CHALLENGES OF PROVIDING NATURAL VENTILATION AND DAYLIGHTING IN SMALL PLOT URBAN DWELLINGS: THE CASE OF ADAMA's 105m^2 PLOT

Yohannis Alemayehu Tegegn

A thesis submitted to the department of Architecture.

College of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's
Environmental Architecture

Office of Graduate Studies

Adama Science and Technology University

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APPROVAL SHEET

I, the advisors of the thesis entitled "**Challenges of Providing Natural Ventilation and Daylighting in Small Plot Urban Dwellings: The Case of Adama's 105m^2 Plot**" and developed by Yohannis Alemayehu Tegegn, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Prof. Ambuj Kumar, PhD	________________	________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Yohannis Alemayehu have read and evaluated the thesis entitled **"Challenges of Providing Natural Ventilation and Daylighting in Small Plot Urban Dwellings: The Case of Adama's 105m^2 Plot"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Environmental Architecture.

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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and College Graduate Committee (CGC).

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DECLARATION

I hereby declare that this Master Thesis entitled "**Challenges of Providing Natural Ventilation and Daylighting in Small Plot Urban Dwellings in Ethiopia: The case of Adama's 105m^2 Plot**" is my own work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been accordingly acknowledged through citation.

Yohannis Alemayehu Tegegn	____________________	____________________
Name of the Student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Challenges of Providing Natural Ventilation and Daylighting in Small Plot Urban Dwellings in Ethiopia: The case of Adama's 105m^2 Plot"** prepared under my guidance by Yohannis Alemayehu submitted in partial fulfillment of the requirements for the degree of Master's in environmental architecture. Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Prof. Ambuj Kumar, PhD	____________________	____________________
Name of the Student	Signature	Date

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ABBREVIATIONS AND ACRONYMS

ACH	Air Changes per Hour
AC	Alternating Curren
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Modeling
CIBSE	Chartered Institution of Building Services Engineers
CFD	Computational Fluid Dynamics
DF	Daylight Factor
GIS	Geographic Information System
IAQ	Indoor Air Quality
IES	Illuminating Engineering Society
IESNA	Illuminating Engineering Society of North America
Lux	Luminous flux per unit area (lumens per square meter)
NMA	National Meteorological Agency (Ethiopia)
RH	Relative Humidity
sDA	Spatial Daylight Autonomy
SP	Sample Plot (used as identifier for sample dwellings, e.g., SP01)
SVF	Sky View Factor
UDI	Useful Daylight Illuminance
US DOE	United States Department of Energy
VT	Visible Transmittance
WHO	World Health Organization
WWR	Window-to-Wall Ratio

ABSTRACT

Although it has been challenging to ensure adequate natural ventilation and daylighting in such high-density urban settings, small-plot residential development is steadily spreading across Adama City. This study evaluates the indoor environmental quality of eight small-plot dwellings (≤105m²) with various site layouts and orientations. It focuses on airspeed, relative humidity, daylight illuminance, and indoor air temperature. Multiple daily measurements of the indoor environmental factors in each home's living room, bedroom, kitchen, and toilet were made during the hottest months of April 29–May 1. The outcomes were then contrasted with the IES daylighting recommendations and ASHRAE 55 thermal comfort criteria. While the master bedrooms in all tests recorded 0 lux at around 0 lux daylight and very low air speed, indicating acute lack of sunshine and ventilation, quantitative data show that most rooms, particularly bedrooms and bathrooms, lack the recommended thermal comfort requirements and daylight. While sunshine levels in large locations stay below 140 lux, below the standards for comfort, indoor temperatures in east-west aligned and closed homes can rise above 30°C during the hottest hours. Air speed readings are consistently less than 0.2 m/s, typically 0.01 m/s, which limits the efficiency of natural ventilation. Even if T-junction layouts help a little, the issue still exists, particularly in deep interior locations like bathrooms and master bedrooms. According to qualitative data collected from the existing buildings through interviews with the architects, urban planners, and occupants, the main obstacles are narrow plot widths, shared walls, and few formal regulations. The occupants report frequent overheating, poor indoor quality, and a lack of daylight, frequently turning to artificial lighting and mechanical fans for ventilation or not using any ventilation at all. It is determined that Adama City's current small-plot development methods fall short in addressing the vital problems of daylighting and natural ventilation. Poor indoor environmental quality is the outcome of these flaws, particularly in densely populated urban areas. Adopting an integrated strategy that combines design innovation and policy reform is crucial to enhancing comfort and sustainability. Important steps include promoting layouts that improve natural airflow and daylight penetration, giving passive design techniques like stack ventilation and skylights priority, and updating urban legislation to better promote ideal plot arrangements. In the quickly urbanizing context of Adama, such coordinated design and policy initiatives are required to successfully increase indoor environmental quality.

Key words: Daylight, Enclosed, Natural Ventilation, Orientation, Small-Plot, T-junction

CHAPTER ONE

INTRODUCTION

1.1. Background Of Study

Passive design measures such as daylighting and natural ventilation in sustainable architecture lead primarily to thermal comfort, in the sense that the occupants remain satisfied with the ambient indoor conditions while avoiding the use of mechanical systems such as artificial light and air conditioning (Givoni, 1998; Lechner, 2014; Nicol & Humphreys, 2002). Indoor air quality is enhanced through these measures, creating airflow and maximizing daylight, and hence providing healthier, visually comfortable interior spaces (Baker & Steemers, 2014).

Urban densification and quick urbanization in Ethiopian towns such as Adama presented challenges for the implementation of these concepts, particularly in small urban plots whose space curtails airflow and daylight penetration (Yilma, 2021; Wondimu & Tadesse, 2022). Natural ventilation and daylighting were features in traditional Ethiopian dwellings, yet contemporary urban dwellings attempt maximizing land use, leading to inefficiency in building designs that minimize the same (Demissie & Alemayehu, 2021; Mekonnen et al., 2019).

Adama's high population growth and land shortages led us here, subdividing plots into residential units to satisfy the need for homes, thereby complicating the implementation of efficient passive strategies (Kumssa & Jones, 2015; Zhang et al., 2022). Research indicates that building orientation, window location, and building material selection determine much of the value in ventilation and the quality of daylight (e.g., building orientation toward prevalent wind directions can increase cross-ventilation, and lower overheating, in dense urban areas (Pereira et al., 2019; Zhang et al., 2021)). In Adama, environmental optimization for maximizing land use is often secondary, however, resulting in poor indoor air quality and high usage of artificial lighting (Wondimu & Tadesse, 2022).

Daylighting is particularly significant since it reduces the cost of energy and enhances occupant well-being. Research shows that maximizing daylight use can decrease artificial lighting requirements by as much as 30%, yet poor daylighting in the urban homes in Ethiopia leads to increased energy costs and adverse health consequences (Moore et al., 2017; Demissie & Alemayehu, 2021; Wondimu & Tadesse, 2022).

A second example is the low awareness and technical skills for the implementation of passive design concepts in Ethiopia's urban residential building sector. Although conventional building designs incorporate optimum practices such as cross-ventilation and shading, most contemporary projects adopt these at the expense of cost reduction (Fekadu, 2023; Mekonnen et al., 2019). This indicates the requirement for enhanced learning and support through policies in promoting passive design in urban residential buildings.

This paper attempts to find solutions for such challenges in Adama through the analysis of existing limited spaces in the existing buildings and recommending new methods for enhancing natural ventilation and daylighting in small urban plots. Merging findings of conventional Ethiopian architecture with advanced passive design features like optimal building orientation, window placement in relation to wind directions, the use of shading devices, and the selection of building materials that contribute to enhanced thermal comfort, it is probable that there can be built health-conscious, energy-saving homes in the limited spaces (Givoni, 1998; Pereira et al., 2019; Bisen & Narad, 2023).

1.2. Statement Of the Problem

Adama, being a fast-growing city in Ethiopia, struggles with balancing urbanization with sustainable design for housing. The residential zones in the city, marked with small plots and high-density development, tend to favor the first desirable building for profit-gain rather than environmentally responsive architecture. Indigenous Ethiopian design elements like courtyards, window placement, and passive cooling strategies have been left in favor of small, profit-oriented schemes that strongly limit the penetration of daylight and natural ventilation (Demissie & Alemayehu, 2021; Mekonnen et al., 2019). All this has contributed towards decreasing the indoor environmental quality, where poorly ventilated interiors and overdependence on artificial lighting result in healthcare issues such as respiratory ailments, heat stress, and visual discomfort (WHO, 2018).

It is exacerbated by Adama’s climatic conditions, in which high temperatures necessitate thoughtful architectural design to maintain thermal comfort. Presently, however, modern building designs often lack proper shading considerations, cross ventilation, or orientation design, leading to overheating inside building spaces and high energy usage for cooling and illumination (Yilma, 2021). Exacerbating these problems, Ethiopia’s Climate Resilient Green Economy Strategy (2011) and Urban Building Code (2020) stress green practices, yet support is poorly enforced, especially in intermediate-sized cities such as Adama. Overseeing regulatory control is fragmented, and constructors often skirt guidelines because of cost considerations and lack of information (Wondimu & Tadesse, 2022).

Prior work on Ethiopian urban housing has centered on Addis Ababa and Dire Dawa, pointing out systemic problems such as overcrowding and inefficiency in energy (Goshu et al., 2017; Doda, 2017). Yet, there isn't work specifically on Adama's various urban fabrics, including informal settlements, preurban expansions, and planned neighborhoods. In addition, while global guidelines embrace passive design strategies, the relevance in Ethiopia's small urban plots has remained an under researched area. For example, in other contexts in the Global South (Kumar & Kaushik, 2019), there is the suggestion for modular venting systems and light shelves, yet these solutions in Ethiopia's high density, resource constrained environments remain infrequently evaluated.

These conditions result in significant negative impacts on residents' health, increasing the prevalence of respiratory diseases, heat-related illnesses, and visual discomfort due to poor indoor air quality and inadequate natural lighting (WHO, 2018). The excessive dependence on artificial lighting and mechanical cooling raises household energy expenses, placing financial strain on families and contributing to higher overall energy consumption in the city. This increased demand burdens Adama's electrical infrastructure and conflicts with Ethiopia's Climate Resilient Green Economy Strategy goals by driving up greenhouse gas emissions. Furthermore, weak enforcement of building regulations and fragmented oversight hinder progress toward sustainable urban development, ultimately threatening public health, economic well-being, and environmental sustainability in Adama's rapidly growing residential areas.

1.3. Objectives

1.3.1. General Objective

To identify the challenges in achieving effective natural ventilation and daylighting in small plot urban dwellings and develop strategies to improve indoor air quality and promote sustainable urban living in Adama city

1.3.2. Specific Objectives

1. To examine the important limiting factors in natural ventilation and daylight in small urban residential plots.
2. To evaluate the effectiveness of the current architectural designs and building practices in overcoming these constraints.

3. To develop strategies to improve daylighting and natural ventilation in the study area.

1.4. Research Questions

1. What are the key factors that limit natural ventilation and daylight penetration in small urban residential plots in Adama?
2. How effective are the current architectural designs and building practices in addressing the constraints related to natural ventilation and daylight in these small plots?
3. What strategies can be developed and implemented to enhance daylighting and natural ventilation in small urban residential dwellings in Adama?

1.5. Significance Of the Study

1.5.1. Significance to the City Administration of Adama

This study provides the city administration with critical insights into the challenges and opportunities related to natural ventilation and daylight in small-plot urban dwellings. The findings can inform urban planning and housing development strategies that improve residents' health and comfort while reducing energy consumption. By highlighting the limitations of current building practices and regulatory enforcement, the research supports the city's efforts to promote sustainable urban growth and climate resilience.

1.5.2. Significance to the Policy Makers

The study provides evidence-based guidelines that policy makers can use to improve building codes and urban planning rules to more effectively deal with the challenges of small plot lots. It suggests opportunities to increase enforcement measures and incentives to support environmentally responsive design and align local policies with Ethiopia's Climate Resilient Green Economy Strategy and national sustainability.

1.5.3. Significance to the Scientific Community

This research contributes to existing international literature on sustainable housing in dense urban environments, in this case, in the lesser-studied context of Ethiopian intermediate cities such as Adama. Through analysis of the efficiency of existing architectural design and investigation of new approaches to natural ventilation and daylight, the research enriches scholarly discussion on appropriate passive design options available in resource-scarce contexts.

1.5.4. Significance to the Researcher

This study is perceived to provide the potential to acquire expertise in sustainable urban planning and in collaboration with multidisciplinary approaches that combine architecture, urban planning, and environmental health. It serves as the starting platform for future research and professional work geared towards improving lives in the ever-growing cities and contributing to Ethiopia's sustainable development agenda. It provides guidance on further research.

1.6. Scope Of the Study

1.6.1. Thematic Scope

The study studies on the challenges of achieving natural ventilation and daylighting in small plot G+0 residential buildings within dense urban areas. It goes in how limited plot size, urban density, and building configuration affect passive environmental performance, emphasizing sustainable design strategies suitable for G+0 dwellings.

1.6.2. Spatial Scope

The research is specially limited to Adama City, Ethiopia, targeting selected neighborhoods which are characterized by small plot residential developments. It tries to examine housing units typically built on plots of 105 m^2, in Lugo Sub city, Adama Town.

1.6.3. Temporal Scope

The study covers current conditions during 2020–2025, reflecting recent housing trends and construction practices. Field measurements were taken in the Adama's high hot temperature season, which are April and May, and the measurements for parameters were taken between April29- May01. The other climatic data were taken from the local meteorological data, which were taken as secondary data sources.

1.7. Limitation Of the Study

This study presents findings from field measurements and observations of environmental parameters—temperature, relative humidity, air speed, and daylight illuminance in eight small-plot ($\leq$105 m^2), single-story (G+0) dwellings in Adama City during the hottest months (April–May). Measurements were taken at three specific times of the day (3:00 AM, 7:00 AM, and 11:00 AM) across major rooms and analyzed by orientation (E-W and N-S) and configuration (T-junction and enclosed), with comparisons to ASHRAE 55 and IES standards. While these results address the research objectives, several limitations must be acknowledged. The study's scope is confined to single-story dwellings on small plots within Adama's specific climatic and socio-economic context, limiting the direct applicability of conclusions to multi-story buildings or different urban environments. The sample size is limited to eight homes due to time constraints and equipment availability, and data collection relied on spot measurements rather than continuous monitoring, potentially missing diurnal and seasonal variations. Additionally, although occupant behavior influences ventilation and daylighting, its impact was not extensively examined within this study. These limitations should be considered when interpreting the findings and drawing conclusions.

1.8. Operational Definitions

Enclosed Configuration: A building layout where dwellings are surrounded by shared walls with limited openings, restricting natural ventilation and daylight penetration. (Perplexity.ai)

Small Plot Urban Dwellings: Residential units built on plots of approximately 105 m^2 or less, which is nearly half the recommended 200 m^2 minimum for hot climates like Adama, Ethiopia, posing challenges for thermal comfort and ventilation. (Model Urban Block Standard, 2020)

T-junction Configuration: A building arrangement where structures meet perpendicularly, forming a "T" shape intended to improve airflow and daylight but often limited by small plot sizes in dense urban areas. (Perplexity.ai)

1.9. Organization Of the Document

It is divided into four chapters that will facilitate the process and the findings in an understandable and logical manner.

Chapter One presents the study by revealing the background and the relevance of natural ventilation and daylighting issues in small-plot urban residences, specifically in Adama City. It describes the reasons why indoor environmental quality is important in dense urban areas.

Chapter Two is devoted to an in-depth literature review capturing salient concepts, including Natural ventilation, ventilation strategies, daylighting fundamentals, and Adama's climatic and urban context. In addition, gaps in the literature that the present work endeavors to fill are identified where necessary.

Chapter Three presents the methods applied in the research in the present study. It discusses the method used to select the dwellings in the sample, the procedure for collecting the data, the equipment and instruments used, and the methods applied for the analysis. It further describes the process for the measurement of temperature, humidity, airflow, and daylight, and how the measurements were evaluated.

Chapter Four displays and discusses the findings from field measurement and qualitative surveys. It looks at indoor environmental quality in buildings with varying orientations and site configurations. It contrasts the findings with existing standards for thermal comfort and daylighting guidelines to determine the principal variables controlling occupant comfort.

The last one summarizes the major findings and concludes the study. It offers practical advice on how architects, urban planners, and policymakers can enhance small-plot dwellings' daylighting and natural ventilation. The chapter further indicates avenues for further research.

Lastly, Appendix I-V consists of supplementary supporting items, including questionnaire surveys, detailed tabular data, field measurement photographs, and equipment specifications.

CHAPTER TWO

LITERATURE REVIEW

2.1. Theoretical Literature Review

2.1.1. Fundamentals of Natural Ventilation

Natural ventilation refers to the flow of fresh outdoor air into a building without mechanical systems, driven by wind pressure differences and buoyancy (stack) effects. Wind driven ventilation occurs when wind creates higher pressure on the windward side of a building and lower pressure on the leeward side, inducing crossflow through openings. Buoyancy (stack) ventilation arises from temperature differences, warm indoor air rises and escapes through high openings, drawing cooler air in through low openings. These passive forces have been studied since the mid-20th century (ASHRAE, Emmerich, Gan, 2019).

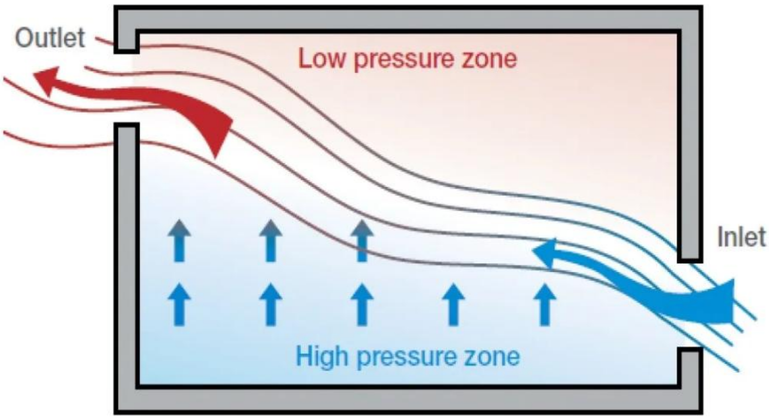

Figure 2.1. *Natural Ventilation (Source: Web)*

Importantly, natural ventilation has well documented benefits for indoor air quality and comfort, it helps control temperature, humidity, and removal of pollutants without energy use (Conzatti et al., 2025). In fact, guidelines like ASHRAE 62.1. (2019) recognize that properly designed natural ventilation can maintain acceptable air quality while reducing operating costs . For example, (Conzatti et al., 2025) note that "natural ventilation plays a crucial role in maintaining a healthy indoor environment by controlling temperature, humidity and pollutant concentrations" (ASHRAE 2015). In passive design theory, openings (windows, vents) are carefully sited to harness prevailing winds and stack effects; architectural form (e.g. atria, light wells, courtyards) may be used as vertical conduits to enhance airflow. In summary, theoretical models of natural ventilation emphasize airflow continuity, stack and wind pressure principles, and often assume steady-state flow.

2.1.2. Fundamental of Daylighting

Daylighting refers to the use of natural sunlight and skylight to illuminate building interiors. In theory, daylight is defined as the combination of direct solar radiation (sunlight) and diffuse sky radiation. As Wong, 2017 emphasizes, "the sun is the biggest source of light, the light we receive today comes from the sun in two ways: directly as sunlight or as diffuse skylight".

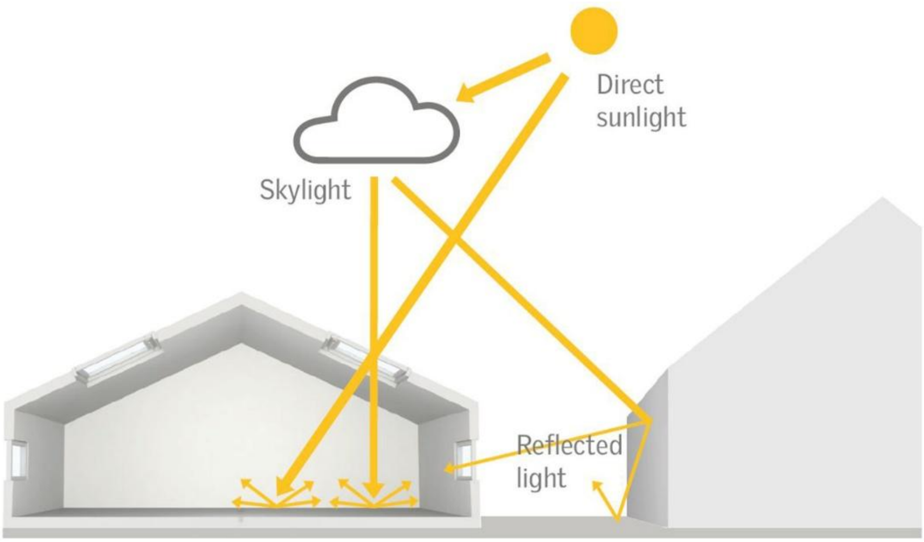

Figure 2.2. *Daylight (Source: Web)*

In practice, designers use metrics such as the *Daylight Factor* (DF), the percentage ratio of indoor illuminance to outdoor horizontal illuminance under overcast sky to quantify daylight availability at a point. DF and related metrics (e.g. Spatial Daylight Autonomy, Useful Daylight Illuminance) form the theoretical basis for designing and assessing daylighting strategies (Littlefair, 1988).

Theoretically, daylighting has numerous advantages. Natural light contributes towards visual comfort and has beneficial effects on the body. Research observes that natural light promotes health and mood, for instance. Exposure to daylight maintains human circadian rhythms, vitamin D production and counteracts Seasonal Affective Disorder. Wong, 2017 summarizes literature in evidence that "using natural light can help to maintain good health, cure some medical ailments, and reduce psychological sadness related to Seasonal Affective Disorder". In comparison to artificial light, daylight is dynamic and broad in its spectrum, enhancing visual conditions and reducing eye strain. Theoretically, daylighting is also an important passive solar tool, and with proper design, it can greatly minimize energy usage in electric lighting and even heating. Wong, 2017 summarizes that lighting can account for the order of 20-40% building energy, and that daylighting can greatly reduce it. Indeed, daylighting is often the most straightforward form of passive solar gain; energy saving (and reduction in CO2) is projected from well-designed daylighting (e.g. 223 million tones CO2, 24,000MW energy saving worldwide as cited in Wong, 2017). Of course, theory also issues caveats: too much daylight may lead to glare or overheating if not controlled, so the designs need to balance luminous comfort with thermal regulation.

2.1.3. Passive/ Bioclimatic Design Principles

The theory involves using the local climate to inform building design by incorporating smart architectural features such as building orientation, shape, materials, and passive elements to optimize airflow and natural lighting (Lechner, 2014; Givoni, 1998). For example, designing thin east and west façades reduces solar heat gain while still capturing morning and evening light (Wong, 2017). Cross-ventilation is enhanced by placing windows on opposing walls, allowing wind to flow through the building effectively (ASHRAE, 2015). Architectural elements like courtyards act as vertical wind channels, like the airflow through an open-topped bottle, improving ventilation (Conzatti et al., 2023). Daylighting strategies include installing high-level windows to direct light deeper into rooms and using light shelves to reflect sunlight further inside (Littlefair, 1988; Moore et al., 2017). When walls cannot provide sufficient daylight, roof openings such as skylights are incorporated. The most effective bioclimatic designs integrate these strategies concurrently to maximize comfort and energy efficiency (Demissie & Alemayehu, 2021). As Duncan and Hawkes (1995) demonstrated, such things as high ceilings and sunshades can deflect the heat while still admitting good light. An interesting fact is that we can use two tasks for one window, for instance, an opening window high up, admitting both fresh breezes and daylight. Yet, in actual design, we always must balance. Additional windowing lets in lighter but can result in overheating. Special features such as roof projections and tilted slats can deflect the sun while still admitting the wind and some light. Today, designers use computer software to assist in computing the balances ideally. Innovative concepts such as the "smart wall," which changes its openings automatically (Shi et al., 2023), illustrate the convergence of technology with these climate-responsive designs while retaining the fundamental nature-based rules.

2.1.4. Thermal Comfort and Adaptive Theories

The fundamental notion behind daylight theory and natural ventilation is related to thermal and visual comfort. We apply the Predicted Mean Vote (PMV) model, but it doesn't perfectly apply for buildings with natural ventilation. The adaptive theory provides better insight. It explains that individuals in naturally ventilated buildings can acclimate to warmer temperatures through their habits and expectations. Research by Hailu et al. (2021) confirms it: individuals remain comfortable in hot-dry climates at 32°C inside, whereas in the West, the comfort interval is lower (20-50°C). Nicol's field experience in Iraq and Western Australia provides similar observations - those sitting remain comfortable at higher temperatures in warmer locations. It implies that in hot locations buildings might sustain higher indoor temperatures if individuals are acclimatized.

Daylighting impacts comfort too. Better natural light requires fewer electric lights and can improve the mood of individuals. Excessive direct sunlight through the window, however, can lead to glare and overheating issues. Due to these reasons, theories on comfort give emphasis on providing the users with the ability to control their surroundings - such as the ability to open the window or adjust shading devices (Fabi et al., 2012; Croitoru & Wilkinson, 2020). In this manner, individuals can tailor their own level of ventilation and light.

2.2. Empirical Literature Review

2.2.1. Natural Ventilation

Several studies have studied natural ventilation using actual building measurements, computer simulations, and examples of design. It has been proven in field tests that passive ventilation design can reduce indoor temperatures and enhance air quality. Problems mostly result when the design is less than optimum, or site conditions are unfavorable. One interesting result comes from the work of Conzatti et al. (2025), who contrasted simple calculations with detailed CFD simulations. They found that the Warren model (an historical method for window sizing) produced similar results to sophisticated computer simulations in the design for refugee shelters. It is significant because it indicates that the simple methods can perform well in the absence of high-technology tools. In the same vein, NIST's 2011 investigation into natural cooling concluded that the use of natural ventilation could save both building and energy expenses in office spaces. Their report highlights the advantages of natural ventilation, especially when combined with mechanical systems.

Field surveys in high-density urban environments frequently indicate inadequate ventilation. In dense urban environments, wind flows at street level are reduced, and high-rise, narrow dwellings frequently have only one or two facets exposed to wind flows. Research (e.g. Evins et al., 2012) indicates that rooms with single-sided openings never benefit from efficient cross-ventilation. Researchers additionally point out that surroundings such as buildings, vegetation, or terrain can deflect or prevent wind, resulting in very site-specific natural ventilation. For instance, an AIVC document on urban ventilation indicates that slight differences in terrain and neighboring buildings can induce uneven flow patterns, hindering the function of natural ventilation. Inadequate ventilation has been measured in the form of high indoor concentrations of CO_2 and temperature, day and night. In an experiment in low-income dwellings in an urban tropical climate, natural ventilation for instance provided only 1–3 °C less temperature compared with sealed buildings, too little for the attainment of comfort (university thesis data).

Conzatti et al. (2025) explicitly affirm that in campuses such as those for northern Ethiopian refugees, simple models provide sound design advice: wind-driven scenarios presented near-identical window sizes for the simple model and the sophisticated CFD (99% correlation), and buoyancy-driven cases presented 94–97% correlation. Empirical consistency increases the confidence that in low-resource contexts, architects can trust rules-of-thumb for preliminary design.

Negative aspects document where ventilation goes wrong. In extremely dense multi-level blocks (such as Addis Ababa condominiums), measurement campaigns established that many units experience stagnant air and high thermal discomfort. For the Yeka Abado condominium case study (Ayalew & Sokido, 2021), occupants complained of ventilation issues: corridors and major stairwells were often stagnant, while cross-ventilation was obstructed by internal partitioning. Nearly 60% of surveyed occupants indicated window design and building orientation as the major reasons for poor natural light (by implication, similarly for airflow) (Ayalew & Sokido, 2021).

Generally, empirical data indicate that successful ventilation is contingent on design and circumstance. Under the right application, however, natural ventilation can maintain CO_2 concentrations at less than 1000 ppm (an indoor air quality threshold) using operable windows alone, as discovered in wind-driven configurations by Conzatti et al. However, most small-house designs in high-density locations fail these ideals short: narrow layouts, single-sided entries, and obstructions in the outdoors too often result in under-ventilation and the need for fans, if not AC. These observations emphasize the value in detailed site- and form-specific design, and the power of low-order design rules in enhancing performance (NIST, 2011; Conzatti et al., 2025).

2.2.2. Daylighting

Empirical studies on daylighting in small or dense buildings consistently show challenges in meeting recommended illuminance levels. Field measurements and simulations reveal that window size, placement, and type are crucial. The IEA Task 31 report (Li et al., 2012) compared vertical side-windows, dormer windows, and roof windows in a typical room. Their analysis showed that roof windows (skylights) produced much higher illuminance than vertical side windows under the same conditions. For example, in South-facing rooms, roof windows delivered 20–50% higher illuminance on work planes than vertical windows (Kjeld Johnsen et al, 2006). The study's charts show that vertical windows often fall well below recommended levels except near the facade, whereas roof lights provide more uniform lighting deeper into the space (Kjeld Johnsen et al, 2006). This suggests that in narrow-lot contexts where side-window area is limited, roof lights or light wells could greatly improve daylighting.

Actual building surveys confirm inadequate daylight in many cases. In the Addis Ababa condominium study by Ayalew & Sokido, 2021, 66% of occupants reported natural light problems. Residents identified window design (size and location) as the dominant cause (55.9% cited this), followed by building orientation (42.9%). In quantitative terms, 45.3% of the households surveyed said daylight was insufficient, while only 33.4% found it sufficient. Over half of occupants (52.3%) still used artificial lighting in at least one room during the daytime. These findings illustrate a common empirical pattern: without generous glazing (e.g. >15% window-to-floor area), interior daylight frequently fails recommended criteria and people compensate with lamps.

Energy-wise, the implications are significant. Wong, 2017 summarizes that lighting can consume 20–40% of total building energy. Thus, insufficient daylight has a direct penalty in electricity use and associated emissions. Empirical daylight can create glare or solar heat potential overheating trade-offs: poorly managed daylight can create glare or solar heat gain that increases cooling loads. In summary, real-world data show that meeting daylight targets in small urban dwellings is difficult without targeted strategies (roof lights, light shelves, high-level glazing). Comparing studies, one learns that roof or clerestory glazing often yields that most daylight benefit in deep-plan units (Wong, 2017), whereas side windows alone usually light only a shallow perimeter.

2.2.3. Interplaying Ventilation and Daylighting

Several empirical and simulation studies highlight the trade-offs and synergies when optimizing both ventilation and daylight. Openings that admit daylight (large windows, skylights) also provide ventilation when operable. However, designers must balance solar heat gain, glare, and privacy. One approach has been the use of integrated façade systems. For example, parametric studies (Shi et al., 2023) design adaptive facades whose louvers or panels adjust to simultaneously optimize view, daylight and airflow. These simulations demonstrate that with multi-objective optimization, it is possible to improve both Useful Daylight Illuminance and Air Changes per Hour significantly (Abdollahi Rizi et al., 2023).

Field evidence is less common, but suggestive. In the Wegagen Bank headquarters (Gelan et al., 2022), occupants reported that plentiful daylight and operable windows jointly improved comfort and productivity. Respondents noted that bright natural light "leads to user comfort and safety" and that uniform daylight "increased building occupant productivity". Although this is an office case, it supports the general idea that daylighting and fresh-air strategies can complement to improve indoor environmental quality.

Overall, empirical evidence indicates that while ventilation and daylight often compete for façade area and shading design, they can be integrated through thoughtful design (e.g. combining clerestory windows with low vents). However, most existing case studies deal with one or the other; truly integrated empirical research in small-plot dwellings is scarce. This highlights a gap: designers often optimize for daylight (e.g. in commercial green building design) or ventilation (e.g. in passive cooling studies) without full awareness of interactions. Some modeling studies (e.g. cross-disciplinary parametric simulations) confirm that co-optimizing can yield gains in both domains, but practical examples in the literature remain limited.

2.3. Contextual Literature Review

2.3.1. Urban Housing and Climate in Ethiopia

Ethiopian cities such as Adama are experiencing rapid urban densification, often on very small plots that range between 4 to 6 meters in width (Modern Urban Block, 2020). Typical urban housing in these cities consists of multi-story perimeter blocks or row houses with shared walls, resulting in only two narrow façades exposed to the outside environment. This configuration severely limits window size and orientation options, constraining natural ventilation and daylighting potential (Gaisma ,2022). Adama's climate is classified as tropical warm semi-arid (Köppen BSh), characterized by high solar radiation and modest rainfall, with peak daytime temperatures frequently exceeding 30–35 °C for much of the year (Regassa et al., 2020). These climatic conditions create a strong demand for effective cooling strategies, primarily through ventilation and shading, alongside careful daylighting design to minimize overheating while ensuring adequate natural light indoors.

Despite these climatic demands, modern Ethiopian building practices have often overlooked bioclimatic adaptation. Hailu et al., 2021 report that "almost all modern buildings in the country are designed and built without taking due account of climatic factors". Orientation, form and materials are frequently chosen without regard to climatic zone, as most housing (especially government-built condominiums) follows a standardized design regardless of location. For example, in the hot Semera area, federal "modular" condominium blocks were erected without considering of the extreme outdoor heat, leading many residents to avoid living there due to poor thermal comfort. By contrast, local traditional dwellings (e.g. Tukul huts or adobe houses) exploit passive strategies; they use porous natural roof materials and compact forms that stay cool, and many still feature small courtyards or high eaves (Hailu et al, 2021). In Semera, (Hailu et al. 2021) note that traditional houses "offer people pleasant inside temperatures, despite the severe hot desert climate", whereas the contemporary blocks caused "indoor thermal discomfort" and were largely uninhabited. Overall, this contrast shows that traditional knowledge in Ethiopia favors passive ventilation and daylighting, but urbanization and new construction have eroded these features.

Cultural practices in Ethiopian urban housing significantly influence internal layouts and ventilation behaviors. For example, traditional homes often include distinct guest and sleeping rooms, resulting in smaller intermediate spaces that limit airflow (Teshome & Mulugeta, 2018). Window-opening habits vary with climate zones; residents in cooler highland areas tend to keep windows closed more often, while those in warmer lowlands commonly open windows at night to enhance ventilation (Fikre & Tadesse, 2020). Construction predominantly uses heavy masonry and earth blocks, which provide high thermal mass that helps stabilize indoor temperatures but reduces immediate air permeability, thereby limiting natural ventilation effectiveness (Gebremedhin et al., 2019). Ethiopian building codes, such as the Addis Ababa municipal regulation, require window openings to be at least 15% of the floor area to ensure adequate daylight and ventilation. However, studies in Addis Ababa's Yeka Sub-city reveal that many apartments barely meet this standard and still experience poor daylight penetration and ventilation challenges (Gebremedhin et al., 2019; Teshome & Mulugeta, 2018). These findings highlight the gap between regulatory requirements and actual building performance, emphasizing the need for improved design strategies and enforcement to enhance indoor environmental quality in dense urban dwellings.

2.3.2. Traditional vs. Modern Architectural Practices

Ethiopian vernacular architecture historically integrated climate-responsive features. For example, the circular tukul huts have steep thatched roofs that shed rain and allow hot air to escape, while mud walls provide thermal mass. High gabled roofs and ventilated attics are common in many regions. Courtyard houses (found in Gondar and Harar) bring light and air into dense blocks. However, nearly all these passive features have largely disappeared in recent developments. Gelan (2022) observe that Ethiopian engineers frequently import "traditional building designs from other countries (particularly Europe and Asia)" without adaptation, ignoring local environmental needs. Such foreign-oriented design often misses the value of Ethiopian precedents. Even in projects billed as "green," local experts note that emphasis is more on technology (solar panels, elevators) than on simple passive cooling.

Modern low-income housing (such as government condominiums) tends to be dense blocks of uniform apartments with continuous exterior walls, long corridors, and minimal inner courtyards. Fenestration is often conservative to save money or meet privacy norms, leading to small or few windows on side walls. As Ayalew & Sokido (2021) found, vertical fenestration was a key shortcoming: 55.9% of residents attributed daylight problems to "window opening design". In other words, window size and placement in these buildings were empirically too small to deliver adequate light (and by extension air). Orientation is also often random: many such blocks do not optimize east-west alignment and so get suboptimal sun exposure (the Yeka buildings had up to 40% of windows receiving insufficient sunlight due to orientation).

The net effect is that even though the climate is sunny, many modern Ethiopian homes are darker and hotter than traditional ones. In focus groups at the Wegagen Bank building, occupants explicitly connected daylight to productivity and well-being, praising the "uniform and sufficient daylighting" and noting it improved staff performance. At home, the reverse is true: the Ayalew (2021) survey showed 45.3% of residents had insufficient daylight, leading to over half relying on artificial lights by day. This suggests that modern practice often fails to capture daylight through design, unlike traditional houses which were typically brighter inside.

2.3.3. Ethiopia-Specific Empirical Findings

Ayalew (2021) conducted a comprehensive study on daylight performance in the Yeka Abado condominium buildings in Addis Ababa, revealing significant natural light deficiencies. Survey results indicated that 66.4% of inhabitants reported insufficient natural light in their units. Performance analysis showed that only about 60% of rooms met the minimum recommended illuminance levels of 300-450 lux. The study identified window area as the dominant factor limiting daylight, with only 40.5% of windows exposed to adequate sunlight. Furthermore, shading caused by adjacent buildings, especially in narrow street rows, reduced daylight even for south-facing windows, exacerbating interior dimness. These findings highlight the critical impact of urban form, building geometry, and fenestration design on daylight availability in high-density housing (Ayalew, 2021).

Thermal measurements also reflect poor ventilation and heat gain. In Addis Ababa's condominiums, post-occupancy surveys revealed that more than half the occupants used fans or A/C even when outside temperatures were moderate, due to stuffy interiors. In rural Ethiopia's new settlement housing, measurements found that indoor temperatures were often 3-5 °C higher than outdoors during midday, indicating inadequate airflow and sharing (Weldeyesus et al., 2019). These empirical results highlight that both daylighting and ventilation in Ethiopia are often "insufficient" under current practices.

2.3.4. Culture and Behavioral Context

Local behavior and expectations shape how building features are used. Ethiopian families often prefer privacy and security, which can limit window opening (especially on lower floors). Curtains and shades are used heavily for glare control. Cultural comfort norms mean that people may tolerate a warm interior (Closing windows for security at night) or light dimness (e.g. using lamps even in daylight). Gelan et al., 2022 report that Ethiopian professionals believe that access to daylight has strong effects on well-being and productivity, and that buildings with poor daylighting led to increased artificial lighting use and higher energy consumption (Abdollahi Rizi, 2023). In focus interviews, users equated a "bright building" with comfort and alertness. Thus, even if designs allow light, occupants may still switch on lights if habituated. This suggests that solutions must combine physical design with user education on daylight use.

2.3.5. Ethiopian building code of standard

According to the Ethiopian Building Code Standard (EBCS, 2014), lighting is classified as a building service under Building Spatial Design (EBCS-12). The code sets out the following standards and guidelines for lighting:

i) All spaces intended for human occupancy must have access to natural light through exterior glazed openings.

ii) The minimum net glazed area for such spaces should be at least 15% of the floor area of the room.

iii) These exterior glazed openings must open directly onto a public way, yard, or court, as specified in section 6 of the code.

a. Required exterior openings are permitted to open into a roofed porch where the porch:

- Abuts a public way, yard or court.
- Has a ceiling height of not less than 2100 mm.
- Has a longer side at least 65 percent open and unobstructed.

b. Skylights are not required to open directly onto a public way, yard or court.

iv) Glazed wall openings and skylights shall be free of obstruction and provided with means for cleaning to maintain adequate supply of natural light and prevent the use of artificial light.

v) All occupancies other than dwelling occupancy shall be provided with means to generate at least 5% of their energy consumption themselves.

vi) For the purpose of natural lighting, any room may be considered as a portion of an adjoining room where one-half of the area of the common wall is open and unobstructed and provides an opening of not less than 1/10th of the floor area of the interior room or 2.5 m^2, whichever is greater.

vii) All building spaces shall be provided with artificial light of an average illumination complying with relevant standards and EBCS 10.

EBCS 10 states the recommended lighting requirement for different types of interiors, tasks and workspaces. In addition, EBCS 10 lighting requirements states:

i) For indoor workplaces that are manned full-time, a minimum rated illuminance of 200.0lx shall be provided unless other factors (such as nature of operation, physiological reasons) require different values.

ii) In interior designed for permanent human occupation, a minimum rated illuminance of 100.0 lx is required.

iii) If tasks are performed at fixed-location workplaces outdoor that correspond to tasks performed indoors (e.g., operation of wood-work machines), then a rated illuminance specified for such tasks in EBCS 10 for indoor workplaces shall be provided.

iv) At no stages in the useful life of the lighting installation shall the mean illuminance, E, obtained at the workplaces be less than 0.8 times the value of the rated illuminance; at no single workplace shall illuminance ever fall to less than 0.6 times the rated illuminance.

The Ethiopian Building Code Standard (EBCS) focuses mainly on consideration of artificial light. There is only limited consideration of natural lighting in buildings. The required level of illuminance as well as limit to glare caused by natural light are not clearly specified in EBCS. (Dagmawi H., 2021).

Table 2.1. *Standard Illuminance Levels for Residential Spaces (in Lux) (Source: V-TAC)*

Room Type	Recommended Illuminance (Lux)	Purpose/Remarks
Living Room	100–300 lux	General activities, reading, relaxing. 100 lux minimum, 200–300 lux preferred for older occupants.
Bedroom	50–150 lux	Relaxation and comfort; reading lamps may provide localized 300–500 lux.
Kitchen (General Area)	200–300 lux	Sufficient for general use and movement.
Kitchen (Worktop)	300–750 lux	Task lighting for food preparation. Bright and shadow-free areas.
Dining Area	150–300 lux	Comfortable lighting for meals; often combined with mood lighting.
Bathroom	100–200 lux	General visibility and safety. Vanity/mirror area may need 300+ lux.
Corridor / Hallway	50–100 lux	Orientation and movement, especially at night.
Stairs	100–150 lux	Safety and visibility.

2.3.6. Key Parameters and Standards for Natural Ventilation and Daylighting

When dealing with the challenges in the provision for daylighting and natural ventilation in small-plot residential buildings, it is necessary to determine the important design parameters, variables, and standards that determine efficient performance. Natural ventilation and daylighting depend on an extensive interplay of architectural, environmental, and climatic considerations, whose proper coordination against established benchmarks is necessary for ensuring occupant comfort, energy efficiency, and design code compliance.

The following table consolidates crucial variables and accepted standards for daylighting and natural ventilation, from best practices worldwide with the use, where applicable, of pertinent Ethiopian environmental data. They will constitute the basic parameters for the assessment of the sufficiency of the ventilation and the lighting provisions in the area under investigation. They will be used in the analysis of the existing residential buildings, and design guidelines will be developed based on how the parameters can be enhanced in the limited contexts of small plots.

The variables highlighted include air change rates, window-to-wall ratios, minimum illuminance levels, ventilation strategies, and spatial configurations, which are central to achieving passive environmental control in compact urban settings like Adama City.

a. **Air Change Rate (ACH)**
   The number of times the air within a defined space is replaced with outside air in one hour. It measures ventilation effectiveness and is critical for maintaining indoor air quality and thermal comfort (CIBSE, 2005).
b. **Window-to-Wall Ratio (WWR)**
   The ratio of total window area to the total exterior wall area. It influences both natural ventilation capacity and daylight penetration. Higher WWR can enhance daylight but may increase heat gain or loss (Mahdavi & Doppelbauer, 2010).
c. **Opening Area Ratio**
   The proportion of operable window or vent openings relative to the floor area of the room. This determines the airflow potential for cross or single-sided ventilation (Givoni, 1998).
d. **Cross-Ventilation Path Length**
   The distance air must travel across a room between two opposing openings. Affects the efficiency of air movement; ideally kept below 12 meters for effective natural ventilation (Santamouris, 2005).
e. **Minimum Illuminance Level**
   The lowest acceptable level of light (measured in lux) required for a particular task or space. For residential spaces like living rooms, this is typically around 100–300 lux (IESNA, 2011).
f. **Daylight Factor (DF)**
   The ratio of indoor illuminance at a point to the outdoor illuminance under overcast sky conditions, expressed as a percentage. A DF of 2%–5% is generally

recommended for habitable rooms (Littlefair, 1991).

g. **Sky View Factor (SVF)**

The portion of the sky visible from a point, affecting both daylighting and cooling potential by radiative heat loss at night. Lower SVF in dense urban areas reduces daylight availability (Oke, 1988).

h. **Glazing Visible Transmittance (VT)**

The fraction of visible light transmitted through glazing material. Higher VT enhances daylight admission but may require shading to control glare and heat (ASHRAE, 2017).

i. **Shading Coefficient (SC)**

The ratio of solar heat gain through a window with shading to that through an unshaded clear glass. This indirectly affects daylight and cooling loads (ASHRAE, 2017).

j. **Room Depth (RD)**

The distance from the window wall into the interior. Natural light penetration typically extends up to 2–2.5 times the window head height (Phillips, 2004).

k. **Window Orientation**

The compass direction that windows face, which determines exposure to sunlight and prevailing winds, influencing daylight quality and natural ventilation potential (Olgyay, 1992).

l. **Airflow Rate (m^3/s)**

The volume of air flowing through an opening per second. A key factor for achieving thermal comfort through natural ventilation, depending on pressure differences and opening sizes (Allard, 1998).

Table 2.2. *Key Parameters and Standards for Daylighting*

Category	Parameter / Variable	Recommended Standard / Typical Value	Source
Daylighting	Minimum Daylight Factor (DF)	2%–5% for living spaces	EN 17037 (2018); BRE Digest 209
	Window-to-Wall Ratio (WWR)	20%–40% (residential buildings)	CIBSE LG10; US DOE guidelines
	Uniformity Ratio (min/avg)	≥ 0.3	EN 17037
	Glazing Visible Transmittance (VT)	0.5–0.7	IESNA Handbook
	External Shading Factor	0.3–0.5 (for tropical/sunny climates)	Olgyay (1963); Givoni (1998)
	Window Orientation	South or southeast preferred (for balanced daylight and solar gain)	Lechner (2014)

Table 2.3. *Key Parameters and Standards for Natural Ventilation*

Category	Parameter / Variable	Recommended Standard / Typical Value	Source
Natural Ventilation	Air Changes per Hour (ACH) – Bedroom	4–6 ACH (minimum for healthy ventilation)	WHO (2009); ASHRAE 62.1
	ACH – Living Room	6–8 ACH	Same as above
	Effective Opening Area	≥5% of floor area (for single-sided ventilation)	EN 15251; CIBSE Guide A
	Cross-Ventilation Requirement	Inlet and outlet openings at opposite facades; ≥15% façade area	Givoni (1998); Szokolay (2004)
	Windowsill Height	≤1.1 m (to maximize airflow at occupant level)	WHO (2009); ASHRAE 62.1
	Prevailing Wind Direction	Design aligned to capture dominant NE-SW wind in Adama	National Meteorological Agency (Ethiopia)
	Stack Ventilation Height Difference	≥3 m vertical difference between inlet and outlet openings	Givoni (1998); Szokolay (2004)

Category	Parameter / Variable	Recommended Standard / Typical Value	Source
	Obstruction Factor	Minimize blockage of wind paths by adjacent buildings	Olgyay (1963)

2.3.7. Gaps and Opportunities in the Ethiopian Context

Existing literature highlights an essential deficiency in building studies in Ethiopia. Despite the country being equipped with good climate conditions and high demand for urban dwellings, few studies have investigated the application of integrating daylight and natural ventilation in local conditions efficiently. Domesticated in its own country, the problem is acknowledged in Ethiopia's own housing policy reports as stating there being "not enough location-specific studies and design guidelines for Ethiopian cities" in relation to passive cooling and Illumination solutions. Most research available has concentrated on daylight, and thermal comfort individually, in temperate climates mainly. The literature in the case through the Ethiopian case studies (Ayalew et al., 2021; Hailu et al., 2021; local building code) offers some proof, yet complete guidelines or performance figures for dense dwellings remain limited.

Designers might resort to applying generic rules (such as the 15% window rule) devoid of empirical confirmation.

With the large numbers living in small-plot dwellings and the limited electrification in some zones, there is an urgent need for local solutions. In some cases, low-cost methods such as "solar chimneys" (roof vents), light pipes, or adapted courtyards may be adapted for the needs of Ethiopian cities. Theoretical ideas such as adaptive thermal comfort and combined daylight-ventilation design remain to be fully transferred into local building practice. As Gelan et al. stress, there is an urgent need for an institutional and legal framework for green building practice. In short, the contextual literature indicates both need and potential: Ethiopian urban housing stands to benefit greatly from design strategies proven through local research and adapted building codes that take its special density and climate issues into consideration.

2.3.8. Climatic Condition of the study area

Adama (Nazret) has a hot semi-arid (BSh) climate, with warm temperatures throughout the year, marked wet and dry seasons, and high solar radiation. The climate in the city is influenced by its 1,712-meter elevation and location near the Great Rift Valley, yielding moderate humidity and day-to-day temperature fluctuations.

As seen in Table 2.4, Adama experiences relatively stable climate conditions, with 20.7°C (69.3°F) average annual temperatures. May is the hottest month, with daytime temperatures peaking at 29.1°C, while the coolest month is December, with daytime and nighttime temperatures averaging 25.3°C and 12.1°C, respectively. The typical diurnal range is 10–15°C, induced by clear skies and low humidity. Such thermal regimes dictate the application of passive warming and cooling measures in building design, with the need for passive cooling measures being extremely important in small plot homes where the retention of heat is compounded by urban forms of high densities. Adama experiences 371 mm (14.6 inches) of annual precipitation, in the form of two wet seasons (March–May and July–September). August is the wettest month (136 mm), while December and January are dry (<5 mm). Average relative humidity is 45–64%, reaching its higher values in rainy months, with the potential, in cases where precipitable areas lack proper ventilation, to impact evaporative cooling possibilities and indoor environmental quality.

Table 2.4. *Data: 1991 - 2021 Min. Temperature °C (°F), Max. Temperature °C (°F), Precipitation / Rainfall mm (in), Humidity, Rainy days. Data: 1999 - 2019: avg. Sun hours (Climatedata.org)*

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	19 °C (66.1) °F	20.6 °C (69.2) °F	21.9 °C (71.4) °F	22.5 °C (72.5) °F	22.7 °C (72.8) °F	22 °C (71.5) °F	20.7 °C (69.3) °F	20.2 °C (68.4) °F	20.7 °C (69.3) °F	20.8 °C (69.4) °F	19.5 °C (67.2) °F	18.3 °C (65) °F
Min. Temperature °C (°F)	12.4 °C (54.3) °F	13.7 °C (56.6) °F	15.5 °C (59.9) °F	16.7 °C (62.1) °F	16.5 °C (61.6) °F	15.8 °C (60.4) °F	15.7 °C (60.2) °F	15.3 °C (59.5) °F	15.2 °C (59.4) °F	15.3 °C (59.5) °F	13.6 °C (56.5) °F	12.1 °C (53.8) °F
Max. Temperature °C (°F)	26.2 °C (79.1) °F	28 °C (82.5) °F	28.7 °C (83.7) °F	28.9 °C (84) °F	29.1 °C (84.5) °F	28.5 °C (83.4) °F	26.8 °C (80.3) °F	26.1 °C (79) °F	26.8 °C (80.3) °F	26.8 °C (80.2) °F	26 °C (78.9) °F	25.3 °C (77.5) °F
Precipitation / Rainfall mm (in)	5 (0)	10 (0)	27 (1)	34 (1)	30 (1)	20 (0)	59 (2)	88 (3)	69 (2)	19 (0)	7 (0)	3 (0)
Humidity(%)	46%	37%	40%	46%	46%	51%	60%	64%	58%	43%	41%	44%
Rainy days (d)	1	2	3	5	4	3	11	14	11	2	1	1
avg. Sun hours (hours)	9.7	10.1	10.3	10.5	10.8	10.9	10.5	10.3	10.2	10.1	9.9	9.7

The Stereographic Sun-Path Diagram (*Figure 3*) reveals critical solar angles for Adama:

- **Summer Solstice (June):** Maximum solar altitude of 78°, with sunrise at 6:06 AM and sunset at 6:43 PM (12h 36m daylight).

- **Winter Solstice (December):** Solar altitude drops to 57°, with shorter daylight hours (11h 28m).

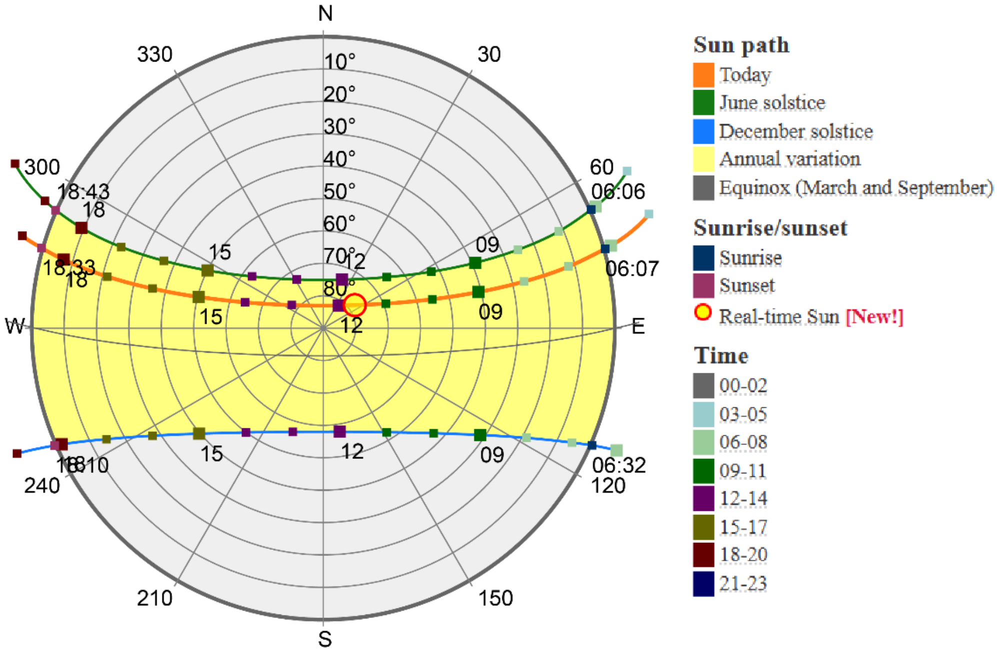

Figure 2.3. *Sun path Diagram (Source: Gaisma, 2025)*

As shown in *Figure 2.4* (Sunset Times), daylight duration varies from 11h 28m (December) to 12h 36m (June), with the sun rising earliest in June (6:09 AM) and setting at the latest in July (6:45 PM).

Prevailing winds originate from the southeast, with average speeds of 2.4 m/s (Climate-Data.org). Seasonal shifts occur during the rainy period (July–September), when northwestern gusts occasionally enhance cross-ventilation potential.

Table 2.5. *Average Annual Wind Speed of Adama (Source: Gaisma 2025)*

Months	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Wind Speed(m/s)	4.32	4.21	3.94	3.64	3.60	3.93	3.76	3.41	3.10	3.39	3.74	3.98

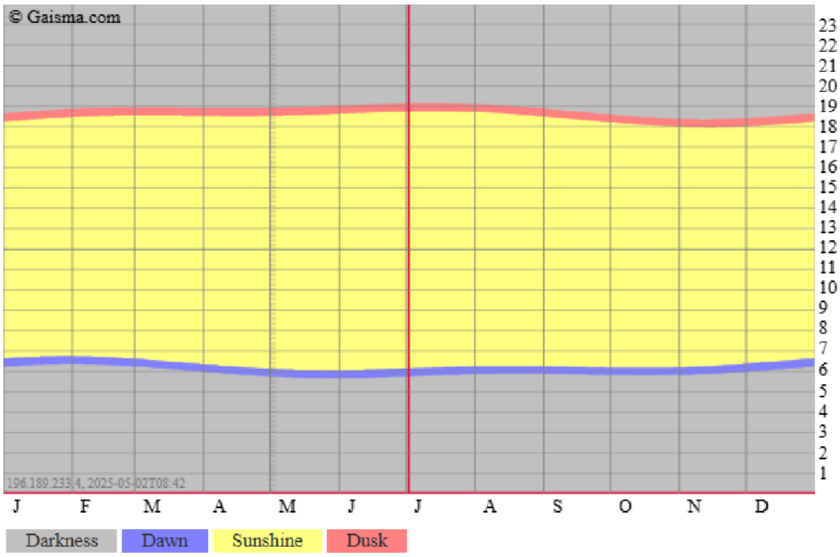

Figure 2.4. *Annual Sunrise and Sunset Graph of Adama (Source: Gaisma 2025)*

2.4. Strategies to Improve Daylighting and Natural Ventilation in Small-Plot Urban Dwellings

Improving natural ventilation and daylighting in small-plot urban dwellings, such as those in Adama, requires context-specific design strategies that address the challenges posed by high density, limited façade exposure, and local climatic conditions.

2.4.1. Architectural and Design Strategies

Research highlights the effectiveness of incorporating operable skylights and ventilation shafts to enhance airflow and daylight penetration in deep interior spaces where traditional cross-ventilation is limited (Demissie & Alemayehu, 2021; Wondimu & Tadesse, 2022). These passive features are particularly suitable for Adama's small plots, where narrow façades restrict window size and placement.

Stack ventilation, achieved through vertical shafts or chimneys, has been shown to significantly improve indoor air exchange in dense urban settings by exploiting buoyancy-driven airflow (Conzatti et al., 2023; Tong et al., 2017).

This approach is practical and cost effective in hot, dry climates like Adama's, facilitating night-time cooling and reducing indoor heat buildup.

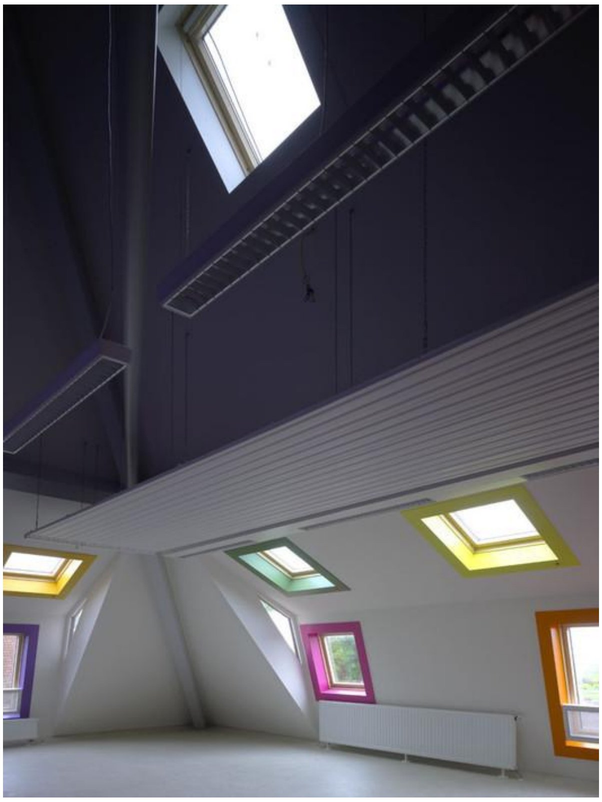

Figure 2.5 . *Sun-Filled space created by skylight (Source, ArchDaily)*

To optimize daylighting, studies recommend maximizing window-to-wall ratios within regulatory limits, using light shelves, and applying reflective interior surfaces to distribute daylight deeper into rooms (Moore et al., 2017; Wong, 2017). In small plots, where window area is constrained, skylights and light tubes serve as critical elements to bring daylight into enclosed or interior rooms (Demissie & Alemayehu, 2021).

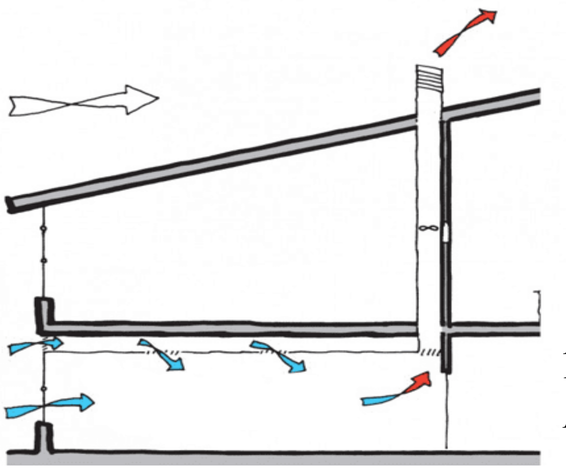

Figure 2.6. *A visualization of how night-cooling ventilation works in a building design (Source, Passivent.com)*

2.4.2. Urban Planning and Policy-Level Strategies

Beyond architectural interventions, effective strategies require supportive urban planning and policy frameworks. Current Ethiopian building codes (EBCS-12) mandate minimum glazing but do not adequately address the spatial constraints of small plots or promote integrated ventilation solutions (Wondimu & Tadesse, 2022). Scholar's advocate revising these codes to incentivize passive design measures tailored to dense urban fabrics, including flexible setbacks and plot layouts that increase façade exposure (Demissie & Alemayehu, 2021).

Incentives for adopting passive ventilation and daylighting features such as tax breaks or technical assistance can encourage developers to prioritize environmental quality alongside density (Tong et al., 2017). Pilot projects demonstrating the feasibility and benefits of such strategies in Adama's context are also recommended.

2.5. Research Gap

While Olyad's (2022) research has provided valuable insights into thermal comfort in condominium buildings in Adama, focusing on multi-story developments with limited façade exposure, it did not address the unique challenges faced by small-plot, single-story (G+0) urban dwellings. These dwellings, characterized by shared walls and minimal openings typically limited to the front façade, experience distinct constraints that significantly affect natural ventilation and daylighting. Moreover, there is a lack of focused research examining how these architectural and regulatory limitations impact indoor environmental quality in low-rise, dense urban housing within Adama's hot, dry climate. This specific gap in knowledge initiated this study, aiming to investigate and develop tailored architectural and urban planning strategies to improve natural ventilation and daylighting in small-plot, single-story dwellings, thereby addressing a critical and underexplored aspect of sustainable urban housing in Adama.

Table 2.6. *Summary of reviewed literature*

Topic	Authors	Year	Summary
Fundamentals of Daylighting Design and Metrics	Tregenza & Wilson	2011	Introduces daylight factor (DF) and spatial daylight autonomy (sDA) as metrics for evaluating daylighting performance.
Thermal and Visual Comfort Adaptation	Fabi, Andersen, Corgnati, & Olesen	201 2	Reviews adaptive thermal comfort models, showing occupant behavioral adaptation to indoor environmental conditions.
Passive Design Strategies for Hot Climates	Brown & DeKay	2014	Outlines passive cooling and ventilation strategies such as cross-ventilation, stack effect, and shading devices for hot climates.
Ventilation Standards for Residential Buildings	ASHRAE Standard 62.2	2016	Specifies minimum residential ventilation rates to ensure healthy indoor air quality.
Importance of Daylighting in Building Design	Wong, I. L.	2017	Reviews the benefits of daylighting for energy savings, occupant health, and psychological well-being; emphasizes the potential of daylight to reduce artificial lighting loads.
Daylighting and Ventilation in International Building Codes	International Residential Code (IRC)	2018	Sets minimum glazing and operable window area standards for habitable rooms to ensure adequate daylighting and ventilation.
Thermal Comfort in Ethiopian Traditional and Modern Buildings	Hailu, Gelan, & Girma	2021	Field study comparing traditional and modern Ethiopian buildings; shows traditional forms offer better thermal comfort through passive design.
Daylight Access and Ventilation	Ayalew & Sokido	2021	Analyzes natural lighting conditions in Yeka Abado condominium housing in

Challenges in Condominium Housing			Addis Ababa; highlights window sizing, building orientation, and daylight deficiencies.
Application of Green Building Concepts in Ethiopia	Gelan, Mekuria, & Simane	2022	Examines green building practices in Ethiopia, emphasizing the role of daylighting and natural ventilation in occupant comfort and energy savings.
Climate Data for Adama City	Climate-Data.org (Meteorological sources)	2024	Provides climate classification and data relevant for designing ventilation and daylighting systems for Adama.
Natural Ventilation Principles and Modelling	Conzatti, de Pando, Chater, & Coley	2025	Discusses natural ventilation models for shelter design, validating simple airflow predictions against advanced CFD simulations; emphasizes the importance of window placement and sizing for passive ventilation.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

Adama City, located at approximately 8°33′N latitude and 39°16′E longitude. The city experiences a subtropical agro-climatic zone characterized by warm temperatures and distinct seasons, with peak temperatures occurring in May and the coldest in December (Bulti & Sori, 2017). The city is administratively divided into six sub-cities Abageda, Boku, Dabesoloke, Lugo, Bole, and Dembela, each further subdivided into kebeles, the smallest local administrative units (City of Adama, 2024).

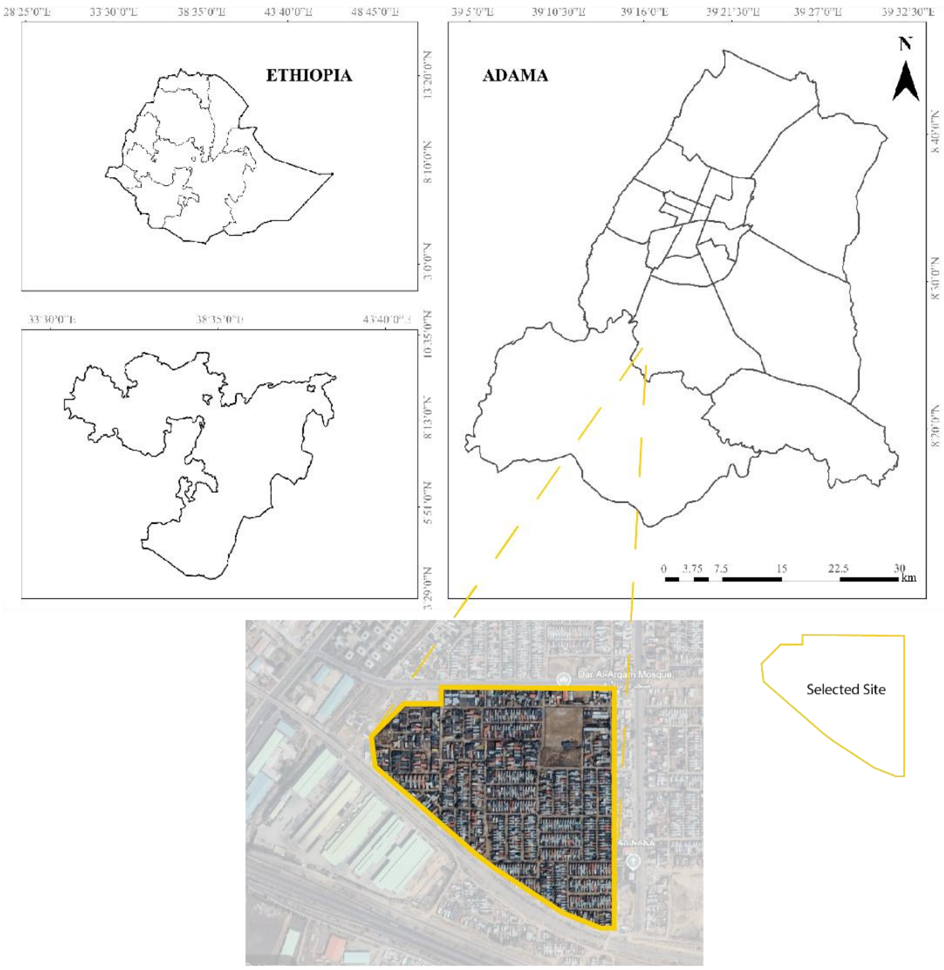

Figure 3.1. *Location Map of the Study Area (Source: Onasimus B., 2024)*

Adama belongs to the tropical (BSh) climate type in the Köppen-Geiger climate classification, with an annual average temperature of 20.7°C and an annual mean precipitation of 371 mm, concentrated primarily from June through September (Climate-Data.org, 2024). The relatively warm and dry climate, along with high urbanization rates, necessitates the use of passive cooling measures such as natural ventilation for thermal comfort. In the same manner, proper daylighting in high-density urban neighborhoods is important to enhance indoor environmental quality while reducing the need for artificial light. Such environmental and population characteristics support the suitability of Adama as a case area for investigation into the challenges in achieving natural ventilation and daylighting in small-plot residential zones.

The methods incorporate field observations, simulations, interviews, questionnaires, and observations to triangulate the findings and increase the validity of the outcomes. The chapter explains the design of the research, sampling methods, data collection strategies, methods for analysis, and ethical issues that informed the study.

3.2. Research Design

Figure 3.2 depicts the general process of the research, with the aim of thoroughly examining the challenges in the provision of daylighting and natural ventilation for small plot urban homes. The research is based on the mixed-method approach, in which quantitative field measurement was coupled with qualitative surveys and professional questionnaire. The choice of the approach was for the purposes of ensuring that the measurable parameters of the indoor environmental quality such as the daylight illuminance, temperature, humidity, and the velocity of the air, as well as the experiences and perceptions of dwellers, planners, and the architects, were thoroughly gathered and analyzed.

3.3. Research Approach

This research employed a case study approach focusing on small-plot, single-story residential dwellings in Adama City. Both quantitative and qualitative methods were used: field measurements provided empirical data on environmental parameters, while observations and expert/resident interviews offered contextual insights. This mixed-methods approach allowed for a comprehensive understanding of the challenges and potential strategies for improving natural ventilation and daylighting in the study area.

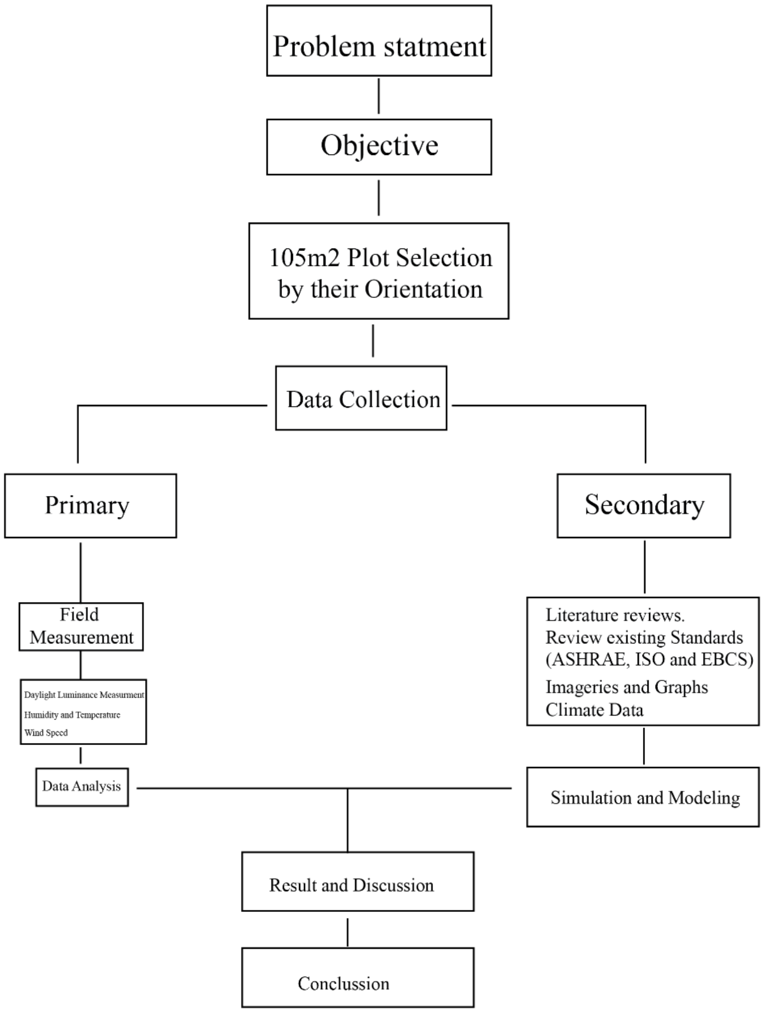

Figure 3.2. *Workflow Chart (Source: Author)*

The major variables being analyzed include building orientation, namely, E-W and N-S axes alignments-and their impact on single-story home natural ventilation and daylighting performance. Combining objective environmental measures with subjective responses from residents and professionals, the design methodology allows for an integrated analysis of the technical and the experiential aspects of indoor comfort and sustainability in Adama's small-housing plots.

3.4. Data Types and Data Sources

The study drew on a combination of primary and secondary data to ensure a comprehensive understanding of the indoor environmental quality in selected homes.

Primary data collection involves on site measurements of key environmental variables such as temperature, relative humidity, air speed, and daylight illuminance. These measurements were taken at specific times, 3:00AM, 7:00AM, and 11:00AM, to capture variations throughout the day. In addition to the quantitative data, Qualitative insights were gathered through field observations and structures interviews conducted with both residents and relevant experts.

To complement the primary data, secondary sources were extensively reviewed. These included policy documents, building codes, historical climatic records, and previous research studies on urban housing and environmental quality in Ethiopia. By integrating both firsthand observations and existing literature, the study was able to provide a well-rounded analysis of the physical and regulatory factors influencing indoor environmental conditions.

3.5. Sampling Design

3.5.1. Population distribution in the study area

As presented in Figure 11, the chosen study area was divided into two principal building orientations: east-west (E-W) and north-south (N-S). There are 11 blue rectangular blocks along the E-W orientation, each having 30 dwellings which correspond to 105 m² plots. Thus, the total E-W oriented units amount to 330 (11 × 30 = 330). Furthermore, there are 16 yellow rectangular blocks representing the N-S orientation, with each having 30 dwellings with the same plot size, leading to an aggregate total number of 480 N-S oriented units (16 × 30 = 480). As such, the study area consists of 810 residential units (330 E-W + 480 N-S), all constructed on 105 m² plots.

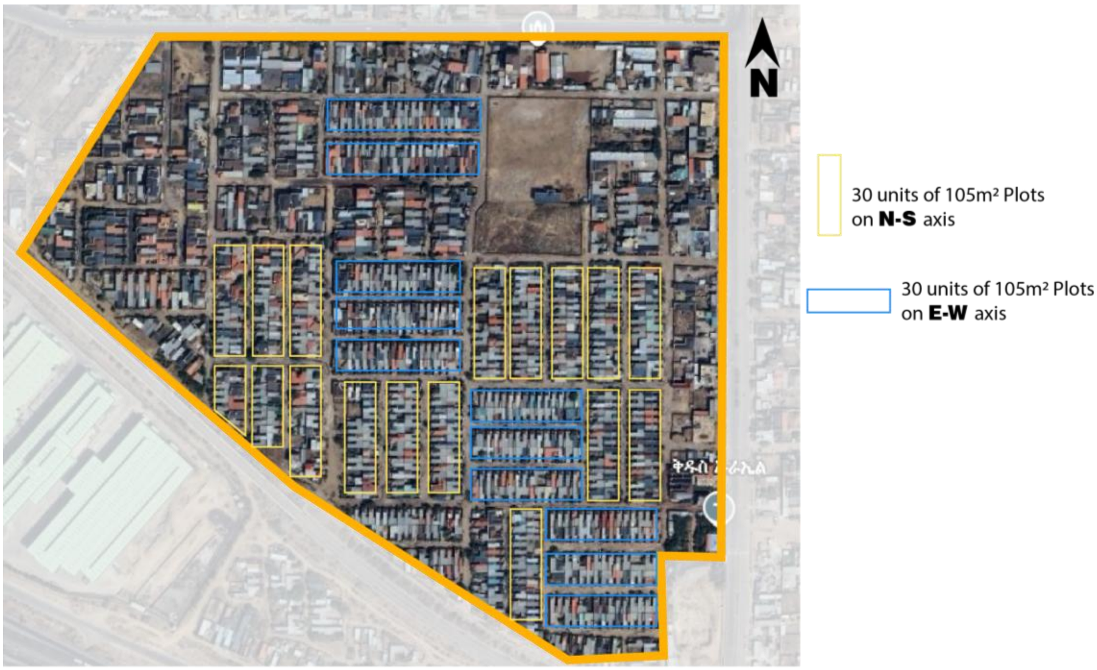

Figure 3.3. Map of residential blocks by orientation and unit count. Blue rectangles represent 11 east-west (E-W) blocks, each with 30 dwellings; yellow rectangles represent 16 north-south (N-S) blocks, each also with 30 dwellings. (Source: Author)

3.5.2. Sampling Techniques

A stratified purposive sampling strategy was employed to ensure representation across the key variable of interest: building orientation. The study area was stratified into four orientation categories based on the primary facade direction:

- E-W Axis (North-facing) , E- W Axis (South-facing)
- N-S Axis (East-Facing), N-S Axis (West Facing)

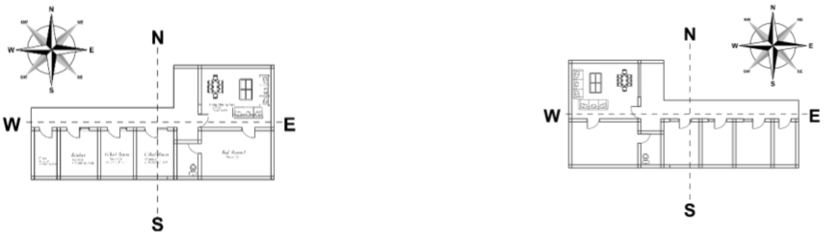

Figure 3.5. *Along E-W axis North Facing Residential Units (Source: Author)*

Figure 3.6. *Along E-W axis South Facing (Source: Author)*

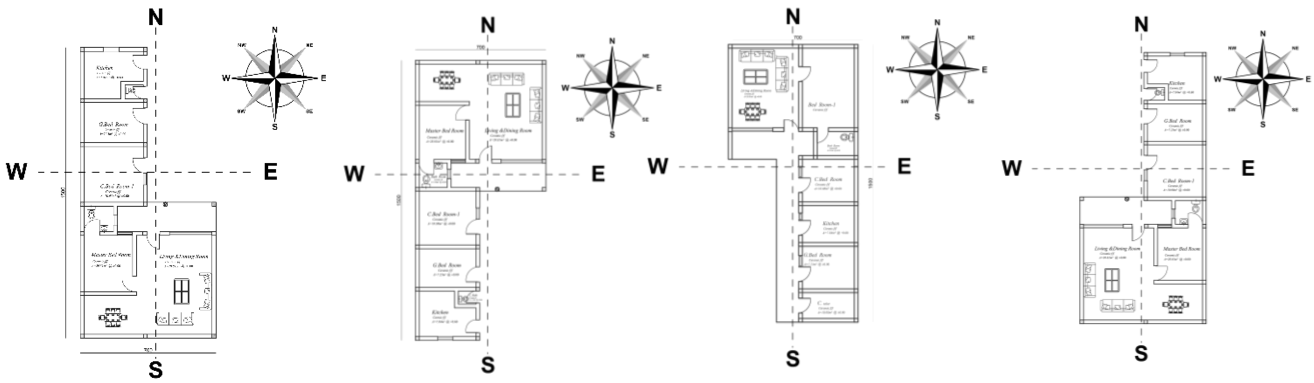

Figure 3.4. *Along N-S axis East Facing (Source: Author)*

From each stratum, 2 households were purposively selected, yielding a total of 8 households. This stratification ensures balanced representation of all orientation directions while controlling for the constant aspect ratio (7×15 m) and plot size (105 m²). Dwellings were further screened to meet inclusion criteria:

- Constructed within the last 5 years (to control material decay).
- No major structural modifications affecting ventilation/daylighting.
- The willingness of residents to participate.

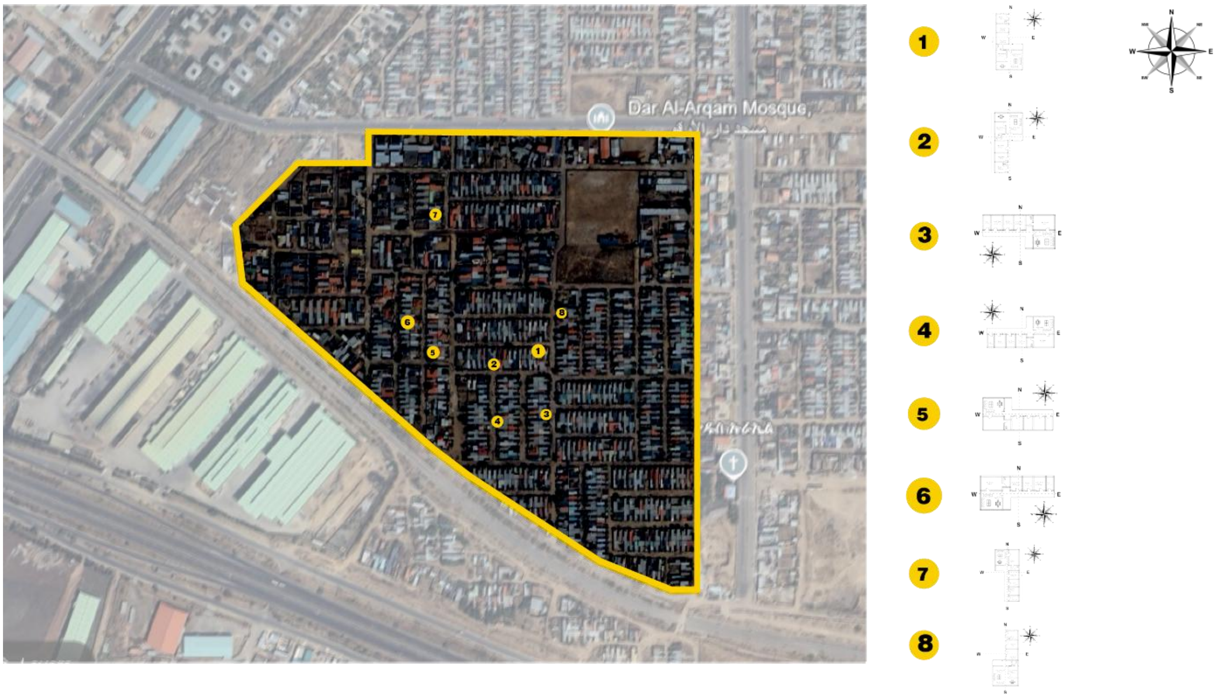

Figure 3.7. *Map Location of the Sample Plots (Source: Author)*

Table 3.1. *Coordinates of the selected plot areas (Source: Author)*

	Plot ID	**Axis Orientation**	**Latitude**	**Longitude**
1	SP01	N-S, E-facing	8°30'34"N	39°15'10"E
2	SP02	N-S, E-facing	8°30'32"N	39°15'09"E
3	SP03	E-W, S-facing	8°30'33"N	39°15'07"E
4	SP04	E-W, N-facing	8°30'32"N	39°15'04"E
5	SP05	E-W, N-facing	8°30'34"N	39°15'06"E
6	SP06	E-W, S-facing	8°30'26"N	39°15'13"E
7	SP07	N-S, W-facing	8°30'31"N	39°15'08"E
8	SP08	N-S, W-facing	8°30'31"N	39°15'12"E

3.5.3. Sample Size for Qualitative Data

The qualitative component of this study involved purposeful sampling of three key stakeholder groups to capture diverse perspectives on natural ventilation and daylighting challenges in small urban dwellings:

Residents (Interviewed)

A total of eight households were purposively selected to represent the two dominant buildings orientations (E-W and N-S) and configurations (T-junction and enclosed) typically of small-plot urban housing in Adama. This sample size balanced the need for diversity and representativeness with practical constraints such as limited equipment and time for field measurements. From each household, two occupants were interviewed to capture diverse perspectives on indoor environmental quality, including differences in gender, age, or daily activities which helped reduce individual bias and provided richer, more reliable insights. Interviewing two residents per household also allowed cross verification of occupant behaviors and comfort perceptions. This approach aligns with qualitative research guidelines indicating that 6-12 interviews typically suffice to reach thematic saturation in focused case studies (Guest, Bunce, & Johnson, 2006), while complementing the qualitative data collected in this mixed methods study.

Architects (Questionnaire)

In Adama, there are about 10 architectural design offices, each typically staffed with two to three architects. This means roughly 30 architects are actively involved in residential design across the city. Their experience and perspectives offer important insights into local housing practices and challenges.

8 architects with a minimum of 3 years' experience in residential design in Adama were purposively selected to participate. They completed structured questionnaires. This sample size balances the need for diverse professional viewpoints with practical constraints and is consistent with expert sampling strategies in qualitative research. (see APPENDIX-I)

Urban Planners (Questionnaire):

4 urban planners involved in housing policy and urban development regulation in Adama were similarly engaged through questionnaires. Their smaller number reflects the more limited pool of professionals directly involved in local residential planning but ensures inclusion of regulatory perspectives critical to understanding systemic challenges. (see APPENDIX-I)

3.5.4. Scientific Justification

- The resident sample size ensures representation across all orientation categories, capturing variation in lived experience while maintaining manageability for detailed analysis.
- The architect and planner samples are sufficient to achieve thematic saturation within professional groups, given their specialized knowledge and the focused scope of inquiry.
- Combining questionnaires with interviews enhances data richness, allowing for both

breadth and depth in professional insights.

3.6. Data Collection Methods

3.6.1. Field Measurements (Primary Quantitative data)

Measurements were taken in the field for an uninterrupted three-day interval, from 29th April through 01 May 2025, during the hottest high season in Adama. It was selected as the optimum sampling interval for the most unfavorable indoor environmental conditions for thermal comfort as well as daylight availability, since the high outdoor temperatures and high solar radiation during the interval pose the strongest challenges for passive design methods.

The measurement concentrated on the major occupied spaces in each sampled home, living rooms, bedrooms, kitchens and dining. The spaces were prioritized since the total occupant hours in them account for most occupant time and represent the most important spaces in evaluating indoor environmental quality. To record temporal variability and diurnal patterns, sampling at three different points in the day was performed:

3:00 AM(Morning): This time captures the baseline indoor conditions before solar gain and occupant activity increase, providing insight into nighttime cooling and residual heat retention.
7:00 AM (Afternoon): Measurements currently reflect the transition period when solar radiation begins to influence indoor environments and occupants typically start their daily activities.
11:00 AM (Late afternoon): This period often corresponds to high solar exposure and rising outdoor temperatures, critical for evaluating daylight penetration and natural ventilation effectiveness under stress conditions.
Each parameter was measured using calibrated, industry standard instruments to ensure accuracy and repeatability:
Daylight Illuminance: Measured with a digital lux meter, readings were taken at a height of 1.2 meters above the floor, approximating the occupant's eye level. The lux meters were

Figure 3.8 . *Lux meter (Source: Aliexpress)*

positioned at the geometric center of each room to capture representative daylight levels. Measurements were conducted with all artificial lighting turned off, and window and door positions were set to their typical daily usage as observed before to measurement. This approach ensured that reading reflected realistic occupant conditions rather than artificially controlled environments. (see APPENDIX-II).

Indoor Air Temperature and Relative Humidity: Recorded simultaneously using a digital thermohygrometer placed adjacent to the lux meter. These parameters are critical for assessing thermal comfort and moisture related to indoor air quality issues. The instruments were allowed to stabilize for at least two minutes before readings were logged to ensure accuracy.

Figure 3.9. *Thermohygrometer (Source: Aliexpress)*

Air Velocity: Measured using a handheld anemometer at the same height and location as other measurements. Air velocity provides a direct indicator of natural ventilation effectiveness and air movement, which significantly influence occupant comfort in naturally ventilated buildings. Several precautions were taken to minimize measurement bias and external disturbances: Lamp, refrigerators, TVs, and cooking appliances, which were potential internal heat sources, were switched off during the measurement. Occupants were asked to leave the windows and doors in normal positions, though, but not perform any activities that would artificially disturb indoor conditions during the measurement interval.

Figure 3.10. *Anemometer (Source: Aliexpress)*

The measurement was performed under clear weather conditions, excluding those typical meteorological events (e.g., heavy precipitation or gales) that might bias the result. A checklist (APPENDIX II) was used for each measurement session, to record contextual variables such as window/door, usage of shading devices, availability of occupants, and any salient environmental features.

This strict measurement protocol guaranteed the gathered data reflects the actual indoor environmental conditions perceived by the occupants in small plot homes in Adama. The multi-time process captures the dynamic changes in environmental parameters, thereby creating an excellent dataset for subsequent analysis and simulation verification.

3.6.2. Qualitative Data Collection

The data were gathered using structured interviews and questionnaires with residents, planners, and architects. Such data captures the perceptions, experiences, and expert knowledge that quantitative measurement cannot.

Resident surveys: Conducted interviews while undertaking field measurements to acquire knowledge about occupants' perceptions concerning their comfort, behavioral adjustments (e.g., window opening behaviors and usage of artificial light or fans), and room-specific issues regarding ventilation and daylight.

Professional surveys and interviews: Utilized Google form for efficient information collection, targeting planners and architects to inquire about design practices, regulatory issues, and suggested solutions for enhanced indoor environmental quality in limited urban plots.

Secondary Data Collection

The secondary data was gathered from reputable sources including meteorological agencies, climate databases (Gaisma, Ethiopian Meteorological Agency), and urban planning archives. For the purposes of the current study, the secondary data gathered include:

Climatic information: Hourly and monthly temperature, relative humidity, wind speed and direction, solar radiation, and sun-path diagrams. Such data determines the environmental limiting conditions directly affecting the potential for natural ventilation and daylighting.

Urban planning and regulatory writings: Building codes, zoning, and building standards applicable in Adama's residential setting.

Prior work and literature: Published works on passive design solutions, local building types, and environmental comfort guidelines (ASHRAE 55, IES guidelines).

The utilization in the mixed-methods approach in the study using secondary data is scientifically preferable as it offers an already validated, all-inclusive environmental baseline without having to collect extensive primary data, saving both resources and time. It also enables you to place your original findings into wider climatic and regulatory contexts, improving the analysis's depth and usability.

3.7. Data Analysis Methods

This research used quantitative and qualitative data analysis approaches together in order to thoroughly analyze the challenges for daylighting and natural ventilation for small urban dwellings.

3.7.1. Quantitative Data Analysis

a. Data Preparation and Cleaning

The field measurement data, including illuminance, temperature, relative humidity, and air velocity, were initially quality checked for consistency, completeness, and outliers. Missing and erroneous values were resolved through data cleansing.

b. Benchmarking Against Standards

Results were compared against existing comfort and daylighting standards (e.g., ASHRAE 55 for thermal comfort, IES for daylighting) to determine compliance and indicate deficiencies.

Table 3.2. *ASHRAE55 and IES Standards for Residential Rooms*

Parameter	Living/Dining	Kitchen	Bedroom	Toilet/Bathrooms
Temp. (°C)	20–26	20–26	20–26	20–26
RH (%)	30–60	30–60	30–60	30–60
Airspeed (m/s)	0.05–0.2	0.0–0.2	0.0–0.2	0.0–0.2
Daylight (lux)	120–300	200–500	100–200	50–100

c. Simulation Validation

The outputs from the daylighting and ventilation (Ecotect) simulations were confirmed against field measurement. Any discrepancies were assessed and, where necessary, simulation parameters were modified for enhanced accuracy.

d. Visualization

Data was visualized using tables, line charts, bar charts, and spatial diagrams to facilitate interpretation and communication of key findings, and the tools used for these are Excel and Adobe Illustrator.

3.7.2. Qualitative Data Analysis

a. Transcription and Coding

The residents, planners, and architect interviews and surveyed responses were transcribed and thematically coded in an organized manner. Recurring patterns, perceptions, and issues concerning daylighting and ventilation were identified through thematic analysis.

b. Triangulation

Qualitative findings were cross-referenced with quantitative results and observational data to ensure validity and to provide a holistic understanding of the research questions.

c. Integration of Results

Quantitative and qualitative findings were integrated in the interpretation phase, using joint displays and narrative synthesis to explain how measured environmental conditions align with or differ from occupant experiences and professional perspectives.

3.7.3. Solar Geometry and Sun path Analysis

Adama city lies at the coordinates of about 8.54°N and 39.27°E, situated in the zone near the equator where the solar angles remain high throughout the year. The geographical location leads to high solar radiation during the dry and hot seasons, having a direct impact on the building thermal and daylighting conditions. In Lugo Subcity, and the 105 Sefer neighborhood in particular, solar geometry has an important bearing in defining the orientation and the building design strategy for residential buildings. The Adama sun-path, produced through simulation and modeling software Revit, reflects the path the sun takes throughout the seasons, including major solar altitude and azimuth angles that impact solar exposure onto building facades.

The solar altitude in the solar noon in the hottest summer months (April and May) is about 79° to 80°, and the sun rises about 74° and 76° azimuth in the east-northeast and sets about 284° and 286° azimuth in the west-northwest. The consequence is that buildings along the east-west orientation experience high solar incidence on their south and north facades in the morning and afternoon, whereas those oriented along the north-south direction experience high solar radiation on the east and west facades during the sunrise and sundown hours.

The "105 Sefer" Neighborhood's typical 7×15 m plot orientation aligns predominantly along these cardinal axes, making the sun-path analysis essential for understanding how solar radiation impacts indoor thermal comfort and daylight availability. The sun-path diagram overlaid with the neighborhood's building orientations reveals periods of high solar gain, which can lead to overheating, glare, and increased cooling loads if not properly mitigated.

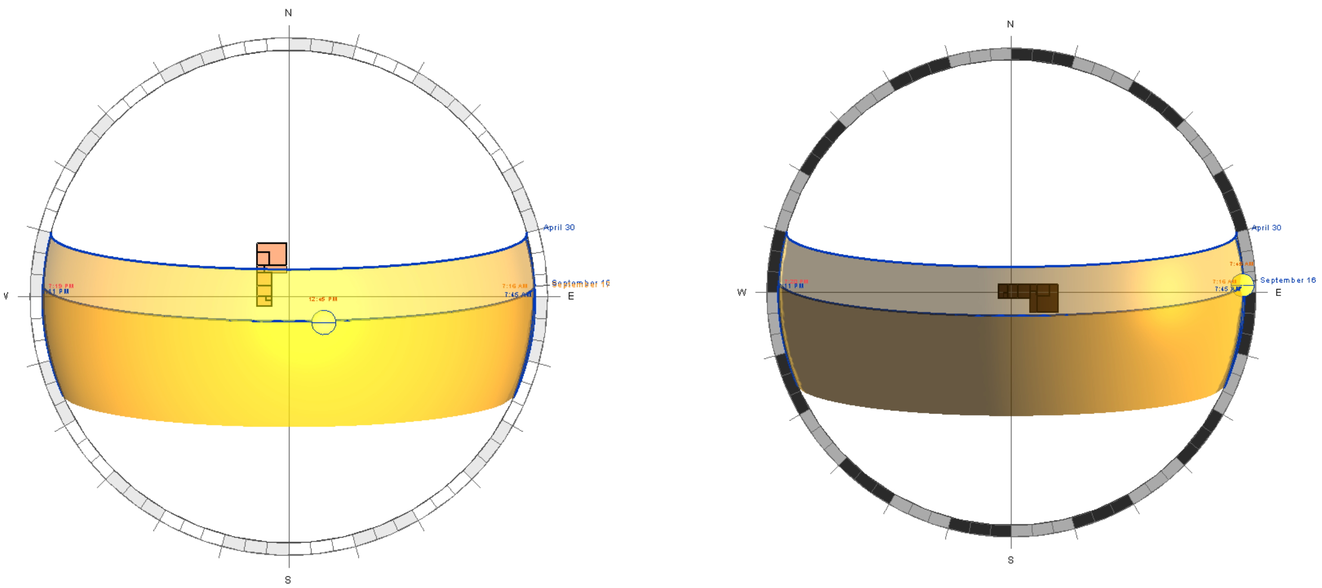

Figure 3.11. *Annual Sun path Diagram along the building with N-S axis, East Facing (Source; Revit)*

3.8. Simulation and Modeling

To complement empirical data, daylighting and ventilation simulations were conducted using a combination of Autodesk Revit 2025, Ecotect 2011. The 3D models of all sampled dwellings were first developed in Autodesk Revit 2025, leveraging its advanced Building Information Modeling (BIM) capabilities to ensure precise representation of architectural geometry, window and door placements, and material properties. Revit 2025's enhanced tools for architectural modeling, including features such as auto-join and lock for adjacent walls, multiple loop mullion profiles for curtain walls, and improved interoperability for exporting models in standard formats gbXML, facilitated efficient and accurate preparation of simulation ready models.

3.9. Ethical Considerations

This investigation was performed in compliance with the ethical guidelines of Adama Science and Technology University. All the participants, such as residents, architects, and urban planners, were given detailed descriptions of the purpose, procedures, and participant rights in the study. Informed written consent was sought prior to participation. Confidentiality and anonymity were assured. Personal identifiers were eliminated from the dataset, and data were kept secure, with access restricted to the research group alone. Participants were informed that they could withdraw, penalty-free, at any point. The investigation entailed negligible risk, as data collection proceeded using non-invasive environmental monitoring and voluntary surveys/interviews.

3.10. Instrumentation and Equipment Details

Table 3.3. *Instruments and Equipment List*

Indicator	Test Instrument	Specific Objective	Specification
Air Speed	**Anemometer**	To measure the speed or volume of air movement of room.	**0~30m/s** temperature measurement: -10 to 50'C Wind power rating:0~12 Sampling rate: 0.5 seconds Overload indication: >**45m/s** Maximum / mean value: **MAX/AVG** Data retention:
Daylight illumination	**Lux Meter**	To measure the level of daylight illuminance) which affects indoor thermal comfort.	Comes with a wide test range of **0.1-200000lx** and **0.01-20000Fc**, this light meter supports auto ranging among **4 ranges**.
Indoor Temperature and Relative humidity	**Thermohygrometer**	To measure the air temperature of the room. Hot-Cold (°C). And relative humidity (water vapor in air) of room. Percentage.	Temperature range: Indoor - **50~+70** - Humidity range: **10%~99% RH**

3.11. Validity and Reliability Measures

The validity of environmental measures was assured through the calibration of instruments before actual deployment and the application of standardized measurement procedures. Multiple, alternating measures were made during different times of day to capture temporal variation and minimize random errors. Qualitative instruments (questionnaires and interview guides) were pilot tested with a small group of participants to ensure clarity and relevance of questions. Two independent coders performed thematic coding of qualitative data to maximize reliability, with disagreements resolved through discussion. Cross-validation and increased overall credibility for the study were achieved using triangulation of data sources-field measures, surveys, interviews, and simulations.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Introduction

The results of environmental measurements and observations made on eight small-plot (≤105 m²) residential buildings (SP01-SP08) in Adama City during the height of the hot season (April–May) are presented and discussed in this chapter. Key rooms (living/dining, master bedroom, and bathroom) are analyzed for temperature, relative humidity, air speed, and daylight illuminance at three local times of day (3:00 AM, 7:00 AM, and 11:00 AM). The results are benchmarked against ASHRAE 55 and IES standards and compared across building orientation (E-W vs. N-S) and configuration (enclosed vs. T-junction). The discussion addresses the main questions of the study and satisfies the research objectives by highlighting spatial, design, and policy challenges.

4.2. Demographic Profile and Response Rate of The Respondents

As we can see from *Figure 4.1* The questionnaire respondents comprised six architects with over three years of experience, two urban planners, and two professionals with dual expertise in architecture and urban planning. This diverse and experienced group provides a robust foundation for understanding the practical and regulatory challenges in small-plot residential design.

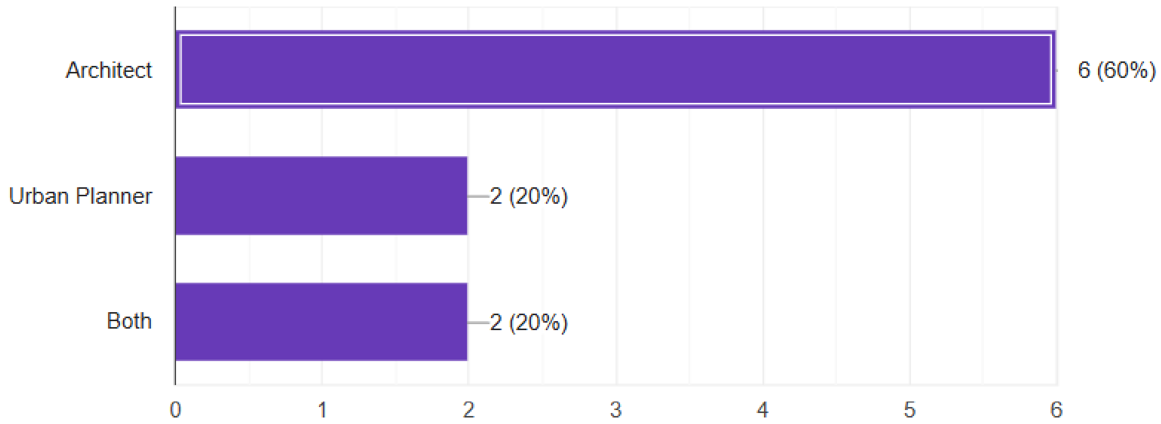

Figure 4.1. *Profile of Respondents (Source: Survey)*

Regarding their direct experience, responses varied widely: while some professionals had designed only a few small-plot projects, others reported involvement in numerous such developments. Notably, one respondent identified solely as an urban planner, indicating the multidisciplinary nature of housing development in Adama. This diversity of experience enriches the dataset and reflects the range of perspectives influencing design decisions.

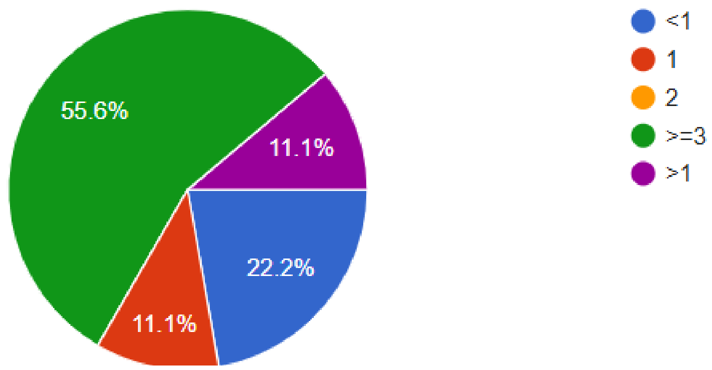

Figure 4.2. *Experience level of the respondents (Source: Survey)*

4.3. Important Limiting Factors in Natural Ventilation and Daylight in Small Urban Residential Plot in Adama

4.3.1. Design Constraints Limiting Natural Ventilation and Daylighting

Most respondents identified narrow plot width (80%) and orientation constraints (80%) as the primary physical limitations affecting their ability to provide effective natural ventilation and daylighting. These constraints are compounded by deep building plans (50%) and local regulations (50%) that restrict setbacks and window placement. The prominence of narrow plot widths aligns with the small-plot typology prevalent in Adama, where limited frontage restricts cross-ventilation and daylight penetration. Orientation constraints further exacerbate these issues by limiting solar access and prevailing wind exposure, particularly in densely built neighborhoods.

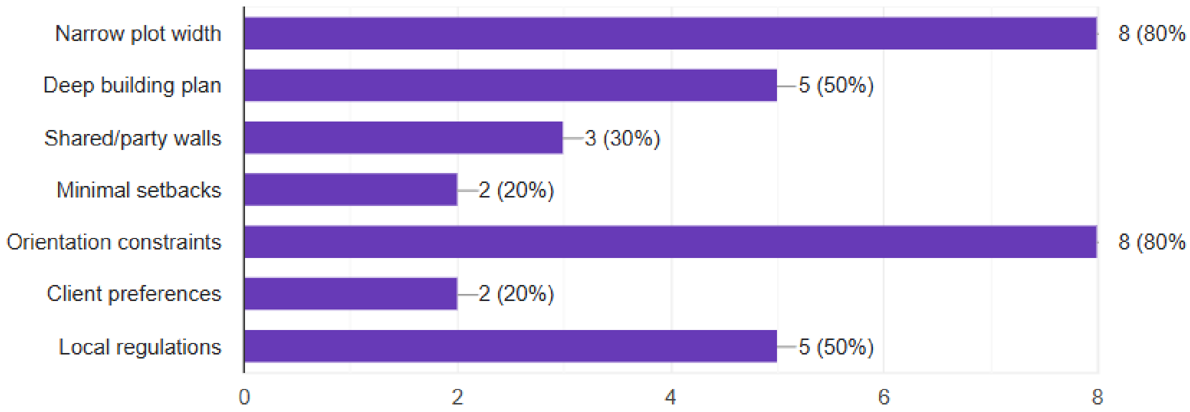

Figure 4.3. *Respondents' response on Design Constraints Limiting Natural Ventilation and Daylighting (Source: Survey)*

Interestingly, client preferences (20%) and shared walls (30%) were less frequently cited, suggesting that while they influence design, spatial and regulatory factors dominate the challenge. The relatively low emphasis on material availability or budget constraints indicates that the core issues are structural and policy-related rather than economic.

4.3.2. Policy Barriers Affecting Indoor Environmental Quality

Respondents highlighted several significant policy-related barriers:

- **Focus on density over quality (66.7%)** and **lack of awareness (66.7%)** were the most cited issues, reflecting a planning paradigm that prioritizes maximizing housing units at the expense of occupant comfort.
- **Lack of clear standards (55.6%)** and **limited enforcement (33.3%)** further hinder efforts to improve IEQ, as ambiguous or unenforced regulations fail to incentivize or mandate good design practices.
- **Economic constraints (33.3%)** were noted but were not the predominant barrier, reinforcing the view that policy and regulatory frameworks are more critical.

These findings resonate with the quantitative results showing suboptimal thermal comfort and daylighting, suggesting that systemic policy reform is necessary to enable better design outcomes.

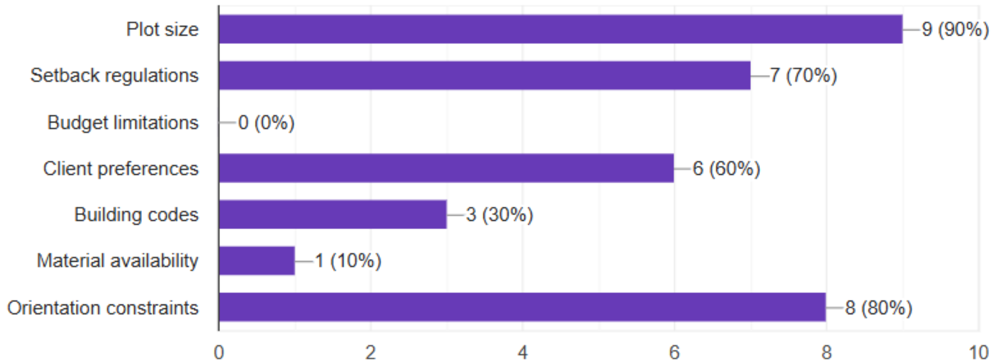

Figure 4.4. *Respondents' response on Policy Barriers Affecting Indoor Environmental Quality (Source: Survey)*

4.3.3. Building Orientation, And Configuration

The sun's path and prevailing wind patterns in Adama City have a profound impact on the indoor environmental quality of small plot (105 m²) urban dwellings. During the hot season, the city experiences high solar angles and intense solar radiation, particularly affecting east-west (E-W) oriented facades. In these small plots, building orientation and configuration become even more critical, as limited space restricts options for optimal window placement and cross-ventilation.

Analysis of the eight sample dwellings reveals that most are aligned with either E-W or N-S axes, but most enclosed plots are E-W oriented. This orientation exposes the longest building facades to direct morning and afternoon sun, resulting in significant heat gain and elevated indoor temperatures-especially in living rooms and bedrooms-during peak hours. For example, E-W enclosed samples (SP01, SP03) recorded the highest temperature peaks (up to 32°C at 7:00 AM), with minimal improvement overnight due to limited night-time ventilation. In contrast, N-S oriented dwellings (SP05–SP08) showed more moderate temperature fluctuations, benefiting from reduced direct solar exposure on the longer facades.

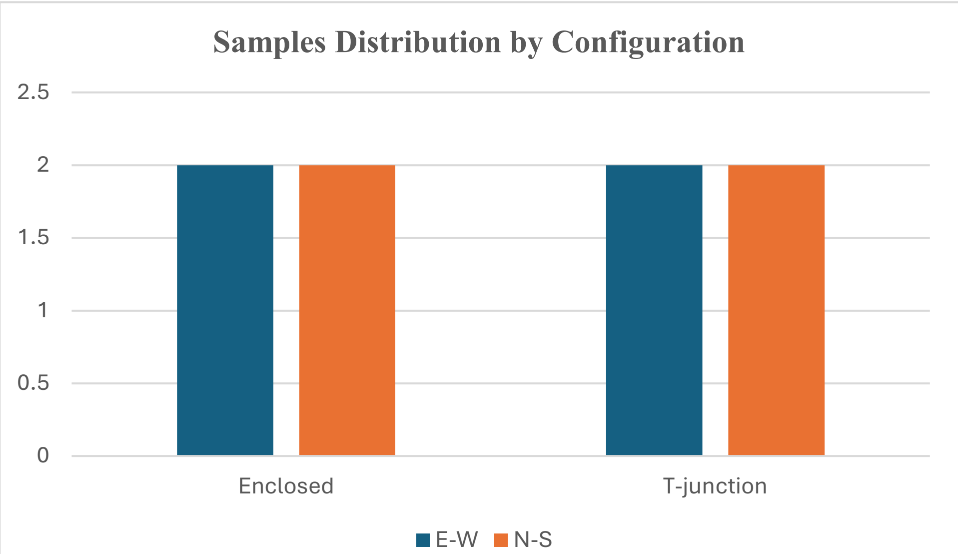

Figure 4.5. *Distribution of Samples by Orientation and Configuration (Source: Survey)*

T-junction configurations, which provide at least one open side to a street or open space, consistently performed better in both daylighting and ventilation compared to fully enclosed plots. T-junction samples (SP02, SP04, SP06, SP08) achieved higher illuminance levels in living areas and slightly lower peak temperatures, indicating that even modest access to wind and daylight can partially mitigate the limitations imposed by small plot size. However, these improvements are not sufficient to meet recommended comfort standards, especially in private or deep-plan spaces such as bedrooms and bathrooms.

4.3.4. Indoor Temperature

Indoor temperature is a critical indicator of thermal comfort in small-plot urban dwellings in Adama. Field measurements from eight sampled houses showed that peak indoor temperatures were highest in east-west (E-W) oriented, enclosed plots, with living and master bedroom temperatures reaching 30–32°C at 7:00 AM, exceeding the ASHRAE 55 comfort threshold of 20°C to 26°C1. These elevated temperatures are primarily due to prolonged solar exposure on the long E-W façades and limited cross-ventilation caused by plot constraints.

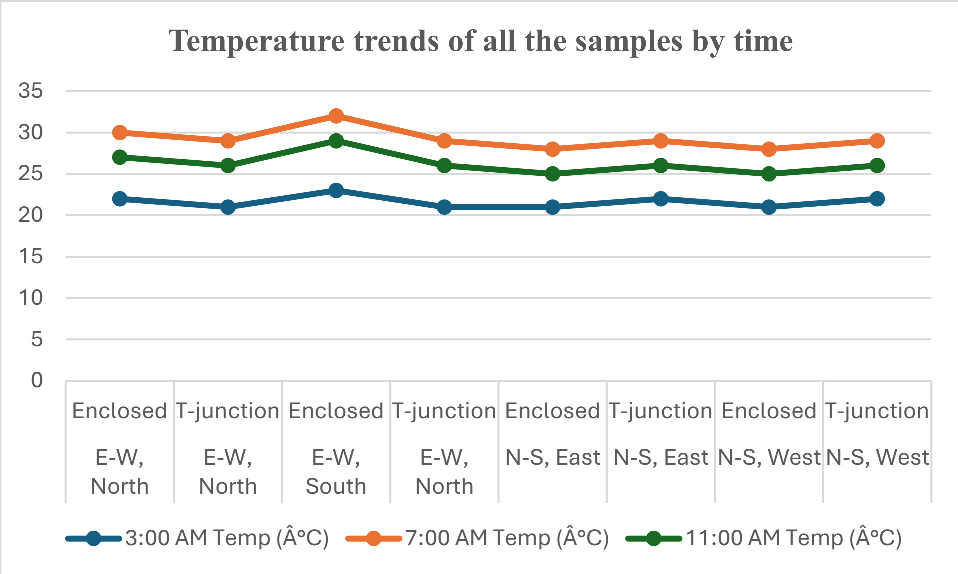

Figure 4.6. *Temperature trends of all the samples by time (Source: Author)*

In contrast, north-south (N-S) oriented dwellings, especially those with T-junction configurations, exhibited more moderate peak temperatures around 28–29°C in living rooms and below 28°C in bedrooms. Despite these improvements, all homes retained heat overnight, with temperatures at 3:00 AM rarely falling below 20°C, indicating inadequate nighttime cooling likely due to high thermal mass and insufficient ventilation.

Notwithstanding these variations, all samples showed a notable retention of heat over the course of the night, with temperatures at 3:00 AM hardly ever falling below 20°C. This suggests inadequate cooling at night, most likely because of both high thermal mass and inadequate ventilation. The living rooms and master bedrooms in E-W enclosed plots were the most troublesome areas; they failed to cool down sufficiently during the night and quickly became overheated during the morning peak.

4.3.5. Daylight Illuminance

Daylight illuminance measurements taken in living rooms, dining areas, master bedrooms, and bathrooms at three key times (3:00 AM, 7:00 AM, and 11:00 AM) reveal significant challenges

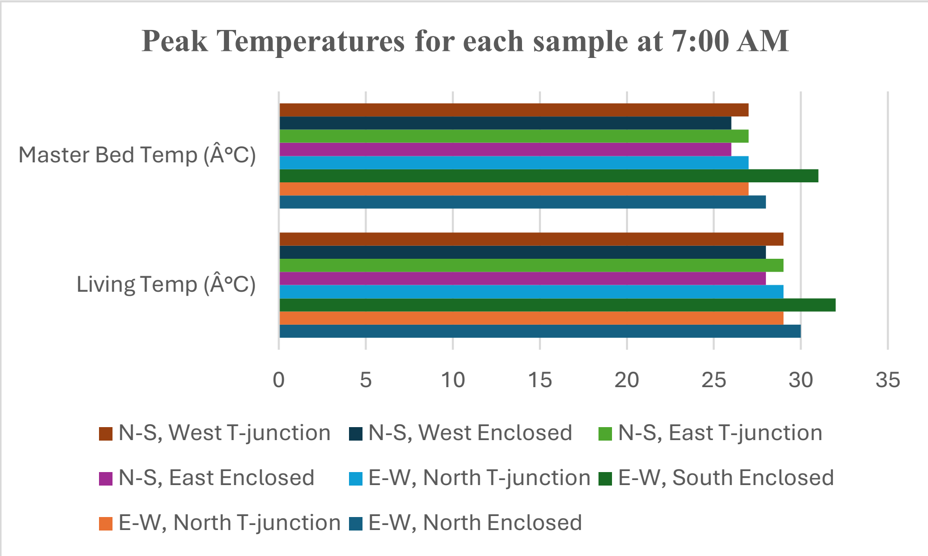

Figure 4.7. *Comparison of peak (7:00 AM) temperatures by sample, room, orientation, and configuration. (Source: Author)*

in achieving adequate daylighting in Adama's small-plot (105 m²) urban dwellings. Across all samples, spaces with limited façade exposure and deep floor plans, particularly master bedrooms and bathrooms, consistently recorded very low illuminance levels—often below 10 lux even during peak daylight hours.

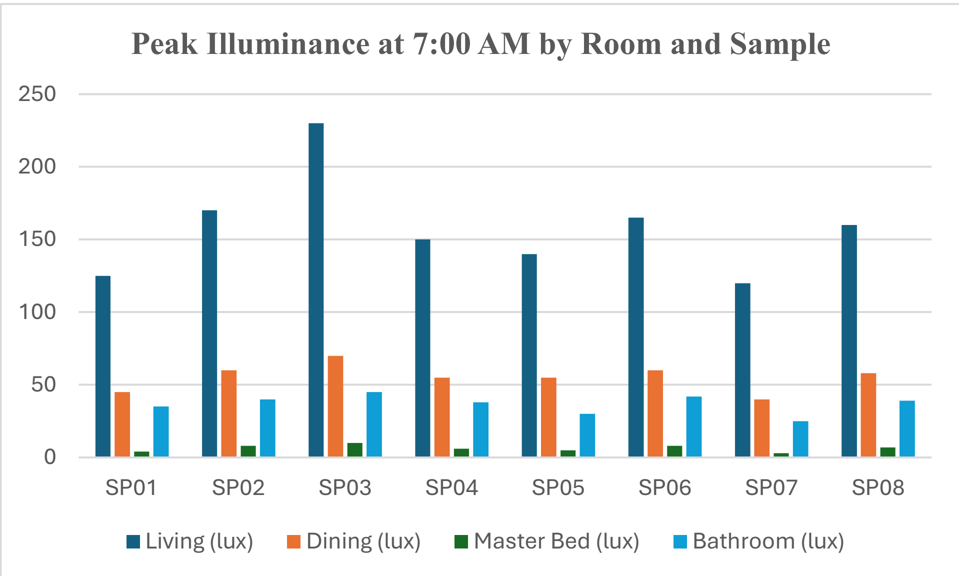

Figure 4.8. *Measured Peak Illuminance at 7:00 AM by Room and Sample (Source: Author)*

Living rooms and dining areas generally performed better, especially in dwellings with T-junction configurations, but still rarely exceeded 170 lux at 7:00 AM, falling well short of the Illuminating Engineering Society (IES) recommended minimum of 300 lux for living spaces. Enclosed east-west (E-W) oriented plots (e.g., SP01, SP03) showed the poorest daylight performance, with living room illuminance peaking at only 125–130 lux and bedrooms as low as 2–4 lux. In contrast, T-junction plots (SP02, SP04, SP06, SP08) consistently outperformed enclosed layouts, with living room peaks between 150 and 170 lux and modest improvements in dining areas. However, even in these better-performing configurations, bedrooms and bathrooms remained severely underlit, highlighting persistent daylight penetration challenges in small, dense plots.

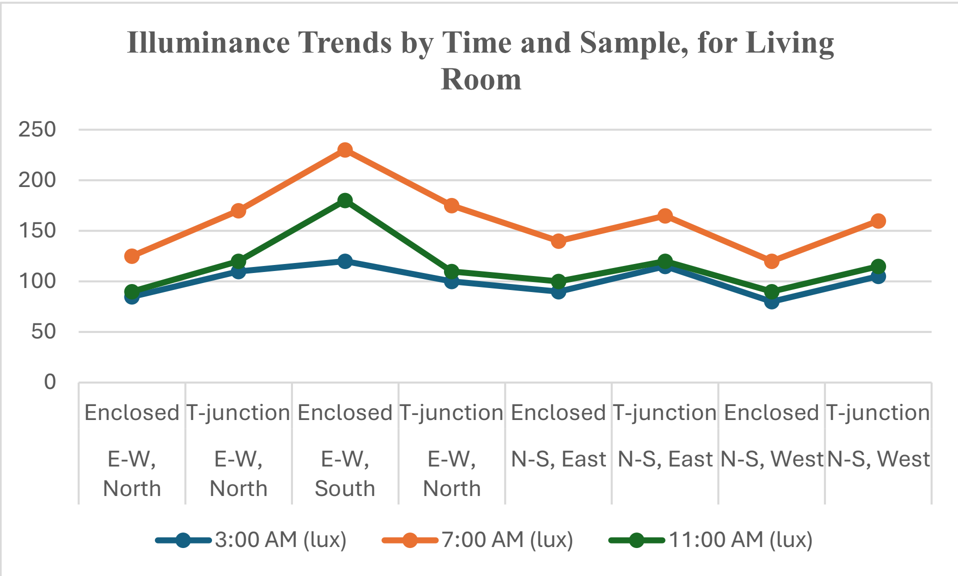

Figure 4.9. *Illuminance Trends by Time and Sample, Living Room (Source: Author)*

These results demonstrate the critical impact of both building orientation and configuration on daylight availability. E-W orientations combined with enclosed site conditions limit side lighting opportunities and create deep, poorly lit interiors. T-junction configurations, by providing at least one open façade, improve daylight access in public rooms like living areas but do not fully resolve daylight deficiencies in private or interior rooms.

Notably, none of the sampled rooms consistently met the IES daylight standards at any time of day, underscoring the inadequacy of current designs to provide sufficient natural light. The spatial constraints inherent in 105 m² plots, combined with suboptimal window placement and orientation, severely restrict daylight penetration. While T-junction configurations offer some improvement, even their best-performing rooms fall short of international benchmarks, emphasizing the need for design strategies that address these fundamental limitations.

4.3.6. Relative Humidity

Relative humidity (RH) measurements taken in eight small-plot (105 m²) dwellings at critical times (3:00 AM, 7:00 AM, and 11:00 AM) across multiple room types indicate that RH generally remains within the ASHRAE 55 recommended comfort range of 30–60%. Early morning RH values ranged between 42–46%, midday values dropped to 32–41%, and late morning values stabilized around 38–44%. Unlike temperature and daylight, RH showed less pronounced variation across different building orientations and configurations.

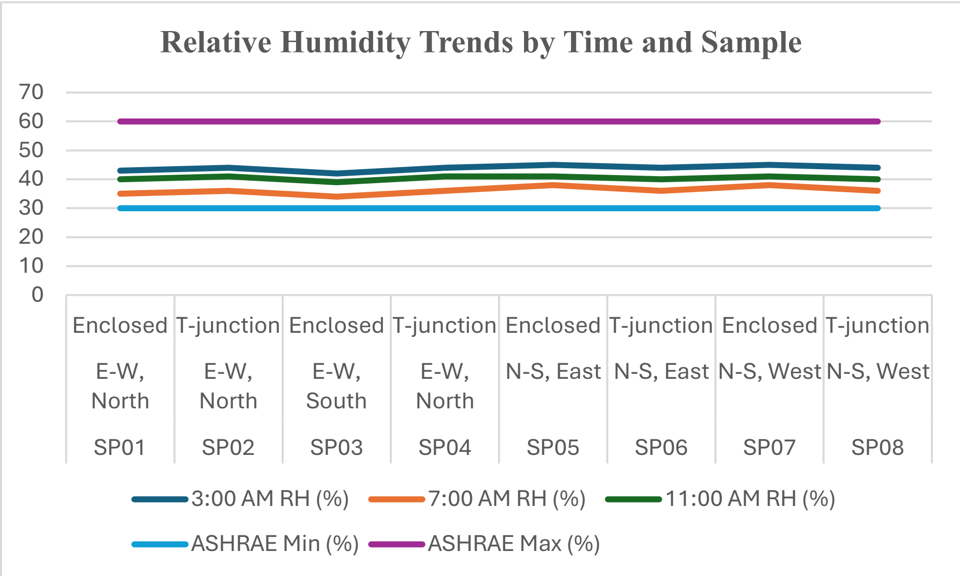

Figure 4.10. *Relative Humidity Trends by Time and Sample (Source: Author)*

However, subtle differences were observed: east-west (E-W) oriented samples tended to have slightly lower RH during peak temperature hours (7:00 AM), with living room values as low as 34–36%, compared to north-south (N-S) oriented samples maintaining 36–38%. This inverse relationship between temperature and RH reflects the physical property that warmer air holds more moisture, lowering relative humidity at higher temperatures.

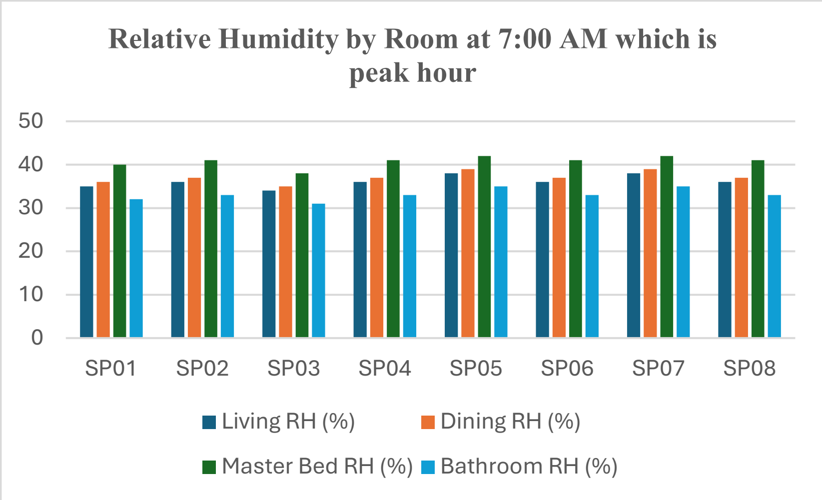

Figure 4.11. *Relative Humidity by Room at 7:00 AM which is peak hour (Source: Author)*

While RH levels alone do not present a critical limiting factor in Adama's small-plot housing, their interaction with elevated indoor temperatures and limited airflow especially in enclosed configurations can exacerbate thermal discomfort and indoor air quality issues. The data suggests that insufficient natural ventilation, common in dense, narrow plots, restricts air exchange and contributes to less stable humidity conditions throughout the day. Therefore, improving ventilation strategies is essential to maintaining balanced indoor humidity levels and enhancing overall thermal comfort.

4.3.7. Air Speed

Airspeed measurements in living rooms, dining areas, master bedrooms, and bathrooms of eight small-plot (105 m²) dwellings at 3:00 AM, 7:00 AM, and 11:00 AM indicate significant limitations in natural ventilation effectiveness. Across all samples, recorded airspeeds were consistently below the ASHRAE Standard 55 recommended minimum of 0.2 m/s, which is necessary to enhance thermal comfort in hot climates by promoting convective and evaporative

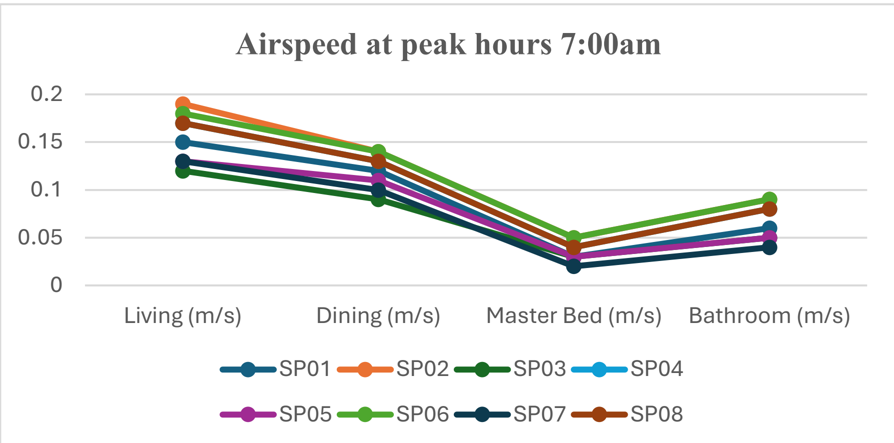

Figure 4.12. *Measure air speed for every room for every sample, and peak hour(7:00am) (Source: survey)*

heat loss.

T-junction configured homes (SP02, SP04, SP06, SP08) showed slightly higher maximum airspeeds—up to 0.18–0.19 m/s at 7:00 AM—compared to enclosed plots (SP01, SP03, SP05, SP07), which mostly ranged between 0.12–0.15 m/s. Although T-junction layouts provide somewhat better access to prevailing winds, the improvement remains insufficient to meet comfort standards. Differences between east-west and north-south orientations were minimal, though north-south T-junction homes (SP06, SP08) exhibited marginally better ventilation, likely due to alignment with local wind patterns.

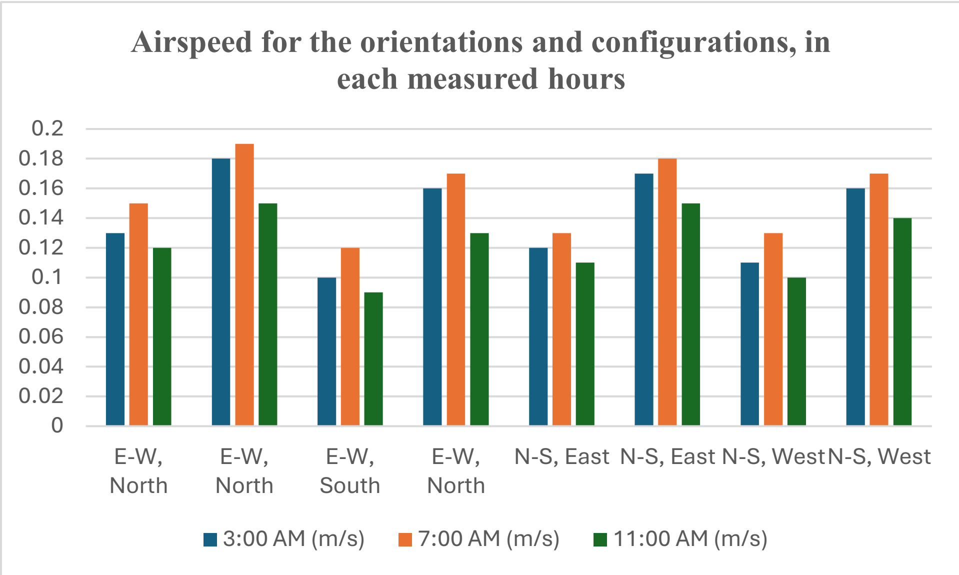

Figure 4.13. *Airspeed for the orientations and configurations, in each measured hour (3:00am, 7:00am, 11:00am) (Source: Measurement)*

These findings highlight the critical constraints posed by compact plot sizes, high building density, and limited façade exposure, which collectively restrict opportunities for effective cross-ventilation. Bedrooms and bathrooms where occupants spend considerable time and are vulnerable to thermal discomfort showed particularly low airspeeds, raising concerns about occupant well-being.

4.4. The Effectiveness of the Current Architectural Designs and Building Practices in Overcoming the Constraints Identified

4.4.1. Building Orientation and Configuration

Current architectural practices in the study area predominantly feature two main building orientations east-west (E-W) and north-south (N-S) and configurations including enclosed plots and T-junction layouts. The data show that while N-S oriented buildings with T-junction configurations perform better in terms of temperature moderation and airflow, the overall effectiveness remains limited. T-junction designs provide improved access to prevailing winds and daylight through multiple façades, resulting in slightly lower peak indoor temperatures (27–29°C compared to 30–32°C in E-W enclosed plots) and marginally higher airspeeds (up to 0.19 m/s). However, these improvements fall short of meeting ASHRAE 55 thermal comfort and IES daylighting standards, indicating that current orientation and configuration choices only partially address the constraints.

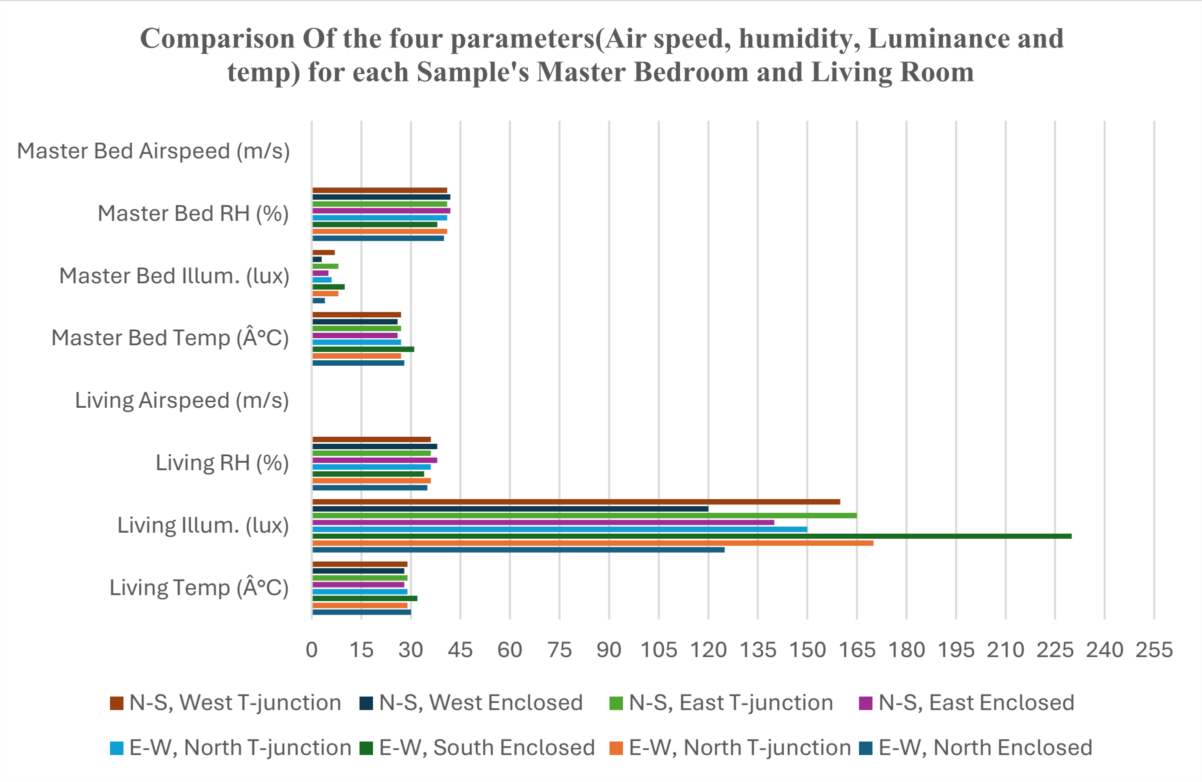

Figure 4.14. *Comparison Of the four parameters (Air speed, humidity, Luminance and temp) for each Sample's Master Bedroom and Living Room*

Statistical comparison using the mean and the range for all the samples verifies these tendencies. For instance, the E-W enclosed samples' mean living room peak temperature was 31°C, while in the N-S T-junction samples, it was 28.5°C. The living room peak illuminance averaged 127 lux for E-W enclosed, 168 lux for the T-junction, and merely 6 lux for the master bedrooms in all the samples. Air speed averaged 0.13 m/s in the enclosed and 0.18 m/s in the T-junction, with no room in any sample falling below the ASHRAE 55 minimum.

4.4.2. Window Placement and Size

The study reveals that window openings in most dwellings are primarily located on the front façade, often limited in size due to plot constraints and shared party walls. This single-sided ventilation strategy restricts cross-ventilation potential and daylight penetration, particularly in deeper rooms such as bedrooms and bathrooms. Despite some attempts to incorporate larger or additional windows in T-junction configurations, the measurements indicate that air speed rarely reaches the recommended 0.2 m/s threshold, and daylight illuminance remains below the 300-lux standard in most rooms. These findings suggest that current window design practices inadequately overcome the spatial limitations inherent in small plots.

The simulation results clearly demonstrate the ineffectiveness of the current openings in the N-S enclosed house layout providing adequate daylight. The daylight analysis shows that sunlight primarily illuminates only the areas immediately adjacent to windows and exterior walls, with brightness sharply decreasing deeper into the living spaces, dining areas, bedrooms, and especially back rooms. Uniform sky factor mapping reinforces this, revealing that only a narrow strip near the windows achieves values above 10%, while most of the interior barely reaches 2%. According to lighting guidelines, living spaces should receive at least 300 lux, yet most rooms fall well below this threshold.

This limited daylight penetration is consistent with resident reports describing their homes as dim and reliant on artificial lighting during the day. The combination of small window sizes, deep room layouts, and the enclosed plan restricts natural light access, underscoring that while the N-S orientation may modestly improve thermal conditions, it does not resolve the fundamental daylighting deficiencies caused by inadequate openings. These findings highlight that both orientation and spatial layout must be addressed together to create comfortable, energy-efficient homes.

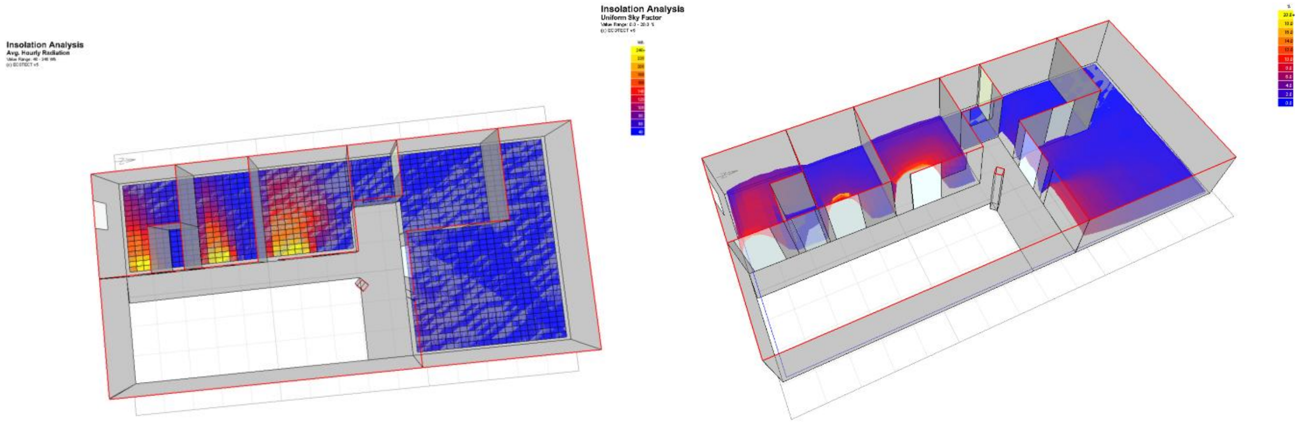

Figure 4.15. *Average hourly radiation analysis simulation result N-S enclosed (Source: Ecotect)*

4.4.3. Use of Passive Ventilation Features

Passive ventilation features such as ventilation stacks, solar chimneys, or operable skylights are largely absent or minimally integrated in the sampled dwellings. The lack of vertical ventilation elements limits the exploitation of the stack effect, which could otherwise enhance airflow in deep interior spaces where cross-ventilation is impractical. Consequently, indoor air movement remains insufficient, especially in bedrooms and bathrooms, contributing to thermal discomfort and poor indoor air quality. The absence of such features highlights a gap in current building practices that could be addressed to improve natural ventilation effectiveness.

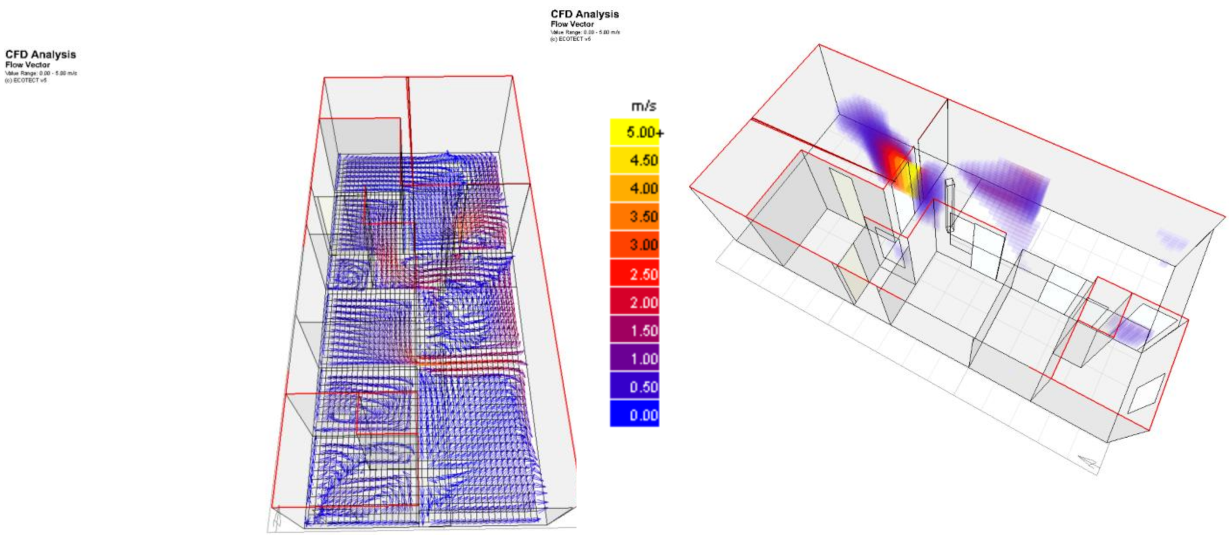

Figure 4.16. *CFD Result for N-S Oriented and Enclosed building of the sample (Source: Ecotect)*

The CFD results shown in Figure 4.16 clearly indicate that the current openings and ventilation strategies in the N-S enclosed dwelling are largely ineffective in promoting adequate air movement. Airflow vectors are mostly concentrated near the openings and corridors, with minimal penetration into the deeper living spaces and bedrooms. The highest air velocities, represented by yellow and red zones, occur only at entry points but rapidly diminish to blue and purple areas, indicating airspeeds well below 0.5 m/s. This aligns with the measured data, where airspeeds in living rooms and bedrooms rarely exceeded 0.15 m/s and frequently fell below the ASHRAE 55 recommended minimum of 0.2 m/s for thermal comfort. These findings demonstrate that the existing ventilation openings and design features fail to ensure sufficient natural ventilation throughout the interior spaces, highlighting the need for improved strategies to enhance airflow in such layouts.

4.4.4. Occupants' Feedback and Behavioral Adaptations

Interviews with 16 residents (two occupants from each of the eight sampled households) provided valuable insights into the effectiveness of current building orientations and designs in delivering thermal comfort, analyzed using the ASHRAE 55 thermal preference scale. This scale ranges from +3 (Hot) to -3 (Cold), with 0 indicating neutral thermal perception.

Table 4.1. *ASHREA 55 Thermal Preference Scale (Humphreys, 2007)-All Respondents (n=16)*

PMV Value	**+3 (Hot)**	**+2 (Warm)**	**+1 (Slightly warm)**	**0 (Neutral)**	**-1 (Slightly cool)**	**-2 (Cool)**	**-3 (Cold)**
3:00 AM	**0** (0%)	**1** (6.3%)	**5** (31.2%)	**8** (50.0%)	**2** (12.5%)	**0** (0%)	**0** (0%)
7:00 AM	**7** (43.8%)	**5** (31.2%)	**3** (18.7%)	**1** (6.3%)	**0** (0%)	**0** (0%)	**0** (0%)
11:00 AM	**5** (31.2%)	**6** (37.5%)	3 (18.7%)	**2** (12.5%)	**0** (0%)	**0** (0%)	**0** (0%)

Residents reported the most favorable thermal conditions during the early morning (3:00 AM), when 50% felt "neutral" and 31.2% felt only "slightly warm," consistent with measured indoor temperatures of 19–23°C. However, at the peak heat period (7:00 AM), thermal discomfort was widespread: 43.8% of respondents felt "hot" and 31.2% felt "warm," correlating with indoor temperatures ranging from 28–32°C. By 11:00 AM, thermal perceptions improved slightly, though 68.7% still reported feeling "hot" or "warm."

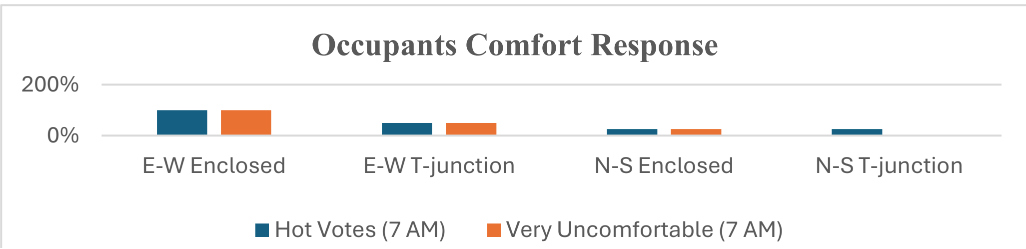

Figure 4.17. *Occupants Comfort Response*

__Table 4.2.__ ASHRAE 55 Thermal Preference by Building Orientation and Configuration (7:00AM, Peak Hour) (Source: Survey)

Configuration	**Orientation**	**Hot (+3)**	**Warm (+2)**	**Slightly warm (+1)**	**Neutral (0)**	**Slightly cool (-1)**	**Cool (-2)**	**Cold (-3)**
Enclosed	**E-W**	4 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
T-junction	**E-W**	2 (50%)	2 (50%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Enclosed	**N-S**	1 (25%)	2 (50%)	1 (25%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
T-junction	**N-S**	0 (0%)	1 (25%)	2 (50%)	1 (25%)	0 (0%)	0 (0%)	0 (0%)

The data clearly indicates that building orientation and design significantly influence occupant comfort. At 7:00 AM, all residents in east-west (E-W), enclosed homes reported feeling “hot,” aligning with the highest recorded temperatures of 30–32°C in these dwellings. Homes with an E-W T-junction design performed somewhat better; half of the residents described their thermal sensation as “warm” rather than “hot,” suggesting that increased openness and ventilation help but do not fully resolve overheating issues.

North-south (N-S) oriented homes showed improved comfort levels. Only 25% of residents in enclosed N-S homes felt “hot” during peak heat, and none in N-S T-junction homes reported feeling “hot.” In fact, some occupants in N-S T-junction homes reported “neutral” thermal comfort at the hottest time, highlighting the positive impact of orientation combined with more open layouts on indoor thermal conditions.

__Table 4.3.__ Thermal Sensation Votes by Orientation and Configuration (7:00AM) (Source: Survey)

Orientation	**Configuration**	**Very Uncomfortable (+3)**	**Uncomfortable (+2)**	**Slightly Uncomfortable (+1)**	**Neutral (0)**
E-W	**Enclosed**	4 (100%)	0 (0%)	0 (0%)	0 (0%)
E-W	**T-junction**	2 (50%)	2 (50%)	0 (0%)	0 (0%)
N-S	**Enclosed**	1 (25%)	2 (50%)	1 (25%)	0 (0%)
N-S	**T-junction**	0 (0%)	1 (25%)	2 (50%)	1 (25%)

These occupant responses, supported by the Sensation Scale findings, reinforce the conclusion that current architectural and ventilation strategies provide limited relief from thermal discomfort, particularly in E-W enclosed homes. The N-S T-junction configuration emerges as the most effective existing strategy, offering comparatively better thermal comfort during peak heat periods. Nonetheless, the pervasive reports of discomfort across all building types underscore the need for improved design interventions to enhance natural ventilation and reduce indoor overheating in Adama's small-plot urban dwellings.

4.5. Context Base Strategies to Improve Daylight and Natural Ventilation in Adama

The study's findings highlight several situation-specific tactics that can be used to directly address the daylighting and natural ventilation issues that have been noted in Adama's small-plot urban homes. These tactics were created in direct reaction to the measured environmental data, simulation results, and resident comments covered in previous parts; they are not general suggestions. North-south (N-S) oriented homes with T-junction layouts typically beat east-west (E-W) enclosed homes in terms of daylighting and thermal comfort, according to field measurements and simulations. For instance, although both stayed below international norms, N-S T-junction dwellings displayed better sunshine levels and lower peak inside temperatures. This suggests that using T-junction or comparable multi-facade layouts and orienting new construction along the N-S axis can assist reduce overheating and enhance ventilation and daylighting. The data did, however, also reveal that even these arrangements had drawbacks, particularly in inner and private spaces, underscoring the necessity for more design improvements.

Single-sided front façade apertures are insufficient for efficient ventilation and daylighting, according to the examination of existing strategies (window placement). Deeper rooms had a dramatic decline in air speed and illumination, especially in bathrooms and bedrooms. To improve cross-ventilation and daylight penetration, particularly in rooms that are distant from the outer walls, it is necessary to increase and reposition apertures, such as by installing windows on numerous façades or by incorporating high-level openings and skylights.

Measured airspeeds and simulation results showed that vertical ventilation techniques are crucial. Stack ventilation, solar chimneys, or operable skylights could greatly improve air movement, especially in dense, single-story layouts where cross-ventilation is constrained by plot constraints, as evidenced by the consistently low airspeeds and insufficient nighttime cooling in all sampled homes, regardless of orientation.

Further evidence that lowering room depth and avoiding internal barriers can improve the efficacy of any ventilation or daylighting strategy comes from the measured and simulated results, which show a sharp decrease in both daylight and airflow with increasing room depth. More natural light and air may enter interior areas thanks to shallow room layouts and open-plan designs, which directly address the study's findings.

Furthermore, a comparison of enclosed and T-junction layouts revealed that higher ventilation and daylighting efficiency was linked to greater façade exposure, which was attained in T-junction designs. Despite the limitations of small plot sizes, this research supports the potential of shared courtyards or plot consolidation as urban design techniques to enhance façade area and enhance environmental quality.

CONCLUSION

This study identified the key limiting factors affecting natural ventilation and daylight penetration in small-plot urban dwellings in Adama. The narrow plot widths, shared party walls, and restrictive building orientations significantly reduce opportunities for airflow and sunlight access to interior rooms. Deep floor plans combined with local zoning regulations on setbacks and window placement further constrain design flexibility. These physical and regulatory limitations result in poor indoor environmental quality, as evidenced by low airflow velocities and inadequate daylight levels measured in the sampled homes.

The evaluation of current architectural designs and building practices, supported by field data, showed that reliance on front façade openings alone is inadequate. East-west oriented, enclosed homes exhibited the poorest thermal and lighting conditions, while north-south oriented homes with T-junction configurations performed somewhat better, with temperatures ranging from 27°C to 29°C and marginally improved airflow and daylighting. However, even these better-performing layouts failed to provide sufficient ventilation and daylight in deeper rooms. Resident and expert feedback further highlighted ongoing discomfort related to heat and insufficient natural light, underscoring the limitations of existing design approaches.

The empirical evidence indicates that current designs do not meet the requirements for comfortable indoor environments, necessitating the development of targeted strategies. Recommended interventions include orienting buildings along the north-south axis to reduce solar heat gain, incorporating stack ventilation systems such as vertical shafts and operable skylights to enhance airflow, and integrating skylights to improve daylight penetration and air exhaust in interior spaces. Additionally, promoting alternative plot layouts, encouraging vertical development, and revising zoning policies to allow flexible setbacks and incentives for passive design adoption are essential for overcoming the constraints identified through measurements and observations.

RECOMMENDATION

Considering the study's findings and considering Adama's climatic, socio-economic, and urban development context, the following practical recommendations are proposed for architects, city administrators, and urban planners. These strategies aim to improve natural ventilation and daylighting in small-plot urban dwellings while being feasible and applicable within existing local constraints.

For Architects and Builders

- Prioritize site orientation: Design buildings predominantly along the north-south axis to minimize solar heat gain on façades and maximize daylight penetration, which is crucial in Adama's hot, dry climate.
- Incorporate stack ventilation: Utilize vertical ventilation shafts or stacks to enhance airflow by allowing warm air to escape through high openings (roof vents or skylights) and drawing cooler air in through lower openings, especially in deep interior spaces where cross-ventilation is limited.
- Use operable skylights: Integrate skylights that provide daylight and act as exhaust points for warm air, improving indoor comfort without compromising privacy. Fresh air skylights are particularly effective in kitchens, bathrooms, and interior rooms with restricted ventilation.
- Combine passive strategies: Given the constraints of small plots and shared walls, architects should creatively combine multiple passive design elements to optimize indoor environmental quality.
- Promote vertical development: Where feasible, design multi-story (vertical) dwellings to increase living space without further reducing plot sizes, allowing better façade exposure for ventilation and daylighting.

For City Administration

- Revise setback and building codes: Implement flexible setback regulations that encourage building designs with increased façade exposure and vertical ventilation features such as stacks and skylights.
- Facilitate plot merging: Encourage and support the merging of adjacent small plots to create larger building footprints, improving opportunities for natural ventilation and daylighting while enabling vertical development.
- Provide incentives: Offer tax benefits, technical assistance, or expedited approvals for projects that incorporate passive ventilation and daylighting strategies proven to

enhance occupant comfort and reduce energy consumption.

- Raise awareness: Conduct educational campaigns targeting developers, builders, and residents about the benefits and feasibility of passive design strategies in Adama's urban context.

For Urban Planners

- Promote alternative plot layouts: Advocate for urban planning approaches that increase building perimeter exposure, allowing more windows and ventilation openings despite high density.
- Balance density with livability: Develop planning guidelines that reconcile the need for urban densification with adequate provision of daylight and natural ventilation to ensure sustainable, healthy living environments.
- Integrate passive design in zoning: Embed requirements for passive ventilation and daylighting features into zoning and urban development policies, ensuring new developments adhere to climate-responsive design principles.
- Support vertical growth and plot consolidation: Encourage vertical development and the merging of small plots as strategies to optimize land use while improving indoor environmental quality.

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APPENDIX-I

Questionnaire for Architects and Urban Planners "*Challenges of Providing Natural Ventilation and Daylighting in Small Plot Urban Dwellings in Ethiopian Cities: The Case of Adama*"

My name is Yohannis Alemayehu , and I am conducting my M.Sc. thesis research in Environmental Architecture at Adama Science and Technology University. My thesis is entitled **"Challenges of Providing Natural Ventilation and Daylighting in Small Plot Urban Dwellings in Ethiopian Cities: The Case of Adama."**

The aim of this research is to identify the key challenges and opportunities in achieving effective natural ventilation and daylighting in small plot urban dwellings, with a focus on the context of Adama city. Your professional insights and experiences as an architect/urban planner are invaluable for understanding current practices, constraints, and potential solutions in the design and planning of these residential environments.

I kindly request your participation in this survey. The information you provide will be used solely for academic purposes and will remain confidential. Your feedback will contribute significantly to the development of practical recommendations for improving indoor environmental quality and promoting sustainable urban living in Ethiopian cities.

Thank you very much for your time and support.

5. How do you prioritize natural ventilation and daylighting in your design process?

- ○ Always a priority
- ○ Often considered
- ○ Sometimes considered
- ○ Rarely considered
- ○ Not considered

6. Which passive design strategies do you commonly use? (Select all that apply)

- ☐ Building orientation
- ☐ Courtyards
- ☐ Cross-ventilation
- ☐ Light wells
- ☐ Shading devices
- ☐ Window sizing/placement
- ☐ Other: ______

7. What materials do you typically specify for windows and walls in these projects?

Your answer ______

8. Have you used simulation tools (e.g., DesignBuilder, Ecotect, Revit) to assess your designs for daylighting or ventilation?

- ☐ Yes (please specify):
- ☐ No
- ☐ Other: ______

A. Background Information

1. Are you an Architect or Urban Planner?

- ☐ Architect
- ☐ Urban Planner
- ☐ Both

2. Years of professional experience:

- ○ <1
- ○ 1
- ○ 2
- ○ >=3

3. Number of small plot (≤105m²) residential projects designed in Adama:

Your answer ______

B. Design Practice and Constraints

4. What are the main constraints you face when designing for small plots in Adama?
(Select all that apply)

- ☐ Plot size
- ☐ Setback regulations
- ☐ Budget limitations
- ☐ Client preferences
- ☐ Building codes
- ☐ Material availability
- ☐ Orientation constraints
- ☐ Other: ______

C. Room-Specific Challenges

9. In your experience, which activity rooms are the most difficult to provide with adequate natural ventilation and daylighting in 105m² small plot dwellings? (Select all that apply)

- ☐ Living Room
- ☐ Master Bedroom
- ☐ Other Bedrooms
- ☐ Kitchen
- ☐ Bathroom
- ☐ Dining Area
- ☐ Other: ______

10. Please briefly explain the main reasons for the above difficulties:

Your answer ______

11. What plot or building layout features most limit your ability to provide effective natural ventilation and daylighting? (Select all that apply)

- ☐ Narrow plot width
- ☐ Deep building plan
- ☐ Shared/party walls
- ☐ Minimal setbacks
- ☐ Orientation constraints
- ☐ Client preferences
- ☐ Local regulations
- ☐ Other: ______

12. What are the most significant policy barriers to improving indoor environmental quality in small plot dwellings? (Select all that apply)

- ☐ Lack of clear standards
- ☐ Focus on density over quality
- ☐ Limited enforcement
- ☐ Economic constraints
- ☐ Lack of awareness
- ☐ Other: ____

13. When you cannot provide adequate natural ventilation or daylighting through passive means, what solutions or compensations do you typically implement?

- ☐ Mechanical ventilation
- ☐ Artificial lighting
- ☐ Larger windows (where possible)
- ☐ Skylights/light wells
- ☐ None/Not possible
- ☐ Other: ____

14. Are there any activity rooms where you feel the current building code or urban regulations make it impossible to meet minimum ventilation or daylight standards?

- ☐ Yes (please specify which rooms and why):
- ☐ No
- ☐ Other: ____

15. Have you observed or received feedback on any health or comfort issues from residents that you believe are directly related to poor ventilation or daylighting in specific rooms?

- ○ Yes (please describe)
- ○ No
- ○ Other: ____

D. Effectiveness, Feedback, and Recommendations

16. What are the most common complaints or feedback you receive from residents regarding indoor environmental quality?

Your answer

17. In your opinion, what are the most effective ways to improve natural ventilation and daylighting in small plot dwellings in Adama?

Your answer

18. What recommendations would you make for future building codes or urban planning policies to improve indoor environmental quality?

Your answer

Submit   Page 1 of 1   Clear form

Link of the google form: **https://forms.gle/G1a6X4LU7yCXXmdj6**

APPENDIX-II

1. **Daylight Illuminance**

Site name: **Lugo Sub city** **Axis: N-S**

Building placement: N-S, E-facing

Table 1. *Measured Dylight Illuminance of Building N-S, E-facing*

Daylight Illuminance (Lux)						
Date	**Time**	**Living room/ Dining**	**M. Bedroom**	**Toilet**	**Kitchen**	**C. B.Room**
29/04/25	3:00AM	98	7	15	102	125
	7:00AM	147	25	27	135	140
	11:00AM	109	15	19	76	86
30/04/25	3:00AM	102	10	16	110	101
	7:00AM	145	37	30	123	120
	11:00AM	115	16	19	105	98
01/05/25	3:00AM	115	14	18	121	135
	7:00AM	160	27	32	152	146
	11:00AM	105	12	17	111	116

2. **Air speed**

Site name: Lugo Sub city **Axis: N-S**

Building placement: N-S, E-facing

Table 2. *Measured Air Speed of Building N-S, E-facing*

Air Speed (m/s)						
Date	**Time**	**Living room/ Dining**	**M. Bedroom**	**Toilet**	**Kitchen**	**C.B.Room**
29/04/25	3:00AM	0.13	0.04	0.02	0.10	0.06
	7:00AM	0.15	0.05	0.03	0.13	0.08
	11:00AM	0.12	0.04	0.02	0.09	0.06
30/04/25	3:00AM	0.12	0.04	0.02	0.09	0.06
	7:00AM	0.16	0.05	0.03	0.14	0.08
	11:00AM	0.13	0.04	0.02	0.10	0.06
01/05/25	3:00AM	0.13	0.04	0.02	0.10	0.06
	7:00AM	0.15	0.05	0.03	0.13	0.08
	11:00AM	0.12	0.04	0.02	0.09	0.06

3. Temperature

Site name: Lugo Sub city **Axis: N-S**

Building placement: N-S, E-facing

Table 3. *Measured Temperature of Building N-S, E-facing*

Temperature (°C)						
Date	**Time**	**Living room/ Dining**	**M. Bedroom**	**Toilet**	**Kitchen**	**C. B. Room**
29/04/25	3:00AM	21	19	20	20	22.4
	7:00AM	28	26	27	26	27.5
	11:00AM	25	23	24	24	30.0
30/04/25	3:00AM	22.8	24.2	25.5	23.7	22.7
	7:00AM	28.5	29.3	30.4	28.3	27.7
	11:00AM	31.2	32.3	33.0	31.4	30.2
01/05/25	3:00AM	22.6	24.1	25.3	23.5	22.5
	7:00AM	28.4	29.2	30.3	28.2	27.6
	11:00AM	31.1	32.2	32.9	31.3	30.1

4. **Humidity**

Site name: **Lugo Sub city** **Axis:** ____________

Building placement: **N-S, E-facing**

Table 4. *Measured Humidity of Building N-S, E-facing*

Humidity (%)						
Date	**Time**	**Living room/ Dining**	**M. Bedroom**	**Toilet**	**Kitchen**	**C. B. Room**
29/04/25	3:00AM	45	46	45.5	46	40.4
	7:00AM	38	42	36.2	39	31.7
	11:00AM	41	44	31.0	42	27.6
30/04/25	3:00AM	42.8	44.2	46.0	41.9	40.2
	7:00AM	33.4	34.2	36.4	33.5	31.5
	11:00AM	28.4	30.3	31.2	29.2	27.8
01/05/25	3:00AM	43.1	43.9	45.7	42.0	40.3
	7:00AM	33.2	34.4	36.3	33.7	31.6
	11:00AM	28.3	30.2	31.1	29.1	27.7

APPENDIX-III

Figure 1. *Measuring equipment being placed in the study area (Source: Author)*

Figure 2. *105m^2 Plot located in T-junction along N-S, E-facing*

Figure 3. *105m^2 Plot enclosed with adjucent plots*

Figure 1. *Pictures taken Inside the compound (Source: Author)*

Figure 3*. Kitchen Interior Picture (Source: Author)*

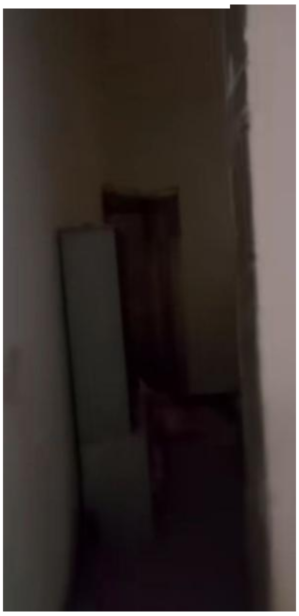


Figure 2. *Bedroom Interior Picture (Source: Author)*

APPENDIX-IV

Table 1. *Indoor Environmental Parameters for All Samples (April 29–May 01, Adama City) (Source: Author)*

Sample	Orientation	Config.	Room	Time	Temp (Â°C)	Illuminance (lux)	RH (%)	Airspeed (m/s)
SP01	E-W, North	Enclosed	Living	3:00 AM	22	85	43	0.13
				7:00 AM	30	125	35	0.15
				11:00 AM	27	90	40	0.12
			Dining	3:00 AM	21	25	44	0.11
				7:00 AM	28	45	36	0.12
				11:00 AM	25	35	39	0.1
			Master Bed	3:00 AM	20	0	45	0.02
				7:00 AM	28	4	40	0.03
				11:00 AM	25	2	42	0.02
			Bathroom	3:00 AM	21	15	45	0.05
				7:00 AM	29	35	32	0.06
				11:00 AM	26	20	38	0.05
SP02	E-W, North	T-junction	Living	3:00 AM	21	110	44	0.18
				7:00 AM	29	170	36	0.19
				11:00 AM	26	120	41	0.15
			Dining	3:00 AM	20	35	45	0.13
				7:00 AM	27	60	37	0.14
				11:00 AM	24	50	40	0.12
			Master Bed	3:00 AM	19	3	46	0.04
				7:00 AM	27	8	41	0.05
				11:00 AM	24	5	43	0.03
			Bathroom	3:00 AM	20	20	45	0.07
				7:00 AM	28	40	33	0.09
				11:00 AM	25	25	39	0.07

SP03	**E-W, South**		Living	3:00 AM	23	120	42	0.1
				7:00 AM	32	180	34	0.12
				11:00 AM	29	130	39	0.09
			Dining	3:00 AM	22	40	43	0.08
				7:00 AM	30	70	35	0.09
				11:00 AM	27	55	38	0.07
			Master Bed	3:00 AM	21	2	44	0.02
				7:00 AM	31	10	38	0.03
				11:00 AM	28	5	41	0.02
			Bathroom	3:00 AM	22	18	45	0.04
				7:00 AM	31	45	31	0.05
				11:00 AM	28	22	37	0.04
SP04	**E-W, North**	**T-junction**	Living	3:00 AM	21	100	44	0.16
				7:00 AM	29	150	36	0.17
				11:00 AM	26	110	41	0.13
			Dining	3:00 AM	20	32	45	0.12
				7:00 AM	27	55	37	0.13
				11:00 AM	24	45	40	0.11
			Master Bed	3:00 AM	19	2	45	0.03
				7:00 AM	27	6	41	0.04
				11:00 AM	24	4	43	0.03
			Bathroom	3:00 AM	20	17	45	0.06
				7:00 AM	28	38	33	0.08
				11:00 AM	25	23	39	0.06
SP05	**N-S, East**	**Enclosed**	Living	3:00 AM	21	90	45	0.12
				7:00 AM	28	140	38	0.13
				11:00 AM	25	100	41	0.11
			Dining	3:00 AM	20	28	46	0.1

				7:00 AM	26	55	39	0.11
				11:00 AM	24	40	42	0.09
			Master Bed	3:00 AM	19	1	46	0.02
				7:00 AM	26	5	42	0.03
				11:00 AM	23	3	44	0.02
			Bathroom	3:00 AM	20	13	46	0.04
				7:00 AM	27	30	35	0.05
				11:00 AM	24	18	41	0.04
SP06	**N-S, East**	**T-junction**	Living	3:00 AM	22	115	44	0.17
				7:00 AM	29	165	36	0.18
				11:00 AM	26	120	40	0.15
			Dining	3:00 AM	21	38	45	0.13
				7:00 AM	27	60	37	0.14
				11:00 AM	24	50	40	0.12
			Master Bed	3:00 AM	20	3	45	0.04
				7:00 AM	27	8	41	0.05
				11:00 AM	24	5	43	0.03
			Bathroom	3:00 AM	21	19	45	0.07
				7:00 AM	28	42	33	0.09
				11:00 AM	25	27	39	0.07
SP07	**N-S, West**	**Enclosed**	Living	3:00 AM	21	80	45	0.11
				7:00 AM	28	120	38	0.13
				11:00 AM	25	90	41	0.1
			Dining	3:00 AM	20	22	46	0.09
				7:00 AM	26	40	39	0.1
				11:00 AM	24	30	42	0.08
			Master Bed	3:00 AM	19	0	46	0.01
				7:00 AM	26	3	42	0.02

				11:00 AM	23	2	44	0.01
			Bathroom	3:00 AM	20	10	46	0.03
				7:00 AM	27	25	35	0.04
				11:00 AM	24	13	41	0.03
SP08	N-S, West	T-junction	Living	3:00 AM	22	105	44	0.16
				7:00 AM	29	160	36	0.17
				11:00 AM	26	115	40	0.14
			Dining	3:00 AM	21	36	45	0.12
				7:00 AM	27	58	37	0.13
				11:00 AM	24	48	40	0.11
			Master Bed	3:00 AM	20	2	45	0.03
				7:00 AM	27	7	41	0.04
				11:00 AM	24	4	43	0.02
			Bathroom	3:00 AM	21	18	45	0.06
				7:00 AM	28	39	33	0.08
				11:00 AM	25	26	39	0.06

APPENDIX-V

Mode Button:
Pressing lightly for changing mode: normal/max/min modes.
Pressing a bit longer for choose Lux or Fc.
Hold Button:
short press for holding the LCD reading.

Auto Power OFF: This instrument will be Auto Power OFF if there is no any button pressing in 5 minutes. This design is for saving battery power consumption.

Care and Maintenance:
When the instrument is not in use, store the instrument in a stable, dust-free environment out of direct sunlight. Remove the battery from the instrument if it is to be stored for periods of more than one month, or when the low battery power symbol appears on the display.

Battery replacement
When the low battery icon appears on the display, replace the battery as soon as practical.
1. Remove the rear battery compartment cover.
2. Replace one 9V battery.
3. Cover the compartment door.

Specifications:
Large LCD characters display
Range:0.1~200,000Lux,0.01~20,000Fc
Resolution:0.1Lux/0.01Fc
Accuracy:±4%
Measurement speed: 2 times/second
Units: Lux & Fc
Hold function
Auto range
Auto Power OFF: After approx. 5 minutes
Power Supply: One 9V battery
Low power of battery detecting
Operating Environment:14 to 122°F (-10 to 50°C),10%~90%RH
Dimensions:145 X 67 X 32mm
Weight: 170g(6.0 oz)

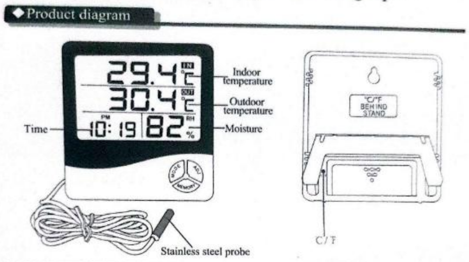
Display in Lux		Display in Fc	
Range	Resolution	Range	Resolution
200	0.1	20	0.01
2000	1	200	0.1
20000	10	2000	1
200000	100	20000	10

Illuminance standard reference table:

Lux	Place
75~30	Ware House,Garage, Darkroom, Lounge
150~75	Corridor, Toilet, Locker room, Channel,Guest room
300~150	Classroom, Hall, Restaurant, Ward, Living room
750~300	Laboratory, Conference room, Kitchen
1500~750	Hall channel, Operation room, Counter,Workshop
3000~1500	Ultra precision workshop
10000~30000	Visual function checking room

User manual of Hygrother-mograph

◆Product diagram



◆Product Specification

Temperature Measuring Range:-50°C~+70°C(-58°F~+158°F)
Temperature Measuring Accuracy:±1°C(1.8°F)
Temperature Resolution:0.1°C(0.2°F)
Humanity Measuring Range:10%RH-99%RH
Humanity Measuring Accuracy:±5%RH
Humanity Resolution:1%
Used Battery:AAA1.5V

◆Basic Function

Temperature/Humidity Display
°C/°F Temperature Switch Display
Maximum/Minimum Temperature and Humidity Memory Function
12/24Hourly Clock
Hourly Chime Function
Daily Alarm Function.
Calendar Display Function

Figure 1. *Measurement Equipment's specification. (Source: From products brochures)*