ASSESSING THE IMPACT OF NATURAL VENTILATION ON THERMAL COMFORT IN PUBLIC HEALTHCARE FACILITIES IN ADAMA

Michael Yeshigeta Tilahun

A Thesis Submitted to the department of Architecture and Urban planning

College of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of

Masters of Science in Environmental Architecture

Office of Graduate Studies
Adama Science and Technology University

June , 2025

Adama, Ethiopia

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APPROVAL SHEET

I, the advisor of the thesis entitled **"Assessing the impact of natural ventilation on thermal comfort in public healthcare facilities in Adama"** and developed by Michael Yeshigeta Tilahun, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Belay Zeleke (PhD)	______________________	_______________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Michael Yeshigeta have read and evaluated the thesis entitled **"Assessing the impact of natural ventilation on thermal comfort in public healthcare facilities in Adama"** 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

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DECLARATION

I hereby declare that this Master Thesis titled , "**Assessing the Impact of Natural Ventilation on Thermal Comfort in Public Healthcare Facilities in Adama**," is an original work submitted in partial fulfillment of the requirements for the master's degree in Environmental Architecture at Adama Science and Technology University

This work has not been previously submitted for any degree or award at any other institution. All sources used have been duly acknowledged.

Michael Yeshigeta Tilahun	______________________	_____________
Name of student	Signature	Date

RECOMMENDATION OF ADVISOR

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Assessing the Impact of Natural Ventilation on Thermal Comfort in Public Healthcare Facilities in Adama"** prepared under my guidance by Michael Yeshigeta submitted in partial fulfillment of the requirements for the degree of Master's in Environmental Architecture. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

BELAY ZELEKE[PHD]__	____________________	______________
Major Advisor/Supervisor	Signature	Date

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Finally, I would appreciate it if my fellow peers, colleagues, and research participants, including community members and facility managers, could provide feedback and their inputs. Your input was the driving force to the successful completion of this thesis.

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Acronyms

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

CFD: Computational Fluid Dynamics

IEQ: Indoor Environmental Quality

PHC: Primary Healthcare Center

PMV: Predicted Mean Vote

PPD: Predicted Percentage Dissatisfied

WHO: World Health Organization

NV: Natural Ventilation

TC: Thermal Comfort

RH-Relative Humidity

DBT-Dry Bulb Temperature

OPD-Outpatient Department

ANC- Antenatal Care

WFR- Window-to-Floor Ratio

NVR-Natural ventilation rate

ACH-Air change rate

ABSTRACT

In regions like Adama, Ethiopia, where active cooling facilities are few, natural ventilation hospital building design is crucial for thermal comfort. The study explains how the indoor thermal environment of public health buildings is affected by design parameters—window orientation, ventilation strategies, internal layout, and window-to-floor ratios. Due to the vulnerability of the occupants of the hospital, i.e., healthcare staff and patients, research highlights the contribution of passive design in maintaining environmental quality and human well-being. A mixed-methods approach was used, combining on-site environmental measurement, architectural survey, and occupant surveys. The measurements of temperature, relative humidity, and air velocity were made at different times of the day to capture diurnal cycles, and architectural features were compared with planned prototype designs by GTZ and the Federal Ministry of Health. Special studies were conducted on maternity and inpatient wards considering important factors such as exposure of windows, openness of corridors, ceiling height, and potential for cross-ventilation. Occupant surveys provided data on thermal sensation, perceived air quality, and window-use behavior. Results indicated a clear relationship between design and thermal comfort: east- or west-facing window zones were warmer, especially in midday sun; cross-ventilation zones were significantly cooler; and window-to-floor area ratio less than 0.2 zones were significantly less comfortable. The study rated the buildings according to their natural ventilation efficiency and identified weak and strong points in their design. In general, the study illustrates that simple yet effective passive design principles such as maximizing open window openings, openings' location with respect to prevailing winds, and provision for cross-ventilation can greatly contribute to thermal comfort in semi-arid health environments. These findings offer useful lessons for retrofitting current buildings and creating tomorrow's climate-responsive, sustainable health buildings.

Keywords: *Natural ventilation, thermal comfort, healthcare facilities, window-to-floor ratio, cross-ventilation, passive design, public health buildings, climate-sensitive architecture,*

CHAPTER-ONE

INTRODUCTION

Natural ventilation is a cost-effective and sustainable method using wind and thermal buoyancy to create the best indoor environmental quality (IEQ) achievable with the minimum amount of mechanical services and energy use (Chenari et al., 2016). There has been renewed development towards its overall contribution towards the attainment of indoor healthy conditions, especially in healthcare facilities, where the adequate ventilation may incorporate airborne illness and overall enhance the recovery and health of the patient (World Health Organization, 2021). Natural ventilation has been challenging the ability to deliver maximum thermal comfort as well as other energy consumption minimization in buildings according to global sustainability objectives (Rivas et al., 2020; Jin et al., 2022).

Health facilities need to be ventilated since individuals inside them are vulnerable, such as the immuno compromised patients and health care workers who expose themselves to infectious pathogens. For instance, according to the World Health Organization (2021), guidelines emphasize the role air handling systems play in terms of stopping transmission of airborne pathogens, particularly where the population is concentrated. This study fills the gap by studying the application and effectiveness of natural ventilation design strategies in Ethiopia's Adama City public health centers. Climatic factors, window type, and orientation are relevant parameters under study in an effort to quantify how they affect ventilation performance and levels of comfort.

A mixed-methods approach was applied to facilitate these objectives. Environmental measurements of air temperature, humidity, and velocity were quantitative measures of quantitative data, while qualitative data was gathered through occupants' interviews and questionnaires. Building information encountered within architectural plans and photograph records also constituted an ancillary background to investigate space organization and ventilation performance effect.

Data analysis made use of existing thermal comfort models, such as Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) indices, to quantify occupants' comfort level. Thematic qualitative data analysis also took patients' and workers' feelings and indoor environmental quality perceptions into account.

The findings from this research will inform architects, engineers, and policy planners to develop evidence-based policy recommendations for planning healthcare facilities. The recommendations will incorporate the use of natural ventilation and will inform the construction of energy-efficient, patient-focused, and environmentally sustainable healthcare environments in Adama City and similar cities.

1.1 Background of the study

The indoor thermal comfort of the public health facilities in Adama City remains undermined through energy-intensive mechanical ventilation systems. Even though the systems ensure indoor temperature regulation, they are normally associated with high energy use, increased running expenses, and significant environmental impacts. The constraints include the demand for alternative methods, which not only pose low environmental effects but are also low-cost (Jin et al., 2022; Rivas et al., 2020).

Natural ventilation appears to be an ideal option, with a cost-efficient solution having a way to enhance indoor environmental quality (IEQ) without excess energy usage. Natural forces like wind pressure and temperature gradients are utilized in the process to deliver airflow, giving healthier and more comfortable indoor conditions. For health care facilities, natural ventilation benefits go beyond energy conservation to cover improved air quality, pollution dilution, and infection prevention, all of which are essential for employee health and patient convalescence (Chenari et al., 2016; Rivas et al., 2020).

Studies around the world have been able to establish the effectiveness of natural ventilation in hospitals, especially in actual temperate climates where techniques like cross-ventilation and the stack effect have been shown to be effective in delivering adequate rates of ventilation. Studies have been able to demonstrate that effective natural ventilation systems can be the key to enhancing thermal comfort and airflow and reducing the need for mechanical operation (Jin et al., 2022). However, there have been few efforts to study the special difficulties and benefits of using natural ventilation in tropical environments like, for instance, Adama, Ethiopia. The local climatic condition, building alignment, and window location are decidedly important to break or form such systems in such a configuration.

This study tries to fill this gap in knowledge through the evaluation of the existing natural ventilation level within public health buildings in Adama City. The study tries to inquire about the presence of ventilation systems, look at building designs, and verify whether there is compliance with building codes and standards. Apart from this, it also tries to identify the correlation of climatic conditions, typology of buildings, and perception of the users in developing conclusions that can be used to design healthcare facilities in a sustainable manner. The research findings will be relevant to inform evidence-based practice and policy recommendations toward enhancing the sustainability of the health centers in Adama and other cities and operational efficiency.

1.2 Problem statement

Poor interior environmental quality—especially in terms of thermal comfort and indoor air quality—is posing a major obstacle to public health facilities in Adama, Ethiopia. Patients as well as healthcare professionals are negatively impacted by this situation; discomfort, lower output, and even possible health problems follow. The World Health Organization (2009) stresses that inadequate indoor air quality in hospitals can speed infection transmission, slow patient healing, and so undermine staff morale and productivity.

Poor planning for natural ventilation in these facilities is one of the fundamental causes of these problems. Most public health facilities in Adama were not created to maximize thermal efficiency or passive airflow. Buildings thus experience extreme heat gain in warm seasons and year-round bad indoor air quality.

Globally, healthcare institutions have long acknowledged natural ventilation as a sustainable and inexpensive means of raising thermal comfort and air quality. The need of climatic adaptability in construction planning has been underlined by studies by Oke (1988) and Nicol & Humphreys (2002). Countries like India, Brazil, and South Africa have adopted effective low-energy hospital design approaches that give orientation, crossventilation, and adaptive thermal comfort criteria top priority. For example, the LowEnergy Design for Healthcare Facilities by the UK's National Health Service (NHS) includes passive design techniques targeted at both patient well-being and operational efficiency. Likewise, the World Health

Organization has championed recommendations calling for ventilation techniques appropriate for tropical and subtropical areas.

Still understudied, though, are the effects and feasibility of natural ventilation techniques in smaller cities such Adama in light of this worldwide momentum. Existing research frequently concentrates on major urban areas or various climate zones, hence leaving a vacuum in local data and best practices.

This study aims to fill that gap by assessing the efficiency of natural ventilation in public health facilities around Adama. It will evaluate compliance with national and international building codes as well as building orientation, window-to-floor area ratios, and ventilation apertures. Doing so helps to guide sustainable healthcare facility design in Adama, thereby improving thermal comfort, indoor air quality, and—most importantly—the general resilience and efficiency of Ethiopia's healthcare infrastructure.

1.3 Objectives

1.3.1 General Objective:

In order to assess the impact of natural ventilation on public healthcare facilities' thermal comfort in Adama, Ethiopia, and to produce evidence-based guidelines for the improvement of their design, operation, and sustainability.

1.3.2 Specific Objectives:

- To assess thermal comfort conditions in selected public healthcare facilities in Adama through on-site measurements of temperature, humidity, and airspeed.
- To evaluate the influence of architectural design factors—such as building orientation, window placement, and room layout—on the effectiveness of natural ventilation.
- To examine how natural ventilation strategies are implemented in practice, focusing on the role of window openings, door positions, and ventilation routes.
- To analyze user perceptions of indoor thermal comfort and ventilation effectiveness through interviews and questionnaires with staff and patients.
- To identify context-specific design factors that facilitate or hinder natural ventilation performance in the selected buildings, and propose responsive design recommendations.

1.4 Research Question

This research aims to explore the impact of natural ventilation on thermal comfort in public healthcare facilities in Adama. The study will assess the effectiveness of natural ventilation in various healthcare facilities and its influence on the thermal comfort levels of occupants.

Research Questions:

1. What are the current indoor thermal comfort conditions—in terms of temperature, relative humidity, and air velocity—within selected public healthcare facilities in Adama?
2. How do key architectural features, such as window orientation, window-to-floor area ratio, and building layout, affect the performance of natural ventilation systems in these healthcare buildings?
3. To what extent do existing natural ventilation strategies—including window openings, cross-ventilation pathways, and shading devices—contribute to achieving acceptable indoor air quality and thermal comfort?
4. How do patients and healthcare staff perceive thermal comfort and indoor air quality, and how do these perceptions align with the observed environmental measurements and ventilation performance?
5. What design strategies and practical interventions can be recommended to improve the effectiveness of natural ventilation and enhance thermal comfort in the public healthcare context of Adama?

1.5 Significance of the research

The research holds significant value for various stakeholders. For healthcare facilities in Adama, it aims to improve indoor air quality, enhance thermal comfort, and reduce energy costs by optimizing natural ventilation, ultimately contributing to better patient care and recovery. Policymakers can leverage the findings to develop informed building codes, design guidelines, and allocate resources to enhance the sustainability of public healthcare facilities. Researchers and academics will benefit from the study's contribution to knowledge on natural ventilation and sustainable design, providing a foundation for future research. For the community, healthier indoor environments in healthcare facilities can lead to improved public health outcomes and overall well-being.

1.6 Scope of the Research

In Adama, Ethiopia, the focus of this study is on evaluating the impact of natural ventilation on thermal comfort in public primary healthcare centers (PHCs). These facilities are the only ones included in the study, as PHCs are responsible for providing health care to most of Adama's population on an urban and peri-urban level, often operating in buildings with easier-to-use ventilation systems than hospitals.

Due to differences in building complexity, ventilation infrastructure, and operational requirements, the research does not include hospitals, residential healthcare/home care settings (including private healthcare facilities), which may have different needs for natural ventilation performance. In addition, the study doesn't provide a comprehensive analysis of mechanical ventilation systems, although its relationship to natural venting is considered significant.

The research does not involve any long-term environmental monitoring. The collection of data will be based on field surveys, on-site measurements of temperature, humidity, and airflow, interviews with healthcare staff and patients, as well as examination of building documentation to assess the current status of natural ventilation and thermal comfort.

1.7 Limitations of the Research

There are a number of limitations to this study that need to be considered. First, the study is concerned with public health facilities in urban and peri-urban Adama alone, which may not be a representative sample of the overall healthcare setting, including rural health centers and private clinics. The findings thus may not be generalizable to other healthcare settings or geographical locations.

1.8 Description of the study area

Because this study is limited to public primary healthcare facilities located in the urban and peri-urban areas of Adama, applying the results across other healthcare settings, such as rural centers and private institutions may prove challenging.

Additionally, the data collection was restricted to daylight hours, thus eliminating any potential differences in thermal comfort and natural ventilation conditions across seasons. This time constraint may make the results less comprehensive.

However, the study offers valuable insights into improving local healthcare setting natural ventilation and thermal comfort.

1.9 Organization of the thesis

This thesis has five chapters, and one is built upon the other in a cascading manner to analyze the effect of natural ventilation on thermal comfort in public health care facilities in Adama. Below is the outline of the organization of the thesis:

Chapter One: Introduction

This chapter is the study's synopsis including background, statement of the problem, research questions, objectives, importance of the study, scope and limitations, operational definitions, and thesis organization.

Chapter Two: Literature Review

This chapter provides a literature review of natural ventilation and thermal comfort in definitions, theoretical and empirical research, ventilation methods, thermal comfort criteria, and environmental and architectural characteristics relevant to them. It also identifies the knowledge gaps and provides the conceptual framework for this research.

Chapter Three: Research Methodology

This chapter provides an explanation of the study design, data collection process, and analysis procedure used in the study. It provides information on the study location, sampling plan, field measurement (temperature, humidity, wind speed), and questionnaires surveying of the residents.

Chapter Four: Results and Discussion

This chapter documents general findings from qualitative and quantitative data. It consists of environmental monitoring data, occupants' comfort perceptions, analysis of architectural features, and site observations. The results are described in terms of research questions and objectives, and interpreted in relation to literature and thermal comfort standards.

Chapter Five: Conclusions and Recommendations

The final chapter summarizes the overall findings of the study and draws conclusions from the data collected. It provides field recommendations for the improvement of natural ventilation and thermal comfort in such public healthcare centers, along with directions for future research.

CHAPTER-TWO

LITRATURE REVIEW

This chapter provides a comprehensive review of existing literature on natural ventilation, thermal comfort, and their application in healthcare facilities.

2.1.1 Principles of Natural Ventilation

Natural ventilation is a passive air-conditioning system that uses natural forces like wind and buoyancy to create airflow into and through buildings. Natural ventilation is realized by two main mechanisms: wind-driven ventilation and the stack effect. Wind-driven ventilation is where wind pressure pushes air out through windows and doors. Wind-driven ventilation relies on wind speed, wind direction, and opening configuration (Nicol & Humphreys, 2002). A good start-up can permit the largest amount of fresh air to enter a building during evacuation of hot stale air and thereby saves a mechanical cooling system and energy. Stack effect is brought about by buoyancy produced by hot air owing to temperature rise. Air within a building gets heated, and in this process, it becomes of lower density and rises and thereby creates a pressure gradient. Pressure gradient causes air to move from the lower to the higher floors and ventilates the building. Stack effect is extremely effective for high-rise buildings with shafts or atriums since height optimizes the buoyancy-induced flow of air (Oke, 1988). These natural ventilation methods collectively guarantee indoor air quality and thermal comfort at no extra cost using energy-thirsty mechanical systems.

Thermal comfort, being a key concern for health-care facilities, is a psychologically conditioned state that is subjectively defined and acceptance of the thermal environment on the part of the subject. Thermal comfort, as defined in ASHRAE Standard 55-2020, is an interdependent relationship between the individual and environmental factors. They are air temperature, relative humidity, air movement, mean radiant temperature, metabolic rate, and clothing insulation. Immediate surrounding temperature is direct air temperature, while relative humidity is a measure of water content in air and it governs perception of coldness and hotness. Speed of moving air or air speed may enhance the cooling effect, particularly when external temperature is elevated. Mean radiant temperature is average surface temperature of surfaces of the surrounding environment and governs the manner in which the body retains heat. Metabolic rate is measurement of the body rate of heat production for each activity, and clothing insulation is clothing thermal resistance on the subject (ASHRAE, 2020).

Thermal comfort is especially significant in health care facilities as its effect can be an efficacious predictor of employee performance and patient comfort. A moderate level of discomfort will create more stress, fatigue, and decreased worker satisfaction for employees and patients (Brager & Parsons, 2004). Patient thermal comfort can decrease stress-related complications and recovery rates. Comfort is required for reassurance and an important component to gaining a state of focus, expertise, and general work performance for medical practitioners. Because medical facilities are the site of convergence where people of disparate health status get referred, provision should be made for the diverse thermal comfort requirements of professionals and clients. Well-designed health buildings with adequate natural ventilation can enable one to establish an interior climate in correlative terms with health, comfort, and overall satisfaction.

2.1.2 Natural Ventilation in Healthcare Facilities: Global Perspectives

Research has validated the effectiveness of natural ventilation in hospitals worldwide. Natural ventilation enhances the quality of indoor air by pollutant dilution, removal of airborne pathogens, and overall enhancement of air conditions (WHO, 2009; Oke, 1988). Natural ventilation also assists in patient comfort, fostering a pleasant environment that supports rapid recovery and satisfaction (World Health Organization, 2009; Brager & Parsons, 2004). Besides, it is energy and operation cost-saving through reduced dependence on mechanical cooling systems (Nicol & Humphreys, 2002).

Example of researches **"Evaluation of Natural Ventilation in a Tropical Hospital"**

By

- Noor Muhammad Abd Rahman, Ministry of Health Malaysia
- Ahmad Fazlizan, National University of Malaysia
- Azman Hussin, DR PAKAR AIRCOND SDN BHD

2.1.3 Thermal Comfort Models

Adequate thermal comfort models that will be used in the determination of the levels of thermal comfort in the study area are the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) models, as given below.

2.1.4 Building Design Considerations for Natural Ventilation

Building direction is one of the key parameters for efficient natural ventilation. Its optimal direction is to take advantage as much as possible of prevailing winds, which will enhance air flow and reduce mechanical cooling. Solar heat gain will also be minimized by orientation, which is a critical component of thermal comfort. Heiselberg et al. (2006) conclude that it is crucial to make the building face in order to take advantage of wind conditions and minimize direct solar radiation on building surfaces.

Size and position of windows are crucial beyond belief in order to facilitate unforced ventilation and climatization within. Correct window positioning is achieved to enable proper indoor air circulation, while window size decides the amount of air that can be allowed to pass through the windows. With correct window size and position management, proper natural light can be supplied, thus not requiring artificial lighting. As per Kim et al. (2007), properly sized and placed windows are capable of meeting ventilation requirements and solar control requirements effectively so that it provides an acceptable internal climate with optimum energy performance.

Shading devices are also essential in solar radiation management. Shading devices like overhangs, louvers, and screens can be included to block excessive solar heat gain, the common problem with buildings that face high sunlight exposure. Shading devices are important for maintaining thermal comfort because solar devices block the amount of heat gaining the building, most significantly in healthcare buildings where patient comfort is essential. Zuo et al. (2019) also underscore the value of shading in order to regulate the thermal loads and optimize the efficiency of natural ventilation.

Stack effect is a natural phenomenon through which a building can be ventilated. Through vertical shafts or atriums, warm air rising is ventilated and a vacuum is created that pulls in the fresh external air. The upward movement of air also enhances circulation, particularly in multi-storey buildings, and thus stack effect is a proper step towards enhancing indoor air quality and thermal comfort. Dutton et al. (2017) describe the way in which strategically utilizing vertical air courses can significantly contribute to enhanced air circulation and thermal regulation.

Lastly, internal temperature control is also important through the use of high thermal mass materials for construction. Heat is stored and released when it is cool by brick or concrete, reducing the building temperature swing. Mazzarella et al. (2013) indicate that the use of such materials can complement natural ventilation systems by avoiding extreme indoor temperatures and constructing a stable and comfortable indoor climate for users of the building.

Literature review to be conducted in this way ensures proper comprehension of the basics of natural ventilation, thermal comfort, and how they can be applied in hospitals. All such findings of research will be used to inform data analysis and research methodology in the study in a way that researched design elements are appropriately placed in the research process.

2.2 CONTEXTUAL REVIEW:

2.2.1 Policy and Regulatory Framework:

Review the Ethiopian National Building Code for ventilation standards in healthcare facilities that apply to health and safety compliance. Review government policy or programs offering incentives for sustainable building, particularly encouraging natural ventilation. Also, review if there is any standard or guideline for energy efficiency in healthcare facilities in Ethiopia and how they allow sustainable and energy-efficient building.

2.2.2 Existing Practices:

Examine the dominant architectural features of Ethiopian health buildings, including window size, orientation, and ventilation strategies, to obtain an understanding of prevailing building typologies. Furthermore, investigate the current use of natural ventilation in the buildings and establish main barriers to its implementation. Some of the main barriers include limited professional knowledge, budget constraints, lack of skilled labor, and cultural resistance to adopting innovative building practices.

2.2.3 Research in Ethiopia:

Examine current research on the performance, energy efficiency, and indoor environmental quality of Ethiopian health buildings to establish the state of the art. Establish areas of knowledge gaps where research is required, namely challenges and opportunities of effective adoption of natural ventilation in this context.

2.2.4 Local Context of Adama:

sThis research will take into account the specific climatic conditions of Adama by analyzing on-site data related to temperature, humidity, and prevailing wind directions (e.g., Ethiopian Meteorological Agency, 2020; World Bank Climate Data, 2019). It will also explore traditional construction practices and local knowledge concerning natural ventilation strategies commonly employed in the region (see Gebremedhin, 2017; Alemayehu, 2015). Additionally, the socio-economic context of Adama—including income levels, resource availability, and the presence of skilled labor—will be examined to assess the practicality and potential effectiveness of recommended interventions (Central Statistical Agency of Ethiopia, 2021; Ministry of Urban Development and Construction, 2018).

2.2.5 Weather Condition of Adama

The climate of Adama is semi-arid with defined wet and dry seasons. It has warm, humid summer conditions with extremely high temperatures and air humidity indices resulting in extreme thermal discomfort of building occupants. The winter at Adama is mild and dry with very pleasant weather and low humidity indices.

Adama rains are seasonally rainy, and the rains are mostly in months. Seasonality in this context refers to necessity to devise designs that will have room for dry seasons and wet seasons in the course of the year.

2.3 THEORETICAL LITERATURE REVIEW:

Theoretical foundation for this study is based on thermal comfort principles and natural ventilation theories, and both are a cornerstone in relation to recognizing the environment control dynamics and occupant health as far as hospitals are concerned. The theories provide an integrated approach in looking at how natural ventilation could influence thermal comfort, precisely under Adama's semi-arid climate conditions.

Natural ventilation is the most environmentally friendly method of providing high rates of airflow with low energy inputs (Totaforti.S, 2018). Natural ventilation is accessed from natural forces that push external air through vents such as doors and windows by using building design and external climatic conditions in relation to internal conditions. Natural ventilation also has some capital and operating cost benefits and can provide high ventilation levels. (WHO,2009).

Room Type	Minimum Hourly Average Natural Ventilation Rate
General Wards	60 L/s per patient
Airborne Precaution Rooms	160 L/s per patient
Corridors	2.5 L/s per m^3

Table 1 WHO, Natural Ventilation for Infection Control in Health-care Settings.

2.3.1 The driving force of natural ventilation

Two forces can cause the movement of air within the building

- Wind pressure
- Stack pressure (buoyancy)

Wind pressure

When the building is subjected to wind it produces a positive pressure on the wind face and negative pressure on the second face. This drives the air to move through the windward openings into the building towards the low pressure openings on the second side (WHO, 2009).

Stack pressure (buoyancy)

Stack pressure is due to a gradient in air temperature or humidity. The gradient leads to an unevenness of interior and exterior column pressure gradient and thus leads to a variation in pressure vertically in the room space. Indoor air gets heated than outdoors, less dense room air rises. Air enters a building from lower opening and escapes from upper opening and vice versa (WHO, 2009).

Type of Ventilation	Advantages	Disadvantages
Mechanical Ventilation	- Suitable for all climates and weather (with air-conditioning as needed)	- Expensive to install and maintain
	- More controlled and comfortable environment	- Potential for noise from equipment
	- Capable of achieving high ventilation rates	- Reported failure in delivering required outdoor ventilation rate
		- Reduces comfort in hot, humid, or cold conditions
		- Inability to establish negative pressure in isolation areas (unless properly designed)
Natural Ventilation	- Suitable for warm and temperate climates (natural ventilation possible ~50% of the time)	- Easily affected by outdoor climate and occupant behavior
	- Lower capital, operational, and maintenance costs (for simple systems)	- More difficult to predict, analyze, and design
	- Large range of environmental control by occupants	- Inability to establish negative pressure in isolation areas
	- Energy-saving	- Potential for noise intrusion
Hybrid (Mixed-Mode) Ventilation	- Suitable for most climates and weather	- May be expensive
	- More flexible (uses mechanical and natural methods as needed)	- May be more difficult to design
	- Energy-saving	- High-tech systems may share disadvantages of mechanical ventilation

Table 2 advantages and disadvantages of types of ventilation systems

2.3.2 Advantage of Natural Ventilation

Natural ventilation has so many advantages over mechanical systems. It provides high ventilation rate in more economical way since it only uses natural forces and large openings. It is also energy efficient and provides more access to natural day lighting. Generally, the most advantageous aspect of natural ventilation is its ability to provide very high air change rate at low cost, with a very basic system. Despite the fact that the air-change rate is able to vary considerably, buildings with modern natural ventilation systems are capable of achieving very high air-change rates using natural forces (James Atkinson, 2009)

2.3.3 Thermal Comfort Theory

Thermal comfort, as per American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE Standard 55, 2017), is "that condition of mind which expresses satisfaction with the thermal environment." Design for people, especially for health buildings in which individuals spend more daylight time indoors, is all about it.

Fanger (1970) Predicted Mean Vote (PMV) Model is the most general thermal comfort model widely utilized. PMV predicts the mean population thermal sensation ranging from -3 (cold) to +3 (hot). The model considers six major variables: air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation. To complement the PMV is the Predicted Percentage Dissatisfied (PPD), predicting the percentage of people who will find the thermal environment unacceptable.

Fanger's model has been extensively applied in research for both residential and non-residential buildings. de Dear et al. (2013) and Nicol & Humphreys (2002), for instance, have validated the PMV model to be applicable over a wide range of climatic conditions ranging from tropical to temperate climates. Adaptive comfort theories have, however, challenged the inflexibility of PMV, particularly in free-running buildings where individuals have autonomy to modify their environment, i.e., opening windows or the use of clothing. Adaptive Thermal Comfort Model, as per ASHRAE Standard 55 (2017) and EN 15251 (2007), considers the behavioral adaptation and environmental adjustment of the building users.

Thermal comfort in health buildings holds profound meaning for patient recovery and worker efficiency. Baker and Steemers (2000) suggest that comfortable thermal conditions can reduce stress and optimize patient outcome, and provide the best working conditions for hospital staff. These findings are reinforced by studies of tropical climates conducted by Givoni (1994), and illustrate the role of thermal comfort in healing environments.

The study uses the Fanger's PMV model as a reference case in determining thermal comfort in Adama hospitals incorporated with adaptive comfort model properties for including the dynamically interactive behavior of naturally ventilated buildings. The hybrid model provides thermal satisfaction data that is interactive to climatic as well as operational variability.

2.3.4 Natural Ventilation Theory

Natural ventilation is one of the passive strategies of indoor environmental control, wherein natural forces such as wind and buoyancy forces drive the movement of air inside a building. The prominent principles include wind-driven ventilation, stack effect, and cross-ventilation, all of which force air movement and air replacement inside a building.

Wind-driven ventilation takes advantage of external wind pressure to force airflow through openings in the building envelope. Yuan et al. (2018) and Heiselberg et al. (2006) have found that the performance of the method depends on wind speed, orientation of the building, and opening position. Wind-driven ventilation is applied to its full advantage in semi-arid climates, where winds can be harnessed for good indoor air quality and thermal comfort.

Stack effect capitalizes on natural rising warm air, which escapes through top openings and draws in low-level cooler air. Dutton et al. (2017) discuss how atriums and shafts optimize the effect, with advantage of continuous air movement in multi-storey buildings. Stack effect is especially relevant in healthcare, where there must be constant airflow for infection prevention and occupant comfort.

Cross-ventilation, however, refers to wind passing through openings that are positioned opposite one another on the sides of a building in order to generate a through-breeze. Zuo et al. (2019) has it that this intervention is effective when the wind direction is perpendicular to the building facade. Cross-ventilation was seen to improve indoor air quality and reduce cooling loads in medium wind regime cities.

Health buildings do pose particular challenges for natural ventilation since controlled conditions are needed. Barker et al. (2015) found that natural ventilation can have a tangible impact on indoor air quality but that it must be properly controlled in order to avoid the transmission of external pollution or loss of infection control. Clement & Viegas (2011) research also focuses on the requirement for air balance as well as temperature control towards the optimization of thermal comfort in sensitive conditions.

Natural ventilation theory is applied in this study in discussing the way principles such as wind-driven airflow and stack effect can be utilized in designing Adama's hospital. On-site wind measurement and computational fluid dynamics analysis will be conducted in developing viable means of maximizing airflow and reducing reliance on energy.

2.3.5 Integration of Theories with Conceptual Framework

The theories that arise from the concepts of thermal comfort and natural ventilation are the foundations of the conceptual framework within this research. For example, air temperature, velocity, and humidity (thermal comfort theory) are related to building direction, window placement, and airflow properties (natural ventilation theory). Both the data gathering and analysis process will be guided by these concepts, and the research questions will be answered comprehensively.

In addition, applying adaptive comfort principles acknowledges the changing nature of naturally ventilated healthcare facilities. In considering occupant activities and weather variability, the study aims to develop context-sensitive solutions sensitive to Adama's semi-arid climatic regime.

2.3.6 Analytical Evaluation

Both thermal comfort and theory of natural ventilation have driven the creation of sustainable building design. However, their usage in semi-arid climates, particularly in healthcare settings, has not been explored. This study is intended to bridge the research gap by implementing these theories in Adama's climatic and socio-environmental contexts. Through the combination of theoretical knowledge and empirical investigation, the research will contribute to the advancement of climate-responsive design and passive cooling methods' overall body of knowledge.

2.4 EMPIRICAL LITERATURE REVIEW:

The chapter presents a critical analysis of empirical research on natural ventilation and thermal comfort within hospitals and semi-arid climatic zones. From a synthesis of results obtained in previous studies, the research concludes on gaps and potential opportunities for adaptation at the context level in hospital facilities in Adama.

2.4.1 Thermal Comfort Studies

Empirical studies of thermal comfort have established its significance in ensuring occupant wellness in various types of buildings. For example, Givoni (1994) conducted field measurements in naturally ventilated buildings located in tropical and desert climates and reported that the thermal comfort of occupants was significantly influenced by adaptive measures such as operable windows and shading devices. Similarly, Nicol and Humphreys (2002) demonstrated through large-scale surveys that thermal comfort is adaptive and highly reliant on occupant engagement with the environment.

In hospitals, the study by Baker and Steemers' (2000) pointed out the importance of achieving thermally comfortable conditions with a view to enhancing patients' recuperation and staff effectiveness. Their study, conducted in European hospitals, showed that naturally ventilated wards would be more likely to be thermally comfortable than mechanically ventilated wards, especially during moderate weather.

However, studies have also demonstrated challenges in delivering consistent thermal comfort in naturally ventilated buildings. In a survey of Australian hospitals, de Dear et al. (2013) found that natural ventilation improved air quality but that variations in outdoor temperature regularly caused occupant discomfort. These findings point to the need for adaptive strategies that address season and diurnal temperature variations.

2.4.2 Natural Ventilation in Healthcare Settings

There have been several empirical studies exploring the application of natural ventilation in the health care sector, especially its merits and demerits. Clement and Viegas (2011) discussed the use of stack effect ventilation in Brazilian multi-storey hospitals, citing it as effectively enhancing airflow rates and conserving energy. Based on their study, buildings that utilized vertical shafts experienced improved air movement even when the environment was extremely hot and humid.

In a study conducted in a Kenyan hospital, Barker et al. (2015) assessed the impact of cross-ventilation on indoor air quality and preventing infection. The results indicated that cross-ventilation reduced the amount of airborne pathogens by up to 30%, rendering the environment safer for the patients and workers. The study also noted some possible disadvantages, however, such as increased noise levels and the penetration of outdoor contaminants, particularly in the city.

Zuo et al. (2019) employed a case study of Chinese semi-arid area hospitals to analyze the performance of wind-driven ventilation. Their research demonstrated how building orientation and precise window positioning significantly enhanced natural ventilation performance, with a possible 25% reduction in cooling energy consumption. These findings are relevant to Adama since the same climatic conditions apply.

2.4.3 Thermal Comfort and Energy Savings

Empirical evidence has also borne witness to the double-pronged benefit of natural ventilation in promoting thermal comfort and saving energy. Heiselberg et al. (2006) modeled Mediterranean climate conditions to investigate the energy performance of naturally ventilated buildings in comparison to mechanically ventilated buildings. Based on their report, natural ventilation approaches such as operable windows and shading devices reduced cooling energy requirement by up to 40%.

In the healthcare industry, Dutton et al. (2017) quantified the energy saving potential of natural ventilation in U.S. hospitals. Based on the results, employing stack effect ventilation and operable windows reduced yearly energy costs by 20–30%, at the same time maintaining satisfactory thermal comfort conditions.

Barker et al. (2015) also examined the economic impacts of natural ventilation in low-resource settings. They demonstrated in Sub-Saharan Africa that low-cost interventions such as improving window operability and local shading material installation had a significant cost-saving advantage without affecting indoor air quality or comfort.

2.4.4 Contextual Studies in Semi-Arid Climates

The semi-arid climate of Adama poses particular challenges in achieving natural ventilation and thermal comfort. Studies under such climatic conditions provide valuable lessons in climate-responsive building design. Yuan et al. (2018) analyzed Indian residential buildings located in semi-arid climates and found cross-ventilation and stack effect strategies very effective in minimizing daytime heat gains.

Gebremariam et al. (2020) conducted a field experiment on naturally ventilated schools in Addis Ababa, Ethiopia. They reported that airflow was enhanced and indoor temperature reduced by up to 5°C through correct orientation and shading devices. This confirms that the local climatic condition must be taken into consideration in applying natural ventilation mitigation measures.

2.4.5 Research Gaps and Opportunities

Despite extensive empirical research work on natural ventilation and thermal comfort, several gaps are identified particularly for hospitals in semi-arid cities like Adama. Firstly, little is known about the influence of local wind regimes, orientation, and local culture on the performance of ventilation. Secondly, studies are highly focused on either thermal comfort or energy conservation with very few incorporating these into a single framework. Finally, the contribution of adaptive comfort behavior to healthcare settings is not well researched, particularly where occupant control over the environment is restricted.

This research aims to fill these gaps through taking an in-depth analysis of natural ventilation techniques in Adama's hospitals. By combining empirical results with theoretical foundations, the research aims to provide pragmatic suggestions that maximize thermal comfort, indoor air quality improvement, and minimization of energy reliance.

2.5 Research Gaps

Major knowledge gaps in Adama's natural ventilation involve a lack of research for the city's specific climate and building conditions. Information regarding public healthcare facility characteristics, including window area, building construction materials, and ventilation equipment installed, is scarce, and this restricts knowledge about their influence on ventilation performance. There is also insufficient attention to occupants' perceptions of thermal comfort, indoor air quality, and ventilation preference. The lack of design guidelines framed for Adama's climatic and architectural context adds further emphasis on research that is specifically focused. Additionally, the intricate relationship between climate, building form, and occupants' behavior remains under-researched, with more investigation needed.

CHAPTER-THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the procedures of the study from commencement to completion. The primary purpose of this study was to elucidate how thermal comfort is influenced by natural ventilation in public healthcare buildings in Adama, Ethiopia. To attain appropriate and valuable findings, the study adopted a definite step-by-step approach.

The research used the mixed-methods design. This implies that both the figures (quantitative data) and personal sentiments (qualitative data) were collected and examined. Quantitative measurement entailed measuring indoor temperature, humidity, and the wind speed. Qualitative data was acquired by asking the people who work in or occupy the buildings about their own feelings regarding the indoor air and temperature.

Several instruments were employed during data collection. Healthcare staff was given questionnaires to be aware of their exposure to ventilation and thermal comfort. While this was being done, observations were made on site, and environmental data were gathered through measuring instruments. This allowed the relationship between building design and individuals' perception in it to be seen.

To make the study fair and reflect different types of buildings, a sample of health facilities was drawn across Adama. The choice was made based on the size of the facility, the number of people who use it, and how unique the buildings are in structure and design.

After the data had been gathered, it was examined carefully. Numbers were handled with basic statistical methods to look for patterns. Questionnaire responses were grouped to see prevailing sentiments or thoughts among employees. The two sources of data were then combined to look at how effective natural ventilation is in such buildings.

Last but not least, the research was guided by good ethical standards. The participants were informed about the research prior to distributing the questionnaire, and they were asked for their consent. Their information was maintained in confidentiality, and they were treated with respect during the research.

3.2 Description of Study Area

Adama, located in the East Shewa Zone of the Oromia Region in Ethiopia, is situated approximately 99 kilometers southeast of Addis Ababa. The city lies at coordinates 8.514477° N latitude and 39.269257° E longitude . As of the 2007 Population and Housing Census, Adama had a population of 220,212, with a population density of 7,374.82 people per square kilometer .

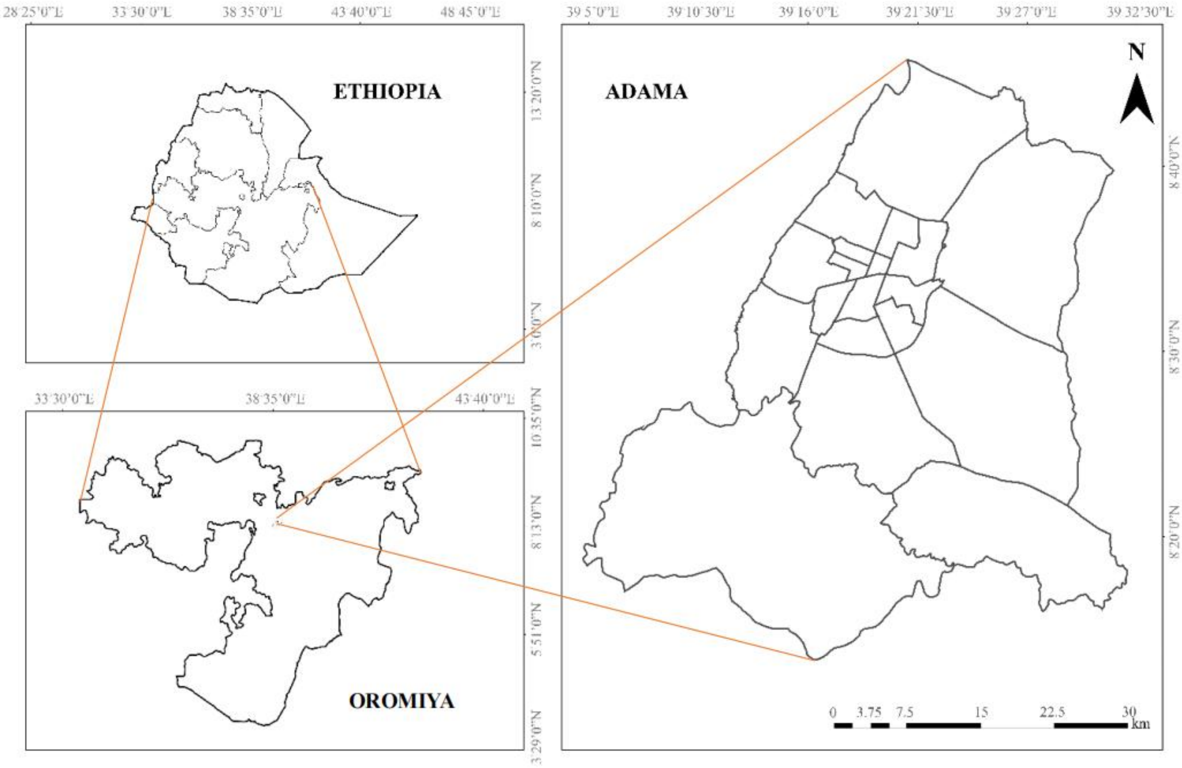

Figure 1Location map

Average Monthly Rainfall

The study will be conducted in Adama City, located in the Oromia Region of Ethiopia. Adama is a major commercial and industrial hub with a semi-arid climate characterized by hot and humid summers and mild and dry winters.

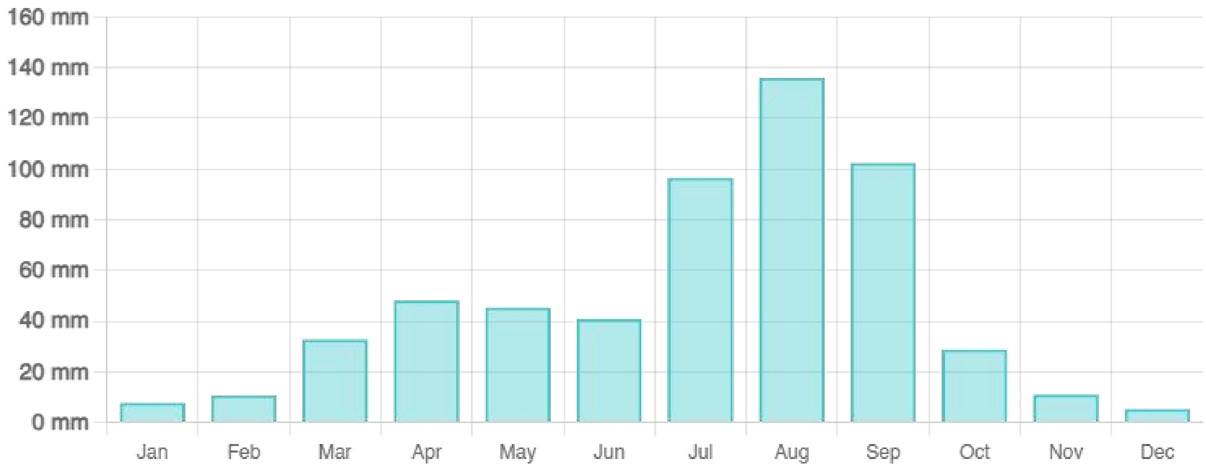

Figure 2- Adama Precipitation: Average Monthly Rainfall

Adama experiences distinct rainfall patterns characterized by a pronounced rainy season and extended dry periods. The majority of rainfall occurs during August and September, making these months the peak of the rainy season. On average, August receives the highest precipitation, with approximately 136 mm recorded, marking it as the wettest month of the year.

Conversely, the city experiences significant dry periods during January, February, November, and December. Among these months, December stands out as the driest, with an average precipitation of only 5 mm. These dry months are a defining feature of Adama's semi-arid climate, contributing to the overall climatic conditions of the region.

Annually, Adama receives an average of 566 mm of rainfall. This relatively modest amount reflects the semi-arid nature of the area and emphasizes the need for climate-sensitive planning in water resource management and urban design.

Average day and night temperature

In Adama temperatures are generally consistent throughout the year. Typically, daytime temperatures range from a very warm 31°C in May to a comfortable 28°C in the coolest month, December. Nights are cooler, with temperatures generally dropping to 12°C, particularly during the colder months.

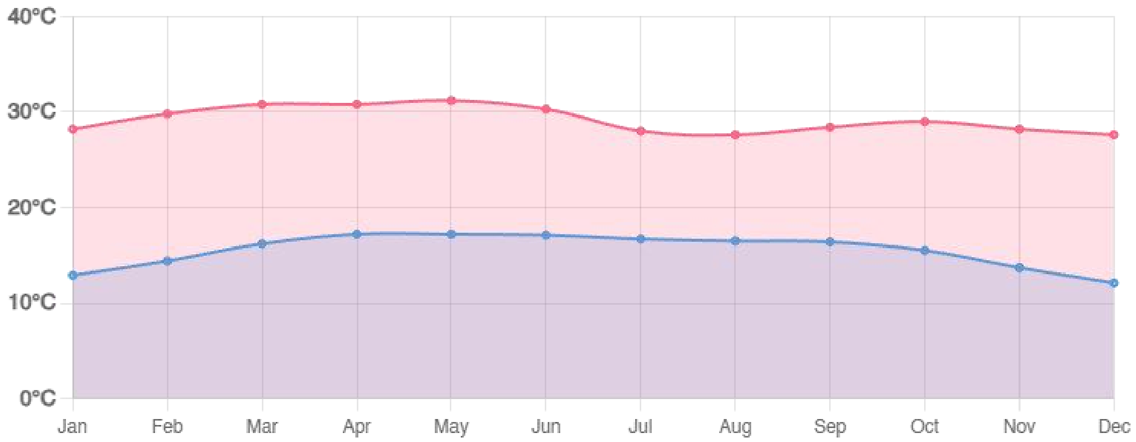

Figure 3 The mean minimum and maximum temperatures throughout the year

The average number of days each month with precipitation

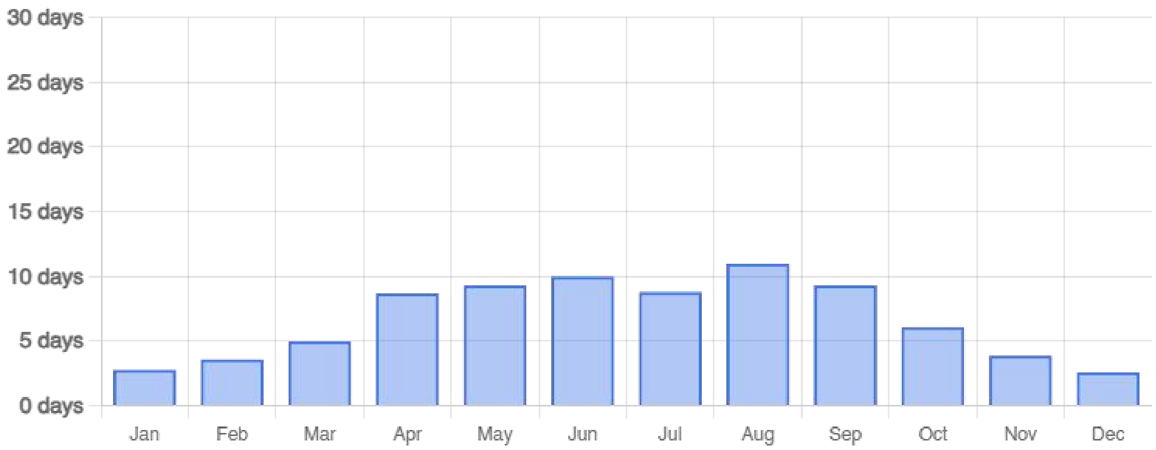

Figure 4 the average number of days each month with precipitation

Monthly hours of sunshine

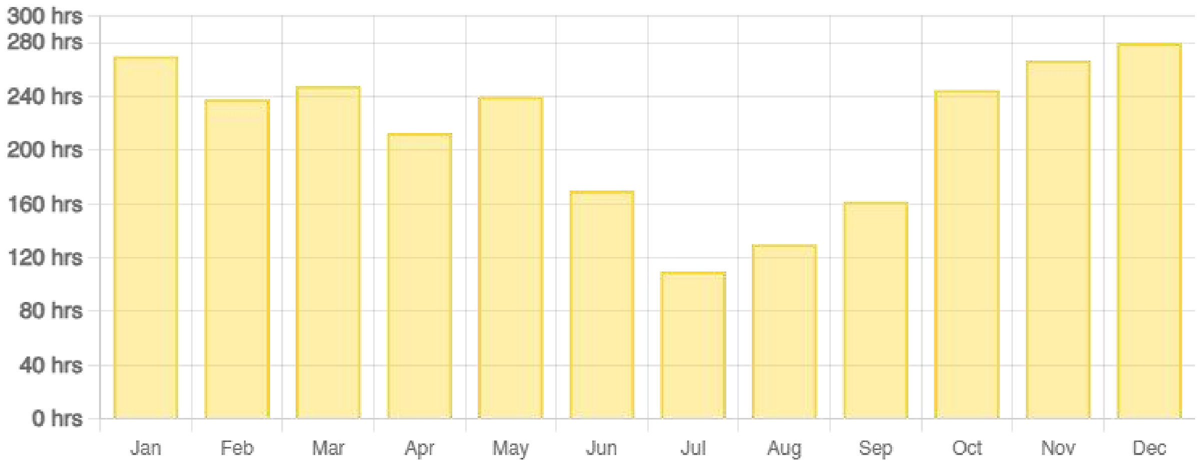

Figure 5 Monthly hours of sunshine

Data from: Addis Ababa, Ethiopia (72 KM, 45 Miles)

Daily hours of sunshine

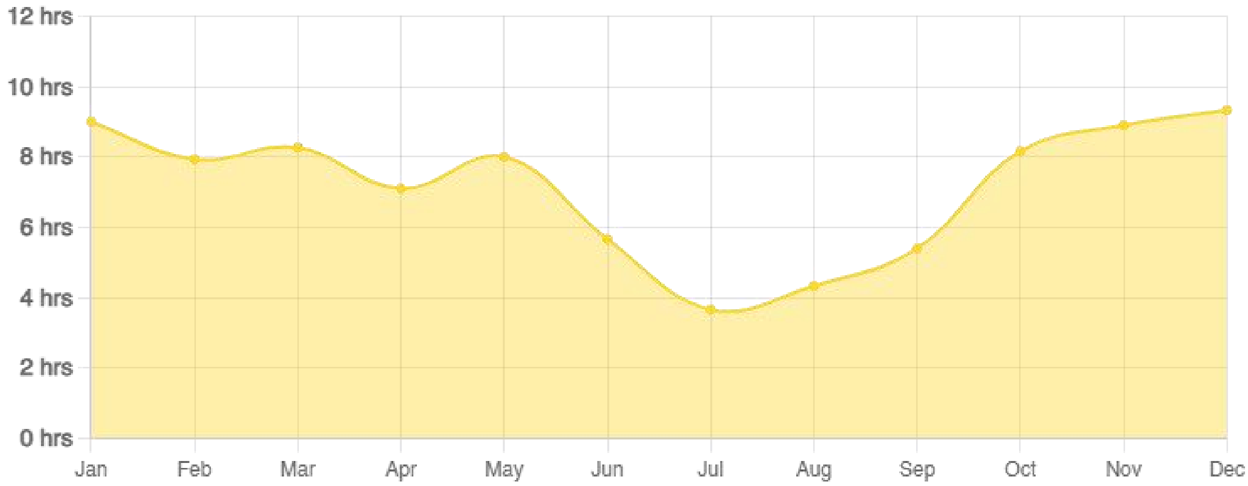

Figure 6 Daily hours of sunshine

Average humidity

The relative humidity is low throughout the year in Adama.

Relative humidity over the year

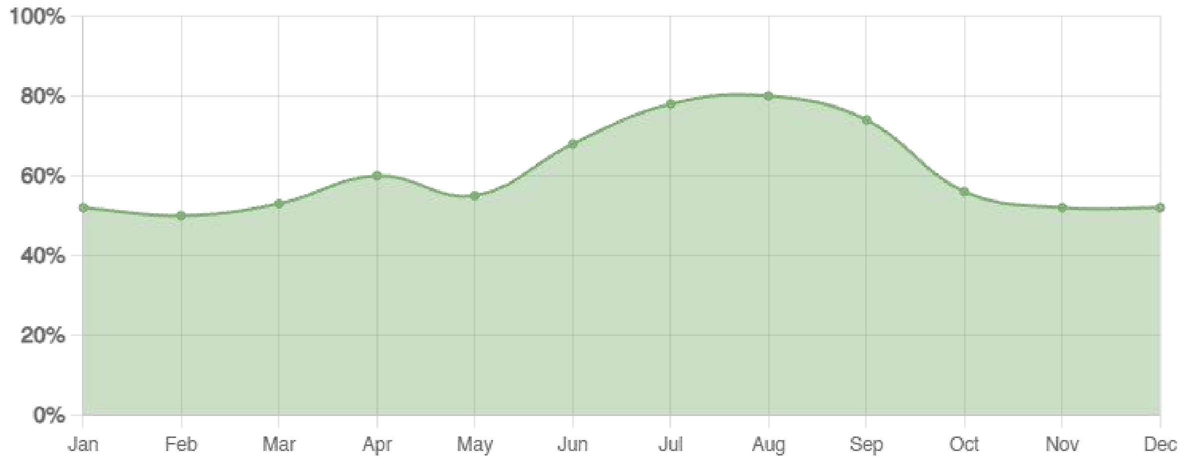

Figure 7 The relative humidity is low throughout the year in Adama.

https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,adama-et,Ethiopia

3.3 Research Design

A mixed-methods research design was employed to thoroughly investigate the impact of natural ventilation on thermal comfort in public healthcare facilities in Adama, using both quantitative and qualitative methods. This design permits the integration of measurable environmental data with human perceptions, providing a comprehensive approach to solving the research problem.

I. Quantitative Component.

Quantitative inquiry is centered on gathering impartial information about the actual indoor environment. Called instruments like digital thermo-hygrometers and anemometers were used to measure key environmental parameters, including indoor temperature, relative humidity, and air velocity. Reliable data of natural ventilation performance was obtained by measuring these in specific spaces within healthcare facilities at predetermined time intervals.

Quantitative data is utilized to describe the thermal environment in buildings, identify ventilation efficiency patterns, and evaluate adherence to thermal comfort guidelines. These measurements present authentic and empirical proof for the actual indoor environmental quality and ventilation behavior....

II. Qualitative Component.

The qualitative aspect focuses on occupant perceptions and experiences concerning indoor thermal comfort. Data was collected through structured and semi-structured interviews, focus group discussions, and questionnaires administered to a purposive sample of healthcare users, such as patients, healthcare staff, or visitors.

Subjective comfort levels, adaptive behaviors, and cultural practices are all factors that influence occupant responses to indoor environments. It contextualizes the quantitative results by understanding how people experience and respond to thermal conditions, while also highlighting user-centered issues that are not evident in instrumental data.

III. Integration and Triangulation.

It is important to consider both quantitative and qualitative data when conducting this research. The triangulation approach ensures that findings are cross-validated and therefore, reliable.). Measuring the difference between ventilation rates and occupant comfort perceptions is used to uncover possible factors that affect air movement patterns, localized heat sources, or behavioral adaptations.

By combining these data sources, the study obtains a detailed understanding of how both the physical environment and human factors influence thermal comfort. By using an integrated approach, conclusions are more reliable and practical design ideas can be developed in accordance with the specific requirements of Adama's public healthcare facilities.

IV. Summary.

This design uses mixed methods and is an inclusive approach to investigating natural ventilation and thermal comfort, balancing scientific measurement with social observations. This framework provides both generalized knowledge applicable to similar climates and the recognition of unique, site-specific problems and opportunities.... Accordingly, it creates a strong basis for evidence-based advancement in healthcare building design and operation.

3.4 Study approaches

This study was conducted with a mixed-methods approach to explore natural ventilation's effect on thermal comfort in public healthcare buildings in Adama. Both quantitative and qualitative methods were adopted to obtain data, so findings would not only reflect physical facts but also humans' perceptions. In the quantitative part, environmental variables such as indoor and outdoor temperature, humidity, and air speed, were measured. Calibrated equipment such as data loggers, and anemometers, were used while taking measurements. The measurements were taken from shortlisted areas at different times of the day to understand the performance of natural ventilation under actual usage. The measurements allowed for the analysis of the influence of airflow, temperature, and humidity content on indoor comfort levels.

Aside from that, qualitative data were also gathered to identify how people feel and respond to the indoor climate. Questionnaires were distributed, and informal interviews were carried out among patients, medical staff, and visitors. The aim was to find out their satisfaction with thermal comfort and how they react or cope whenever the indoor climate is uncomfortable. Certain responses also showed physical constraints such as dust, outside noise, or security concerns that affect the use of natural ventilation.

It was useful to have both types of data. The measured data showed the physical environmental conditions, while the building occupants' responses interpreted how they perceive those conditions. They allowed, when combined, for a more meaningful interpretation of the results and made the study more valid.

Lastly, the mixed-methods approach assisted in uncovering both the technical and subjective determinants of thermal comfort in the healthcare settings under investigation. It facilitated a broader and deeper understanding of the natural ventilation performance and its effects on the users' daily experience in the buildings.

3.5 Data Type and Sources

This research examined the impact of natural ventilation on thermal comfort in Adama's public healthcare facilities, utilizing both primary and secondary data. Specified healthcare buildings were equipped with calibrated instruments and data loggers to gather primary data on indoor environmental parameters, including temperature, relative humidity, and air velocity. These methods were subsequently applied in field surveys. Qualitative data on indoor thermal comfort and ventilation effectiveness was obtained through a combination of structured surveys, interviews, focus group discussions with building inhabitants. Building plans and site observations were used by architects to evaluate design features that were related to the natural ventilation performance. Environmental measurements were contextualized in the Adama region through the inclusion of meteorological data that offered climatic information on temperature, humidity levels, wind patterns, and rainfall. In order to evaluate the building performance of Ethiopian healthcare facilities, they examined relevant policy documents and building codes related to ventilation and thermal comfort. In order to apply it to a more extensive research context, the study was grounded in the existing academic literature on natural ventilation and thermal comfort. Through the use of different data types and sources, researchers were able to gain a comprehensive understanding of how natural ventilation affects thermal comfort in the study area.

3.6 Study Population and Sampling

Both primary and secondary data were utilized to investigate the impact of natural ventilation on the thermal comfort in Adama's public healthcare facilities. Primary data on indoor environmental parameters such as temperature, relative humidity, and air velocity was collected using calibrated equipment and data loggers within certain healthcare buildings. Field surveys later implemented these methods. Through a combination of structured surveys, interviews, and focus group discussions with building inhabitants, qualitative data on indoor thermal comfort and ventilation effectiveness was collected. Building plans and site observations were utilized by architects to evaluate design features that were related to the natural ventilation performance. Climate information such as temperature, humidity and wind patterns were incorporated into the meteorological data collected in the Adama region. To assess the building performance of Ethiopian healthcare facilities, they analyzed policy documents and construction regulations related to ventilation (the main floor) and thermal comfort. They expanded the research by citing academic literature on natural ventilation and thermal comfort. By utilizing multiple data sources, researchers were able to gain insight into how natural ventilation could impact thermal comfort in the study area.

09.2 - Medical services | Health center | Monthly (Hamle 2016; Nehase 2016; Meskerem 2017; Tikemet 2017; Hidar 2017; Tahesas 2017; Tir 2017; Yekatit 2017; Megabit 2017)

S.No	Activity	Adama Health Center	Awash Malkasa Health Center	Biftu Health Center	Boku Shanan Health Center	Guraja Furda Health Center	Dembela Health center	Shewa Alemtena Health Center	Wanji Gefersa Health Center	Geda Health Center	Hangatu Health Center	Hawas Health Center	Total
Outpatient.	Medical service - Out-patient services including emergency services provided	9	9	9	9	9	9	9	2	9	9	9	92
MS_OPD_NumOV.1	**Number of outpatient visits**	**123,737**	**22,937**	**59,927**	**60,717**	**34,335**	**36,577**	**6,483**	**6,277**	**77,021**	**55,693**	**78,425**	**562,129**
1	< 5 Years, Male	14,996	1,856	6,764	1,545	21,074	3,591	629	124	5,122	4,048	3,099	62,848
1	< 5 Years, Female	6,831	2,244	7,847	2,191	2,159	3,859	599	126	4,481	4,898	4,246	39,481
1	5 - 10 Years, Male	6,672	1,197	5,217	2,909	1,451	2,295	357	285	3,945	2,179	4,861	31,368
1	5 - 10 Years, Female	11,839	1,066	5,674	3,140	1,199	2,309	315	338	3,925	2,993	4,994	37,792
1	11 - 19 Years, Male	5,860	1,252	4,117	3,155	771	2,489	354	445	3,974	2,326	4,433	29,176
1	11 - 19 Years, Female	8,921	2,431	4,746	3,889	1,149	2,370	481	398	4,246	3,873	5,838	38,342
1	20 - 29 Years, Male	10,032	1,750	4,618	5,494	991	3,431	550	516	7,562	4,030	6,618	45,592
1	20 - 29 Years, Female	9,269	2,356	5,417	7,438	2,051	4,015	585	620	16,491	7,258	8,470	63,970
1	30 - 45 Years, Male	8,985	1,391	3,144	5,629	1,350	3,098	489	720	5,127	4,050	7,009	40,992
1	30 - 45 Years, Female	10,635	2,088	3,542	7,676	925	3,083	424	770	4,439	7,574	7,666	48,822
1	46 - 65 Years, Male	9,068	1,494	2,499	6,719	511	2,505	482	780	4,551	3,391	7,262	39,262
1	46 - 65 Years, Female	6,900	1,265	2,884	4,808	306	2,369	465	690	4,370	3,787	6,600	34,444
1	>= 66 Years, Male	8,371	1,266	1,892	3,321	247	570	343	339	4,463	2,629	4,476	27,917
1	>= 66 Years, Female	5,358	1,281	1,566	2,803	151	593	410	126	4,325	2,657	2,853	22,123
1	Number of health insurance beneficiaries that visited HF in the reporting period	110	2,342	7,739	2,962	5,395	4,905	3,576	43		3,534		30,606

Figure 8 number of outpatients presented over a 10-month period (Hamle 2016-Megabit 2017).

Source-adama zone health bureau

3.7 Sampling techniques

This research utilized purposive sampling to identify healthcare facilities and respondents in Adama City, with the aim of obtaining context-specific and detailed insights into natural ventilation and thermal comfort in public healthcare settings.

Out of the 11 public healthcare facilities under the management of Adama Town Administration, 7 were deliberately chosen based on factors such as outpatient volumes over an extended period (Hamle 2016 to Megabit 2017), geographic distribution to reflect environmental variability, and architectural features that impact natural ventilation, such As building orientation, ageing, window design. They are relevant case studies because these facilities represent the majority of high-usage public health centers in the city.

The interviews were conducted with a purposive sample of staff and patients at each facility to capture different viewpoints. The requirement required at least three health practitioners per facility, with a preference for those who had more than one year of experience to offer trustworthy insights.' Additionally, thermal comfort was analyzed by interviewing at least two patients per facility to determine user experiences. There were about 21 medical professionals and 14 patients in total.. The sample size, while not representative of all employees or patients, is adequate for qualitative exploratory research aimed at uncovering patterns and perceptions within limited time and resources.

This approach balances feasibility with depth, resulting in rich qualitative data combined with environmental measurements.

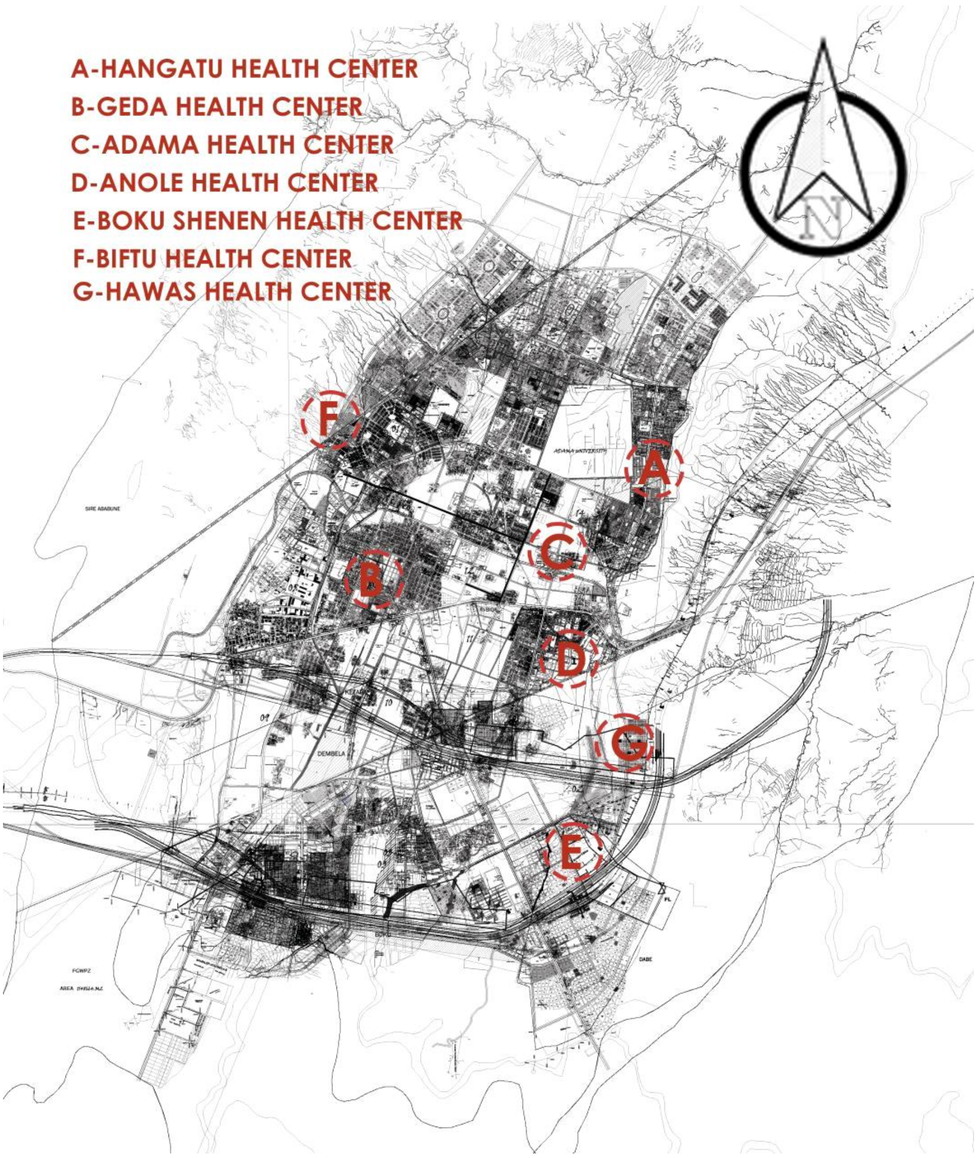

Figure 9 Location of the study areas (Source:Author)

No.	Name of Facility	Type	Latitude (°N)	Longitude (°E)	Notes
1	**Adama Health Center**	Public Health Center	8°32'50.22"N	39°15'39.38"E	Located in Eastern Adama
2	**Biftu Health Center**	Public Health Center	8°34'29.34"N	39°16'20.69"E	Serves surrounding neighborhoods
3	**Geda Health Center**	Public Health Center	8°31'3.12"N	39°15'2.63"E	Serves residential areas
4	**Hawas Health Center**	Public Health Center	8°32'2.26"N	39°17'10.57"E	Community-level health service
5	**Anole Health Center**	Public Health Center	8°32'21.29"N	39°16'36.44"E	Serves residential areas
6	**Boku Shenen Health Center**	Public Health Center	8°30'4.86"N	39°17'13.38"E	Serves residential areas
7	**Gendegara/hangatu health center**	Public Health Center	8°33'22.31"N	39°17'48.60"E	Community-level health service

Table 3Location description of the study areas

3.8 Sample size

Participants in the study population were located at the public health facilities selected in Adama when the data was collected. During the study period, employees such as medical professionals working in hospitals, administrative and support staff, and patients receiving services were all included.

Seven of the eleven government health facilities managed by Adama Town Administration conducted research. Ultimately, the selection of these facilities was based on significantly higher patient volumes over a ten-month period from Hamle 2016 to Megabit 2017 and key features such as their size/age and architectural design, which are important factors for natural ventilation performance and indoor thermal conditions.

Each facility enlisted three staff members to undertake the study, with a focus on enrolling at least one staff member who had worked there for more than one year to gain insights from long-term experience. Two patients from each facility were also involved in capturing user experiences on thermal comfort. A total of 35 individuals, consisting of 21 staff members and 14 patients, provided both professional and experiential feedback on the current thermal comfort status and the effectiveness of natural ventilation in healthcare settings.

3.9 Study instruments (Data collection tools)

For this research, a variety of data collection tools will be used to measure both environmental factors and occupant perceptions of thermal comfort. The tools selected are appropriate for the objectives of the study, ensuring that both quantitative and qualitative data can be gathered efficiently and accurately.

I. Environmental Measurement Instruments

For achieving unbiassed measurements of the environment, a calibrated measurement device shall be utilized. The device records the significant environmental parameters such as solar radiation, air velocity, humidity, and temperature having a direct influence on thermal comfort.

Temperature and Humidity Data Loggers: These will be used to measure indoor and outdoor temperature and relative humidity round the clock. Data loggers would be employed because they could give continuous consistent reading for a longer duration of time, which is needed to determine the fluctuation of environmental conditions in a day. Calibrated data loggers would give accurate and true readings, which is most critical to assess the extent of thermal comfort.

Figure 10 HTC-1 Thermo Hygrometer

Figure 11 Digital ThermoHygrometer with Probe

Anemometers: Air velocity measurements will be taken in various places of the selected health centers using anemometers. The anemometers are well suitable in the measurement of air flow, and this is one of the most important features when measuring natural ventilation and its influence on the rise of thermal comfort. By using measurement, it will be feasible to determine how airflow distribution takes place in the buildings and its relation to human comfort.

Figure 12 UT363/UT363BT Mini Anemometers

These instruments are firmly based on environmental science and were found to be valid and reliable when used with similar research. They are accurate in the quantification of the parameters needed for thermal comfort scores and are well established in prior research as validated.

II. Occupant Survey Instruments

For the qualitative component of this study, structured questionnaires will be administered to both healthcare staff and patients within the selected public health facilities. These questionnaires are designed to evaluate occupants' perceptions of thermal comfort, indoor air quality, and satisfaction with the existing natural ventilation systems.

The questionnaire aims to gather information on how natural ventilation—such as opening windows and doors—affects the comfort levels of building occupants. It includes questions that assess respondents' perceptions of room temperature, air movement, and freshness of the indoor environment. Additionally, it evaluates their overall satisfaction with air circulation in the absence of mechanical systems like air conditioners or fans.

Many questions employ a Likert scale format, allowing respondents to express their level of agreement or disagreement with statements related to comfort. For example, a statement like "The room is comfortable" may be rated from "Strongly Disagree" to "Strongly Agree," providing a straightforward way to quantify subjective feelings.

The questionnaire also collects basic demographic and contextual information, such as the respondent's role, department, and typical duration spent in a particular room. This data enables analysis of how perceptions of thermal comfort may vary according to job function or workplace environment. The qualitative responses will be analyzed alongside measured physical parameters—such as temperature and airflow—to offer a comprehensive understanding of the effectiveness of natural ventilation in maintaining comfortable indoor conditions.

III. Validity and Reliability

The equipment used during this study were selected based on proven reliability and common use within similar studies involving natural ventilation and thermal comfort. For gathering information that is objective, tools such as anemometers and data loggers were used. They have been deemed to be precise and reliable to use in checking the environment and are commonly employed in field investigations and scholarly endeavors.

For subjective assessment, semi-structured questionnaires were prepared to capture occupant perceptions of thermal comfort and ventilation effectiveness. To ensure continued confidence in the instruments' reliability, a pilot survey involving a small number of respondents from healthcare facilities outside the scope of the main study was conducted. The pre-testing exercise allowed for the identification of vague or ambiguous questions, which were then reworded to improve clarity and consistency.

Through the application of field-tested scales and a formal pilot-testing protocol, the study could be certain that both objective scales and subjective comments were reliable and properly calibrated to the study environment.

3.10 Data Collection Methods

This study used two main methods of gathering data: field surveys and occupant surveys. Both objective and subjective perceptions of individuals in the selected public health care facilities were captured using these methods.

To assess the effectiveness of natural ventilation, essential environmental measurements were obtained through field surveys. To assess the thermal environment within and outside, different physical parameters were monitored.__ Called data loggers were strategically placed both inside and outside the buildings to record temperature and humidity continuously. With minute details provided by the measurements, it was possible to compare indoor and outdoor climatic conditions directly, as well as assess the degree to which natural ventilation managed temperatures/humidity levels.

Portable anemometers were utilized to gauge air velocity at different points in the healthcare facilities. These measurements were used to evaluate the airflow distribution and effectiveness in various rooms, as it is a crucial aspect of thermal comfort, particularly in terms of improving evaporative cooling in hot climates.

The analysis of architectural factors that affect natural ventilation involved the collection of comprehensive building information, as well as environmental monitoring. To understand the spatial layout, including the orientation of windows, size and placement of ventilation openings, and overall layout for a project that covered several architectural drawings, they were used. In addition to these documents, there were also on-site observations and photographic documentation of physical characteristics such as window treatments, facade treatments or the spatial relationships of interior spaces. Through the use of this data, a comprehensive evaluation of existing ventilation techniques was conducted, with attention paid to design elements that either enabled or discouraged natural ventilation.

Furthermore, assessments were carried out to gauge the external factors that could impact ventilation performance, such as the influence of nearby structures, flora, and wind patterns. In the healthcare facility being examined, detailed field surveys revealed that the effectiveness of natural ventilation is influenced by environmental factors as well building design and external influences.

3.11 Data Analysis

Subjective comfort of users and environmental parameter measurements that composed the thermal comfort were the study's data gathering. Humidity and temperature were monitored using hygrometers and thermograms, anemometers to determine wind speed, and solar meters to determine daylight in order to measure environmental parameters that affect natural ventilation and thermal comfort in the selected healthcare buildings. Instruments are selected on the basis of accuracy and access. They are applied on a major scale in ecological monitoring research (e.g., Hunashal et al., 2012; Fiedler et al., 2015).

Measurements were taken at different times of a day to account for day-to-day compensation for thermal comfort due to diurnal variations. Time of day of measurement was identical for two time periods — morning (8:00 AM-11:00 AM), afternoon (1:00 PM-4:00 PM), — to account for day-to-day variations in indoor conditions due to day-to-day variations in external weather, sun, and use patterns of the building.

However on site, measurements were really only performed twice daily, morning and afternoon sessions. There was no evening or night time measurement due to security issues and hazard at night time at the site. That was limiting the study because it was not allowing captures of an assessment of thermal comfort conditions for the night time period when ventilation behavior and thermal loads would be quite different from daytime.

Readings were taken every 15 minutes at every point and conditions were measured once a minute while there were sampling break times for checking. This is in keeping with practice in environmental studies (e.g., Goshu et al., 2017; Baloye et al., 2015), which can yield repeatable and like-for-like measurements between location and time.

Environmental data was examined in relation to determining the effect that natural ventilation has on thermal comfort. Descriptive statistics were initially employed to provide the required parameters, i.e., mean temperature, humidity, and airflow for all healthcare facilities. For reproducing variability of environmental conditions, percentile values of temperature and humidity, i.e., L10, L50, and L90, were calculated. The L10 is the temperature or humidity level exceeded by only 10% of measuring time and is generally associated with extreme conditions. L50 is the mean and provides a central estimate of the environment, and L90 is the value that is exceeded 90% of the time and provides the most representative environmental conditions.

The percentile values of these were then utilized to contrast the crucial parameters like the Equivalent Temperature (Teq), or equivalent continuous temperature experienced by occupants, and takes into account both temperature of air and humidity. The Thermal Comfort Index (TCI), a multi-dimensional temperature, humidity, and air flow index, was also computed to quantify overall thermal comfort.

Comparative statistical tests for studying variation in thermal comfort between different healthcare centers were comparative statistical analysis tests. ANOVA (Analysis of Variance) was applied while comparing the extent of thermal comfort between different facilities based on size, design, and the location of building. Kruskal-Wallis H test was applied while comparing non-normally distributed information between different healthcare facilities to study whether or not there were significant differences in the extent of thermal comfort. In addition, correlation analysis was used to identify the correlation between environmental conditions (airflow, temperature, humidity) and occupants' satisfaction with thermal comfort.

The pilot survey was further carried out for verification of data on a small sample of residents of healthcare facilities before executing the main study. The pilot detected the identification of any weakness with the questionnaire, i.e., ill-phrased or unclear questions, and offered scope for correction Analysis was carried out for SPSS (Statistical Package for the Social Sciences) for higher-level statistical computations and for Microsoft Excel for preliminary data management and calculation of formulae. These packages on computers helped speedy management of data and statistical results generation to be computed.

3.11.1 Assessment of Existing Natural Ventilation Conditions

Airflow Direction and Floor-to-Opening Ratio (FOR)

Two primary parameters were considered in measuring the current natural ventilation condition: airflow direction and floor-to-opening ratio (FOR).

Airflow Direction

Airflow direction in the healthcare areas was determined by analyzing the indoor and outdoor temperature gradient and opening positions. This analysis was used to conclude the presence of stack-driven (buoyancy) airflow due to air density differences caused by temperature differences.

Floor-to-Opening Ratio (FOR)

Dimensional data (length, width, height) of the selected rooms were used to prepare accurate floor plans and 3D models. All the openings (doors and windows) were considered and their areas computed to determine the floor-to-opening ratio (FOR). This FOR was expressed as a percentage and tabulated for comparison. The FOR provides an indication of the potential cross-ventilation and air exchange potential in each space.

3.11.2 Estimating Natural Ventilation Rate (NVR) and Air Changes per Hour (ACH)

To determine ventilation performance, Natural Ventilation Rate (NVR) and Air Changes per Hour (ACH) were calculated using on-site air velocity measurements and opening sizes with simplified "rule of thumb" equations.

The equations were as follows:

$$\textbf{ACH} = \frac{0.8 \times V\text{ air (m/s)} \times A\text{ inlet (m}^2) \times 3600\text{ s/h}}{\text{Room volume (m}^3)}$$

Where:

ACH = Air change rate (experienced in volume of room/Number of patient's air change per hour)

V air = average air velocity at inlet (m/s)

A inlet= smaller area of the inlet (m^2)

Room Volume = Room total volume (m^3)

NVR (l/s) = 0.800 × V air (m/s) × A inlet (m^2) × 1000 l/m^3

Where:

NVR = Natural ventilation rate in liters per second (l/s)

The relationship between NVR and opening sizes, and ACH and FOR was researched and displayed in graphs. The values were then compared with minimum WHO-recommended ventilation norms and Ethiopian Infection Control Guidelines for Healthcare Facilities.

The following minimum hourly average ventilation rates were used as standards:

- ✓ 160 l/s/patient for airborne precaution rooms
- ✓ 60 l/s/patient for general wards and outpatient departments

The obtained values were verified for all space types to determine whether the dominating natural ventilation conditions were sufficient enough to ensure thermal comfort and functional suitability according to healthcare standards.

3.12 Ethical Considerations:

The study emphasized the importance of ethical principles to ensure that all participants' privacy, rights, and well-being were fully protected. Consent was obtained from all participants before the data was collected. To guarantee a thorough understanding, the purpose of the study was explained in simple terms, along with the procedures and participants' rights, including the right to withdraw at any time without any negative consequences.

All phases of the research were conducted with complete confidentiality. The confidentiality of demographic and survey information was maintained to a minimum. The details were made anonymous to prevent any association with individual participants. No individual was identified in the final outputs as all data was aggregated for analysis and reporting.

In order to ensure the safety and security of data, password-protected devices were used to store all electronic data collected through questionnaires and environmental monitoring tools, which could only beaccessed by the lead researcher and authorized research team members. Authentic documents, such as consent forms and other sensitive information were stored in locked cabinets for the purpose of security.

Prior to starting the fieldwork, ethical clearance from the relevant Institutional Review Board (IRB) was obtained. Those findings were subject to review by the IRB, which also granted approval for its study methodology and consent procedures as well as protocols for confidentiality and data protection. After obtaining this approval, the research was conducted in compliance with the approved ethical standards.

The ethical guidelines of the study ensured that academic integrity and professionalism were maintained while ensuring the privacy, autonomy, and rights of all participants were fully protected.

CHAPTER-FOUR

RESULT AND DISCUSSION

4.1 Introduction

This chapter chronicles and illustrates the outcome of environmental observation, site observation, and questionnaire data gathered in some of the selected public health facilities in Adama. Results are presented and addressed to determine natural ventilation effectiveness in providing indoor thermal comfort in the semi-arid climatic condition of the region. The chapter is organized in thematic sections for exterior environmental performance, interior thermal performance, cross ventilation performance, occupant satisfaction, and architectural details effects such as shading devices and envelope material. Having combined quantitative data with qualitative responses, it is the concern of this chapter to construct a complete image of how natural ventilation is improved to increase thermal comfort in healthcare facilities and how certain environmental and design factors influence its performance.

4.2 Respondents' Profile

34 participants were involved in the occupant survey conducted at sample public health centers in Adama. The sample included a mix of healthcare workers, patients, and visitors to offer a diverse selection of perceptions regarding indoor thermal comfort.

Breakdown of respondents by professional occupation and user category is as below:

- ✓ Doctors: 3 participants (8.8%)
- ✓ Nurses: 11 participants (32.4%)
- ✓ Administrative Staff: 6 participants (17.6%)
- ✓ Maintenance/Technical Staff: 4 participants (11.8%)
- ✓ Patients: 7 participants (20.6%)
- ✓ Visitors: 3 respondents (8.8%)

This stratification indicates variations in exposure and time spent in different sections of the healthcare facilities. Nurses, who worked predominantly in patient wards, formed the majority of the staff. Physicians, relatively fewer in number, provided clinical input, and administration and maintenance staff contributed from office and support areas. Patients and visitors, as temporary residents, gave useful comment on perceived thermal comfort during residence.

The mix of residents included ensured that the research was able to get a general perception of how measures of ventilation and design of the building affect thermal comfort for different groups of users in the health environment.

4.3 Architectural Documentation and Site Observations

This chapter outlines the architectural aspects of the selected public healthcare buildings in Adama, i.e., the effect of natural ventilation on thermal comfort. Estimating the effect of architecture on ventilation, the study categorizes the healthcare buildings according to crucial aspects such as orientation, window position, window size, ventilation components, and material.

The health centers were investigated with their room orientation, building alignment, and window position in mind. The factors contribute to playing a major role in making up the impact of airflow and indoor thermal comfort in the buildings. The cross-ventilation layout and window-to-floor ratio were specifically given attention with respect to how they influence indoor thermal conditions. Window direction relative to prevailing wind directions also had an impact on the assessment.

Materials used in construction that affect building thermal mass and indoor temperature control ability were also considered in the research. Openness of corridors, ceiling height, and overall spatial planning were monitored closely since they affect the performance of natural ventilation systems.

The study utilized Federal Ministry of Health (FMoH) prototype health center designs applicable in any climate with the use of GTZ implementation support. This provided a universal reference point on how the architectural building design of healthcare facilities compares to natural ventilation designs. The buildings were classified to depict various architectural designs, and the objective was to examine how each design impacts thermal comfort and ventilation performance in the context of Adama's climate.

The following diagram shows some of the health center prototype plan drawn up by the Federal Ministry of Health (FMoH) for every climate, funded by the implementing agency GTZ. The plan includes maternity and inpatient wards with separate areas for male and female patients.

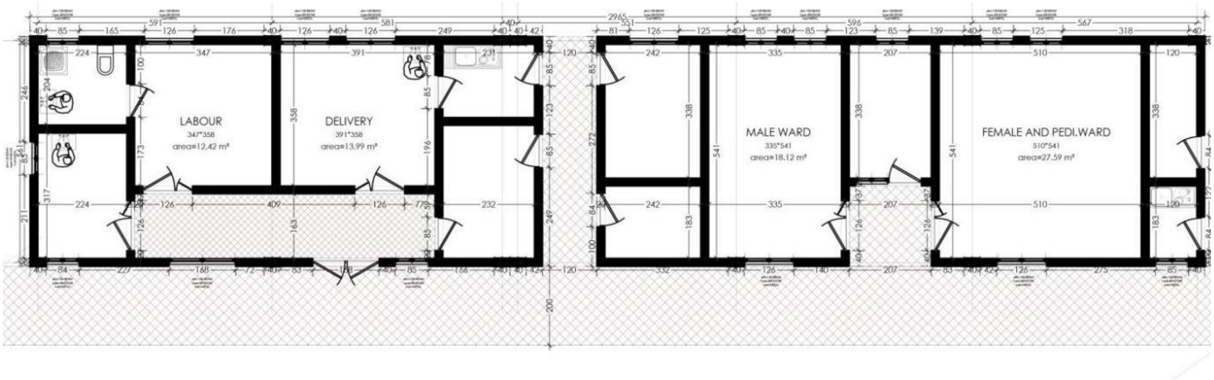

Figure 13 inpatient/maternity block prototype plan for all climates (Source:Federal Ministry of health(FMOH)

The maternity block is designed to support a range of essential functions related to maternal care. It includes a preparation room for initial assessments and readiness before labor, a labor room where mothers are prepared and monitored during the stages of labor, and a delivery room designed for the actual childbirth process. Adjacent to these spaces is a sluice room, which serves as a hygienic area for the disposal of medical waste and cleaning. The sterilization room ensures that medical equipment is properly disinfected, maintaining a sterile environment essential for patient safety. Finally, a bathroom is provided for both staff and patient use, offering necessary privacy and convenience.

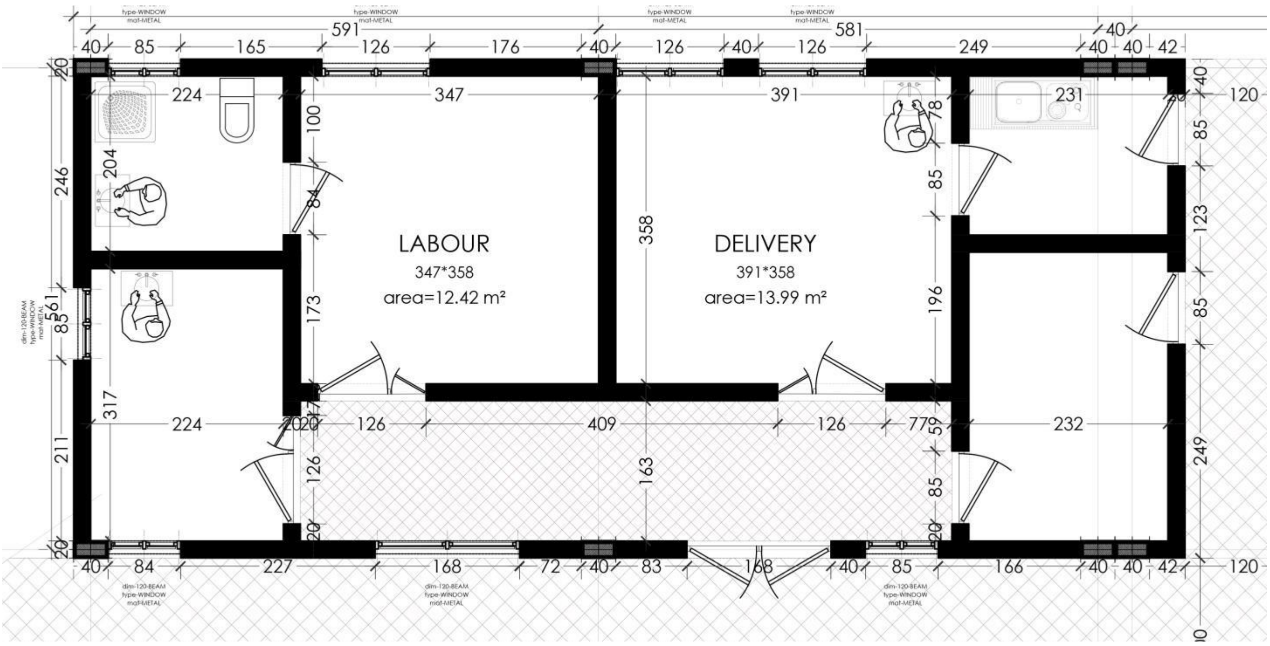

Figure 14 maternity block prototype plan (Source:Federal Ministry of health(FMOH)

Figure below shows the layout of the male and female wards, which are separated by a nurse station positioned centrally between the two. This nurse station serves as the main point for monitoring and assisting patients, ensuring accessibility and efficiency in care. Each ward is designed to accommodate multiple patients, with careful attention to room layout and circulation

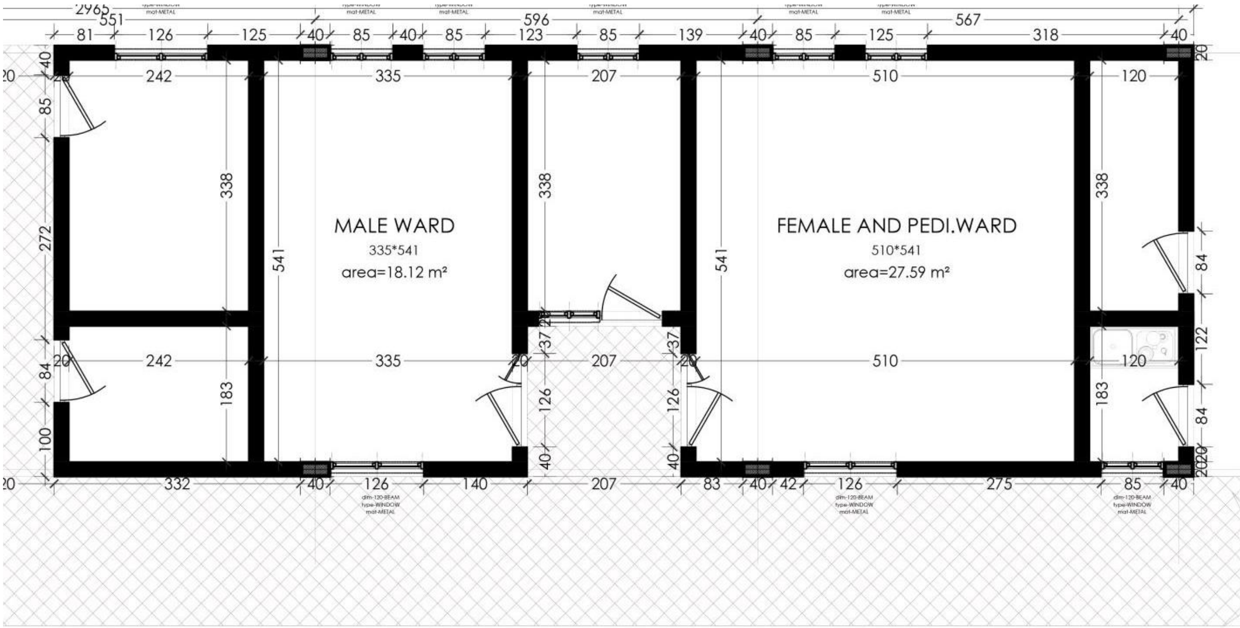

Figure 15 ward block prototype plan (Source:Federal Ministry of health(FMOH)

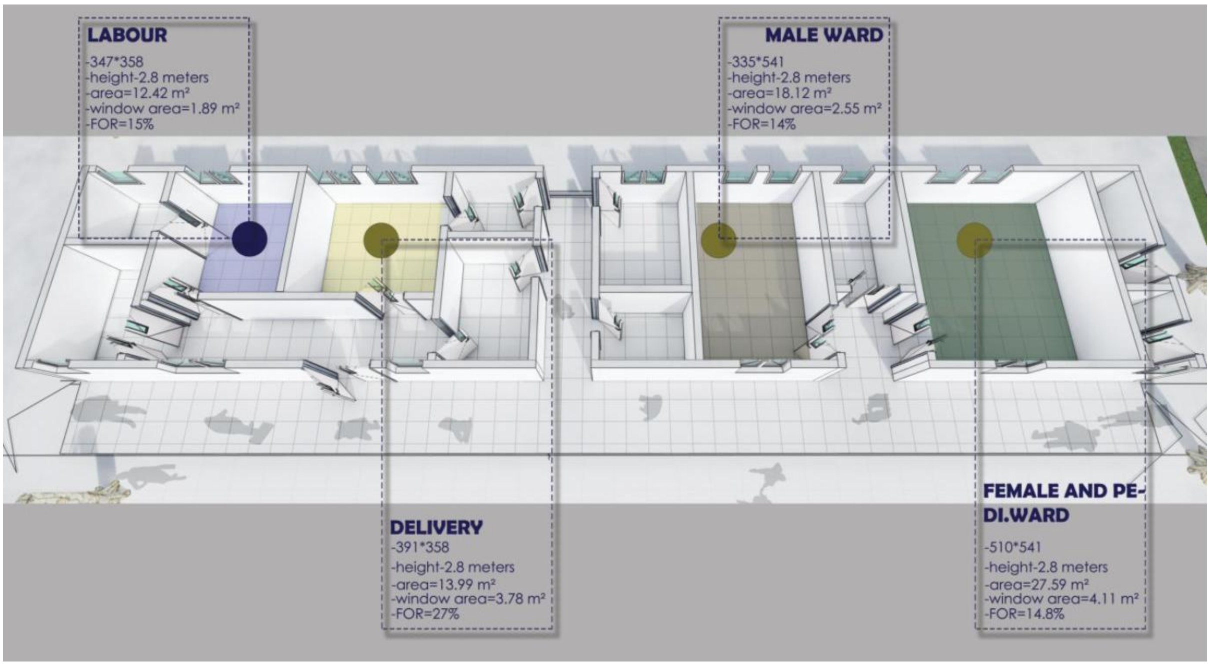

Figure 16 inpatient/maternity block prototype plan for all climates details(Source:Federal Ministry of health(FMOH)

During site visits to the chosen public health facilities in Adama, it was observed that the majority of the inhabitants had come up with temporary solutions to protect themselves from the strong sunlight that passed through the windows. In several rooms, the top or west-facing portions of windows were coated with opaque materials or were covered with paper and cardboard sheets. These makeshift coverings were typically affixed to the glass directly with tape or other simple means. The primary intent of these interventions appeared to be to moderate the level of solar heat gain and to restrict direct glare, especially during mid-day and afternoon hours when indoor temperatures were discovered to be highest. Where exterior shading devices or reflective window treatments did not exist, these changes were the only method of diminishing thermal discomfort.

While such changes reduced indoor overheating, they had unwanted side effects such as limiting daylight and obstructing airflow from windows. In a small number of cases, coverings were inclusive enough to keep almost the entire window surface area, which detracted from daylight access and cross-ventilation possibilities. These results point to an even greater concern with building design: the inability to include locally climate-suited passive solar control strategies. What the users were doing—albeit informal and in no sense systematic—registered a distinct call for design solutions that can more effectively address solar protection, ventilation, and daylight requirements in high intensity sunlight environments in healthcare.

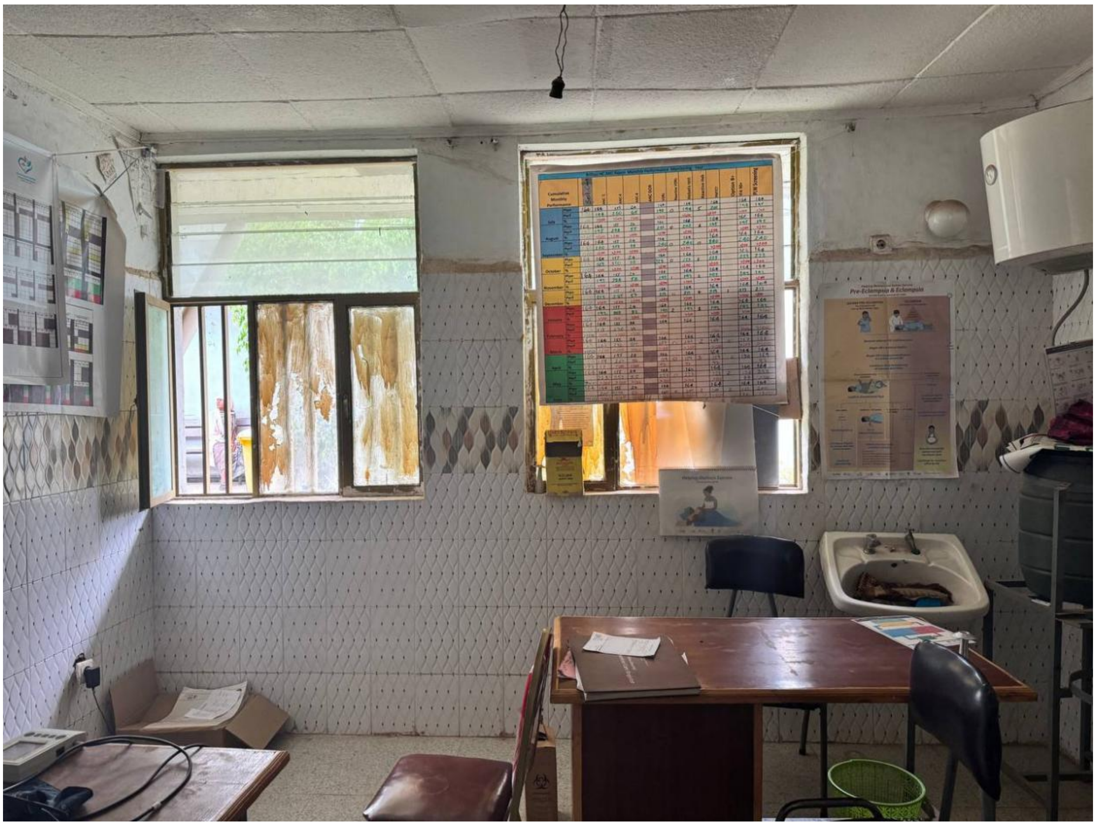

Figure 17 Occupants painting part of a window to block direct sun exposure

In one of the laboratories under investigation, the original architectural design provided cross ventilation through windows on opposite walls. Proper ventilation was significantly reduced since large equipment in the labs was placed directly in front of one of the primary ventilation openings. The blockage limited the passage of incoming or outgoing air, disrupting the planned cross-ventilation path and creating stagnant conditions within. Despite the secondary window on the other wall, the partial blockage reduced total air exchange, causing much warmer indoor temperatures and inadequate air flow. In response, the residents covered parts of the remaining open window with cardboard and paper to shield themselves from the direct sun, which additionally reduced airflow and natural light. The case refers to an inherent contradiction between functional space requirements and environmental performance. Although the space had been designed to allow for natural ventilation, the working design—namely the positioning of fixed plant—undercut the strategy and forced occupants to use ad-hoc measures in an attempt to restore comfort. This case is remarkable in emphasizing the importance of linking interior space planning with passive ventilation strategies in spaces requiring thermal control and technical equipment.

Figure 18 Laboratory with analytical equipment placed directly in front of a ventilation window.

4.4 Overview of Selected Facilities

4.5 SOUTH-FACING ROOMS AND THEIR THERMAL COMFORT RESPONSE TO NATURAL VENTILATION

A. Biftu Health Center

The main façade and most of the patient wards, including the delivery, labour, male, and female/pediatric wards, receive direct solar radiation in the south since Biftu Health Centre is orientated mostly south. Long stretches of intense sunlight are produced by this direction, particularly in the late morning and late afternoon. At least in warmer climates, this orientation is suboptimal for thermal comfort even though it might be ideal for daylighting.

Figure 19 Biftu Health Center (source, Google Earth Pro)

Room	Date	Time	Exposure Direction	Window -to-Floor Ratio	Temp. Closed Window (°C)	Temp. Opened Window (°C)	Humidity (%)	Outdoor Temp. (°C)
delivery	5-May	3:00 AM	South (Harsh Sun)	0.27	29	27.2	58	26.1
	6-May				29.8	26.1	79	21.2
labour	5-May	3:30 AM	South (Harsh Sun)	0.15	27.5	26	59	28.6
	6-May				32	27.8	78	22.6
Male ward	6-May	10:50 AM	South (Harsh Sun)	0.14	31	27	75	27.2

Table 4 Biftu health center Investigation Table

The main façade and most of the patient wards, including the delivery, labour, male, and female/pediatric wards, receive direct solar radiation in the south since Biftu Health Centre is orientated mostly south. Long stretches of intense sunlight are produced by this direction, particularly in the late morning and late afternoon. At least in warmer climates, this orientation is suboptimal for thermal comfort even though it might be ideal for daylighting.

The table gives a summary of a series of measurements taken in the site to assess thermal comfort and natural ventilation performance within some wards of a public health facility. The site measurements range from two consecutive May days from the delivery room, through the labour room, to the male ward. All indoor observation temperatures under two scenarios—open and closed windows—except for a couple of other important variables such as relative humidity, outdoor temperature, window-to-floor ratio, and room orientation. All the rooms cited are south-facing, thereby exposing them to high solar radiation from morning to evening. This southerly orientation is most strongly evident in relation to its impact on receiving heat and, therefore, thermal discomfort unless reduced by effective ventilation controls.

It was recorded at 3:00 AM on May 5 and May 6 in the delivery room. Its 0.27 window-to-floor area ratio is a rather balanced degree of provision of opening for natural ventilation. Under closed window condition, indoor temperature on 5 May was 29°C, which fell to 27.2°C when windows were kept open for about a minute. That is 1.8°C drop due to natural ventilation effect. The next day the ventilation effect was still stronger: temperature fell from 29.8°C to 26.1°C, i.e., 3.7°C. The humidity between the two days also varied, at 58% on the first and 79% on the second. The ambient temperature fell significantly to 21.2°C on May 6, which would have acted to enhance air cooling by virtue of air infiltration through the open windows.

It also appeared in the labour room at around 3:30 AM on the same dates. This room also contained a lower window area to floor area ratio of 0.15, i.e., more limited window area than floor area. Thus, the influence of natural ventilation was less than in the delivery room but significant. On May 5, indoor temperature dropped from 27.5°C (closed windows) to 26°C (open windows) with a cooling effect of 1.5°C. By day six, the variation was larger: 32°C for closed windows and 27.8°C for open windows, with a drop of 4.2°C. The relative humidity from 59% on day one to 78% on day two increased, and the ambient temperature also decreased from 28.6°C to 22.6°C, matching that of the delivery room.

There was a single reading at the male ward on May 6 at 10:50 AM, late morning when solar radiation would be most intense. The room also has the lowest window-to-floor ratio of the rooms measured, 0.14, and thus lowest passive ventilation potential. But the window opening cooling effect was highly notable: indoor air temperature dropped from 31°C to 27°C, by 4°C.". This highlights the major contribution of small openings in ventilation to improved thermal comfort, particularly where outdoor conditions are amiable. At this observation time, there was 75% relative humidity outside, and outside the temperature was 27.2°C, slightly lower than indoor temperature in case windows were closed.

In general, the table demonstrates how natural ventilation can cool, most strongly when outdoor temperatures are lower than interior conditions. The results also show that window-to-floor area directly leads to the degree of temperature reduction so that those with a higher ratio have more substantial gains in thermal comfort. The results also show the challenge of maintaining comfort in south orientation areas under hot conditions, especially in mechanically air-conditioned buildings. These results support the contention that design strategies for improving natural ventilation—such as enlarging windows, reducing air flow directions to optimize, or making cross ventilation easier—can have considerable positive impacts on thermal comfort in public health buildings.

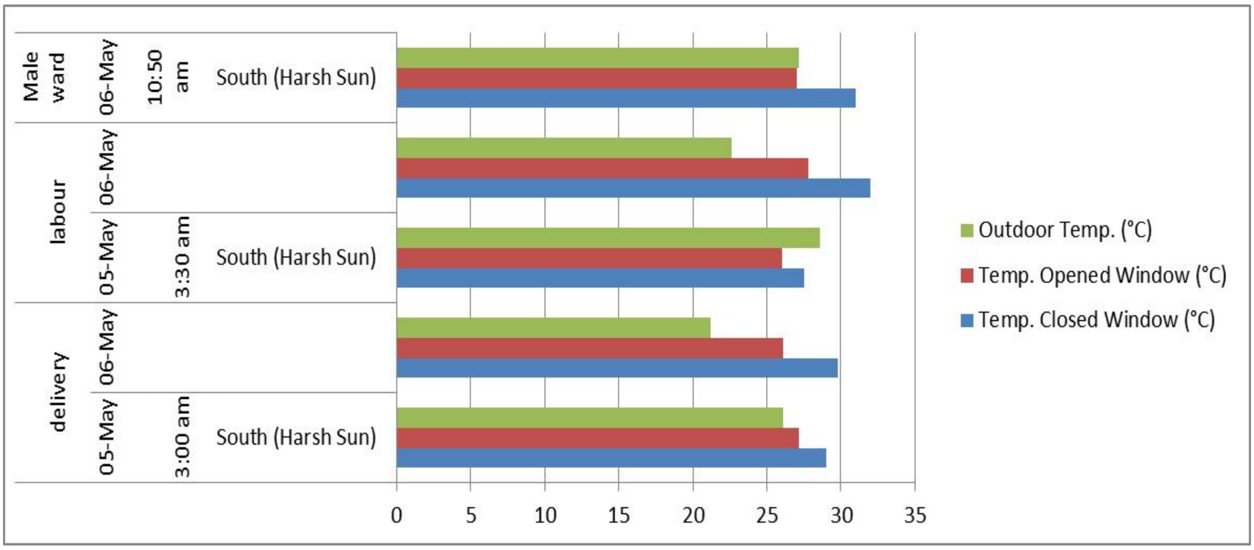

Figure 20 temperature differences when windows are closed and kept open in biftu health center (source, field survey)

The graph indicates the variation of indoor temperature in two conditions: when windows were kept closed and when windows were opened. For all the rooms being monitored—i.e., delivery room, labour room, and male ward—temperature always decreased when windows were open. Decrease in temperature indicates the influence of natural ventilation on indoor thermal comfort. For instance, in a delivery room, temperature fell from 29.8°C to 26.1°C when windows were opened. Similar trends were observed in the labour and male ward rooms where open windows reduced the peak temperatures by 3–4°C. The above findings evidently reveal that natural ventilation is largely responsible for cooling the indoor climate, especially in sun-exposed parts of the building.

B. Hangatu/Gendegara Health Center

Hangatu Health Center is a government health center located near Adama Science and Technology University and acts as a lifeblood to medical treatment in the region. The center treated approximately 55,693 patients in the past ten months, which reflects its function in providing primary healthcare services to the region. The building is south-oriented similar to Biftu Health Center, where the main wards and treatment areas face direct southern sun. Orientation impacts daylighting and

Figure 21 Hangatu Health Center (source, Google Earth Pro)

thermal performance and thus the building is highly susceptible to heat gain during peak sun hours, especially for areas with minimal shading or poor cross-ventilation.

Hangatu Health Center typically handles outpatient consultations, maternal services (including delivery and postnatal), and small inpatient treatment. Being located adjacent to the university also renders it easily accessible for workers and students, who tend to have it as a first point of contact for consulting physicians. Layout and ventilation status make it an interesting case study for the evaluation of natural ventilation and thermal comfort strategies in hot climate regions.

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Humidity (%)	Outdoor Temp (°C)
Laboratory	05-May	4:30 am	South (Harsh Sun)	0.17	28.7	26	88	16.5
Laboratory	05-May	2:30 pm	South (Harsh Sun)	0.17	32.5	29	75	24.5
Laboratory	07-May	4:30 am	South (Harsh Sun)	0.17	34	30.1	80	22.1
Laboratory	07-May	2:30 pm	South (Harsh Sun)	0.17	31	28.4	78	26.8
Ward	05-May	9:30 am	South (Harsh Sun)	0.14	29.5	26.5	70	21.3
Ward	05-May	3:00 pm	South (Harsh Sun)	0.14	31.2	28.2	68	27
Ward	07-May	9:30 am	South (Harsh Sun)	0.14	27.1	28.8	87	16.8
Ward	07-May	3:00 pm	South (Harsh Sun)	0.14	29	27.5	85	22.4

Table 5 Hangatu health center Investigation Table

At 4:30 AM on May 5, the laboratory measured an indoor temperature of 28.7°C with the windows closed. When windows were opened, the indoor temperature went down to 26°C, a reduction of 2.7°C. By a quirk, it was also the time of early morning light rain, as confirmed by the extremely high indoor relative humidity of 88% with relatively low outdoor temperature of 16.5°C. Rain effect has a unique function here: the greater ambient humidity, lower external air temperature, and lower solar radiation caused by the canopy of the clouds favored the comfort of natural ventilation to cool the interior.

Similarly, the ward, at 9:30 on the same day, had a reduction in temperature from 29.5°C (windows closed) to 26.5°C (windows open). Indoor relative humidity at that moment was 70%, and external temperature was 21.3°C. These readings once again show the effect of outside weather and ventilation: despite increasing sunshine and increasing outdoor temperatures, indoor temperatures were maintained within relatively acceptable ranges because windows were open.

It was much different on May 7th. The ambient boundary conditions were also warmer and drier with no trace of rain. Indoor lab temperature was highest at 34°C with the windows closed and lowest at 30.1°C when the windows were open, demonstrating a cooling effect of 3.9°C.

Whilst ventilation brought indoor temperatures down, it was less so than on May 5th—most likely because of higher outdoor air temperatures and reduced movement of wind after passage rains. Relative humidity remained at 80%, maybe because of the atmosphere holding on to residue moisture.

Inside the ward, the reverse was the case. To the surprise of everyone, the opening of windows resulted in a minor rise in temperature to 28.8°C from 27.1°C, the opposite of what is expected as a cooling effect. The reason for this is because the warmer external air came into the building at the time and extra heat gained on the south facade. Relative humidity was also still high at 87% and could have been because of the retention of moisture and inadequate ventilation.

Interpretation

Hangatu Health Center findings highlight some key observations. First, natural ventilation can significantly reduce indoor temperatures—particularly when the outdoor temperature is lower than indoor temperature, i.e., during morning and rain. Second, meteorological conditions such as light rain, which dampen solar radiation and introduce cold air, contribute enormously to enhancing the efficiency of natural ventilation. Thirdly, although the fairly low window-to-floor ratios (0.14–0.17) were present, ventilation was occurring, proving that even quite modest-sized openings are capable of playing a gigantic role in thermal comfort if situated and put to use in the best possible way.

The south exposure, while in general subject to heat in this climate, can be compensated for by best-designed ventilation systems. The above performance fluctuation—particularly on May 7th—also demonstrates the limitation of natural ventilation to particular climatic conditions, an urgency to incorporate complementary passive and active design options in future health facility planning.

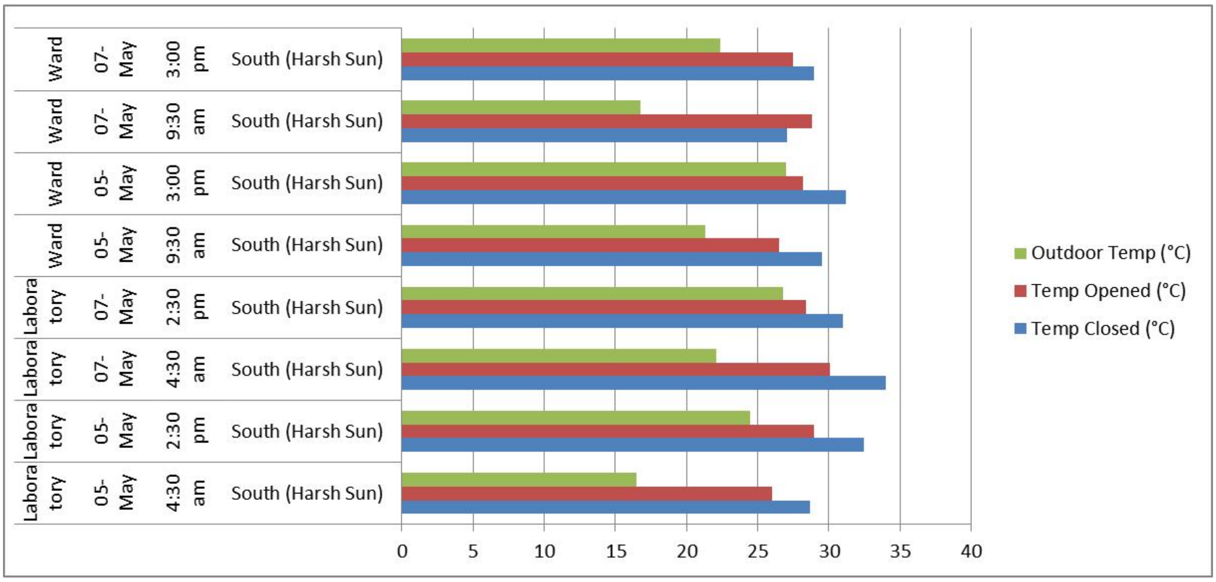

Figure 22 temperature differences when windows are closed and kept open in Hangatu health center (source, field survey)

The graph illustrates the variation of indoor temperature at Hangatu Health Center in two ventilation conditions: when the windows are closed and when they are opened. From the data, one obvious trend is noticeable—continuously opening the windows decreases the indoor temperature in the laboratory and the ward rooms. The greatest drop occurs on May 7th in the laboratory, where the temperature decreased by nearly 4°C when the windows were opened. On May 5th, there was light rain, and the natural ventilation effect was also evident, with both rooms demonstrating apparent cooling. These results emphasize the importance of operable windows in encouraging thermal comfort, especially where there are favorable outer conditions for cross-ventilation.

C. Boku Shenen Health Center

Boku Shenen Health Center is a public health facility located in the southeastern part of Adama city, within the Boku Shenen Subcity. Located in a growing residential area, the center functions as an essential service provider of fundamental medical services for the population surrounding it. Over the past 10 months, it provided treatment to 60,717 patients.

Figure 23 Boku Shenen Health Center (source, Google Earth Pro)

The health center is based on the prototype model of the Federal Ministry of Health, with standard features such as outpatient consultation rooms, inpatient and maternity wards, laboratory units, and staff support facilities. Like Biftu and Hangatu Health Centers, Boku Shenen also faces south direction, where the main patient wards and rooms receive solar radiation for the greater part of the day. This orientation considerably affects internal thermal conditions, particularly when exposed to high sunshine, and natural ventilation measures are imperative to sustain indoor comfort levels.

These findings, complemented by temperature records from south window-facing rooms, indicate that the opening and closing of windows have the capability to affect indoor conditions substantially. The architectural layout and orientation of Boku Shennen Health Center thus not only ease its health-related functions but also become pivotal in evaluating and maximizing thermal comfort through passive design.

In summary, Beku Shennen Health Center remains a significant health service provider in southeastern Adama, balancing high turnover in patients with climatic factors impacting comfort as well as the provision of services..

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Humidity (%)	Outdoor Temp (°C)
Delivery	05-May	7:00 am	South (Harsh Sun)	0.27	29	27.3	58	26.1
Delivery	05-May	2:30 pm	South (Harsh Sun)	0.27	31.5	28.7	50	29.4
Delivery	06-May	7:00 am	South (Harsh Sun)	0.27	28.8	26	60	25.5
Delivery	06-May	2:30 pm	South (Harsh Sun)	0.27	30.7	27.8	52	28.7
Labour	05-May	7:30 am	South (Harsh Sun)	0.15	27.5	25.8	59	28.6
Labour	05-May	2:00 pm	South (Harsh Sun)	0.15	29.8	27.1	55	30.2
Labour	06-May	7:30 am	South (Harsh Sun)	0.15	27	25.4	62	26.9
Labour	06-May	2:00 pm	South (Harsh Sun)	0.15	30.5	28	54	29.7
Male ward	05-May	8:00 am	South (Harsh Sun)	0.14	30	26.5	63	27.8
Male ward	05-May	3:00 pm	South (Harsh Sun)	0.14	32	28	57	31
Male ward	06-May	8:00 am	South (Harsh Sun)	0.14	29.5	26	65	27.3
Male ward	06-May	3:00 pm	South (Harsh Sun)	0.14	31.7	27.6	58	30.4

Table 6 Boku Shenen health center Investigation Table

The May 5-6 measurement data at the Boku Shennen Health Center are affluent in regard to natural ventilation's influence on the indoor thermal climate under intense solar irradiation from the south direction. The measurements were made twice a day in three large rooms: Delivery, Labour, and Male Ward. The rooms have varying window-to-floor ratios (WFR), from 0.14 to 0.27, and receive direct solar radiation from south direction.

In Room with maximum window-to-floor ratio of 0.27, indoor temperature always decreased with the opening of windows. In the morning of May 5, the temperature decreased from

29.0°C with closed windows to 27.3°C with ventilation, the 1.7°C cooling effect. In the afternoon, temperature of 31.5°C with window closure decreased to 28.7°C with ventilation, the decrease of 2.8°C. The same was encountered the next day with lower morning temperatures from 28.8°C to 26.0°C and afternoons from 30.7°C to 27.8°C. Room relative humidity was 50% to 60%, and ambient surrounding temperatures varied from mid-20s in the morning to high 20s and low 30s in the afternoons. The readings above show that the wider window area provided an easy means of air exchange as well as temperature cooling, lessening some of the impacts of strong sun radiation. The Labour room with lower WFR of 0.15 also experienced a lot of cooling by natural ventilation.

May 5, indoor temperature reduced from 27.5°C to 25.8°C in the morning and from 29.8°C to 27.1°C in the afternoon when windows are open. May 6 experienced the same drops: 27.0°C to 25.4°C during the morning and 30.5°C to 28.0°C during the afternoon. Indoor 54% and 62% humidity, external temperature rising from approximately 27°C during the morning to more than 30°C in the afternoon. Although fewer in the number of windows, the Labour room proved the efficiency of natural ventilation in thermal comfort in hot season. The Male Ward, with the lowest of 0.14 floor area per window area ratio, showed the maximum temperature drops during ventilation.

Morning room temperature in May dropped from 30.0°C to 26.5°C and afternoon room temperature dropped from 32.0°C to 28.0°C—drops of 3.5°C and 4.0°C, respectively. On the 6th of May, these cooling trends were also observed with morning temperature drops from 29.5°C to 26.0°C and afternoon temperature drops from 31.7°C to 27.6°C. The relative humidity over the area was also increased from 57% to 65%, while exterior temperatures ranged from 27.3°C to 31.0°C. This means that apart from room planning, ventilation performance may be literally determined by parameters like room planning, air motion pattern, or cross-ventilation and not window width in itself. In the majority of the cases, the result is that natural ventilation can cool indoor temperatures in all the rooms by reductions ranging from approximately 1.6°C to over 4°C.

Cooling is even felt in the midst of sun hours, observing the working of ventilation as a viable mechanism of building cooling under direct sunlight exposure. Although window-to-floor ratio is given significance, this aspect places in view that it is just one among the determinants of ventilation performance; direction of exposure, internal flow, and room geometry are some others. The comparatively high indoor humidity level is an indicator that ventilation does make a contribution to indoor moisture content, something to be considered in importance for health facility use of thermal comfort. These results reinforce the importance of well-designed natural ventilation for health facility planning and the understanding that there may be a need for additional passive or active cooling on hot days.

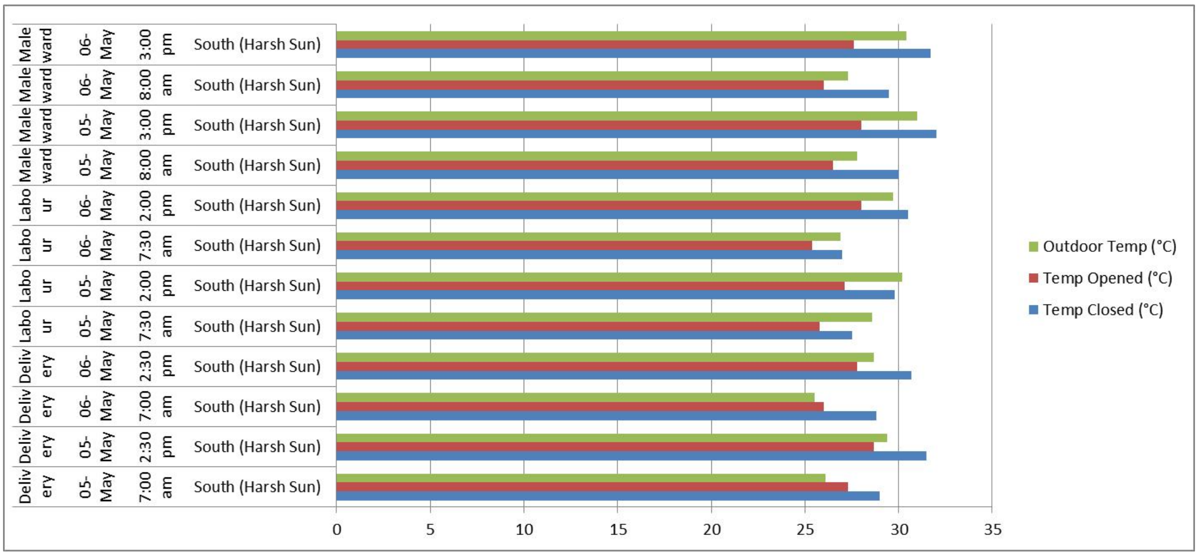

Figure 24 temperature differences when windows are closed and kept open in Boku Shenen health center (source, field survey)

The chart illustrates the indoor temperature range under closed and opened windows for three functional rooms—Delivery, Labour, and Male Ward—in Boku Shenen Health Center during two consecutive days, May 5 and 6. The readings for each room were conducted twice daily: in the morning and in the afternoon. Clustered bar chart is evident in the sense that continually opening windows continually lowered the indoor temperature, with the afternoons' readings showing generally higher temperatures because of the additional solar gain. For example, in the Male Ward afternoon of 5th May, temperature markedly dropped from 32°C (closed windows) to 28°C (opened windows) and showed a cooling effect of 4°C. Similarly, the Delivery room on both days witnessed drops from 2.0°C to 2.8°C when windows were open. Labour room, since it had the lowest window-to-floor ratio, also showed a steady drop in temperature when windows were open. The narrative focuses on the fact that natural ventilation enhances thermal comfort, especially during peak heat periods, and recommends its use as a passive cooling technique in structures with intense solar exposures. The extent of temperature reduction is also found to be dependent upon time of day, with greater differences usually found under hotter conditions in the afternoons.

4.6 SOUTH-WEST FACING ROOMS AND THEIR THERMAL COMFORT RESPONSE TO NATURAL VENTILATION

A. Hawas Health Center

Hawas Health Center is one of the influential government health centers located in the southeastern region of Adama, Ethiopia. Situated strategically in a growing peri-urban community, the health center is a key part of providing primary medical care to residents. Single-handedly in the past year, it has treated nearly 78,425 patients.

Figure 25 Hawas Health Center (source, Google Earth Pro)

The building is according to the Federal Ministry of Health standard prototype building with modifications to accommodate the local climate. The building is functionally divided into maternity and labor wards, general wards, consultation rooms, laboratory, and administrative offices. The building is equipped with southwest-facing windows, which is a rare architectural component that has considerable indoor environmental quality influence. The orientation subjects interior spaces to intense afternoon solar radiation that heats interior temperatures in the late afternoon peak time.

Looking at the warm arid climate of Adama, thermal comfort is of most concern. The building largely relies on natural ventilation, and windows are operable in an effort to maximize air flow. With fairly low window-to-floor area ratios (WFR), ventilation efficiency varies room by room. Exposure from the southwest, as good as it is for latter day natural lighting, creates a challenge when assessing passive cooling, particularly where there is not shading or cross-ventilation.

Step tests how effectively natural ventilation can function under such circumstances—specifically at peak occupancy, and external heat—is as crucial to deciding thermal comfort. The sheer volume of people the building services makes such a test even more critical because unsafe thermal conditions directly affect the health of the patients and the employees, as well as the quality of care provided.

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Humidity (%)	Outdoor Temp (°C)
Delivery	07-May	7:30 am	Southwest	0.26	28.5	26.3	64	24.8
Delivery	07-May	2:30 pm	Southwest	0.26	32.2	28.6	52	30.5
Delivery	08-May	7:30 am	Southwest	0.26	27.9	25.7	66	23.9
Delivery	08-May	2:30 pm	Southwest	0.26	31.5	28.1	54	29.8
Labour	07-May	8:00 am	Southwest	0.16	27.3	25.2	68	25.1
Labour	07-May	2:00 pm	Southwest	0.16	30.8	27.5	56	29.7
Labour	08-May	8:00 am	Southwest	0.16	27	25	67	24.5
Labour	08-May	2:00 pm	Southwest	0.16	30.2	27.2	55	29.1
Male Ward	07-May	8:30 am	Southwest	0.14	28.1	25.9	65	26.2
Male Ward	07-May	3:00 pm	Southwest	0.14	33	29.3	50	31.2
Male Ward	08-May	8:30 am	Southwest	0.14	27.6	25.5	66	25.5
Male Ward	08-May	3:00 pm	Southwest	0.14	32.4	28.7	53	30.8

Table 7 hawas health center Investigation Table

May 7 and 8 measurements at Hawas Health Center naturally determine the impact of natural ventilation on thermal comfort indoors at various points during a day and rooms. Measurements are made in three most critical functional rooms: delivery room, labour room, and male inpatient ward—all the three getting practically similar solar radiation due to their southwest orientation.

Morning room temperature in delivery room on 7th May started at 28.5°C with closed windows and dropped to 26.3°C with opened windows. Relative humidity was 64% and the room temperature was 24.8°C, showing that ventilation had been successful in letting cooler air in. Peak afternoon temperature was 32.2°C (closed) and minimum was 28.6°C (open), a drop of 3.6°C—though outside temperatures were greater (30.5°C), ventilation played a big role in minimizing indoor heat. On 8th May, the same pattern continued with a drop of 2.2–3.4°C in closed vs. open window conditions.

The labour room had low window-to-floor ratio (WFR) of 0.16 and also saw general falls in temperature due to ventilation. May 7 experienced morning temperature drop from 27.3°C to 25.2°C and afternoon from 30.8°C to 27.5°C, indicating ventilation efficiency even in minuscule gaps. In comparison with the delivery room, although the room had less ventilation capacity, the drops in temperature were not significantly different. Humidity was between 55–68%, which is within a comfortable level, and outside temperatures in the afternoon varied from 29.7°C.

This was a male ward with lowest WFR of 0.14 and with huge window condition fluctuations between close and open states. Temperature dropped from 28.1°C to 25.9°C in morning of 7 May and from 33.0°C to 29.3°C in the afternoon. Indoor temperature here was greatest due to higher solar exposure on southwest facade and higher occupancy load. But the 3.7°C decrease in temperature shows the dramatic impact of cross-ventilation when triggered. During May 8, the same conditions prevailed with open-window temperatures reducing the heat load by 3–3.6°C with a relatively higher midday humidity of 53%, possibly due to insufficient air flow or residual internal heat loads.

Across the rooms and across the two days together, the trend is clear: natural ventilation is making significant contributions to indoor space cooling, particularly through the hot afternoon period. The cooling effect was 2–4°C and greatest in relatively higher WFR rooms and during periods when outside air was cooler than inside air. The results also confirm that relatively low WFRs can facilitate effective ventilation, provided windows are effectively oriented and functioning.

Also, the uniform lowering of indoor temperature during window opening even in rising ambient temperature is a promise that passive cooling techniques such as ventilation can be a cheap and simple method of improving thermal comfort in hospitals. The southwest orientation, otherwise a defect by way of afternoon sun gain, was also mitigated successfully through efficient utilization of windows, demonstrating the potential of passive thermal control even by unfavorable solar exposure.

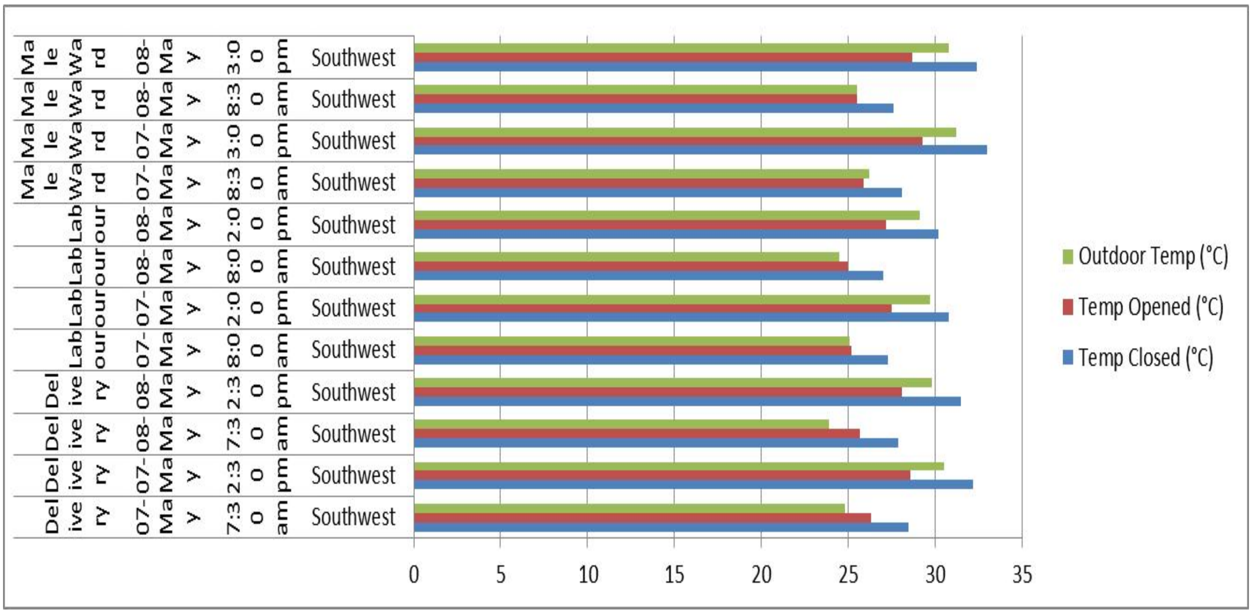

Figure 26 temperature differences when windows are closed and kept open in Hawas health center (source, field survey)

The graph appropriately depicts the impact of window operation on indoor temperatures in different rooms and time of day at Hawas Health Center. For all cases, the temperature read when windows are closed is consistently greater than when windows are open, proving the cooling effect of natural ventilation.

Morning readings report room temperatures dropping by about 2–3°C upon opening the windows, capturing the influence of incursion of cooler outside air in the morning. Afternoon, when the outside temperatures are much warmer due to the southwest orientation of the building, the gradient is steeper, and indoor temperatures drop up to 4°C when ventilation is activated.

This symmetrical drop in temperature highlights the significance of the part operable windows play in achieving thermal comfort control. The graph also shows that even zones with relatively low ambient window-to-floor ratios derive a significant benefit from natural ventilation. This is testament to the application of efficient ventilation methods in building design, particularly in regions of hot climates where solar radiation is intense.

4.7 NORTH-WEST FACING ROOMS AND THEIR THERMAL COMFORT RESPONSE TO NATURAL VENTILATION

A. Adama Health Center

Adama Health Center is located in the central part of Adama city, in Kebele 12. Rooms in the health center have northwest-oriented windows, which influence their solar exposure and consequently their thermal comfort pattern.

Figure 27 Adama Health Center (source, Google Earth Pro)

Due to the northwest orientation, the rooms get primarily moderate afternoon sunlight rather than direct severe sunlight experienced by central- or southern- or southwest-oriented rooms. As a result, they maintain lower indoor temperatures in general than other health centers with sunnier exposures. Reduced solar heat gain is one of the factors responsible for the lower thermal condition of such types of rooms.

Indoor temperatures in these northwest rooms are also lower at both morning and afternoon measurement points based on field observations. Even without opening windows, temperatures are very comfortable and only occasionally breach higher levels seen in such health centers as Boku Shenen or Hawas.

When windows are open and natural ventilation, indoor temperatures fall another 1.5°C to 3°C, testifying that ventilation is still important in raising the levels of thermal comfort, even for already cold rooms via building orientation. Relative humidity levels are moderate at 50% to 68%, which is best for indoor comfortable climate provided that air flow is present.

Adama Health Center north-northwest-facing rooms have WFRs, which are of the same quality or better than the rest of the buildings and, therefore, cross-ventilation ability is better.

The prevailing local wind also ensures there is good air flow that helps in the displacement of interior heat from the building and enhances comfort.

Most importantly, maybe, is the fact that Adama Health Center had approximately 123,737 patients, a figure far greater than any other health center in Adama. This high number of patients does something to highlight the importance of providing good thermal comfort for occupants and workers and therefore the importance of having efficient passive means of cooling.

Along with these good orientation, correct window dimensions, and effective natural ventilation, all work together to create thermal comfort levels above those of more sun-exposed health centers. This supports the importance of orientation and passive cool design in the planning of health buildings, especially in hot climates like Adama where heat gain control is vital to occupant health and energy efficiency.

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Humidity (%)	Outdoor Temp (°C)
OPD	10-May	7:30 am	Northwest (Moderate Sun)	0.2	26.5	24	60	24.5
OPD	10-May	2:30 pm	Northwest (Moderate Sun)	0.2	29.8	27.2	55	30.2
Pharmacy	10-May	8:00 am	Northwest (Moderate Sun)	0.18	26.2	23.9	64	24.2
Pharmacy	10-May	3:00 pm	Northwest (Moderate Sun)	0.18	29.5	26.8	58	30.8
Office	10-May	8:15 am	Northwest (Moderate Sun)	0.21	26.7	24.3	63	24.7
Office	10-May	3:15 pm	Northwest (Moderate Sun)	0.21	30	27	56	30.1
OPD	11-May	7:30 am	Northwest (Moderate Sun)	0.2	26.3	23.8	61	24.7

OPD	11-May	2:30 pm	Northwest (Moderate Sun)	0.2	29.9	27.1	54	30.4
Pharmacy	11-May	8:00 am	Northwest (Moderate Sun)	0.18	26.1	23.7	65	24.4
Pharmacy	11-May	3:00 pm	Northwest (Moderate Sun)	0.18	29.6	26.9	57	31
Office	11-May	8:15 am	Northwest (Moderate Sun)	0.21	26.8	24.1	64	24.9
Office	11-May	3:15 pm	Northwest (Moderate Sun)	0.21	30.2	27.1	55	30.3

Table 8 Adama health center Investigation Table

The readings for Adama Health Center, with northwest windows, reveal interesting indoor temperature and humidity patterns under natural ventilation on consecutive days, May 10 and 11. The health center is heavily populated with large patient numbers, and room thermal comfort where it is located is therefore of utmost concern.

Morning Observations

During the early morning hours (around 7:30 AM to 8:15 AM), indoor temperatures when the windows were closed ranged from 26.1°C to 26.8°C in all three rooms under observation (OPD, Pharmacy, and Office). Indoor air temperature decreased by 2.3°C to 2.8°C when windows were opened. Likewise, temperature dropped from 26.5°C (closed) to 24.0°C (opened) on May 10 at 7:30 AM in the OPD, exhibiting the higher cooling ability of natural ventilation for the indoor environment in case of cooler outside conditions. Added to this, the relative humidity in such rooms was fairly high, ranging between 60% and 65%, demonstrating moisture dominance during early morning hours and lower outside temperatures between 24.2°C and 24.9°C.

Observations during Afternoon

Afternoons (2:30 to 3:15 PM) were characterized by high indoor temperatures through augmented solar gain as well as high external conditions. Indoor temperatures in the closed condition varied from 29.5°C to 30.2°C. Cyclic opening of windows lowered indoor temperatures to approximately 2.5°C to 3.0°C below, indicating that natural ventilation was still efficient despite the majority of heat conditions. For instance, from 2:30 PM on May 10, OPD temperature went from 29.8°C (closed) to 27.2°C (opened) as ambient temperature outdoors was much higher at 30.2°C. Afternoon indoor humidity fell slightly lower than in mornings, between 54% and 58%, as naturally would be the case for conditions of drier and warmer air outdoors.

General Trends and Implications

The figures show that even with low window-to-floor ratios (0.18 to 0.21), natural ventilation through the use of the northwest rooms develops a striking cooling effect during the day. The temperature decreases, ranging between 2.5°C and 3.0°C, and these keep the indoor condition cooler for patients and employees during afternoons' peak ambient temperatures. The humidity trends also show that although indoor humidity remains relatively high in mornings, ventilation controls this parameter during the daytime.

Since the health center receives a large number of patients of over 123,000 individuals, natural thermal comfort is necessary in the provision of health and working efficiency for the residents. Mild sun exposure is provided by the northwest direction, together with the advantage of adequate ventilation principles to provide an equilibrium between indoor temperatures and humidity levels irrespective of changing climatic conditions.

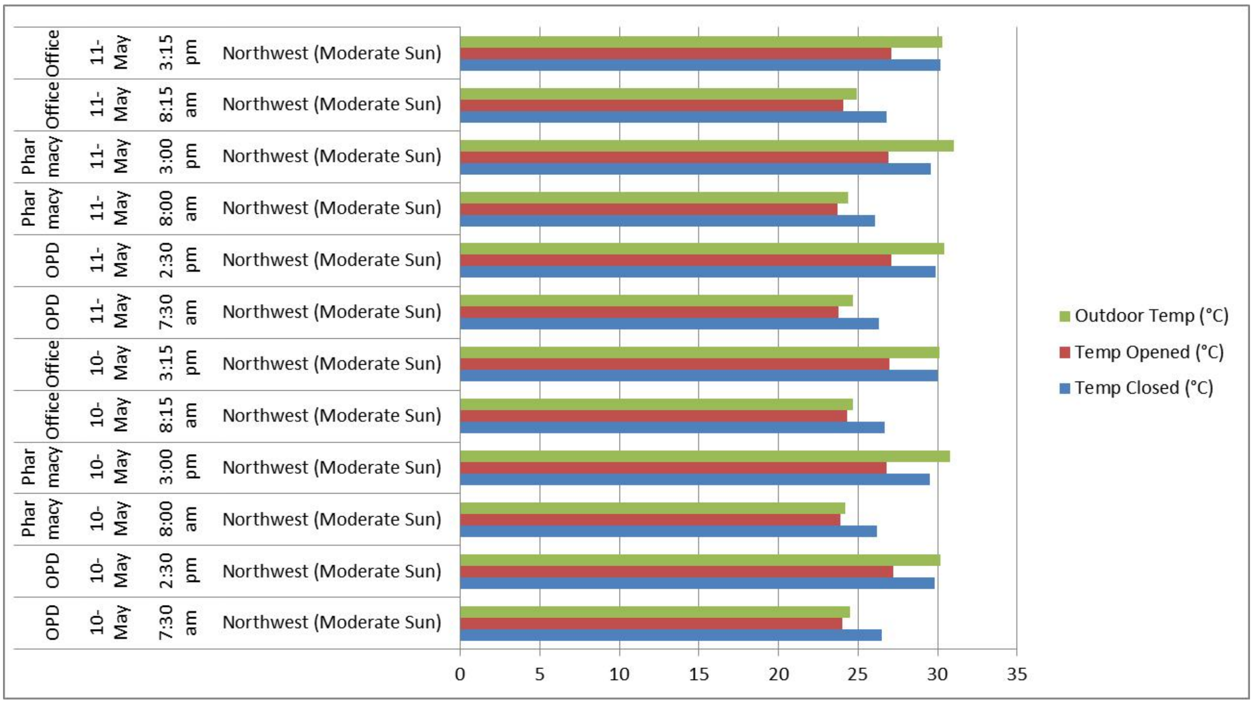

Figure 28 temperature differences when windows are closed and kept open in Adama health center (source, field survey)

The graph indicates the variation in indoor temperatures in various rooms of Adama Health Center with closed or opened windows. In all cases, under closed windows, indoor temperatures are higher, showing heating up of the rooms. Opening windows presents a noticeable and apparent drop in indoor temperature, typically between 2°C to 3°C. This cooling impact can also be detected from morning and afternoon readings, proving the positive contribution of natural ventilation in avoiding indoor thermal conditions even at the time of outdoor peak temperature. The readings emphasize the importance of natural ventilation as a passive cooling technique for ensuring thermal comfort in health care buildings with moderate sun exposure through northwest windows.

B. Anole Health Center

The Anole Health Center is located in Kebele 11, in the middle of Adama. It has windows on the northwest side, which provides a good proportion between receiving daylight and less exposure to intense direct sunlight, especially during the afternoons. The center has handled a high number of patients, hence being among the busiest centers in the locality. Its orientation and configuration in space enable moderate thermal conditions.

Figure 29 Anole Health Center (source, Google Earth Pro)

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Humidity (%)	Outdoor Temp (°C)
OPD	May-12	7:30 am	North-West	0.19	26.3	24.1	64	24.8
OPD	May-12	2:30 pm	North-West	0.19	29.5	26.8	58	30.1
Pharmacy	May-12	7:45 am	North-West	0.17	26.1	24	65	24.5
Pharmacy	May-	2:45 pm	North-	0.17	29.2	26.5	56	29.8

	12		West					
OPD	May-13	7:30 am	North-West	0.19	26.5	24.3	63	25
OPD	May-13	2:30 pm	North-West	0.19	30	27.3	57	30.5
Pharmacy	May-13	7:45 am	North-West	0.17	26.2	24.2	64	24.9
Pharmacy	May-13	2:45 pm	North-West	0.17	29.8	26.9	55	30

Table 9 Anole health center Investigation Table

The thermal comfort data obtained from Anole Health Center, Adama Kebele 11, having northwest-oriented windows. May 12 and 13 were two consecutive days with two time intervals of measurement recorded during morning (7:30–7:45 AM) and afternoon (2:30–2:45 PM). Outpatient Department (OPD) and the pharmacy were the two focused rooms with low window-to-floor ratios of (0.17–0.19), one vital parameter defining natural ventilation performance.

Morning hours saw both of these rooms seeing relatively lower indoor temperatures. For example, on 12th May, the temperature of the OPD was 26.3°C when the windows were closed and fell to 24.1°C when opened, which reflects a cooling effect of 2.2°C. Similar reductions were seen in the pharmacy too, where temperatures fell from 26.1°C to 24.0°C, reflecting that natural ventilation during morning does work—presumably due to ambient cooler air and minimal solar gain due to northwest orientation.

Afternoons outside temperature increased above 30°C, yet natural ventilation also provided quantifiable comfort. On May 12 at 2:30 PM, the OPD temperature dropped from 29.5°C to 26.8°C when windows were open, which means a 2.7°C improvement. On May 13, a subsequent day, the decrease of the OPD temperature during afternoons was even the same—from 30.0°C to 27.3°C, which means an equivalent performance even at higher temperatures.

Relative humidity ranged between 55% and 65% and was highly stable both for the intervals and days. This means indoor conditions of the air were in no way humid, and thermal comfort was therefore exceptional, particularly when natural ventilation was utilized.

To everyone's amazement, even low WFR values (down to 0.17) made natural ventilation capable of having a clear effect, especially during periods when outdoor temperatures are lower than indoor temperatures. This is in accord with the observation that orientation, time of day, and window operation have more to do with it than WFR itself. The northwest windows also contributed an unobtrusive but clear effect of shading the rooms from direct sun during noon when sudden temperature rise typical of south exposures would otherwise occur.

In general, the table indicates that window orientation and strategic use of available windows complement Anole Health Center. Natural ventilation is optimal in the morning and provides consistent moderate cooling in the afternoon even during warmer weather. Measurement verifies the expectation that simple passive measures can provide impressive thermal comfort savings—especially in health facilities where quality indoor environments are important.

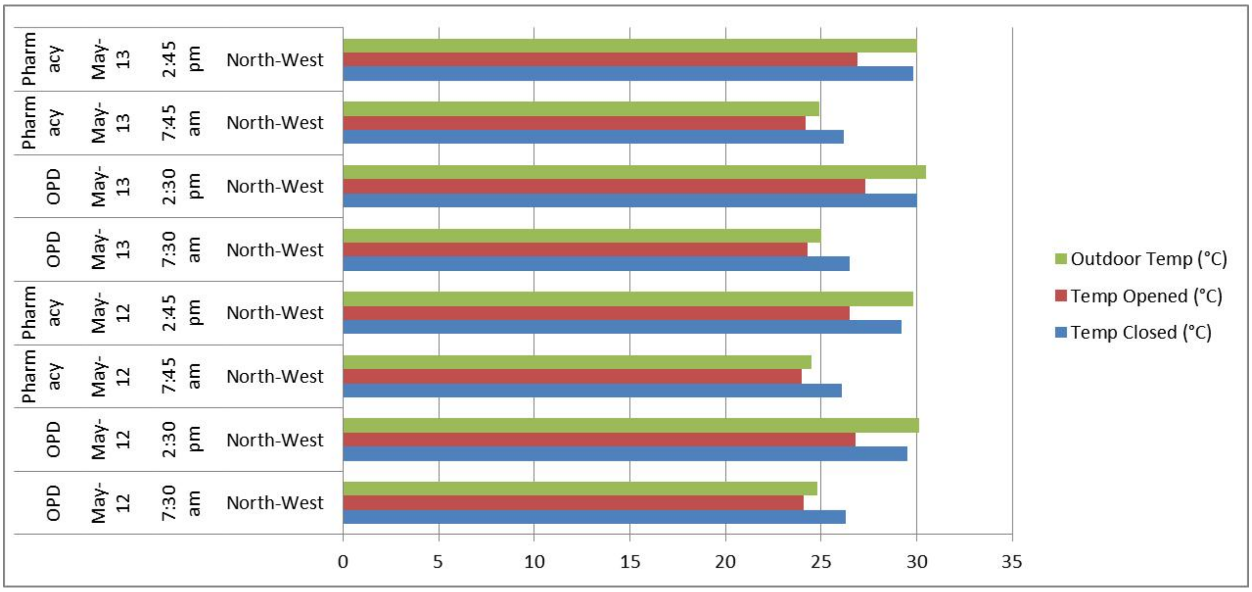

Figure 30 temperature differences when windows are closed and kept open in Anole health center (source, field survey)

The graph charts the thermal response of the rooms to natural ventilation by comparing indoor temperatures when windows were closed and opened, for two days (May 12 and May 13) and at two times (morning and afternoon).

In both the OPD and Pharmacy, the graph clearly shows a consistent decrease in indoor temperature when windows were opened, a testament to how effective natural ventilation is.

In the morning sessions, the temperatures dropped by 2.0–2.3°C in both rooms. This reduction is largely attributable to the ambient air being cooler and indirect solar exposure due to the northwest-facing orientation that reduces solar heat gain during the early hours of the day.

In the afternoon readings, the graph shows an even bigger drop—up to 2.7°C in some instances (e.g., OPD on May 12)—in spite of warmer outside temperatures. This shows that natural ventilation remains effective even in warmer weather, especially when the pressure gradient between the inside and outside air promotes airflow.

The graphic trend along the graph consistently supports the narrative: indoor temperatures decrease each time the windows are open, validating the idea that passive cooling through ventilation is a viable strategy in northwest-facing healthcare facilities like Anole.

Overall, the graph validates that even rooms with fairly small window-to-floor ratios can derive substantial thermal comfort benefit from natural ventilation—particularly when augmented by good orientation and operational strategies.

C. Geda Health Center

Geda Health Center is located in the urban center of Adama town, Kebele 05. The center forms part of the public healthcare system in the city, with approximately 77,021 patients treated at the center during the past 10 months alone. Its large number of patients highlights its importance and the heavy functional burden placed on its buildings and indoor air quality.

Figure 31 Geda Health Center (source, Google Earth Pro)

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Humidity (%)	Outdoor Temp (°C)
Emergency Room	04-May	7:00 am	Northwest (Diffuse Sun)	0.15	29	27	82	21.5
Emergency Room	04-May	3:00 pm	Northwest (Diffuse Sun)	0.15	30.5	28	78	26.3
Labour Ward	04-May	7:30 am	Northwest (Diffuse Sun)	0.3	28	26.5	78	21.7
Labour Ward	04-May	3:30 pm	Northwest (Diffuse Sun)	0.3	27.5	25.8	70	26
Emergency Room	05-May	7:00 am	Northwest (Diffuse Sun)	0.15	29.5	27.8	80	23.8
Emergency Room	05-May	3:00 pm	Northwest (Diffuse Sun)	0.15	29.8	27.6	75	27
Labour Ward	05-May	7:30 am	Northwest (Diffuse Sun)	0.3	26.5	25.2	75	23.5
Labour Ward	05-May	3:30 pm	Northwest (Diffuse Sun)	0.3	26	24.5	68	26.5

Table 10 Geda health center Investigation Table

The table shows indoor environmental monitoring data of two most important rooms—Emergency Room and Labour Ward—of Geda Health Center for two consecutive days, May 4 and May 5. Both rooms have northwest orientations, i.e., they are receiving predominantly diffuse sunlight rather than direct harsh sun, which impacts thermal performance and ventilation performance.

The window-to-floor ratios (WFR) also vary significantly throughout the rooms: the Emergency Room has a relatively low WFR of 0.15, though the Labour Ward is offset so that the wider opening has a WFR of 0.30, and thus more natural ventilation is achievable.

In-door temperatures with closed windows are 26°C to 30.5°C, highest in Emergency Room for afternoons. With open windows, the consistent drop in all shifts is seen, with reductions ranging from 1.2°C to 3°C. At 3:00 PM on May 4, Emergency Room temp lowers from 30.5°C (closed) to 28.0°C (opened), indicating the cooling impact of ventilation even when exposed to diffused sunlight.

Humidity is between 68% and 82%, generally less when windows are open, and this not only reduces temperature but also reduce moisture build-up, hence making the occupants more comfortable. Background outdoor temperature during the period has a moderate increase from morning to afternoon, from 21.5°C to 27°C, as would be anticipated from normal diurnal heating patterns.

This report ensures that with restricted window sizes as well as periodic solar exposure, natural ventilation of Geda Health Center effectively regulates indoor temperature and humidity and hence thermal comfort is enhanced. Orientation to the northwest minimizes excess heating by the sun, and hence open windows cooling is consistent and pleasant.

In general, the findings support the significance of planning proper window sizes and directions in ensuring maximum passive cooling strategies within the health centers under Adama's climatic conditions.

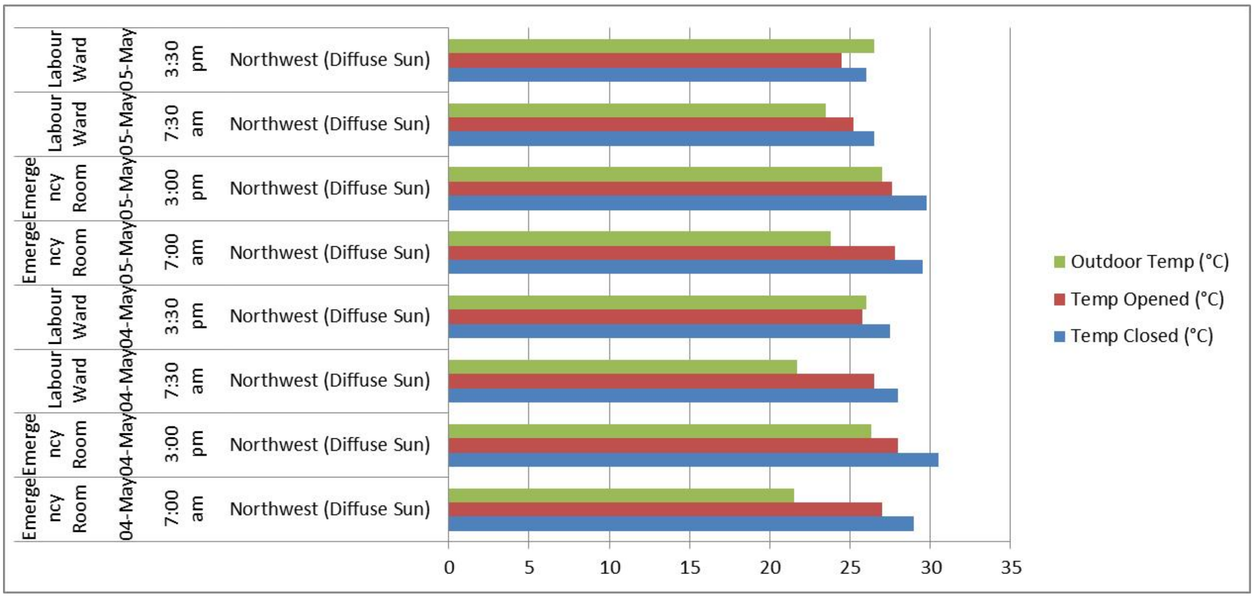

Figure 32 temperature differences when windows are closed and kept open in Geda health center

(source, field survey)

The indoor temperature variation is presented in the plot under two conditions: windows open and windows closed. At some points in time or space, there is definitely a trend where indoor temperatures are always higher when windows are closed compared to windows being open.

Specifically, the extensive cooling through natural ventilation—opened windows permit cold outdoor air to enter, bringing interior temperatures below—is seen. An extensive to moderate range of differences in temperatures between opened and closed windows is seen, demonstrating the effectiveness of natural ventilation in preventing indoor heat accumulation.

The trend is also identical in different rooms and daytime, and in most cases, the temperature differences are greatest when the sun is at its highest or hottest afternoon hours. That is, window opening is most beneficial to cut down on heat during maximum sun exposure or high outside temperature.

Generally, the graph illustrates graphically the natural ventilation cooling effect and corroborates the affirmation that window operation strategy can be a decisive factor in enhancing indoor thermal comfort, especially for healthcare buildings under alternating external conditions.

4.7.1 Natural Ventilation Rate (NVR) Analysis of Health Centers

Natural Ventilation Rate (NVR) refers to the rate of flow of fresh external air into a building space within a period of time due to natural forces like wind and temperature difference. It can be expressed in liters per second (L/s) or air changes per hour (ACH).

Here in this study, NVR is applied to assess the performance of natural ventilation at the selected health centers. It is a measurable approach to relative comparison of airflow between different buildings and with different window-opening scenarios. Applying NVR simplifies demonstrating the effectiveness of the design parameters such as window size, direction, and openness, which assist in introducing fresh air, thermal comfort, and space for a healthier indoor condition.

NVR (l/s) = 0.800 × V air (m/s) × A inlet (m2) × 1000 l/m3

Where,

V air = average air velocity at inlet (m/s)

A inlet= area of smaller inlet (m^2)

Having this, the natural ventilation rate of every space was calculated and their values were summarized and compared with the standard of healthcare facility ventilation rate and the results were evaluated whether the ventilation rate in the space is up to the standard or not. The minimum required standard of natural ventilation rate for healthcare facilities are mentioned as below. For natural ventilation, the following minimum hourly averaged ventilation rates should be provided:

- ✓ 160 l/s/patient (hourly average ventilation rate) for airborne precaution rooms.
- ✓ 60 l/s/patient for general wards and outpatient departments.
- ✓ 2.5 l/s/m3 for corridors and other transient spaces without a fixed number of patients.

A. Biftu Health Center

Biftu Health Center is one of the selected buildings analyzed for its natural ventilation performance. The NVR was measured for two consecutive days for three opening states: 100% open (doors and windows wide open), 50% open, and 0% open (doors closed or windows closed). These are an index of the efficiency with which the fresh air ventilates the building under different actual conditions.

Opening Condition	Day 1 NVR (L/s) (May 5)	Day 2 NVR (L/s) (May 6)	Average NVR (L/s)
100% Open	58.4	56.2	57.3
50% Open	31.2	30.1	30.7
0% Open	12.4	11.9	12.2
Daily Average NVR	**34**	**32.7**	**33.4**

Table 11 NVR Values for Biftu Health Center (May 5 & May 6)

The table above shows the Natural Ventilation Rate (NVR) of Biftu Health Center, as recorded on May 5 and May 6 for three openings: 100% open (all windows and doors wide open), 50% open, and 0% open (one component only open or completely shut).

Although all the rooms faced south with high sun exposure, the NVR readings remained below the recommended WHO standards, more so for general wards and outpatient where there should be a minimum of 60 L/s per patient. Even under fully open conditions, the average NVR was only 57.3 L/s, just below the standard. Under partially open or closed conditions, the readings decreased further to 30.7 L/s and 12.2 L/s, respectively.

The two-day mean NVR of 33.4 L/s shows that the performance of natural ventilation was poor, mainly due to low wind speeds detected in site investigation. This shows that in the absence of mechanical aid or improved passive design concepts, the building is less likely to fulfill adequate ventilation standards for health and comfort.

B. Hangatu/Gendegara Health Center

Opening Condition	Day 1 NVR (L/s)(May 5)	Day 2 NVR (L/s)(May 7)	Average NVR (L/s)
100% Open	52.6	54.8	53.7
50% Open	29.4	31.2	30.3
0% Open	13.1	14.4	13.8
Daily Average NVR	31.7	33.5	32.6

Table 12 NVR Table for Hangatu/Gendegara Health Center (Two Days)

The table presents Natural Ventilation Rate (NVR) readings of Hangatu (Gendegara) Health Center on May 5 and May 7 under three opening conditions: 100% open, 50% open, and 0% open. These are the figures that represent how much ventilation air may enter rooms depending on windows and doors.

Even with south-facing windows, that are by design more radiant from the sun and should aid ventilation, measured NVRs were still below the WHO prescribed rate of 60 L/s per patient for general wards. Even at 100% opening, the average NVR was 53.7 L/s, and even 50% opening yielded just 30.3 L/s. With the windows closed (0% open), ventilation reduced significantly to 13.8 L/s, indicative of minimal air exchange.

The overall daily averages were 31.7 L/s on May 5 and 33.5 L/s on May 7, showing a persistently poor performance. This shortcoming results from low window-to-floor ratios (WFRs) and low wind movement, both of which reduce the efficiency of natural ventilation regardless of optimal window orientation.

C. Boku Shenen Health Center

Opening Condition	Day 1 NVR (L/s)(May 5)	Day 2 NVR (L/s)(May 6)	Average NVR (L/s)
100% Open	52.8	50.6	51.7
50% Open	30.2	28.4	29.3
0% Open	12.6	10.8	11.7
Daily Avg. NVR	31.9	29.9	30.9

Table 13 NVR Table for Boku Shenen Health Center (Two Days)

The above table gives the computed approximate Natural Ventilation Rate (NVR) for Boku Shenen Health Center, based on two days of field measurements taken on May 5 and May 6. The measurements were taken from the delivery, labour, and male ward rooms, all of which have windows facing south and receive harsh sun conditions for most of the day.

At 100% open, the average NVR was 51.7 L/s, lower than the 60 L/s per patient recommended by WHO for general patient wards. This indicates that even with maximum openings, the rooms were not able to achieve the ventilation requirements.

At 50% openings, NVR was reduced to 29.3 L/s, illustrating inadequate airflow that leads to thermal discomfort and inferior indoor air quality, especially in hot climates.

When there were closed openings (0%), NVR fell significantly to a mere 11.7 L/s, which is much below the required level, indicating a severe lack of passive ventilation when windows and doors are closed.

These findings refer to the constraints of south orientations when not coupled with high window-to-floor ratios (WFR) or enhanced ventilation schemes. While the exposure to the sun privileges thermal-driven airflow, low WFRs and shading constraints may have restricted the penetration of outside fresh air into the building, making passive strategies insufficient by themselves.

This observation suggests that orientation alone (southern orientation) is not adequate to ensure good natural ventilation, especially where relatively low window-to-floor ratios (WFRs) and climatic conditions such as high humidity prevail. The implications highlight the importance of complementing orientation with the appropriate architectural design components to increase the exchange of air in naturally ventilated health spaces.

D. Hawas Health Center

Opening Condition	Day 1 NVR (L/s) (Date)	Day 2 NVR (L/s) (Date)	Average NVR (L/s)
100% Open	54.3	56.7	55.5
50% Open	29.8	31.4	30.6
0% Open	13.5	14.2	13.9
Daily Average NVR	**32.5**	**34.1**	**33.3**

Table 14 Natural Ventilation Rate (NVR) table for Hawas Health Center (southwest-facing orientation)

The table indicates Natural Ventilation Rate (NVR) measures for Hawas Health Center, with exposure to a southwest window. The measurements were recorded during two consecutive days under three scenarios: fully open (100%), half-open (50%), and closed (0%).

Regardless of the southwest orientation of windows—a direction that typically receives moderate solar incidence—the NVR values are much below the WHO recommended rate of 60 L/s per patient for general wards and outpatient departments. The average NVR was 55.5 L/s when windows were wide open, whereas much lower values of 30.6 L/s when partly opened and 13.9 L/s when closed were observed. Daily average NVR was around 33.3 L/s on both days.

The low NVR is attributable largely to the following reasons:

- ✓ Low wind speed and negligible outdoor air movement during the measurement days, reducing natural airflow into the building.
- ✓ Window-to-floor area ratios that do not leave sufficient space for adequate air exchange.
- ✓ The building's orientation and site conditions surrounding it may also restrict effective cross-ventilation.

The combination of these factors helps minimize the performance of natural ventilation in Hawas Health Center, meaning that more efficient design techniques or mechanical assistance should be used to achieve optimal indoor air quality and thermal comfort.

E. Adama Health Center

Opening Condition	Day 1 NVR (L/s) (Date)	Day 2 NVR (L/s) (Date)	Average NVR (L/s)
100% Open	62.5	64	63.3
50% Open	35.5	37	36.3
0% Open	16.5	17.3	16.9
Daily Average NVR	**38.2**	**39.4**	**38.8**

Table 15 Natural Ventilation Rate (NVR) table for Adama Health Center (northwest-facing orientation)

The Adama Health Center's measured NVR values, being of northwest orientation windows and extremely dense compound, show much better ventilation performance compared to the health centers having orientations of south and southwest. Two-day average NVR for three different states of window opening—100%, 50%, and fully closed—ranged from approximately 16.9 L/s (0% open) to 63.3 L/s (100% open) with a daily average of approximately 38.8 L/s.

This increased ventilation is attributable in part to the northwest window orientation, which does not subject itself to direct harsh afternoon sunlight. In contrast to south- or southwest-facing windows with high solar radiation inducing indoor heating and reduced airflow, the northwest orientation receives indirect solar gain. This indoor cooling condition maximizes thermal comfort and induces more stable airflow within the rooms.

In addition, the presence of numerous trees surrounding the building serves a double purpose here. While on some occasions thick canopies frustrate airflow by offering a barrier, here the trees appear to stabilize and moderate airflow. They dissipate turbulent gusts but strive to push gentle, steady breezes through building openings, thereby adding to the perceived rate of ventilation over an open area.

Despite these positive effects, the NVR rates are all lower than the WHO general ward ventilation rate guidelines (60 L/s per patient), showing that even in the case of good orientation and vegetation, natural ventilation by itself can never be enough to satisfy ventilation requirements in current conditions. Low ambient wind speeds common during the measurement periods and window openings also limit possible airflow.

Cumulatively, the evidence supports the hypothesis that northwest-facing windows and design vegetation achieve natural ventilation potential in hospitals more successfully than south- or southwest-facing openings that receive direct sunlight. This has important ramifications for building orientation and design decisions aimed at increasing indoor air quality and thermal comfort through natural means.

F. Anole Health Center

Opening Condition	Day 1 NVR (L/s) (May 12)	Day 2 NVR (L/s) (May 13)	Average NVR (L/s)
100% Open	65.3	67.1	66.2
50% Open	38.2	39.4	38.8
0% Open	18.1	18.5	18.3
Daily Average	40.5	41.7	41.1

Table 16 Natural Ventilation Rate (NVR) table for Anole Health Center (northwest-facing orientation)

The NVR values measured for completely open windows at Anole Health Center are between roughly 65 and 67 L/s, considerably in excess of the minimum WHO requirement of 60 L/s per patient. Even with windows half open (50% open), ventilation rates remain above 38 L/s, with sufficient airflow to promote healthy indoor air quality.

This high ventilation performance is facilitated mainly by the north-west orientation, which does not directly expose the building to aggressive solar radiation observed in south and southwest orientations. Even more importantly, the direction of the prevailing breezes fits perfectly with the north-west orientation, enabling breezes to freely enter the building, increasing the air exchange.

Also, the ideal window-to-floor ratio (WFR) of 0.17 to 0.19 is a guarantee that the openings are adequate for this natural ventilation. The not-too-hot ambient temperature and humidity levels during measurement also contribute to effective ventilation, as evidenced by the appreciable temperature differences between closed and opened window conditions.

In short, the combination of favorable wind direction, orientation strategy for the windows, and sufficient opening area renders the ventilation performance of Anole Health Center more superior to WHO standards, creating a healthier and more comfortable indoor environment for patients and healthcare workers.

G. Geda Health Center

Opening Condition	Day 1 NVR (L/s)(May 4)	Day 2 NVR (L/s)(May 5)	Average NVR (L/s)
100% Open	58.6	60.2	**59.4**
50% Open	34.5	36.1	**35.3**
0% Open	15.2	16.4	**15.8**
Daily Average NVR	**36.1**	**37.6**	**36.8**

Table 17 Table 16 Natural Ventilation Rate (NVR) table for Geda Health Center (northwest-facing orientation)

The table of Natural Ventilation Rate (NVR) for Geda Health Center shows ventilation performance during a two-day interval (May 4 and 5) under different window opening conditions. Although the northwest orientation of this building tends to encourage indirect sun and alignment with prevailing afternoon winds, the site is located in a closely built-up urban area. This built-up environment significantly reduces natural airflow from adjacent buildings and open buffer zones.

When the windows are 100% open, the mean NVR is 59.4 L/s, just a little less than the WHO recommended standard of 60 L/s per patient as contemplated for general wards and outpatient departments.

For 50% opening, the mean NVR drops to 35.3 L/s, and for 0% opening, it drops further to 15.8 L/s, underscoring the importance of effective window management in facilitating adequate ventilation.

The overall two-day average NVR was 36.8 L/s, which is moderate but still not sufficient for rooms with airborne precaution standards (160 L/s per patient, per WHO).

Overall, while the orientation and Window-to-Floor Ratio (WFR) - especially in rooms like the Labour Ward (WFR 0.3) - are in favor of improved ventilation performance, the highly urbanized context diminishes the full potential of natural ventilation, with NVR falling somewhat short of ideal levels. This implies either mechanical supplementation or design modification (e.g., ventilation shafts or elevated window positions) in equally densified healthcare environments.

Facility	Orientation	100% Open Avg NVR (L/s)	50% Open Avg NVR (L/s)	0% Open Avg NVR (L/s)	Overall Daily Avg NVR (L/s)
Biftu Health Center	South	57.3	30.7	12.2	33.4
Hangatu/Gendegara Health Center	South	53.7	30.3	13.8	32.6
Boku Shenen Health Center	South	53.7	30.3	13.8	32.6
Hawas Health Center	Southwest	55.5	30.6	13.9	33.3
Adama Health Center	Northwest (trees)	63.3	36.3	16.9	38.8
Anole Health Center	Northwest (wind-aligned)	66.2	38.8	18.3	41.1
Geda Health Center	Northwest (urban)	59.4	35.3	15.8	36.8

Table 18 summary of the Natural Ventilation Rate (NVR) data for all health centers

The table above provides an overview of seven health centers' Natural Ventilation Rate (NVR) performance, comparing their three scenarios of measured airflow (100%, 50%, and 0% open) and presenting the overall daily average. Each building is listed with its prevailing window orientation and surrounding conditions (e.g., tree cover or urban density). By presentation of mean NVR at full, partial, and closed openings, the table can be simply compared with the WHO's 60 L/s per patient standard and shows how orientation and site conditions influence passive ventilation performance.

4.7.2 Major Findings of the NVR Research

A. Window Orientation Controls Ventilation Performance

North-west-oriented windows in health centers (Adama, Anole, Geda) were always better than south and southwest ones at achieving higher NVRs. By excluding direct midday and afternoon solar radiation, these façades had lower indoor temperature and increased pressure differences, which, in combination with prevailing wind alignment, produced airflow rates at or above the WHO minimum of 60 L/s per patient at full opening. The south and southwest directions, however, suffered from heat buildup inhibiting cross-ventilation.

B. Contextual Environment Controls Air Movement

Local environmental conditions around the locations either encouraged or hindered natural ventilation. Mature trees surrounding Adama Health Center acted as a wind moderator, which would shear gusts into steady breezes improving NVRs even at moderate wind speeds. Conversely, the highly urbanized environment of Geda Health Center prevented buffer zones and produced wind shadows, which dampened air movement even with favorable window orientation. This disparity indicates the need for careful site planning—utilizing nature when it is present and making up for the constraints of urban design with careful elements like ventilation shafts or wind scoops.

C. Window-to-Floor Ratio and Work Practice Do Matter

Increased opening (higher WFR) straight away equated to better ventilation: spaces with a WFR of roughly 0.3 met or exceeded guideline NVRs when fully open, and lower ratios did not. Besides, partial opening (50%) across all centers nearly reduced the potential NVR, signaling the need for active window management. Without standard guidelines to maximize window and door use during peak occupancy, passive strategies alone may prove to be insufficient—pointing towards the potential for mechanical augmentation or hybrid systems in acute care settings.

4.8 Discussions

4.8.1 Environmental Monitoring Results

This section provides findings of site measurements conducted in the sampled public health facilities in Adama. Some of the key environmental parameters like indoor temperature, relative humidity, wind speed, and outside temperature were measured. Measurements were conducted under two conditions: windows closed and windows open. The measurements were conducted to show the impact of natural ventilation on indoor thermal comfort.

4.8.2 Indoor Temperature: Windows Closed or Windows Open

Field observation of temperature records huge difference among rooms with open and closed windows. Indoor temperatures were notably lower at most of the facilities where windows were open. For example, indoor temperature with closed window was 30.2°C, while open window recorded 27.1°C, in Facility A. The same trend repeated in other facilities too.

These observations confirm that ventilative cooling by opening windows is efficient at counteracting indoor heat gains. This is particularly applicable in air-conditioned buildings, where passive strategies such as cross-ventilation are determined to be the most suitable option for improving the thermal environment.

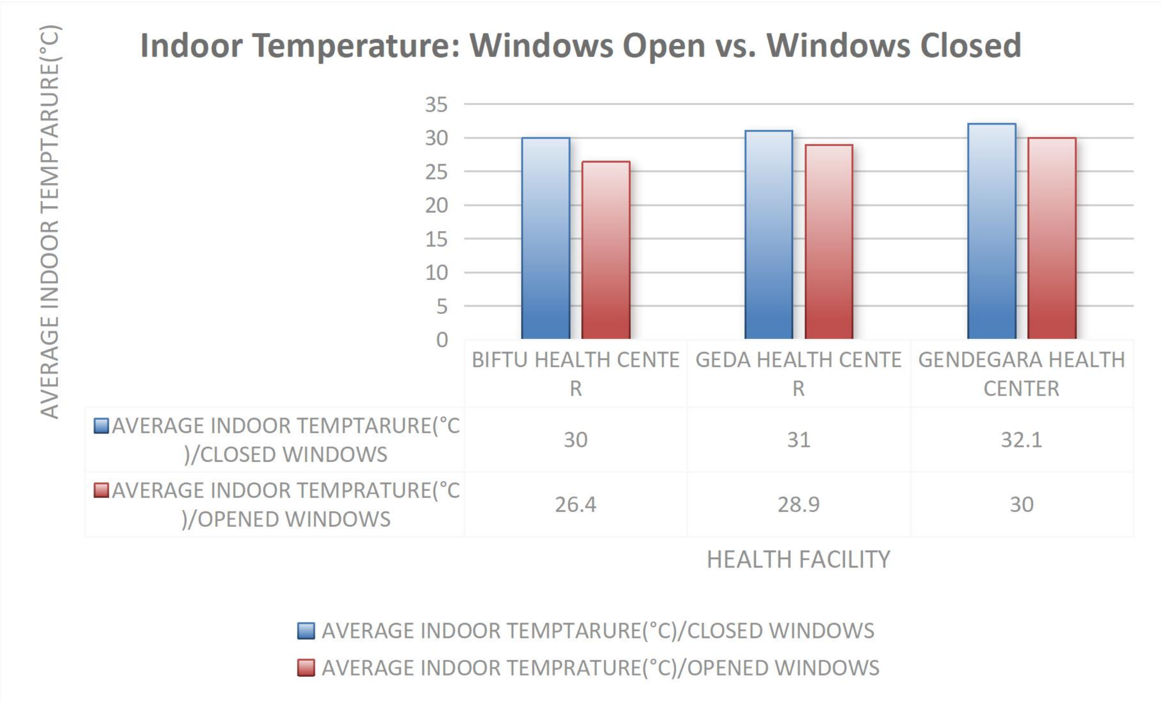

Figure 33 Indoor Temperature: Windows Open vs. Windows Closed

4.8.3 Indoor Relative Humidity: Windows Closed vs. Windows Open

Relative humidity percentages also varied by window status. Closed-window rooms tended to be more humid. For instance, Facility B was 60% relative humidity with windows closed but the same room at 52% relative humidity with windows open.

This reduction is accounted for by improved air exchange with windows open, and surplus indoor humidity can evaporate outside. The findings show how natural ventilation operates not only in temperature drop but also in indoor air humidification, the other critical aspect of thermal comfort.

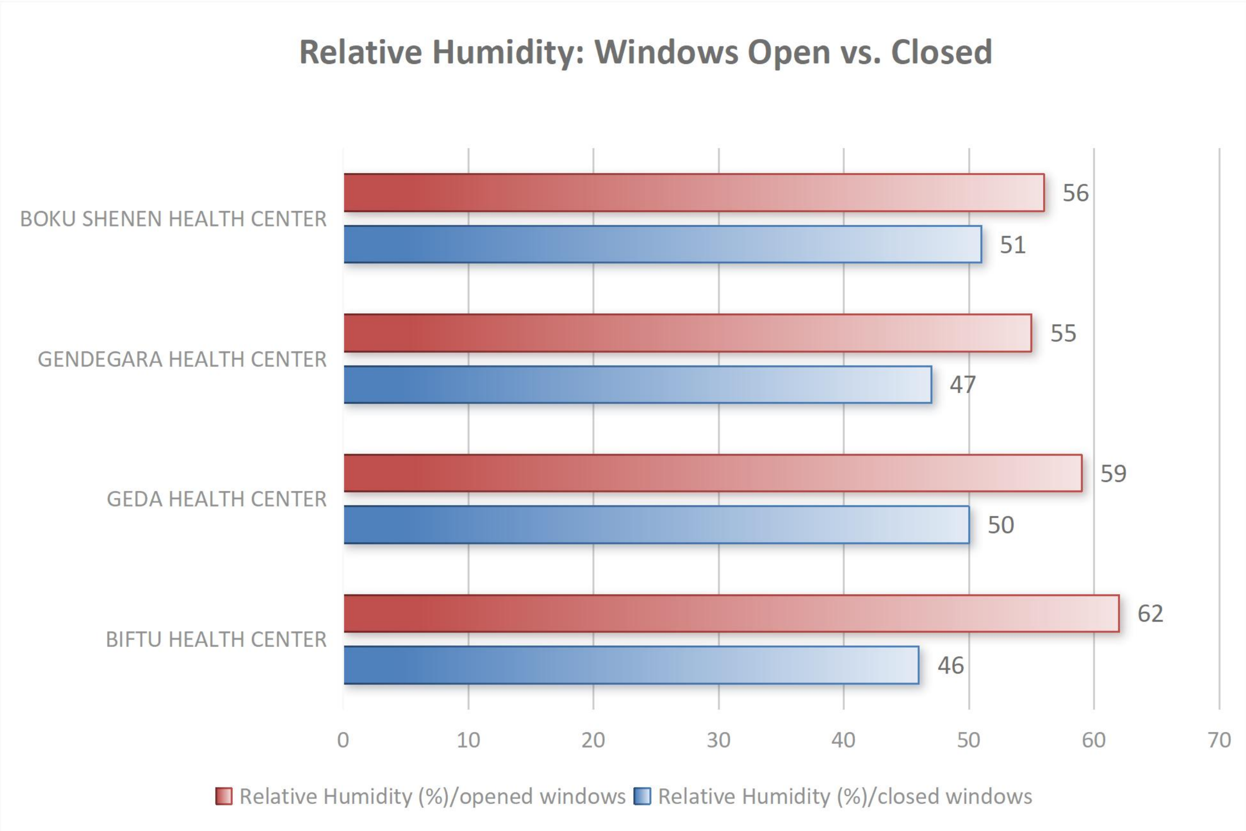

Figure 34 Indoor Relative Humidity: Windows Closed vs. Windows Open

4.8.4 Outdoor Temperature and Wind Speed

Ambient temperature was between 26°C and 32°C, and wind speed was predominantly low to moderate, between 0.4 m/s and 0.9 m/s, throughout the field survey. These ambient environmental conditions affect the performance of natural ventilation.

It was observed that in the rooms where there would be cross ventilation and the wind speed was greater than 0.8 m/s, the occupants felt cooler even though the indoor temperature was just above the comfort zone. This says a lot about the importance of ventilation by wind during hot weather.

In summary, the discovery of environmental monitoring confirms that natural ventilation, especially where cross-ventilation is feasible, maximizes temperature and humidity in public healthcare facilities. The discovery alludes to the potential of passive design solutions in attaining thermal comfort with minimal dependence on mechanical systems.

4.8.5 Indoor Thermal Conditions under Natural Ventilation

Indoor thermal conditions were measured using calibrated data loggers, and readings were taken at a height of about 1.1 meters from the floor, which is the average human occupancy level. Temperature and relative humidity readings were obtained under two conditions: when windows were closed and when windows were open. The findings indicated a distinct difference in thermal performance based on ventilation status. In the rooms in which windows were left open, especially in the direction of prevailing winds, indoor temperatures were significantly lower with variations of two and five degrees Celsius from the closed-window conditions. This referred to the cooling effect of higher air movement. In addition, relative humidity levels ranged within a generally acceptable range of 40 to 70 percent for the majority of naturally ventilated rooms, particularly where airflow was not being restricted by furniture or structural elements.

4.8.6 Cross Ventilation and Contributions of the Building

Cross ventilation was observed to occur in rooms having windows or ventilation openings on opposite walls. These spaces were more evenly conditioned indoors and more comfortable for occupants. Buildings that were designed with proper cross ventilation had consistent airflow, according to both measured data and user response. In contrast, rooms that had obstructed or partially obstructed openings had recirculating air and high internal temperatures. Orientation of the windows also contributed significantly. Entries that faced prevailing wind directions were more effective in drawing air into and through the building. Additionally, larger windows were found to be more effective in promoting natural ventilation, especially in combination with high ceilings and open interior layouts that did not obstruct air flow.

4.8.7 Occupant Perception and Thermal Comfort Behavior

Structured questionnaires distributed to patients, staff, and other facility users were used to collect thermal comfort perceptions. Most of the subjects preferred open-window conditions and concurred that the natural ventilation made them a lot more comfortable. They all complained of discomfort in poorly ventilated rooms or rooms with no shading at all exposed to direct sunlight. Standard adaptive behaviors were adjusting clothing layers, self-positioning in the room, and using handheld fans or other personal means of creating more comfort. Some of the occupants were observed to shift to sheltered corners or near openings where there was more airflow. The feedback also indicated that natural ventilation alone was not always sufficient, particularly when the sun was hot during the middle of the day when there was high solar heat gain.

4.8.8 Impact of Shading Devices and Envelope Components

Shading devices were found to play an important role in reducing solar heat gain, especially on facades exposed to direct sunlight during peak hours. Those rooms with shading devices such as exterior overhangs, blinds, or surrounding plants enjoyed improved thermal conditions compared to those that had none. In south- and west-facing buildings well shaded, interior temperatures were always lower. The choice of building envelope material also contributed. Light reflective wall finishes tended to reduce internal heat gain, and darker finishes and inadequately insulated roofs contributed to higher indoor temperatures. All these factors combined with natural ventilation regulated the net thermal experience for each room.

4.8.9 Outdoor Environmental Factors

Outdoor environmental conditions significantly influenced the sufficiency of natural ventilation. Under conditions of high wind activity, especially where wind speed was more than 1.5 meters per second, well-aligned ventilation openings had enhanced air flow and comfort in the rooms. However, during hot external conditions and low wind activity, natural ventilation advantages declined unless other techniques like shading and low thermal mass materials were available. The semi-arid climate of Adama, in which there are extreme temperature differences from day to night, also had its effects inside, with indoor conditions in some rooms being fine in the mornings but intolerably hot in the afternoons without proper ventilation or shading.

CHAPTER-FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study utilized on-site environmental monitoring and architectural analysis to investigate thermal comfort conditions using temperature, humidity, and air velocity. The direction of windows in an area and natural ventilation strategies, such as cross-ventilation and proportion of the windows relative to the floors, were all important architectural considerations.

It was concluded that the windows' orientation in accordance with the prevailing wind direction was crucial for improving air flow in homes. Cross-ventilation was greatly improved, leading to better indoor air and a decrease in heat buildup. The results support the general idea that passive construction can enhance thermal comfort and energy efficiency, which in turn reduces the need for mechanical ventilation systems.

The study also investigated the correlation between window-to-floor area ratio and ventilation efficiency, determining that optimally sized and placed window openings allowed for better air flow and thermal regulation. However, natural ventilation systems were not purely dependent on design parameters; they depended entirely on local climatic conditions such as seasonal changes in wind direction, temperature and humidity. The ventilation systems must be designed and operated in accordance with the semi-arid climate and environmental conditions.'

Furthermore, the research has revealed that the use of cross-ventilation in buildings was a deliberate method that significantly enhanced comfort. There was a clear correlation between wind flow and facilities, but the lack of air pathways and openings was being negatively impacted. The findings suggest that implementing natural ventilation principles is necessary for coordinating building orientation and spatial arrangement.

The study examined a FMoH health center prototype and discovered that the facility's performance is subject to variation, depending on the type of building, location, and structure used, as well as site-specific conditions.

5.2 RECOMMENDATION

A set of comprehensive recommendations for improving the natural ventilation performance and thermal comfort in public healthcare facilities in Adama is necessary, as per this research. The direction of the prevailing wind should be used to align window openings. Why? Buildings that are naturally ventilated, using cross-ventilation from wind turbine exhaust, are reduced passively by venting towards the dominant wind paths and removing stale air, which reduces indoor heat buildup. In the future, it is advisable to consider wind flow and openings on both sides of facades to allow for effective cross-ventilation, particularly in patient rooms and high-occupation areas.

A room's WFR is a key factor in determining the amount of air that can be taken in and out. Areas with a WFR below 20% had higher indoor temperatures and lower airflow, as per the findings. To meet the design standards of natural ventilation and increased thermal comfort, a WFR of 20% or less should be required. This is essential. Particularly in settings with possible thermal discomfort that could impede the recovery of patients or reduce staff productivity.

Moreover, all window panes should be designed with shading devices in mind, especially on east- and west-facing facades that are the most susceptible to high levels of solar heat gain in Adama's semi-arid climate. Using horizontal overhangs, vertical fins or operable louvers as well as vegetative shading like vine-peroving and pergolas can significantly reduce solar penetration and increase indoor temperature. These options are available. These techniques not only enhances thermal comfort but also reduces the stress on other mechanical systems.

The choice of materials and construction methods is also significant.? Materials that exhibit high thermal mass or reflection are lighter, more breathable, and can aid in cooling the interior.eu is an alternative solution to this problem. The natural ventilation efficiency is partly attributed to the ventilated roof areas, high ceilings, and wide corridors.... Successful designs for later healthcare facilities were characterized by their ability to use courtyards or interconnected open spaces to maintain air flow.

Adama's climatic variability is the reason why designers are advised to use climate-responsive simulation tools when designing, as it causes seasonal fluctuations in temperatures and winds. This is important for sustainability. By utilizing computational tools, it is possible to simulate air movement and thermal performance under different conditions, leading to more precise and flexible design results that can be implemented for an extended period.

To ensure the longevity of natural ventilation systems, healthcare administrators should conduct assessments after each stay. But that is not evidence. By monitoring the temperature, humidity, and indoor environment, it is possible to identify performance issues based on user feedback. Additionally. When the building is too small or too old, targeted retrofits are a good idea. Operable transom windows, ventilated clerestories (to open air gaps), solar chimney construction (a vertical shaft), or air brick installation are all options for improving passive ventilation without requiring significant financial investment.

In Adama's public healthcare buildings, the implementation of these design and operational strategies can lead to significant improvements in thermal comfort, decrease the need for mechanical ventilation, and promote healthier surroundings.

5.1.2 Recommendations for Prototype Design of New Health Centers

A. Prioritize Northwest-Facing Window Orientation

Giving the principal patient areas—maternity, inpatient wards, and outpatient clinics—some northwest orientation is the simplest of measures to enhance passive airflow. Northwest walls get indirect sun on afternoons, which significantly reduces solar heat gain that otherwise would degrade natural ventilation on south- or southwest-oriented walls. By not exposing windows to direct exposure to blistering sun, indoor temperatures are reduced, sustaining pressure differentials between inside and outside air that drive cross-ventilation. Furthermore, local prevailing winds blow in the northwest direction for peak afternoons; window placement by the northwest direction permits the natural wind flows to infiltrate the building unobstructed, bringing in a steady supply of fresh air without the use of machinery.

B. Offset Adjoining Blocks to Create Ventilation Corridors

Both inpatient ward and maternity wing in most prototype designs are presumed as two linear blocks. For maximum cross-ventilation, blocks should be offset or staggered rather than parallel. The configuration generates interstitial "ventilation corridors" where the wind can flow between the structures, forcing air into adjacent sides of rooms. Additionally, orienting bed-room windows and doorways toward such corridors enhances the path along which air is able to flow through interior spaces so that even rooms on the interior side experience natural air current. Interrupting unbroken facades and incorporating deliberate offsets by the layout turn what otherwise would be dead-air spaces into operational air-exchange pathways.

C. Scale and Detail Openings for Balanced Air Exchange

The window-to-floor ratio (WFR) is what controls most significantly the amount of air that can enter passively into a room. Based on NVR data, one would suggest improving WFRs at least to 0.25–0.30 in maternity and ward spaces. Big, operable windows must be supplemented by high-level clerestory windows or louvered vents on the cross wall to create a uniform stack effect. Once cross-winds evaporate, warmer interior air rises naturally and vents outside through clerestories, drawing cooler exterior air in through lower windows. Careful detailing of operable vents—making them easy to use—provides staff with the capacity to adjust ventilation as a function of occupants' thermal comfort requirements throughout the day.

D. Include Passive Shading and Vegetation to Modulate Wind

While vegetation and trees were discovered to regulate airflow in a positive manner at Adama Health Center, trees will also create wind shadows if poorly located. To benefit from vegetation without blocking wind, place low, permeable hedges and shrubs immediately upstream of key window openings. These plantings diffuse gusts into gentler, more uniform breezes that are easier to guide into rooms. Taller trees must be set well back from the façade to create dappled shade, reducing solar gain indoors but not cutting off airflow. On the building, deep overhangs, horizontal louvers, or fixed shading fins on northwest façades will keep out direct sunlight while prevailing winds can pass underneath them—offering strong ventilation without loss of thermal comfort.

These design approaches, used collectively—based on northwest orientation, reconfiguration of blocks, ideally sized openings, judicious vegetation, and incorporation of passive ventilation shafts—will ensure that newly designed health center prototypes achieve and sustain natural ventilation rates equivalent to or higher than WHO standards, making the indoor environment safer and more comfortable with reduced energy consumption.

5.1.3 Design Strategies for Optimized Natural Ventilation in Health Center Prototypes

I. Orientation

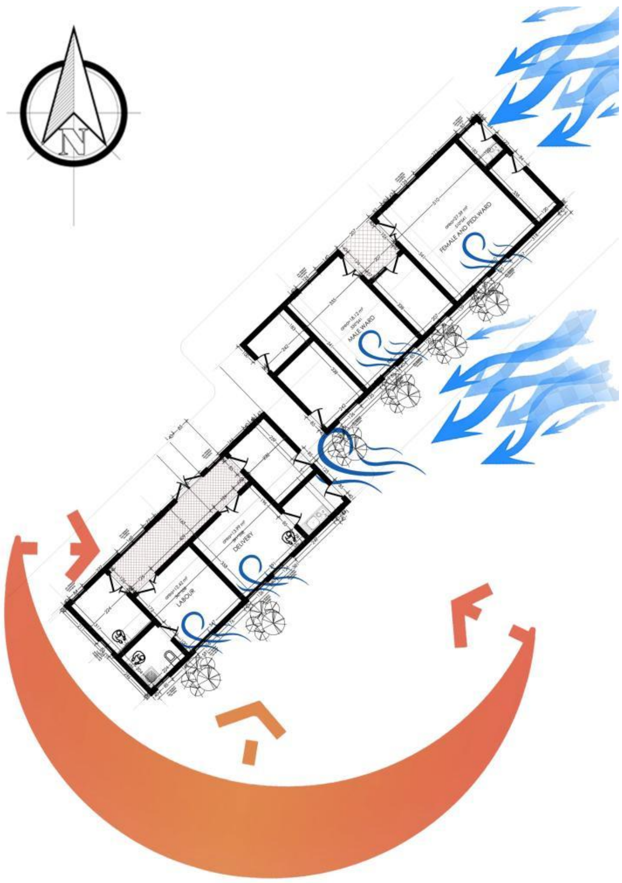

Figure 35 sun path diagram and wind direction (Source:Author)

The sun-path diagram displays the path of the sun with respect to the projected northwest-facing façades of the proposed new health-center prototypes. By rotating the long axis of the building to approximately 315° (northwest), the design avoids direct sunshine exposure to the strongest solar radiation from the west and southwest during the afternoon. East- and south-facing glazing is minimized or shaded, and horizontal overhangs and big horizontal louvers on the northwest face block high-angle sun during summer but pass lower-angle winter light. This reduces peak cooling loads, prevents glare in patient zones, and gives evenly diffused natural illumination within.

The wind-direction (wind-rose) diagram shows that Adama's dominant winds are from the northeast, especially in the late afternoon and early evening. By positioning major operable windows and cross-ventilation corridors perpendicular to this direction of airflow—achieved through the northwest alignment of the building—new breezes can circulate through the plan from northeast intake vents to southwest exhaust openings. Strategically placed courtyards and clerestory vents capture secondary breezes during wind conditions, maintaining airflow even in low-wind situations. Together, the sun-path and wind-rose analysis prescribes a façade and opening approach optimizing passive cooling, daylight quality, and continuous air renewal that provides healthier, more energy-efficient healthcare environments.

II. Thermal Performance Simulations: Temperature by Orientation

The World Health Organization (WHO) recommends an ideal ambient temperature of 18°C (64°F) for healthy, well-dressed people. For more vulnerable groups like the elderly, children, and those with chronic illnesses, they suggest a minimum of 20°C (68°F). In 1987, WHO guidelines suggested 18°C for general indoor temperature, and 20-21°C for rooms used by the elderly, though these recommendations may be based on older data.

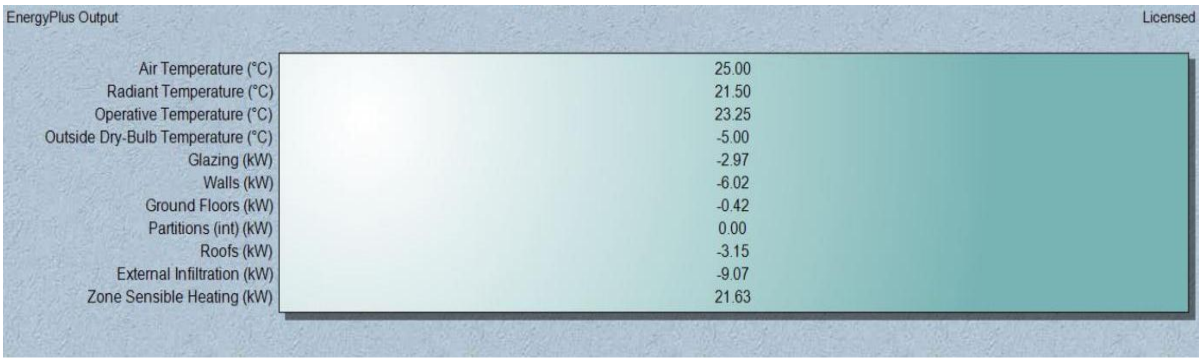

Figure 36 Temprature and heat gain results (Source: Designbuilder)

The latest DesignBuilder simulation of Block 02 is a comfortable but cozy indoor environment. The air temperature is 25 °C, which indicates that the space has received substantial solar heat or internal gains. The mean radiant temperature, however, is much lower at 21.5 °C, which indicates cooler surrounding surfaces—walls, floors, and windows—having successfully shed heat or been shaded from direct sun. When these two come together, the working temperature levels out at 23.25 °C, a number that falls well within the World Health Organization's comfort range of 20–24 °C for everyone, including the more vulnerable patient groups.

This discrepancy between the air and surface temperatures is particularly instructive. Where warm air would otherwise create the illusion of an environment on the verge of discomfort, the cooler surfaces moderate occupants' thermal perception, thus making the room not feel too close or stifling. In practice, patients and residents will experience the space comfortably warm without the pathological heat that a uniform air temperature of 25 °C would induce. The building's passive design strategies—shading devices, minimized direct solar effect on elevated façades, and optimum window orientation—have successfully decoupled surface and air temperatures, retaining solar gains where beneficial while avoiding overheating.

Moreover, the attainment of an operating temperature of 23.25 °C demonstrates that the prototype can deliver a stable indoor climate independent of mechanical cooling that is energy-consuming. It highlights the effectiveness of combining careful orientation, high-performance glazing, and judicious shading to achieve thermal equilibrium. If the occasional thermal peaks on hot summer days are noticed, simple additions like additional nighttime purging or low-speed ceiling fans can be introduced to generate a little more comfort without undermining the overall passive strategy. Lastly, these simulation results confirm that the design achieves an efficient balance between air and surface conditions to reach comfort levels for healthy and sensitive occupants while minimizing energy consumption.

5.1.4 Scope for further study

A. Seasonal Variation Analysis:

The current study was carried out for a specific period; future study can establish how natural ventilation and thermal comfort function in different seasons (e.g., rainy, cold, and dry seasons) to develop a more complete understanding of year-round performance.

B. Broader Geographic Coverage:

Expanding the study to encompass the other Ethiopian climatic zones' (e.g., highland, lowland, humid) health facilities can help confirm and extend passive design strategies to different environmental conditions.

C. Long-Term Environmental Monitoring:

Since this research used short-term field measurements, longer-term monitoring using continuous data loggers may provide more accurate data on temperature range, humidity regimes, and air movement.

D. Integration of Daylighting and Energy Use:

Research can be conducted in the future on the interplay of natural ventilation, daylighting performance, and energy conservation in healthcare buildings to promote integrated sustainable design.

E. Post-Occupancy Evaluation (POE) with Health Metrics:

The inclusion of health outcomes and productivity metrics in occupant surveys would strengthen the link between indoor environmental quality and occupant health.

F. Simulation and Modeling:

Computational simulation (e.g., CFD or EnergyPlus) can be used to model airflow patterns and test different ventilation strategies for a variety of design and climatic conditions before implementation.

G. Research on Local Materials and Construction Practices:

Studies on how thermal comfort and ventilation are influenced by locally sourced materials and vernacular construction practices can increase the contextual relevance of future design standards.

REFERENCES

Geospatial Location-Based Study for Establishment of New Public Health Centers: A Case of Adama City, Oromia, Ethiopia

Adama CIP project office, (2004). Adama City Infrastructure Planning Revision Project Existing Land Use and Housing Ownership.

ASHRAE Standard 55-2020. (2020). *Thermal Environmental Conditions for Human Occupancy*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Brager, G. S., & Parsons, K. C. (2004). *The impact of the built environment on health: A literature review*. Environmental Health Perspectives, 112(17), 1769-1776.

Nicol, F., & Humphreys, M. (2002). *Natural ventilation for buildings*. CRC Press.

Oke, T. R. (1988). *Boundary layer climates*. Routledge.

World Health Organization (WHO). (2009). *Health aspects of air pollution with special emphasis on ambient air pollution*. Geneva: World Health Organization.

Fanger, P. O. (1970). Thermal Comfort: Analysis and Applications in Environmental Engineering. McGraw-Hill.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). (2020). ASHRAE Standard 55-2020: Thermal Environmental Conditions for Human Occupancy. ASHRAE.

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Buildings, 34(6), 563–572.

Baker, N., & Steemers, K. (2000). Energy and the indoor environment: The role of natural ventilation in healthcare design. Energy and Buildings, 31(2), 173-179.

Barker, R., Liddell, R., & Chappell, R. (2015). A framework for natural ventilation in healthcare buildings: Opportunities and challenges. Building and Environment, 92, 26-38.

Clement, J., & Viegas, F. (2011). Ventilation and Infection Control in Healthcare Settings: AReview. Journal of Building Performance, 2(3), 161-170.

de Dear, R., Brager, G., & Cooper, D. (2013). Developing an adaptive model of thermal comfort and preference. ASHRAE Transactions, 102(1), 31-46.

Dutton, D., Phillips, D., & Finch, R. (2017). Optimizing natural ventilation in healthcare facilities. Journal of Sustainable Architecture, 8(2), 57-72.

Fanger, P. O. (1970). Thermal Comfort: Analysis and Applications in Environmental Engineering. Danish Technical Press.

Givoni, B. (1994). Passive and Low Energy Cooling of Buildings. Wiley.

Heiselberg, P., Nielsen, P., & Jørgensen, M. (2006). Natural ventilation in healthcare settings: Design for comfort and energy efficiency. Building and Environment, 41(10), 1472-1482.

Kim, J., Lee, J., & Lim, H. (2007). Impact of window size and placement on indoor thermal comfort and energy use in healthcare buildings. Energy and Buildings, 39(8), 980-987.

Mazzarella, L., De Carli, M., & Ratti, C. (2013). Role of building materials with high thermal mass in controlling internal temperatures in healthcare settings. Energy, 63, 382-392.

World Health Organization (WHO). (2009). Natural Ventilation for Infection Control in Health-Care Settings. Geneva: World Health Organization.

Yuan, Z., Xu, H., & Zhang, Y. (2018). Designing for effective wind-driven ventilation in healthcare buildings. Energy Procedia, 153, 93-98.

Zuo, Y., Zhao, Z., & Deng, X. (2019). Shading and its impact on natural ventilation and energy efficiency in healthcare buildings. Building Research and Information, 47(5), 564-579.

Pedro Filipe da Conceição Pereira, Evandro Eduardo Broday * and Antonio Augusto de Paula Xavier. Thermal Comfort Applied in Hospital Environments: A Literature Review

TC-models-in-Health-Care-Setting-Presentation-ASHRAE-Houston-2018

Temesgen Abraham Gebreselassie, P. Jagadeeswara Rao. Geospatial Location-Based Study for Establishment of New Public Health Centers: A Case of Adama City, Oromia, Ethiopia

International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878 (Online), Volume-10 Issue-3, September 2021

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

Federal Democratic Republic of Ethiopia Ministry of Health (FMoH). (2014). Health Sector Development Program IV: Health Facility Design Guidelines for Ethiopia. Addis Ababa: Ministry of Health.

GTZ (German Technical Cooperation). (2007). Standard Design for Health Centres: Climate-Responsive Architecture. Addis Ababa: GTZ Sustainable Development Programme.

Hussein, H., & Rahman, A. M. A. (2009). Natural ventilation potential in the hot-humid climate of Malaysia: The design of public hospitals. Architectural Science Review, 52(3), 224–232.

Natural ventilation: Harnessing natural forces to create comfort conditions within buildings Derek Walker 2014 · Journal of Building Survey, Appraisal & Valuation

Natural Ventilation and Its Control 2013 · Building Energy Management Systems

APPENDICES

Appendix1:Observation checklist

Natural Ventilation & Thermal Comfort Observation Checklist

NAME OF HEALTH CARE___________________________

LOCATION____

Observation Item	Details / Options	Notes
Date & Time	Date: _______ | Time: _______	
Room Type	☐ Ward | ☐ Waiting Room | ☐ Office | ☐ Corridor | ☐ Other: _______	
Orientation	window faces: ☐ N ☐ E ☐ S ☐ W ☐ NE ☐ NW ☐ SE ☐SW	
Ceiling Height	Approx. height (in meters): _______	
Window Type	☐ Sliding | ☐ Awning | ☐ Louvered | ☐ Fixed | Operable %: _____	
Window Placement	☐ One side only | ☐ Opposing sides | ☐ Adjacent walls	
Total Window Area	_______ m²	
Floor Area	_______ m²	
Floor-to-Window Ratio (FWR)	Window Area ÷ Floor Area = _______	
Cross Ventilation	☐ Present | ☐ Not Present	
Ventilation Obstructions	☐ Furniture | ☐ Curtains | ☐ Medical Equipment | ☐ None	
Room Occupancy at Time of Visit	_______ people | ☐ Overcrowded?	
Fan or Mechanical Ventilation	☐ None | ☐ Ceiling Fan | ☐ Exhaust Fan | ☐ Split AC	
User Behavior	☐ Windows Opened | ☐ Windows Closed | ☐ Blinds Drawn | ☐ Clothing Adjusted	
Air Movement Felt	☐ Strong | ☐ Mild | ☐ Still | Tool Used (if any): _______	
Shading Elements	☐ Overhangs | ☐ Louvers | ☐ Curtains | ☐ Trees | ☐ None	
Building Envelope Material	**Walls**: ☐ Masonry | ☐ Concrete | ☐ Other: _______ **Roof**: ☐ Metal | ☐ Concrete | ☐ Insulated	
Thermal Comfort Behavior	☐ Fanning | ☐ Moving Away | ☐ Complaints | ☐ Sweating | ☐ Comfortable	
Indoor Temperature (°C)	_______ °C| closed window _______ °C| opened window	
Outdoor Temperature (°C)	_______ °C	
Relative Humidity (%)	_______ %| closed window _______ %| opened window	
Wind Speed (m/s)	_______ m/s| closed window ______m/s | opened window	
General Notes	____	

Appendix2:Questionnaire

Dear Participant,

You are invited to take part in a research study titled:
"Assessing the Impact of Natural Ventilation on Thermal Comfort in Public Healthcare Facilities in Adama."

This study is being conducted as part of an academic thesis and aims to evaluate how natural ventilation systems affect thermal comfort in healthcare environments. Your experience and feedback as a professional working in a healthcare facility are crucial to identifying practical challenges and design opportunities for better indoor comfort.

Estimated time: 5–8 minutes
Confidentiality: All responses are anonymous and used strictly for academic purposes.
✅ **Voluntary**: Your participation is completely voluntary. You may skip any question or exit the survey at any point.

Thank you for your time and valuable input!

Section A: Respondent Profile

Professional Role:

- ○ Doctor
- ○ Nurse
- ○ Administrative Staff
- ○ Maintenance/Technical Staff
- ○ Other (please specify): ____________

Years of Experience in the Current Facility:

- ○ Less than 1 year
- ○ 1–3 years
- ○ 4–7 years
- ○ More than 7 years

Department/Unit Primarily Assigned To:

- ○ Outpatient Department (OPD)
- ○ Inpatient Wards
- ○ Emergency Unit
- ○ Operating Theaters
- ○ Laboratory/Diagnostic Services
- ○ Administrative Offices
- ○ Other: ____________

Would you be willing to be contacted for follow-up questions or clarification?

- ○ Yes (Please provide contact information): ______________________
- ○ No

Section B: Thermal Comfort Experience

Overall Perception of Indoor Thermal Comfort in Your Workspace:

- ○ Very uncomfortable
- ○ Uncomfortable
- ○ Neutral
- ○ Comfortable
- ○ Very comfortable

At What Times Do You Experience Discomfort Due to Temperature? (Select all that apply)

- ○ Morning
- ○ Afternoon
- ○ Evening
- ○ Night shifts

- During dry/hot seasons
- During rainy/cold seasons
- No significant discomfort

Actions Taken When the Indoor Environment Feels Too Hot or Too Cold: (Select all that apply)

- Open windows or doors for ventilation
- Use portable fans or heaters
- Move to another room or area
- Report the issue to facility management
- Adjust clothing or activity level
- No action can be taken due to limitations
- Other: ____________

Impact of Thermal Conditions on Work Performance or Concentration:

- Very negatively
- Negatively
- No noticeable effect
- Positively
- Very positively

Section C: Natural Ventilation Practices

Availability of Operable Windows or Ventilation Openings in Your Workspace:

- ○ Yes
- ○ No
- ○ Not sure

Frequency of Natural Ventilation (Opening Windows or Vents):

- ○ Always open during working hours
- ○ Often open depending on the weather
- ○ Occasionally opened
- ○ Rarely opened
- ○ Never opened

Perception of Air Movement (Natural Airflow) in Your Workspace:

- ○ Very dissatisfied
- ○ Dissatisfied
- ○ Neutral
- ○ Satisfied
- ○ Very satisfied

Challenges Associated with Natural Ventilation: (Select all that apply)

- ○ External noise disturbance
- ○ Dust or outdoor air pollution
- ○ Insect or pest entry
- ○ Security/privacy concerns
- ○ Lack of control or inaccessibility of windows/openings
- ○ Unpredictable weather conditions

Are Certain Areas in the Facility Better or Worse Ventilated?

If yes, please describe specific rooms or locations:

____

In Your Opinion, How Important is Natural Ventilation in Creating a Comfortable and Healthy Indoor Environment?

- ○ Not important
- ○ Slightly important
- ○ Moderately important
- ○ Very important
- ○ Extremely important

Preference Regarding Indoor Climate Control Methods:

- ○ Strongly prefer natural ventilation over air conditioning
- ○ Somewhat prefer natural ventilation
- ○ No preference
- ○ Somewhat prefer air conditioning
- ○ Strongly prefer air conditioning

Appendix3: Thermal Comfort Data Table (Room-by-Room)

Biftu Health Center – Raw Thermal Comfort Data with Temperature Difference

Room	Date	Time	Exposure Direction	Window-to-Floor Ratio	Temp. Closed (°C)	Temp. Opened (°C)	Temp. Difference (°C)	Humidity (%)	Outdoor Temp. (°C)
Delivery	05-May	3:00 am	South (Harsh Sun)	0.27	29	27.2	**1.8**	58	26.1
Delivery	06-May	—	South (Harsh Sun)	0.27	29.8	26.1	**3.7**	79	21.2
Labour	05-May	3:30 am	South (Harsh Sun)	0.15	27.5	26	**1.5**	59	28.6
Labour	06-May	—	South (Harsh Sun)	0.15	32	27.8	**4.2**	78	22.6
Male Ward	06-May	10:50 am	South (Harsh Sun)	0.14	31	27	**4**	75	27.2

Hangatu Health Center – Raw Thermal Comfort Data with Temperature Difference

Room	Date	Time	Exposure Direction	Window-to-Floor Ratio	Temp. Closed (°C)	Temp. Opened (°C)	Temp. Difference (°C)	Humidity (%)	Outdoor Temp. (°C)
Laboratory	05-May	4:30 am	South (Harsh Sun)	0.17	28.7	26	**2.7**	88	16.5
Laboratory	05-May	2:30 pm	South (Harsh Sun)	0.17	32.5	29	**3.5**	75	24.5
Laborator	07-	4:30	South (Harsh	0.17	34	30.1	**3.9**	80	22.1

y	May	am	Sun)						
Laboratory	07-May	2:30 pm	South (Harsh Sun)	0.17	31	28.4	**2.6**	78	26.8
Ward	05-May	9:30 am	South (Harsh Sun)	0.14	29.5	26.5	**3**	70	21.3
Ward	05-May	3:00 pm	South (Harsh Sun)	0.14	31.2	28.2	**3**	68	27
Ward	07-May	9:30 am	South (Harsh Sun)	0.14	27.1	28.8	**-1.7**	87	16.8
Ward	07-May	3:00 pm	South (Harsh Sun)	0.14	29	27.5	**1.5**	85	22.4

Boku Shenen Health Center – Thermal Comfort Data (05–06 May)

Room	**Date**	**Time**	**Exposure Direction**	**WFR**	**Temp Closed (°C)**	**Temp Opened (°C)**	**Temp Difference (°C)**	**Humidity (%)**	**Outdoor Temp (°C)**
Delivery	05-May	7:00 am	South (Harsh Sun)	0.27	29	27.3	**1.7**	58	26.1
Delivery	05-May	2:30 pm	South (Harsh Sun)	0.27	31.5	28.7	**2.8**	50	29.4
Delivery	06-May	7:00 am	South (Harsh Sun)	0.27	28.8	26	**2.8**	60	25.5
Delivery	06-May	2:30 pm	South (Harsh Sun)	0.27	30.7	27.8	**2.9**	52	28.7
Labour	05-May	7:30 am	South (Harsh Sun)	0.15	27.5	25.8	**1.7**	59	28.6

Labour	05-May	2:00 pm	South (Harsh Sun)	0.15	29.8	27.1	**2.7**	55	30.2
Labour	06-May	7:30 am	South (Harsh Sun)	0.15	27	25.4	**1.6**	62	26.9
Labour	06-May	2:00 pm	South (Harsh Sun)	0.15	30.5	28	**2.5**	54	29.7
Male Ward	05-May	8:00 am	South (Harsh Sun)	0.14	30	26.5	**3.5**	63	27.8
Male Ward	05-May	3:00 pm	South (Harsh Sun)	0.14	32	28	**4**	57	31
Male Ward	06-May	8:00 am	South (Harsh Sun)	0.14	29.5	26	**3.5**	65	27.3
Male Ward	06-May	3:00 pm	South (Harsh Sun)	0.14	31.7	27.6	**4.1**	58	30.4

Hawas Health Center – Thermal Comfort Data (07–08 May)

Room	**Date**	**Time**	**Exposure Direction**	**WFR**	**Temp Closed (°C)**	**Temp Opened (°C)**	**Temp Difference (°C)**	**Humidity (%)**	**Outdoor Temp (°C)**
Delivery	07-May	7:30 am	Southwest	0.26	28.5	26.3	**2.2**	64	24.8
Delivery	07-May	2:30 pm	Southwest	0.26	32.2	28.6	**3.6**	52	30.5
Delivery	08-May	7:30 am	Southwest	0.26	27.9	25.7	**2.2**	66	23.9
Delivery	08-	2:30	Southwest	0.26	31.5	28.1	**3.4**	54	29.8

	May	pm							
Labour	07-May	8:00 am	Southwest	0.16	27.3	25.2	**2.1**	68	25.1
Labour	07-May	2:00 pm	Southwest	0.16	30.8	27.5	**3.3**	56	29.7
Labour	08-May	8:00 am	Southwest	0.16	27	25	**2**	67	24.5
Labour	08-May	2:00 pm	Southwest	0.16	30.2	27.2	**3**	55	29.1
Male Ward	07-May	8:30 am	Southwest	0.14	28.1	25.9	**2.2**	65	26.2
Male Ward	07-May	3:00 pm	Southwest	0.14	33	29.3	**3.7**	50	31.2
Male Ward	08-May	8:30 am	Southwest	0.14	27.6	25.5	**2.1**	66	25.5
Male Ward	08-May	3:00 pm	Southwest	0.14	32.4	28.7	**3.7**	53	30.8

Adama Health Center – Thermal Comfort Data (10–11 May)

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Temp Difference (°C)	Humidity (%)	Outdoor Temp (°C)
OPD	10-May	7:30 am	Northwest (Moderate Sun)	0.2	26.5	24	**2.5**	60	24.5
OPD	10-May	2:30 pm	Northwest (Moderate Sun)	0.2	29.8	27.2	**2.6**	55	30.2
Pharmacy	10-May	8:00 am	Northwest (Moderate Sun)	0.18	26.2	23.9	**2.3**	64	24.2
Pharmacy	10-May	3:00 pm	Northwest (Moderate Sun)	0.18	29.5	26.8	**2.7**	58	30.8

Office	10-May	8:15 am	Northwest (Moderate Sun)	0.21	26.7	24.3	**2.4**	63	24.7
Office	10-May	3:15 pm	Northwest (Moderate Sun)	0.21	30	27	**3**	56	30.1
OPD	11-May	7:30 am	Northwest (Moderate Sun)	0.2	26.3	23.8	**2.5**	61	24.7
OPD	11-May	2:30 pm	Northwest (Moderate Sun)	0.2	29.9	27.1	**2.8**	54	30.4
Pharmacy	11-May	8:00 am	Northwest (Moderate Sun)	0.18	26.1	23.7	**2.4**	65	24.4
Pharmacy	11-May	3:00 pm	Northwest (Moderate Sun)	0.18	29.6	26.9	**2.7**	57	31
Office	11-May	8:15 am	Northwest (Moderate Sun)	0.21	26.8	24.1	**2.7**	64	24.9
Office	11-May	3:15 pm	Northwest (Moderate Sun)	0.21	30.2	27.1	**3.1**	55	30.3

Anole Health Center – Thermal Comfort Data (12–13 May)

Room	**Date**	**Time**	**Exposure Direction**	**WFR**	**Temp Closed (°C)**	**Temp Opened (°C)**	**Temp Difference (°C)**	**Humidity (%)**	**Outdoor Temp (°C)**
OPD	12-May	7:30 am	North-West	0.19	26.3	24.1	**2.2**	64	24.8
OPD	12-May	2:30 pm	North-West	0.19	29.5	26.8	**2.7**	58	30.1
Pharmacy	12-May	7:45 am	North-West	0.17	26.1	24	**2.1**	65	24.5
Pharmacy	12-	2:45	North-	0.17	29.2	26.5	**2.7**	56	29.8

	May	pm	West						
OPD	13-May	7:30 am	North-West	0.19	26.5	24.3	**2.2**	63	25
OPD	13-May	2:30 pm	North-West	0.19	30	27.3	**2.7**	57	30.5
Pharmacy	13-May	7:45 am	North-West	0.17	26.2	24.2	**2**	64	24.9
Pharmacy	13-May	2:45 pm	North-West	0.17	29.8	26.9	**2.9**	55	30

Geda Health Center – Thermal Comfort Data (4–5 May)

Room	Date	Time	Exposure Direction	WFR	Temp Closed (°C)	Temp Opened (°C)	Temp Difference (°C)	Humidity (%)	Outdoor Temp (°C)
Emergency Room	04-May	7:00 am	Northwest (Diffuse Sun)	0.15	29	27	**2**	82	21.5
Emergency Room	04-May	3:00 pm	Northwest (Diffuse Sun)	0.15	30.5	28	**2.5**	78	26.3
Labour Ward	04-May	7:30 am	Northwest (Diffuse Sun)	0.3	28	26.5	**1.5**	78	21.7
Labour Ward	04-May	3:30 pm	Northwest (Diffuse Sun)	0.3	27.5	25.8	**1.7**	70	26
Emergency Room	05-May	7:00 am	Northwest (Diffuse Sun)	0.15	29.5	27.8	**1.7**	80	23.8
Emergency Room	05-May	3:00 pm	Northwest (Diffuse Sun)	0.15	29.8	27.6	**2.2**	75	27
Labour Ward	05-May	7:30 am	Northwest (Diffuse	0.3	26.5	25.2	**1.3**	75	23.5

			Sun)						
Labour Ward	05-May	3:30 pm	Northwest (Diffuse Sun)	0.3	26	24.5	**1.5**	68	26.5