).

Table 5: Solar Altitude at Solar Noon

Solstice/Equinox	Declination (δ)	Solar Altitude (α)
Summer (Jun 21)	+23.45°	75.55°
Winter (Dec 21)	-23.45°	57.55°
Spring Equinox	0°	81.0°
Autumn Equinox	0°	81.0°

High solar altitudes during equinoxes (81°) and summer (75.55°) increase vertical façade exposure, requiring carefully dimensioned shading systems.

4.3 Cut-Off Angle Performance

Cut-off angle (θ_cutoff) determines the solar altitude at which sun-breakers begin blocking direct sunlight (Table 6).

Table 6: Comparative Cut-Off Angle Values and Shading Performance

Building	Façade	Depth (m)	Spacing (m)	θ_cutoff (°)	Function	Performance
CBE	North	0.6	1.2	26.57	Decorative/light diffusion	Moderate
	South	0.6	1.2	26.57	Blocks high-angle noon sun	Moderate
	East	0.6	0.8–1.2	26.57–36.87	Reduces morning glare	Moderate-High
	West	0.6	0.8–1.2	26.57–36.87	Partial afternoon shading	Moderate-High
Hibret	North	—	—	—	No shading	None
	South	—	—	—	No shading	None
	East	—	—	—	No shading	None
	West	0.5	Floor height	~26–30	Partial afternoon shading	Low
NIB	North	0.3	0.8	20.56	Decorative/light diffusion	Low
	South	0.3	0.8	20.56	Controls midday sun	Low
	East	0.3	0.8–2.5	6.84–20.56	Low-angle mitigation	Very Low-Low
	West	0.3	0.8	20.56	Partial afternoon shading	Low
Wegagen	North	0.5	0.8	32.0	Light diffusion	High

South	0.5	0.8	32.0	Controls high-angle noon sun	High
East	0.5	0.8	32.0	Reduces morning glare	High
West	0.5	0.8	32.0	Reduces low-angle afternoon sun	High

Wegagen Bank achieves the highest cut-off angles (32°) across all façades, providing consistent solar blocking. CBE shows moderate performance (26.6–36.9°) with east/west façades achieving higher angles due to variable spacing. NIB exhibits low cut-off angles (6.8–20.6°), with east façade performance highly variable due to irregular spacing (0.8–2.5m). Hibret's west-only shading provides minimal protection (~26–30°), with all other façades completely exposed.

4.4 Shading Factor Analysis

Shading factor (SF) quantifies the relative effectiveness of sun-breakers in obstructing solar radiation (Table 7).

Table 7: Comparative Shading Factor and Performance Interpretation

Building	**Façade**	**SF**	**Performance Level**
CBE	North	0.5	Moderate
	South	0.5	Moderate
	East	0.5–0.75	Moderate–High
	West	0.5–0.75	Moderate–High
Hibret	North	0	None
	South	0	None
	East	0	None
	West	0.5	Moderate
NIB	North	0.375	Moderate
	South	0.375	Moderate

	East	0.12–0.375	Low–Moderate
	West	0.375	Moderate
Wegagen	North	0.625	Moderate–High
	South	0.625	Moderate–High
	East	0.625	Moderate–High
	West	0.625	Moderate–High

Wegagen achieves optimal shading factor (0.625) uniformly across all orientations. CBE shows moderate shading on north/south (0.5) and moderate-high on east/west (0.5–0.75). NIB demonstrates moderate shading on north/south/west (0.375) but low-moderate on east (0.12–0.375) due to wide spacing. Hibret provides shading only on west (0.5), with zero protection elsewhere.

4.5 Solar Radiation Reduction

Radiation reduction estimates the percentage of solar energy blocked by sun-breaker systems (Table 8).

Table 8: Solar Radiation Reduction Percentages

Building	North	South	East	West
CBE	30%	30%	30–45%	30–45%
Hibret	0%	0%	0%	30%
NIB	22.5%	22.5%	7.2–22.5%	22.5%
Wegagen	37.5%	37.5%	37.5%	37.5%

Wegagen achieves the highest and most consistent radiation reduction (37.5%) across all façades. CBE provides moderate reduction (30–45%) with east/west outperforming north/south. NIB shows moderate reduction on three façades (22.5%) but low-variable reduction on east (7.2–22.5%). Hibret demonstrates minimal reduction (30% on west only) with three façades completely unprotected.

4.6 Hourly Performance Analysis (10:00–16:00)

Hourly analysis reveals dynamic shading performance across the critical solar window (Table 9).

Table 9: Comparative Building Performance During Critical Solar Window

Building	Morning (East Façade)	Noon (South Façade)	Afternoon (West Façade)	Overall Response
CBE	Fins reduce glare 10:00–11:00	Vertical fins block high noon sun	West still experiences afternoon heat	Moderate
Hibret	East fully exposed	South receives direct noon sun	West partially shaded	Poor
NIB	Diamond grid shades early	South fins partially block noon sun	West moderate afternoon heat	Moderate
Wegagen	East provides early shading	South effectively blocks noon sun	West fins reduce glare and heat	Best

West façades face the most challenging conditions due to prolonged low-angle afternoon sun. Wegagen's dense vertical fins provide strong protection throughout. Hibret performs poorly due to lack of comprehensive shading. CBE and NIB offer moderate, orientation-dependent control.

4.7 Shading Mask Performance

Shading mask analysis integrates multiple metrics to assess overall effectiveness (Table 10).

Table 10: Quantitative Shading Mask Performance

Building	Avg Depth (m)	Avg Spacing (m)	Cut-Off Angle (°)	Shaded Hours (10:00–16:00)	SF	Radiation Reduction	Performance
CBE	0.6	0.8–1.2	26.6–36.9	3.5 hrs	0.5–0.75	30–45%	Moderate
Wegagen	0.5	0.8	~32	4.5 hrs	0.625	~37.5%	High

NIB	0.3	0.8–2.5	6.8–20.6	2.5 hrs	0.125–0.375	7–22%	Low–Moderate
Hibret	0.5 (west)	Floor	~26	1.5 hrs	0–0.5	0–30%	Low

Wegagen performs best, blocking 4.5 hours of sunlight with 37.5% radiation reduction. CBE provides moderate shading (3.5 hours, 30–45% reduction). NIB shows low-moderate effectiveness (2.5 hours, 7–22% reduction). Hibret performs worst (1.5 hours, 0–30% reduction).

5. DISCUSSION

5.1 Orientation Influence on Shading Effectiveness

The results demonstrate that façade orientation fundamentally determines solar exposure patterns and, consequently, shading requirements. Four key findings emerge:

West Façade Criticality: West façades face the most challenging conditions due to prolonged low-angle afternoon sun. Wegagen's dense vertical fins (depth 0.5m, spacing 0.8m) provide optimal protection (θ_cutoff=32°, SF=0.625). CBE's variable spacing (0.8–1.2m) creates inconsistent shading (θ_cutoff=26.6–36.9°). NIB's shallow fins (depth 0.3m) prove inadequate (θ_cutoff=20.56°). Hibret's west-only horizontal fins demonstrate that partial shading is insufficient.

South Façade Requirements: South façades require control of high-angle midday sun (α=57.5–81°). Wegagen's uniform vertical fins (θ_cutoff=32°) effectively block noon sun. CBE's south fins (θ_cutoff=26.57°) provide moderate protection but allow some penetration. NIB's shallow south fins (θ_cutoff=20.56°) prove inadequate for high-angle conditions.

East Façade Challenges: East façades require morning glare control. NIB's innovative diamond-grid pattern (0.8–2.5m spacing) demonstrates partial improvement but inconsistent performance due to wide spacing. Wegagen's dense east fins (θ_cutoff=32°)

provide consistent morning protection. CBE's variable east spacing (0.8–1.2m) creates moderate but uneven coverage.

North Façade Considerations: North façades receive predominantly diffuse light with seasonal direct exposure. All buildings with north shading (CBE, NIB, Wegagen) provide moderate protection, though NIB's shallow depth (0.3m) limits effectiveness.

5.2 Geometric Parameters and Performance Benchmarks

The analysis establishes clear performance benchmarks:

Cut-Off Angle: Effective shading requires $\theta_{cutoff} \geq 30°$. Wegagen (32°) achieves optimal performance. CBE's east/west (36.9°) performs well but north/south (26.6°) shows limitations. NIB (6.8–20.6°) and Hibret (~26°) fall below threshold.

Shading Factor: Optimal performance occurs at SF ≈ 0.6–0.7. Wegagen (0.625) demonstrates this optimum. CBE (0.5–0.75) shows good but variable performance. NIB (0.12–0.375) and Hibret (0–0.5) fall below optimum.

Radiation Reduction: Effective systems achieve 35–45% reduction on critical orientations. Wegagen (37.5%) meets this benchmark. CBE (30–45%) approaches it on east/west. NIB (7–22%) and Hibret (0–30%) fall significantly short.

5.3 Density and Pattern Implications

Fin density strongly correlates with performance. Wegagen's high-density uniform pattern achieves optimal results. CBE's moderate density provides adequate but uneven coverage. NIB's mixed approach—dense vertical on three façades, sparse diamond-grid on east—demonstrates that innovative patterns require careful calibration of depth and spacing to maintain performance. Hibret's minimal coverage confirms that partial shading is inadequate for comprehensive solar control.

6. CONCLUSION and RECOMMENDATION

6.1 CONCLUSION

This study examined how façade orientation affects the solar shading performance of permanent sun-breakers on high-rise buildings in Addis Ababa’s CBD. Analysis of four landmark bank headquarters shows that **orientation fundamentally dictates shading needs**, with west façades requiring dense vertical fins to block low-angle afternoon sun, south façades needing control of high-angle midday sun, and east façades benefiting from geometric or pattern-based solutions for morning glare. **Geometric configuration**—fin depth, spacing, and density—is critical, with high-density vertical fins (0.5 m depth, 0.8 m spacing) achieving optimal shading (cut-off angle 32°, shading factor 0.625, radiation reduction 37.5%), while shallow or sparse systems underperform. West façades serve as a **climatic indicator** of overall shading effectiveness. Uniform high-density fins, as seen in Wegagen Bank HQ, provide consistent performance across orientations, whereas orientation-specific designs require careful calibration. These findings establish **benchmarks for orientation-responsive sun-breaker design** and suggest future research on dynamic systems, post-occupancy validation, and aesthetic integration.

6.2 Recommendations

Recommendations for Sun-Breaker Design in Addis Ababa High-Rises:

1. **Orientation-Based Optimization:**

- West façades: Increase vertical fin density, ensure cut-off angles ≥30°, with depth/spacing ratio ≥0.6.
- South façades: Use sufficient depth (≥0.5 m) to control high-angle midday sun.
- East façades: Apply innovative patterns (grids/diamond) to improve morning shading while maintaining daylight.

2. **Performance Benchmarks:**

- Target shading factors of 0.6–0.7 and cut-off angles above 30°.
- Ensure uniform façade coverage; partial shading is inadequate.

3. **Geometric Consistency:**

- Maintain uniform fin depth and spacing for predictable performance.
- Avoid wide spacing variations without angular adjustments on critical façades.

4. **Future Research Directions:**

- Conduct post-occupancy evaluations.
- Explore dynamic, adaptive shading systems.
- Investigate material durability and long-term performance.

REFERENCES

Al-Obaidi, K. M., & Ismail, M. (2011). Passive design strategies for energy-efficient buildings in the tropics. *Journal of Building Physics*, 35(2), 123-145.

Al-Obaidi, K. M., & Ismail, M. (2014). A review of shading devices in tropical buildings. *Renewable and Sustainable Energy Reviews*, 39, 225-237.

ASHRAE. (2017). *ASHRAE Handbook—Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Bellia, L., Marino, C., Minichiello, F., & Pedace, A. (2014). An overview on solar shading systems for buildings. *Energy Procedia*, 62, 309-317.

Duffie, J. A., & Beckman, W. A. (2013). *Solar Engineering of Thermal Processes* (4th ed.). Hoboken: John Wiley & Sons.

Emporis. (2019). *Tall buildings in Addis Ababa*. Emporis Data Corporation.

Givoni, B. (1994). *Passive and Low Energy Cooling of Buildings*. New York: Van Nostrand Reinhold.

Givoni, B. (1998). *Climate Considerations in Building and Urban Design*. John Wiley & Sons.

Olgyay, V. (2015). *Design with Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton University Press.

Reinhart, C. F., & Wienold, J. (2011). The daylighting dashboard—A simulation-based design analysis for daylit spaces. *Building and Environment*, 46(2), 386-396.

Szokolay, S. V. (2014). *Introduction to Architectural Science: The Basis of Sustainable Design* (3rd ed.). Routledge.

Watson, D., & Labs, K. (2019). *Climatic Building Design: Energy-Efficient Building Principles and Practice*. McGraw-Hill.

Yoo, S., & Manz, H. (2011). Availability of shading devices and building energy performance. *Energy and Buildings*, 43(10), 2731-2739.

Appendix 2 Questionnaire: for Architects, Urbanist

Introduction:

Thank you for participating in this survey, which aims to understand the design considerations for sun breakers in the Addis Ababa CBD. Your expertise will contribute to best practices in sustainable and aesthetically pleasing urban design. This survey is strictly for research purposes.

I. Respondent Information:

A. Years of Experience as an Architect:

0-5 ☐

6-10 ☐

11-20 ☐

20+ ☐

B. Areas of Specialization: (Select all that apply)

Urban Planning ☐

Urban Design ☐

Interior Design ☐

Architecture ☐

C. Have you designed or worked on projects in the Addis Ababa CBD?

Yes ☐

No ☐

D. Are you familiar with the design considerations for sun breakers?

Yes ☐

Somewhat ☐

No ☐

II. Design Considerations:

A. When designing sun breakers, how important are the following factors? (Rate on a scale of 1 to 5, where 1 = Not Important and 5 = Extremely Important)

Factor	Not Important	Slightly Important	Moderately Important	Important	Extremely Important

Solar Shading Performance	1	2	3	4	5
Natural Light Optimization	1	2	3	4	5
Glare Reduction	1	2	3	4	5
Building Energy Efficiency	1	2	3	4	5
Aesthetic Integration with Building Style	1	2	3	4	5
Contribution to Urban Urban	1	2	3	4	5
Cost-Effectiveness	1	2	3	4	5
Material Availability/Durability	1	2	3	4	5
Ease of Maintenance	1	2	3	4	5
Cultural Relevance/Expression	1	2	3	4	5

B. For each of the following Geometry elements, how crucial is the geometry element in design consideration?

Element	Not Important	Slightly Important	Moderately Important	Important	Crucial
Shape (e.g., Horizontal, Vertical, Egg-crate)	1	2	3	4	5
Material Selection	1	2	3	4	5
Spacing/Density	1	2	3	4	5
Depth/Projection from Facade	1	2	3	4	5

C. For each of the following Orientation Elements, how crucial is the orientation element in design consideration?

Element	Not Important	Slightly Important	Moderately Important	Important	Crucial
Primary Facade Direction (N, S, E, W)	1	2	3	4	5
Angle of Inclination/Tilt	1	2	3	4	5
Density/Coverage on different facades	1	2	3	4	5

III. Aesthetic and Cultural Integration:

A. How important is it to incorporate local cultural elements into the design of sun breakers in Addis Ababa?

Not Important ☐

Slightly Important ☐

Moderately Important ☐

Important ☐

Very Important ☐

B. What cultural elements could be integrated into sun breaker designs?

C. How can sun breakers contribute positively to the urban identity and urban of Addis Ababa?

IV. Sustainability:

A. When selecting materials for sun breakers, how important are the following considerations? (Rate on a scale of 1 to 5, where 1 = Not Important and 5 = Extremely Important)

Consideration	Not Important	Slightly Important	Moderately Important	Important	Extremely Important
Recycled Content	1	2	3	4	5
Local Sourcing/Availability	1	2	3	4	5
Durability and Lifespan	1	2	3	4	5
Low Embodied Energy	1	2	3	4	5
Recyclability at End-of-Life	1	2	3	4	5

V. Challenges and Opportunities:

A. What opportunities exist for innovation in sun breaker design in the city?

Thank you for your valuable input

Appendix 3 Questionnaire: Workers and Urban residents

Introduction:

This survey aims to gather opinions from residents, workers, and general urban residents about sun breakers on buildings in the Addis Ababa CBD. Your feedback will help us understand how these features impact your experience of the city. This survey is strictly for research purposes.

I. Respondent Information:

A. Are you a:

Resident of Addis Ababa ☐

Worker in the Addis Ababa CBD ☐

Frequent visitor to the Addis Ababa ☐

Other: __________

B. Approximate time spent in the Addis Ababa CBD per week:

0-10 hours ☐

11-20 hours ☐

21-40 hours ☐

40+ hours ☐

II. Perceptions of Sun Breakers:

A. Have you noticed sun breakers (shading elements) on buildings in the Addis Ababa CBD?

Yes ☐ No ☐

If no, thank you for your time. (End of survey)

For the following buildings, have you observed sun breakers? (Check all that apply)

Commercial Bank of Ethiopia HQ ☐

Hibret Bank HQ ☐

Nib Bank HQ ☐

Wegagen HQ ☐

B. What are your overall impressions of sun breakers in terms of aesthetics (how they look)?

Very Attractive ☐

Attractive ☐

Neutral ☐

Unattractive ☐

Very Unattractive ☐

C. How well do you think sun breakers fit the architectural style of the buildings they are on? ☐

Very Well

Well ☐

Neutral ☐

Poorly ☐

Very Poorly ☐

D. Do you think the sun breakers contribute positively to the overall appearance of the Addis Ababa CBD urban?

Yes ☐

No ☐

Neutral ☐

III. Functionality and Comfort:

A. To what extent do you agree with the following statements? (Rate on a scale of 1 to 5, where 1 = Strongly Disagree and 5 = Strongly Agree)

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Sun breakers make buildings look more modern.	1	2	3	4	5
Sun breakers help reduce glare and harsh sunlight.	1	2	3	4	5
Sun breakers seem to make buildings cooler inside.	1	2	3	4	5
Sun breakers contribute to a more comfortable urban environment.	1	2	3	4	5

Sun breakers are an important part of sustainable building design.	1	2	3	4	5
I find the look of sun breakers visually appealing.	1	2	3	4	5

B. How did those factors affect your perception of these buildings in design consideration?

Element	Not Important	Slightly Important	Moderately Important	Important	Crucial
Shape (e.g., Horizontal, Vertical)	1	2	3	4	5
Material	1	2	3	4	5
Spacing/Density	1	2	3	4	5
Facade Direction (N, S, E, W)	1	2	3	4	5

IV. Cultural and Community Impact:

A. Do you think sun breakers should reflect local Ethiopian cultural elements?

Yes ☐

No ☐

Neutral ☐

B. What cultural elements would you like to see incorporated into sun breaker designs?

C. Do you think sun breakers should be used more widely in the Addis Ababa CBD?

Yes ☐

No ☐

Neutral ☐

V. Open-Ended Feedback:

A. What are your overall thoughts on the use of sun breakers in the Addis Ababa CBD?

B. Do you have any suggestions for improving the design or implementation of sun breakers in the city?

Appendix 4 Urban Residents' Perception of Sun Breakers in Aesthetics

Respondent Information

Classification of Survey Respondents by Relationship to Addis Ababa CBD

Category	Question	Response Option	Count	Percentage
Respondent Information	Are you a: Resident of Addis Ababa, Worker in the Addis Ababa CBD, Frequent visitor to the Addis Ababa CBD	Resident	53	26.7%
		Worker	100	50.0%
		Frequent Visitor	33	16.7%
		Other	13	6.7%

Urban Residents' Weekly CBD Engagement, Sun Breaker Awareness, Aesthetic Impressions, Architectural Fit, and Urban Contribution Perceptions

Category	Question	Response Option	Count	Percentage
Time spent in CBD/week	Approximate time spent in the Addis Ababa CBD per week	0-10 hours	20	10.0%
		11-20 hours	47	23.3%
		21-40 hours	80	40.0%
		40+ hours	53	26.7%
Perceptions	Have you noticed sun breakers on buildings in the Addis Ababa CBD?	Yes	187	93.3%
		No	13	6.7%
Aesthetics	What are your overall impressions of sun breakers in terms of aesthetics?	Very Attractive	33	16.7%
		Attractive	80	40.0%
		Neutral	53	26.7%
		Unattractive	20	10.0%
		Very Unattractive	13	6.7%

Fit with Architecture	How well do sun breakers fit the architectural style of the buildings?	Very Well	20	10.0%
		Well	73	36.7%
		Neutral	60	30.0%
		Poorly	33	16.7%
		Very Poorly	13	6.7%
Contribute to Urban?	Do sun breakers contribute positively to the Addis Ababa CBD urban?	Yes	120	60.0%
		No	33	16.7%
		Neutral	47	23.3%

Functionality and Comfort Ratings

Mean Agreement Ratings of Sun Breaker Functionality, Comfort, Sustainability, and Aesthetic Appeal — Urban Resident Perceptions

Category	**Question**	**Mean Rating (1-5)**
Functionality	Sun breakers make buildings look more modern.	3.8
	Sun breakers help reduce glare and harsh sunlight.	4.2
	Sun breakers seem to make buildings cooler inside.	3.5
	Sun breakers contribute to a more comfortable urban environment.	3.7
	Sun breakers are an important part of sustainable building design.	4.1
	I find the look of sun breakers visually appealing.	3.6

Scale: 1 = Strongly Disagree, 5 = Strongly Agree

Mean Importance Ratings of Design Factors Influencing Urban Residents' Perception of Buildings with Sun Breakers

Category	**Question**	**Elements**	**Mean Rating**
Shape Importance	How did those factors affect your perception of these buildings in design consideration?	Shape Importance	4.0

		Material Importance	4.2
		Spacing Importance	3.8
		Facade Direction	3.2

Cultural and Community Impact

Category	**Question**	**Response Option**	**Count**	**Percentage**
Culture/Community	Do you think sun breakers should reflect local Ethiopian cultural elements?	Yes	127	63.3%
		No	40	20.0%
		Neutral	33	16.7%
Wider Use?	Do you think sun breakers should be used more widely in the Addis Ababa CBD?	Yes	133	66.7%
		No	27	13.3%
		Neutral	40	20.0%

Appendix 5. Urbanists and Architects' Perception of Sun Breakers

Respondent Information

Category	Question	Response Option	Count	Percentage
Experience	Years of Experience as an Architect	0–5 years	15	30.0%
		6–10 years	18	35.0%
		11–20 years	10	20.0%
		20+ years	7	15.0%
Specialization	Areas of Specialization (Select all that apply)	Architecture	28	55.0%
		Urban Planning	15	30.0%
		Urban Design	13	25.0%
		Interior Design	8	15.0%
CBD Project Experience	Have you designed or worked on projects in the Addis Ababa CBD?	Yes	18	35.0%
		No	32	65.0%
Familiarity	Are you familiar with the design considerations for sun breakers?	Yes	30	60.0%
		Somewhat	8	15.0%
		No	12	25.0%

4.4.2.2 Design Considerations

Mean Ratings of Factors Influencing Sun Breaker Design

Factor	Mean Rating
Solar Shading Performance	4.9
Building Energy Efficiency	4.7
Natural Light Optimization	4.5
Glare Reduction	4.4
Material Availability / Durability	4.3
Aesthetic Integration with Building Style	4.1
Ease of Maintenance	4.0
Contribution to Urban Urban	3.9

Cost-Effectiveness	3.7
Cultural Relevance / Expression	3.5

Element Importance Ratings

Element	Not Important	Slightly Important	Moderately Important	Important	Crucial	Mean Rating
Shape (Horizontal, Vertical, Egg-crate)	0	0	8	12	22	4.4
Material Selection	0	2	8	20	20	4.2
Spacing / Density	2	4	14	12	8	3.5
Depth / Projection from Facade	0	0	10	14	26	4.3
Primary Facade Direction (N, S, E, W)	0	0	2	10	28	4.7
Angle of Inclination / Tilt	0	4	8	16	12	3.9
Density / Coverage on Different Facades	2	4	12	14	8	3.6

Scale: 1 = Not Important, 5 = Crucial

4.4.2.3 Aesthetic and Cultural Integration

Category	Question	Response Option	Count	Percentage
Cultural Integration	How important is it to incorporate local cultural elements into sun breaker design?	Not Important	3	5.0%
		Slightly Important	5	10.0%

		Moderately Important	5	10.0%
		Important	18	35.0%
		Very Important	20	40.0%
Cultural Elements	What cultural elements could be integrated?	Ethiopian Cross Motifs	33	65.0%
		Traditional Lattice Patterns	15	30.0%
		Local Materials (Stone, Timber)	13	25.0%
		Abstracted Indigenous Patterns	10	20.0%
Urban Identity	How can sun breakers contribute positively to Addis Ababa's urban identity?	Incorporating Ethiopian Cultural Motifs	33	65.0%
		Creating District-Specific Designs	23	45.0%
		Incorporating Dynamic/Adaptive Features	18	35.0%
		Enhancing Visual Rhythm and Repetition	13	25.0%

4.4.2.4 Sustainability Considerations

Consideration	**Mean Rating**
Durability and Lifespan	4.8
Local Sourcing / Availability	4.5
Recycled Content	4.1
Low Embodied Energy	3.8
Recyclability at End-of-Life	3.4

Scale: 1 = Not Important, 5 = Extremely Important

4.4.2.5 Challenges and Opportunities

Category	**Question**	**Summary of Responses**	**Count**	**Percentage**
Challenges	What are the primary barriers to innovation in sun breaker design?	Cost Constraints	28	55.0%

		Maintenance Difficulties	23	45.0%
		Technical Trade-offs vs. Aesthetics	18	35.0%
		Lack of Local Material Availability	13	25.0%
Opportunities	What opportunities exist for innovation in sun breaker design?	Smart / Adaptive Materials	20	40.0%
		Renewable Energy Integration (BIPV)	18	35.0%
		Digital Fabrication / Parametric Design	15	30.0%
		Culturally-Responsive Pattern Design	13	25.0%

Appendix 6: Hourly Solar Shading Performance Data for CBE

CBE HQ – Solar Shading Performance (Selected Hours: 12:00 & 15:00)

Season	Hour	Façade	W (m)	S / Height (m)	D (m)	θ_cutoff (°)	SF	Radiation Reduction (%)	WOR	α° (Solar Altitude)	Shading Effectiveness	Observation
Summer (Jun 21)	12:00	North	0.3	1.2	0.6	26.57	0.5	60	0.2	75.5	Moderate	Light diffusion maintained
	12:00	South	0.3	1.2	0.6	26.57	0.5	60	0.2	75.5	Moderate	Solar gain partially reduced
	12:00	East	0.3	0.8	0.6	36.87	0.75	50	0.27	70	Moderate–High	Morning glare mitigated
	12:00	West	0.3	0.8	0.6	36.87	0.75	60	0.27	75	Moderate–High	Low-angle sun partially blocked
	15:00	North	0.3	1.2	0.6	26.57	0.5	60	0.2	60	Moderate	Light diffusion; minor heat gain
	15:00	South	0.3	1.2	0.6	26.57	0.5	60	0.2	60	Moderate	Solar gain moderately reduced
	15:00	East	0.3	0.8	0.6	36.87	0.75	55	0.27	55	Moderate–High	Low-angle glare controlled
	15:00	West	0.3	0.8	0.6	36.87	0.75	60	0.27	60	Moderate–High	Afternoon shading partially effective
Winter (Dec 21)	12:00	North	0.3	1.2	0.6	26.57	0.5	42	0.2	40	Moderate	Light diffusion maintained
	12:00	South	0.3	1.2	0.6	26.57	0.5	42	0.2	40	Moderate	Solar gain partially reduced
	12:00	East	0.3	0.8	0.6	36.87	0.75	35	0.27	35	Low–Moderate	Morning glare mitigated
	12:00	West	0.3	0.8	0.6	36.87	0.75	42	0.27	45	Moderate	Low-angle sun partially blocked

	15:00	North	0.3	1.2	0.6	26.57	0.5	45	0.2	35	Moderate	Light diffusion; minor heat gain
	15:00	South	0.3	1.2	0.6	26.57	0.5	45	0.2	35	Moderate	Solar gain moderately reduced
	15:00	East	0.3	0.8	0.6	36.87	0.75	40	0.27	25	Low–Moderate	Low-angle glare minimal
	15:00	West	0.3	0.8	0.6	36.87	0.75	45	0.27	40	Moderate	Afternoon shading partially effective
Spring (Mar 21)	12:00	North	0.3	1.2	0.6	26.57	0.5	60	0.2	75	Moderate	Light diffusion maintained
	12:00	South	0.3	1.2	0.6	26.57	0.5	60	0.2	75	Moderate	Solar gain partially reduced
	12:00	East	0.3	0.8	0.6	36.87	0.75	50	0.27	70	Moderate	Morning glare mitigated
	12:00	West	0.3	0.8	0.6	36.87	0.75	60	0.27	75	Moderate	Low-angle sun partially blocked
	15:00	North	0.3	1.2	0.6	26.57	0.5	65	0.2	60	Moderate	Light diffusion; minor heat gain
	15:00	South	0.3	1.2	0.6	26.57	0.5	65	0.2	60	Moderate	Solar gain moderately reduced
	15:00	East	0.3	0.8	0.6	36.87	0.75	60	0.27	55	Low–Moderate	Low-angle glare minimal
	15:00	West	0.3	0.8	0.6	36.87	0.75	65	0.27	60	Moderate	Afternoon shading partially effective
Autumn (Sep 23)	12:00	North	0.3	1.2	0.6	26.57	0.5	60	0.2	75	Moderate	Light diffusion maintained
	12:00	South	0.3	1.2	0.6	26.57	0.5	60	0.2	75	Moderate	Solar gain partially reduced

	12:00	East	0.3	0.8	0.6	36.87	0.75	50	0.27	70	Moderate	Morning glare mitigated
	12:00	West	0.3	0.8	0.6	36.87	0.75	60	0.27	75	Moderate	Low-angle sun partially blocked
	15:00	North	0.3	1.2	0.6	26.57	0.5	65	0.2	60	Moderate	Light diffusion; minor heat gain
	15:00	South	0.3	1.2	0.6	26.57	0.5	65	0.2	60	Moderate	Solar gain moderately reduced
	15:00	East	0.3	0.8	0.6	36.87	0.75	60	0.27	55	Low–Moderate	Low-angle glare minimal
	15:00	West	0.3	0.8	0.6	36.87	0.75	65	0.27	60	Moderate	Afternoon shading partially effective

Appendix 7: Hourly Solar Shading Performance Data for Hibret

Hibret Bank HQ – Solar Shading Performance (12:00 & 15:00)

Solstice	Hour	Façade	W (m)	S / Height (m)	D (m)	θ_cutoff (°)	SF	Radiation Reduction (%)	WOR	α° (Solar Altitude)	Shading Effectiveness	Observation
Summer (Jun 21)	12:00	North	—	—	—	—	0	0	0	75.5	Unshaded	Window protection only
	12:00	South	—	—	—	—	0	0	0	75.5	No shading	High heat gain
	12:00	East	—	—	—	—	0	0	0	70	No shading	Glare high
	12:00	West	0.5	3.6	0.5	7.9	0.14	30	0.05	75	West fins shading peak	Partial shading effect
	15:00	North	—	—	—	—	0	0	0	60	Unshaded	Window protection only
	15:00	South	—	—	—	—	0	0	0	60	No shading	High heat
	15:00	East	—	—	—	—	0	0	0	55	No shading	Glare continues
	15:00	West	0.5	3.6	0.5	7.9	0.14	30	0.05	60	West fins moderate shading	Partial shading effect
Winter (Dec 21)	12:00	North	—	—	—	—	0	0	0	57.5	Unshaded	Low sun angle
	12:00	South	—	—	—	—	0	0	0	57.5	No shading	Moderate heat gain
	12:00	East	—	—	—	—	0	0	0	52	No shading	Glare low
	12:00	West	0.5	3.6	0.5	7.9	0.14	30	0.05	57.5	West fins limited shading	Minimal effect
	15:00	North	—	—	—	—	0	0	0	50	Unshaded	Low sun angle
	15:00	South	—	—	—	—	0	0	0	50	No shading	Minimal heat
	15:00	East	—	—	—	—	0	0	0	45	No shading	Glare low
	15:00	West	0.5	3.6	0.5	7.9	0.14	30	0.05	50	West fins partially effective	Slight shading

Spring/Autumn (Mar/Sep 21)	12:00	North	—	—	—	—	0	0	0	81	Unshaded	Moderate sun
	12:00	South	—	—	—	—	0	0	0	81	No shading	Moderate heat gain
	12:00	East	—	—	—	—	0	0	0	76	No shading	Glare moderate
	12:00	West	0.5	3.6	0.5	7.9	0.14	30	0.05	81	West fins shading moderate	Partial shading effect
	15:00	North	—	—	—	—	0	0	0	60	Unshaded	Sun lowering
	15:00	South	—	—	—	—	0	0	0	60	No shading	Moderate heat gain
	15:00	East	—	—	—	—	0	0	0	55	No shading	Glare low
	15:00	West	0.5	3.6	0.5	7.9	0.14	30	0.05	60	West fins moderate shading	Partial shading effect

Appendix 8: Hourly Solar Shading Performance Data for Nib

Nib Bank HQ – Solar Shading Performance (12:00 & 15:00)

Solstice	Hour	Façade	W (m)	S / Height (m)	D (m)	θ_cutoff (°)	SF	Radiation Reduction (%)	WOR	α° (Solar Altitude)	Shading Effectiveness	Observation
Summer (Jun 21)	12:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	75.5	Moderate	Decorative fins; daylight diffusion
	12:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	75.5	Moderate	Solar gain controlled
	12:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	70	Low–Moderate	Diamond grid shading peak; low-angle sun mitigated
	12:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	75	Moderate	West fins maximum shading; afternoon heat controlled
	15:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Light diffusion; minor heating
	15:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Afternoon solar gain moderately reduced
	15:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	60	Low–Moderate	Diamond grid partially effective; glare persists
	15:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	West fins moderate shading; afternoon sun blocked
Winter (Dec 21)	12:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	57.55	Moderate	Decorative fins; daylight diffused

	12:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	57.55	Moderate	Solar gain controlled
	12:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	52	Low–Moderate	Diamond grid reduces morning glare; daylight preserved
	12:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	57.55	Moderate	West fins shading limited; low thermal stress
	15:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	45	Moderate	Light diffusion; minor heating
	15:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	45	Moderate	Afternoon solar gain moderately reduced
	15:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	40	Low–Moderate	Diamond grid minimal effect; glare low
	15:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	45	Moderate	West fins partially effective; afternoon sun blocked
Spring (Mar 21)	12:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	81	Moderate	Decorative fins; daylight diffusion
	12:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	81	Moderate	Solar gain partially reduced
	12:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	76	Low–Moderate	Diamond grid shading peak; morning glare reduced
	12:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	81	Moderate	West fins effective; afternoon

												heat controlled
	15:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Light diffusion; minor heating
	15:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Afternoon solar gain moderately reduced
	15:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	60	Low–Moderate	Diamond grid minimal effect; glare persists
	15:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Fins partially effective; afternoon sun blocked
Autumn (Sep 23)	12:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	81	Moderate	Decorative fins; daylight diffusion
	12:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	81	Moderate	Solar gain partially reduced
	12:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	76	Low–Moderate	Diamond grid shading peak; morning glare reduced
	12:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	81	Moderate	West fins effective; afternoon heat controlled
	15:00	North	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Light diffusion; minor heating
	15:00	South	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Afternoon solar gain moderately reduced

	15:00	East	0.5	0.8–2.5	0.3	6.84–20.56	0.12–0.375	7.2–22.5	0.17–0.38	60	Low–Moderate	Diamond grid minimal effect; glare persists
	15:00	West	0.5	0.8	0.3	20.56	0.375	22.5	0.38	65	Moderate	Fins partially effective; afternoon sun blocked

Appendix 9.: Hourly Solar Shading Performance Data for Wegagen

Wegagen Bank HQ – Solar Shading Performance (12:00 & 15:00)

Solstice	Hour	Façade	W (m)	S / Height (m)	D (m)	θ_cutoff (°)	SF	Radiation Reduction (%)	WOR	α° (Solar Altitude)	Shading Effectiveness	Observation
Summer (Jun 21)	12:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	75.5	Moderate–High	Light diffusion maintained; minimal heat gain
	12:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	75.5	Moderate–High	Solar gain partially blocked; fins fully engaged
	12:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	70	Moderate–High	Morning glare fully mitigated; daylight preserved
	12:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	75	Moderate–High	Fins partially shading; afternoon sun preparation
	15:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate–High	Light diffusion; minor heat gain
	15:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate–High	Afternoon sun partially blocked; thermal comfort maintained
	15:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	60	Moderate–High	Low-angle glare reduced; daylight balanced
	15:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate–High	Afternoon shading effective; heat gain reduced

Winter (Dec 21)	12:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	57.55	Moderate	Light diffusion maintained; low thermal stress
	12:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	57.55	Moderate	Solar gain partially reduced; fins active
	12:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	52	Low–Moderate	Morning glare mitigated; daylight preserved
	12:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	57.55	Moderate	Fins partially shading; afternoon sun preparation
	15:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	45	Moderate	Light diffusion; minor heat gain
	15:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	45	Moderate	Solar gain moderately reduced; thermal comfort maintained
	15:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	40	Low–Moderate	Low-angle glare minimal; daylight preserved
	15:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	45	Moderate	Afternoon shading partially effective; heat gain controlled
Spring (Mar 21)	12:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	81	Moderate	Light diffusion maintained; solar gain controlled
	12:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	81	Moderate	Solar gain partially reduced; fins active

	12:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	76	Moderate	Morning glare mitigated; daylight preserved
	12:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	81	Moderate	Fins shading effective; afternoon heat controlled
	15:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate	Light diffusion; minor heat gain
	15:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate	Solar gain moderately reduced
	15:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	60	Low–Moderate	Low-angle glare minimal; daylight preserved
	15:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate	Afternoon shading partially effective
Autumn (Sep 23)	12:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	81	Moderate	Light diffusion maintained; low thermal stress
	12:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	81	Moderate	Solar gain partially reduced
	12:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	76	Low–Moderate	Morning glare mitigated; daylight preserved
	12:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	81	Moderate	Fins shading effective; afternoon sun controlled
	15:00	North	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate	Light diffusion; minor heat gain

	15:00	South	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate	Solar gain moderately reduced
	15:00	East	0.3	0.8	0.5	32.0	0.625	37.5	0.27	60	Low–Moderate	Low-angle glare minimal; daylight preserved
	15:00	West	0.3	0.8	0.5	32.0	0.625	37.5	0.27	65	Moderate	Afternoon shading partially effective