EVALUATING ADAPTIVE THERMAL COMFORT MODEL FOR NATURALLY VENTILATED CLASSROOMS IN ADAMA CITY, ETHIOPIA

Ayana Kabeta Rucho

A Thesis Submitted to the Department of Architecture
School of Civil Engineering and Architecture

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

Office of Graduate Studies
Adama Science and Technology University

June, 2024

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master's Thesis entitled "**Evaluating Adaptive Thermal Comfort Model for Naturally Ventilated Classrooms in Adama City, Ethiopia**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma of certificate in any other University. All sources of materials that are used for this thesis have been duly acknowledged by proper citation.

Ayana Kabeta Rucho	____________________	________________
Name of Student	Signature	Date

RECOMMENDATION OF ADVISORS/SUPERVISORS

I, the advisors of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Evaluating Adaptive Thermal Comfort Model for Naturally Ventilated Classrooms in Adama City, Ethiopia**" prepared under my guidance by Ayana Kabeta Rucho submitted in partial fulfillment of the requirements of the degree of Master's of Science in Environmental Architecture. Therefore, I recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Belay Zeleke (PhD)	______________	____________
Major Advisor	Signature	Date
__________________________	______________	____________
Co-advisor	Signature	Date

Approval Page of M.Sc. Thesis

I the advisor of the thesis entitled "**Evaluating Adaptive Thermal Comfort Model for Naturally Ventilated Classrooms in Adama City, Ethiopia**" and developed by Ayana Kabeta Rucho, hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

Belay Zeleke (PhD)	_________________	______________
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APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by Ayana Kabeta Rucho have read and evaluated his thesis entitled "**Evaluating Adaptive Thermal Comfort Model for Naturally Ventilated Classrooms in Adama City, Ethiopia**" 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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LIST OF ACRONYMS

ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineering
ASTU	Adma Science and Technology University
Cd	Coefficient of discharge
CFD	Computational Fluid Dynamics
DBT	Dry-Bulb Temperature
E	East
EPA	End Profile Angle
HSA	Horizontal Shadow Angle
HVAC	Heating Ventilation and Air Conditioning
IAQ	Indoor Air Quality
ITE	Indoor Thermal Environment
ISO	International Standard Organization
MOE	Ministry of Education
N	North
PEQ	Poor Environmental Quality
PMV	Predicted Mean Vote
PPD	Percentage of Persons Dissatisfied
Te	Thermal Environment

TSV Thermal Sensation Vote

S South

SNI Indonesian National Standard

VSA Vertical Shadow Angle

W West

WWR Window to Wall Ratio

ABSTRACT

In educational institutions, a conducive and comfortable atmosphere is crucial to create effective leaning environment for students. Naturally ventilated and thermally comfortable school buildings improve students' health, wellbeing and their educational performance since they spend considerable amount of their time inside classrooms. This study is confined with in Adama city, Ethiopia; only on 4 purposively selected school buildings which aimed to evaluate the orientation based adaptive model of naturally ventilated classrooms to enhance thermal comfort. The study uses both qualitative and quantitative data gathering approaches and implemented by using primary and secondary data sources. 355 respondents were selected using proportionate stratified sampling technique with 12 classroom building blocks (3-blocks per school). Required data were collected for 3 weeks on the months of March and April. Based on the data from the building occupants, objective measurements and software simulation result, classroom building oriented towards the south, southeast and southwest axis are uncomfortable for their users and highly susceptible for the harsh sun penetrating into the classroom. To regulate the indoor air temperature and maximize the natural ventilation for south oriented building with VSA of 60° and HSA of 50° result a wingwall with a depth of 1m and roof eave overhang having a depth of 1.1m will effectively minimize the direct solar gain and increase the natural ventilation by allowing more fresh air inlet from southwest direction at an angle of 45°. For buildings oriented towards the southwest direction, a VSA of 50° and HSA of 48° results a wingwall having a depth of 1.08m and roof eave overhang with 1.6m depth effectively blocks the harsh sun entering the room and increases the amount of fresh air inlet the room. For buildings oriented towards the east and southeast axis, a wingwall having a depth of 1m and a roof eave overhang of a minimum of 0.4m will allow fresh air to enter the room and minimize the direct solar heat penetration into the room. By applying this passive design strategy, the temperature of the classroom during the peak hottest day results a reduction in indoor temperature from 33.3 ℃ and 20℃ for maximum and minimum indoor temperature respectively to 27.5℃ and 18℃. This shows, the recommended design strategy creates a significant change in creating a thermally comfortable and naturally ventilated classrooms.

Keywords: Adaptive model, Classroom buildings, Climate factors, Natural ventilation, Passive design, Thermal comfort, Sun penetration

CHAPTER ONE

1. INTRODUCTION

This thesis study was conducted in Adama city which is located in East Shewa zone of Oromia region, Ethiopia; for the partial fulfillment of the degree of masters in Environmental Architecture at Adama Science and Technology University (ASTU). The study focuses on evaluating adaptive thermal comfort model for naturally ventilated classrooms buildings and create a healthy and comfortable learning environment that increases students' performance in their education.

Most of the time, students learn in classrooms or indoor spaces, especially secondary and preparatory school students are regularly in school classrooms for at least 8 hours of the day. The Indoor Environmental Quality (IEQ) of a place where students learn, study and work different activities related to their education can have a significant impact on their physical and psychological wellbeing; and also, negatively affect their performance (Arif, Katafygiotou et al. 2016). Thermal comfort is one of the key components that is defined as a condition of mind that expresses satisfaction with thermal environment. Both temperature and level of humidity in classrooms highly affects the thermal comfort. Students cannot perform on their education to their best if the temperature inside is too high or too low.

Adama is one of the fastest growing cities in the country. As the number of populations is increasing, there is a high demand of schools. The city is categorized under warm temperate area, especially in winter season the temperature is ranging from 14.3℃ at night to a warm 29.6℃ during the day. This will continue in April and May, with temperature consistently rise to 30℃ and above in the day time (Hirko, Mergia et al.). This in turn highly affects the indoor environmental quality of classrooms. This adversely affects the students' health and educational performance; and it requires a maximum attention to solve the problem. So that, this study is believed that it solves the problem and creates a conducive learning environment for the students.

In this chapter, background of the study which discusses issues from where the problem emerges, statement of the problem, research question, objective of the study, significance of the study, and scope of the study was discussed in detail.

1.1. Background of the Study

Since the global energy crisis of the 1970s, it has become critical for nations to identify strategies for cutting back on all forms of energy consumption. Buildings contribute more than 30% of CO2 emissions and almost 40% of the world's energy usage. Buildings consume a significant amount of this energy for thermal comfort (Yang, Yan et al. 2014).

For many years, natural ventilation served as the main means of cooling and ventilating buildings. According to (Collins 1996) Since the Qin dynasty, which began in roughly 221 BC, China has been practicing feng shui, the traditional Chinese technique for establishing a harmonious environment. Together, Feng and Shui address how the environment affects a building's exterior and interior design as well as how-to live-in harmony with the natural world while fostering an environment that is empowering for people.

Natural ventilation was achieved in the 19th century by opening and closing windows and allowing air to enter via gaps and crevices in buildings. When windows are opened and there is a temperature differential between the interior and exterior air, or there is wind blowing, a significant ventilation rate can be achieved (Van Der Tempel, Wouters et al. 2011).

The majority of schools constructed in the latter half of the 19^{th} century and the first half of the 20th century were utilitarian, conventional spaces intended to accommodate the greatest number of pupils while optimizing classroom area.

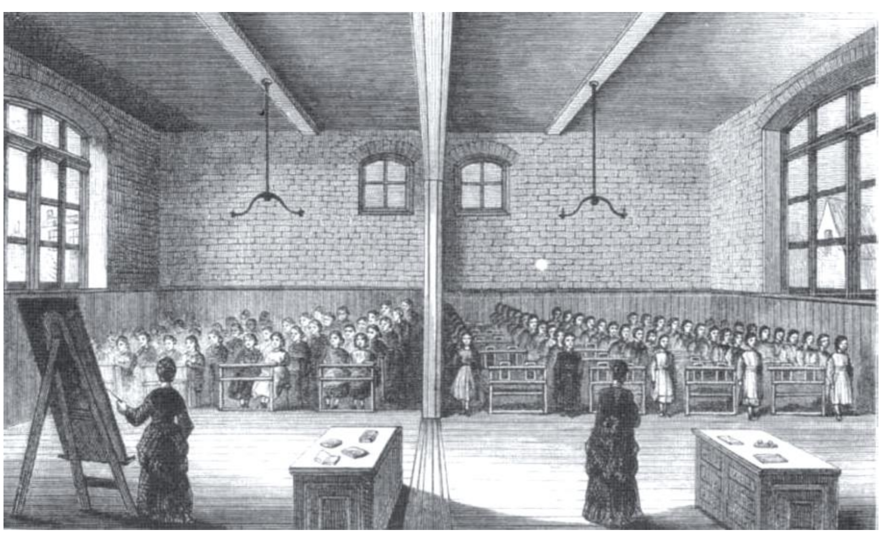


Figure 1:1 From Dudek, 2000, this drawing represents more of a British ideal classroom layout from the turn of the century, originally from the book school Architecture by E.R. Robsan (Baker 2012)

In terms of classroom thermal comfort and air quality, standard practice and common wisdom have undergone significant shift in the 1960s and 1970s. More acceptable fresh air requirements have replaced the outdated guideline requiring every classroom to deliver 30 cubic feet of fresh air per minute for every student. The consensus among planners and designers of schools is that a ventilation system that can remove and dilute harmful elements from the air in classrooms must provide between 10 and 15 cubic feet of fresh air per student each minute (Castaldi 1969).

(Al-Tamimi, Fadzil et al. 2011) It has been reported that 25–28% of the overall heat gain comes from the outside window. Because of this, the location and arrangement of windows greatly affects the comfort and productivity of those who work in the building. Furthermore, different materials react differently to incident solar radiation in terms of their thermal capacities, which are measurements of their capacity to store heat from surfaces and the surrounding air (Stein, Reynolds et al. 1992).

A building's capacity to accept solar radiation and breathe is influenced by its orientation and spatial arrangement. Buildings should be oriented so that their longer sides intercept prevailing winds and their shorter sides face the direction of the strongest solar radiation in order to limit solar gain and increase ventilation. As a result, efficient ventilation is achieved while the heat impact of solar radiation is reduced (Koranteng and Abaitey 2010).

One of the key factors influencing a nation's economic growth and productivity is education. The physical setting in which education takes place has received much too little consideration while institutional procedures and instructional materials have been modified. Enhancing the physical environment of educational facilities is essential for comprehending the educational process, student requirements, and academic achievement (Stadler-Altmann 2015).

According to Preiser and Vischer, "Criteria for designing and building new environment should be depend on the evaluation of the existing ones, and upgrading when appropriate in the design process" is a key component of "Building Performance Evaluation" (BPE) (Cleveland and Fisher 2014). The term "BPE" refers to the innovative, practical, and empirically supported method of designing a physical space that satisfies occupant needs while meeting functional requirements (Mallory-Hill, Preiser et al. 2012). An integrative framework for BPE is created by evaluating the five primary phases of planning, design, building, occupancy, and adaptive reuse.

Feeling comfortable in an interior space directly impacts building occupants' mood. In educational buildings, students spend most of their time inside classrooms in which their primary focus is on academic purpose. There is high concern on air quality in school buildings. Schools present a much higher occupancy than any other buildings, there being four times as many occupants per unit of area than in any other buildings including offices. (Prill, Blake et al. 2002).

Many research's shows that schools have significant indoor environmental problems, while ventilation levels are below the recommended rates (Synnefa, Polichronaki et al. 2003). Due to the fact that children breathe in more air than adults do relative to their weight and that their organs and tissues are still developing, high indoor pollutant concentrations may have a substantial negative effect on students' health. The amount of ventilation in school classrooms has an indirect impact on students' performance and ability to study as well as thermal comfort, indoor air quality, and health (Wargocki, Sundell et al. 2002).

Numerous investigations have examined the effects of higher CO2 concentrations and ventilation rates on indoor air quality complaints and health symptoms. Schools may use mechanical or natural ventilation systems. In mild climates, natural ventilation is a relatively frequent practice. The majority of national rules in moderate climates believe that opening windows can offer enough ventilation rates and do not necessitate the use of mechanical ventilation systems (Richalet, Beheregaray et al. 1994).

It is crucial to make the indoor climate condition comfortable for students. The temperature level inside the classrooms has a significant effect on the health, mood and performance of students. A higher indoor temperature in classrooms will result different health problems such as headaches, chest tightening and affects the students focus. (Turunen, Toyinbo et al. 2014).

1.2. Problem Statement

Healthy and comfortable climatic condition is essential for any type of building and environment. Educational building is a form of public building which contains spaces designed to be used for learning. The main purpose of an educational environment is to support its students in performing on their education with the maximum satisfaction. High level of environmental quality is needed to considerably improve student's attention, learning, hearing and increase their educational performance. Nowadays, the government of Ethiopia gives the maximum attention on education. Due to this most government and private educational buildings are designed and built in different parts of the country. However, the problem is that most of them are not comfortable for their students. This is the result of design and building without consideration of the weather, environment and orientation in relation to natural climatic factors of the proposed site. Not only have these, they also not use different systems to attain their student's comfort regarding condition of the place.

Adama city is located and categorized as a hot zone with warm and humid especially in winter season (Merga, Tabor et al. 2021). The city is one of the fastest growing cities in the country. As the number of populations increase, the number of students in government and private schools also rapidly increase. Currently there are different typologies of school buildings constructed in the city which aims to give their students a better educational environment. Most of these buildings are not comfortable due to their design not integrated with the local climatic condition.

The existing classrooms in Adama city have many problems related with indoor thermal comfort and natural ventilation which occurs mostly from building design, orientation and opening location and lack of adequate passive design strategies. Some of these buildings are constructed without considering the orientation and have insufficient natural ventilation that their window location is not located considering the sun orientation and wind direction to naturally ventilating the internal space of the rooms, and the remaining buildings, their position is not located on the right direction. This problem negatively affects the student's comfort, health and performance on their education. Due to this uncomfortable learning environment, they develop different physical and psychological problems like, depression, headache, lack of interest, loss of performance, absenteeism and etc.

With regard to Adama city to the level of my understanding, there is no research on natural ventilation and indoor thermal comfort was done on considering the sun orientation and wind direction when designing classrooms to minimize the direct solar penetration to the classrooms and to maximize natural ventilation to the interior space. So, the researcher believe that this research will fill the gap in this problem.

1.3. Research Question

1. What is the thermal condition of the existing classrooms buildings?
2. What is the student’s response to indoor climate of selected classrooms buildings?
3. What is the relationship between classroom buildings and building orientations for indoor thermal comfort for the selected building type?
4. What are the recommended passive design strategies for better indoor thermal comfort based on wind direction and sun orientation on selected building?

1.4. Objective of the Study

1.4.1. General Objective

The General aim of the study is to evaluate orientation based adaptive model of naturally ventilated class rooms to enhance thermal comfort in school buildings in Adama City, Ethiopia

1.4.2. Specific Objective

1. To assess the thermal environmental condition of the existing classrooms buildings
2. To analyze the student’s response on the thermal condition of the classroom buildings
3. To assess the relationship of classrooms buildings and building orientations for indoor thermal comfort
4. To develop a design strategy that maximizes natural ventilation and minimizes direct sun penetration on classrooms based on wind direction and sun orientation

1.5. Significance of the Study

The ultimate goal of this study is to add a value and to fill the gap on the existing knowledge and experiences in the fields of Architecture and building sustainability in educational buildings. The outcome of this research paper is significant for the following bodies:

- **For Architects**

This research paper will fill the gap on strategies to be followed while designing and constructing educational building on the local environmental context to make them sustainable.

- **For Researchers/Academicians**

The study will used as an academic input and for researchers and encourage them to do additional research on the field

- **For schools/class rooms**

Creating a comfortable and healthy learning environment for students make them energetic, motivated and more productive

1.6. Delimitation/Scope

1.6.1. Spatial Scope

The scope of this research paper is confined within Adama city and only focuses on assessing a passive design strategy to create naturally ventilated and thermally comfortable classrooms for purposively selected government and private high school and preparatory school classroom buildings in Adama city. The study analyses in detail the existing problem that arises from the design of classrooms, orientation of buildings, the location of openings and their impact on the thermal satisfaction of the students.

1.6.2. Thematic Scope

In this study, thematic boundaries include natural ventilation and thermal comfort for secondary and preparatory school classrooms. To realize this, the researcher first tries to assess building orientation and natural ventilation of selected educational buildings; secondly develop design prototypes of passive design by simulation software (CFD) and finally, develop the scale up strategy by taking a case area of the classrooms for the evaluation of building orientation on determining natural ventilation.

1.7. Operational Definition

Air temperature: The temperature of the air to which a person is exposed, as measured in dry bulb temperature (DBT)

ASHRAE Scale: The ASHRAE seven-point scale is a set of seven options available to people to relate their perception of thermal comfort to a given environment (cold, cool, slightly cool, neutral, slightly warmth, warmth and hot)

Classroom: A specially designed space to teach the students without any interruption

Indoor thermal comfort: according to ASHRAE, it is "a condition of mind which expressing satisfaction with the indoor thermal environment (ITE)." That is, the state of having people neither too hot nor too cold and assessed by subjective and objective evaluation".

Natural ventilation: use of natural forces, i.e., pressure difference generated by wind or air temperature, to introduce and distribute outdoor air into or out of a building

School building: is any structure suitable for use as a classroom, including a school facility like laboratory, library

Thermal environment: the characteristics of the environment that affect a person's heat loss.

Ventilation: provides fresh air into a building to ensure good air quality for occupants' well-being

1.8. Organization of the Study

This thesis is categorized into five chapters. Each chapter examines the content and data of the study properly. Issues that discussed under each chapter were summarized as follows.

Chapter One: the first chapter of this thesis focuses on introducing the issue to be discussed to the reader, objective of the study, research questions, importance of the study, and scope of the study.

Chapter Two: Reviewing different literatures on thermal comfort, natural ventilations, building orientation, and opening locations were discussed under the second chapter.

Chapter Three: The third chapter of this thesis comprising of research methodologies that was used to achieve each specific objective of the research. Describing the study area, Data collection methods, sampling techniques, research design, also discussed under this chapter.

Chapter Four: The fourth chapter of this paper discusses the result and meaning of each collected qualitative and quantitative data, their relation with the thermal environment of the study area, and looking for a scaleup strategy to solve the problem by evaluating the effectiveness of roof eave overhang and wingwall in reducing the solar penetration and increase the fresh air entry to the room spaces by performing different software simulations.

Chapter Five: The last chapter of this thesis paper is conclusion and recommendation. Concluding the paper is based on the result from both primary and secondary sources; and recommending the effective passive design strategy.

CHAPTER TWO

2. LITERATURE REVIEW

Introduction

The second chapter of this paper is reviewing different literatures on the study area. This chapter is divided into two parts; which are the theoretical review and empirical reviews. The theoretical review was carried out by referring different published researches, scientific journals, articles, books and standards which focuses on passive design strategies, natural ventilation techniques, thermal comfort in school classrooms and its impact on the wellbeing and performance of students; and the empirical review focuses on referring different design strategies carried out to solve related problems with the study area and finding out research gaps that needs to be solved.

2.1. Theoretical Literature Review

2.1.1. Thermal Comfort

Thermal comfort is defined by the American Society of Heat, Refrigeration, and Air-conditioning Engineers (ASHRAE), as a state of mind which express satisfaction with the thermal environment (ASHRAE 2004). Studies have also stated that thermal comfort is the result of the interaction and adaptation of environmental and human body parameters and according to ASHRAE, the indoor thermal condition in a building is acceptable when 80% of the building occupants should be thermally comfortable and satisfied in the interior space of the building. The fact that thermal comfort qualities affect the preferences of the users' indoor shows that this concept has dimensions related to social, economic, health, energy, environmental and many other issues.

An educational environment has a range of activities, such as learning, reading, typing and learning activities. Thermal comfort becoming an important requirement in educational buildings for enabling students learn productively. There is a positive effect of the thermal quality of classrooms on students' performance (Pepler 1968). According to (D'Ambrosio, Bellia et al. 2010), providing a comfortable and healthy environment in school classroom is necessary for student's well-being and productivity. An extensive study by Mendel and Heath (Mendell and Heath 2005) showed that a good integration between indoor school environment and the performance and attendance of students is highly interrelated. They found that, warmer temperature inside school classrooms (above 24℃) tended to reduce the performance of students on their education.

The majority of Indonesian schools were constructed as prototypes, with no thought given to the regional climate. Regardless of the comfort and desire of the user-in this example, the secondary school students - who are transitioning from childhood to maturity (ages 11 to 18) the schools were constructed to the same standards. The educational buildings don't take thermal comfort into particular account. The government only provides thermal comfort guidelines for buildings in general. The requirement is based on the (Hamzah, Ishak et al. 2016) which later used in the national standard SNI 03-6572-2001 (McQuiston, Parker et al. 2023); where the building should provide thermal environment as follows:

1. Comfortably cool => 20.5 – 22.8 ℃ (Te)
2. Comfortable => 22.8 – 25.8 ℃ (Te); and
3. Comfortably warm => 25.8 – 28.1 ℃ (Te)

The guideline made use of the effective temperature (Te), which is the temperature of a saturated and stationary atmosphere that would have the same impact as the atmosphere in the investigation in the absence of radiation. According to BS EN ISO 7730:2005 (Standard 2006), the thermal comfort of schools for normal maintained operative temperature during the heating season and the maximum operative temperature during the heating season at maximum occupancy for classroom spaces with normal level of activity including studying, teaching, exam rooms, administrative rooms, staff rooms, practical rooms and computer suits is ranging between 20℃ and 25℃ respectively.

2.1.2. Basic Factors of Thermal Comfort

Regarding the measurement of thermal comfort, Fanger proposed a thermal comfort predictive model. It works on four physical parameters and two individual variables to define PMV (Predicted Mean Vote) (Fanger 1984). These are: Air temperature, Air velocity, Mean radiant temperature, Relative humidity, Clothing insulation, and Activity level

Figure 2:1 Six primary factors used for defining acceptable thermal comfort in the build environment

- **Environmental factors** (Van Hoof 2008)

Air temperature

Air temperature is the temperature, usually measured in degrees Celsius, of the air surrounding the body. This is what is measured using a thermometer.

Air velocity

How quickly air is moving across the building occupant is an important factor in thermal comfort. Moving air in a warm or humid indoor environment can increase heat loss by convection, On the other hand, if it's cold or cool in the building, small air movements can be felt as a draught (Hsieh 1985).

Relative Humidity

If indoor environment has high humidity, it means there is a lot of water in the air. This prevents the evaporation of sweat from the skin, which is the main way we cool down. Relative humidity (the ratio between how much water vapour is in the air and how much water vapour the air can hold at that air temperature) between 40% and 70% does not majorly impact thermal comfort. However, in non-air-conditioned building or where weather conditions outdoors influence the thermal environment indoors, relative humidity can reach above 70%, which makes it hard for building users to cool down (Vellei, Herrera et al. 2017).

Mean Radiant temperature

Radiant temperature, or thermal radiation, is warmth that radiates from a warm object such as the sun, radiators, hot surfaces and machinery, etc. (Davies 1990)

- **Personal factors**

Clothing insulation

Wearing too many or too few clothes for the environment is a major potential cause for thermal discomfort. Even if the environment itself is not consider too warm, wearing too much clothing can cause heat stress. Unfortunately, through the wearing of uniforms, many students are not able to adapt their clothing to suit how hot or cold they are. Schools need to identify how the clothing of their students contributes to thermal comfort or discomfort (Gao, Ooka et al. 2021).

Metabolic heat

The more physically active you are at any work, the more heat you produce. Peoples who do physical work, and produce more heat, need to lose more heat to prevent themselves from overheating. You'll also need to consider the physical characteristics, including size, weight, age, gender and fitness level, as these can impact how warm or cold, they feel (Havenith, Holmér et al. 2002).

2.1.3. Natural Ventilation

Natural ventilation is a system using natural forces to supply fresh air for comfort and heat dissipation. The term natural ventilation is used to indicate the intentional airflow through windows, doors or other openings designed for the purpose, obtained without the use of fans; it is created by pressure differences caused by the wind and/or by temperature differences between the inside and the outside. If the temperature in the indoor space exceeds 26°C or relative humidity is quite high, natural ventilation can improve the thermal comfort. In hot and humid climates, cross ventilation is the simplest strategy to adopt if the indoor temperature is almost the same as the outdoor temperature. Givoni assumes that the maximum allowed indoor air speed is about 2 m/s, thus ventilation maintains comfort up to an outdoor temperature limit of 32 °C. Natural Ventilation approach relies on the natural forces of wind and buoyancy to deliver fresh air to indoor spaces (Walker 2010).

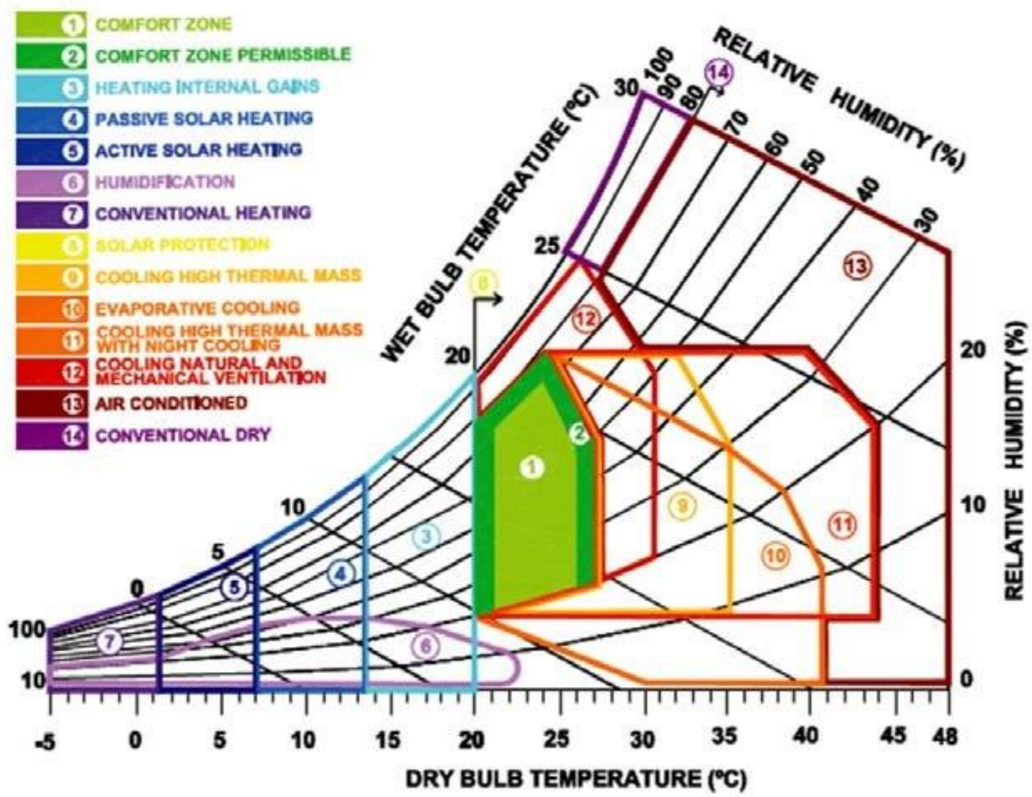


Figure 2:2 Natural Ventilation Zone/Psychrometric chart adapted from Givoni which shows a sustainable building design in tropical climate zone for natural ventilation (Givoni 1992).

2.1.4. Factors affecting natural ventilation

The effectiveness of natural ventilation varies depend on the different factors. These are; dominant wind speed and direction, surrounding environment, building footprint and orientation, outdoor temperature and humidity, window sizing, location, and operable.

❖ **Windows**

Windows are the main and most popular means in which natural ventilation can be allowed into a building's indoor spaces. Natural ventilation through windows can be based on pressure difference (also called wind-driven natural ventilation) or thermal difference (in single-sided ventilation or when placing windows or openings at different heights in cross-ventilation) between inside and outside or between the openings. Occupant-controlled windows are considered an effective method for maintaining indoor air quality and thermal comfort conditions. Window-based natural ventilation can replace mechanical ventilation and air condition systems (in free-running buildings or periodically), thus reducing a significant amount of energy consumption and CO_2 emissions. Accordingly, window design has a strong relationship with natural ventilation performance in different types of buildings. Window design is an early decision task of architects that requires sufficient knowledge supported by experiments and quantitative data (Fung and Lee 2015).

- **Building orientation**

Building orientation is a significant design consideration, mainly with regard to solar radiation and wind. In predominantly humid and hot humid regions which receives sunlight all year around, buildings should be oriented to minimize solar gain and maximize natural ventilation. Orientation of buildings is approximated either in relation to the outdoor wind direction or with respect to the cardinal points and the buildings' opened facades. Buildings may not necessarily be oriented perpendicular to outdoor wind direction in order to maximize the benefit of natural wind. An angle between 90° and 60° to the face of the building was appropriate (Al-Tamimi, Fadzil et al. 2011).

Building orientation parallel to outdoor wind direction would benefit minimally from natural wind flow (Boutet 1987). Maximum air movement through the building is achieved by placing inlet openings in positive pressure zones and outlet openings in negative pressure zones. On the one hand when windows are located on opposite walls of a room, optimum air distribution is obtained when the wind is oblique at an angle of 45° to the inlet window. When windows are located on adjacent walls of a room, on the other hand optimum air distribution is obtained when the wind is incident perpendicular to the window. Ideally, naturally ventilated buildings should be oriented to maximize their exposure to the required wind direction, and designed with a relatively narrow plan form to facilitate the passage of air through the building.

In a study on natural ventilation performance of buildings with respect to their orientation and window location on walls, that optimum air distribution is obtained when the wind is oblique at an angle of 45° to the inlet window (for openings located on opposite walls of a room). On the other hand, optimum air distribution is obtained when the wind is incident perpendicular to the window for windows located on adjacent walls of a room. In a study on evaluation of orientation as design strategy for effective passive ventilation in students' hostels in hot-humid tropical environment of Enugu campus, Nigeria, reported that orientation of buildings with respect to the cardinal points is no longer novel, but rather, that buildings be oriented in relation to the dominant outdoor wind directions and window inlet planes. The studies reveal that there is a correlation between effective ventilation coefficient (ventilation efficiency) and orientation of buildings. The authors recommended the need for proper investigation of wind paths which would provide orientation options for buildings to aid effective natural ventilation (Mba, Sam-amobi et al. 2022).

There are commonly two types of natural ventilation techniques used. These are;

- ➢ wind driven ventilation and
- ➢ stack ventilation.

❖ **Wind Driven Ventilation**

As wind blows across a building, it comes into contact with the windward wall, which develops a positive pressure. Simultaneously the opposite wall, also called leeward wall, develops a negative pressure. If there are any openings on the windward and leeward walls of a building, fresh air will enter through the openings on windward wall and exit through the leeward openings. With stronger wind and larger openings, more air can pass through the building (Khan, Su et al. 2008).

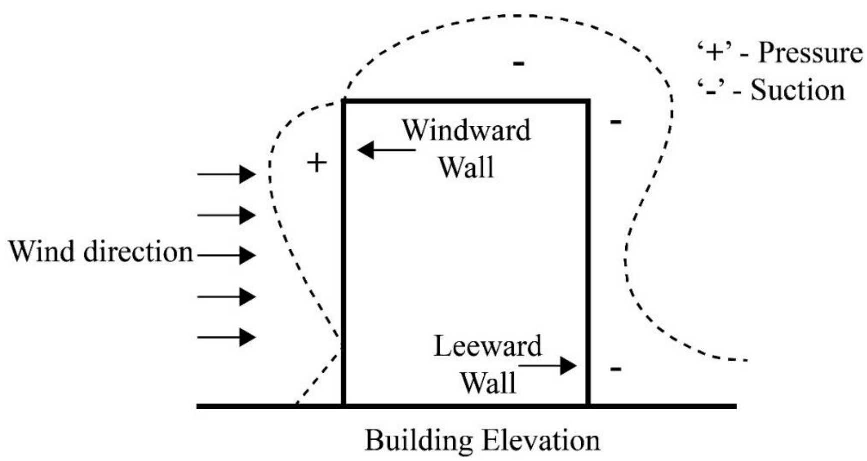


Figure 2:3 Wind driven ventilation technique

❖ **Stack Ventilation**

Stack ventilation also known as buoyancy or thermal ventilation, is primarily induces by temperature differences within a home. As air in a building heat up, it becomes less dense, which causes the air to rise. This warm air will leave the building through a window or openings located higher in the building or the home. Because stack ventilation does not rely on the wind, it can take place with relatively stable air flow on hot summer days with no wind (Gładyszewska-Fiedoruk and Gajewski 2012).

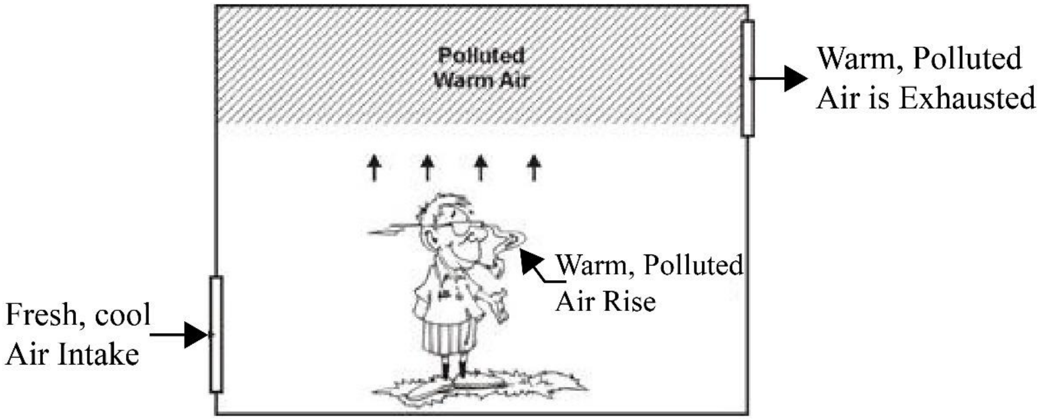


Figure 2:4 Stack ventilation technique

Design considerations for effective natural ventilation in a building (Heracleous and Michael 2019)

- Building Ventilation and Location

Buildings should be oriented so that the windward wall is perpendicular to the summer wind.

- Building form and dimension

Naturally ventilated buildings should not be too deep because it will be difficult for wind driven air to pass through the home.

- Window typologies and controls

Different types of windows will result in different ventilation rates

- External elements

External elements such as trees, adjacent buildings, or other structures may obstruct the wind

- Air inlet and outlets

Air inlet should be low in the room and air outlet should be higher and across the room from the lower inlet. There should be a notable vertical distance between the inlet and the exhaust openings to take advantage of the stack effect.

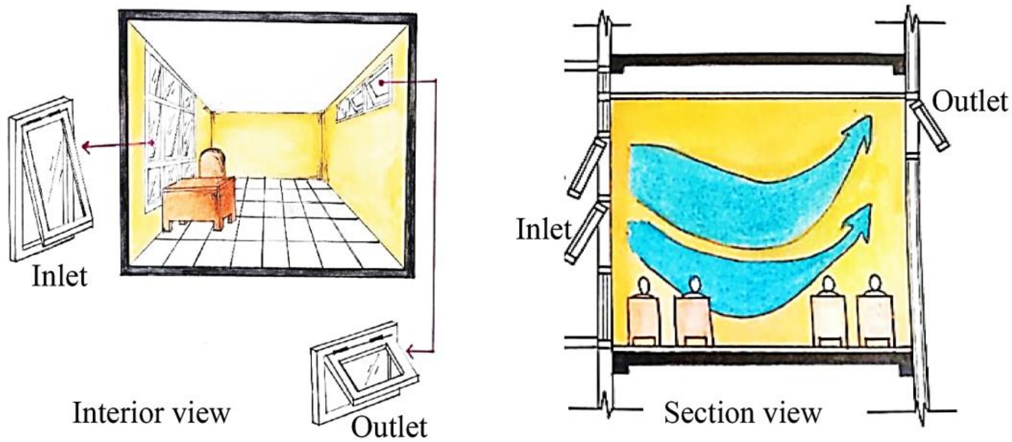


Figure 2:5 Plan view and section view of inlet and outlet openings (A'yun, Widiastuti et al. 2020)

2.1.5. The Role of Ventilation

Fresh air is required to achieve a healthy, fresh, and comfortable indoor environment for people to work and live in. Natural ventilation can ensure the supply of adequate breathing air, adequate ventilation of contaminants, adequate thermal conditioning and moisture dissipation, and contribute to well-being through a connection to the dynamics of nature (Al-Tamimi, Fadzil et al. 2011). The purpose of ventilation is to moderate indoor thermal environment and to eliminate airborne contaminants, which are generated both by human activity and by the building itself. These contaminates are bad odors, moisture; which increases the risk of mold growth, carbon dioxide gas; which may induce lethargy in high concentrations, dust; aerosols and toxic gases resulting from human activity, as well as from the materials of the building, and excessive heat.

Natural ventilation system needs low running cost, zero energy consumption, low maintenance and lower initial cost. It is healthier, and the way it connects with the outside is seen as a psychological benefit. This system does not require energy use through motorized fans, there is less energy use. The effectiveness of natural ventilation is determined by the prevailing outdoor conditions: microclimate (wind speed, temperature, humidity and surrounding topography) and the building itself (orientation, number of windows or openings, size and location).

Buildings are required to protect their occupants from the external environment and to provide them with a good indoor environment. A building that is well adapted to its climate protects its occupants against the extreme conditions observed outdoors without creating uncomfortable internal conditions.

2.1.6. Category of Architectural ventilations

There are four types of natural ventilation techniques. These are; single-sided ventilation (the use of openable windows), cross-flow ventilation (the use of high and low-level louvers), stack ventilation (passive stack turrets) and top-down ventilation (the use of wind catcher system) (Ohba and Lun 2010).

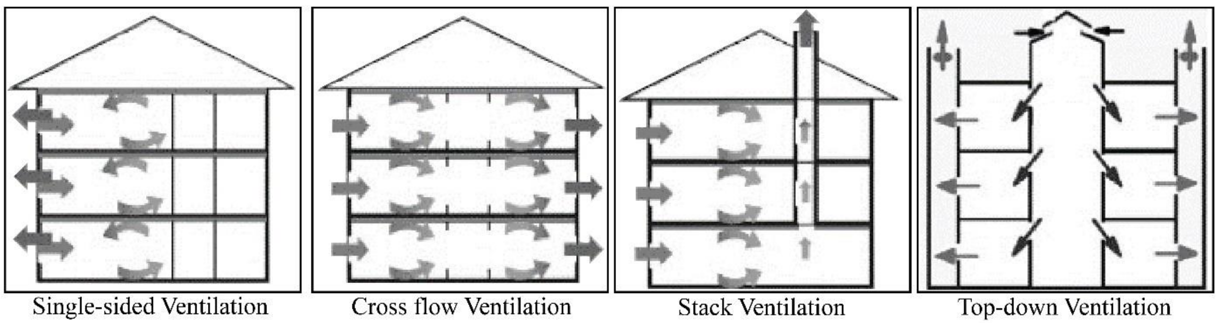


Figure 2:6 Different types of natural ventilation (Ohba and Lun 2010)

Single-sided ventilation is supplied and extracted through the same louvers in the room. With single-sided ventilation, the openings should equal to 4% of the floor surface. This system of ventilation is less efficient, but it is applicable almost everywhere and the internal doors may remain closed. In Cross flow ventilation strategy, the ventilation supply and extraction take place on the same level in a building. The air is supplied and extracted through louvers. The internal door must be opened or equipped with transit ventilation grilles. This system generally achieves good results, except under no wind condition. The stack ventilation measure has two ventilation openings, a low-level grille and a high-level one, are typically placed above the door. Outside air enters through the louvers and extracted through a chimney. In this system, there will be ventilation even when there is no wind (Ohba and Lun 2010). The area that needs to be cooled must be in direct contact with the chimney. On the other hand, the top-down ventilation system uses roof turrets that capture wind from any direction. It is one of the most reliable and popular forms of natural ventilation, simply because it uses the natural elements of wind movement to capture relatively clean, fresh air from above roof level and wind pressure pushes that fresh air supply through the wind-catcher device down into the building below.

2.1.7. Natural Ventilation Principles

The ventilation principle indicates how the exterior and interior airflows are linked, and hence how the natural driving forces are utilized to ventilate a building (Chenvidyakarn 2013).

Furthermore, the ventilation principle gives an indication on how the air is introduced into the building, and how it is exhausted out of it. The starting point in ventilation design is to determine how much ventilation air is required, and for what purposes. In North America, the most widely accepted standard for designing ventilation systems to achieve acceptable indoor air quality in buildings is ASHRAE Standard 62-2007, Ventilation for Acceptable Indoor Air Quality. For indoor air quality, the requirement for ventilation is based on the number of occupants and is 15 cfm per person. This design capability is needed at all times in winter and summer.

Because buildings are one of the most significant energy consumers, there is a tendency all over the world to reduce their energy consumption through design buildings that consume low energy as energy efficient building design. According to (Jaber and Ajib 2011). The first factor is the building design including location, orientation, and layout, opening type and size and structure and building materials. The second factor is the patterns of building use.

Natural ventilation has been canvassed as an integral component of sustainable architecture. Whether wind pressure-driven or buoyancy-driven, natural ventilation's cost effectiveness, propensity to enhance building occupants' productivity, health and wellness, as well as ability to significantly reduce harmful gas emission have been adduced (IDOWU, GWANDI et al. 2018). The control of natural ventilation is one of the most subtle and yet the most important of building design in a tropical environment. It solves two fundamental needs: elimination of foul air to provide good indoor air quality and moisture, and the modification of interior overheating by boosting natural cooling for occupant thermal comfort, particularly in tropical environments (Mba, Sam-amobi et al. 2022).

The shape of the building plan, form of the building roof, and size of building openings constitute the architectural characteristics of the building reported to affect natural ventilation (Boutet 1987). Orientation of building in relation to the direction of outdoor wind pattern affects natural ventilation in buildings. According to (Boutet 1987)**,** buildings may not be necessarily oriented perpendicular to outdoor wind direction in order to maximize the potentials of natural ventilation. Wind directions parallel or less than 30° to inlet opening planes, however, seem to offer little prospect to indoor air flow. The need for solar protection in hot climates as canvassed by (Givoni 1994**)** may, however elicit a building orientation of compromise between natural ventilation and passive cooling requirements.

Previous studies (Boutet 1987), have revealed that some basic building plan forms affect air flow pattern and rate in building spaces. The square, rectangular, as well as U-shaped and T-shaped building forms of various dimensional (length, breadth, and height) proportions exposed to wind at different directions were reported to alter the air flow in varying degrees (Kleiven 2003) posited that the optimum shape for economy and minimal heat loss or heat gain is a compact plan with the least amount of envelope surface exposed to the elements.

2.1.8. Natural Ventilation in schools

Natural ventilation proved to have great potential, combining energy savings and occupants' satisfaction (Harvey 2009). However, the results, particularly in terms of thermal comfort (air temperature) and ventilation rate or level of CO2 concentration, have not always been satisfactory (Coley and Beisteiner 2002). Performed measurements in UK primary schools in winter and during summer, concluding that opening windows between classes- purge ventilation has the potential to reduce CO2 and other contaminant. They concluded that opening windows was not commonly used due to their location (above the occupied zone) or to possible air drafts (Conceiça and Lúcio 2006). Monitored two unoccupied classrooms of one school in south of Portugal with cross ventilation, using the sliding sash window opening, located above the door and main windows. (Mendell and Heath 2005) published a review of 30 case studies, suggesting that poor environmental quality (PEQ) (e.g. insufficient ventilation) is common in schools and linked to health problems, and also it negatively affects students' performance and attendance.

2.2. Empirical Literature Review

In a formal educational environment, a conducive atmosphere is required for effective teaching and learning. The thermal condition, which is largely dependent on effective natural ventilation is one of a dominant issue to create a conducive environment that influence teaching and learning (Olgyay 2015). A well-ventilated classroom and also the removal of odor according to (Nielsen 2001) are critical features of good designs for educational facilities. Architectural design strategies such as building orientation with respect to the wind direction, building shape and form, openings are among other strategies that can be used to achieve natural ventilation (Mba, Sam-amobi et al. 2022).

Thermal comfort of a building basically depends on three factors, these are (relative humidity, wind speed, and temperature). According to (Munonye and Ji 2021). ventilation that can remove heat, cool the body and the building without using any mechanical system. (Idowu 2009). reported that, most public-school buildings in hot humid climates lack conducive thermal environment for teaching and learning due to poor natural ventilation. According to (Singh, Ooka et al. 2019), high energy consumption is often connected to the characteristics of the building envelope and the improper utilization and control of HVAC systems. Students' dissatisfaction was often related to warm sensations during winter and cold sensations during summer due to extensive use HVAC system.

Few studies have been done regarding the effectiveness of naturally ventilated classrooms to create thermal comfort. A study conducted by (Causone 2016) found that, the application of adaptive design strategies, like natural ventilation and operable windows will improve the indoor air quality and thermal comfort of classrooms. This study was only focusing on naturally ventilating classrooms by using windows and it didn't address the effect of windows orientation on natural ventilation, how to minimize the direct solar heat gain into classrooms through openings, how to maximize the air flow in classrooms and also it didn't address the student's perception on the indoor environmental quality.

A study by (Campano, Domínguez-Amarillo et al. 2019) "Thermal perception in mild climate: Adaptive thermal models for schools, in Spain " is focusing only on improving space design and arrangement will provide thermal comfort for school buildings. The study was conducted by gathering data using on-site measurement and surveys during winter, spring and autumn seasons during the time of early morning and at the beginning of the school day and before the midmorning break. The study uses different building features for sampling study classroom buildings, such as; building type, climatic area, building envelope characteristics, and indoor load presence. This study didn't analyze the effect of classroom orientation on thermal discomfort of classrooms; and also, the time of data collection also affects the final result of the study.

Another research conducted by (Mba, Sam-amobi et al. 2022) On "Orientation on Effective Natural Ventilation for Thermal Comfort in Primary School Classrooms in Enugu City, Nigeria" resulted that, there is a significant relationship between building orientation which is the architectural design strategy and the effective natural ventilation and thermal comfort in classroom buildings. The result shows that, classrooms that oriented their longest axis to north-south and window planes aligned are aligned perpendicular to prevailing winds were more effective in facilitating the maximum air-flow and cross ventilation in classrooms. This study also concluded that, the ratio of outlet to inlet windows opening also had a significant effect on creating effective natural ventilation in classrooms. Based on the findings, the study recommends buildings should be oriented with their longer axis to north-south aligned perpendicular to the prevailing winds at an angle between 0°-30°. However, there were a limitation on this study such as small sample size, which may impact the generalizability of the result of the study.

2.2.1. Summary of Literature Reviews and Research Gaps

Even if there are no sufficient researches on naturally ventilated and thermally comfortable classrooms on countries located in the equator and countries with warm and dry climatic conditions, the existing studies have highly focused on the benefits of natural ventilation in classrooms in improving thermal comfort of the indoor space and reducing energy cost. However, there is a research gap on the effectiveness of achieving natural ventilation and occupants' satisfaction. This is due to

- (Mba, Sam-amobi et al. 2022) fail to use sufficient sample size that affects the generalizability of the result of the study
- (Campano, Domínguez-Amarillo et al. 2019), (Causone 2016) limitation on considering the effect of classroom orientation on natural ventilation and also not properly choosing the data collection time; which may affect the result of level of thermal discomfort during the hottest time of the day,
- The studies didn't focus on how to minimize direct solar penetration and increase natural ventilation into the classrooms by adapting passive design strategy based on sun orientation and wind direction of the study area.
- There is no research on the effectiveness of roof eave overhand and wingwall in reducing the direct solar penetration into the room spaces and how this building elements contribute to increase the amount of fresh air that enter the room and regulate the indoor air temperature of classrooms.
- There is no study conducted on this issue in Ethiopian context; So that, this study will contribute a lot.

CHAPTER THREE

3. METHODOLOGY

3.1. Description of The Study Area

Adama, is a city in the central Oromia Region of Ethiopia, and capital of East Shewa zone. The city is found in rift valley between 8° 33’ to 8° 36’ N latitude and 39° 11’ 57” to 39° 21’ 15” E longitude. The city is located 99 km (62 mi) southeast of the capital, Addis Ababa with an average altitude of 1712m above sea level. Adama receives 600mm to 1150mm average rainfall and temperature range between 12 and 33℃ and the city is significantly warmer than Addis and other parts of Ethiopian highlands (Berhanu, Ayana et al. 2022).

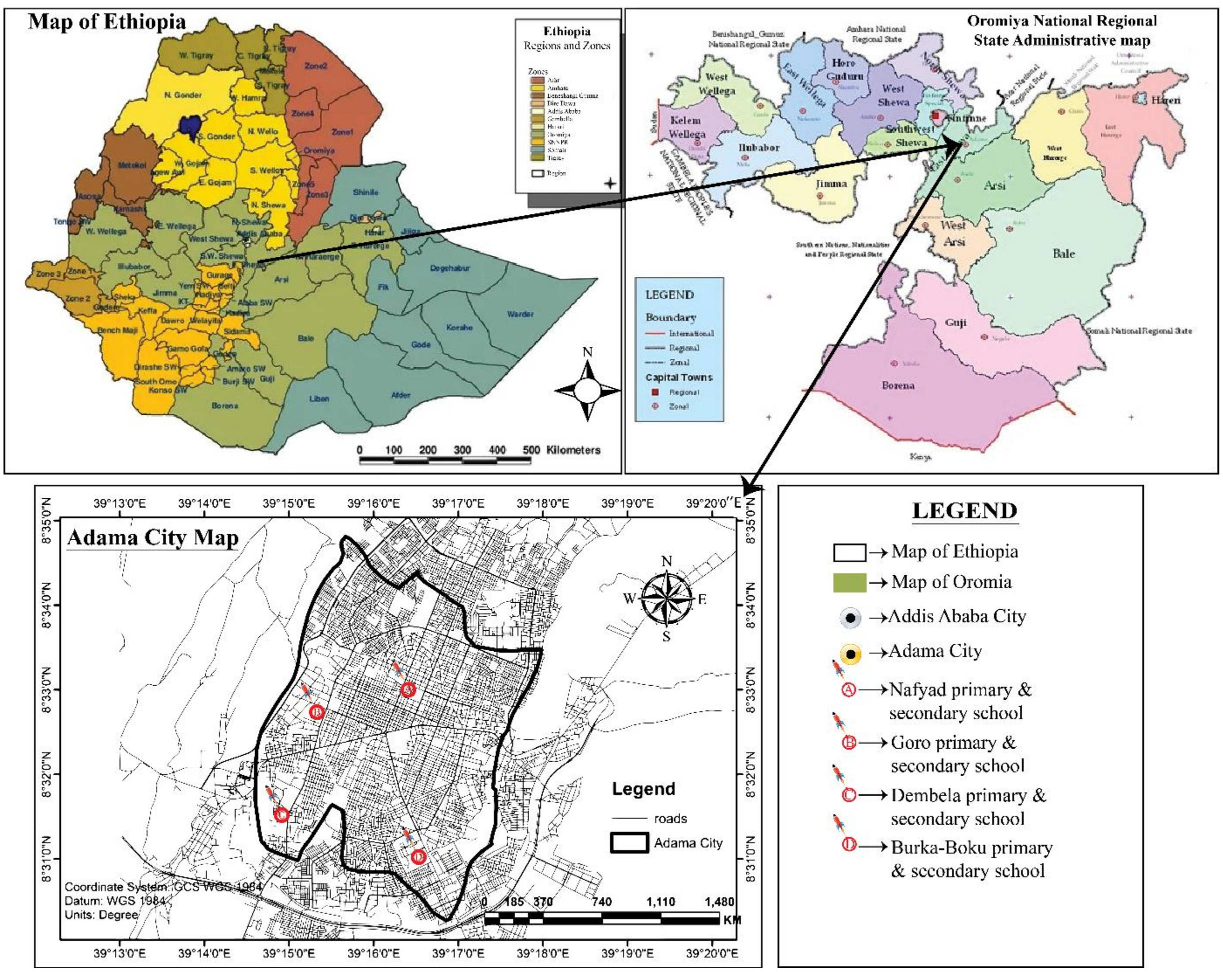


Figure 3:1 Location Map of Adama city, Ethiopia (Source: Author, 2024)

3.2. Research Design

The research design that used in this study is divided into two. These are; qualitative and quantitative research designs. Qualitative (also known as unstructured data) research design focuses at finding answers to questions such as where, how and when. It uses open - ended question. The outcome of this data analysis will be represented in the form of graphs, numbers and charts. The quantitative (also known as structured data) research design focus on finding answers to question like how and why. It uses closed - ended questions and helps the respondents to express their feelings clearly.

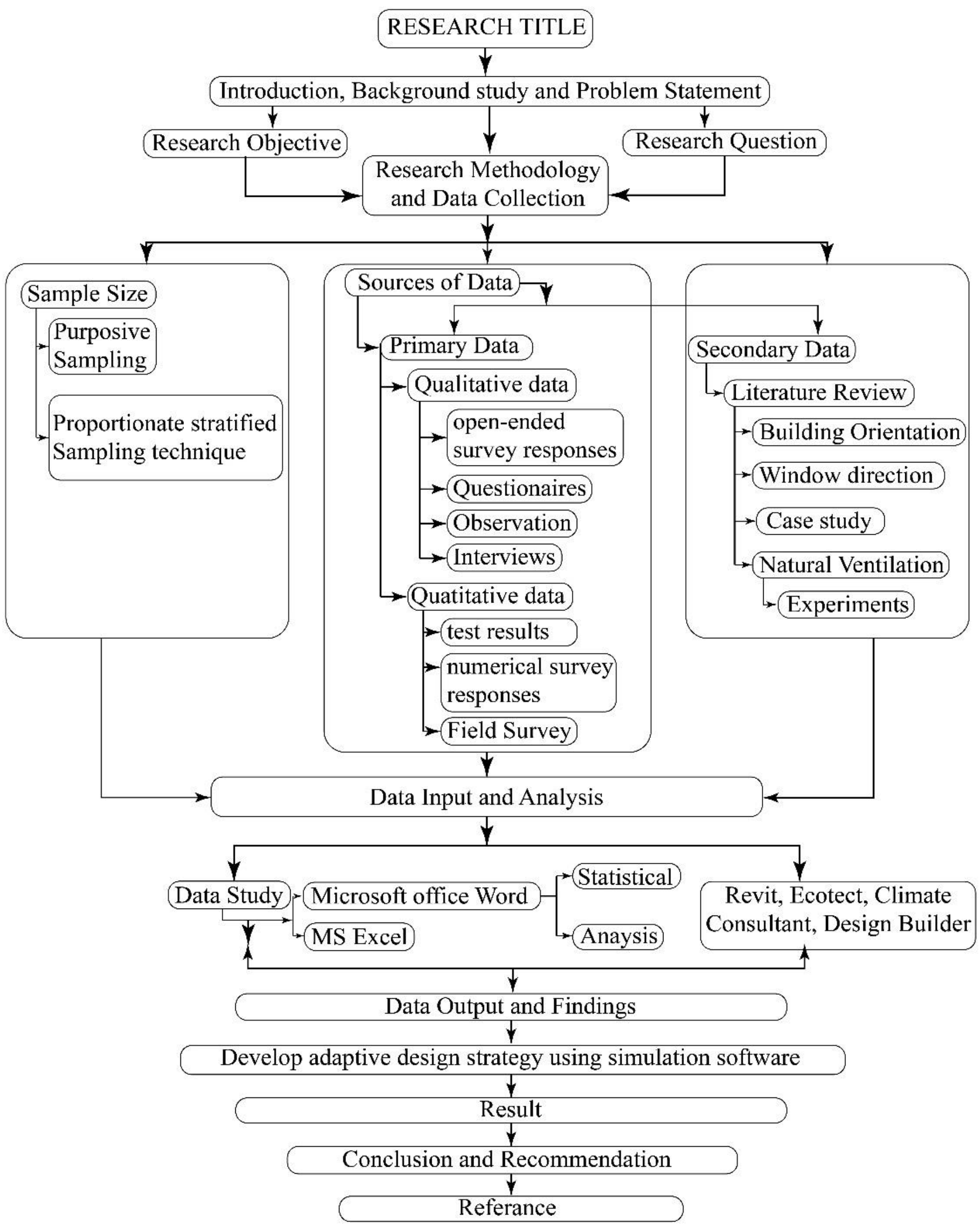


Figure 3:2 Research Design (Source: Author.,2024)

The study applies a descriptive. This research aims to accurately and systematically describe a population, situation or phenomenon. It can answer what, where, when and how questions. A descriptive research design can use a wide variety of research methods to investigate variables

3.3. Study Approach

Both qualitative and quantitative study approach was used. Quantitative Approach Involves the generation of quantitative data which can be subjected to rigorous quantitative analysis in a formal way. This approach can be further sub classified into experimental and Simulation approaches to research. Qualitative Approach is concerned with subjective assessment of attitudes, opinion, and behavior.

3.4. Data Types and Source

The research relied on data collected from different sources based on the study objectives. For the first and second objective of the study, required data to know the thermal condition of existing classrooms and students’ perception on the thermal condition was gathered by primary data sources through observation, field survey and taking required measurements, interviews, and questionaries. For the third objective, data were obtained from secondary sources such as published books, journals, articles, and different standards and relating with primary data. By combining the two data types, effective passive design strategies for thermally comfortable and naturally ventilated classroom were developed.

3.5. Sampling size and Sampling technique

3.5.1. Sampling Technique

The sample buildings were identified through non-probability sampling in general, and purposive or judgmental sampling technique in specific. In this type or method of sampling, the researcher relies on judgments when choosing the samples and he should justify the reason or criteria’s for using this technique.

Both private and governmental schools was taken to know the thermal condition of school classrooms in both school types. For this study, two governmental and two private secondary and preparatory schools were selected based on different criteria discussed under 3.5.2. The selected schools and areas or kebeles they located are listed below.

Table 3:1 Type of selected school buildings for the study and their location

No.	Name of school	School level	Kebele they are located in	Kebele Name
Government School (Secondary and Preparatory schools)				
1.	Dembela Secondary and Preparatory School	Grade 9^{th} – to – 12^{th}	09	Irreecha
2.	Burka - Boku Primary and Secondary School	Grade 9^{th} – to – 10^{th}	11	Bokkuu
Private School (Secondary and Preparatory schools)				
3.	Goro High School	Grade 9^{th} – to – 12^{th}	01	Goro
4.	Nafyad High School and Preparatory	Grade 9^{th} – to – 12^{th}	05	Bole

3.5.2. Selection Criteria of study Buildings

The study schools and buildings were selected under these criteria: Building orientation, Opening direction of the building, size of classrooms (height, length and width), number of students per classroom.

The orientation of a building is a significant architectural concern, particularly in terms of environmental influences (i.e. temperature, humidity, air speed). The orientation of the building determines the quantity of solar radiation that it receives and also transmit it in to the internal space of the classrooms.

Naturally the sun rises due East and set in West direction. The orientation that gets the maximum harsh sun will be south and south-west direction. Therefore, schools and classroom blocks in which most of their classroom buildings and their openings that face to the harsh sun (south and south-west direction) were selected from the existing schools in the city.

Size of the classrooms are a significant factor on the natural ventilation and thermal comfort of classrooms. As the local climate condition is categorized under hot and warm climate, when the room height is not on the minimum standard, the indoor air temperature rises. This intern affects the thermal environmental comfort of building occupants.

From the selected schools, different number of blocks of classrooms was selected based on the above criteria. The number of blocks and number of classrooms per block in each school are discussed in the table below.

Table 3:2 Quantity of blocks, number of classrooms and number of student analysis on the study area

No.	Name of school	Number of blocks selected	Number of classrooms per block	Average Number of students per classroom	Percentage (%)
1.	Burka-Boku Primary and Secondary School	3 - Blocks	4 – classrooms per block 4 * 3 = 12 classrooms	80 students per classroom 80 * 12 = 960 students	31%
2.	Dembela Secondary and Preparatory School	3 - Blocks	4 – classroom per block 4*3 = 12 classrooms	65 students per classroom 65 * 12 = 780 students	25%
3.	Goro High School	3 - Blocks	4 – classrooms per block 4 * 3 = 12 classrooms	60 students per classrooms 60 * 12 = 720 students	23%
4.	Nafyad High School and Preparatory	3 - Blocks	4 – classrooms per block 4 * 3 = 12 classrooms	55 students per classrooms 55 * 12 = 660 students	21%
Total number of students in all selected schools = 3120					

3.5.3. Sample Size Determination

The total number of students of the selected study building were considered as a total study population number, and using (Yamane 1973) formula the sample is generated.

For known population size, the Yamane formula for determining the sample size is given by:

Taro Yamane Formula (Yamane 1973)

Sample size (n) = $\frac{N}{1+Ne^2}$ …….……………………………………...equation 1

Where:

n = sample size

N = population size

e = error (0.05) reliability level 95% or;

e = level of precision or confidence level always set the value of (± 5%) = 0.05

(Yamane 1973) adjusted calculation formula to be more accurate; by increasing of π = population variance from Dichotomous Variable equal to 0.50 and z = z score at significance level α (where z = 2 at α = 0.05 and z = 3 at α = 0.01) as the following formula.

Where:

π = 0.50

e = 0.05

N = Sample size

z = 2 at α = 0.05 and

z = 3 at α = 0.01 as the following formula

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

The total number of students on the selected school and blocks is 3120. So, by directly substituting the population size and other given values on the formula above, we will get the total number of samplings for our study.

$$n = \frac{(Z)^2 (\pi) (1-\pi) (N)}{(Z)^2 (\pi) (1-\pi) + (N) (e)^2} \quad \text{…….………………………………………..equation 2}$$

$$= \frac{(2)^2 (0.5) (1 - 0.50) (3120)}{(2)^2 (0.5) (1 - 0.50) + (3120) (0.05)^2}$$

$$= \frac{3120}{8.8} = 354.55 \approx 355 \text{ sample size}$$

The sample size was distributed to each school based on their percentage or the number of students discussed under table above.

These will be:

- Burka-Boku Primary and Secondary School = 31 % => 110
- Dembela Secondary and Preparatory School = 25% => 89
- Goro High School = 23 % = 82
- Nafyad High School and Preparatory = 21% => 74

After getting the number of respondents in each school, we use proportionate stratified sampling method. In this method, we will categorize the students into two strata as male and female; after knowing the number of both gender in each classroom, we will share the respondents number based on their percentage in the classroom. In this technique, we will avoid data biased.

3.6. Data Collection Tools and Methods

3.6.1. Data Collection Tools

Table 3:3 Data analysis tools, input data and outputs

No:	Software types	Input	Output
1	Microsoft office Word, MS Excel	Raw Data	Graphs, Tables, Text
2	Revit Architecture AUTO CAD, and Arch cad	CAD files	3D models, 2D models
3	Adobe Illustrator	Raw Data	Graphs, Tables, Text
4	Energy Plus	Climate data, building models data	2D models, 3D models
5	Climate consultant	Climate data	Graphs and Text Report
6	Autodesk Ecotect	Climate data, building model data	Image, Graphs and Text Report
7	Design Builder	Climate data, building model data	Image, Graphs, Charts, Text reports

3.6.2. Data Collection Methods

Both qualitative and quantitative data types were applied. Regarding this, the study uses both primary and secondary data sources.

- **Primary Data**

- **Questionnaire and Interview**

Questionnaires were distributed for selected sample respondents. The questions were focused on understanding the satisfaction of the students towards the thermal comfort and indoor air quality of the classrooms, the method that they use to regulate the thermal discomfort. Survey sample questionnaires were distributed to 355 students in selected schools. Semi-structured questionnaire type which includes both open-ended and closed-ended question were used to give the respondents the freedom to answer what they feel. And the questionnaires from each respondent was evaluated according to ASHRAE standard. The ASHRAE thermal sensation scale, which was developed for use in quantifying people's thermal sensation involves a seven-point scale of indoor thermal comfort vote is defined as follows: +3 hot, +2 warm, +1 slightly warm, 0 neutral, –1 slightly cool, –2 cool, –3 cold. Originally, the questionnaire was written in English and then translated to both Afaan Oromo and Amharic to smooth data collection and to make easy for respondents.

The interview was focused on getting a valuable information about the problem, the solution they thought, and whether or not the solution they used is comfortable.

- ❖ To understand the thermal Comfort satisfaction level of the students.
- ❖ To know the impact of direct sun penetration to the interior space of classrooms due to building orientation and opening location on the students

- **Observation**

The data were taken depending on different building parameters like building orientation, climate characteristics, opening location and type, room height, and number of students per classroom. From all these collected data opening location, orientation, Air velocity, relative humidity, and air temperature were determined.

- **Field Survey**

The field survey focused on observation of the thermal comfort of selected classrooms in Adama city and the comfort level of students who study in the selected building and how they are challenged by the indoor environmental quality and also observe the techniques that the students use to inlet and exhaust the air inside the building.

A handled wind speed meter measures wind speed, wind/air temperature was used to measure the indoor and outdoor temperature of classrooms and their humidity.

Figure 3:3 HOLDPEAK Digital Anemometer, Handled wind speed meter outdoor for Wind speed /wind direction /Humidity /Ai Temperature, Ventilation system

Table 3:4 Wind speed Anemometer specification

Measuring Range	
Wind Range	0.3 – 30 m/s (Accuracy, ± 5%)
Temperature Range	0 – 50 ℃ (Accuracy, ± 0.6℃)
Humidity Range	0.1% - 99.9 (Accuracy, ± 5%)

- **Secondary data**

Literature review such as journals and guide books and meteorological data were used to relate the situation of the area with different researchers used also help to figure out what kind of approach help.

3.7. Data Analysis, Interpretation and Presentation

The data which was collected are classified into two, which are qualitative and quantitative data. The quantitative data were coded and entered to computer using the MS excel, and based on the research questions, the variables were analyzed and interpreted descriptively. For qualitative data, the researcher uses personal reflections of respondents to interpret the data by listing the key ideas that express for each topic and finally the data was arranged in relation to each objective and research questions. The final interpretation was done in combination with quantitative part in order to triangulate the concepts from different angles and ensures the validity of data. The data was presented by text, maps, graphs, charts and tables.

3.8. Ethical Consideration and Interpretations

For quality output the study has given prior consideration on awareness creation on rational and objectives of the study. Consent from each respondent and all study participants were obtained before data collection. The anonymity and confidentiality of information was secured. Legal permission was attained from the headmaster of the selected schools. All material used throughout the study was acknowledged. The measuring equipment was located in a way that doesn't disturb the attention of students, and the data was analyzed relatively to the standards without manipulation.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Introduction

This chapter of the thesis discusses in detail the result of data's and it presents the analyzed data which is collected during the study time to achieve the objective of the study. ANSI/ASHRAE Standard 55-2004 Thermal Environmental Condition for Human Occupancy were used for this study. Using this model, indoor temperature of the classrooms, relative humidity, and air-velocity of selected classrooms were analyzed and presented based on the data collected in the months of March and April, 2024 which is the hottest month of the year on the study area.

The study was conducted in purposively selected two private secondary and preparatory schools (Goro secondary and preparatory school and Nafyad secondary and preparatory school), and two government secondary and preparatory schools (Dembela secondary and preparatory school and Burka-Boku secondary and preparatory school) located in different parts of the city. All schools are single story buildings. The study was conducted for 15 working days between 18th March 2024 – to – 5th April 2024 in all selected schools. The data was collected starting from 9:00am – to – 5:00pm the whole survey days. The characteristics of surveyed schools, samples and date of surveys are showed in Table 4:1 below.

Table 4:1 School characteristics, number of sample students and survey days

No	Name of School	Location (Kebele)	No. of blocks	No. of classrooms	No. of samples students	Date of survey
1.	Dembela Secondary and Preparatory School	09 (Irrecha)	3	12	89	18th march – 5th April, 2024
2.	Burka - Boku Primary and Secondary School	11 Bokkuu	3	12	110	18th march – 5th April, 2024
3.	Goro High School	01 -Goro	3	12	82	18th march – 5th April, 2024
4.	Nafyad High School and Preparatory	05 - Bole	3	12	74	18th march – 5th April, 2024

4.2. Site plan and classroom block arrangements

The selected schools are located in different location within the city. The building arrangement and site zoning of the schools also vary one another. This helps to know the effect of different building orientations in relation to the incoming wind and the solar heat gain. The site plan and classroom block arrangements of each school are shown on Figure 4:1below.

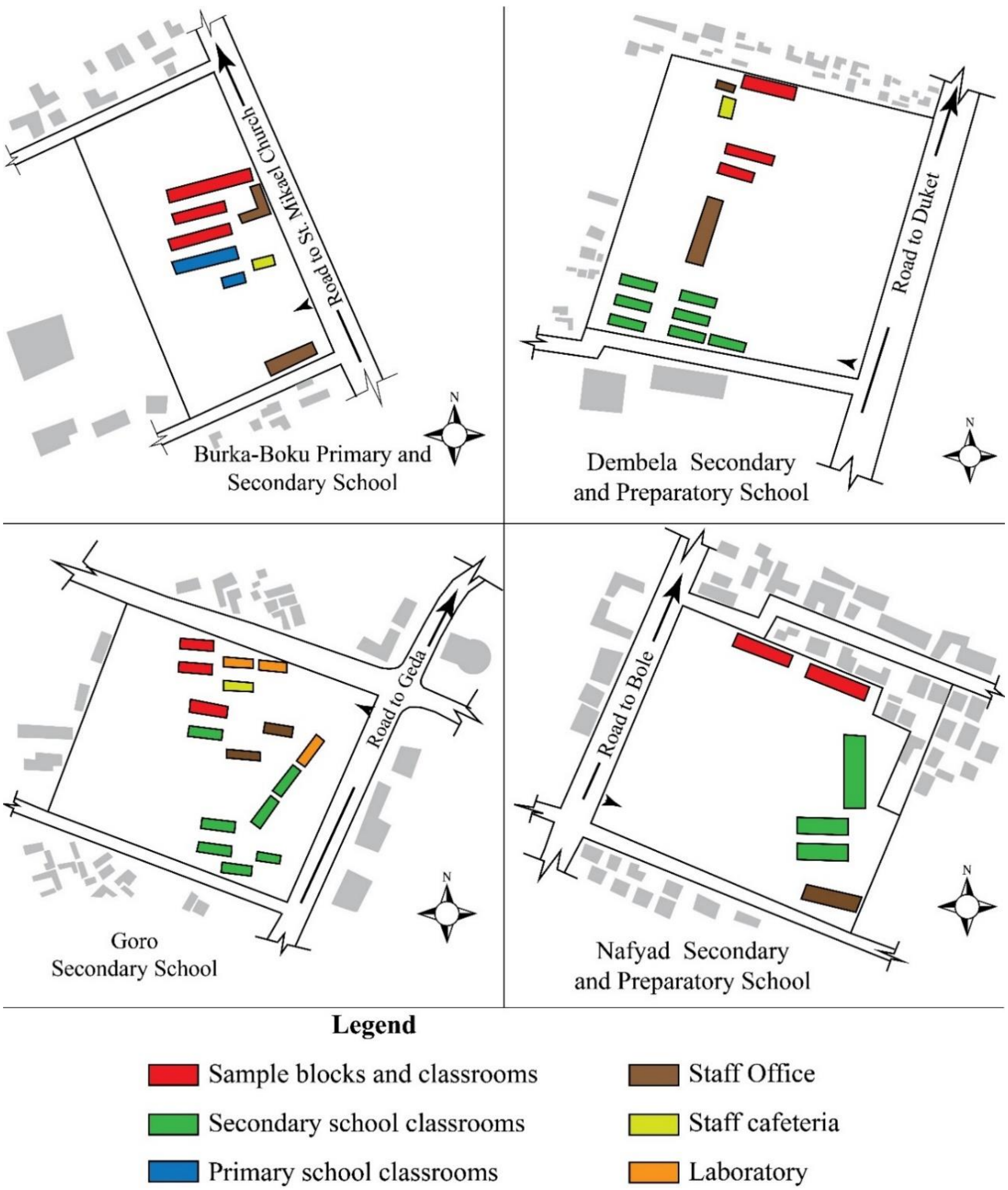


Figure 4:1 Site plan and building block arrangement of all study schools (Source: Author,2024)

4.3. Building orientations of selected school buildings is Adama city

Table 4:2 Building orientations of selected schools in Adama city (Source: Author, 2024)

School name	Classroom Block Orientations			
	NW - SE -axis	NE - SW-axis	S - N-axis	E - W-axis
Burka-Boku Primary and Secondary School	--	Azimuth Angle 25° N (7-Classroom blocks); Azimuth Angle 70° N 1-Office block	--	--
Nafyad Secondary and Preparatory School	Azimuth Angle 340° NW 2-Classroom blocks	--	Azimuth Angle 0° N 1-Classroom block	Azimuth Angle 90° E 3-Blocks (2-Classroom &1-Office)
Goro Secondary School	Azimuth Angle 335° NW 5-Blocks (4-Classroom &1-Office)	Azimuth Angle 35° N	--	Azimuth Angle 90° E 7-Blocks (5-Classroom &2-Office)
Dembela Secondary and Preparatory School	Azimuth Angle 335° NW 11-Blocks (10-Classroom &1-Office)	Azimuth Angle 15° N 1-Office block	--	--

Building orientation is the process of alignment or positioning of a building in relation to the seasonal variation in the sun path of a building and the prevailing wind pattern (Ifeoma and Akande). It plays a significant role in creating a thermally comfortable and naturally ventilated indoor environment in a building. Proper building orientation is a low-cost option that improve the thermal comfort of building occupants and it decrease the energy needed for heating and cooling of a building. As the sun moves from east to west direction, the heat of the day increases and with the building that positioned with their longer side oriented to north-south axis, it shades the sun that penetrated to the south and west facing windows and other openings (Ifeoma and Akande).

As discussed in Table 4:2 above, from the existing classroom buildings in all selected schools, 17 classroom blocks and 2 office building blocks are oriented to NW to SE direction, 9 classroom buildings and 1 office building are oriented in to NE to SW direction, 7 classrooms and 3 office building blocks are oriented to E-W orientation, and only 1 classroom building was oriented to N-S direction. According to this result, 97% of classroom buildings face to the direct sun penetration during the day hour especially in the afternoon and overheating of classrooms from sun radiation is a major problem in schools. This shows that, proper orientation of buildings is not given due consideration. The total number of building typologies and their orientation is also shown on Chart 4:1 below.

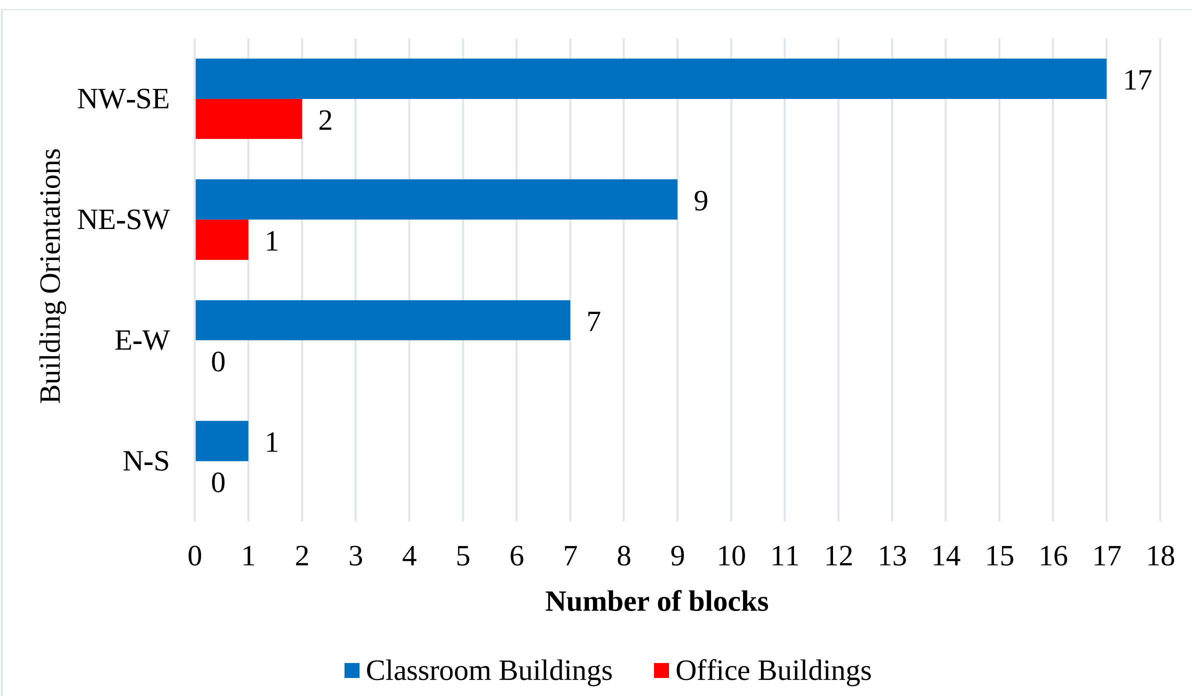
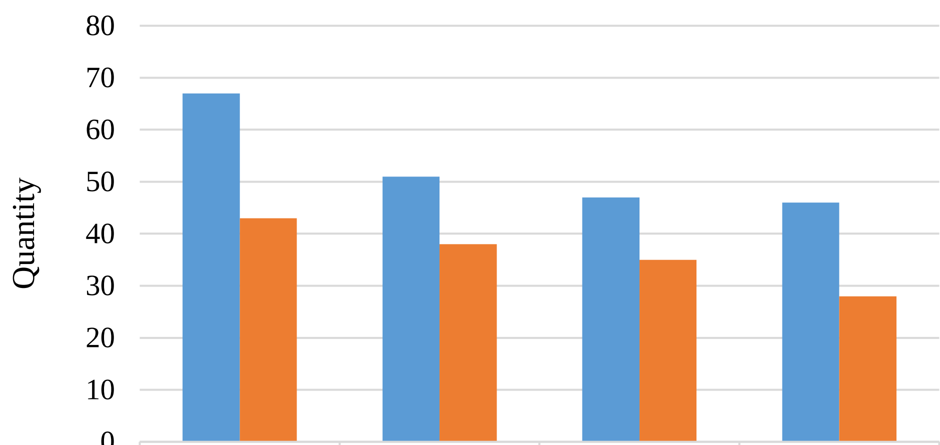


Chart 4:1 Building orientations and number of blocks (Source: Author; 2024)

4.4. Result from demographic survey of respondents

4.4.1. Gender of Respondents

Based on the data gathered from the overall selected study schools, the total number of respondents who participate in this study were 355. From these, Burka-Boku Primary and Secondary School 110 students, Dembela Secondary and Preparatory School 89 respondents, Goro High School 82 respondents, and Nafyad High School and Preparatory 74 students were participated. From the overall numbers of respondents, 211 were male, and the remaining 144 participants are females. Proportionate stratified sampling technique was applied on selecting gender of respondents. The total number of male and female respondents in each school were illustrated in the Chart 4:2 below.



	Burka-Boku	Dembela	Goro	Nafyad
Male	67	51	47	46
Female	43	38	35	28

Chart 4:2 Gender of Respondent (Source: Author from data collection)

Knowing the number of male and female respondents is important to know which groups are more sensitive to the existing microclimatic elements on the study area. According to research (Karjalainen 2007), females are less satisfied with the thermal environments than males, and they feel both cold and hot more often than men, and they have less control over the room temperature during both the winter and summer season. This shows that, since females are more sensitive to their surrounding environment on both hot and cold, they need effective consideration on space design in any activity.

4.4.2. Age of Respondents

According to the data from the survey, the age of the respondents ranged between 15 - to - 23 years. From the total 355 study participants, age groups of respondent's rage between 15 - 17 years are 113 students (which is 31.8 % of the total samples), age groups between 18 - 20 years are 164 students (which are 46.2% of the total samples), and the remaining 78 students (which are 22 % of the total samples) are ranged between the age of 21 - 23 years old.

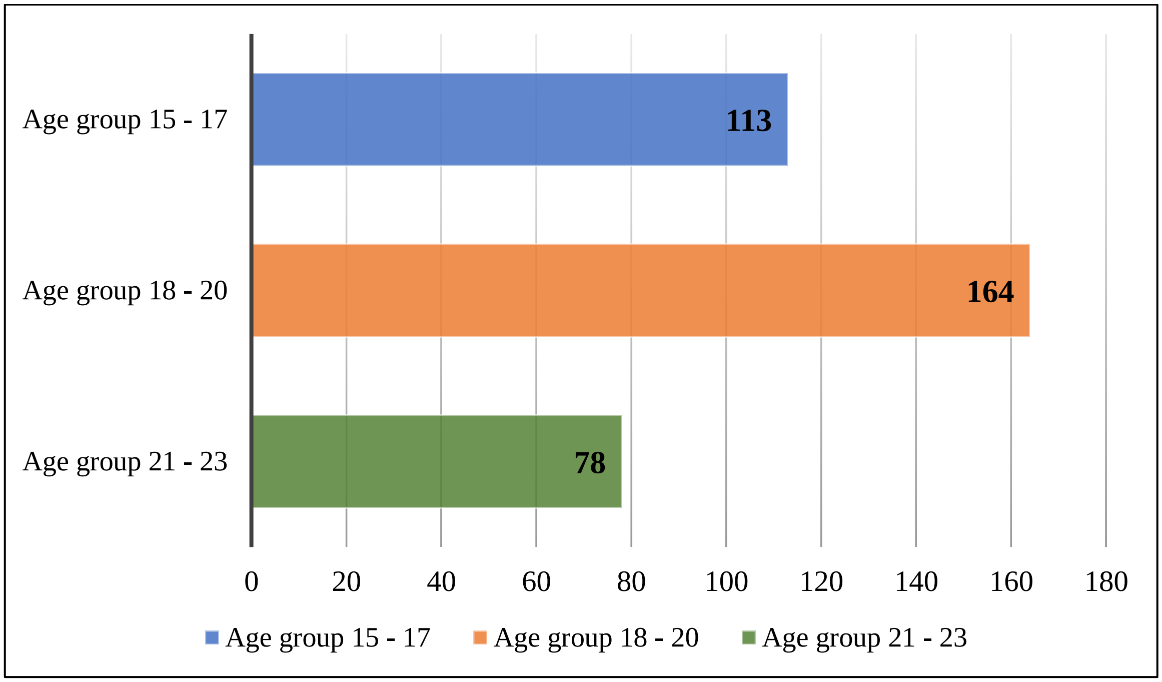


Chart 4:3 Age of Respondent (Source: Author from data collection)

4.4.3. Sitting location of Respondents

The study applies proportionate stratified sampling method, and the sitting location of respondents were distributed and selected equally in the classroom. This helps to know the level of the problem, which location is highly affected, and also helps to know the thermal preference and sensation of the students. The location of measuring instrument was selected based on ASHRAE standard (Standard 1992), that the location of taking objective measurement should be on areas where the occupants are expected to spend more of their time, which is depend on the function of the space. Based on this standard, the measurement was taken in the center of the classroom and 1.0m inward from external walls and windows. Measurements on thermal parameters were estimated on area such as near windows, corners, and also entries.

On the other hand, since the function of selected building was for learning, the activities inside classrooms were sedentary activities; so, the air temperature and wind speed were measured at 0.6m and 1.0m above floor level on those specified locations. And for standing activities, the measurement was taken at 1.1m and 1.7m above floor level. Humidity was also measured on a specified occupied space. The existing classroom layout, sitting location of respondents and proper placement of measuring instruments were shown on Figure 4:2below.

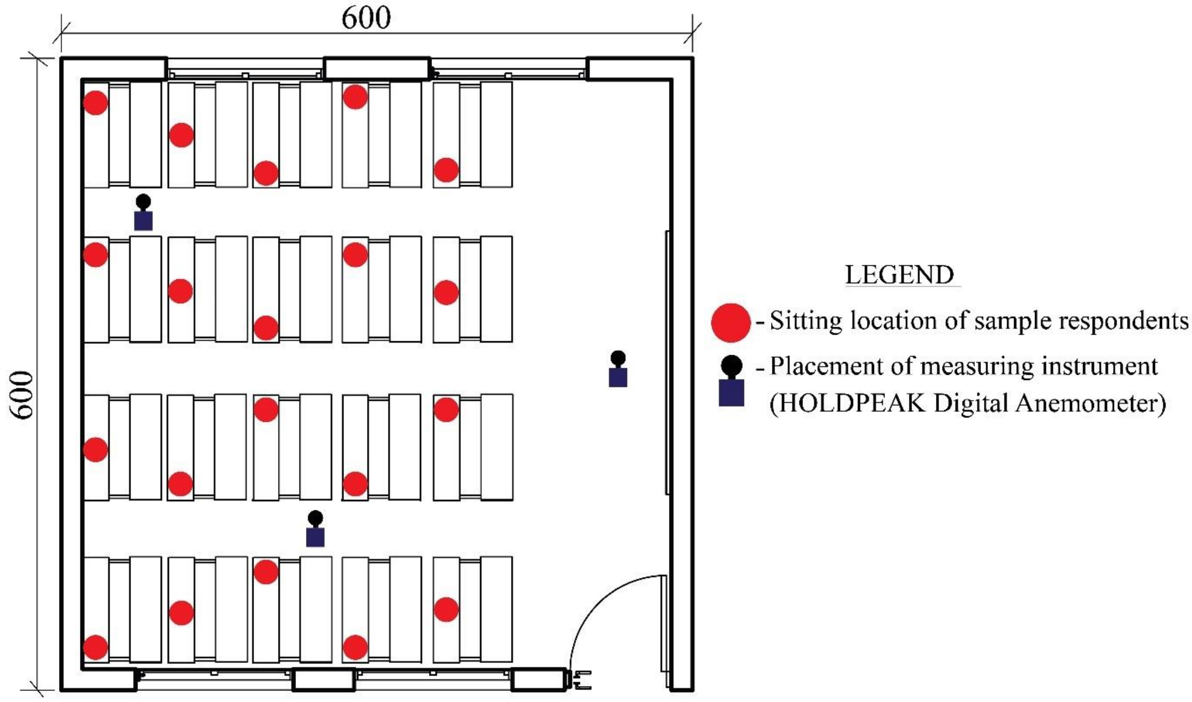


Figure 4:2 Sample Classroom layout, sitting location of respondents, and placement of measuring instrument (Source: Author, 2024)

4.4.4. Clothing of students

Typically, all secondary and preparatory school students in all study schools have a regular uniform clothing, the difference is only of clothing color from school to school.

Dembela Secondary and Preparatory School

Burka - Boku Primary and Secondary School

Nafyad High School and Preparatory

Goro High School

Figure 4:3 Clothing type of students in selected secondary and preparatory schools (Source: Field observation by Author, 2024)

The regular uniform for female students is Knee-length skirt, short-sleeve shirt, bra, and sandals which has a clothing insulation of 0.55 Clo. Few Muslim students wear regular school uniform with hijab that usually the head which has a clothing insulation of 0.81 Clo. The regular uniform for male students in selected schools is Trousers, long-sleeve shirt, T-shirt, and shoes which has a clothing insulation of 0.71 Clo. All clothing insulation values have been taken from (Standard 1992).

4.4.5. Activity type and level of respondents inside classroom

The activity level and type of the respondents affects the thermal comfort of the classroom. According to the result of the analysis taken during the survey and measurement, 323 students which are 91 % of the students' activities inside the classroom is sitting and learning which have a metabolic rate of 1.0 Met units, 6 % were taking exams, and the remaining 3% were standing especially during the break time. Since most of the students spend their time in a sedentary activity, according to (Standard 1992), a sitting posture results in a decrease thermal insulation due to compression of air layers in the clothing. This decrease may be offset by insulation provided by the chair.

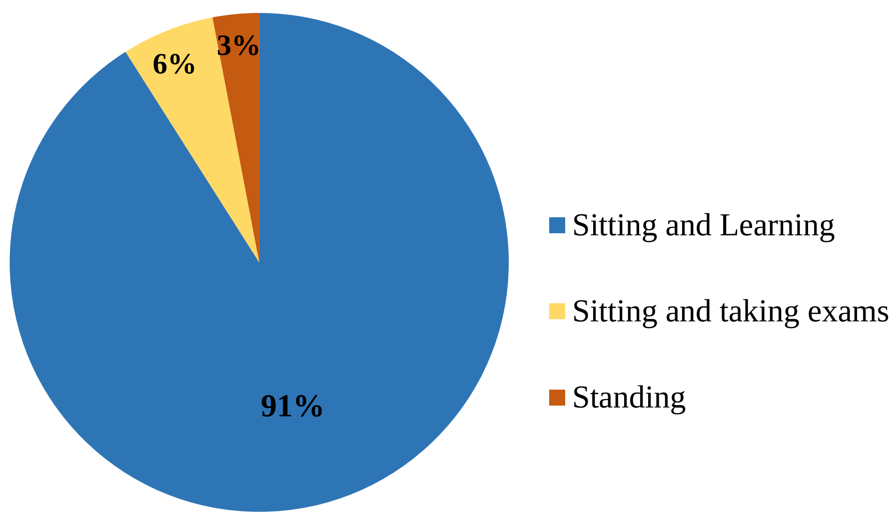


Chart 4:4 Activity type and level of respondents (Source: Field survey by Author)

4.4.6. Building users response on thermal comfort, thermal preference scale, thermal sensation scale, and thermal acceptance level of classrooms

❖ **Thermal Preference Scale**

The preferred thermal environment scale which is defined by ANSI/ASHRAE Standard 55-2004 Thermal Environmental Condition for Human Occupancy was used to assess the thermal preference and sensation of the building occupants. The result of the analysis is discussed on the Table 4:3 below.

Table 4:3 Thermal preference of building occupants

PMV Value	Thermal Preference	Time							
		9:00 - 11:00 am		11:00 - 1:00 pm		1:00 - 3:00pm		3:00 - 5:00 pm	
		No:	%	No:	%	No:	%	No:	%
-3	Cold	0	0.0%	0	0.0%	0	0.0%	0	0.0%
-2	Cool	0	0.0%	0	0.0%	0	0.0%	0	0.0%
-1	Slightly Cool	97	27.4%	4	1.1%	0	0.0%	0	0.0%
0	Neutral	167	47%	88	24.8%	13	3.7%	63	17.8%
+1	Slightly Warm	91	25.6%	74	20.8%	78	22%	117	32.9%
+2	Warm	0	0.0%	143	40.3%	142	40%	92	25.9%
+3	Hot	0	0.0%	46	13%	122	34.3%	83	23.4%

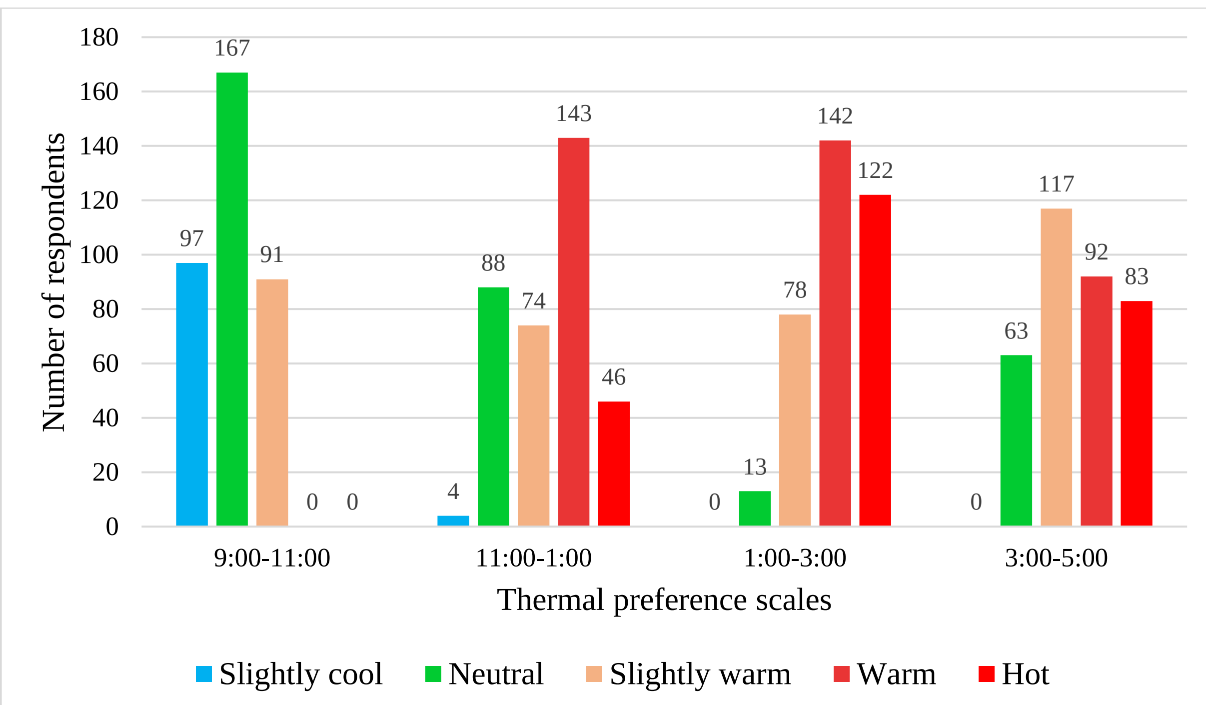


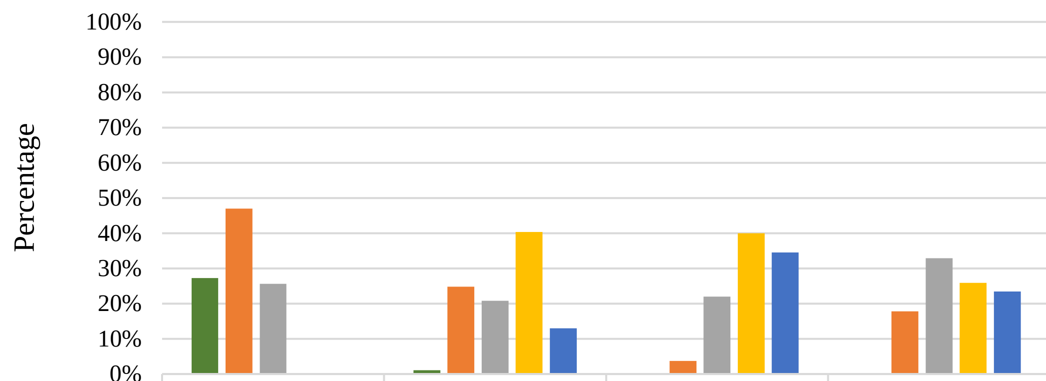
Chart 4:5 Building users Thermal Perception

According to the student's response on thermal environment in the classroom based on the indicators of thermal sensation votes (TSV), about 27.4% of vote slightly cool (-1), about 47% votes neutral (0) option, and the remaining 25.6% of respondents votes slightly warm (+1) option during the time between 9:00am - to - 11:00am. This result shows that, a total of 100% of students voted for the three central options of thermal sensation scale (-1 to +1), and they felt comfortable on the thermal environment of their classrooms during this time. On the other hand, during the times between 11:00am to 1:00pm, 1.1% of respondents vote slightly cool (-1), 24.8% of respondents votes neutral (0) option, 20.8% votes slightly warm (+1), the remaining 40.3% and 13% of respondents votes warm (+2), and hot (+3) options respectively. This result shows that, 46.7% felt comfortable, and the remaining 53.3% of respondents feel not comfortable on the thermal condition of their classrooms. Between the times of 1:00 - 3:00pm, 3.7% feel neutral, 22% votes slightly warm (+1), and the remaining 40% and 34.3% of respondents votes for warm (+2), and hot (+3). This shows that, around 73.3% of sample students felt uncomfortable on the thermal environment of their classroom on this time. During 9:00pm to 11:00pm, 50.7% of respondents votes for neutral (0) and slightly warm (+1) options, and they felt comfortable. The percentage of respondents who voted uncomfortable areas (warm (+2) and hot (+3)) is 49.3%.

- **Thermal Sensation Scale**

(Standardization 1995) suggests additional dimension that are used for the assessment of thermal sensation which depend on subjective response. These dimensions are thermal sensation ranged from "cold" to "hot" to sensational aspects considered to the level of comfortable to very uncomfortable scales, and colder and warmer thermal preference scales are considered to generally acceptable to very unacceptable thermal sensation scales.

The thermal sensation scale and students comfort level was measured to determine whether a specific thermal condition of the classroom can be considered comfortable or not.

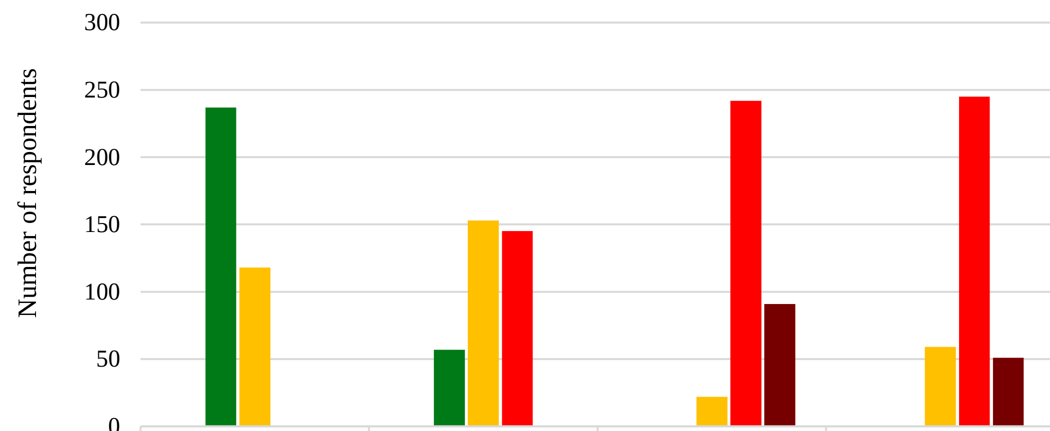


	9:00-11:00	11:00-1:00	1:00-3:00	3:00-5:00
Slightly comfortable	27.3	1.1	0	0
Comfortable	47	24.8	3.7	17.8
Slightly uncomfortable	25.6	20.8	22	32.9
Uncomfortable	0	40.3	40	25.9
Very uncomfortable	0	13	34.5	23.4

Chart 4:6 Thermal sensation scale

➢ **Discussion on Thermal Sensation Scale**

Chart 4:6 shows that, during the study time between 9:00am to 11:00 am, 97 respondents (27.3%) feel slightly comfortable; 167 respondents (47%) experience comfortable, and 92 respondents (25.7%) were feel slightly comfortable on the air temperature of their classrooms. During the time between 11:00am to 1:00pm, 4 respondents (1.1%) feel slightly comfortable, 88 (24.8%) feel comfortable, 74 respondents (20.8%) feel slightly uncomfortable, 143 (40.3%) experience uncomfortable; and the remaining 13 respondents (13%) feel very uncomfortable on the indoor air temperature. Between the hours 1:00pm to 9:00pm, 13 students (3.7%) feel comfortable, 78 students (22%) feel slightly uncomfortable, 142 students or 40% are uncomfortable and the remaining 122 students which are 34.5% are very uncomfortable with the indoor temperature of classrooms. Finally, between the hours of 3:00pm to 5:00pm, 63 students (17.8%) feel comfortable, 117 respondents (32.9%) feel slightly uncomfortable, 92 students (25.9%) feel uncomfortable, and the remaining 83 students (23.4%) are told they are very uncomfortable with the indoor temperature of their classrooms. This result shows that, 100% of respondents are in the comfort range (between slightly comfortable to slightly uncomfortable) in the morning between 9:00am to 11:00 am. Between 11:00am to 1:00pm, only 46.7% of students are on the comfort range, and majority of the students (53.3%) are uncomfortable. 74.5% of students are very uncomfortable between 1:00pm to 3:00pm; and 49.3% also experience uncomfortable with their classroom's temperature between 3:00pm to 5:00pm. This implies that, the existing classroom buildings are uncomfortable and they don't fulfill the minimum requirement of building comfort ranges that is 80% of the total building occupants should experience comfortable which is stated by ASHRAE standard.



	9:00-11:00	11:00-1:00	1:00-3:00	3:00-5:00
Very comfortable	0	0	0	0
Comfortable	237	57	0	0
Acceptable	118	153	22	59
Uncomfortable	0	145	242	245
Very Unvomfortable	0		91	51

Chart 4:7 Thermal acceptance level of classroom users

4.4.7. Students Response on the Air-Velocity inside Classrooms

From the 355 sample respondents from all selected study schools, 251 respondents which is 70.7% rarely felt the air velocity in their classrooms, 82 respondents (23.1%) felt the air velocity just acceptable, and the remaining 22 (6.2%) respondents felt disturbed due to too breezy air flow. This result shows that, based on the student's response, the existing natural ventilation system of the classrooms was not able to supply sufficient airflow into the classrooms and majority of respondents preferred more air movement in their classrooms, and only about 6.2% of respondents need to decrease the air velocity.

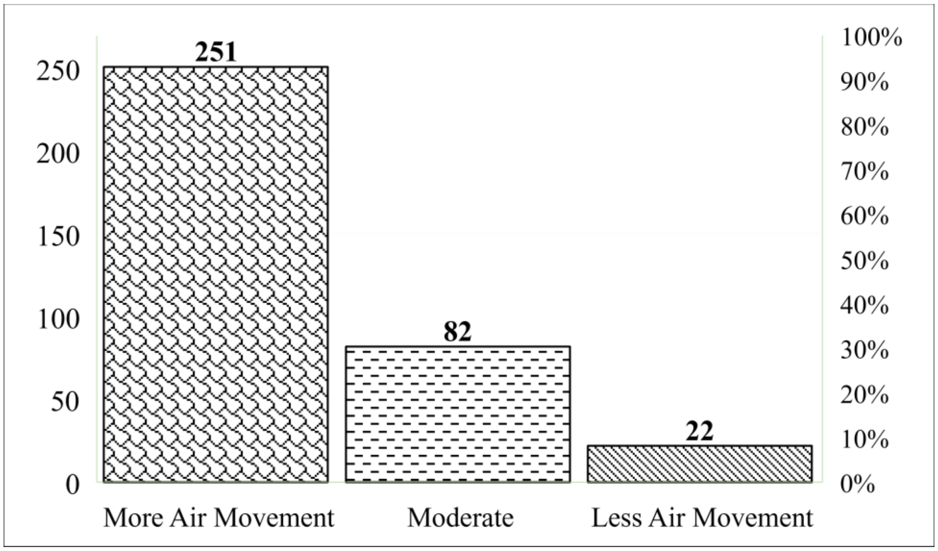


Chart 4:8 Students Response on the Air-Velocity inside Classrooms

4.4.8. Students Response on the Air Humidity of classrooms

According to the student's response to the air humidity inside the classroom based on humidity votes, 259 respondents (73%) voted much too dry and too dry option, and they felt that, the humidity of their classroom was not comfortable. Only 96 respondents (27%) of the respondents voted at the three scales in the centerline, which are slightly dry, just right, and slightly humid options that shows the humidity in the classroom met the respondents need.

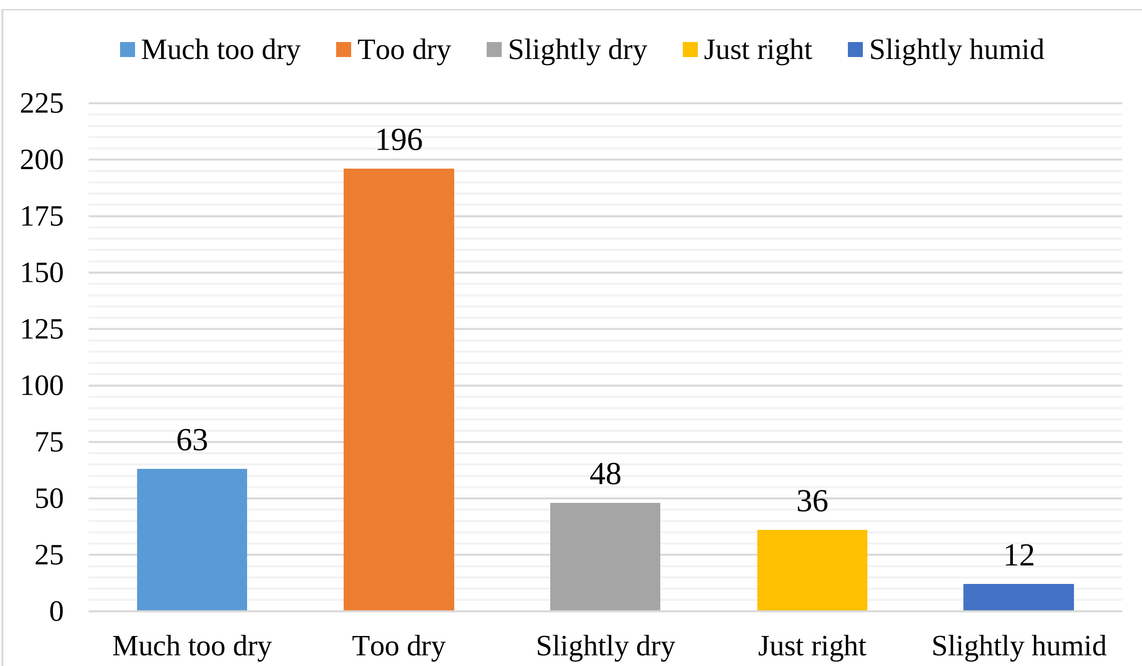


Chart 4:9 Students' response on the air humidity of classrooms

4.5. Building Orientation assessment of the existing classrooms buildings

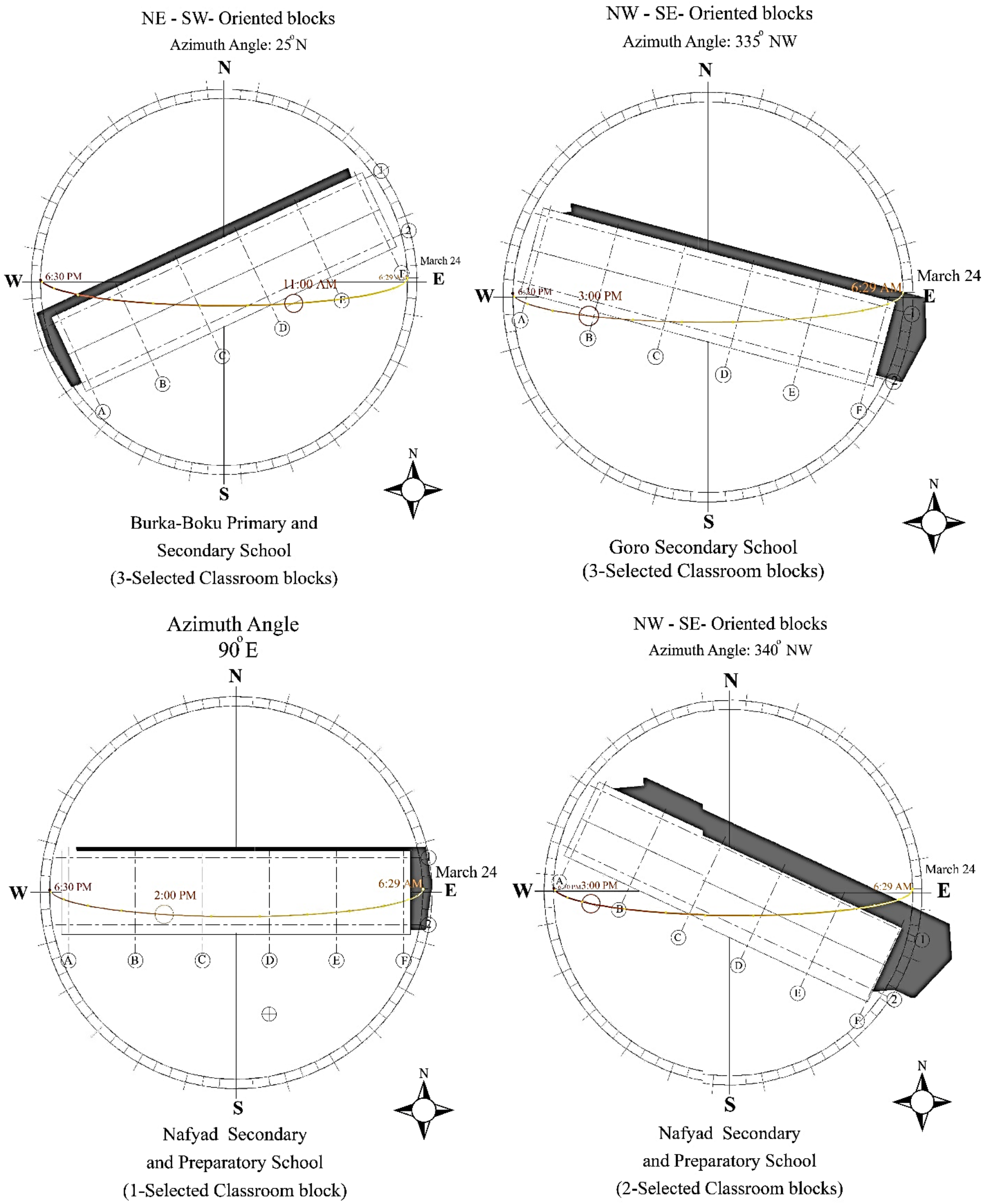


Figure 4:4 Building orientation and sun path diagram of selected school buildings (Source: Author, 2024)

4.5.1. Layout of existing classroom building

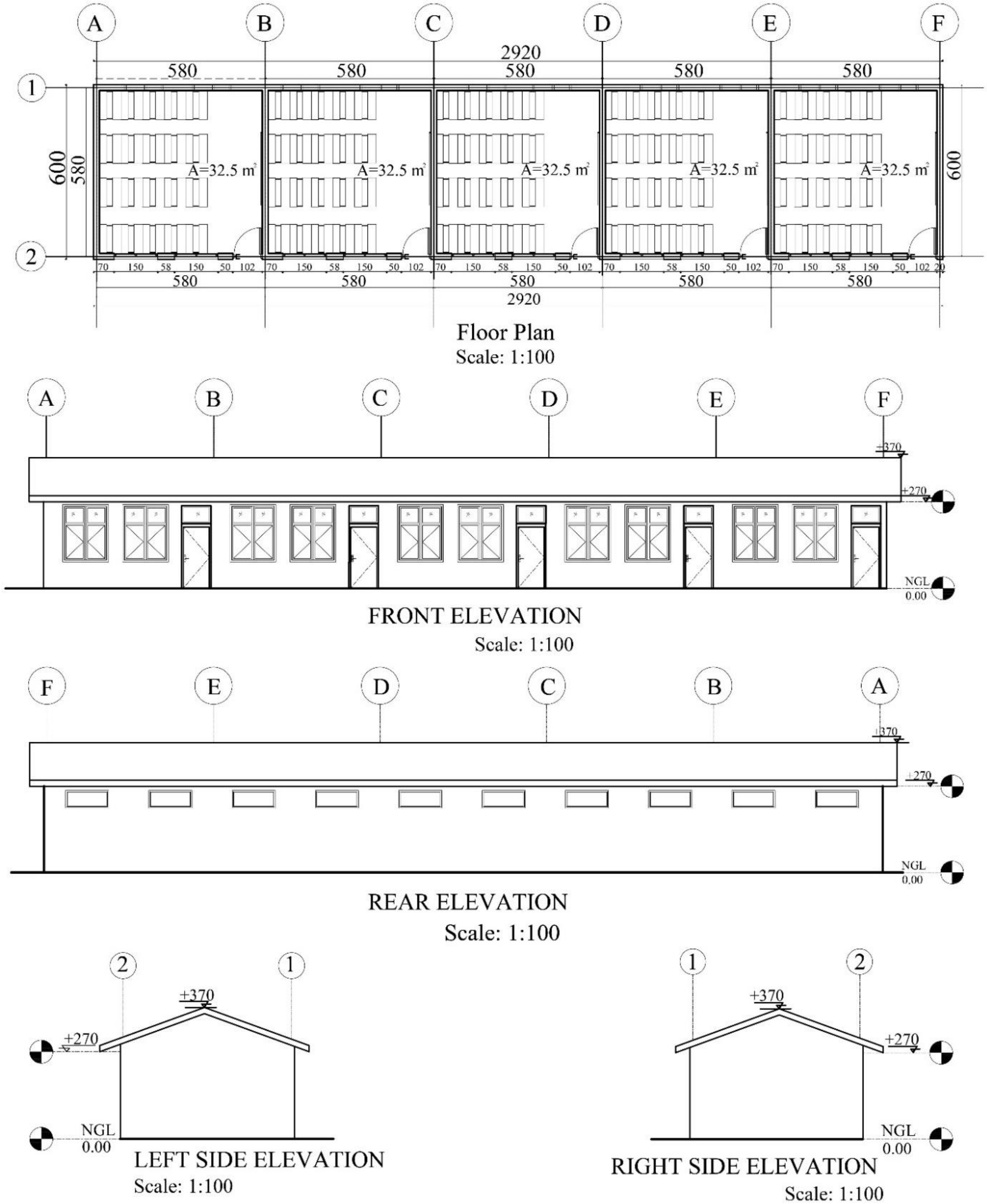


Figure 4:5 Sample layout of existing classroom building (Source: Author, 2024)

4.6. Environmental Variable analysis

To measure the thermal environmental condition of the classrooms, the study applies the six parameters that categorized in to environmental and personal variables that are developed by (Fanger 1984). These are humidity, air temperature, mean radiant temperature and air velocity which are categorized under environmental variables, and clothing insulation and activity level of the students were discussed under personal variables or factor.

All the environmental and personal variables that affect the thermal comfort of building occupants were measured and analyzed in a classroom building that face south east, south and south west orientation of the selected schools. Since the data was collected between 18th March - to - 5th of April, the measurement was taken on sunny and partly sunny days based on the local weather conditions. The result of measurements was discussed below.

4.6.1. Air Temperature

Air temperature is a measure of the amount of atmospheric heat content and its combined effects of absorbed solar radiation. A statistical summary and discussion of the indoor and outdoor air temperature objective measurement of classroom buildings oriented towards southwest, southeast and south axis are shown below.

- **Indoor Temperature of North - West to South- East oriented buildings**

According to the field measurement which was recorded from 18th March - to - 5th April in different times of the day, the highest indoor temperature recorded in southwest oriented classrooms was 32°C in 19th March between 1:00 - 3:00 pm; and the lowest indoor temperature was recorded in 24rd March which was 24°C between 9:00 - 11:00am. The average indoor temperature was 28.5°C.

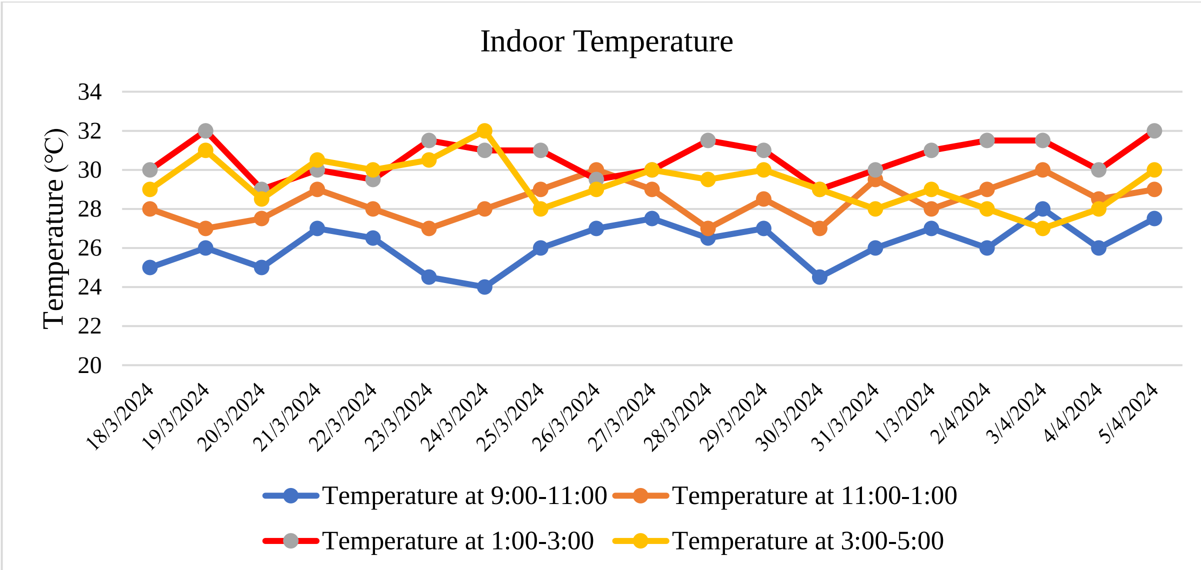


Chart 4:10 Highest and lowest Indoor temperature of NW - SE orientation

- ❖ **Indoor Temperature of North - East to South - West oriented buildings**

Chart 4:11 shows the highest and lowest indoor temperature measurement result for Northeast to Sooutwest oriented classroom buildings. According to the result which was recorded from 18th March - to - 5th April, the highest indoor temperature recorded in buildings that oriented towards southeast direction was 32℃ in 29th March, between 1:00am - 3:00 pm; and the lowest indoor temperature was recorded in 25th of March, which was 25℃ between 9:00am - 11:00am. The average indoor temperature was 28.5℃.

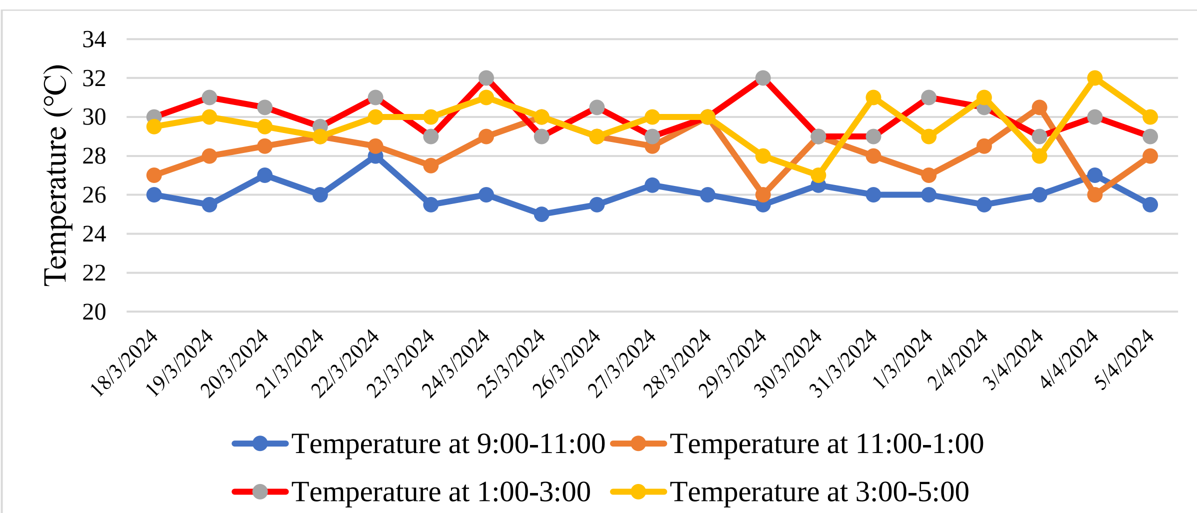


Chart 4:11 Highest and lowest Indoor temperature for NE-SW orientation

❖ Indoor Temperature of East to West oriented buildings

According to Chart 4:12, the highest and lowest indoor temperature for classroom blocks that oriented towards south which was recorded from 18th March - to - 5th April, the highest indoor temperature was 32.5℃ recorded in 26th March between 1:00pm – 3:00 pm; and the lowest indoor temperature was 24.5℃ which was recorded in 28th and 1st of April between 9:00am - 11:00am. The average indoor temperature was 28.5℃.

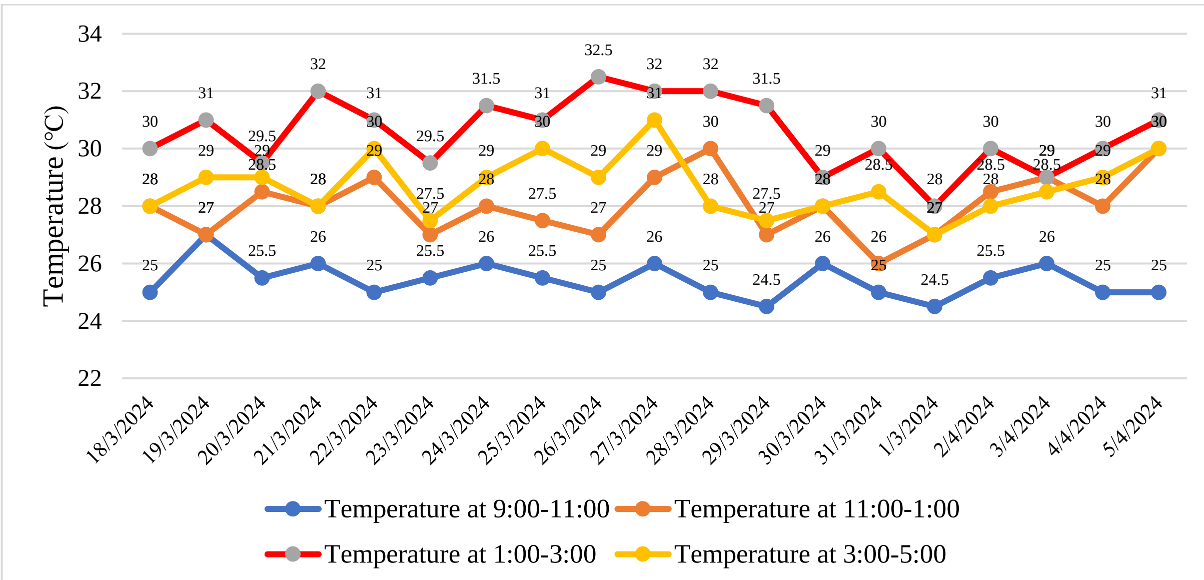


Chart 4:12 Highest and lowest Indoor temperature for South orientation

❖ Discussion on Indoor air temperature of classrooms

According to a study (Mitchell and Braun 2012), in order to create a thermally comfortable classroom environment, the air temperature of the building should be between the range of 20.5 - 22.8℃ (comfortably cool); 22.8 - 25.8℃ (comfortable), or 28.8℃ - 27.1℃ (comfortably warm). According to a guideline by The American Society of Heating and Air Conditioning Engineers (ASHRAE), to satisfy the comfort of building occupants, a building should have a maximum temperature of 68 °F (20℃) to 74 °F (23.3 ℃) during the winter season, and 72 °F (22.2 ℃) to 80 °F (26.6℃) during the summer season.

As illustrated on the charts above, the indoor air temperature of classrooms oriented to southwest, southeast, and south axis was measured. From the result of the measurement, the highest, average, and lowest temperature for southwest facing rooms is 33℃, 28.5℃, and 24℃

respectively; for buildings oriented to southeast axis 33.5℃, 29.25℃, and 25℃ for the highest, average and lowest indoor temperature; and the highest, average and lowest temperature of south facing classrooms are 32.5℃, 28.25℃, and 24℃ respectively.

The result indicates that, all classrooms has experienced high temperature during the day hour especially between 1:00pm - 9:00pm. This shows, the air temperatures are outside the comfort zone as specified on the national standards and ASHRAE standard; and even they didn't satisfy the comfortably warm temperature zone as specified in Indonesian National Standard (SNI).

- ❖ **Outdoor Temperature**

According to Chart 4:13; the highest outdoor temperature recorded was 33℃ in 19th March at 1:00pm to 3:00pm, and 22nd March between 1:00 - 3:00 pm; and the lowest outdoor temperature recorded was in 1st April between 9:00 - 11:00am which was 24.5℃.

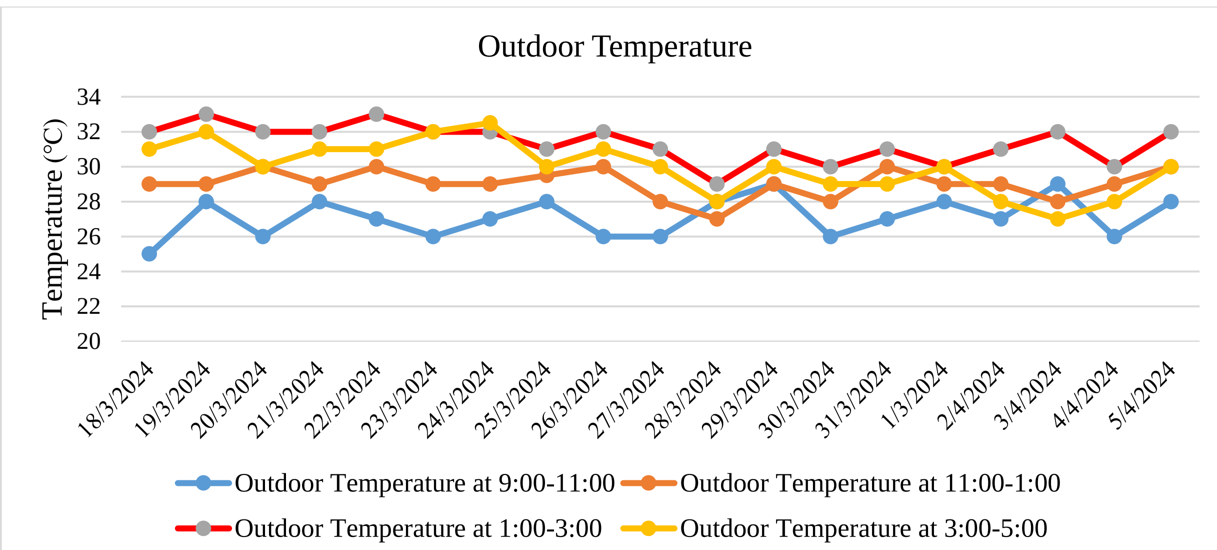


Chart 4:13 Highest and lowest outdoor temperature (Source: Field measurement, 2024)

4.6.2. Relative humidity of classroom buildings

Relative humidity (RH) is a measure of the moisture or amount of water in the air, compared to the potential saturation level of the air. Objective measurements and statistical summary of outdoor relative humidity of classroom buildings oriented towards southwest, southeast and south axis are shown below.

❖ **Relative humidity of Northwest – Southeast axis buildings**

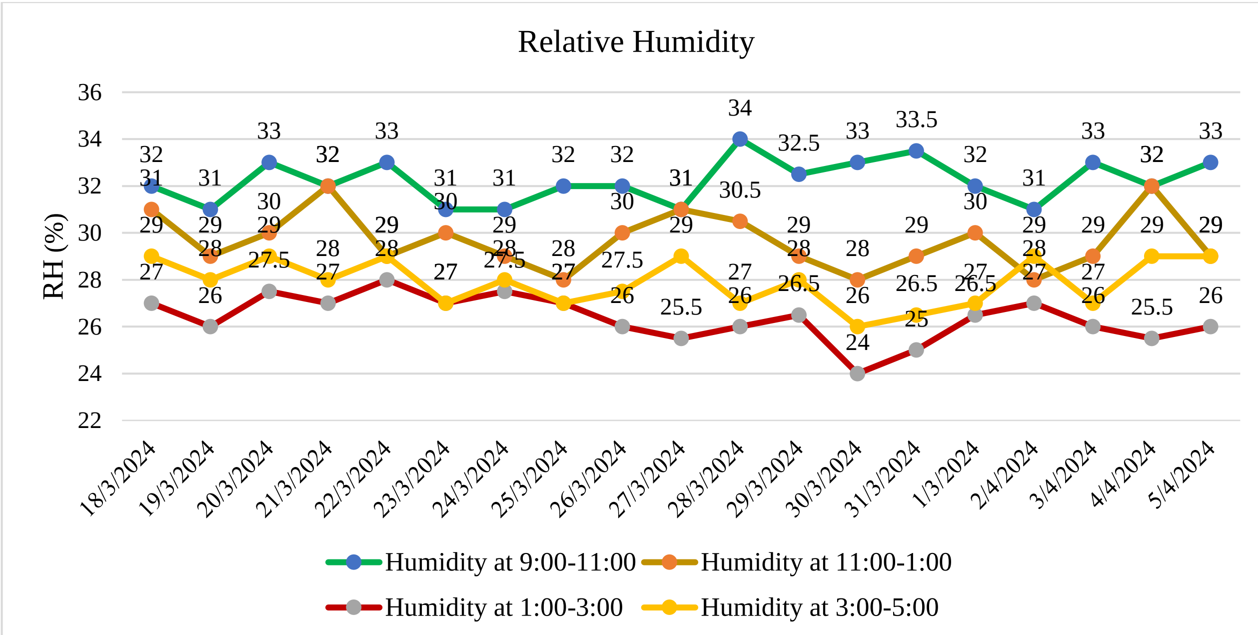


Chart 4:14 Highest and lowest indoor Relative humidity of Southwest oriented buildings (Source: Field measurement, 2024)

According to Chart 4:14, the highest humidity of classroom buildings that oriented towards southwest axis was recorded 34% in 28th March at 9:00am - 11:00am, and the lowest was measured 24% in 30th of March at 1:00pm - 3:00pm.

❖ **Relative humidity of Southwest – Northeast axis buildings**

According to Chart 4:15, the highest humidity of classroom buildings that oriented towards south-east axis was recorded 36% in 21st March at 9:00am - 11:00am, and the lowest was measured 25% in 4th of April at 1:00pm - 3:00pm.

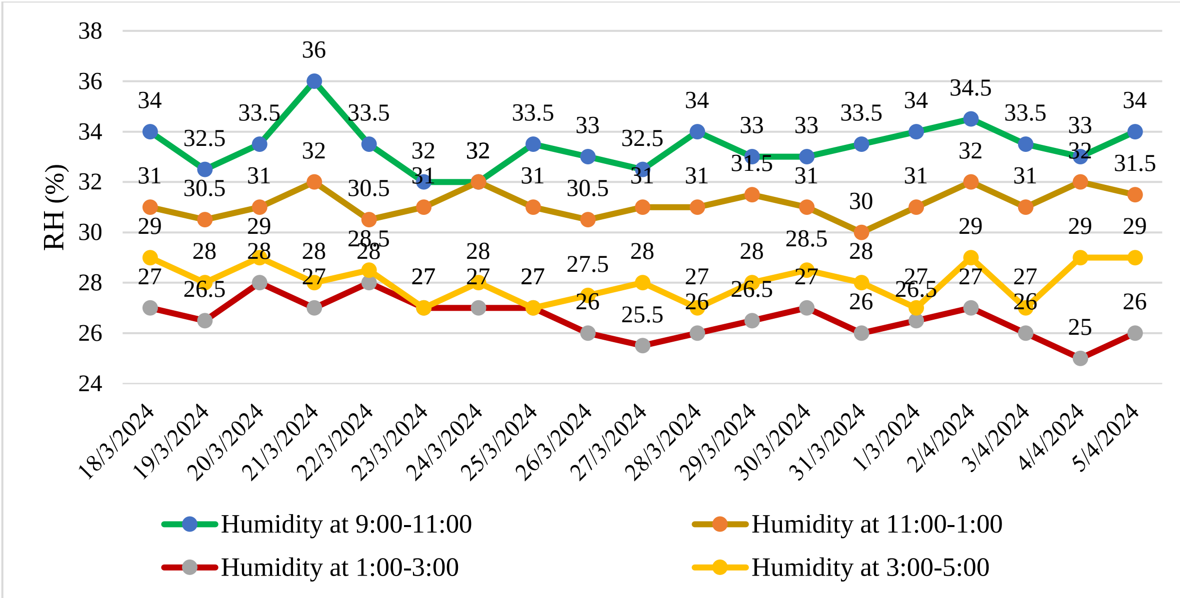


Chart 4:15 Highest and lowest indoor Relative humidity of Southeast oriented buildings

❖ Relative humidity of East – West axis buildings

Chart 4:16 shows that, the highest humidity of classroom buildings that oriented towards south axis was recorded 35% in 30th March, and the lowest was measured 25.5% in 20th March, 27th March and 2nd April at 1:00pm - 3:00pm. This shows the relative humidity is also high during the morning when the outside air temperature is cool, and low in the mid-day and afternoon when the air temperature is warm.

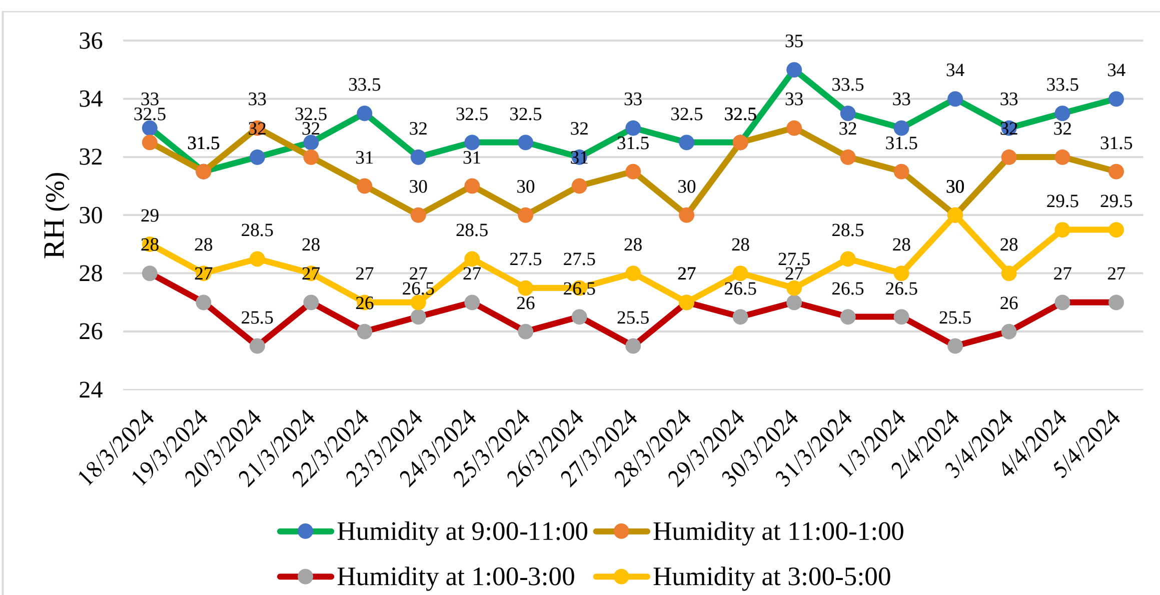


Chart 4:16 Highest and lowest indoor Relative humidity of South oriented buildings

- **Discussion on relative humidity**

The above charts show the highest and lowest humidity of classrooms during different hours of the day. The measurement was taken starting from 18th march to 5th April. According to the result, the highest and lowest humidity of southwest oriented buildings was recorded 34% measured at 28th March at 9:00am - 11:00am, and 24% in 30th of March at 1:00pm - 3:00pm respectively; for buildings oriented to south-east axis was 36% in 21st at 9:00am - 11:00am, and 25% in 4th of April at 1:00pm - 3:00pm as highest and lowest humidity respectively. Highest and lowest humidity of buildings oriented to south axis was 35% in 31st April in the morning and 25.5% in afternoon in 20th March, 27th March and 2nd of April. This shows the relative humidity is better in the morning when the outside air temperature is cool especially for buildings that oriented to south axis.

4.6.3. Correlation between indoor temperature and outdoor temperature

The indoor and outdoor temperature of selected classrooms shows a medium to strong positive correlation throughout the day. In the morning time, especially between 9:00am to 11:00am, as shown on Chart 4:17, both indoor and outdoor temperatures are relatively low and have a correlation coefficient of +0.55. Both the indoor and outdoor temperatures start to rise starting from 11:00am; and the correlation coefficient between 11:00am to 1:00pm was +0.35 which is shown on Chart 4:18; and the temperature is high in the mid-day and afternoon. During this time, the correlation between the indoor and outdoor temperature is strong positive; especially during the afternoon between 3:00pm to 5:00 pm as illustrated on Chart 4:20, the correlation coefficient was + 0.80. This shows that, their relation is high, and the increase in temperature of outdoor results the temperature increases of indoor environment especially on the mentioned hours above.

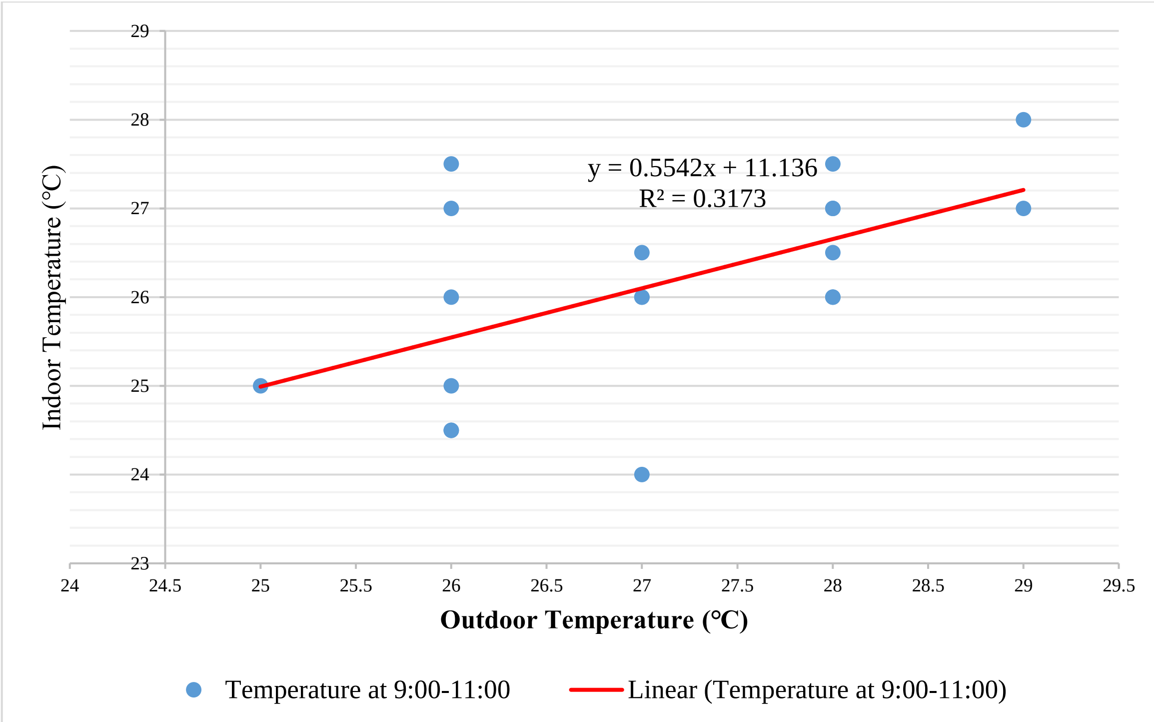


Chart 4:17 correlation between indoor and outdoor temperature between 9:00am to 11:00am

Correlation coefficient (r) between 9:00am to 11:00am is + 0.55

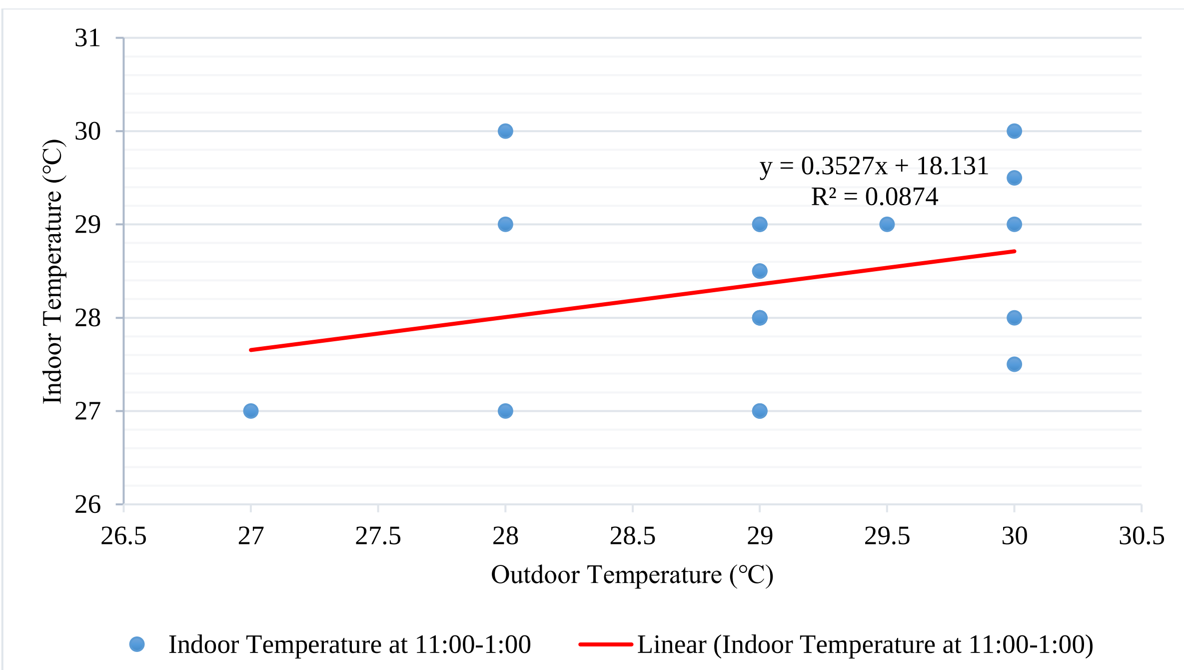


Chart 4:18 Correlation between indoor and outdoor temperature between 11:00am to 1:00pm

Correlation coefficient (r) between 11:00am to 1:00pm is + 0.35.

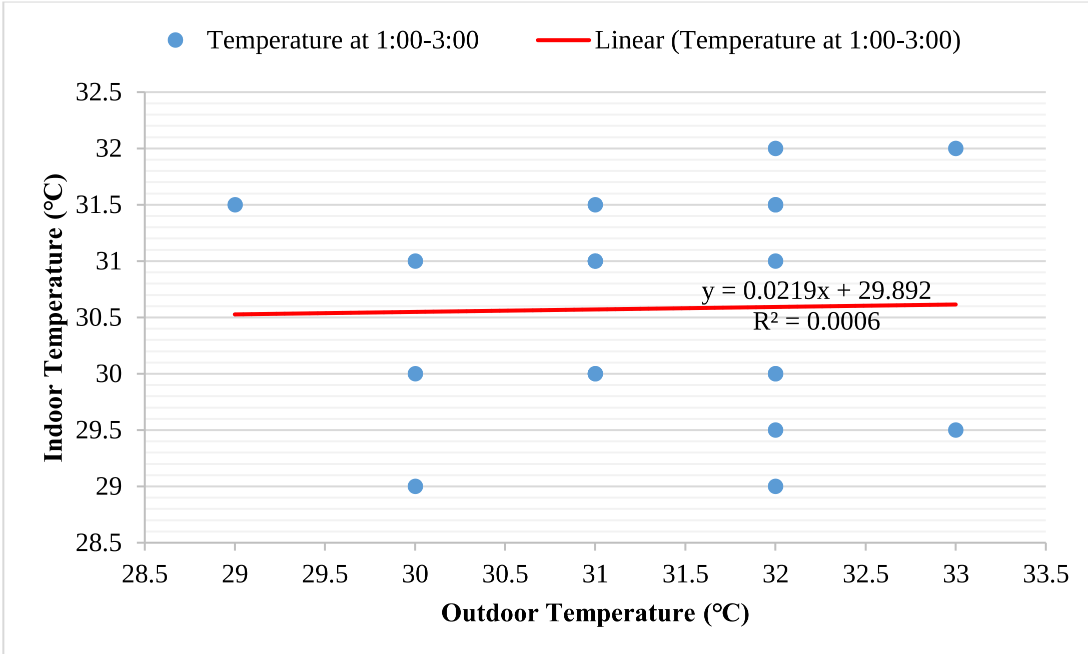


Chart 4:19 Correlation between indoor and outdoor temperature between 1:00pm to 3:00pm

Correlation coefficient (r) between 11:00am to 1:00pm is + 0.022.

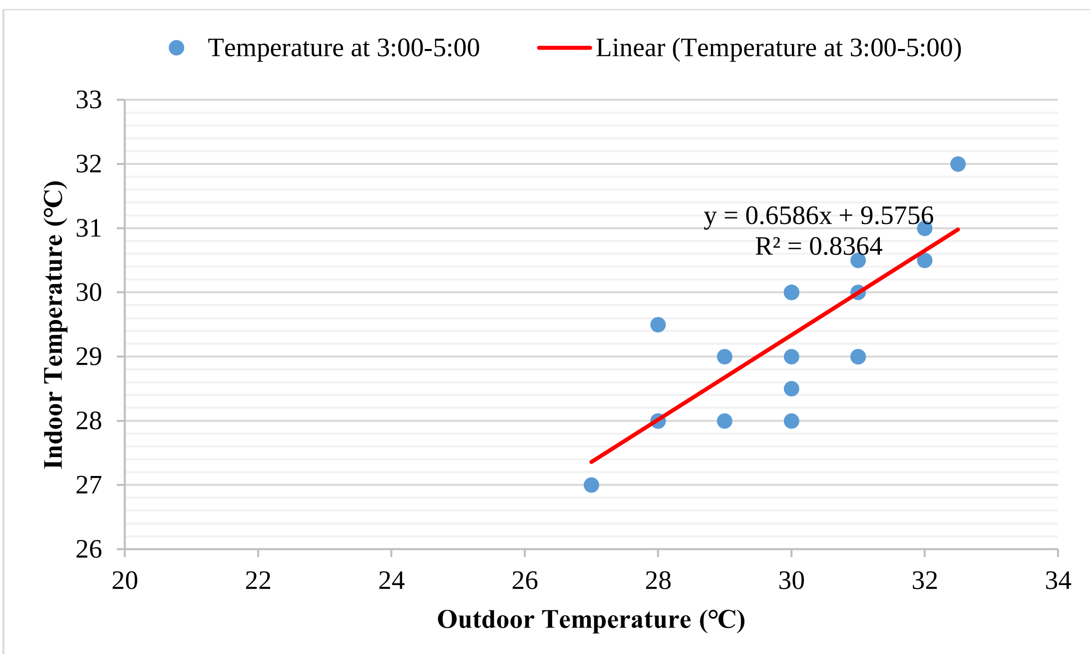


Chart 4:20 Correlation between indoor and outdoor temperature between 3:00pm to 11:00pm

Correlation coefficient (r) between 11:00am to 1:00pm is + 0.80, which shows strong correlation.

4.6.4. Correlation coefficient between indoor air temperature and humidity of classrooms

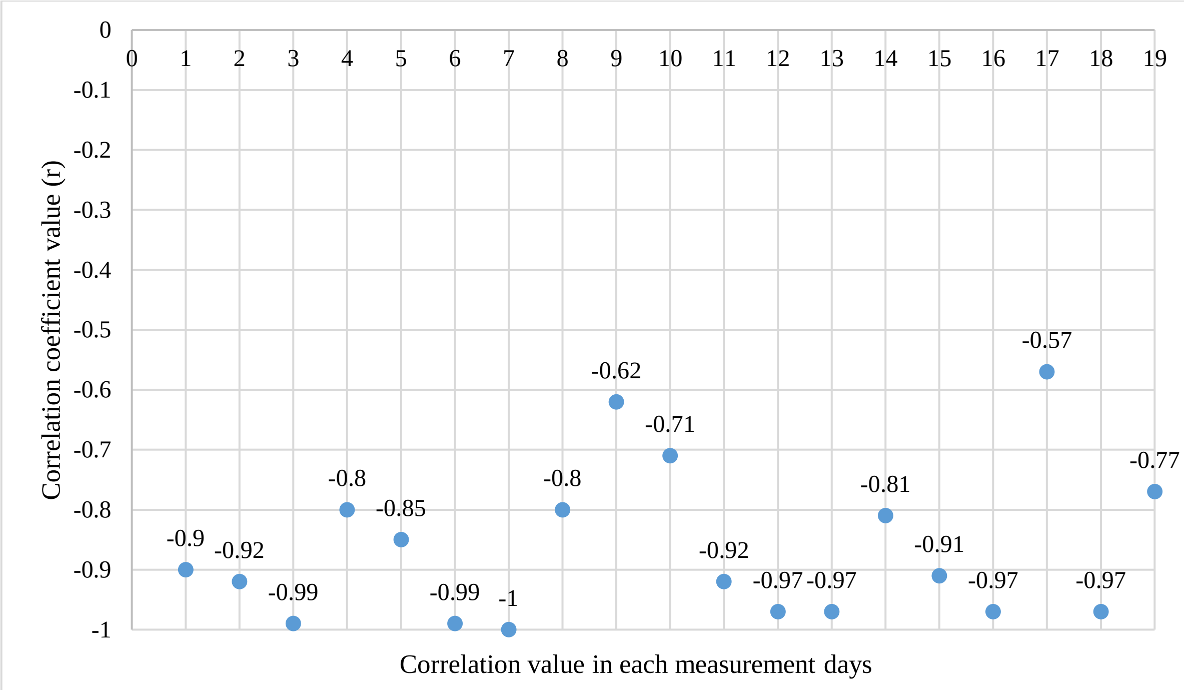


Chart 4:21 Correlation coefficient between indoor air temperature and humidity of classrooms

There is a strong negative correlation ranging between -0.57 to -1 on the indoor temperature and the humidity of classrooms on different times of the day. The result indicates that, there is a strong relation between the air temperature and the humidity of the classroom, and the correlation coefficient shows there is a medium to perfectly negative correlation. The increase of the air temperature on both the outdoor and indoor environment results a decrease in the humidity percentage of the room and vice versa.

This is the result of lack of adapting proper natural ventilation strategies, which used to regulate the indoor air temperature and lack of giving proper consideration to the orientation of the buildings and the wind direction.

4.7. Wind direction and speed measurement on selected days

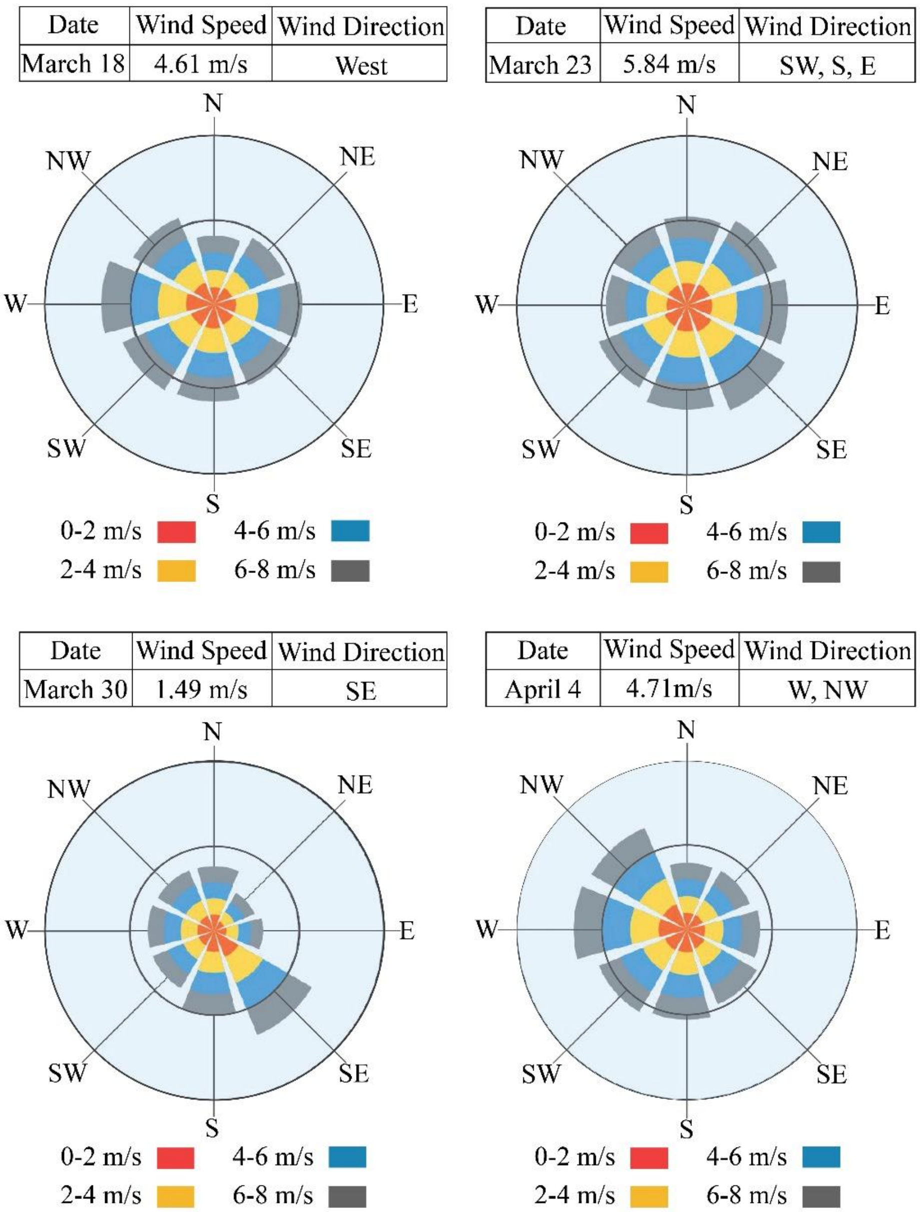


Figure 4:6 Wind rose diagram showing wind speed and direction on selected days

(Source: Field measurement)

Figure 4:6 above shows the wind speed and direction of the study areas during selected days. The air flow of the wind that blows in to the classroom buildings is low compared to the wind speed on Adama during the measurement period. The wind speed inside the classrooms during the measurement time was 4.61m/s, 5.48m/s, 1.49m/s and 4.71m/s for 17th, 23rd, 30th march, and 4th April. But according to the wind direction and speed of Adama city, the wind speed during march mas a minimum of 13m/s and minimum of 11.1m/s relative to different directions as discussed under table 4.4 below. This is the result of orientation of buildings and opening types on the buildings. This highly affects the thermal comfort of the classrooms.

4.8. Wind direction and wind speed of the Adama city

To design a naturally ventilated buildings or a building with a comfortable indoor and outdoor environment, obtaining a reliable information regarding the wind speed and direction is important.

To get the speed and direction of wind on the site, the study uses both field measurement and software simulation results. Wind rose diagram which is used to get the view of wind speed and direction that are typically distributed on a specific location was developed following the result. This diagram uses all the figures that is used to display the exact orientation of cardinal directions (N, S, E & W), intermediate directions (NW, SW, NE&SE,) and intercardinal directions (e.g. NNE, ESE, SSW, NNW, WNW, ENE, etc.)

The wind rose diagram shown on Figure 4:7 below illustrates the annual wind direction and speed of Adama city. The normal educational Callender was for ten months starting from September to June. Even if the wind rose diagram below shows the annual wind direction and speed of the Adama city, the study only focuses on ten (10) months starting from 1st September - to - 30th June. The remaining two months (July and August) are not taken in this study since they are categorized under rainy summer season in which the temperature is relatively decreased and the school is closed.

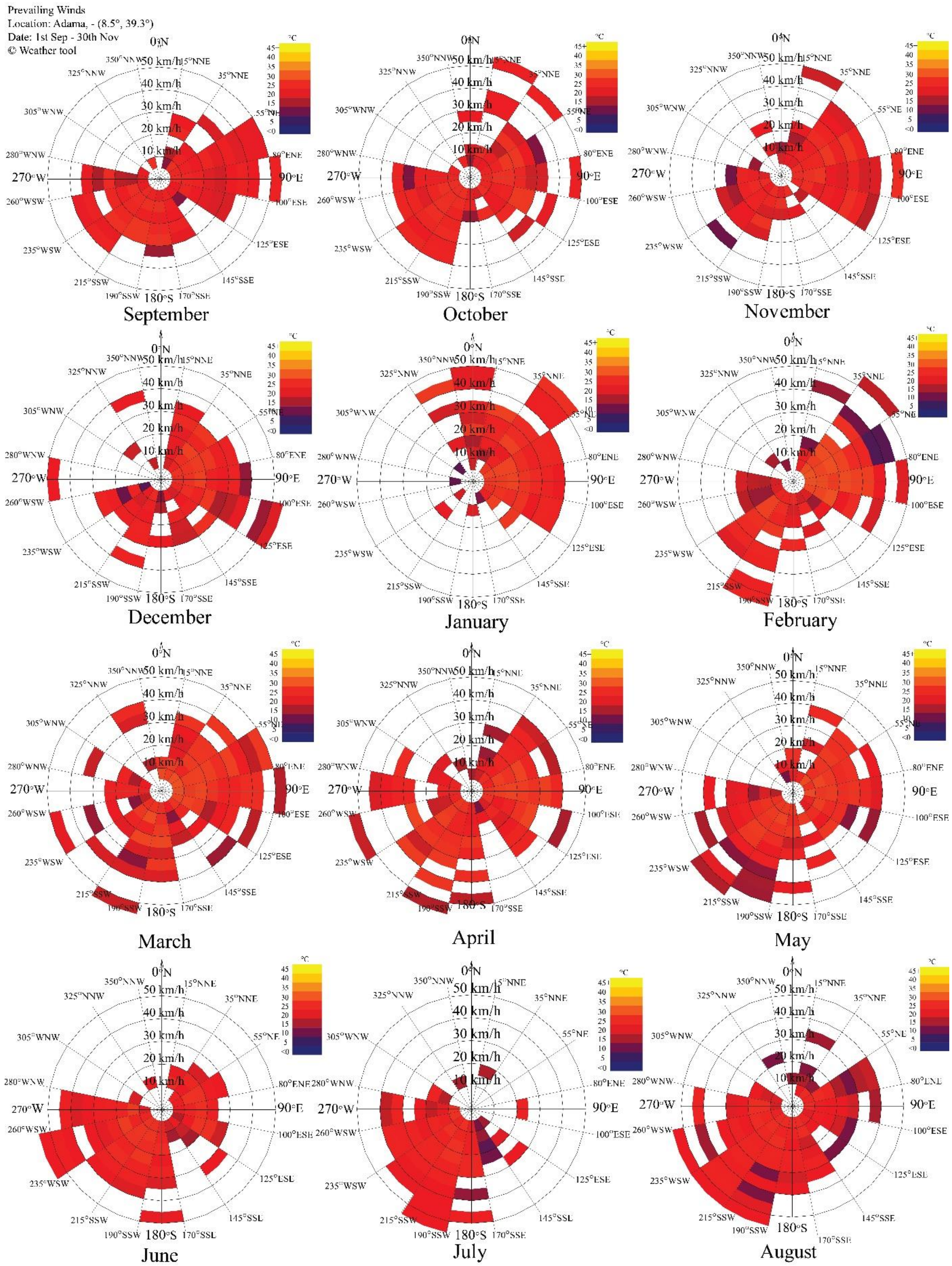


Figure 4:7 Wind rose diagram of Adama city starting from 1st Sep to 31st August (Autodesk Ecotect)

As illustrated on Figure 4:7 above, the wind speed of Adama city ranges from 13.8 m/s the highest to 6.9 m/s the lowest speed in different months of the year. The wind direction and speed of Adama city in each month was discussed in the Table 4:4 below.

Table 4:4 Annual Wind direction and speed of Adama city (Source: Autodesk Ecotect)

No.	Month	Incoming wind direction	Wind speed	No.	Month	Incoming wind direction	Wind speed
1.	September	Southwest	11.1 m/s	7.	March	North	11.1 m/s
		Northeast	13.8 m/s			Northeast	13.8 m/s
		South	8.3 m/s			East	12.5 m/s
2.	October	Southwest	11.1 m/s			Southwest	11.1 m/s
		Northeast	13.8 m/s			South	11.1 m/s
3.	November	Southwest	8.3 m/s	8.	April	South	13.8 m/s
		Northeast	11.1 m/s			Southeast	9.7 m/s
		East	9.7 m/s			East	11.1 m/s
4.	December	Southwest	9.3 m/s			Southwest	11.1 m/s
		South	8.3 m/s			West	12.5 m/s
		East	11.1 m/s			Northeast	11.1 m/s
		Northeast	9.7 m/s	9.	May	South	12.5 m/s
5.	January	East	11.1 m/s			Southwest	13.8 m/s
		Northeast	13.8 m/s			Northeast	11.1 m/s
		North	13.8 m/s			East	11.1 m/s
6.	February	Southwest	11.1 m/s	10	June	South	8.3 m/s
		West	6.9 m/s			Southwest	11.1 m/s
		South	8.3 m/s			SSW	11.1m/s
		East	13.8 m/s			West	11.1 m/s
		Northeast	11.1 m/s			Northeast	8.3 m/s

The orientation of the existing classroom buildings was not aligned considering the wind direction of the site. All buildings have openable windows in only one direction. The fresh air that comes into the building through positive pressure wall inters the room and at the same time the hot air exits the room through leeward walls. In most cases in the study buildings, there is only one-sided openable windows and the remaining north and north east and north west direction windows are fixed windows. There is no way out of the hot air from the classrooms. This limits the wind circulation inside the building and increases the indoor temperature.

4.9. Calculate the natural ventilation requirements and minimum opening area for effective natural ventilation for existing classroom buildings

Adequate Ventilation will ensure a steady supply of fresh air into a building which has numerous benefits, such as moderating the temperatures and humidity, replenishing oxygen, and also create air movement to improve the comfort of building occupants.

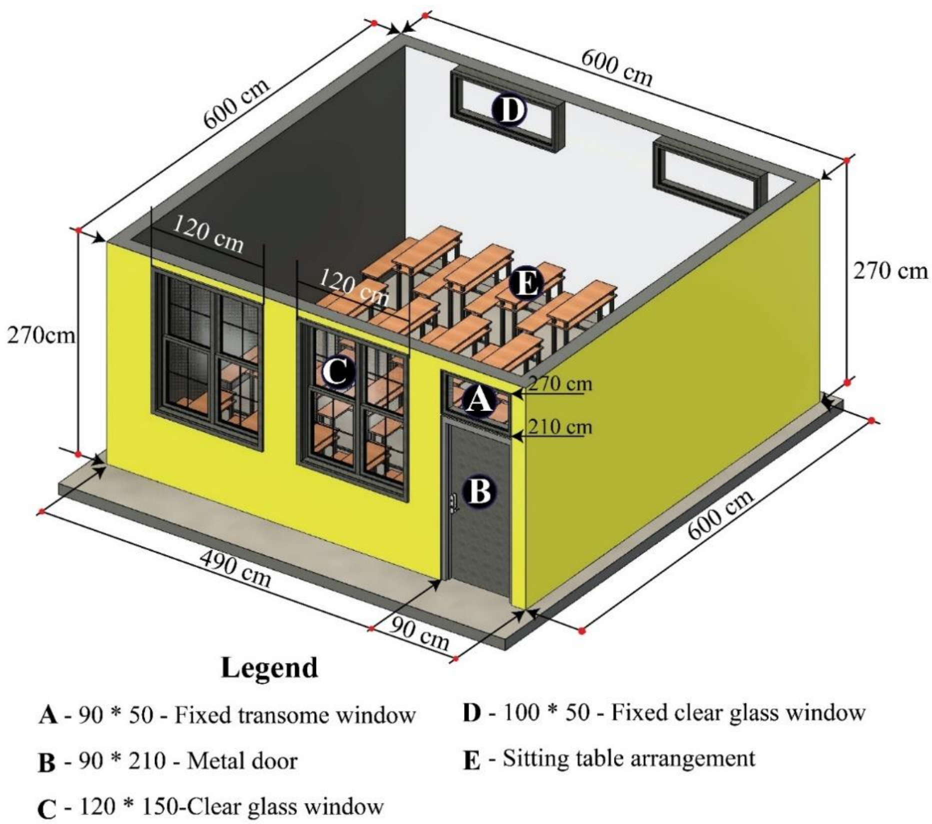


Figure 4:8 Detail of existing classroom buildings (Source: Field measurement by Author, 2024)

As shown on the Figure 4:8 above, the total free floor area of the classroom was 31.36 square meter which is used for an average of 55 students per classroom. This is equivalent to 0.57 square meter of area per student. The total windows are was 3.6 m^2 operable windows and 2.2 m^2 fixed windows which is used for only natural light access to the classroom.

4.9.1. Steps to ventilation calculation

Step 1: Classification

The first step is to understand the type and classification of the building to determine the standard of air quality needed to maintain, and the volume of air required to have circulating

Step 2: Get the required building data

The second step is knowing the number of occupants who will be in the building, the free area % of the ventilation, and the velocity of air in m/s

Step 3: Using formula to get the free opening area requirement for effective natural ventilation

The final step is calculating the free area required to naturally ventilate the building. This will be determined by using the formula below:

Free Area requirement (m^2) = Volume (m^3/s) / (Average wind velocity (m/s) * cd) ......Equation (3) (Source: (De Gids 1978))

Calculating the volume of air required

Ventilation air volume is determined for each building premise or volume

The formula used to calculate is:

$L = V_{prem}. * A_{ch}$ [m^3/h] .... Equation (4) (Source: (De Gids 1978))

Where, L = Volume of air in m^3/s

V_{prem} = premise volume or the volume of the room

A_{ch} = minimum air exchange per hour

To determine the premise volume:

Volume of the room V(m^3) = Length * width * height .... Equation (5)

The size of the selected school buildings is: 5.80m * 5.8m * 2.7m (length, width and height respectively).

Volume of the classroom will be:

$V(m^3) = 5.80m * 5.8m * 2.7m$

$V(m^3) = 90.8\ m^3$

Calculating the air change per hour of the classroom

Air change per hour is a measure of how many times each hour outside air enters a space and is mixed and replaced old air from inside classroom. According to the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (Burley 2022), recommends the school should have an air ventilation rate of 3 - to - 6 times per hour. This means that, the outside air should enter a classroom 3 - to - 6 times per hour, and replaces the hot air into the comfortable level.

Calculating the air change per hour

To calculate the air change per hour of the classroom, we multiply the LSP (Liter per second per person) of the infiltration by 55 (average number of students per classroom), and then divide the number by the total volume (V) of air being exchanged.

A_{ch} = LSP (55) / V (room volume) ....Equation (6) (Source: (Swami and Chandra 1987))

According to (Mendell 2012), the People Outdoor Air Rate R_p for Classrooms (for adult) was 5 L/s/person

L/S/Person = 5

$A_{ch} = (5*55) / 90.8\ m^3$

$A_{ch} = 3.02$; this shows that, the air change per hour of the classroom is 3.

Now, we calculate the ventilation air volume in m^3/s by using the formula above:

L = Vprem. * Ach $[m^3/h]$ .... Equation (7) (Source: (CEN 2007))

- ⇨ $90.8\ m^3 * 3$
- ⇨ $272.4\ m^3/s$

The third step will be finding the area of window in square meter for the effective natural ventilation of the classrooms:

Free area of window required (m^2) = Volume (m^3/s) / (Average wind velocity (m/s) * Cd)

Where; Cd = Coefficient of discharge

The coefficient of discharge (Cd) depends on the direction of the wind relative to the opening and the relative size of entry and exit openings. The value of coefficient of discharge ranges from about 0.3 for wind hitting an opening at a 45^o angle of incidence to 0.6 for wind that hits the opening at a 90^o angle (Passe and Battaglia 2015).

So, depending on the orientation of the buildings, we take the value of coefficient of discharge 0.6 for classroom buildings that face 90^o towards the direction of the wind; and 0.3 for those openings face 45^o to the coming wind direction.

- ⇨ Free area of window required (m^2) for buildings that the wind hits at 90^o
- ⇨ Volume (m3/s) / (Average wind velocity (m/s) * Cd)

Wind velocity is the linear rate of change of direction with respect to time that the wind is traveling at. It calculated as:

(V_w) = √ (2 * F/ (P * A)) .... Equation (8)

Where; V_w = wind velocity

F = Wind force (N)

P = the air density (kg/m^3)

A = the surface area of wind pressure (m^2)

The generic formula used to find the wind load is F = A * P * Cd .... Equation (9) (Source:(Stathopoulos and Alrawashdeh 2020)

Where; F = Wind force or load

A = the projected area of the building face

P = is the wind pressure, and

Cd = is the drag coefficient

The projected area (A): is the area of the two-dimensional face that the wind is hitting. To find the projected area of the building face; we multiply the length of each face by their respective building (wall) height.

The size of the existing school buildings is: 5.80m * 2.7m (length * height respectively). So that, to calculate the projected area of the building that the wind is hitting, we directly multiplying the width with height. For SI unit calculation, area (A) is measured in square meter (m^2).

- ⇨ 5.80 * 2.70
- ⇨ 15.66 m^2 (This value is for the front direction of the existing classroom buildings).

Wind pressure (p): Wind effect applies Bernoulli's principle of fluid dynamics. It states that, at a higher wind speed, the static wind pressure decreases and at a lower speed the static pressure of the wind increases. The air speed on the windward side of the building reduces as it collides with the building. This results an increase in pressure. Conversely, the air speed on the top and the leeward sides of the building increases, and results a reduced wind pressure. A pressure deferential is thus created between windward and leeward walls. The effective pressure difference tends to be greater (about 1.4 times the dynamic wind pressure at eave level for rectangular buildings) when wall openings are about 15% to 20% of the wall area. This means, the average wind speed through the wall opening has the potential to be 18% higher than the local wind speed. Without any opening, the wind pressure difference is about 1.1 times the dynamic pressure at eave level of the building. With a 60% wall opening or more, the wind pressure difference between windward and leeward surfaces of the building remains constant around 1.0 times the dynamic pressure at eave level (Bhatia 2013).

Is the speed of the wind, and it is calculated using the formula $P = 0.613V^2$. It is measured in meter per second (m/s).

$P = 0.613\ (5.80)^2 = 20.62$ m/s

Drag coefficient (Cd): is the force that air is exerted on the building, and it is affected by the shape of the building, the roughness of the building, etc. The standard drag coefficient for a flat building face is 1.4. It has no unit of measurement.

Now, by directly substituting the values on the above formula to find the wind load;

- ⇨ F = A * P * Cd
- ⇨ 15.66 * 20.62 * 1.4
- ⇨ 452 N

Air density (P): is the mass per unit volume of air. The SI unit of air density is kg/m^3. The density of air is 1.2 kg/m^3. To get the total air density of the building, we multiply the volume of the room by the standard density of air.

Air density of the study building (P):

- ⇨ 90.8 * 1.2 kg/m^3
- ⇨ 108.96 kg/m^3

Now, by substituting the values on the above formula to find the wind load;

F = A * P * Cd

= 15.66 m^2 * 108.96 kg/m^3 * 1.4

F = 2388.8 N

$(V_w) = \sqrt{((2 * F) / (P * A))}$

- ⇨ √ ((2 * 2388.8) / (108.96 * 15.66))
- ⇨ √ (4777.6 / 1706.3)
- ⇨ √ (2.8)
- ⇨ 1.67 m^3/s

Average wind velocity (m/s) = 0.54 m/s from measurement

Substituting the values on the formula to find the average wind velocity;

The final step will be finding the required free area of windows for cross ventilation of the classroom. To get this value, we use the formula below:

Free area of window required (m^2) = Volume (m^3/s) / (Average wind velocity (m/s) * Cd)

Where; Coefficient of discharge (Cd) = 0.6

- ⇨ (1.67 m^3/s) / (0.54 m/s * 0.6)
- ⇨ (1.64 m^3/s) / (0.324 m/s)
- ⇨ 5.06 $m^2 \approx 5\ m^2$

So that, the minimum windows area required on the windward face wall for effective natural ventilation of a single classroom will be 5 m^2. This is equivalent to 16% of window to wall ratio (WWR) of the building; which is the optimal window to wall ratio for the selected building type. For buildings that face to the incoming wind direction at an angle of 45^o, the coefficient of discharge will be reduced to 0.3.

This means, the Free area of window required (m^2) for classroom buildings that face 45^o towards the wind direction: = Volume (m^3/s) / (Average wind velocity (m/s) * Cd)

Where; Coefficient of discharge (Cd) = 0.3

- ⇨ (1.67 m^3/s) / (0.54 m/s * 0.3)
- ⇨ (1.64 m^3/s) / (0.162 m/s)
- ⇨ 10.1 $m^2 \approx 10\ m^2$

So that, for classroom building the incoming wind hits at 45^o, the minimum windows area required on the windward face wall for effective natural ventilation will be 10 m^2. This is equivalent to 30.3% of window to wall ratio (WWR) of the building; which is the optimal window to wall ratio for the selected building type.

Regarding the classroom buildings that has to be newly construct, the study follows the Ethiopian standard size of classrooms. The Ethiopian standard of classrooms is 47 m^2. The standard number of students per classroom is 50, and there will be 24 tables; each table are for 2 students.

4.10. Standard classroom layout prepared by the Ministry of Education (MOE)

According to a standard prepared by the Ethiopian Ministry of Education (MOE), the standard classroom size for primary and secondary schools in Ethiopia is 7.5meter * 6.25 meter (length * width) with a minimum floor height of 3 meter (Bekele 1966). The standard number of students per classroom is 50; and there will be 24 tables per classroom. Each table are for 2 students. based on this, the average floor area per person is $47m^2$ / 50students which results 0.94 square meter per student. According to office for the revision of Addis Ababa master plan, norms and standards of the Addis Ababa structure plan components, the clear height of the classrooms should not be less than 3 meters. Windows use of steel framed glass window.

This standard didn't address the effect of different climate factors on the thermal environment and overall indoor air quality of classrooms, and its effect on the health, comfort and performance of students. The opening size of the classrooms, their orientation to the local wind direction and speed, and also the sun orientation and its impact on the indoor thermal environment is not addressed well.

The sample design layout which is prepared by the Ministry of Education (MOE) is used in different parts the country without giving a consideration to the local climate condition of the area, and different environmental and personal parameters that contribute to the occupant's thermal comfort/discomfort. The standard classroom design layout prepared by MOE is illustrated on Figure 4:9 below.

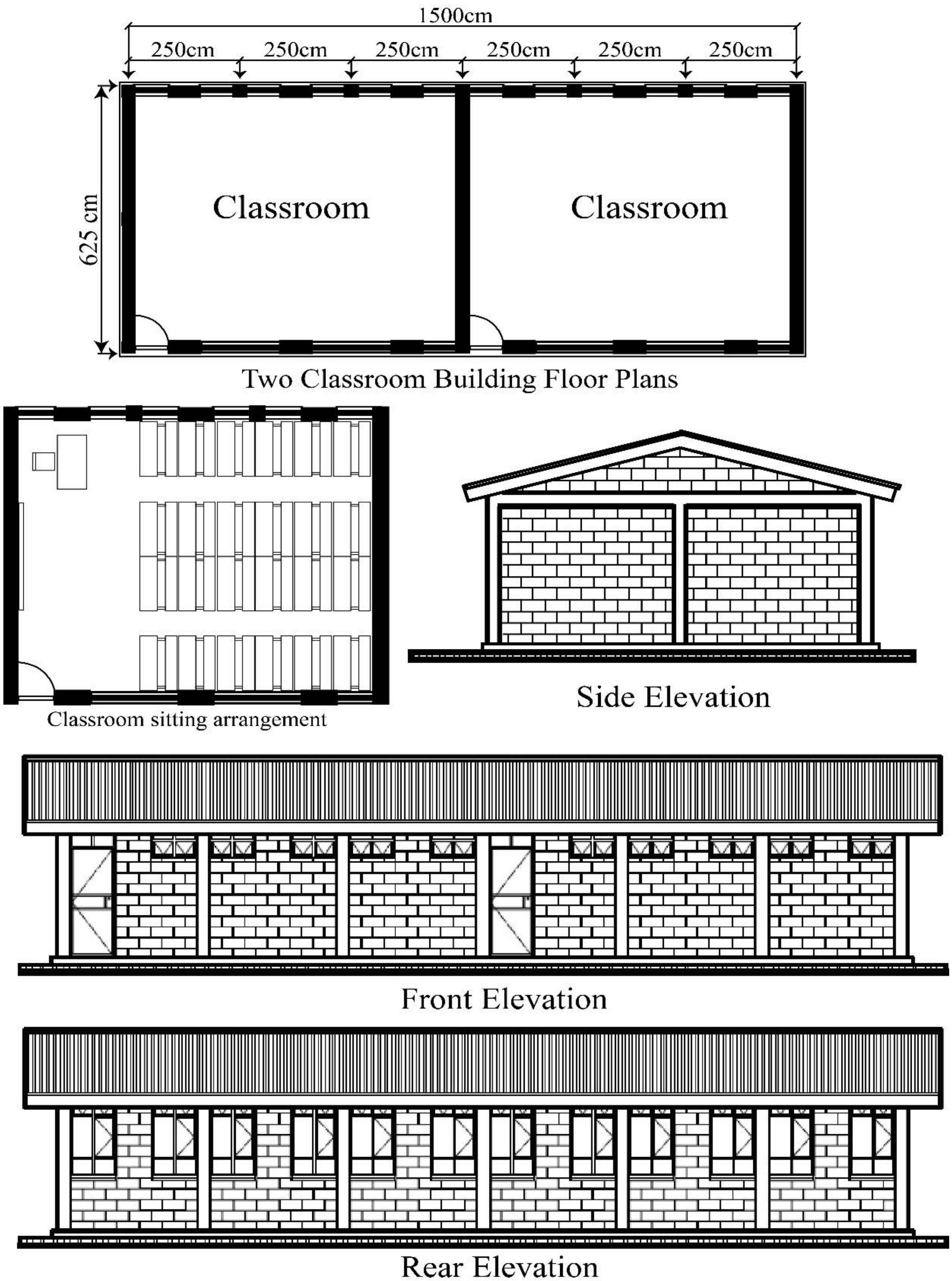


Figure 4:9 Standard layout of classroom (Source: (Bekele 1966))

4.10.1. Steps to ventilation calculation for the proposed classroom building

The steps to calculate the ventilation calculation and the amount of free area of the classrooms is the same as we discussed above with the steps to calculate the ventilation of the existing classroom buildings. The only difference is that of the area of classrooms and clear floor height of the room. So that, by following the same procedure, we calculate the amount of ventilation and free area requirement of the classrooms as follows.

Step 1: Building Classification

Step 2: Get the required building data

Step 3: Using formula to get the free opening area requirement for effective natural ventilation

Free Area requirement (m^2) = Volume (m^3/s) / (Average wind velocity (m/s) * cd)

Calculating the volume of air required

Ventilation air volume is determined for each building premise or volume

The formula used to calculate is:

$L = V_{prem.} * A_{ch}$ [m^3/h]

Where, L = Volume of air in m^3/s

V_{prem} = premise volume or the volume of the room

A_{ch} = minimum air exchange per hour

To determine the premise volume:

Volume of the room V(m^3) = Length * width * height

The size of the selected school buildings is: 7.50m * 6.25m * 3.0m

Volume of the classroom will be:

V(m^3) = 7.50m * 6.25m * 3.0m

V(m^3) = 140.6 m^3

Calculating the air change per hour of the classroom

Calculating the air change per hour

A_{ch} = LSP (55) / V (room volume) (Source: (Swami and Chandra 1987)).

According to (Janssen 1989), the People Outdoor Air Rate R_p for Classrooms (for adult) was 5 L/s/person

L/S/Person = 6

A_{ch} = (6*50) / 140.6 m^3

A_{ch} = 3; this shows that, the air change per hour of the classroom is 3.

Now, we calculate the ventilation air volume in m^3/s by using the formula above:

L = Vprem. * Ach [m^3/h] (Source: (CEN 2007))

- ⇨ 140.6 m^3 * 3
- ⇨ 421.8 m^3/s

The third step will be finding the area of window in square meter for the effective natural ventilation of the classrooms:

Free area of window required (m^2) = Volume (m^3/s) / (Average wind velocity (m/s) * Cd)

Where; Cd = Coefficient of discharge

Cd = 0.3 - for wind hitting an opening at a 45^o angle of incidence

Cd = 0.6 for wind that hits the opening at a 90^o angle (Kleiven 2003).

- ⇨ Free area of window required (m^2) for buildings that the wind hits at 90^o
- ⇨ Volume (m3/s) / (Average wind velocity (m/s) * Cd)

Wind velocity is the linear rate of change of direction with respect to time that the wind is traveling at. It calculated as:

$(V_w) = \sqrt{}\ (2 * F/ (P * A))$

Where; V_w = wind velocity

F = Wind force (N)

P = the air density (kg/m^3)

A = the surface area of wind pressure (m^2)

Wind load (F) = A * P * Cd (Source: (Stathopoulos and Alrawashdeh 2020).)

Where; F = Wind force or load

A = the projected area of the building face

P = is the wind pressure, and

Cd = is the drag coefficient

The projected area (A): The size of the proposed classroom buildings is: 7.50m * 3.0m (length * height). So that, to calculate the projected area of the building that the wind is hitting, we directly multiplying the width with height.

- ⇨ 7.50 * 3.0
- ⇨ 22.50 m^2 (This value is only for the front direction of the existing classroom buildings).

Wind pressure (p):

$P = 0.613V^2$

$P = 0.613\ (7.50)^2 = 34.5$ m/s

Drag coefficient (Cd): The standard drag coefficient for a flat building face is 1.4.

- ⇨ F = A * P * Cd
- ⇨ 22.5 * 34.5 * 1.4
- ⇨ 1086.7 N

Air density (P): The density of air is 1.2 kg/m^3.

Air density of the study building (P):

- ⇨ 140.6 * 1.2 kg/m^3
- ⇨ 168.7 kg/m^3

Substituting the values on the above formula to find the wind load;

F = A * P * Cd

= 22.5 m^2 * 168.7 kg/m^3 * 1.4

F = 5314 N

(V_w) = √ ((2 * F) / (P * A))

- ⇨ √ ((2 * 5314) / (168.7 * 22.5))
- ⇨ √ (10628 / 3795.75)
- ⇨ √ (2.8)
- ⇨ 1.67 m^3/s

Average wind velocity (m/s) = 0.54 m/s from measurement

Substituting the values on the formula to find the average wind velocity;

The final step will be finding the required free area of windows for cross ventilation of the classroom. To get this value, we use the formula below:

Free area of window required (m^2) = Volume (m^3/s) / (Average wind velocity (m/s) * Cd)

Where; Coefficient of discharge (Cd) = 0.6

- ⇨ (1.67 m^3/s) / (0.54 m/s * 0.6)
- ⇨ (1.64 m^3/s) / (0.324 m/s)
- ⇨ 5.06 m^2 ≈ 5 m^2

So that, the minimum windows area required on the windward face wall for effective natural ventilation of a single classroom will be 5 m^2. This is equivalent to 10.65% of window to wall ratio (WWR) of the building; which is the optimal window to wall ratio for the proposed classroom building. For buildings that face to the incoming wind direction at an angle of 45^o, the coefficient of discharge will be reduced to 0.3.

This means,

Free area of window required (m^2) for classroom buildings that face 45^o towards the wind direction: = Volume (m^3/s) / (Average wind velocity (m/s) * Cd)

Where; Coefficient of discharge (Cd) = 0.3

- ⇨ (1.67 m^3/s) / (0.54 m/s * 0.3)
- ⇨ (1.64 m^3/s) / (0.162 m/s)
- ⇨ 10.1 $m^2 \approx 10$ m^2

So that, for new proposed classroom buildings in which the incoming wind hits at 45^o, the minimum windows area required on the windward face wall for effective natural ventilation will be 10 m^2. This is equivalent to 21.3% of window to wall ratio (WWR) of the building; which is the optimal window to wall ratio for the proposed classroom building.

4.11. Cross ventilation

In naturally ventilated classrooms, the design of windows, its size and location have a great influence on the air change rate of the buildings indoor space or the distribution of clean air with in the building. Cross ventilation is the simplest and most effective approach to ventilate a room. It is driven by pressure difference between the windward wall and leeward sides of the room. In cross ventilation results a good air change rate with in the room. In order to achieve this, the optimum opening area and its location on the building façade results a specific air change rate at a given velocity.

The windows used for cross ventilation should be located in a way that the incoming clean air is well distributed within the room and should be located at the level of the building occupant. According to a study (Staritcyna, Pollock et al. 2016), in cross ventilated rooms to get the efficient air circulation in the room, inlet and outlet openings (wind ward and leeward walls) should be placed on opposite walls of the room with different height.

Different building features can help to let outside air into the building. Architectural building features like building wing wall to direct air into the room. If the prevailing wind direction is at an angle greater than 60° to the surface normal of the window, wing walls are recommended to steer the air into the room. According to this study, the depth of the wing wall should be at least

0.5 - 1 times the width of the windows. The spacing between wing walls will be 1x to twice (2x) the width of the windows. Casement window types are effective in warm climates, since they allow twice the openable area for natural ventilation, compared to other types of windows such as sliding openings (Mujeebu and Bano 2022).

Ethiopia belongs to the southern hemisphere; and the country is located to the southern Equator, it is also part of the eastern hemisphere. Most of the country's territory is located above 2000 meters of altitude. Countries located near the equator receives more solar radiation than those countries located farther from the equator (Tsigie, Feyissa et al. 1999).

In hot tropical climates, it is important to minimize the direct solar penetration into the buildings through glazed surfaces by orienting the building to the way that reduces the amount of heat gain during the hottest period, sizing openings with proper location, using effective window to wall ratio, and using appropriate solar protection by adapting passive design strategies through careful design and orientation of the building that maximizes shading during the overheated periods to reduce the heat gain, and that maximizes the solar heat gain during cold times.

According to (Habitat 2018), for countries located in the equator and have tropical climates, the most appropriate building orientation that minimizes the direct solar heat gain is along East-West axis in which the longest façade of the building facing towards north and/or south, and minimizing openings on the east and west directions. To avoid the unwanted heat gain during overheated period, windows and other glazed facades of the building should be properly shaded. In doing so, the direct heat gain in school classroom buildings during the early morning hours especially before 9:00am do not have adverse effect on the thermal comfort of building occupants. Since in most government and private schools, the classroom building occupancy hours are between 9:00am to 5:00pm, more concern was given on minimizing the direct solar heat gain and maximizing natural ventilation to create thermally comfortable environment for building users.

4.12. Wing-wall

Wing walls are an external projection used for effectively improve the natural ventilation of a building. By positioning properly, wing walls produce high- and low-pressure regions on the inlet and outlet windows respectively (Kumar, Chandrasekhar et al. 2015). On building facades where the prevailing wind direction is at an angle on greater than 60 degrees to the surface which is normal to the window, wing walls are recommended to direct the incoming air into the room.

According to (Mujeebu and Bano 2022), the depth of the wing wall should be at least 0.5 - 1 time the width of the windows. On the other hand, the spacing between wing walls should be at least twice (2x) the width of the windows. This number depends upon the number of windows installed on the wall. Casement windows are especially recommended in warm and also humid climate area. These types of windows allow at least twice the openable area for natural ventilation, since they are 90% openable, compared to sliding windows and other window types.

4.13. Solar geometry

In order to minimize the direct solar heat gain and providing adequate natural ventilation for building occupants, having good understanding of solar geometry, solar radiation, and also wind movement in different hours of the day with different seasons of the year is essential.

Solar geometry is the measure of the angle of the sun to the earth and to the corresponding amount of solar energy that hit the building surface. So, it is important to consider the position of the sun when deciding the orientation of buildings, their openings and the amount of sunlight entering the building. Solar radiation is a short-wave radiation from the sun that heats the building directly through openings such as windows, glazed facades, or other opening, and through different fabrics of building components. The suns position at various times of the year can be found through two different angular coordinates. These are: the solar altitude angle and solar azimuth angle (Maestre López-Salazar 2019).

Solar azimuth (α): is the angle between the direction due North and that of the perpendicular projection of the sun down onto the horizon line, and it is measured clockwise. Thus, the values are 0° North, 90° East, 180° South, and 270° West.

Solar altitude (β): is the angle between the line joining the center of the sun with the observation point and the horizontal plane.

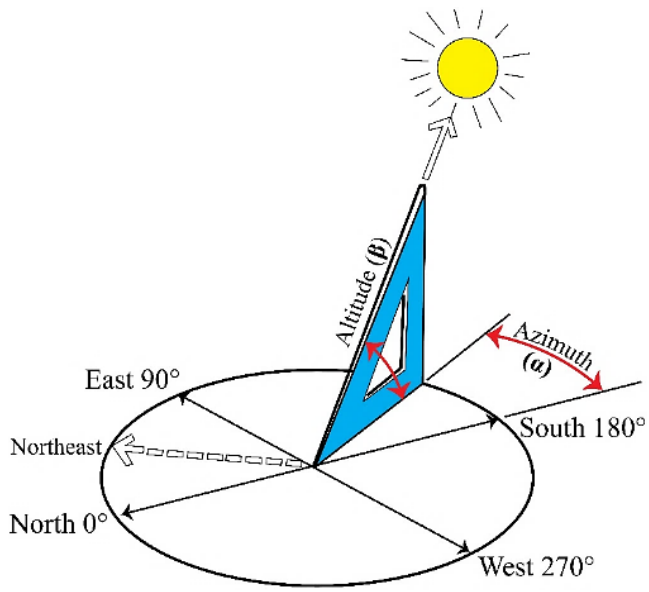


Figure 4:10 Solar azimuth and Solar altitude of solar geometry (Source: Solar Geometry + Orientation)

4.13.1. Steps to calculate the size of wing wall width and roof eave depth

To get the appropriate size of wing wall which is used to minimize the direct solar heat gain and to direct the incoming wind to enter into the classrooms, and the roof eave depth used to block the solar penetration to the classrooms through windows, the following steps should be following.

i. Determine the wind direction and speed on the respective study area

ii. Getting required building data and detail size and orientation of building openings

iii. Determining the overheated times. This includes the time, date and month when the classrooms get the maximum solar penetration

iv. Using the appropriate sun path diagram of the study area. This helps to get the altitude and azimuth angle of the sun at the overheated periods

v. Applying solar shading protractor to get HAS and VSA

vi. Calculating the size of the wing wall and roof eave overhang depth

Since this study focuses on creating a comfortable learning environment for students, proper passive design strategies will be prepared for both the existing classroom building to make them thermally comfortable and naturally ventilated for the students through adapting design strategies; and creating a design proposal for newly schools to be constructed. The detail size and dimension of windows and doors used on the existing classrooms and opening type and sizes to be adapted on new classroom designs are shown on the Figure 4:11 below.

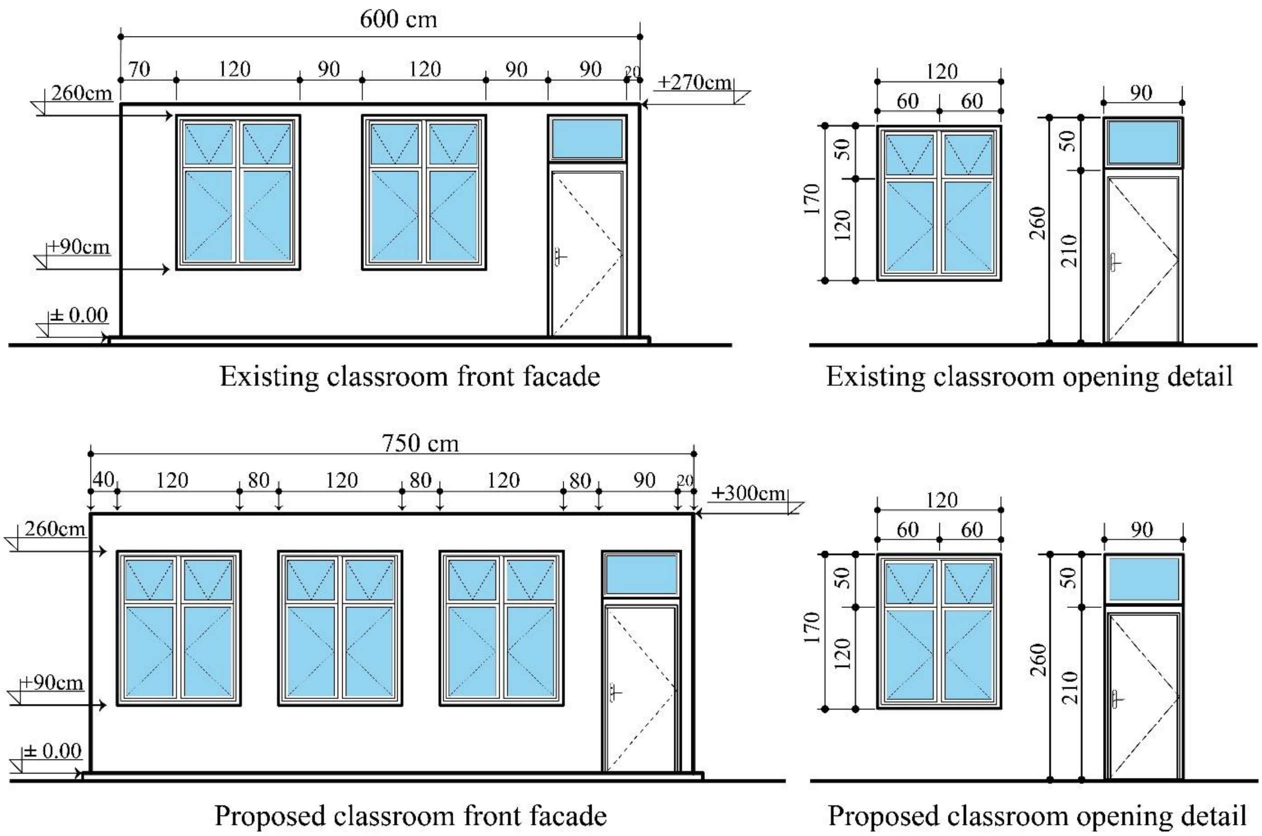


Figure 4:11 Existing and Proposed Windows and door detail dimensions (Source: Author & (Bekele 1966))

❖ Shading Dimensions

To determine the size of roof eave overhand and wing wall dimension used for the windows to minimize the direct solar penetration into the room and to direct the income wind to the rooms, two angles will be used. These are the Horizontal Shadow Angle (HSA) and the Vertical Shadow Angle (VSA).

❖ Horizontal Shadow Angle (HSA)

Horizontal shadow angle (HSA) is used to illustrate the performance of vertical shading elements of the building. It is the difference in azimuth angle between the sun's position on the sky and the orientation of the building façade or window.

❖ Vertical Shadow Angle (VSA)

Vertical shadow angle (VSA) is used to describe the performance of horizontal shading element. It is the angle between the horizontal plane of the building façade and a tilted plane which contains the sun or the edge of the shading device.

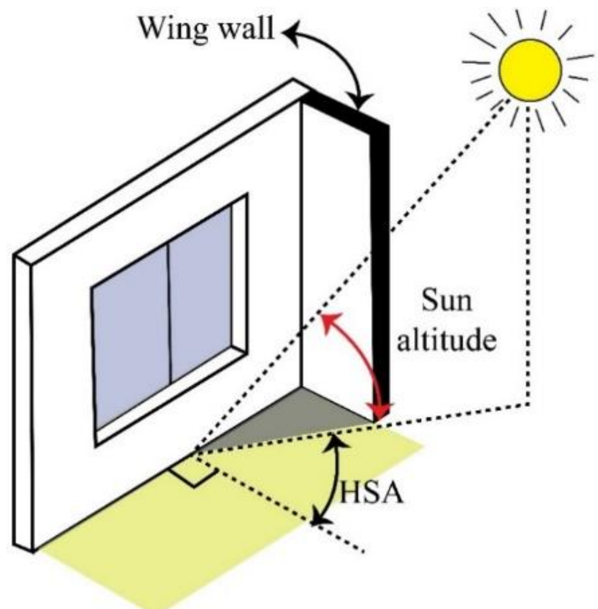


Figure 4:12 Wing-wall and roof eave overhang used to reduce the direct solar gain and used to direct the wind to the interior room space(Source: (Corrado, Serra et al. 2004))

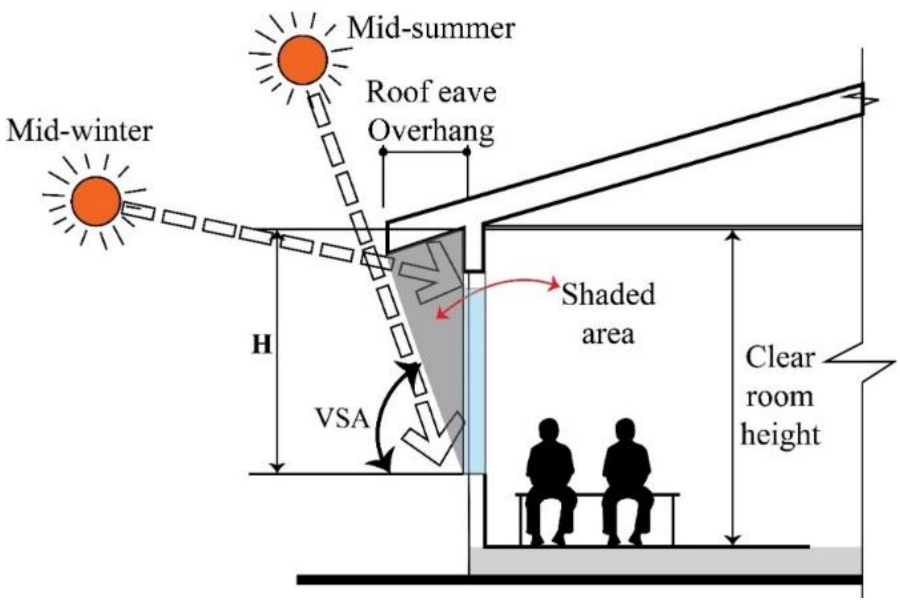


Figure 4:13 Roof eave overhang which used to reduce the direct solar heat gain of the roof through windows (Source: (Mostafa, Zisis et al. 2022))

- **Solar Protractor, Vertical Shadow Angle (VSA) and Horizontal Shadow Angle (HSA)**

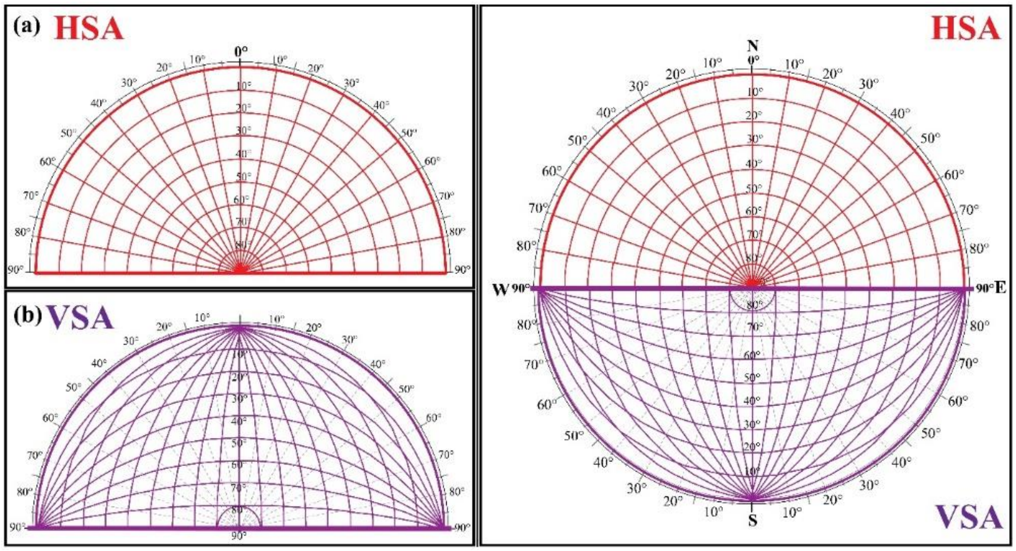


Figure 4:14 Vertical Shadow Angle (VSA), Horizontal Shadow Angle (HSA), and End Profile Angle (EPA) (Source: solardata.uoregon.edu)

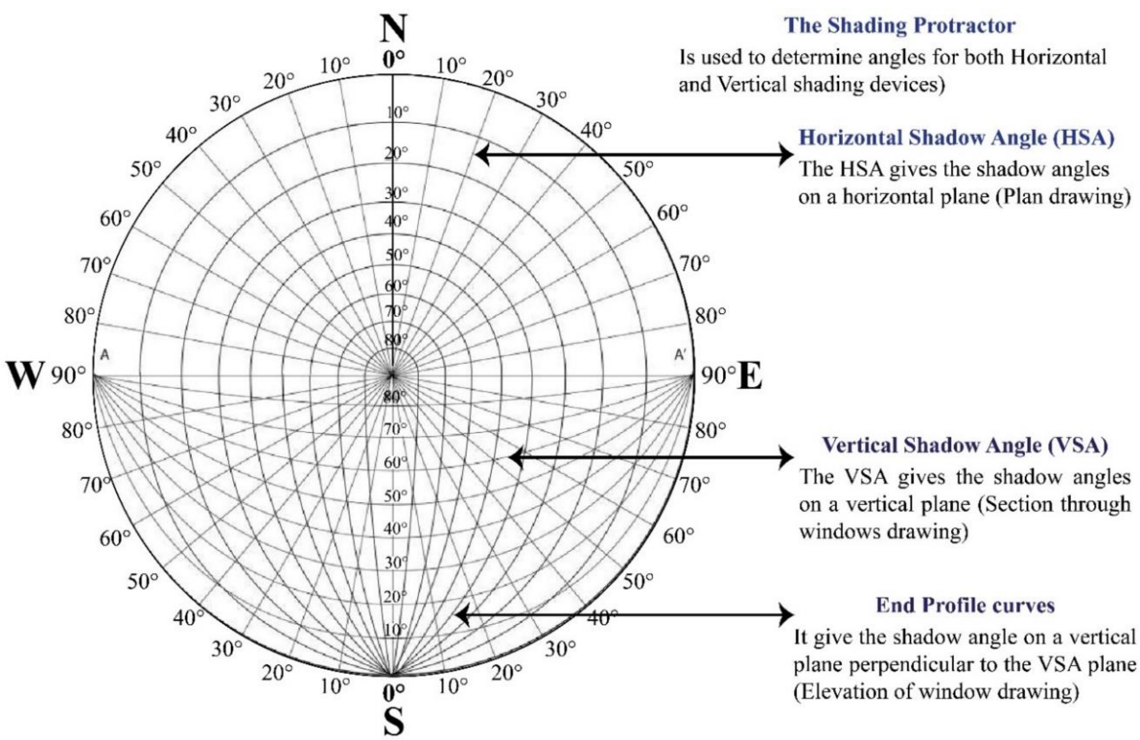


Figure 4:15 Solar shading protractor Source:(Kitio 2013))

The depth of the roof overhang and wing wall can be calculated using HAS and VSA.

Horizontal Shadow Angle (**HSA**)

$$HSA = AZI - ORI$$

Where, AZI = Azimuth angle

ORI = Building façade orientation

Vertical Shadow Angle (**VSA**)

$$VSA = \arctan(\tan(\text{altitude angle} / \cos(HSA))$$

❖ **Sun Path diagram**

Sun path diagram is a method of representing the sun’s position as it changes in the sky throughout the year. It is projected onto a horizontal plane using the four cardinal directions which are East, West, North and South. It is also a method used to develop a specific diagram for any latitude, since the position of the sun at any time of the day and year can be plotted on the horizontal plane on the sun path diagram (Habitat 2018).

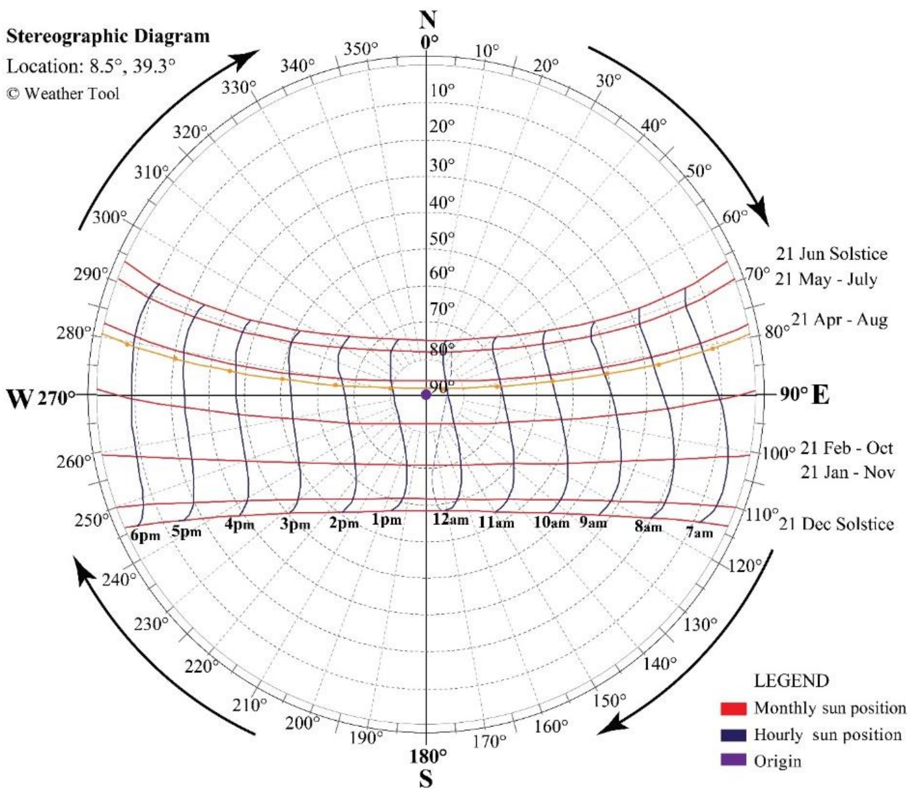


Figure 4:16 Sun path diagram of Adama city (Source: https://www.sunearthtools.com/)

4.14. Optimum Orientation in Adama City

As shown on the Figure 4:17 below, the best optimum orientation to locate a building in its longest side of the building is through East-West axis, with the front façade of the building towards the North axis between 315° Northwest to 45° Northeast. And the hottest and worst orientation for the front façade of the building is towards the South orientation between 135° Southeast to 225° Southwest. The existing classroom buildings on the selected schools, the front façade of the buildings faces towards the South, Southeast and mostly Southwest orientation. This results the direct solar heat gain enters the rooms and make them overheated. This in turn affects the thermal comfort of the students. So that, these buildings need a strategy to minimize the direct heat gain to make the thermally comfortable and naturally ventilated. The remaining orientations between 45° Southeast to 135° Southwest; and between 225° southwest to 315° Northwest orientation is considered as an average building orientations for thermal comfort.

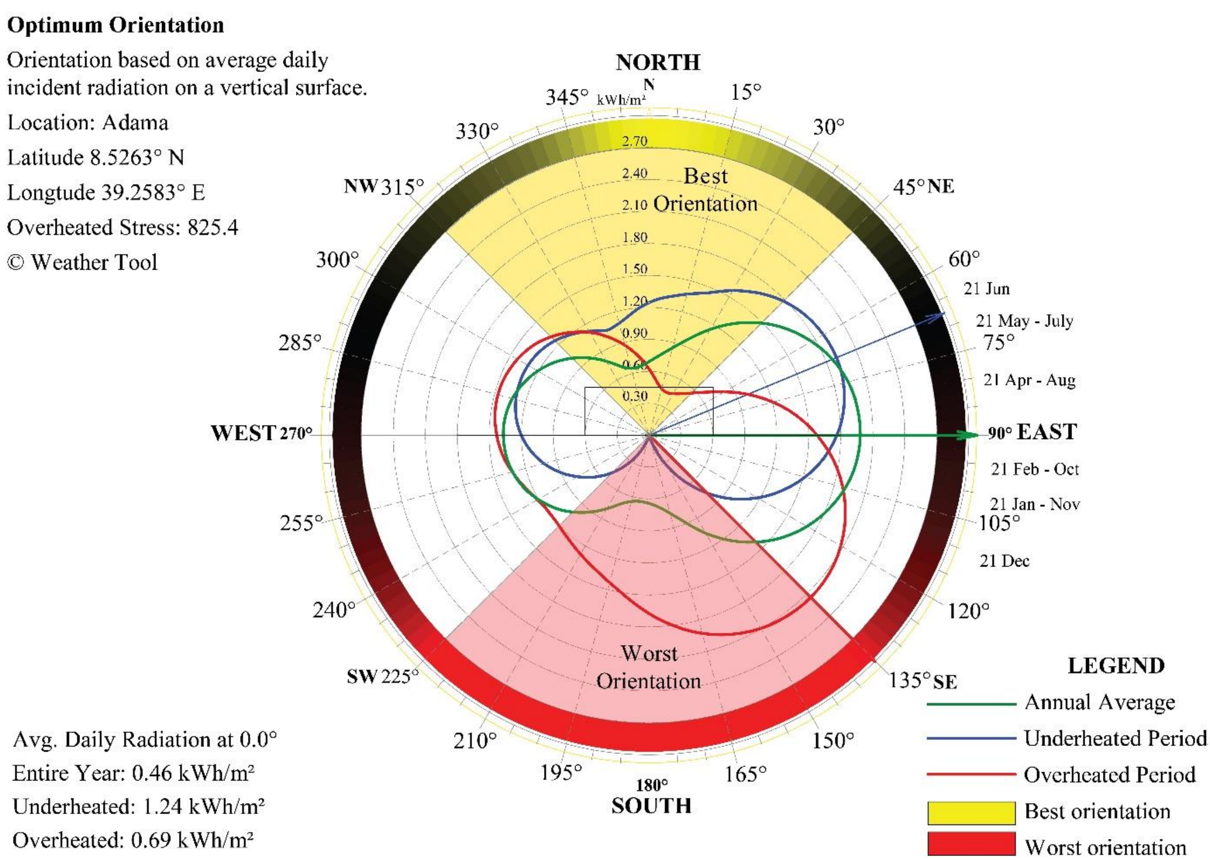


Figure 4:17 Optimum Orientation in Adama city (Source: Autodesk Ecotect & Author)

4.15. Time plot table of Adama city

Time plot table is a data from climate consultant simulation software. It is used to know the thermal environmental characteristics of the study area on different hours, days and months of the year. It uses three color representation to illustrate the cold, comfortable, and hottest hour of the day with their respective months. Since the human thermal comfort is primarily defined by dry bulb temperature and relative humidity, there are also different sources that uses different definitions. These time plot table uses the California Energy Code Comfort Model, 2013 standard.

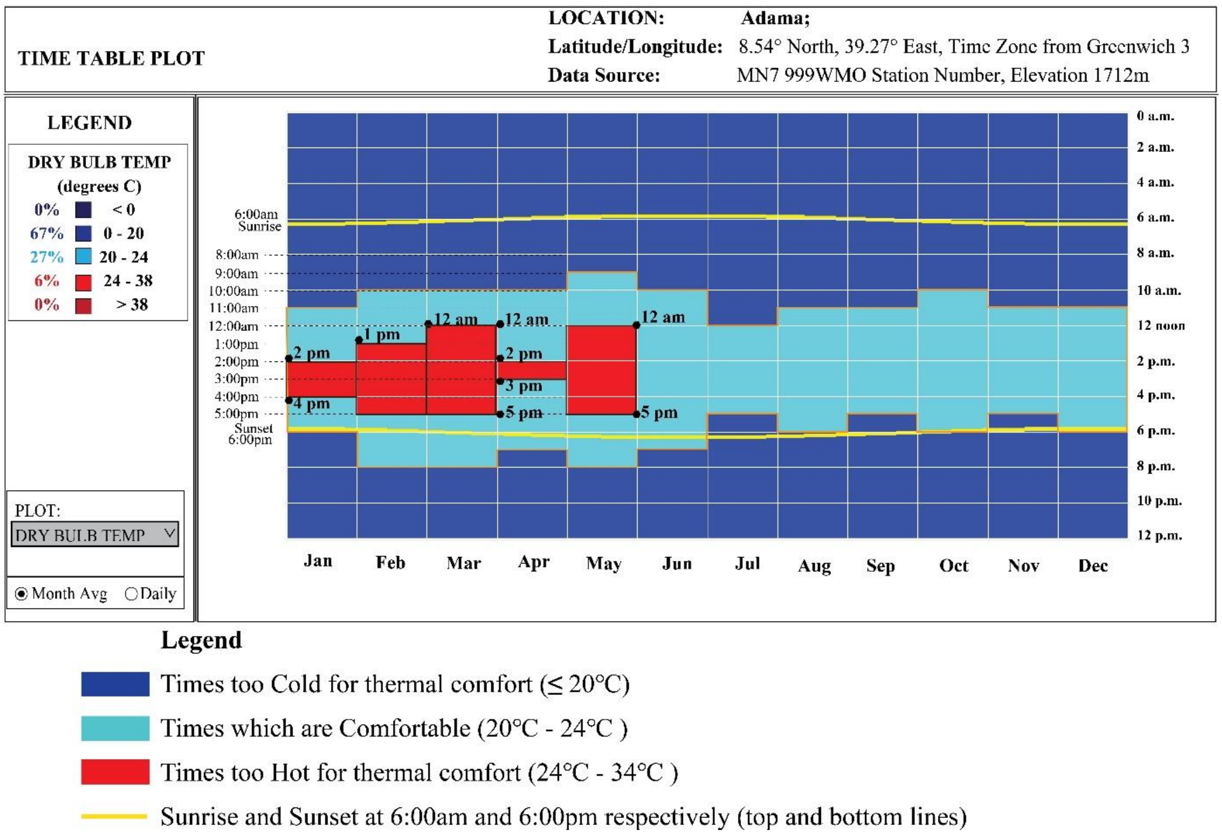


Figure 4:18 Time plot table showing the hottest, comfortable, and cold hours and months of Adama city (Source: Climate Consultant)

As tried to illustrate on Figure 4:18 above; the hottest months and the overheated hours are starting from January to May between the hours of 12:00am to 5:00pm. This means; on the month of January, the overheated hours are between 2:00pm to 4:00pm, on February between 1:00pm to 5:00pm, on march between 12:00am to 5:00pm, on April between 2:00pm to 3:00pm, and on the month of May the overheated hours are between 12:00am and 5:00pm. This result shows that, during these hours the indoor temperature of the classroom buildings become very hot. This in turn affects the thermal comfort of the indoor environment and also the students' performance on their activity.

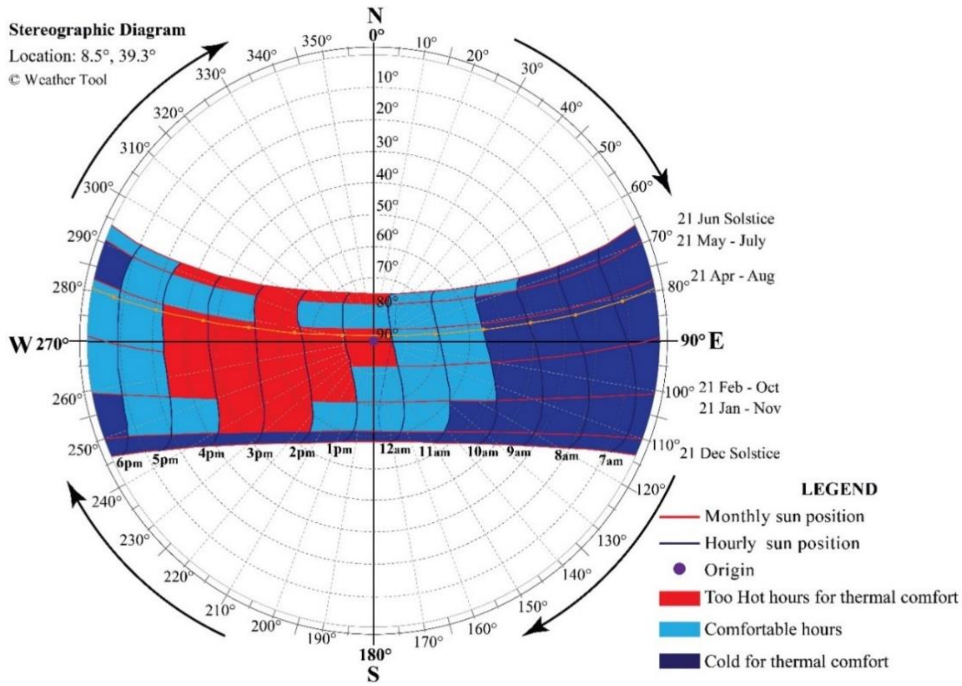


Figure 4:19 Stereographic diagram showing the overheated, comfortable and cold months and hours of Adama city. (Source: Autodesk Ecotect, sunearthtool.com, and Author)

4.16. South facing classroom building's roof eave overhang and wing-wall depth calculation

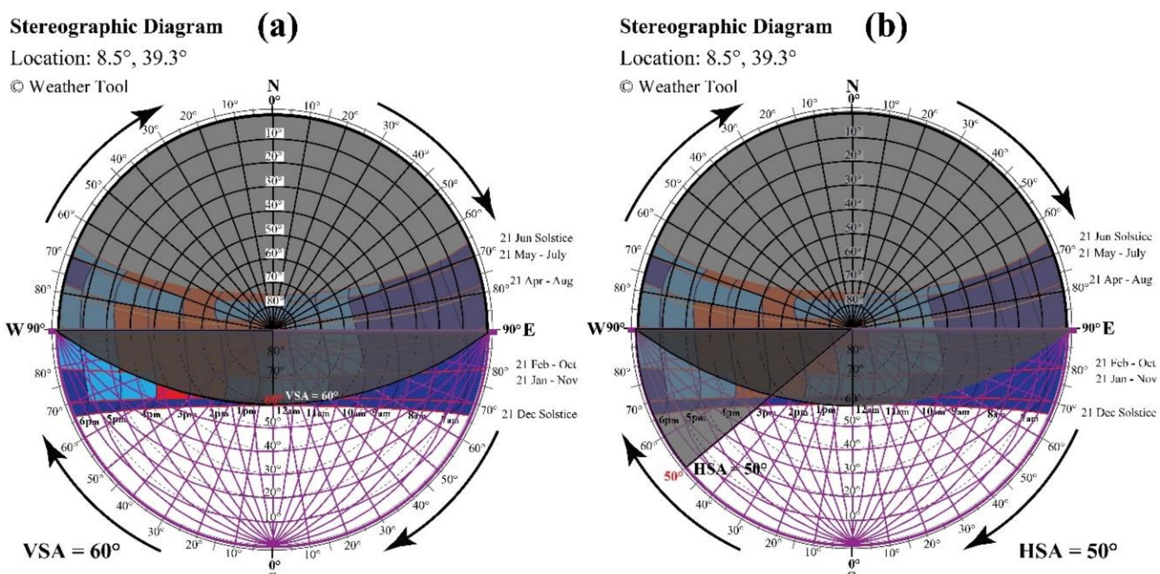


Figure 4:20 South orientation Vertical Shadow Angle (VSA) and Horizontal shadow angle (HSA)

As shown on Figure 4:20 above, a roof eave overhand at a cut-off angle of 60 degrees will result a complete shade from direct solar heat gain to the classroom buildings that face towards the south axis.

Roof eave overhang Depth = Height / tan (VSA)

⇨ $\frac{2m}{\tan(60°)}$, since tan (60°) is 1.75;

⇨ 2m / 1.75

⇨ 1.1 m

Wing-wall depth = Width of opening / tan (HSA)

⇨ 1.2m / tan (50°), since tan (50°) is 1.2;

⇨ 1.2m / 1.2

⇨ 1m

The result shows that, the roof eave overhang depth that is used to block the direct solar penetration to the classrooms oriented towards the south axis is 1.1 meter; and the depth of the wing wall that is used to block the direct solar heat gain and at the same time used to direct the incoming wind to inter into the classrooms is 1 meter.

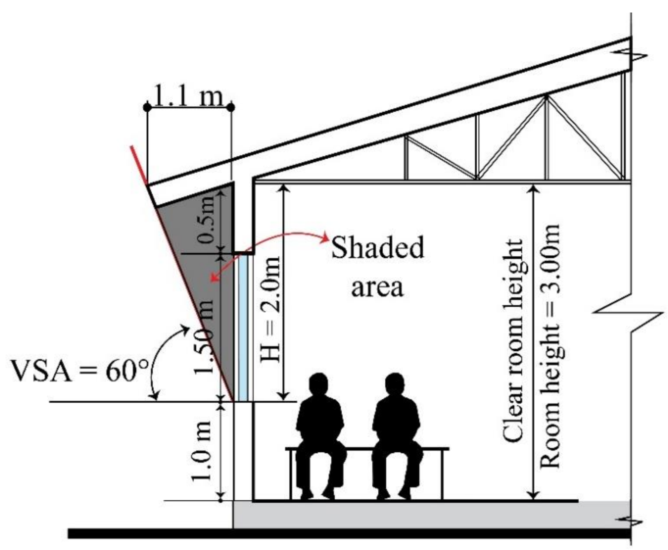


Figure 4:21 South orientation roof eave overhang depth

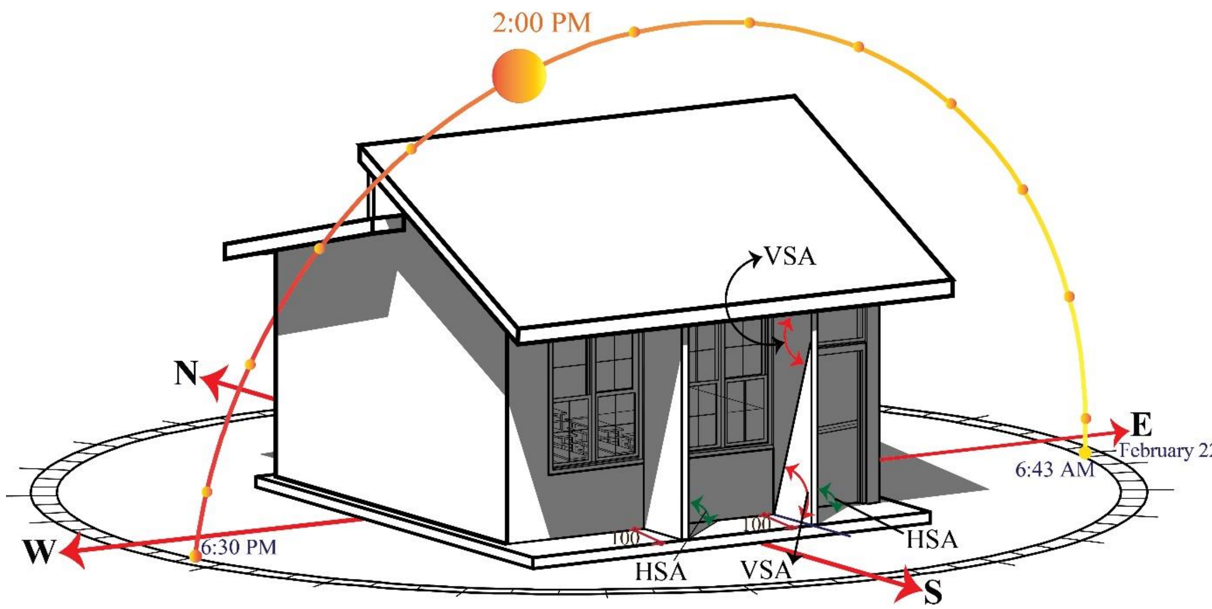


Figure 4:22 South oriented classroom building shaded with roof eave overhang and wing wall

4.17. Southwest facing classroom building's roof eave overhang and wing-wall depth calculation

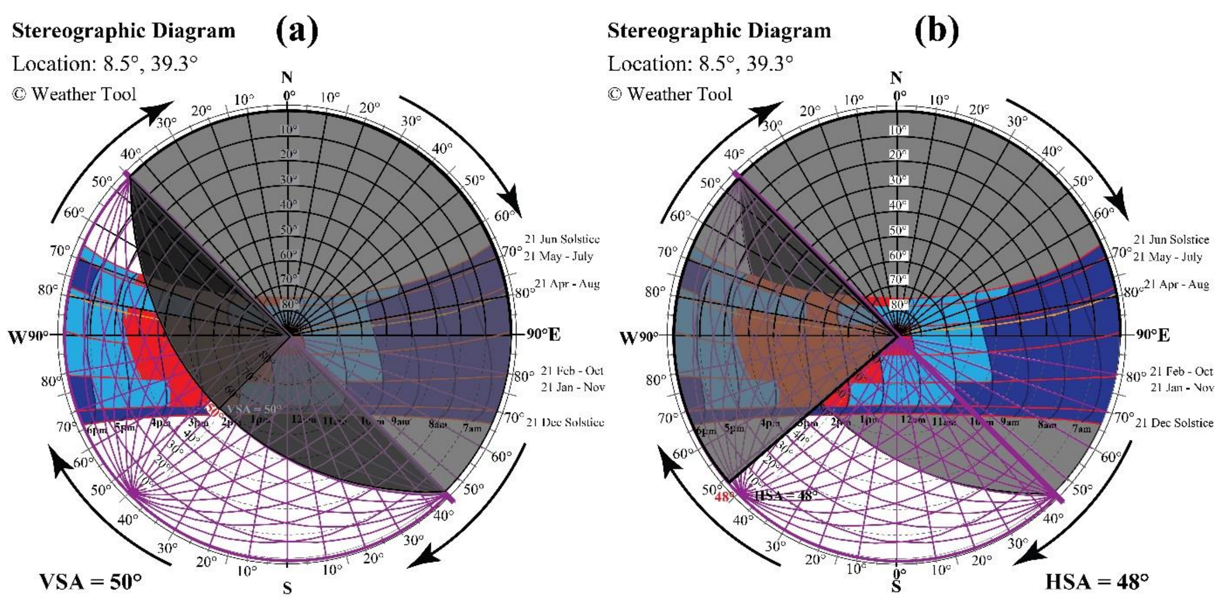


Figure 4:23 Southwest orientation VSA and HSA

As shown on Figure 4:23 above, a roof eave overhand at a cut-off angle of 50 degrees will result a complete shade from direct solar heat gain to the classroom buildings that face towards the southwest axis.

Roof eave overhang Depth = Height above windows sill / tan (VSA)

- ⇨ $\frac{2\text{m}}{\tan(50°)}$, since tan (50°) is 1.2;
- ⇨ 2m / 1.2
- ⇨ **1.6 m**

Wing-wall depth = Width of opening / tan (HSA)

- ⇨ 1.2m / tan (48°), since tan (48°) is 1.11;
- ⇨ 1.2m / 1.11
- ⇨ 1.08m

The result shows that, the roof eave overhang depth that is used to block the direct solar penetration to the classrooms oriented towards the southwest axis is 1.6 meter; and the depth of the wing wall that is used to block the direct solar heat gain and at the same time used to direct the incoming wind to inter into the classrooms is 1.11 meter.

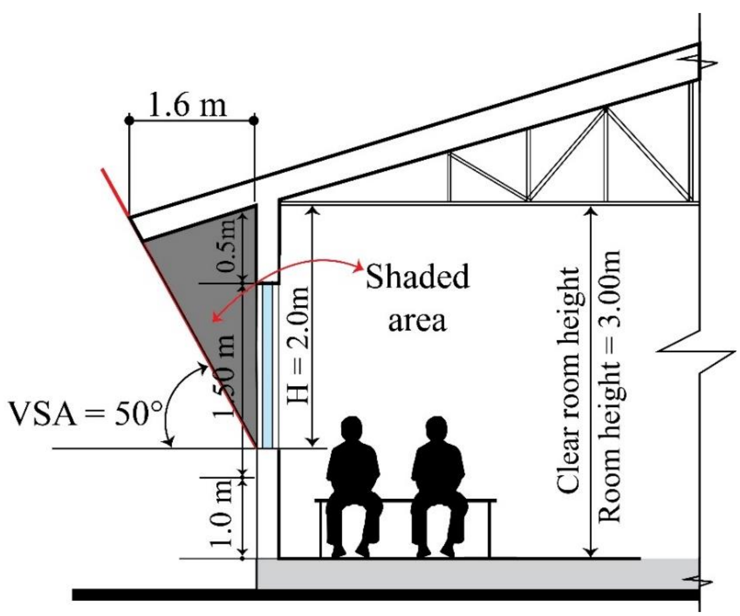


Figure 4:24 Southwest orientation roof eave overhang depth

The result of the required roof eave overhang depth to minimize or fully block the direct solar heat penetration to the southeast oriented classroom buildings is 1.6 meters.

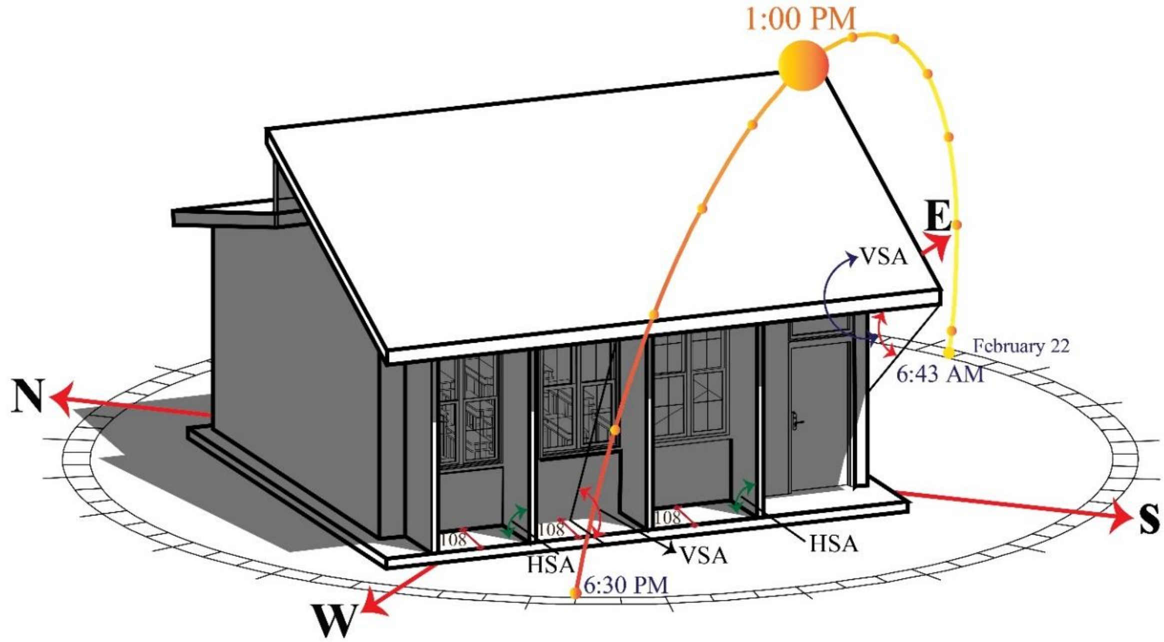


Figure 4:25 Southwest oriented classroom building shaded with roof eave overhang and wing wall

4.18. East and Southeast facing classroom building's roof eave overhang and wing-wall depth calculation

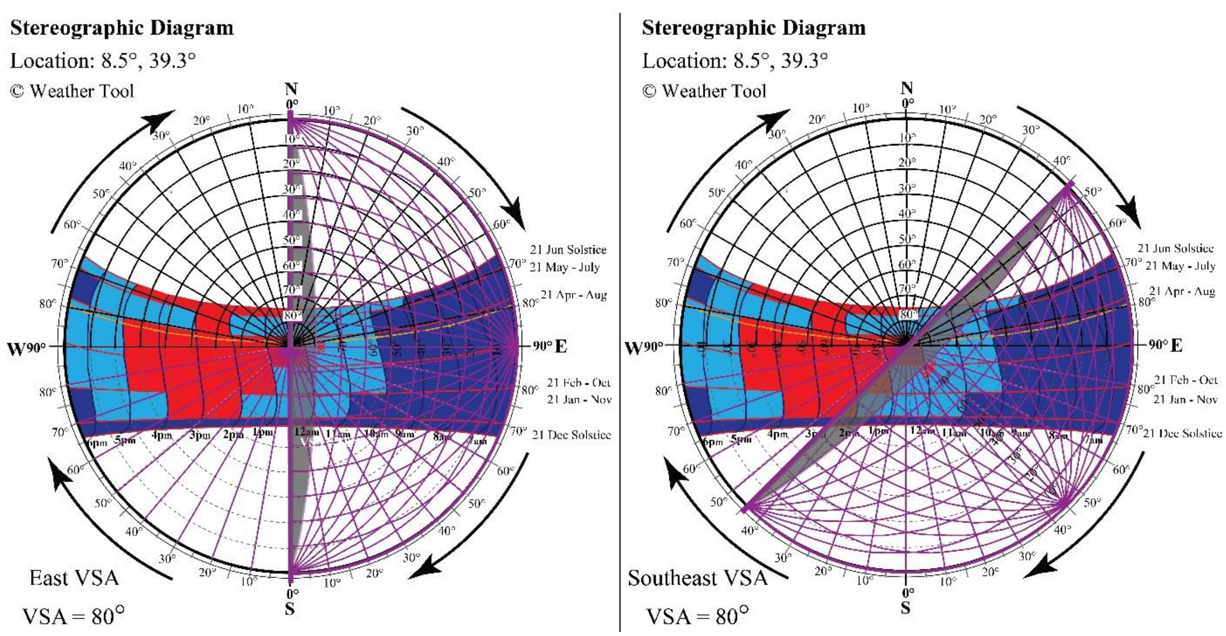


Figure 4:26 East and Southeast orientation Vertical Shadow Angles (VSA)

As shown on Figure 4:26 above, a roof eave overhand at a cut-off angle of 80 degrees will result a complete shade from direct solar heat gain to the classroom buildings that face towards the East and Southeast axis-oriented buildings.

Roof eave overhang Depth = Height above windows sill / tan (VSA)

⇨ $\frac{2m}{\tan(80°)}$, since tan (80°) is 5.6;

⇨ 2m / 5.6

⇨ **0.4 m**

This result shows that, the required roof eave overhang on the east and southeast axis-oriented buildings is 0.4m. This shows, there is no need to extend the roof eave overhang on east and southeast axis-oriented classrooms, since they are not affected by the direct solar heat penetration onto the classrooms.

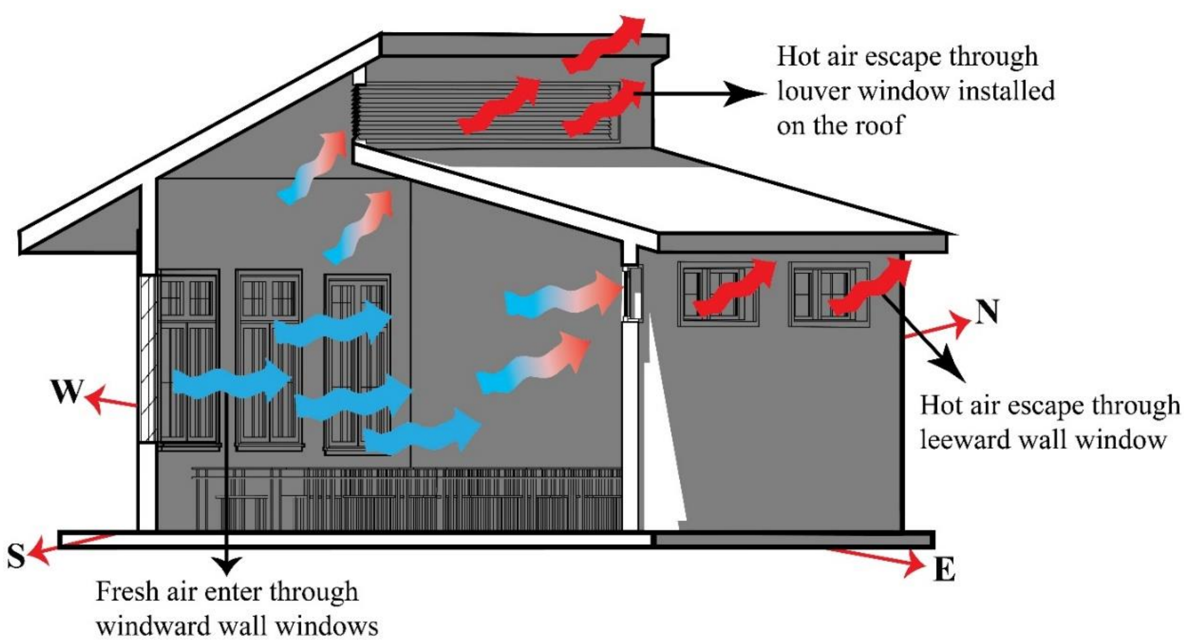


Figure 4:27 A passive design model of Southwest facing classrooms which is naturally ventilated and minimize direct solar gain (Source: Author; 2024)

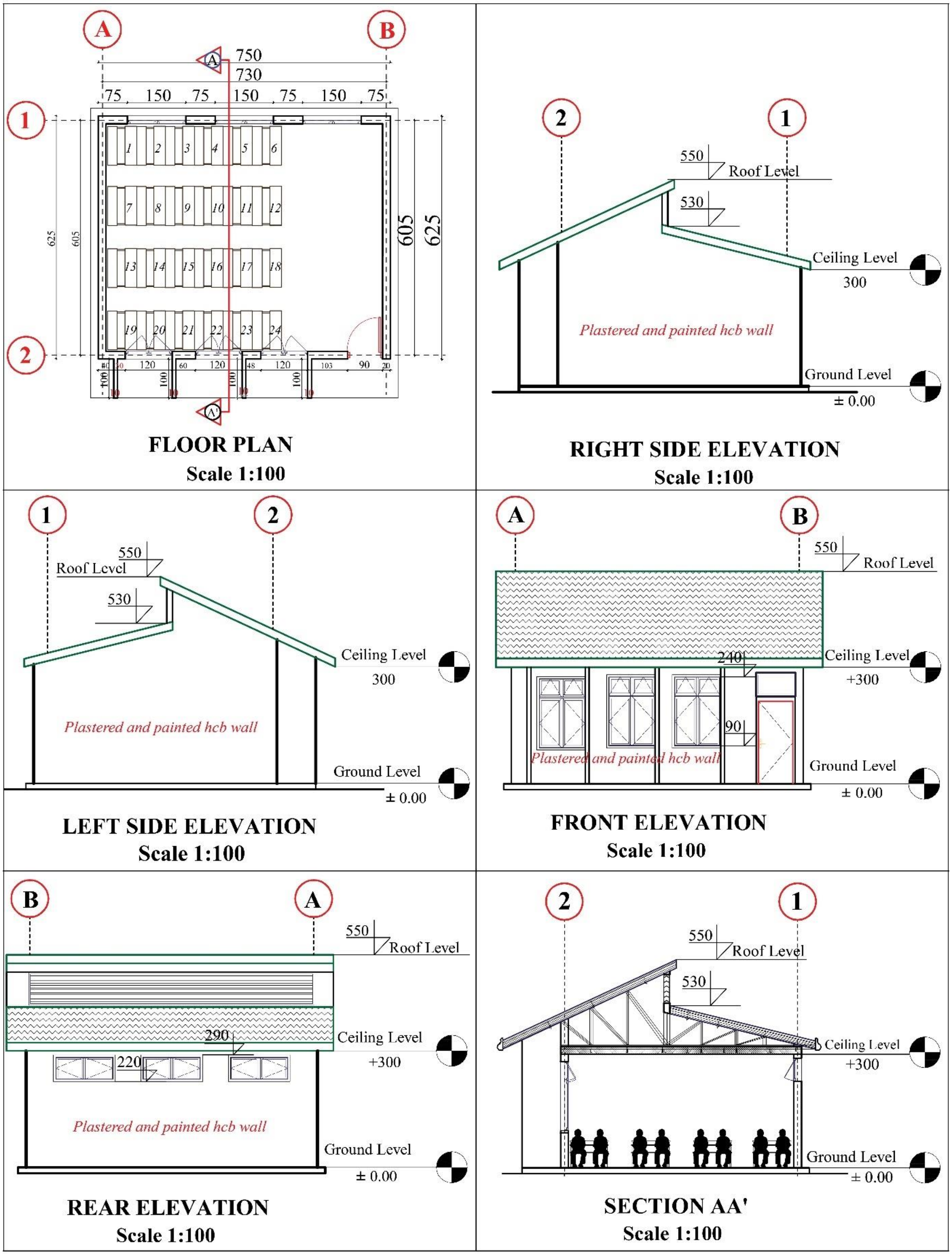


Figure 4:28 Proposed passive design model that minimizes the direct solar penetration and maximize natural ventilation

4.19. CFD Simulation of Southwest facing classrooms

As shown on Figure 4:29, the classroom building facing towards southwest orientation, the incoming wind enters the room through the inlet openings installed on the windward wall and cool the room; and the hot air escapes through the openings on the leeward wall and louvers installed on the roof top. This helps moderating the indoor air temperature naturally and reduce the cooling load.

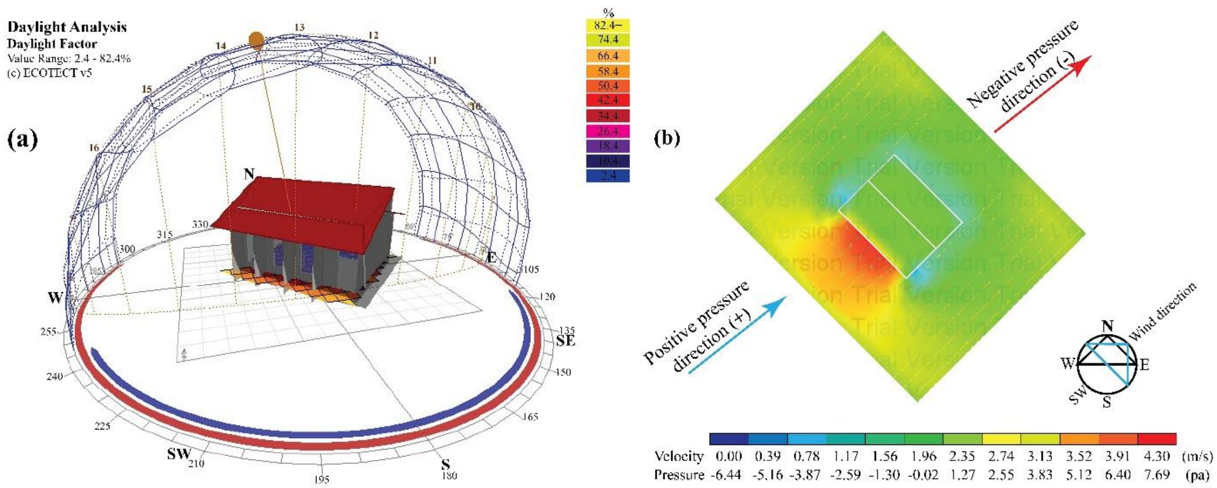


Figure 4:29 (a) Daylight access of southwest facing classrooms through the warm hours and (b) Internal and Exterior CFD simulation of southwest facing classroom

Figure 4:29 (a) and (b) shows the daylight access to the southwest facing classrooms and both the internal and external computational fluid dynamics simulation result of southwest facing rooms respectively. The CFD simulation result shows both the positive pressure zone and negative pressure zone of the classroom building facing southwest axis. As shown on the figure above, since the classroom building was oriented towards southwest direction in which the afternoon harsh sun directly enters the room, the roof eave overhang and wing walls blocks the solar penetration to the room; and at the same time the wing wall directs the incoming wind from 90° to southwest axis to enter the classrooms and cool the interior space to create a comfortable indoor environment for the students.

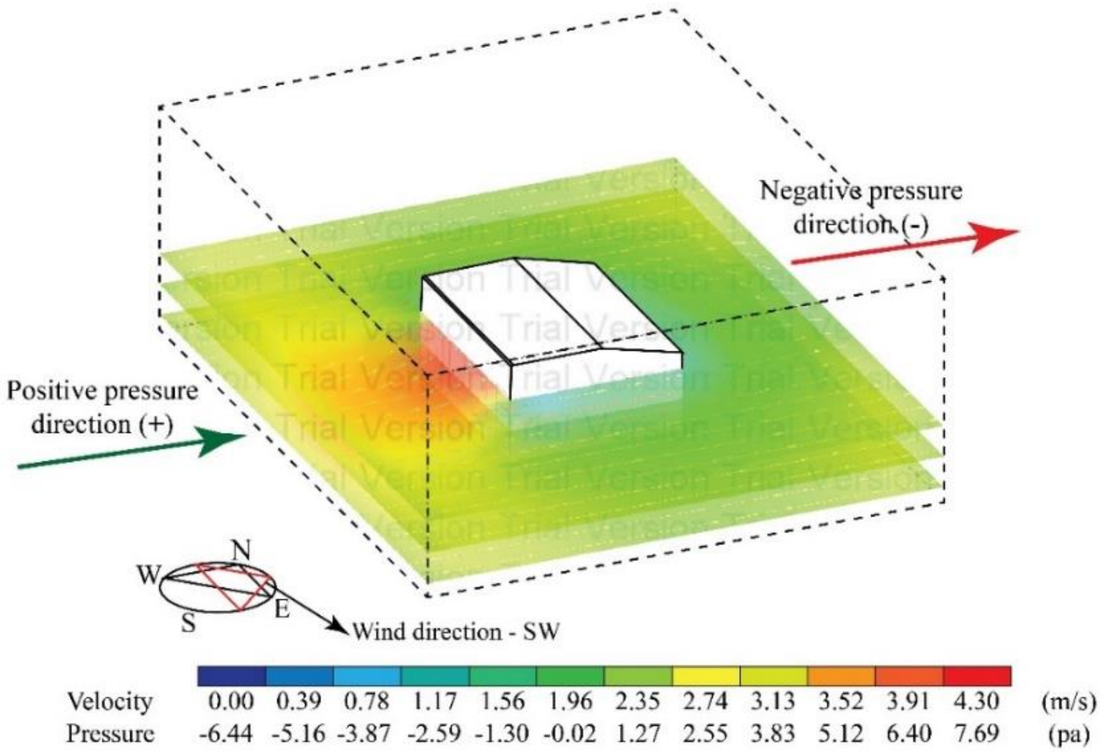


Figure 4:30 External Computational Fluid Dynamics (CFD) simulation of SW facing classroom

4.20. CFD Simulation of South facing classrooms

On the other hand, Figure 4:31 (a) and (b) below shows the daylight access to the south facing classrooms and; the internal and external computational fluid dynamics simulation result of south facing rooms respectively. The CFD simulation result shows both the positive pressure zone and negative pressure zone of the classroom building facing south axis. As shown on the figure, the classroom building was oriented towards south direction. Classrooms oriented to this axis are susceptible to the harsh sun. So, the roof eave overhang and wing walls blocks the solar penetration to the room; and at the same time the wing wall directs the incoming wind from 45° of southwest axis to enter the classrooms and cool the interior space to create a comfortable indoor environment for the students.

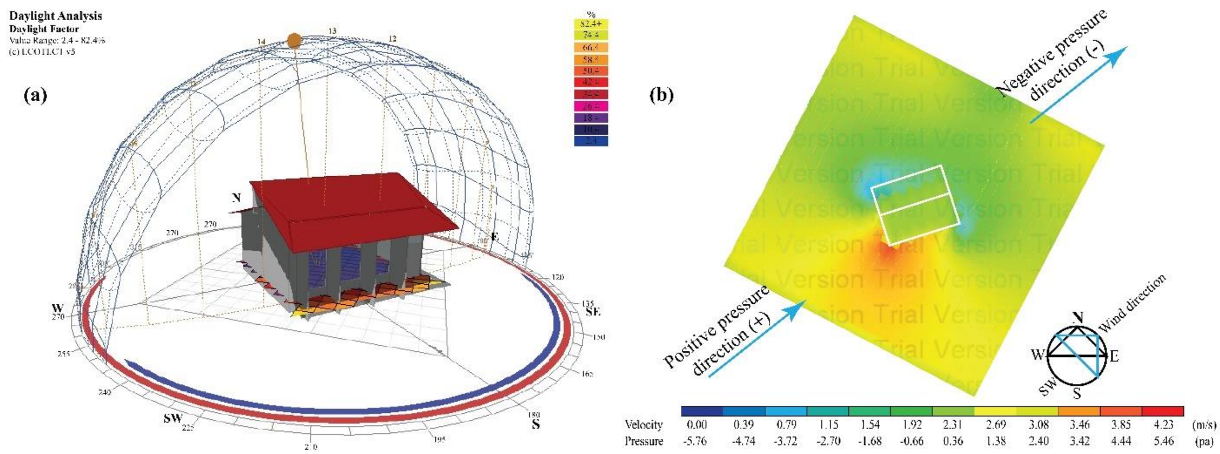


Figure 4:31 (a) Daylight access of south facing classrooms and (b) Internal and Exterior CFD simulation of south facing classroom

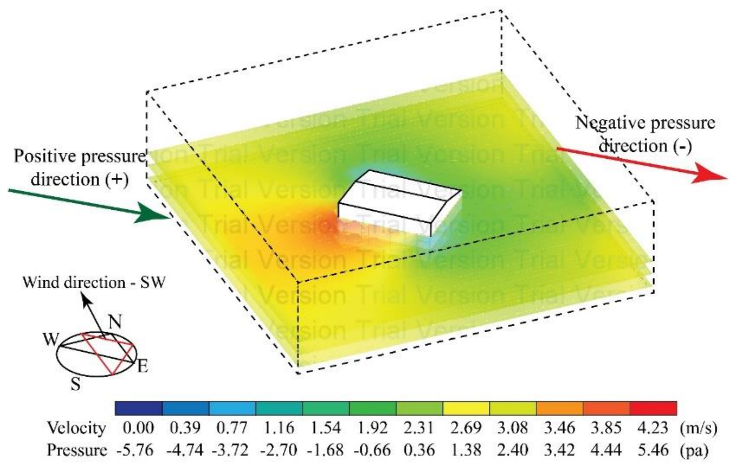


Figure 4:32 External Computational Fluid Dynamics (CFD) simulation of South facing classroom

4.21. CFD Simulation of North facing classrooms

On the other hand, Figure 4:33 (a) and (b) below shows the daylight access to the north facing classrooms and; the internal and external computational fluid dynamics simulation result of north facing rooms respectively. The CFD simulation result shows both the positive pressure zone and negative pressure zone of the classroom building facing north axis. As shown on the figure, the classroom building was oriented towards north direction. Classrooms oriented to this axis are good in terms of good indoor temperature and lack of direct sun penetration during the day hour. Even if there is no direct sun penetration, the wing wall installed on the exterior of the classroom facing towards the north axis, it increases the level of wind that coming from the northeast direction especially on the months of September to May as shown on the wind rose diagram of Adama city. So that, the wing wall directs the incoming wind from 45° of northeast axis to enter the classrooms and cool the interior space to create a comfortable indoor environment for the students.

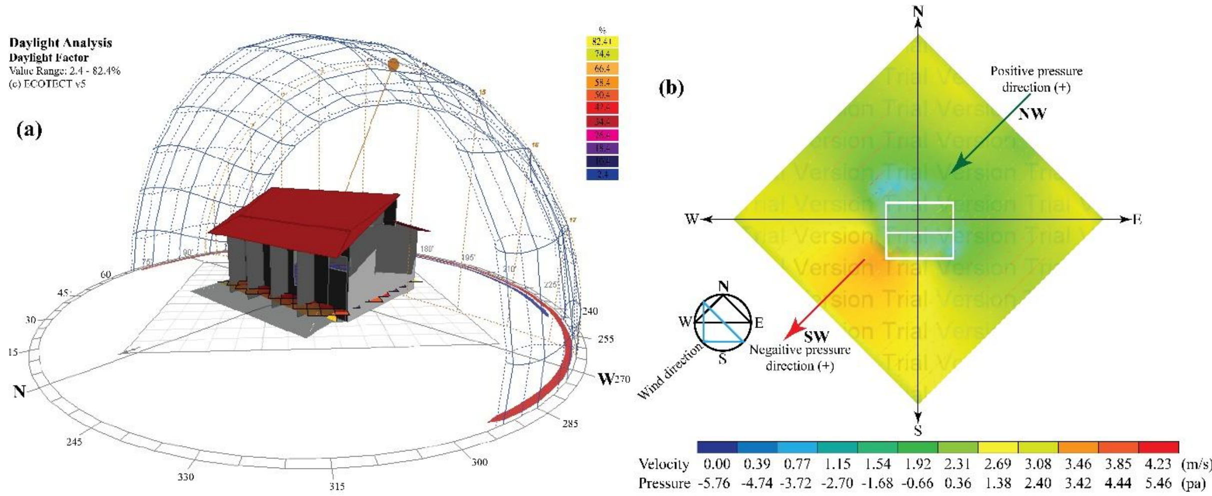


Figure 4:33 (a) Daylight access of south facing classrooms and (b) Internal and Exterior CFD simulation of North facing classroom

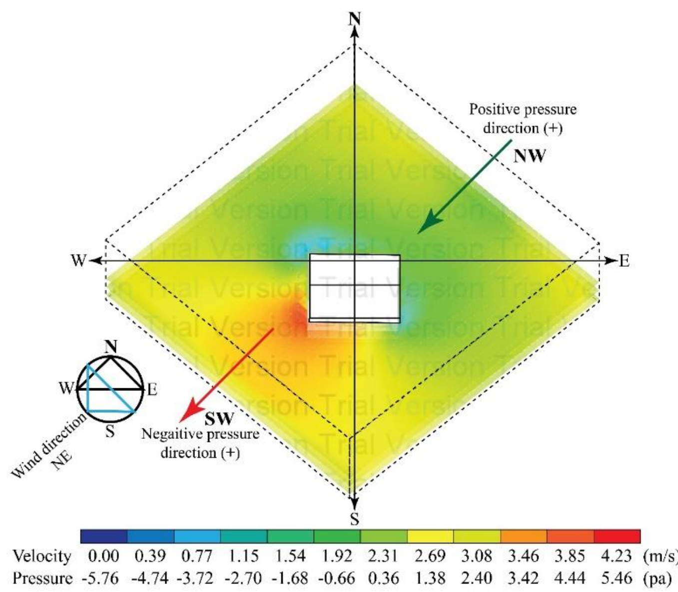


Figure 4:34 External Computational Fluid Dynamics (CFD) simulation of North facing classroom

4.22. CFD Simulation of Southeast facing classrooms

On the other hand, Figure 4:35 (a) and (b) below shows the daylight access to the southeast facing classrooms and; the internal and external computational fluid dynamics simulation result of southeast facing rooms respectively. The CFD simulation result shows both the positive pressure zone and negative pressure zone of the classroom building facing north axis. As shown on the figure, the classroom building was oriented towards southeast direction. Classrooms oriented to this axis are good in terms of good indoor temperature and lack of direct sun penetration during the day hour. Even if there is no direct sun penetration, the wing wall installed on the exterior of the classroom facing towards the north axis, it increases the level of wind that coming from the northeast direction especially on the months of September to May as shown on the wind rose diagram of Adama city. So that, the wing wall directs the incoming wind from 45° of south and southwest axis to enter the classrooms and cool the interior space to create a comfortable indoor environment for the students.

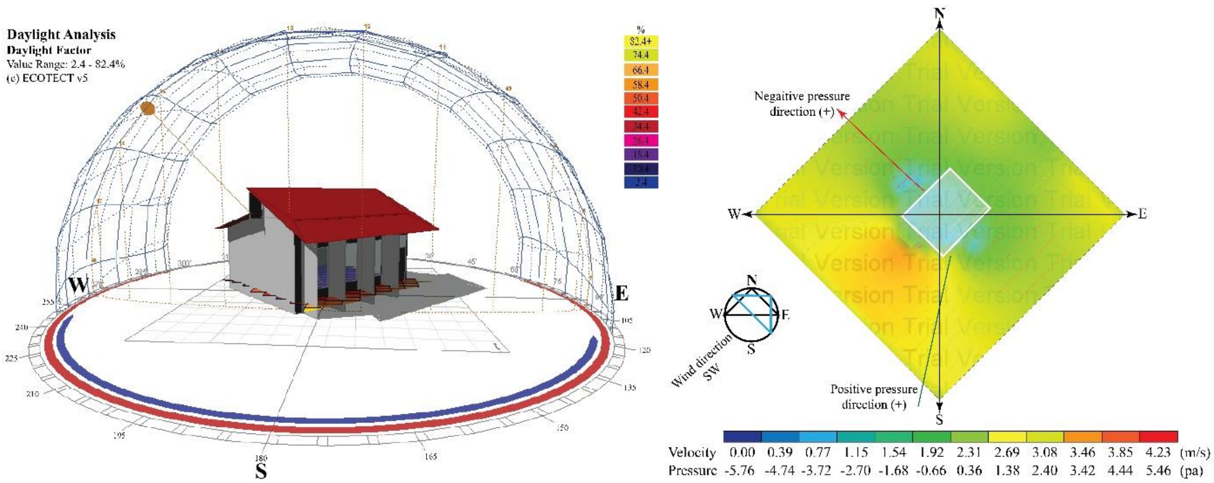


Figure 4:35 (a) Daylight access of southeast facing classrooms and (b) Internal and Exterior CFD simulation of Southeast facing classroom

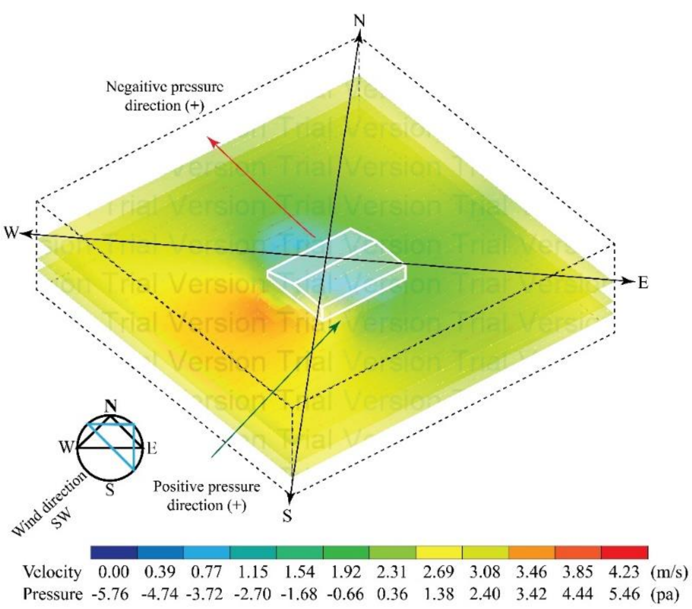


Figure 4:36 External Computational Fluid Dynamics (CFD) simulation of Southeast facing classroom

4.23. Indoor daylighting and temperature comparison of existing and proposed classroom design

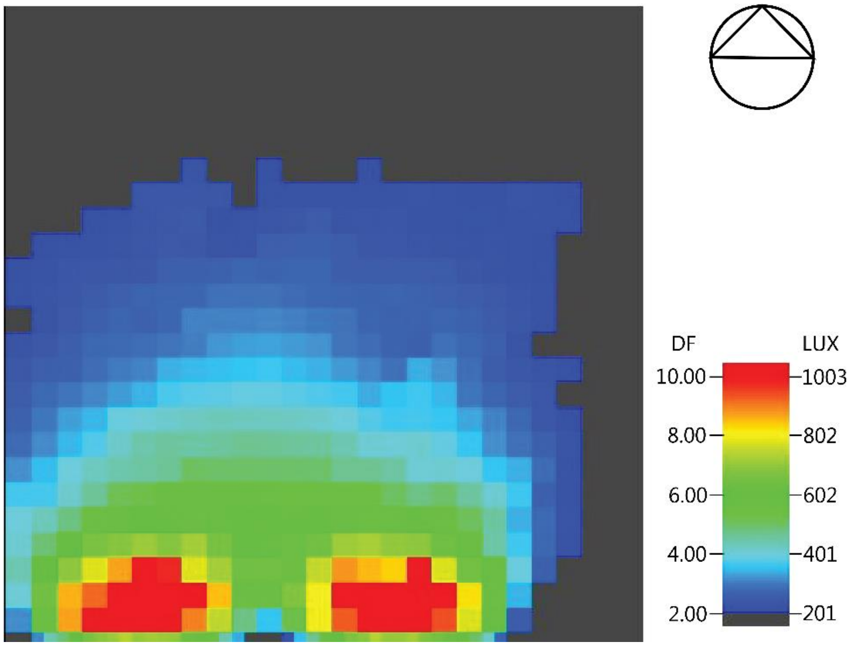


Figure 4:37 Indoor daylighting of existing classroom building (Source: Design builder simulation)

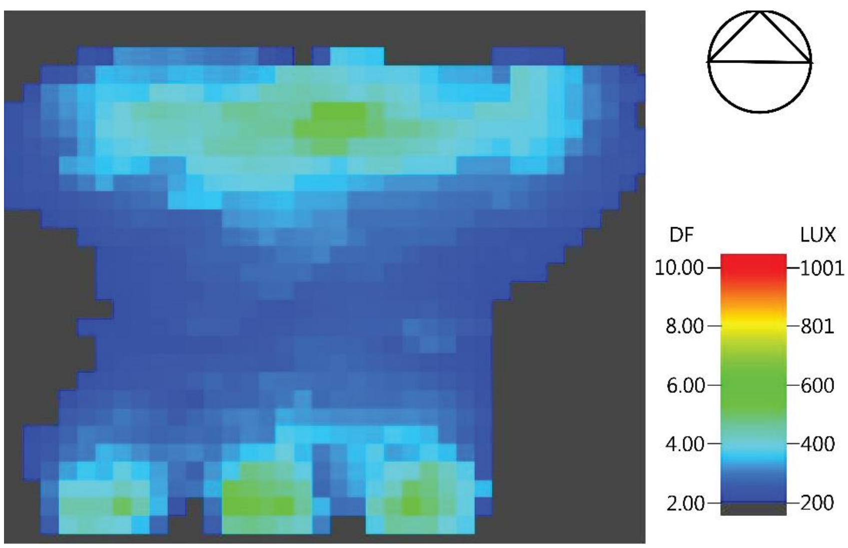


Figure 4:38 Indoor daylighting of Proposed classroom building (Source: Design builder simulation)

Table 4:5 temperature comparison of existing and proposed classroom design (Source: Autodesk Ecotect simulation)

Existing Classroom Building				Proposed Classroom Building		
Hr.	Inside (°C)	Outside (°C)	Temp.Dif (°C)	Inside (°C)	Outside (°C)	Temp.Dif. (°C)
0	22.7	18.3	4.4	20	18.3	1.7
1	22	17	5	21	17	4
2	21.3	15.6	5.7	19	15.6	3.4
3	20.9	15	5.9	18.5	15	3.5
4	20.5	14.4	6.1	19	14.4	4.6
5	20.2	14	6.2	18.5	14	4.5
6	20	14.1	5.9	18	14.1	3.9
7	21	15.9	5.1	19	15.9	3.1
8	22.2	18.5	3.7	20	18.5	1.5
9	**25.1**	21.2	**3.9**	**23**	21.2	**1.3**
10	**27.9**	23.7	**4.2**	**25**	23.7	**1.3**
11	**30.4**	25.8	**4.6**	**26.5**	25.8	**0.7**
12	**32.4**	27.5	**4.9**	**27.5**	27.5	**0**
13	**33.3**	27	**4.6**	**27**	27	**0**
14	**33.1**	26	**3.7**	**27.5**	26	**1.5**
15	**31.9**	26	**2.4**	**25.5**	26	**0.5**
16	**30.2**	26	**1.3**	**25.5**	26	**0.5**
17	**27.8**	26	**0.2**	**26**	26	**0**
18	27	25.8	1.2	26.8	25.8	1
19	26.8	24.7	2.1	26.5	24.7	1.8
20	26.3	23.6	2.7	26	23.6	2.4
21	25.5	22.6	2.9	25.2	22.6	2.6
22	24.3	21.5	2.8	24.2	21.5	2.7
23	23.7	20.4	3.3	23.6	20.4	3.2

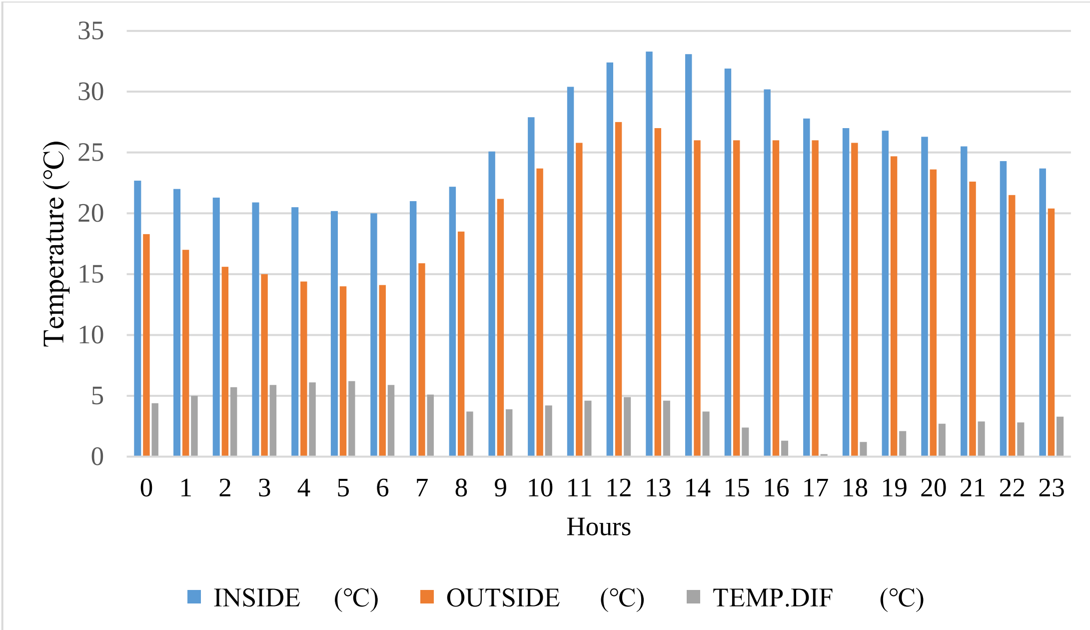


Chart 4:22 Indoor temperature, Outdoor temperature and temperature difference of existing classroom buildings (Source: Autodesk Ecotect and Author)

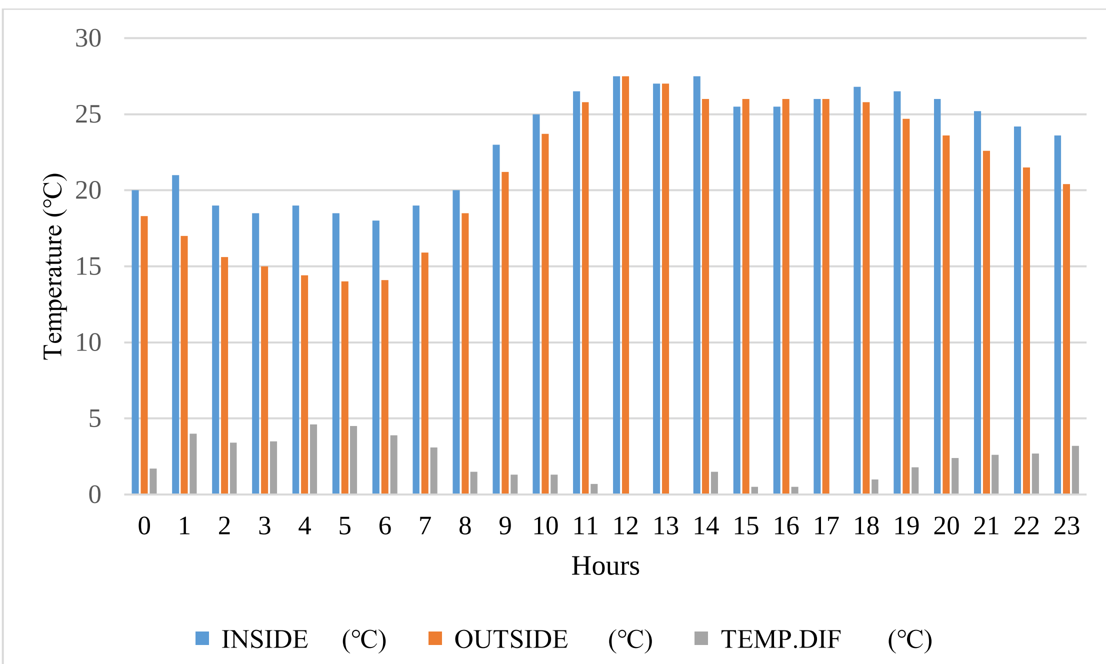


Chart 4:23 Indoor temperature, Outdoor temperature and temperature difference of proposed classroom buildings (Source: Autodesk Ecotect and Author)

The temperature data show on Table 4:5 above shows that, the installation of wingwall, design of roof eave overhang and installation of proper openings results the indoor temperature moderation on the building. As shown on the Chart 4:22 and Chart 4:23 above, the hourly temperature of the peak hottest day which is February 22 (based on a result from Autodesk Ecotect climate data simulation using Adama city climate data), it shows a significant change on the indoor temperature. The result shows, maximum and minimum indoor temperature of the existing classroom building on the selected day was 33.3 °C and 20°C respectively. But, after the proper passive design model, the indoor temperature of the classroom building on selected day was result a significant change and lowered to 27.5°C and 18°C for maximum and minimum temperature respectively.

4.24. Psychrometric Chart showing Comfort zone and naturally ventilated adaptive zone of classrooms

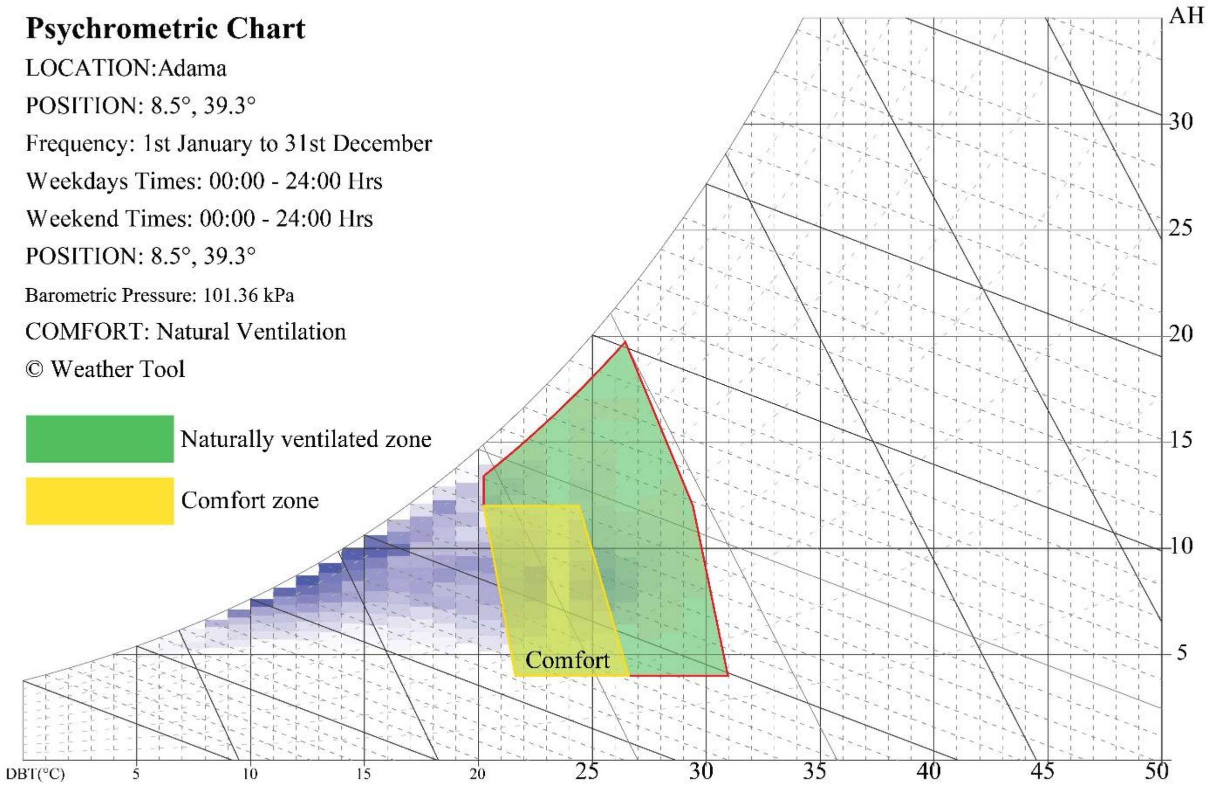


Figure 4:39 Psychrometric Chart of Comfort zone and naturally ventilated adaptive zone of classrooms (source: Autodesk Ecotect simulation and Author)

Figure 4:39 shows that, adapting passive design strategy that incorporates the use of wingwall, roof eave overhang and proper opening size and location for naturally ventilating the classrooms and creating a thermally comfortable indoor environment results a significant result. The thermal comfort level and the effect of natural ventilation on regulating the air temperature of the classrooms also shown on Figure 4:40 below.

4.25. Comfort before and after comparison of classrooms on passive solar cooling and natural ventilation

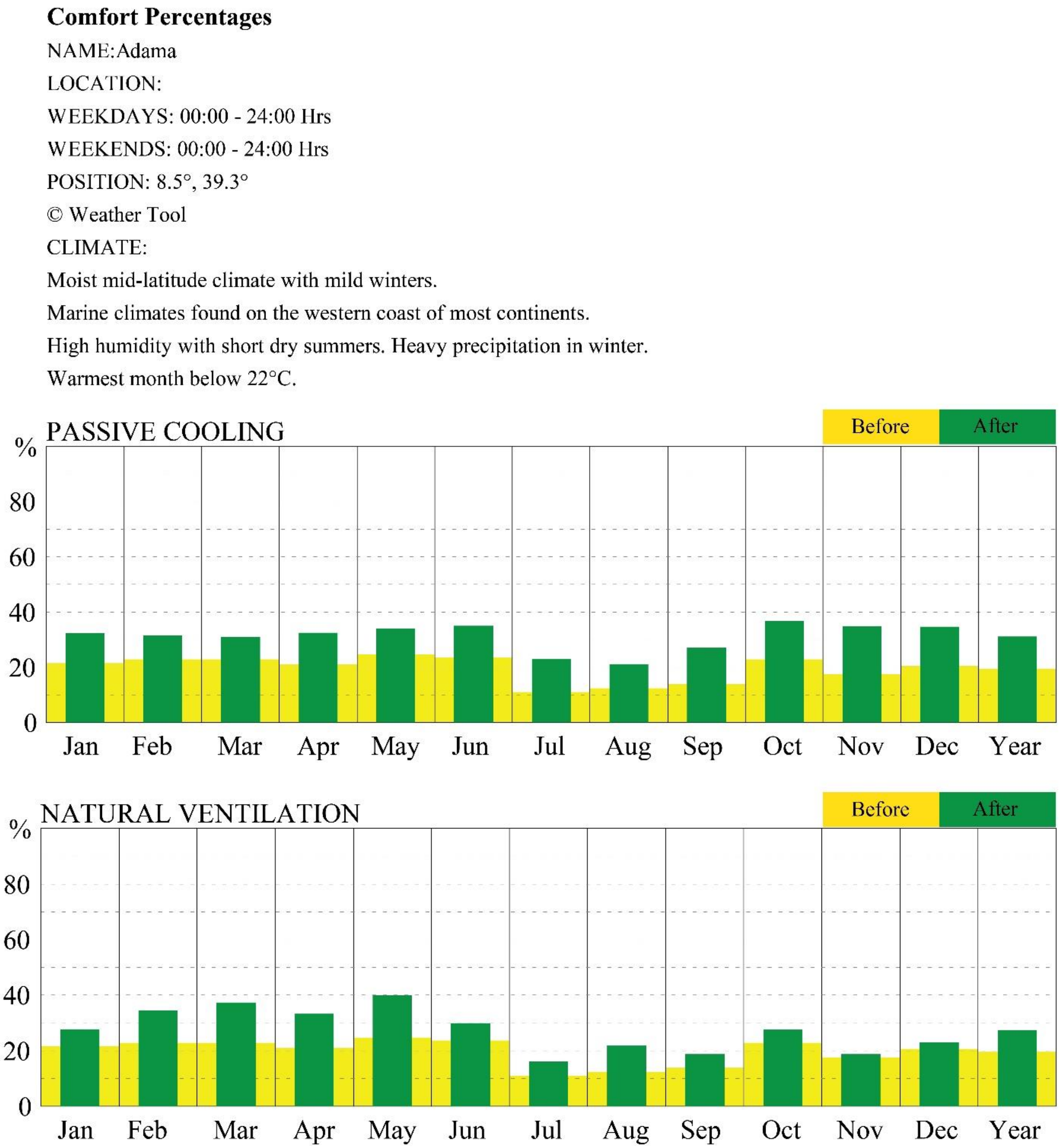


Figure 4:40 Comfort percentage comparison of before and after effect of natural ventilation and passive solar heating of classrooms (source: Autodesk Ecotect simulation)

4.26. Summary of Discussions

To get the existing thermal condition and level of natural ventilation of the selected classroom buildings, the students' response towards the indoor thermal environment of their school buildings, a total of 355 respondents were selected from a total of 12 purposively selected classroom buildings from four different schools. From the total respondents; 211 were male which are 59.4%, and the remaining 144 which accounts 40.6% were females. According to studies, females are less satisfied with the thermal environment than male, and feel both cold and hot more often that male students. The age of selected respondents ranges from 15 - to - 23 years old. And the maximum percentage were students between the age of 18 - 20 years old. The activity type and level of students for the maximum students were sitting and learning for the maximum hours of the day and this covers a total of 91%. The activity type and level have a direct effect on the thermal condition of the classrooms, since activities takes place fast will increase the metabolic rate of the students and in turn it increases the body temperature and the temperature of the classroom. But for the selected study area, the activities of the students are a sedentary activity and a normal level of metabolic rate according to ASHRAE standards. From the selected classroom building, 3 blocks oriented towards the southeast axis at an angle of 25°, 3 oriented towards the southwest axis at an angle of 335° Northwest, 2 oriented to southwest axis at an angle of 340° northwest, and the remaining buildings oriented towards the south axis with an angle of 90° east. These buildings highly susceptible to the afternoon harsh sun and the indoor temperature is relatively high especially during the day hour starting from 11:00am to 5:00pm. According to the thermal preference vote of the students, a total of 50.3% of the respondents feel warm and hot during the day between 11:00am – 1:00pm; 73.3% feel warm and hot between 1:00pm – 3:00pm, and 49.3% feel the same between 3:00pm-5:00pm. The remaining students range between comfortably cool to comfortably warm temperature. These findings show that; the existing indoor temperature creates a discomfortable learning environment that affects the student's health and performance. From the measurement on the environmental variables on the site, the indoor air temperature of southwest oriented buildings shows that the maximum and minimum temperature was 32℃ and 24℃ respectively which is measured between 1:00pm -3:00pm and 9:00am-11:00am respectively. On the other hand, the indoor air temperature of southeast oriented buildings shows that the maximum and minimum temperature was 32℃ and 25℃ respectively which is measured between 1:00pm -3:00pm and

9:00am-11:00am respectively. The indoor air temperature of south facing building measured 32.5℃ at 1:00pm-3:00pm and 28℃ at 3:00am-5:00pm for maximum and minimum temperature respectively. These findings show that, the indoor air temperature is very high and it affects the students comfort especially during the afternoon starting from 11:00pm. On the other hand, the existing classroom building design lacks a any technique to naturally ventilate the building by using the wind direction of the site. The opening types installed on the building didn't allow more air flow inside the room. the openable windows only installed on one direction, and the opposite wall windows are fixed and only used for natural light. This affects the natural ventilation level of the classroom. As shown on Figure 4:7; based on the simulation result and field measurement, the wind direction on the site is mainly from Southwest and Northeast directions. For buildings face to the incoming wind direction at an angle of 90°, the minimum windows area required on the windward face wall for effective natural ventilation of a single classroom will be 5 m^2. This is equivalent to 10.65% of WWR of the building. For buildings that face to the incoming wind direction at an angle of 45°, the minimum windows area required on the windward face wall for effective natural ventilation will be 10 m^2. This is equivalent to 21.3% of WWR of the building. Based on the results, the application of wingwall and increasing the roof eave overhang techniques results a great performance on moderating the indoor temperature, minimize the direct solar gain of south, southeast and southwest oriented buildings. The proposed passive design model for south oriented buildings with windows of 2m height and 1.2m width with a VSA of 60° results 1.1m of roof eave overhang and HSA of 50° results a wingwall having a depth of 1m results good performance in blocking the direct solar radiation onto the classrooms and result an effective natural ventilation. For buildings face to southwest direction using similar opening sizes, a VSA of 60° result 1.6m of roof eave overhang depth and an HSA of 48° results a wingwall having a depth of 1.08m effectively blocks the direct solar gain and naturally ventilate the building. Buildings oriented into east and southeast direction do not need much roof eave overhand to block the direct solar penetration; since HSA of 80° and also VSA of 80° results a minimum roof overhang of 0.4m is enough to block the incoming solar radiation, but a wingwall having 1m depth is used for effectively direct the incoming wind from the east and southeast direction during all months.

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATION

5.1. Conclusion

In this study, Orientation based adaptive model of naturally ventilated classroom that enhance thermal comfort was examined. In doing so, the study was conducted using both the objective and subjective evaluation approaches on both personal and environmental variables that have a direct influence on thermal perception of building occupants. The subjective evaluation includes structured questionnaires, interviews, observations; and environmental variables including air temperature, air velocity, relative humidity were measured for three consecutive weeks (15 working days) in the warmest months of March and April. The study adapts ASHRAE (Standard 1992) and ASHRAE 55's 7-point thermal sensation scales. The questionnaire was distributed on the selected schools and classrooms based on their percentage on the number of classroom blocks, classroom orientation, and number of students per classroom. 355 students/respondents were participated on this study; and 12 classroom building blocks each have 4 classrooms were used for data analysis and the selected classroom building layouts with different orientation were used for computer software simulations. As the result from subjective evaluation, objective measurements and computer simulation shows the thermal environment of classrooms have uncomfortable, discomfortable and experiences a warmer indoor climate condition. Classroom buildings face towards the north, northeast, and northwest orientation have a minimum to no effect on their thermal condition since they are oriented towards the optimum orientation and they didn't get the direct solar penetration in their indoor spaces. But classrooms face the south, southeast and southwest orientation are susceptible to the direct solar heat gain during the hottest periods of the day especially those buildings face the south and southwest direction. These buildings do not use any technique to moderate the increase in air temperature of the classrooms. The size of classrooms, the roof design, their window to wall ratio to naturally ventilate the room, and the orientation of the classrooms highly affect the thermal environment of the buildings comfort of the building users. There is an average of 60 students per $36m^2$ of classrooms which is equivalent to $0.6m^2$ per student. The roof overhand of all selected buildings is about 0.5m width, and it is unable to minimize the direct solar penetration to the rooms, and the openings installed on the buildings don't have proper size and orientation.

The new proposed classroom buildings are based on computer software simulation using Autodesk Ecotect for simulating the south and southwest oriented classroom buildings. The study uses the sun protractor of Adama city to get the overheated months and hours in each orientation and wind rose diagram of Adama city to get the wind direction and speed in each month. The study evaluates in detail the application of wingwall which used to direct the incoming wind to enter the room, increasing the roof eave overhang to minimize the direct solar penetration into the room spaces and adapting proper opening areas to allow the fresh air enter the room. The result shows that, the application of all these techniques results a great performance on moderating the indoor temperature, minimize the direct solar gain of south, southeast and southwest oriented buildings. The existing classroom designs and openings have a very low performance on students' thermal comfort; and new proposed passive design model for south oriented buildings with windows of 2meter height and 1.2 width with a VSA of 60° results 1.1 meter of roof eave overhang and HSA of 50° results a wingwall having a depth of 1-meter results good performance in blocking the solar radiation onto the classrooms effective natural ventilation during all months except the month of January; since in this month the wind direction is from north, northeast and east direction. For buildings face to southwest direction using similar opening sizes, a VSA of 60° result 1.6 meter of roof eave overhang depth and a HSA of 48° results a wingwall having a depth of 1.08 meter effectively blocks the direct solar gain and naturally ventilate the building by allowing the incoming air to enter the room and cool the interior spaces. Buildings oriented into east and southeast direction do not need much roof eave overhand to block the direct solar penetration; since HSA of 80° and also VSA of 80° results a minimum roof overhang of 0.4 meter, which is enough to block the incoming solar radiation on the selected months, but a wingwall having 1 meter depth is used for effectively direct the incoming wind from the east and southeast direction during all months. For building face the north axis, a wingwall having a depth of 1 meter will increase the amount of fresh air entry that coming from the northeast direction at an angle of 45°.

5.2. Recommendation

Based on the findings of the study and the result of the analysis, I recommend that to achieve a naturally ventilated, thermally comfortable and local climatic adaptable classroom design, the following strategies should be implemented well;

- Having a good understanding of the local environmental climatic factors including the sun path diagram and wind direction and speed is important. This will make us understand the months and times in which the building is susceptible to excessive solar heat. By considering this factor, it is possible to develop a passive design model that naturally ventilated and reduce the direct solar penetration onto the buildings.
- It is important to consider the location of the building site, building alignment, opening type and size, location of windows, function of the building, type of building occupants prior to design and construction.
- Wingwall plays a significant role on both minimizing the solar penetration and allows more fresh air to enter the room. It directs the incoming wind at an angle of 45° to enter and cool the room.
- Roof eave overhang minimizes the direct solar penetration to the classrooms. This technique plays a significant role in moderating the indoor air temperature of the building.
- Wind driven cross ventilation technique plays a significant role in creating a naturally ventilated, thermally comfortable classroom building that also minimizes the cooling load.
- Effects of building material properties, topography, health condition of building occupants are factors which affect the thermal environment of a building; and they need a future study by other researchers.
- As overall, to create a naturally ventilated building, incorporating roof eave overhang, wingwall, and proper user-controlled windows/opening area results a passive adaptable building model with better indoor thermally comfortable environment.

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APPENDIX - I

Questionary form for students

Date: ______/______/______ Time: _________

Researcher Name: Ayana Kabeta
Department of Architecture
MSc In Environmental Architecture
School of Civil Engineering & Architecture
Adama Science and Technology University

General description

Dear respondents the purpose of these questionnaires is to support Research on "**Evaluating orientation based adaptive model of naturally ventilated classrooms to enhance thermal comfort** on selected school buildings in Adama city. Your answer plays a great role in this research, please provide the required information on the following questions by marking (**x**). you can ask the data collector for any help regarding the questionnaire. All responses will be treated in strict confidentiality and will be used for academic research only. Thank you for your priceless cooperation in advance.

(To be filled by the data collector)

- Survey Number: _______ Classroom no.& Building Orientation ________________________
- Sky condition: ☐ Clear ☐ Mixed (Sun & Clouds) ☐ Overcast
- Approximate Outside Air Temperature (°C): _________
- Seasonal Condition: ☐ Winter ☐ Spring ☐ Summer ☐ Fall

Demographic Information (To be filled by the respondents)

Gender ______________ Age group ___________ Weight _________________

1. Sitting Location in classroom (Place an "X" in the approximate place where you most often sit)

2. Activity level inside the classrooms

☐ Sitting ☐ Standing ☐ Learning ☐ Taking exams

3. Equipment's inside the classroom

☐ Computer ☐ Ceiling fans ☐ Printer ☐ Lighting ☐ wooden side arm chair

4. Clothing (Specify the type of clothing you were wearing)

☐ Trousers, short-sleeve shirt, stockings ☐ Trousers, long-sleeve shirt, shoes

☐ Trousers, long-sleeve shirt plus suit jacket ☐ Trousers, long-sleeve shirt, vest, T-shirt, and shoes

☐ Knee-length skirt, short-sleeve shirt, (sandals) ☐ Knee-length skirt, long-sleeve shirt, full slip

5. Please mark an (X) on the scale below at the place that best represents how you feel at this moment.

☐ Cold ☐ Cool ☐ Slightly Cool ☐ Neutral ☐ Slightly Warm ☐ Warm ☐ Hot

6. Are the thermal conditions of this classroom acceptable to you right now?

☐ Acceptable ☐ Not acceptable

7. Please check the box that best represents how you feel at this moment about the Air Movement right now in this classroom.

☐ Acceptable ☐ Not acceptable

8. What would you prefer right now?

☐ More air movement ☐ Moderate ☐ Less air movement

9. Does the present rate of air movement (too little or too much) bother you in any way?

☐ Yes ☐ No

10. How do you feel about air velocity in the classroom at this moment?

Much too still	too still	slightly still	just right	slightly breezy	too breezy	much too breezy
☐	☐	☐	☐	☐	☐	☐

11. How do you feel about humidity in the classroom at this moment?

Much too dry	too dry	slightly dry	just right	slightly humid	too humid	much too humid
☐	☐	☐	☐	☐	☐	☐

12. Which of the following mechanism do you use to regulate the classroom temperature?

☐ Air-conditioner ☐ Ceiling fan ☐ Portable fan ☐ Windows ☐ Other

13. In which time period of the day do you start feeling overheated? (local time zone)

☐ 2:00 ☐ 3:00 ☐ 4:00 ☐ 5:00 ☐ 6:00 ☐ 7:00 ☐ 8:00 ☐ 9:00

14. In which time of the day do you experience the hottest periods? (local time zone)

☐ 2:00 ☐ 3:00 ☐ 4:00 ☐ 5:00 ☐ 6:00 ☐ 7:00 ☐ 8:00 ☐ 9:00

15. Do you think the orientation of the building affects the temperature of your classroom?

☐ Yes ☐ No

16. How often are building openings (windows or doors) opened in your classroom to allow natural airflow? ________________________Hours.

17. Does the temperature in the classroom affects your concentration on your learning?

☐ Yes ☐ No

18. Do you experience discomfort due to direct sunlight in your classroom?

☐ Yes ☐ No

19. What changes would you recommend to enhance the thermal comfort in your classroom?

____.

APPENDIX - II

Afaan Oromo questionary form for sudents

Guyyaa: ______/______/______ Sa'aatii: _________

Researcher Name: Ayana Kabeta
Department of Architecture
MSc In Environmental Architecture
School of Civil Engineering & Architecture
Adama Science and Technology University

Ibsa waliigalaa

Kabajamtoota deebii kennitoota, dursinee tumsa issin nuuf gootaniif galattefachaa, kaayyoon gaaffilee kanaa Qorannoo “Evaluating orientation based adaptive model of naturally ventilated classrooms to enhance the thermal comfort the Case of Adama city” jadhu deggeruu dha. Deebiin keesan qorannoo kana keessatti gahee guddaa qaba, Kanaafuu, gaaffilee armaan gadii irratti odeeffannoo barbaachisu mallattoo (**x**) kaa’uun kenna. Gaaffilee ilaalchisee gargaarsa kamiyyuu nama odeeffannoo walitti qabu gaafachuu dandeessu. Deebiin kennamu hundi iccitii cimaadhaan kan ilaalamu yoo ta’u, qorannoo akaadaamii qofaaf kan oolu ta’a.

(Nama daataa walitti qabuun kan guutamu)

- Lakkoofsa Unka: _______ Lakk.daree fi Kallatii Gamoo/daree barnootaa _______________
- Haala samii: ☐ Ifa ☐ Walmakaa (Aduu fi Duumeessa) ☐ Duumeessa
- Tilmaama Teempireechara Qilleensaa alaa (°C): _________.

Odeeffannoo Dimogiraafii (Deebii kennitootaan kan guutamu).

Saala ______________ umurii ___________ Ulfaatina (Kg)_________________.

1. Bakka taa’umsaa daree keessatti (“X” tilmaama bakka yeroo baay’ee itti tessu kaa’i).

2. Sadarkaa sochii daree barnootaa keessaa

☐ Dhaabbatee ☐ Taa'ee Barachuu ☐ Qormaata fudhachuu

3. Meeshaaleen daree keessa jiran

☐ Kompiitaraa ☐ Fanii qillensaa ☐ Maxxansaa ☐ Ifa ☐ Teessoo harka cinaa mukaa

4. Uffata (Gosa uffata uffatte ibsi).

☐ Suree, shamizii harka gabaabaa, stookiingii ☐ Suree, shamizii harka dheeraa, kophee

☐ Suree, shamizii harka dheeraa fi jaakkeetii ☐ Suree, shamizii harka dheeraa, sadariyaa, T-sharti, fi kophee

☐ Sirkii jilba gahu, fi shamizii harka gabaabaa, ☐ Sirkii jilba gahu, shamizii harka dheeraa, slipi guutuu

5. Yeroo kanatti miira sitti dhaga’amu akka gaariitti bakka bu’utti iskeelii armaan gadii irratti (**X**) mallatteessi.

☐ Diilallaa'aa ☐ Baay'ee Qabbanaawaa ☐ Xiqqoo Qabbanaawaa ☐ Giddu galeessa
☐ Xiqqoo Ho'aa ☐ Ho'aa ☐ Baay'ee Ho'aa

6. Haalli ho’aa daree kanaa yeroo ammaa kana siif fudhatama qabaa?

☐ Fudhatama kan qabu dha ☐ Fudhatama hin qabu

7. Sochii Qilleensaa yeroo ammaa daree kana keessatti maaltu sitti dhaga’ama?

☐ Mijataa dha ☐ Mijataa miti

8. Yeroo ammaa kana maal filatta?

☐ Sochii qilleensaa baay’ee ☐ Giddugaleessa ☐ Sochii qilleensaa xiqqaa

9. Saffisni sochii qilleensaa amma jiru karaa kamiinuu si dhiphisaa?

☐ Eeyyee ☐ Lakki

10. Yeroo kanatti saffisa qilleensaa daree keessatti maaltu sitti dhagahama?

☐ Garmalee goggogaa ☐ Baay'ee goggogaa ☐ Xiqqoo goggogaa ☐ Giddu galessa
☐ Xiqqoo qilleensa qabeessa ☐ Garmalee qilleensa qabeessa ☐ Baay'ee garmalee qilleensa qabeessa

11. Yeroo kanatti jiidhinni daree keessatti maaltu sitti dhagahama?

☐ Baayyee goggogaa ☐ Garmalee goggogaa ☐ Xiqqoo goggogaa ☐ Giddu galessa
☐ Xiqqoo jiidha ☐ Garmalee jiidha ☐ Baay'ee garmalee jiidha

12. Ho’a daree to’achuuf mala armaan gadii keessaa isa kam fayyadamta?

☐ Fanii qillensaa ☐ Fanii socho'aa ☐ Foddaa ☐ Kan biroo

13. Guyyaa keessaa yeroo kam keessatti garmalee ho’uun sitti dhaga’amuu jalqaba?

☐ 2:00 ☐ 3:00 ☐ 4:00 ☐ 5:00 ☐ 6:00 ☐ 7:00 ☐ 8:00 ☐ 9:00

14. Guyyaa keessaa sa'aatii kam keessatti yeroon ho'aan si mudata?

☐ 2:00 ☐ 3:00 ☐ 4:00 ☐ 5:00 ☐ 6:00 ☐ 7:00 ☐ 8:00 ☐ 9:00

15. Oranteshiniin/kallatiin gamoo kanaa ho’a daree keessanii irratti dhiibbaa qaba jettanii yaaddu?

☐ Eeyyee ☐ Lakki

16. Banaan gamoo (foddaan ykn balbala) daree keessan keessatti qilleensi uumamaa akka seenuuf sa'aatii meeqaaf banaa gootu? Sa'aatiiwwan______________________.

17. Ho’i daree keessatti xiyyeeffannaa barumsa kee irratti qabdu irratti dhiibbaa qabaa?

☐ Eeyyee ☐ Lakki

18. Daree keessan keessatti ifa aduu kallattiin dhufuun miira tasgabbii dhabuun isin mudataa?

☐ Eeyyee ☐ Lakki

19. Mijataa ho’aa daree keessan keessatti argamu guddisuuf jijjiirama akkamii gorsitu?

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APPENDIX - III

<u>የአማርኛ መጠይቅ ቅጽ</u>

ቀን: ______/______/______ ሰአት: __________

የጥናት አድጊው ስም: አያና ቃበታ የአርክቴክቸር ትምህርት ክፍል MSc በ Environmental Architecture የሲቪል ምህንድስና እና አርክቴክቸር ትምህርት ቤት አዳማ ሳይንስ እና ቴክኖሎጂ ዩኒቨርሲቲ

<u>አጠቃላይ መግለጫ</u>

ውድ ምላሽ ሰጭዎች: የእነዚህ መጠይቆች አላማ በአዳማ ከተማ በተመረጡት የትምህርት ቤት ህንጻዎች ላይ የሙቀት ምቾትን ለማሻሻል በተፈጥሮ አየር የተሞላ የመማሪያ ክፍሎችን በኦሬንቴሽን ላይ የተመሰረተ አስማሚ ሞዴልን መገምገም ነው። የእርስዎ መልስ በዚህ ጥናት ውስጥ ትልቅ ሚና ይጫወታል፣ እባክዎን ለሚከተሉት ጥያቄዎች አስፈላጊውን መረጃ ላይ የ(x) ምልክት ያድርጉ። መጠይቁን በሚመለከት ለማንኛውም እርዳታ መረጃ ሰብሳቢውን መጠየቅ ይችላሉ። ሁሉም ምላሾች በጥብቅ ሚስጥራዊነት ይያዛሉ እና ለአካዳሚክ ምርምር ብቻ ጥቅም ላይ ይውላሉ። ለምታደርጉት ውድ ትብብር እናመሰግናለን።

<u>(በመረጃ ሰብሳቢው የሚሞላ)</u>

- የዳሰሳ ቁጥር:________ የክፍል ቁጥር & የሕንፃ አቀማመጥ ___________________________
- የሰማይ ሁኔታ:- ☐ የጠራ ☐ የተቀላቀለ (ፀሐይ እና ደመና) ☐ የተጋነነ
- ግምታዊ የአየር ሙቀት (°C) : ___________
- ወቅታዊ ሁኔታ: ☐ የክረምት ☐ ጸደይ ☐ የበልግ ☐ የበጋ

<u>(በመላሾች የሚሞላ)</u>

ጾታ ________________ ዕድሜ ___________ ክብደት ______________________

1. በክፍል ውስጥ የመቀመጫ ቦታ (ብዙ ጊዜ በሚቀመጡበት ቦታ ላይ "X" ያስቀምጡ)

2. በክፍሎቹ ውስጥ የእንቅስቃሴ ደረጃ

☐ ተቀምጦ መማር ☐ ቆሞ መማር ☐ ፈተናዎችን መውሰድ

3. በክፍል ውስጥ የሉ መሳሪያዎች:

☐ የኮምፒውተር ☐ ጣሪያ ማቅዝቀዣ ☐ ፕሪንተር ☐ የእንጨት ጎን ክንድ ወንበር ☐ ሙብራት

4. አልባሳት (የለበሱትን የልብስ አይነት ይግለጹ)

☐ ሱሪ፣ አጭር እጅጌ ሸሚዝ፣ ስቶኪንጎችን ☐ ሱሪ፣ ረጅም እጅጌ ያለው ሸሚዝ፣ ጫማ

☐ ሱሪ፣ ረጅም እጅጌ ያለው ሸሚዝ እና ሱት ጃኬት ☐ ሱሪ፣ ረጅም እጅጌ ያለው ሸሚዝ፣ ሰደሪያ፣ ቲሸርት እና ጫማ

☐ የጉልበት ርዝመት ቀሚስ፣ አጭር እጅጌ ሸሚዝ፣ ጫማዎች ☐ የጉልበት ርዝመት ቀሚስ፣ ረጅም እጅጌ ሸሚዝ፣ ሙሉ ተንሸራታች

5. እባኮትን (X) በዚህ ጊዜ የሚሰማዎትን ስሜት በሚወክል ቦታ ላይ ከታች ባለው ሚዛን ላይ ምልክት ያድርጉ።

☐ በጣም ቀዝቃዛ ☐ ቀዝቃዛ ☐ ትንሽ ቀዝቃዛ ☐ ገለልተኛ ☐ ትንሽ ሙቅ ☐ ሙቅ ☐ በጣም ሙቅ

6. የዚህ ክፍል የሙቀት ሁኔታዎች አሁን ለእርስዎ ተቀባይነት አላቸው?

☐ ተቀባይነት አለው ☐ ተቀባይነት የለውም

7. እባኮትን በዚህ ክፍል ውስጥ ስላለው የአየር እንቅስቃሴ በዚህ ጊዜ ምን እንደሚሰማዎት በተሻለ የሚወክል ሳጥን ላይ ምልክት ያድርጉ።

☐ ተቀባይነት ያለው ☐ ተቀባይነት የለውም

8. አሁን ምን ይመርጣሉ?

☐ ተጨማሪ የአየር እንቅስቃሴ ☐ መጠነኛ ☐ ያነሰ የአየር እንቅስቃሴ

9. አሁን ያለው የአየር እንቅስቃሴ መጠን (በጣም ትንሽ ወይም በጣም ብዙ) በማንኛውም መንገድ ይረብሽዎታል?

☐ አዎ ☐ አይ

10. በዚህ ጊዜ በክፍል ውስጥ ስላለው የአየር ፍጥነት ምን ይሰማዎታል?

☐ እጅግ በጣም ደረቅ ☐ በጣም ደረቅ ☐ ትንሽ ደረቅ ☐ ገለልተኛ ☐ ትንሽ ነፋሻማ

☐ በጣም ነፋሻማ ☐ እጅግ በጣም ነፋሻማ

11. በዚህ ጊዜ በክፍል ውስጥ ስላለው እርጥበት ምን ይሰማዎታል?

☐ እጅግ በጣም ደረቅ ☐ በጣም ደረቅ ☐ ትንሽ ደረቅ ☐ ገለልተኛ ☐ ትንሽ እርጥብ

☐ በጣም እርጥብ ☐ እጅግ በጣም እርጥብ

12. የክፍል ሙቀትን ለመቆጣጠር ከሚከተሉት ውስጥ የትኛውን ዘዴ ይጠቀማሉ?

☐ የአየር ማቀዝቀዣ ☐ የጣሪያ ማራገቢያ ☐ ተንቀሳቃሽ ማራገቢያ ☐ መስኮት ☐ ሌላ

13. በቀኑ ውስጥ በየትኛው ጊዜ ውስጥ ከመጠን በላይ ሙቀት ይሰማዎታል? (በአካባቢያዊ የሰዓት አቆጣጠር)

☐ 2:00 ☐ 3:00 ☐ 4:00 ☐ 5:00 ☐ 6:00 ☐ 7:00 ☐ 8:00 ☐ 9:00

14. በቀኑ ውስጥ በጣም ሞቃታማ ወቅቶች ያጋጥሙዎታል? (በአካባቢያዊ የሰዓት አቆጣጠር)

☐ 2:00 ☐ 3:00 ☐ 4:00 ☐ 5:00 ☐ 6:00 ☐ 7:00 ☐ 8:00 ☐ 9:00

15. የሕንፃው አቅጣጫ በክፍልዎ ሙቀት ላይ ተጽዕኖ ያሳድራል ብለው ያስባሉ?

☐ አዎ ☐ አይ

16. በክፍልዎ ውስጥ የተፈጥሮ አየርን ለመፍቀድ የሕንፃ ክፍት (መስኮቶች ወይም በሮች) ምን ያህል ጊዜ ይከፈታሉ? ሰዓታት.

____

17. በክፍል ውስጥ ያለው የሙቀት መጠን በትምህርትዎ ላይ ያለዎትን ትኩረት ይነካል?

☐ አዎ ☐ አይ

18. በክፍልዎ ውስጥ ቀጥተኛ የፀሐይ ብርሃን በመኖሩ ምክንያት ምቾት ማጣት ያጋጥምዎታል?

☐ አዎ ☐ አይ

19. በክፍልዎ ውስጥ ያለውን የሙቀት ምቾት ለማሻሻል ምን አይነት ለውጦችን ይመክራሉ?

____

APPENDIX - IV

Indoor Temperature (℃)

Building Axis: North – West to South- East oriented buildings

Building orientation: Southwest

Date	Temperature at 9:00-11:00am	Temperature at 11:00am-1:00pm	Temperature at 1:00-3:00pm	Temperature at 3:00-5:00pm
18/3/2024	25	28	30	30
19/3/2024	26	27	32	30
20/3/2024	25	27.5	29	30
21/3/2024	27	29	30	30
22/3/2024	26.5	28	29.5	30
23/3/2024	24.5	27	31.5	30
24/3/2024	24	28	31	30
25/3/2024	26	29	31	30
26/3/2024	27	30	29.5	30
27/3/2024	27.5	29	30	30
28/3/2024	26.5	27	31.5	30
29/3/2024	27	28.5	31	30
30/3/2024	24.5	27	29	30
31/3/2024	26	29.5	30	30
1/3/2024	27	28	31	30
2/4/2024	26	29	31.5	30
3/4/2024	28	30	31.5	30
4/4/2024	26	28.5	30	30
5/4/2024	27.5	29	32	30

Indoor Temperature (°C)

Building Axis: North - East to South - West oriented buildings

Building orientation: Southeast

Date	Temperature at 9:00-11:00am	Temperature at 11:00-1:00pm	Temperature at 1:00-3:00pm	Temperature at 3:00-5:00pm
18/3/2024	26	27	30	29.5
19/3/2024	25.5	28	31	30
20/3/2024	27	28.5	30.5	29.5
21/3/2024	26	29	29.5	29
22/3/2024	28	28.5	31	30
23/3/2024	25.5	27.5	29	30
24/3/2024	26	29	32	31
25/3/2024	25	30	29	30
26/3/2024	25.5	29	30.5	29
27/3/2024	26.5	28.5	29	30
28/3/2024	26	30	30	30
29/3/2024	25.5	26	32	28
30/3/2024	26.5	29	29	27
31/3/2024	26	28	29	31
1/3/2024	26	27	31	29
2/4/2024	25.5	28.5	30.5	31
3/4/2024	26	30.5	29	28
4/4/2024	27	26	30	32
5/4/2024	25.5	28	29	30

Indoor Temperature (℃)

Building Axis: East to West oriented buildings

Building orientation: South

Date	Temperature at 9:00-11:00am	Temperature at 11:00-1:00pm	Temperature at 1:00-3:00pm	Temperature at 3:00-5:00pm
18/3/2024	25	28	30	28
19/3/2024	27	27	31	29
20/3/2024	25.5	28.5	29.5	29
21/3/2024	26	28	32	28
22/3/2024	25	29	31	30
23/3/2024	25.5	27	29.5	27.5
24/3/2024	26	28	31.5	29
25/3/2024	25.5	27.5	31	30
26/3/2024	25	27	32.5	29
27/3/2024	26	29	32	31
28/3/2024	25	30	32	28
29/3/2024	24.5	27	31.5	27.5
30/3/2024	26	28	29	28
31/3/2024	25	26	30	28.5
1/3/2024	24.5	27	28	27
2/4/2024	25.5	28.5	30	28
3/4/2024	26	29	29	28.5
4/4/2024	25	28	30	29
5/4/2024	25	30	31	30

Outdoor Temperature (°C)

Date	Outdoor Temperature at 9:00-11:00am	Outdoor Temperature at 11:00-1:00pm	Outdoor Temperature at 1:00-3:00pm	Outdoor Temperature at 3:00-5:00pm
18/3/2024	25	29	32	31
19/3/2024	28	29	33	32
20/3/2024	26	30	32	30
21/3/2024	28	29	32	31
22/3/2024	27	30	33	31
23/3/2024	26	29	32	32
24/3/2024	27	29	32	32.5
25/3/2024	28	29.5	31	30
26/3/2024	26	30	32	31
27/3/2024	26	28	31	30
28/3/2024	28	27	29	28
29/3/2024	29	29	31	30
30/3/2024	26	28	30	29
31/3/2024	27	30	31	29
1/3/2024	28	29	30	30
2/4/2024	27	29	31	28
3/4/2024	29	28	32	27
4/4/2024	26	29	30	28
5/4/2024	28	30	32	30

Relative humidity (%)

Building Axis: Northwest – Southeast oriented buildings

Building orientation: Southwest

Date	Humidity at 9:00-11:00am	Humidity at 11:00-1:00pm	Humidity at 1:00-3:00pm	Humidity at 3:00-5:00pm
18/3/2024	32	31	27	29
19/3/2024	31	29	26	28
20/3/2024	33	30	27.5	29
21/3/2024	32	32	27	28
22/3/2024	33	29	28	29
23/3/2024	31	30	27	27
24/3/2024	31	29	27.5	28
25/3/2024	32	28	27	27
26/3/2024	32	30	26	27.5
27/3/2024	31	31	25.5	29
28/3/2024	34	30.5	26	27
29/3/2024	32.5	29	26.5	28
30/3/2024	33	28	24	26
31/3/2024	33.5	29	25	26.5
1/3/2024	32	30	26.5	27
2/4/2024	31	28	27	29
3/4/2024	33	29	26	27
4/4/2024	32	32	25.5	29
5/4/2024	33	29	26	29

Relative humidity (%)

Building Axis: Southwest - Northeast oriented buildings

Building orientation: Southeast

Date	Humidity at 9:00-11:00am	Humidity at 11:00-1:00pm	Humidity at 1:00-3:00pm	Humidity at 3:00-5:00pm
18/3/2024	34	31	27	29
19/3/2024	32.5	30.5	26.5	28
20/3/2024	33.5	31	28	29
21/3/2024	36	32	27	28
22/3/2024	33.5	30.5	28	28.5
23/3/2024	32	31	27	27
24/3/2024	32	32	27	28
25/3/2024	33.5	31	27	27
26/3/2024	33	30.5	26	27.5
27/3/2024	32.5	31	25.5	28
28/3/2024	34	31	26	27
29/3/2024	33	31.5	26.5	28
30/3/2024	33	31	27	28.5
31/3/2024	33.5	30	26	28
1/3/2024	34	31	26.5	27
2/4/2024	34.5	32	27	29
3/4/2024	33.5	31	26	27
4/4/2024	33	32	25	29
5/4/2024	34	31.5	26	29

Relative humidity (%)

Building Axis: East – West oriented buildings

Building orientation: South

Date	Humidity at 9:00-11:00am	Humidity at 11:00-1:00pm	Humidity at 1:00-3:00pm	Humidity at 3:00-5:00pm
18/3/2024	33	32.5	28	29
19/3/2024	31.5	31.5	27	28
20/3/2024	32	33	25.5	28.5
21/3/2024	32.5	32	27	28
22/3/2024	33.5	31	26	27
23/3/2024	32	30	26.5	27
24/3/2024	32.5	31	27	28.5
25/3/2024	32.5	30	26	27.5
26/3/2024	32	31	26.5	27.5
27/3/2024	33	31.5	25.5	28
28/3/2024	32.5	30	27	27
29/3/2024	32.5	32.5	26.5	28
30/3/2024	35	33	27	27.5
31/3/2024	33.5	32	26.5	28.5
1/3/2024	33	31.5	26.5	28
2/4/2024	34	30	25.5	30
3/4/2024	33	32	26	28
4/4/2024	33.5	32	27	29.5
5/4/2024	34	31.5	27	29.5