EFFECT OF ORIENTATION AND WINDOW TO WALL RATIO ON NATURAL VENTILATION: THE CASE OF CONDOMINIUM HOUSES IN ADAMA CITY, ETHIOPIA

Musa Degefa Kabeto

A Thesis Submitted to the School of Civil Engineering and Architecture

Department of 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

October, 2024

Adama, Ethiopia

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DECLARATION

I declare that this thesis proposal entitled **"Effect of Orientation and Window to Wall Ratio on Natural Ventilation: The Case of Condominium Houses in Adama City, Ethiopia."** is my own work and has not been submitted to any university for a similar purpose. The references used in this proposal are duly recognized by proper citations.

__Musa Degefa Kabeto______ _________________ ______________________

Name of student Signature Date

RECOMMENDATION OF ADVISOR

I, the major advisor of this research proposal, hereby certify that I have closely advised the student while developing this proposal and read the draft thesis proposal entitled "**Effect of Orientation and Window to Wall Ratio on Natural Ventilation: The Case of Condominium Houses in Adama City, Ethiopia**.**"** prepared under my guidance by Musa Degefa Kabeto, ID No PGR/24507/14. Therefore, I recommend the submission of the proposal to the department for further review and evaluation.

____Yared Girma (PhD)____	____________________	________________
Major Advisor	Signature	Date
______________________	____________________	________________
Co-advisor	Signature	Date

APPROVAL SHEET

I the advisor of the thesis entitled "**Effect of Orientation and Window to Wall Ratio on Natural Ventilation: The Case of Condominium Houses in Adama City, Ethiopia**." and developed by Musa Degefa Kabeto, hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

Yared Girma (PhD)		
Major Advisor	Signature	Date
Co-advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by Musa Degefa Kabeto have read and evaluated his thesis entitled "**Effect of Orientation and Window to Wall Ratio on Natural Ventilation: The Case of Condominium Houses 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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ACRONYMS AND ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
ASTU	Adama Science and Technology University
AR	Aspect Ratio
AZI	Azimuth
Clo	Cloth insulation [$m^2 \cdot K/W$]
E	East
EBCS	Ethiopian Building Code Standards
HVAC	Heating ventilation air-conditioning
IAQ	Indoor Air quality
IHDP	The Integrated Housing Development Programme
Max	Maximum
Min	Minimum
NMA	National Meteorological agency
N	North
R2	The Square of the correlation coefficient
RH	Relative Humidity
S	South
W	West
WFR	Window Floor Ratio
WWR	Window to wall ratio

LOCAL TERMS

Atana tera (Solee) condominium site located in (kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Cherkacherk (Adodee) condominium site (located in kebele 04) -The case study condominium site and its name is derived from around or adjacent name which is popular for local community. HYa

Duket (Jallisi) condominium site (located in kebele 09) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Ganda gara (Lujoo) condominium site (located in kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Goro condominium site (located in kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Moenco (Diko) condominium site, (located in kebele 05) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Silase condominium site (located in kebele 01) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Sodober (Wenji road) condominium site (located in kebele 09) - The case study condominium site and its name is derived from around or adjacent name which is popular for local community.

Kebele - The smallest administrative unit in Adama.

ABSTRACT

Natural Ventilation is an effective method for passive cooling, increasing indoor air quality and minimizing energy consumption of a condominium building. The aim of this paper is to assess the natural ventilation of selected residential buildings in terms of building orientation relative to wind direction, WWR and window size. This study is confined with in Adama city, Ethiopia; only on 4 purposively selected condominium buildings which aimed to evaluate the orientation based to investigate the effect of orientation and WWR of natural ventilation at a specific condominium location in Adama city in various orientations on a distinct solar axis (i.e., S–N, with window to wall ratios (i.e., South: 48.97%, *East:* 74.41%, *West:* 51.00%, *North:* 20.46%*) and* 16:15 or 1:1.07 *aspect ratio and E–W with window to wall ratios (i.e., South:* 51.00%, *East:* 39.60%, *West:* 25.3%, *North:* 74.41%*) and* 28:15 or 1:1.87 *aspect ratio and wall surface to floor area ratio 58% using a field survey, and data collected during the hottest months of the year, April and May 2024. The study used both qualitative and quantitative data gathering approaches and implemented by using primary and secondary data sources. First, data loggers were used to take measurements of air speed per hour, relative humidity, and indoor air temperature airspeed, for both building orientations. In addition, using a standard questionnaire, the residents were asked about their fresh air in their households. Secondly, the collected data processed using Excel and Ecotect software used for simulation and wind direction of location. According to the data gathering and analysis, the result demonstrates the Airspeed for the north-south orientation of the building is between 1.94 and 1.15 m/s; indoor temperature for the north-south orientation of the building is between 29 and 25 degrees Celsius. When the building is oriented east-west axis, Airspeed is between 1.2 and 0.2 m/s; the air temperature is between 35 and 28 degrees Celsius. While relative humidity for north-south building orientation is 76-42, for south-north building orientation is 55-28. Finally, based on the Environmental measured and adaptive model of ASHRAE-55 and ISO-7730, the results showed that the east-west orientation affect natural ventilation when compared to the south-north orientation.*

Keywords: Natural ventilation, WWR, Building orientation, Airspeed, Wind Direction, Thermal comfort.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This paper is written for a study conducted in the administrative city of Adama, Ethiopia. In partial fulfillment of a Degree of Masters in Environmental Architecture at Adama Science and Technology University. The study aimed to analyzing the Effect of Orientation and Window to Wall Ratio on Natural Ventilation: The Case of Condominium Houses in Adama City, Ethiopia.”. Understanding that the sun’s paths and wind’s directions are different for every location is critical for designing building orientation that allows for passive solar gain while reducing solar radiation and ventilating the indoors. This chapter discusses the background of the study; the statement of the problem; the objective; research questions; the significance of conducting the study; the scope of the study; and limitations.

Ventilation is a way of improving the air quality of rooms by circulation. The position of the inlet and outlet greatly influences the thermal comfort. Natural ventilation or non-mechanical airflow through buildings has been canvassed as an integral component of sustainable architecture (Guyer et al., 2013). Natural ventilation depends on pressure differences to move fresh air through buildings. Pressure differences can be caused by wind or the buoyancy effect created by temperature differences or differences in humidity. It is useful to think of a natural ventilation system as a circuit, with equal consideration given to supply and exhaust. Openings between rooms such as transom windows, louvers, grills, or open plans are techniques to complete the airflow circuit through a building. This natural ventilation of buildings depends on climate, building design and human behaviors.

In general, when building occupants are more satisfied with their working environment, productivity and job satisfaction also increase. Thus, the benefits of using natural ventilation are significant even beyond the energy benefit.

The study focuses on evaluation of Building Orientation on Determining Ventilation Oriented Optimum WWR of selected condominium buildings in Adama town and how the size, shape, type and placement of openings affects natural ventilation of the buildings.

1.2 Background of the study

Ventilation rates for acceptable indoor air quality are currently assessed by using the ASHRAE Standard 62.1. In this Standard there are two procedures for estimating the amount of fresh air required. The first is referred to as the ventilation rate and is a prescriptive approach stating that, for office buildings, there is a requirement of 10 l/s per person of fresh air (nonsmoking). A comparison of Standards for the indoor environment is given in the ASHRAE Handbook on Fundamentals (Edition, 2019).

Natural ventilation is a more effective instrument to improve indoor air quality in buildings, protect the health, provide thermal comfort and reduce unnecessary energy consumption (Gage, Stephen A., G.R. Hunt, 2012). Natural ventilation in a building means opening a window to let fresh air into a room. The airflow through the opening is due to wind and buoyancy. The wind has a mean and a fluctuating component that may vary over the opening and produce a 'pumping effect'. When the indoor temperature is higher than outdoor, the buoyancy makes the cold air enter at the lower part and the hot air exit at the upper part of the opening (Germano, 2006; Ventilation, n.d.2009).

The amount of ventilation will depend critically on the size, shape, type and placement of openings, especially the inlets, determine the velocity and pattern of internal airflow. Maximum air movement through the building is achieved by placing inlet openings in positive pressure zones and outlet openings in negative pressure zones (Gage, Stephen A., G.R. Hunt, 2012). The most common device for natural ventilation is the operable window for which the mechanism involved is primarily wind-driven ventilation, although buoyancy may have a non-negligible effect (Abdullah & Alibaba, 2020).Operable windows are often used to control natural ventilation. They are well adapted to deliver the very large airflow rates needed to evacuate pollutants or to evacuate heat, particularly for passive cooling. The effect of window size depends on whether or not openings are cross ventilating. If openings are on one surface only, size has little effect on airflow. In cross-ventilated rooms, airflow is determined mainly by the area of the smallest openings, average indoor velocity and number of air changes (Bhatia, n.d.2020).

Orientation is just the compass direction of the building faces. Orienting the building so that its shorter axis aligns with prevailing winds will provide the most wind ventilation, while orienting it perpendicular to prevailing winds will provide the least passive ventilation. However, buildings do not have to face directly into the wind to achieve good cross-ventilation. Internal spaces and structural elements can be designed to channel air through the building in different directions. In addition, the prevailing wind directions listed by weather data may not be the actual prevailing wind directions, depending on local site obstructions, such as trees or other buildings.

Our country Ethiopia lies in the tropical zone. Ethiopian highlands cover most of the country, resulting in a cooler climate than other regions on the equator. Most major cities are located in elevated regions over 2000m with a mild climate throughout the year, but Adama city is located in the great rift valley and the weather condition is a hot zone with a warm dry season. For example, Addis Ababa, the capital city, is estimated to have 7204 Natural Ventilation Hours and Bahir Dar in the northwest of the country displays 8136 Natural Ventilation Hours (Yacob, 2014).

This research paper mainly assesses the nature of the selected buildings in terms of building orientation and climate, how the size, shape, type and placement of openings affect natural ventilation of the buildings, and finds out how to maximize passive design rather than using mechanical air conditioning.

In Ethiopia, there is a gap between the actual climatic and environmental context of the country and current codes and regulations. The building code of standards miss detailed guidelines for natural ventilation and the numbers provided shows vagueness. For example on EBCS-II, opening parts of window is specified in relation to the floor area regardless of orientation height local and climate. In Adama, the majority of buildings poorly designed in terms of orientation, ventilation and WWR. Because designs are duplicated and repetitive the same orientation and types of design in different parts of the country for different climate conditions and wind direction. As a result, the study motivated me on how orientated buildings are affect natural ventilation WWR. Lack of previous research studies related to the topic in Ethiopia is the second motivation of the study, so other studies from foreign country with the same climate region is used to provide theoretical and scientific foundation for the research.

1.3 Statement Problems

Architects usually focus on the beauty of the buildings and provide openings by giving priority to the aesthetic quality of the buildings, but it is mandatory to consider natural ventilation. Since there is no local standard of size in the area and orientation is provided, the designer refers only to the general level of other countries, so contextualizing the standard is imperative. As reported by (Idowu, O.M., 1 Gwandi, S.G., 1 Humphrey, S.1 And Marafa, 2018), asymmetrical placement of the windows in a one-sided ventilation can produce more air flow inside a room than a symmetrical placement. The existing condominium buildings at Adama town has too many ventilation problems related with its WWR, climate condition, and orientation. Some condominium buildings have insufficient natural ventilation that the window size is not enough for naturally ventilated buildings, so they use mechanical air conditioning to increase ventilation rates in rooms housing patients with airborne infection. The others have sufficient window size but on the wrong orientation. The rest have right window size and orientation, but the air distribution is not smooth because the position of the openings is not in the right direction. In addition, problems related to mechanical ventilation can cause noise (especially from high-powered fans), the increase or decrease in temperature in the room and the need for a constant supply of electricity.

In Ethiopia, there is a gap between the actual climatic and environmental context of the country and current codes and regulations. The building code of standards miss detailed guidelines for natural ventilation and the numbers provided present ambiguity. Ethiopia has different climate zone in different regions but the standard available for buildings natural ventilation is the same. This will lead to over or under ventilated rooms in both case it creates discomfort and health problem. It has been noted that buildings in hot dry climates especially Adama city were traditionally of insulated mass construction and small openings contemporary homes in the study area seem to deviate from this norm.

In Adama, Most condominium house designs are built repetitively, duplicating in same orientation, wind direction and types of design in different parts of the country for different climate conditions, without regard to orientation, wind direction, window to wall ratio, and aspect ratio. The intention of designing condominium houses by the government for the federal and different regions in mass is not consider the climate condition of the location. Currently, the majority of condominium houses use the same orientation, wind direction, WWR, material, and fenestration. In Ethiopia, there are no regulations and monitoring systems regarding building orientation to improve the thermal comfort of condominium houses by considering orientation, wind direction, and climatic conditions. In addition, there are no recommendations or principles for designing condominium houses in various climates to address the issues of indoor thermal comfort and wind direction. Furthermore, no research has been done in Adama city on the effect of orientation and WWR on natural ventilation of residential buildings. Hence, this study is intended to fill up the gaps that should be considered before duplicating and repeating condominium houses.

1.4 Research Questions

1) What is the level of the airspeed, indoor temperature, and relative humidity of selected building typologies?
2) What are the relationships of the wind direction respect to building orientation, and WWR in the case study of selected buildings?
3) Which orientation is the best optimum orientation for the natural ventilation of the selected building typologies?

1.5 Objectives

1.5.1 General Objective

The General objective of the study is to investigate effects of building orientation and WWR on natural ventilation of condominium buildings in Adama city, Ethiopia.

1.5.2 Specific Objectives

1. To measure air speed, indoor temperature and humidity of selected building typologies.
2. To examine the relationships of the Wind direction respect to Building orientation, and WWR for natural ventilation of the condominium buildings.
3. To identify best optimum building orientation based on wind direction and WWR, for Natural ventilation of condominium building.

1.6 Significance of the study

The ultimate aim of a research is to contribute in some way to the existing knowledge we have in the field of Architecture and Environmental sustainability. This research is important because this is a relatively a new idea that could potentially fill the gap between sustainable environment and natural ventilation. And more importantly it tries to answer what the difference between the trend of building and designing in Adama town and the passive design theory of building. Based on this study, the government can create a general optimum WWR for different orientations, climates and building heights. Proper implementation of the standard will improve the energy performance of the building. Also used for providing acceptable indoor environmental quality and maintaining a healthy, comfortable, and productive indoor climate rather than the more prevailing approach of using mechanical ventilation. According to different studies, it is stated that proper implementation of the WWR and orientation for the natural ventilation strategy can minimize up to 78% of a building's energy consumption depending on local weather and air quality. Providing optimum ventilation-oriented window size for natural ventilation will provide acceptable thermal comfort conditions and reduce health problem for occupants by reducing over and under ventilation of a room. For the occupants the optimum airflow through the opening provided will reduces the embodied energy, capital, maintenance, and operational costs of mechanical equipment and the space needed to accommodate the equipment. Natural ventilation regulates the indoor climate and changes the air in the building through openings in the façade and/or roof. The result is lowered CO2 levels for a fresh indoor climate and a cool indoor temperature during the summer months.

It has its own significance for the Ethiopian building code standards policymaker, to have its own standards that consider detailed guidelines for natural ventilation based on the local context.

Finally, this research paper will have its own significance as an academic input, social transformation, economic development and technological improvement. The outcome of the research depends on the facts collected from up dated resources and current situations. This in turn will add to reliability of the information gathered.

1.7 Delimitation/Scope

The scope of the research paper is confided within the Adama town only focusing on selected residential buildings, mainly determining of naturally ventilation oriented optimum WWR of the buildings related with building orientation. The site selected based on the three criteria, which are the most livable buildings, resident zone in structure plan, and a well-organized community. The study deals with building science related to natural ventilation. Even if window is also used for daylight, this study focuses only on natural ventilation, WWR and orientation. Only building with simple geometry (flat façades) located in an open terrain is discussed on the study because the findings can be generalized to apply to all buildings of same type.

To realize this, the research first tried to assess natural ventilation of selected buildings which are the main source of polluted air inside the room; secondly to develop design prototypes of passive design by simulation software (CFD) and finally to develop the scale-up strategy by taking a case area of the residential buildings for the evaluation of building orientation on determining ventilation oriented optimum WWR of the buildings.

1.8 Operational Definition of the Study

Natural Ventilation: is the procedure of entering fresh air into a home from outside. This new air, forces the dirty, warm air in the rooms out by the opening in the roof. This can be operated without mechanical assistance. While that was a brief introduction, its practical application and usage is much more involved.

Building Orientation: is just the compass direction of the building faces. Orienting the building so that its shorter axis aligns with prevailing winds will provide the most wind ventilation, while orienting it perpendicular to prevailing winds will provide the least passive ventilation.

Wind-Based Ventilation (Cross-Ventilation): moving wind near a building will produce different sections of low and high pressure. The windward part of the house is an area that is high pressure, while the leeward part & roof are low pressure. Placing different types and sizes of openings in the low and high-pressure sections can force air to transfer through the building at an increased rate and in the desirable direction.

Buoyancy-Driven Ventilation (The Stack Effect): This type of Natural Ventilation seems complex, but it works fundamentally like a fireplace. Because warm air goes up and cool air remains low, this procedure forces warm air to rise.

Indoor air quality (IAQ): is the quality of the air in and around buildings and structures.

Relative Humidity: The ratio of the actual amount of water vapor in the air to the maximum amount of water vapor that the air can hold at that air temperature, expressed as a percentage.

Air Speed/velocity: speed of air movement at a point, regardless of direction (Candido et al., 2010). The faster the air moves, the greater the heat exchange between the person and the air that the person is in contact with (measured in m/s).

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, warmth, warmth and warmth).

Beaufort scale: also can be used to measure and describe the effects of different wind velocities on objects on land or at sea. Beaufort arranged the numbers 0 to 12 to indicate the strength of the wind from calm (force 0) to hurricane (force 12). Here’s a wind force scale adapted to land.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Literature Review

2.1.1 Natural Ventilation

Natural ventilation, as the name implies, is a system using natural forces to supply fresh air for comfort and heat dissipation (Walker 2010). 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 (Givoni 1992). 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 (Fung and Lee 2015). 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 to deliver fresh air to indoor spaces. For sustainable building design in tropical climate the natural ventilation zone is illustrated in (Figure 2:1).

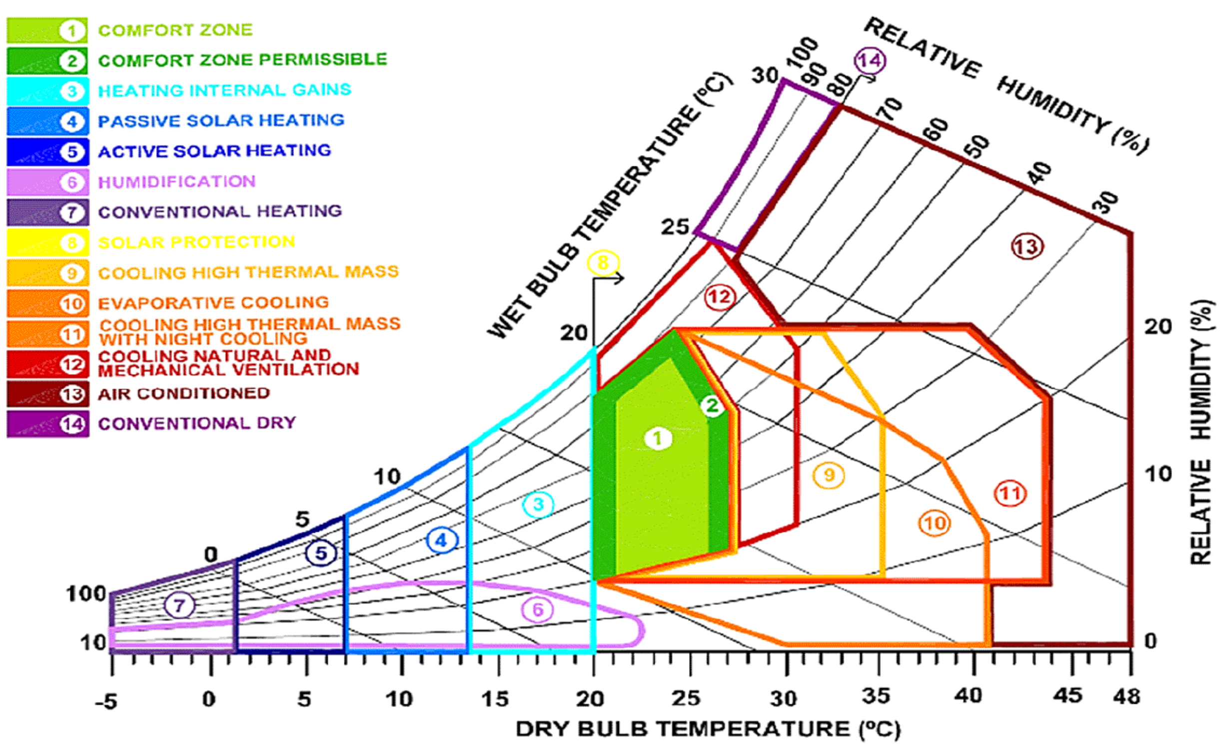


Figure 2: 1 Natural Ventilation Zone (Source: Psychrometric chart adapted from Givoni.)

2.1.1.2 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 (Ahmed & Corresponding, 2011). The purpose of ventilation is 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 (Boutet 1987).

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 (Al-Tamimi, Fadzil et al. 2011).

2.1.1.3 Benefits of Natural Ventilation

Natural ventilation has several benefits: 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 (Mba, Samamobi et al. 2022).

The primary reason for using natural ventilation over mechanical ventilation is energy efficiency. Because natural ventilation 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). The design of natural ventilation system necessitates knowledge of the mechanism of air flow through buildings and also of factors which have a bearing on air flow patterns indoors (Khan, Su et al. 2008).

2.1.1.4 Aspects of natural ventilation

1. Natural Driving Forces: The first aspect is the natural forces utilized to drive the ventilation. The driving forces can be wind, buoyancy or a combination of both.

2. Natural Ventilation Principles: The second aspect is the ventilation principle used to exploit the natural driving forces to ventilate a space. This can be done by single-sided ventilation, cross ventilation, or stack ventilation.

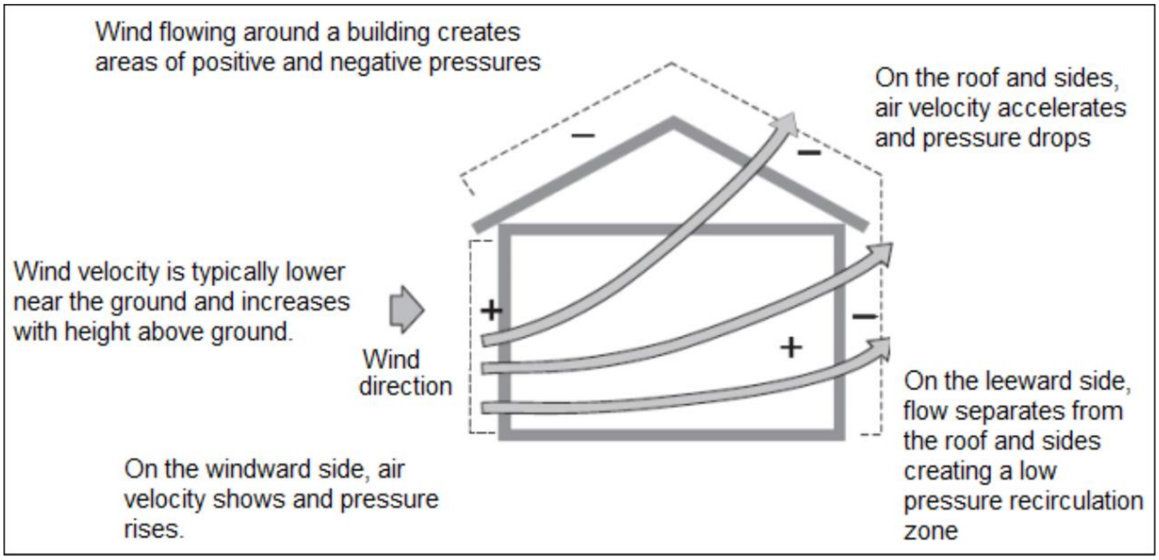


Figure 2: 2 Natural ventilation principles

3. Architectural Elements: The third aspect is the characteristic architectural elements used to enhance natural ventilation. The most important characteristic elements are wind towers, wind scoops, chimneys, double façades, atria, and embedded ducts (Heracleous and Michael 2019).

1. Natural Ventilation Driving Forces

Natural ventilation is provided from two sources: thermal buoyancy and wind.

a. Wind: - The air moves from higher (positive) pressure regions to the lower (negative) pressures regions. This phenomenon is based on Bernoulli's principle, which uses pressure differences to move air. The pressures generated by natural wind are typically - 0.004 to 0.14 inches of water column (in-wc) (Hsieh 1985).

b. Buoyancy: - The warm air is less dense than cool air so it rises and creates a difference in pressure which in turn induces air movement. This phenomenon is called "the thermal buoyancy" and is sometimes referred to as "the stack effect". The pressures generated by buoyancy are quite low ranging from - 0.001 to 0.01 inches of water column (in-wc) (Hsieh 1985).

The magnitude and pattern of natural air movement through a building depends on the strength and direction of these natural driving forces and the resistance of the flow path. Stack ventilation, can operate when no wind pressure is available. The absence of wind can occur at certain times, due to its variability, or in certain sites, due to blocking effect of other buildings or vegetation. It can also operate in deep plan buildings where the distance from openings in the perimeter, and the presence of partitions, make wind-driven cross ventilation impractical (Bhatia, 2012).

2.1.2 Wind Effect

Natural ventilation is induced by differences in air pressure across the building. When wind strikes a building, a region of higher pressure is created on windward wall and a negative pressure on the leeward side of the building façade. A pressure gradient is thereby created across the building in the direction of the incident wind. This pressure gradient around a building in turn creates a negative pressure area inside the building that encourages air to move through the building and via its openings. The air moves through from the opening in the positive pressure façade to the opening in the negative pressure one (Al-Tamimi, Fadzil etal. 2011).

Wind effect uses Bernoulli's principle of fluid dynamics, which states that at higher speeds the static pressure decreases and at lower speeds the static pressure increases. The air speed on the windward side of the building reduces as it collides with the building, resulting in an increased pressure. Conversely, the air speed on the top and the leeward sides of the building increases, resulting in reduced pressure. A pressure differential is thus created between windward and leeward walls. The effective pressure difference tends to be greatest (about 1.4 times the dynamic pressure at eaves level for typical rectangular buildings) when wall openings are about 15% to 20% of wall area. This means that the average wind speed through wall openings has the potential to be 18% higher than the local wind speed (Ohba and Lun 2010).

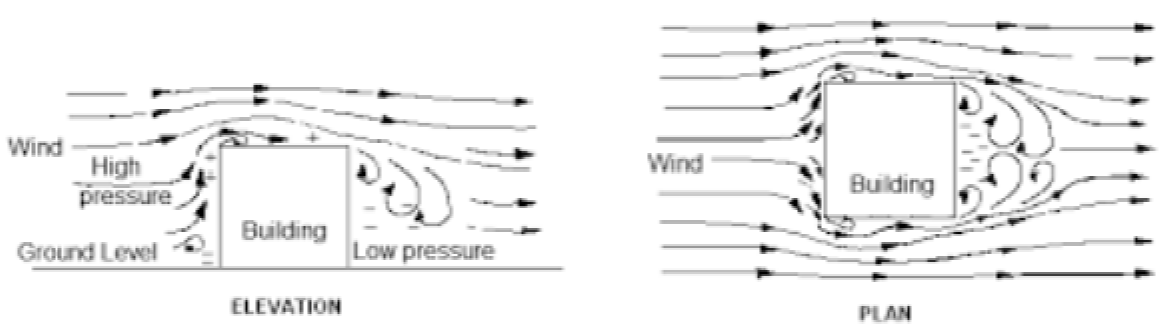


Figure 2: 3 Wind speed/direction on a building creates positive and negative pressures

Without any openings the wind pressure difference is about 1.1 times the dynamic pressure at eaves level. With a 60% wall opening or more, the wind pressure difference between windward and leeward surfaces remains constant around 1.0 times the dynamic pressure at eaves level.

2.1.2.1 Factors Affecting Flow due to Wind

The magnitude of air movement in a building is a dependent on the pressure differential between the outlets and inlets, which in turn is dependent on the wind speed, wind direction and building shape. Wind speed increases with height and is lower towards the ground due to frictional drag. The building geometry, relative position and size of openings; building location in relation to surroundings; and the terrain geographical location of the building, create wind flow changes affecting building pressures. The dynamic wind pressure on any specific position on a building's surface (façade) can be calculated using the Bernoulli's equation (Chenvidyakarn, 2013).

2.1.2.2 Applications and Limitations of Wind Driven Ventilation:

The relative importance of wind acting directly on an opening may be either an advantage or a disadvantage, depending on the time of year.

- During warm weather, the wind becomes an advantage and techniques are used to take full advantage of the prevailing wind direction.
- During cold and mild weather conditions, the relatively high-speed wind can create uncontrolled drafts and discomfort. During cold weather periods, the ventilation should be restricted to minimum rates (Walker 2010).

2.1.3 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, 2012). Furthermore, the ventilation principle gives an indication on how the air is introduced into the building, and how it is exhausted out of it. Infiltration through the building envelope can also play a certain role, depending on the air-tightness of the building envelope. However, this form of ventilation is usually both unintended and unwanted. 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. The ventilation principles used in the building to exploit the natural driving forces are classified as Single-sided ventilation, Cross-ventilation and stack ventilation (Chenvidyakarn 2013).

a. Single-Sided Ventilation

Single sided ventilation relies on airflow through openings on only one side of an enclosed space. The air enters from one opening and leaves from the same opening or from another opening in the same wall. With single ventilation opening in the room, the main driving force for natural ventilation is wind turbulence (Bhatia, n.d.). Compared to other strategies, lower ventilation rates are generated and the depth of penetration of the airflow into the space is limited (Figure 2:4). According to ASHRAE standard, single sided ventilation is generally effective for room depths not more than 2.5 times the height of the room and the ventilation opening area should be between 5% to 10% of the room's floor area. If more than one ventilation opening is provided and openings are separated by a horizontal distance, the ventilation rate is enhanced by the flow from one window to the other due to the difference in wind pressure coefficients at the location of each window (Bhatia, n.d.2022).

Advantages:

- Single sided ventilation is popular because openings are located on only one face of an enclosed space.

Disadvantages:

- No defined exit route for air;
- Net driving forces may be small resulting in poor ventilation;
- Not suitable for deep plan spaces. Depth of penetration is restricted to approximately 2.5 x ceiling height

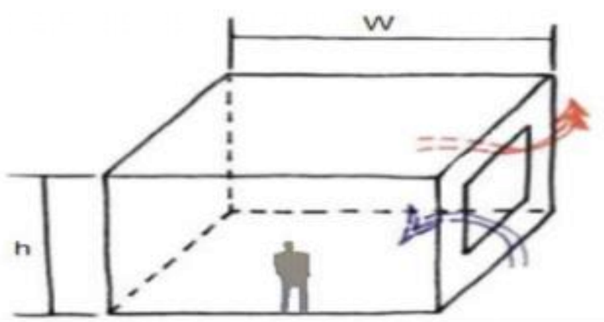


Figure 2: 4 Single-side ventilation (Source: Design options for HVAC distribution systems, 2012)

Cross Ventilation

Cross ventilation relies on airflow between ventilation openings on opposite sides of a space. Simply, the air enters from one opening (in the windward wall) and travels across the space to leave from another opening in the opposite side (in the leeward wall). As the air moves across a cross-ventilated space, it picks up heat and pollutants (Bhatia, n.d.).

Cross ventilation can be considered as the most effective technique that can grant a consistent large airflow with deep air penetration across the ventilated space (Figure 2:5). The airflow in the cross ventilation is a wind driven airflow, unless a difference in height between the inlet and outlet openings within the same wall is provided. According to ASHRAE standard, Cross ventilation is the most suitable technique for ventilating deep plan buildings. The depth of the room can be up to 5 times the height (Jaber and Ajib 2011).

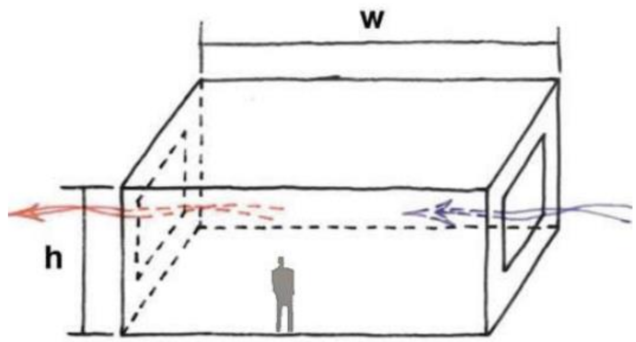


Figure 2: 5 Cross-Ventilation (Source: Design options for HVAC distribution systems, 2012)

Cross Ventilation provides the maximum interior velocities and the best overall air distribution pattern. Openings in both positive and negative pressure zones are mandatory for cross ventilation. For windows on adjacent walls, the overall room air distribution is 10% to 20% higher average velocities when the wind incidence angle is perpendicular to the building face. For windows on opposite walls, oblique wind incidence angles give 20% to 30% higher average velocities than perpendicular winds (Gage, Stephen A., G.R. Hunt, 2012).

Cross ventilation can be considered as the most effective technique that can grant a consistent large airflow with deep air penetration across the ventilated space. The airflow in the cross ventilation is a wind driven airflow, unless a difference in height between the inlet and outlet openings within the same wall is provided, and thus thermal buoyancy starts to play a significant role (Mba, Sam-amobi et al. 2022).

Advantages:

- A high rate of ventilation is possible under favorable weather conditions;

- It can be used in relatively deep-plan spaces with two or more perimeter walls containing windows that can be opened;
- For equivalent size of openings, cross flow covers a larger zone than the single-sided openings (Boutet 1987).

Drawbacks:

- Effective cross-ventilation requires a relatively clear path for air to flow across the space;
- Inappropriate window design and positioning may result in disruptive drafts;
- Design of interior layout etc. can be more complex than for single sided solutions.

b. Stack Ventilation

Stack ventilation is driven through the building by thermal buoyancy. The warm air inside the building is less dense than cooler air outside, and thus will try to escape from openings high up in the building envelope. The cooler denser air will enter through lower openings in the building envelope. The process will continue if the air entering the building is continuously heated, typically by casual or solar gains (Boutet 1987). Stack ventilation occurs naturally whether we design it or not, and has been consciously used for centuries in traditional and vernacular buildings ranging from Indian tepees to churches. It requires a minimum difference of 3°F between indoor and outdoor temperatures (Mba, Samamobi et al. 2022).

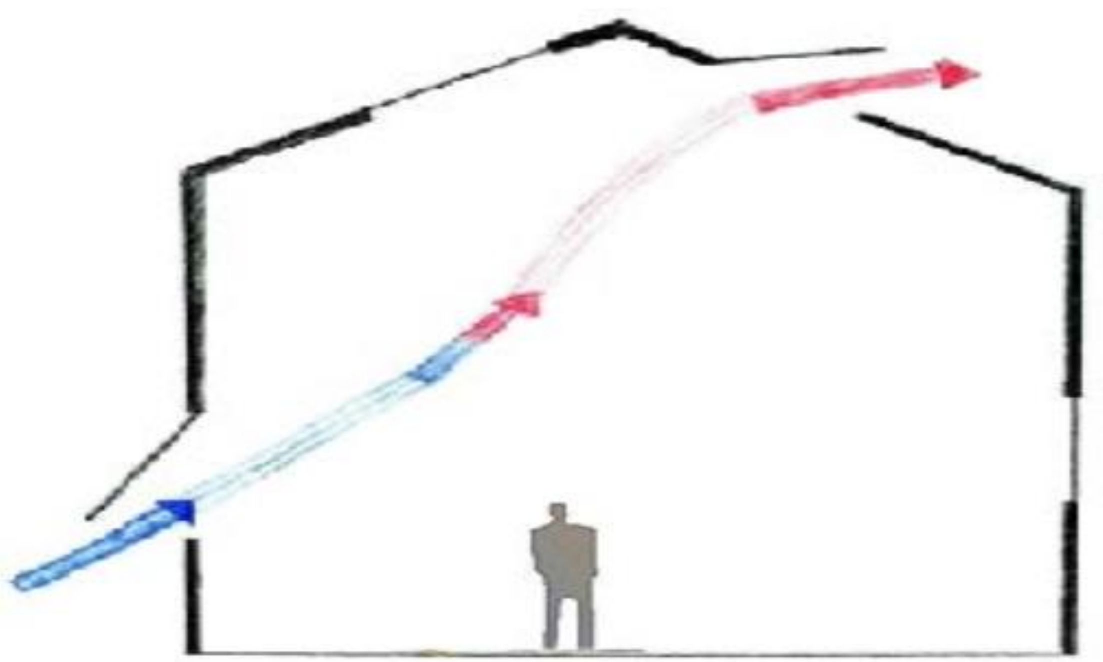


Figure 2: 6 Stack Ventilation (Source: Design options for HVAC distribution systems, 2012)

2.1.4 General Recommendations

Single-sided Ventilation:

- Single sided ventilation is generally effective for room depths NOT more than 2.5 times the height of the room.
- The ventilation opening area should be between 5 to 10% of the room's floor area.

This technique is more suitable for moderate climates and not effective in hot climates.

Cross Ventilation:

- Cross ventilation is the most suitable technique for ventilating deep-plan buildings. The depth of the room can be up to 5 times the height.
- The opening area required is approximately 2% of the floor area (1% on each side of the space) (Khan, Su et al. 2008).

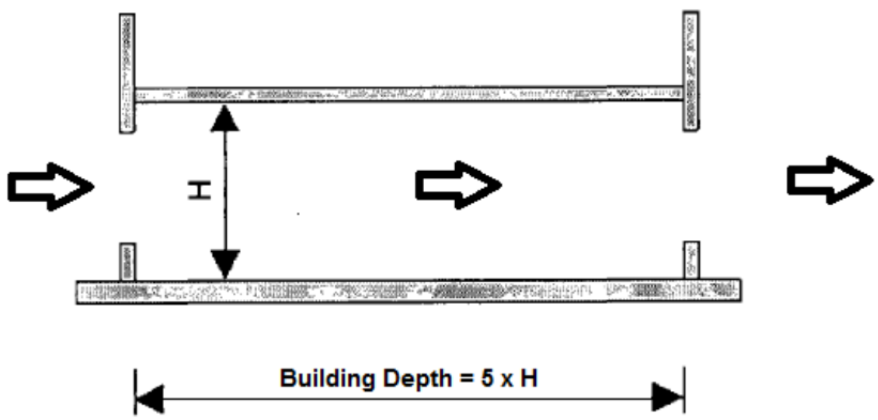


Figure 2: 7 Cross Ventilation design recommendation

Stack Ventilation:

- Stack ventilation can be effective across a width of 5 times the floor-to-ceiling height from the inlet to where the air is exhausted to the stack.
- This rule is based on a building with a large stack or atrium running down the center of the building and spaces on either side of the stack having a maximum depth limit of 5 times the floor-to-ceiling height of individual levels (Walker 2010).

Shape of the Building

The form of the building can have a significant influence on the way a natural ventilation system is able to work (Khan, Su et al. 2008).

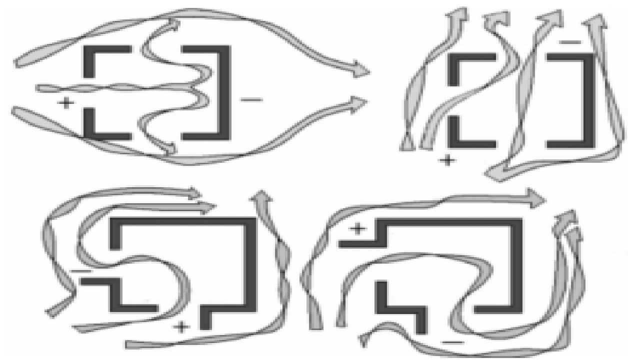


Figure 2: 8 Shape of the Building

Note the key facts:

- Naturally ventilated buildings are relatively narrow in plan. The maximum width that one could expect to ventilate naturally is estimated as 25 ft.
- The height and shape of a building and the angle of the roof are important. For the best ventilation performance, the building aspect ratio (length/width) should be kept low.
- For simple rectangular shapes, the long façade should face the direction of the summer wind.
- The irregular shapes of buildings can have large variations in pressure and can enhance natural ventilation.
- Single story deep plan buildings can be naturally ventilated through roof outlets. Multi-story deep plan buildings shall consider atriums in the middle (A'yun, Widiastuti et al. 2020).

2.1.5 Building Spacing and Arrangement

Arrange buildings to provide for good air flow around all structures.

- A linear arrangement of homes lined up parallel to the wind direction creates poor airflow.
- A linear arrangement of homes lined up at an angle to the wind direction provides good airflow.
- A staggered arrangement of homes creates good airflow regardless of wind direction.
- Spacing buildings by a distance of at least five times the height of the upwind building provides greater natural ventilation opportunities for the downwind building (Heracleous and Michael 2019).

2.1.6 Building Orientation

The building orientation with respect to wind direction significantly affects natural ventilation performance. Since the building orientation is mostly associated with the street orientation, the optimum ventilation potential could be obtained in an oblique orientation (Al-Tamimi, Fadzil et al. 2011).

- According to ASHRAE,the optimum angle, which provides the best air circulation inside spaces, could be obtained by orienting the inlet 45° to the prevailing wind. Inlet openings facing the incoming wind at 90° provides the maximum airflow.
- The long façade of the building and the majority of the openings should be oriented with respect to the prevailing summer breezes i.e., north-south orientation for westerly wind (A'yun, Widiastuti et al. 2020).

2.1.7 Design of optimal Openings

The WWR controls both the ventilation rate and air velocity within the interiors. The general rule of maximizing the natural ventilation effectiveness is to have inlet and outlet openings as large as possible. According to ASHRAE, highest flow per unit area of openings is obtained when the inlet is small and the outlet is large by at least 25%, and the inlet window height is limited to 1m and the inlet width is up to two-thirds of the wall width (Figure 2:9) (Guyer et al., 2013).

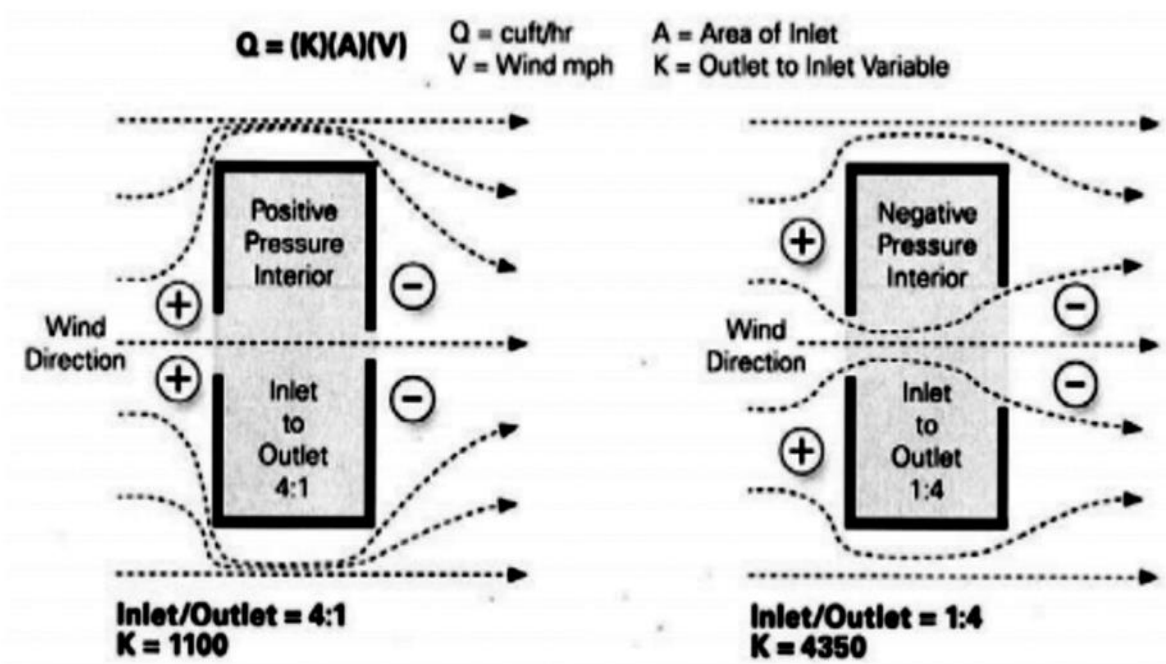


Figure 2: 9 Inlet to outlet relation of opening (Source: Design options for HVAC distribution systems, 2012)

Key Facts:

Greatest flow per unit area of openings is obtained when:

- The inlet is small and the outlet is large by at least 25%.
- The inlet window height is limited to 3.6 ft. and the inlet width is up to two thirds of the wall width.

The effect of window size depends on whether or not openings are cross ventilating. If openings are on one surface only, size has little effect on airflow. In cross ventilated rooms, airflow is determined mainly by the area of the smallest openings (Guyer et al., 2013). Average indoor velocity and number of air changes are highest when inlet area is equal to or slightly less than outlet area as in the Equation 1.

Outlet area/inlet area = 1.25……………………………. Equation 1

Ventilation is more efficient for a greater number of incidence angles when inlets are larger than the outlets. If concentrated flow in a restricted area of the room is desired, the inlets may be sized smaller than the outlets and placed immediately adjacent to the living space to be ventilated (Figure 2:10). In general, use the largest area of openings possible with inlet area equal to or slightly less than outlet area (Guyer et al., 2013)..

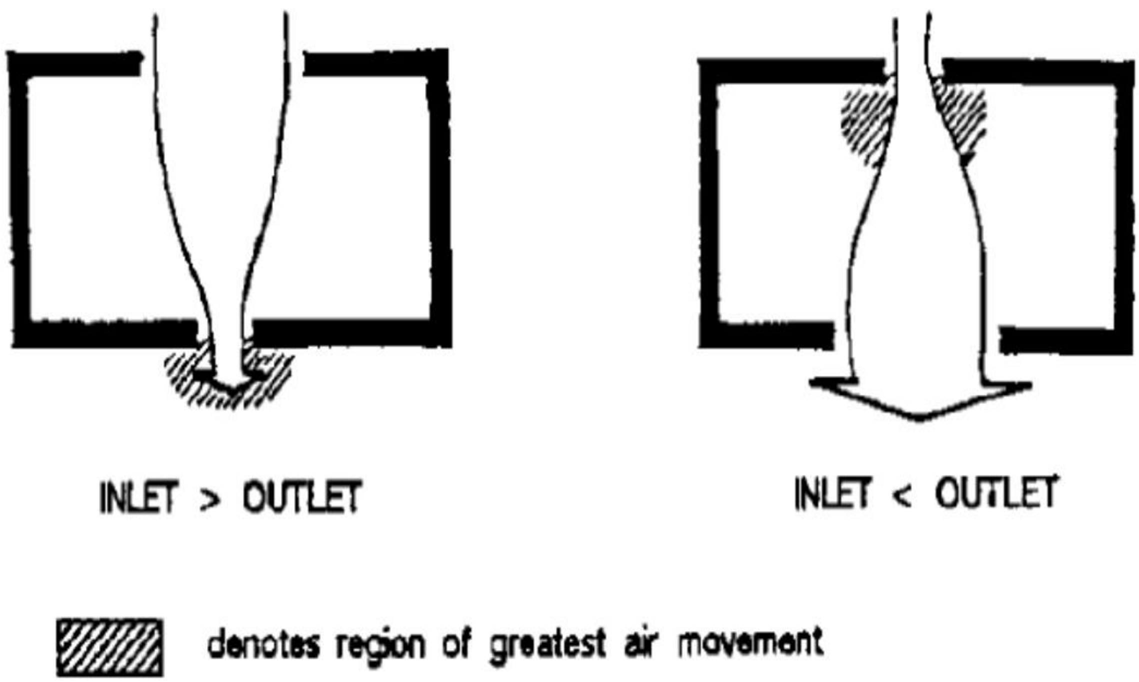


Figure 2: 10 The effect of relative WWR on airflow (Source: Guyer, 2013)

Design decisions for the use of natural ventilation in buildings need an estimation of the appropriate size of the openings and of their location in the façade. The study verified that, conditions of natural ventilation are influenced by the size of the windows, (Helenice and Marieli, 2017). The rate of interior airflow is determined by the magnitude of the pressure difference across the building and the resistance to airflow of the openings. UFC state that; the size, shape, type and location of the openings, especially the inlets, determine the velocity and pattern of internal airflow. Designing opening for ventilation should consider factors; predominant external wind speed and direction, Building envelope, and Location and type of inlet and outlet (Guyer et al., 2013)..

A study by (Campano, Domínguez-Amarillo et al. 2019), Indoor airspeeds, even under the most favorable conditions, are only 30% to 40% of the free exterior wind speed in cross-ventilated spaces, 5% to 15% of the free exterior wind speed in rooms with openings in one wall only and 3% to 5% in rooms with one opening (Figure 2:11).

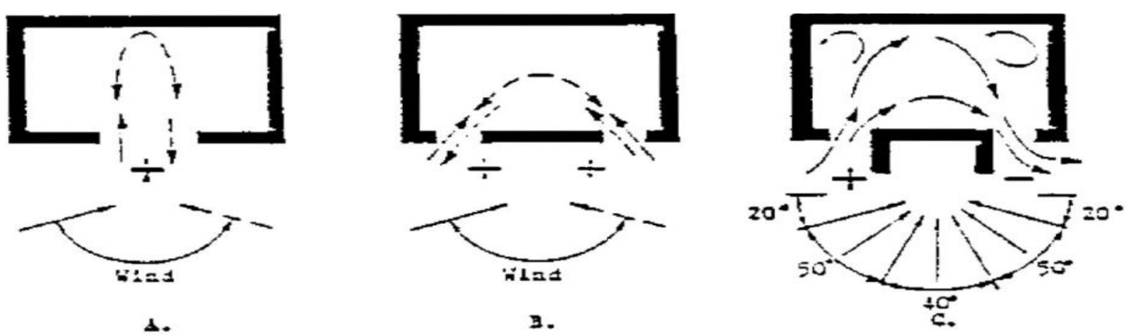


Figure 2: 11 Ventilation in rooms with openings in one wall (Source: Unified Facilities criteria, 2004)

A. **Worst case:** one opening. Ventilation is dependent upon pulses (fluctuation) of the wind.
B. **Better:** two windows placed as far as possible and facing obliquely into the wind. Ventilation is better because there is greater difference in pressure between the two openings.

C. **Best:** two openings placed far apart with appropriate location wing walls facing obliquity into the wind. Wing walls improve ventilation by creating positive and negative pressure zones that drive airflow (Sacht, 2017).

For wind-driven ventilation, outlet height has little impact on interior airflow, but inlet height has a great effect on the airflow pattern in the room. Positive pressures built up on the windward face of the building can direct the airflow up to the ceiling or down to the floor of the room. These positive pressures are related to the area of the windward face (UFC, 2004). Thus, a window located high on the wall directs airflow up to the ceiling because the positive pressure built up on the building face is larger below the window than above it (UFC, 2004).

The effect of window size depends on whether or not openings are cross ventilating. If openings are on one surface only, size has little effect on airflow. In cross-ventilated rooms, airflow is determined mainly by the area of the smallest openings; average indoor velocity and number of air changes is highest when inlet area is equal to or slightly less than outlet area. The air flow pattern due to the wind depends on the relative position of the openings. The best conditions are created when the outlet opening is higher and wider than the inlet (Figure 2:12) (the ideal is to have them of equal area) (Santamouris, 2005).

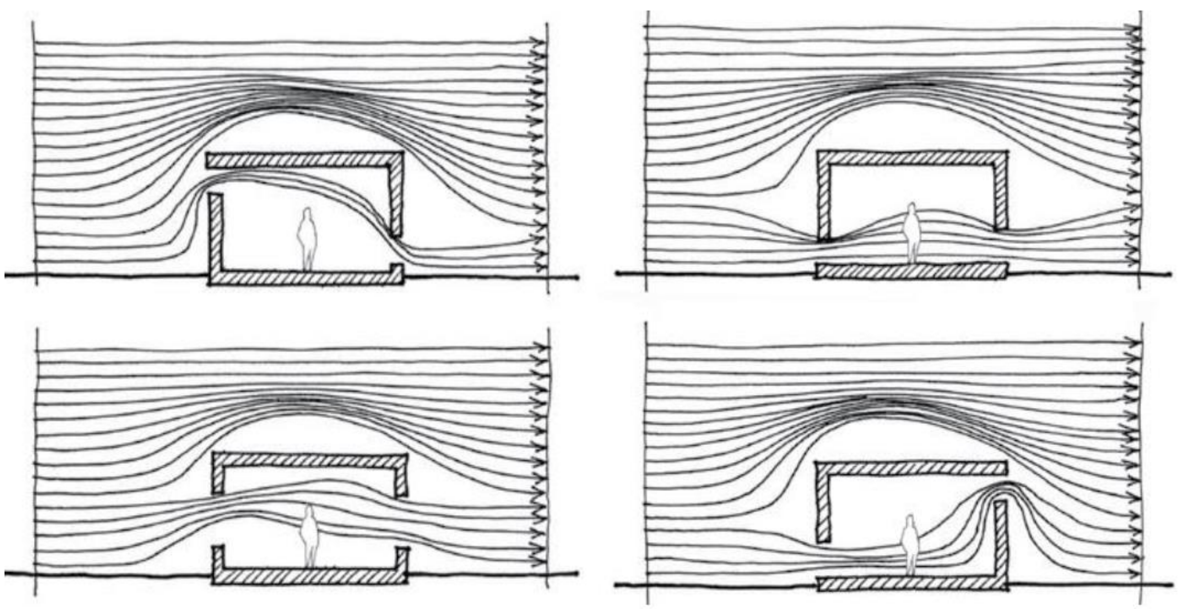


Figure 2: 12 Airflow pattern, according to the relative position of the openings (Source: Sustainable Building Design for Tropical Climates ,2015)

(Georgakis and Santamouris, 2005), For an elongated building without openings, the largest pressure differences (which drive cross-ventilation) occur when the building is perpendicular to the prevailing wind. However, this orientation does not necessarily result in the best average interior velocity rates or airflow distribution. For bodily cooling, the goal is to achieve the highest average room velocity in which air movement occurs in all occupied parts of the room. When windows are in adjacent walls, the optimum ventilation occurs with the long building face perpendicular to the wind, but a shift of 20 to 30 degrees from perpendicular will not seriously impair the building's interior ventilation. This allows a range of orientations for resolving possible conflicts with the optimum solar orientation (Guyer, 2013). Wind approaching at an incidence angle of 45 degrees results in interior velocities that are 15 to 20 percent lower than when the wind approaches perpendicular to the face. When windows are in opposite walls, a 45-degree incidence angle gives the maximum average indoor air velocity and provides better distribution of indoor air movement. Wind approaching at 90 degrees is 15 to 20 percent less effective. Wind parallel to the ventilation face produces ventilation depending entirely on fluctuations in the wind and is therefore very uncertain (Figure 2:13) (Guyer, 2013).

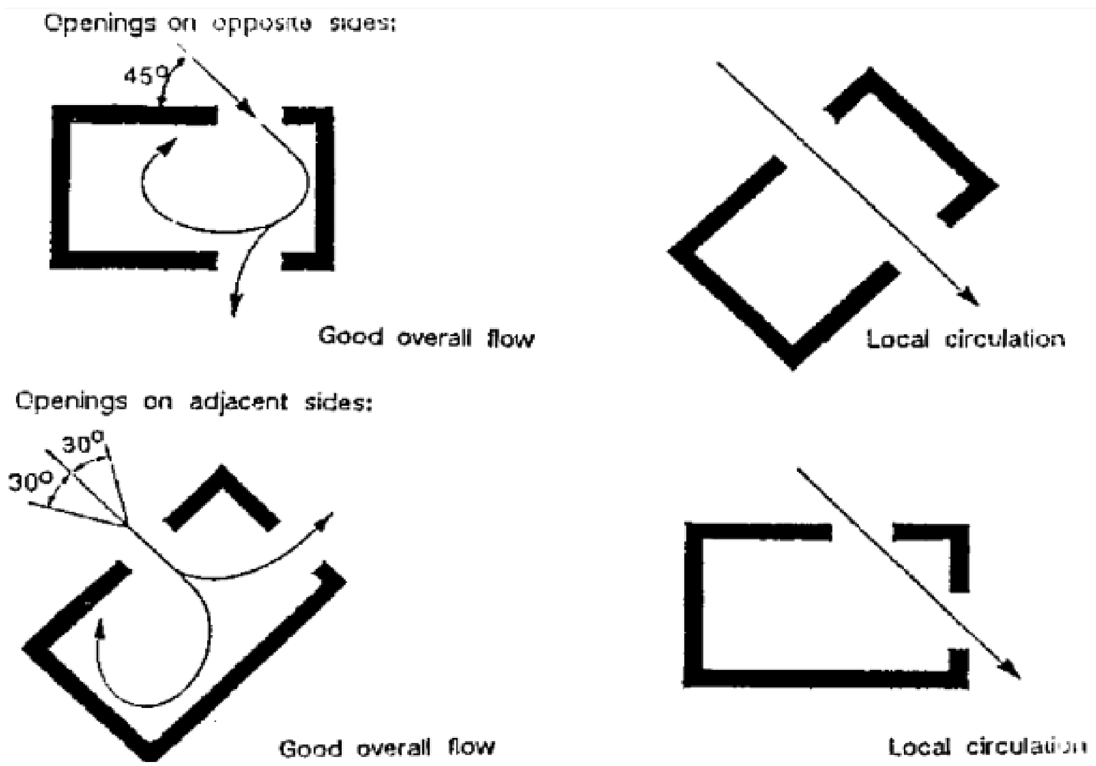


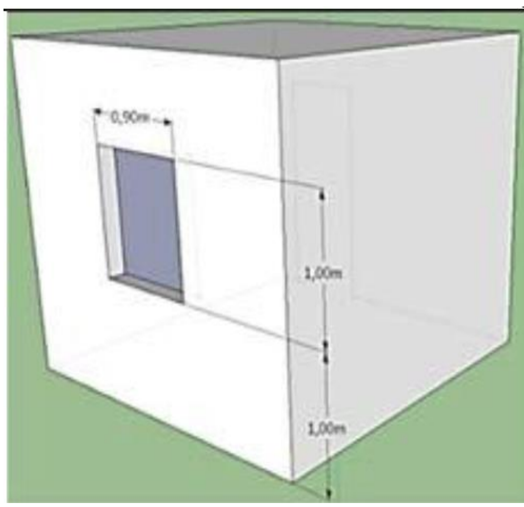
Figure 2: 13 Effect of wind incidence angle on interior airflow (Source: Guyer, 2013)

As the wind blows onto and around buildings, it creates regions in which the static pressure is above or below that of the undisturbed air stream. Positive pressure on the windward side forces air into the building, and negative pressure on the leeward side pulls it out of the building. Pressures on the other sides are negative or positive depending on the wind incidence angle and the building shape. The rate of interior airflow is determined by the magnitude of the pressure difference across the building and the resistance to airflow of the openings. The size, shape, type and location of the openings, especially the inlets, determine the velocity and pattern of internal airflow (UFC, 2004).

When designing and placing windows and openings for ventilation, the following factors must be considered: predominant external wind and directions when the winds occur. Construction of the building envelope and landscaping may hinder or facilitate natural ventilation of the interior spaces. Location and type of inlets has the largest effect on the airflow pattern through the space, Location and outlets type has little effect on airflow pattern. Number of air changes per hour has little to do with body cooling; the airflow velocity and distribution pattern are more important, and changes in indoor airflow direction tend to retard airspeed (Bhatia, 2012).

It was verified that, the conditions of natural ventilation were influenced by the variation of the angle of wind incidence (Sacht, 2017), which affected significant changes in the values of the pressure coefficients and air change rates per hour. Regarding the distribution of the airflow in the internal environment, the best performances were recorded when the wind moved through the window at an angle between 0° and 45°. According to the study, the highest rates were reached when the wind moved obliquely in the building (45°). The worst performance occurs when the wind moved parallel to the openings (90°), where the internal airflow has reduced velocities. In Table 1 below the two different dimensions of windows with respect to wind speed and the incident angle are given (Sacht, 2017).

Ventilation rate in two different WWR



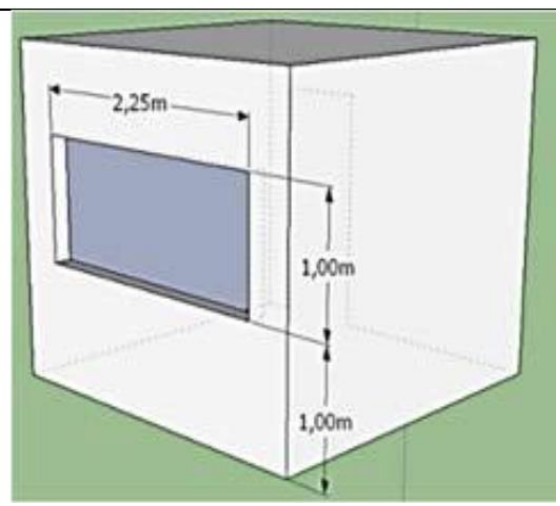
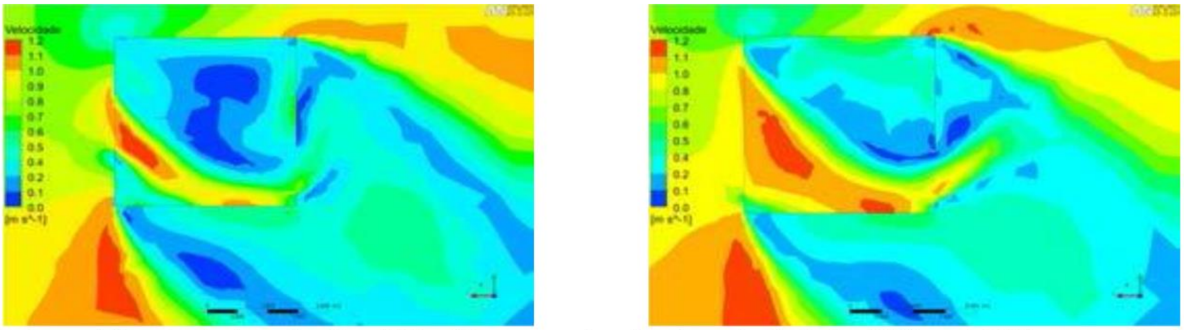


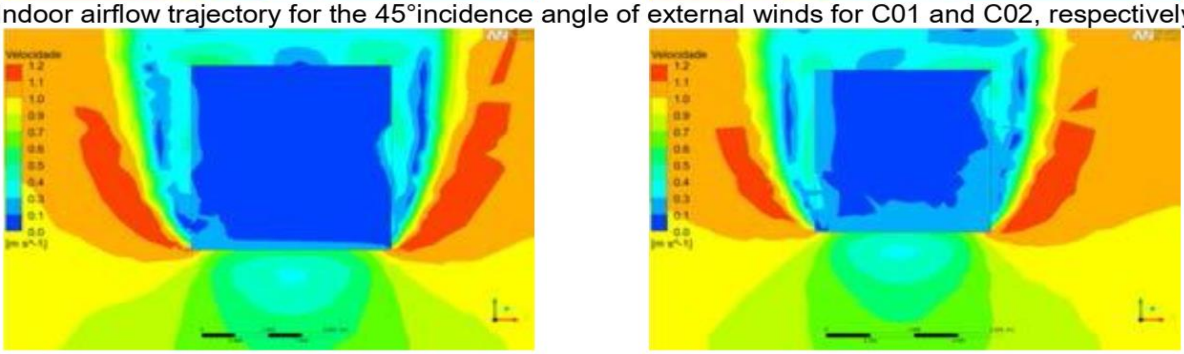
Figure 2: 14 Ventilation rate respect to WWR

CASE 01 = 10% of the area of the floor CASE 02 = 25% of the area of the floor

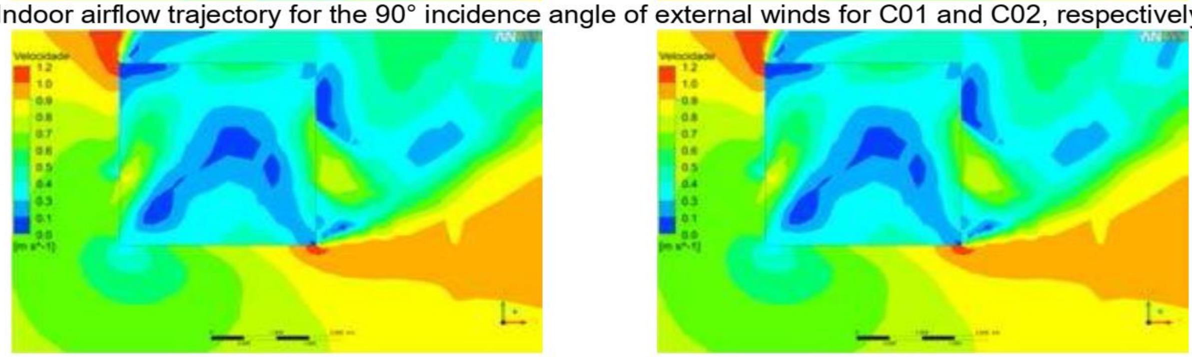
Trajectory of the airflow in the internal environment for the 0° incidence angle of external winds for C01 and C02, respectively.



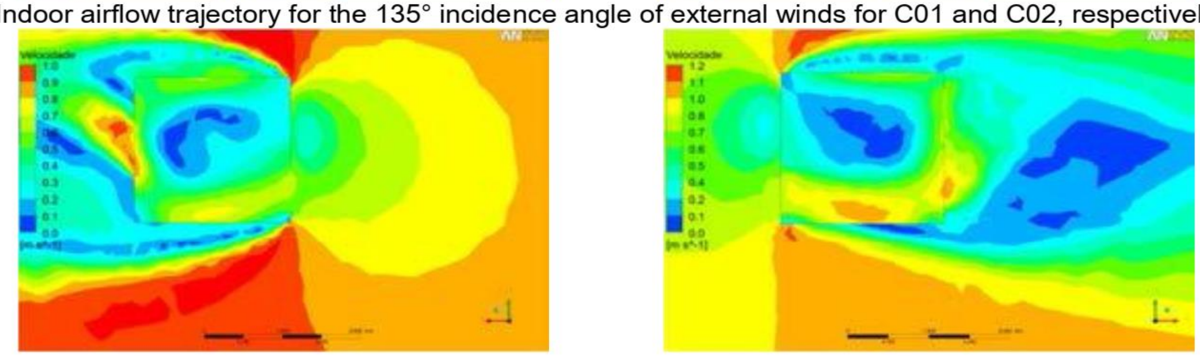
Indoor airflow trajectory for the 45°incidence angle of external winds for C01 and C02, respectively



Indoor airflow trajectory for the 90° incidence angle of external winds for C01 and C02, respectively.



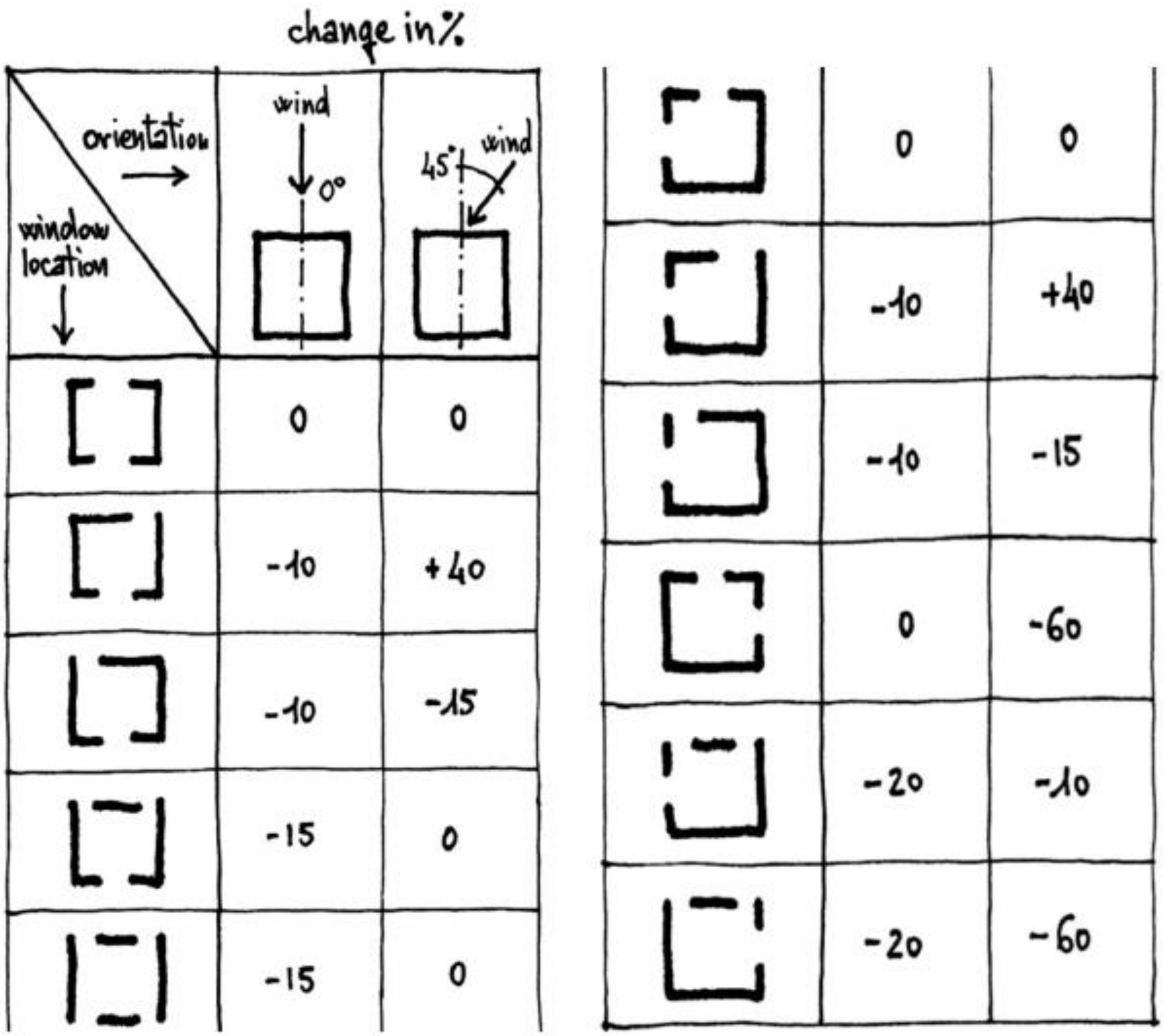
Indoor airflow trajectory for the 135° incidence angle of external winds for C01 and C02, respectively.



(Source: Windows Size and the performance of natural ventilation, 2017)

Figure 2: 15 Indoor airflow trajectory for the 180° incidence angle of external winds for C01 and C02, respectively.

The values of internal air speed deriving change if the location of windows is changed, i.e., if they are not centered and opposite. For a given external wind velocity, the value of the average internal air velocity must be corrected according to figure below.



(Source: sustainable building design for tropical climates, 2015)

Figure 2: 16 Effect of window location on indoor air motion

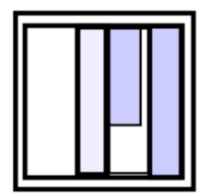
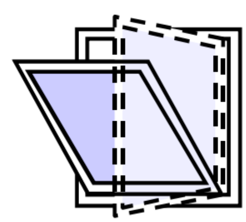
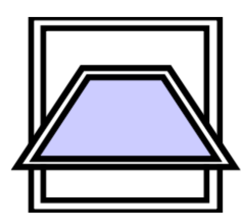
2.1.8 Architectural Elements

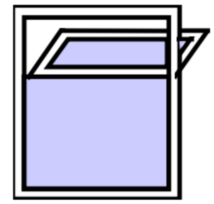
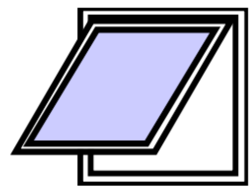
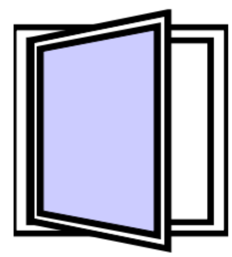
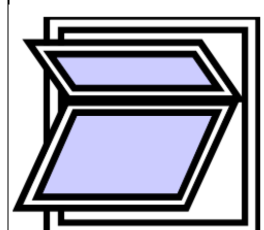
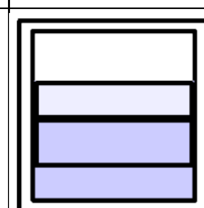
Specialized architectural features are often introduced to the building design to enhance and aid natural ventilation performance. The most important elements are openings in the façade, windows, wind towers, wind scoops, chimneys, double façades, atria, embedded ducts, etc. An overview over the various elements is provided below together with the ventilation principle the individual element is most likely to be associated with (Fung and Lee 2015).

2.1.8.1 Windows

Good window design is vital to ensure effective natural ventilation; different window types have varying ventilation characteristics, acoustic properties and weather protection. Windows (together with doors and roof lights) have the advantage of being easily shut by the user and are easy to seal effectively. Their performance can be compromised by blinds, shutters or louvers used for solar control or blackout purposes and this needs to be taken into account when selecting the window type (Al-Tamimi, Fadzil et al. 2011).

Table 2:1 Characteristics of different window designs

Window Type2	**Airflow**	**Ventilation Effectiveness**	**Comments**	**Position of Opening**
Horizontal sliding sash	Very good	Medium	No obstruction of internal blinds or external paths can be draughty	
Tilt and turn	Good	Medium	Control is complex. Can reflect noise into room and turn function can be difficult with blinds good at providing draught free winter ventilation	
Centre pivot	Very good	Good	Can obstruct blinds and prevent glare control for VDU use and reflect noise into room	

Bottom hung inward opening fan light	Medium	Very good	May obstruct blinds. Can provide good control of external noise from ground level	
Top-hung outward opening	Good – but less so if restricted opening	Good	Can reflect noise into the room. Can pose a hazard if opening over a pathway or playground	
Side-hung casement	Good	Poor	Poor security when open and rain can enter. Can pose a hazard if opening over a path or playground	
Upper fanlight and outward opening casement	Good	Very good	Good all-round performance. Can pose a hazard if opening over a path or playground possible rain ingress	
Vertical double	Very good	Medium	No obstruction of internal blinds or external paths.	

2.2 Contextual Literature Review

2.2.1 Condominium Housing in Ethiopia

Condominium housing is a relatively recent concept in Ethiopia. It's the same age as the IHDP. Condominium Housing in Ethiopia covers the Ethiopian government's ambitious intentions and efforts since 2005 G.C. to build housing for low- and middle-income people, create considerable employment, and stimulate small businesses (Planning. 2010).

2.2.2 Condominium Housing in Adama city

Adama, like most other cities in the country, has a severe housing crisis. Following the condominium proclamation approved by the Ethiopian government, the Adama city municipality has built several condominiums in different parts of the city between 2005 and 2006 G.C to solve this problem. According to figure 2:19 is eight (8) condominiums site in Adama city, and they are Duket and Sodober site (located in kebele 09), Silase, Atana tera and Goro site (located in kebele 01), Ganda gara (lujoo), and Cherkacherk (adodee) site (located in kebele 04), Moenco site, (located in kebele 05). Then, building selection is depending on the following determinant factors.

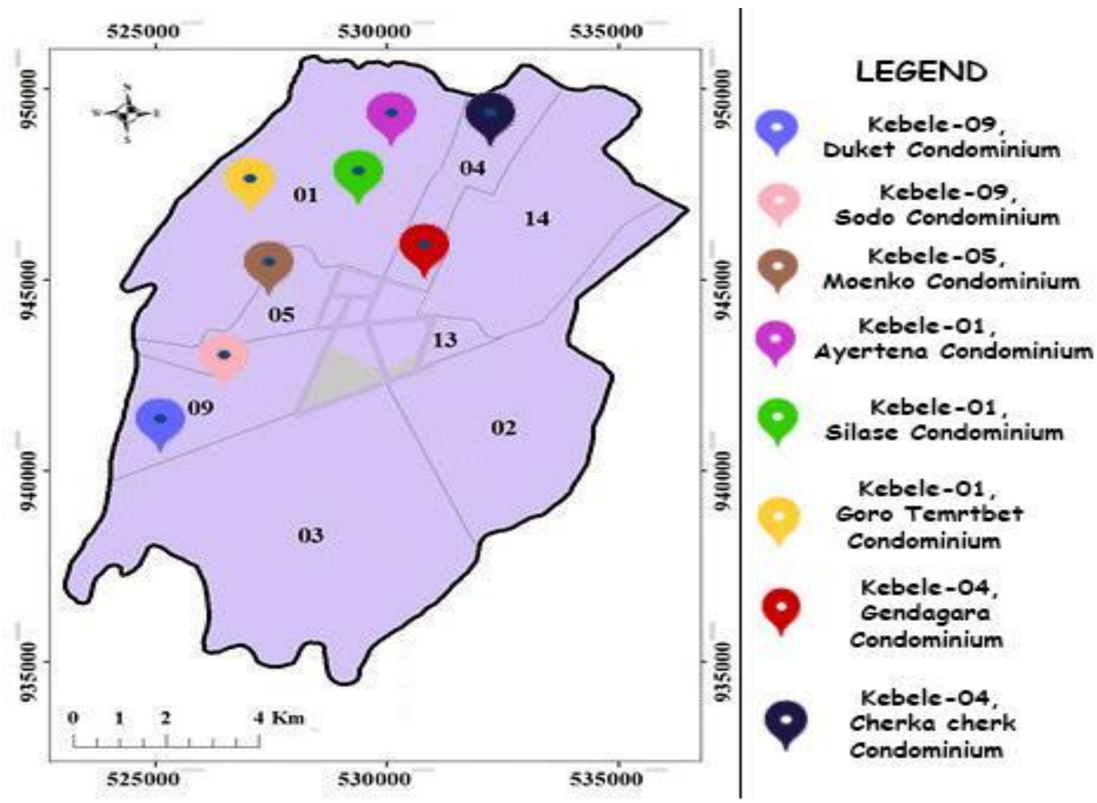


Figure 2: 17 Location of Condominium site found in Adama city

2.2.3 Ethiopian building codes and standard

Every space designed for human occupation must be provided with natural light through outside glass openings, according to the Ethiopian Building Code and Standard (EBCS) amended in 2014. If one-half of the shared wall is open and unobstructed, any room should be regarded a section of a neighboring room for daylight illumination, should provide an opening of not less than l/l0th of the inner room's floor area of 2.5 m2. A space designed for human occupation must have a minimum net glazed area of 15% of the total floor area of the room served (EBCS, 2020).

2.2.4 Condominium orientation in Adama

Around 70% of buildings in Adama city are oriented on an east-west axis or south orientation, and all exterior faces of buildings get solar radiation throughout the year. As a result, the interior temperatures in these surroundings are high, affecting thermal comfort. Building orientation should be examined concerning the sun to decrease facades facing east and west and to accept local prevailing winds, as a result of the combination between building orientation and natural ventilation. Therefore, building orientation should place a premium on decreasing solar gain while boosting natural ventilation.

2.2.5 Potential of Natural Ventilation

Ethiopia located at the Northern hemisphere the trade wind blows predominantly from the northeast. Trade winds are the powerful prevailing winds that blow across the tropics. According to National Geographic, trade winds are generally very predictable. The trade wind and the Local wind has a great impact on Wind drive natural ventilation. As both wind types can be predicted it is mandatory to study both in order to design naturally ventilated building. For natural ventilation to be effective there has to be a close relationship between the architecture and the air circulation system. This includes the opening design and Orientation. Regions located near the equator such as Adama 8.55° N 39.27° E receive far more solar radiation compared to those located farther from the equator (Walker 2010).

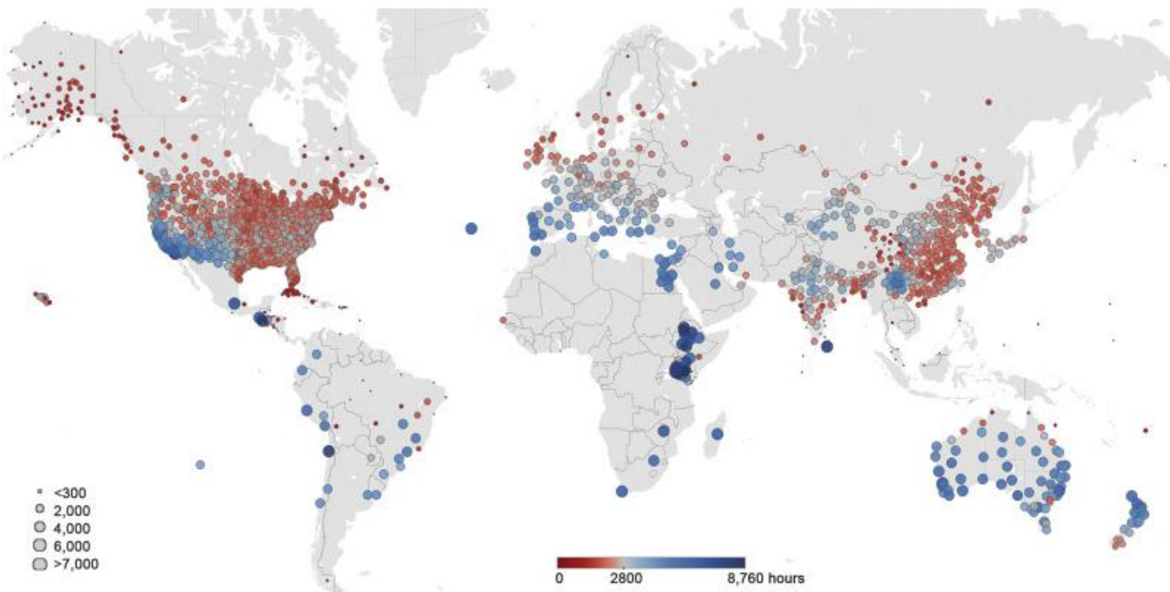
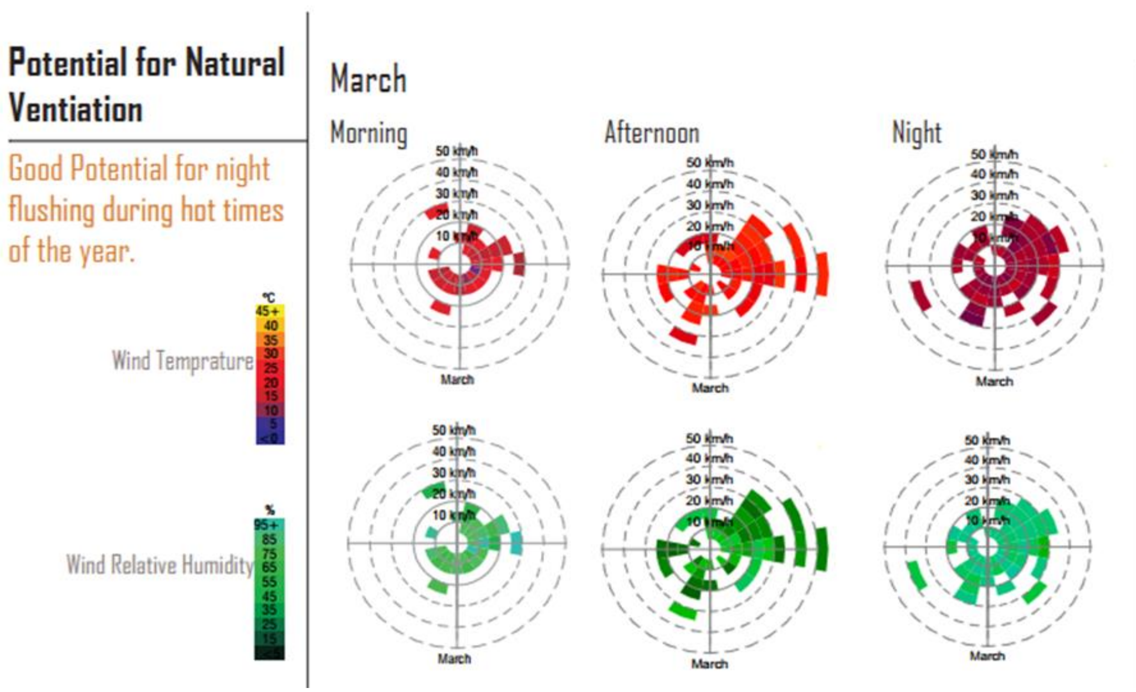


Figure 2: 18 Map showing natural ventilation prediction Potential of direct ventilation, Potential of high ventilation and potential of low ventilation respectively (source: Chen, 2017)

2.2.6 Application of Natural Ventilation in Adama

Depend on figure 2:19, Annual Average wind speed 3.5 m/s. The wind blows from east to west during the winter and northeast to northwest in Summer. The minimum wind speed occurs during September (1.65m/s), while the wind with high velocity occurs during December, January, and February (3.05-3.2 m/s) (Fung and Lee 2015).



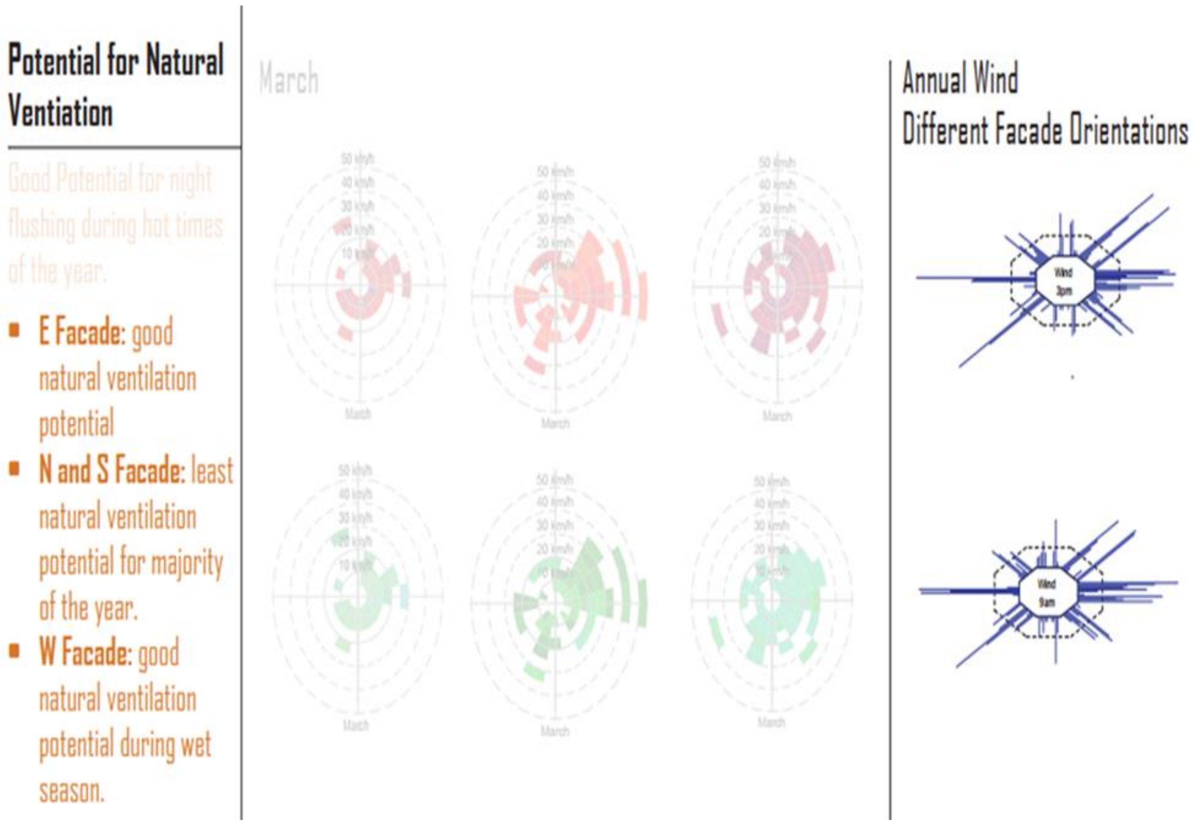


Figure 2: 19 Wind condition in Addis Ababa (Source: Climate responsive building guidelines, 2006)

There is a limited study about natural ventilation including all cities of Ethiopia. In Addis Ababa, the capital of Ethiopia outdoor air temperature and humidity are in a comfortable range providing great potential for natural ventilation during daytime all throughout the year. It is conductive to provide night flushing during relatively hot times of the year. East and West openings have greater potential for good natural ventilation than North and South openings (Figure 2:19), (Yacob, 2014).

2.2.7 Window sizing for natural ventilation

2.2.7.1 Window size for cross ventilation

When the inlet and outlet windows are equal, the wind speed at the height of the window is calculated using (Equation 4) with the reference height of 10m and correction factors given in (Figure 2:20). By assuming that inlet window size is equal to outlet window size (Figure 2:21). When the air flow angle is at 45^0 “K” is equal to 0.3 (a). when the airflow angle is perpendicular to the window the value of “K” is 0.6 (Khan, Su et al. 2008).

Figure 2: 20 Plan of the room with equal windows size at an angle of 450 (a) and 900 (b) respectively

To determine the effect of a different ratio between inlet and outlet window area (Figure 21), the same calculation is used with the ratio of the windows. Tracing the graph using the ratio between the inlet and outlet to get the airflow rate (GładyszewskaFiedoruk and Gajewski 2012).

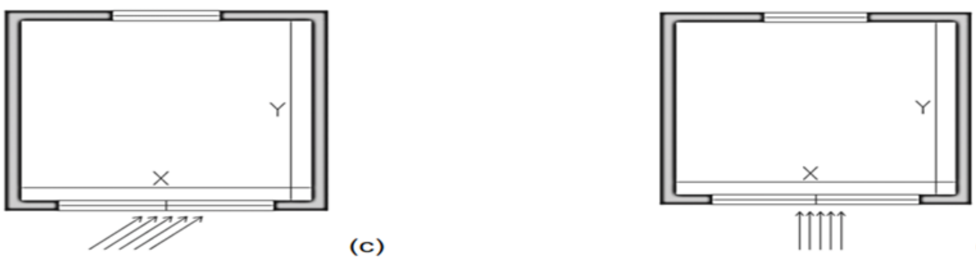


Figure 2: 21 19 Plan of the room with different windows size at an angle of 450 (a) and 900 (b) respectively

2.2.7.2 Average wind speed

The mean monthly wind speed over the year (in meters per second)

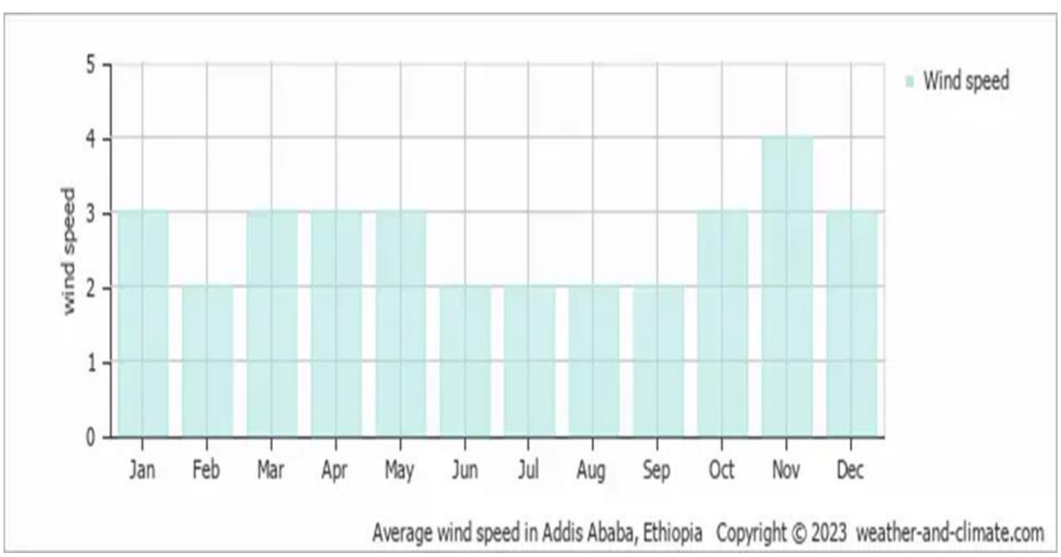


Chart 2:1 Average wind speed diagram of Adama city (Source: Addis Ababa, Ethiopia (72 KM, 45 Miles)

2.3 Empirical Literature Review

2.3.1 Data Analysis and Interpretation

The daily means wind is taken from NASA(MARRA-2) and represents estimates at 10m and 50m above the local surface over a 0.50 latitude x 0.50 longitude grid. Wind direction at a given height in meters as the meteorological convention. The meteorological convention gives the direction from which the wind originates and wind direction is measured in degree clockwise from due north. To calculate wind speed at different height Equation 4 has been used, for correction factors as a function of the **height** and **roughness** of the ground (Table 5) is used.

$$\frac{V_z}{V_{10}} = KZ^{\alpha} \quad \text{………………………….. Equation 4}$$

Where: V_z = Wind speed at height Z (m/s)

V_{10}=Wind speed at 10m (m/s)

K and α are two coefficient that vary depend on the types of ground (Source: Kolendowicz, 2007)

Table 2:2 Correction factors as a function of the height and roughness of the ground

Terrain	**α**	**K**
Open countryside, flatland	0.17	0.68
Low-density urban periphery	0.20	0.52
Urban area	0.25	0.35
Downtown	0.33	0.21

(Source: Sustainable Building Design for Tropical Climates, 2015)

Average wind speed is categorized by using the Beaufort's scale. The Beaufort's scale is a system originally developed by Admiral Beaufort (1805) and subsequently revised by other works giving an approximate estimate of wind speed, (Kolendowicz, 2007).

Table 2:3 Beaufort scale of wind speed (Source: Kolendowicz, 2007)

Beaufort No.	**Wind speed(m/s)**	**Description**	**Land condition**	**Comfort**
0	0–0.5	Calm	Smoke rises vertically	No noticeable wind
1	0.5–1.5	Light air	Smoke drifts	
2	1.6–3.3	Light breeze	Leaves rustle	Wind felt on face
3	3.4–5.4	Gentle breeze	Wind extends flags	Hair disturbed, clothing flaps
4	5.5–7.9	Moderate breeze	Small branches in motion, raises dust and loose paper	Hair disarranged
5	8.0–10.7	Fresh breeze	Small trees in leaf begin to sway	Force of wind felt on body
6	10.8–13.8	Strong breeze	Whistling in elegraph wires, large branches in motion	Umbrellas used with difficulty Difficult to walk steadily Noise in ears
7	13.9–17.1	Near gale	Whole trees in motion	Inconvenience in walking
8	17.2–20.7	Gale	Twigs broken from trees	Progress impeded Balance difficult in gusts
9	20.8–24.4	Strong gale	Slight structural damage (chimney pots and slates)	People blown over in gusts
10	24.4–28.5	Storm	Seldom experienced inland. Trees up rooted, considerable structural damage	

2.3.2 Wind rose method of Adama City

A wind rose is a graphical tool used to give a succinct view of how wind speed and direction are typically distributed at a particular location. The wind rose is given in polar coordinate system. Typically, the wind rose shows the frequency of winds speed blowing from particular directions over a specified period (NMA, 2021).

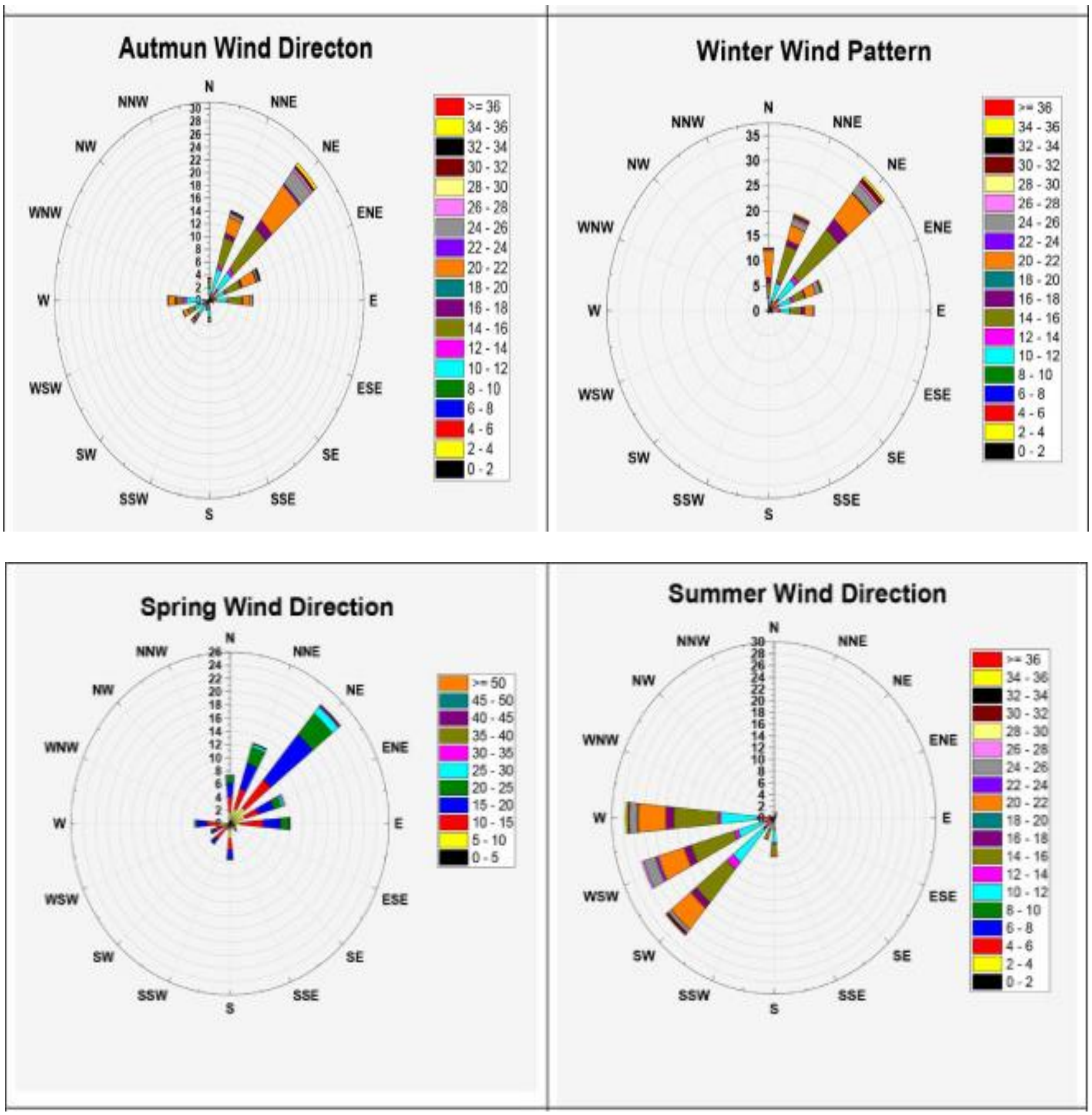


Figure 2: 22 Seasonal wind rose patterns. The different colors of the legend partition or spoke describe speed strength

2.4 Summary of Literature Reviews and Research Gaps

Even if there are no sufficient researches on naturally ventilated and thermally comfortable condominium 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 condominium 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 residential building 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 residential 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 residential building.
- There is no study conducted on this issue in Ethiopian context; So that, this study will contribute a lot.

CHAPTER THREE

METHODS AND MATERIALS

3.1 Description of The Study Area

Adama, is a city in the central Oromia Region of Ethiopia. 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. Located in the East Shewa Zone 99 km (62 mi) southeast of the capital, Addis Ababa, the city sits between the base of an escarpment to the west, and the Great Rift Valley to the east. Adama is a reformed city in the region, with a city administration made up of 14 urban and four rural kebeles. The Great Rift Valley is to the east, and the foot of an escarpment is to the west.

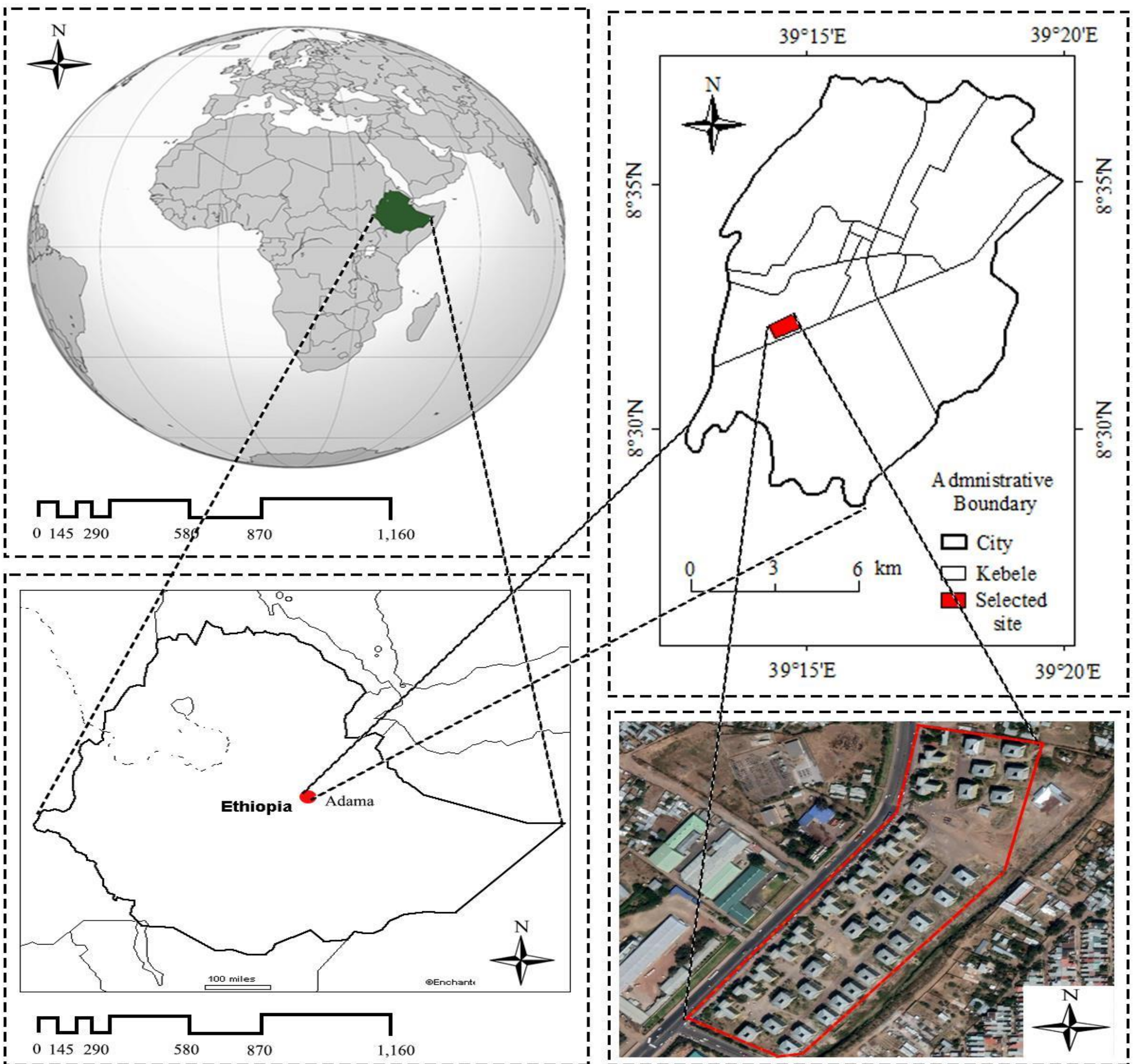


Figure 3: 23 Location map of study area (Source: own data)

3.2 Research Design

In this research design, there are two terminators that are interdependent: orientation and natural ventilation. The natural ventilation of the building, which is controlled by ASHRAE and ISO standards, will be affected if it is not oriented in line with weather conditions, sun's paths, and wind direction. finally, the best orientation for the selected location in the city is found by comparing all four of the axis. It also includes the method and procedures used in collecting and analyzing measures of variables specified in the problem statement (Figure 3:24).

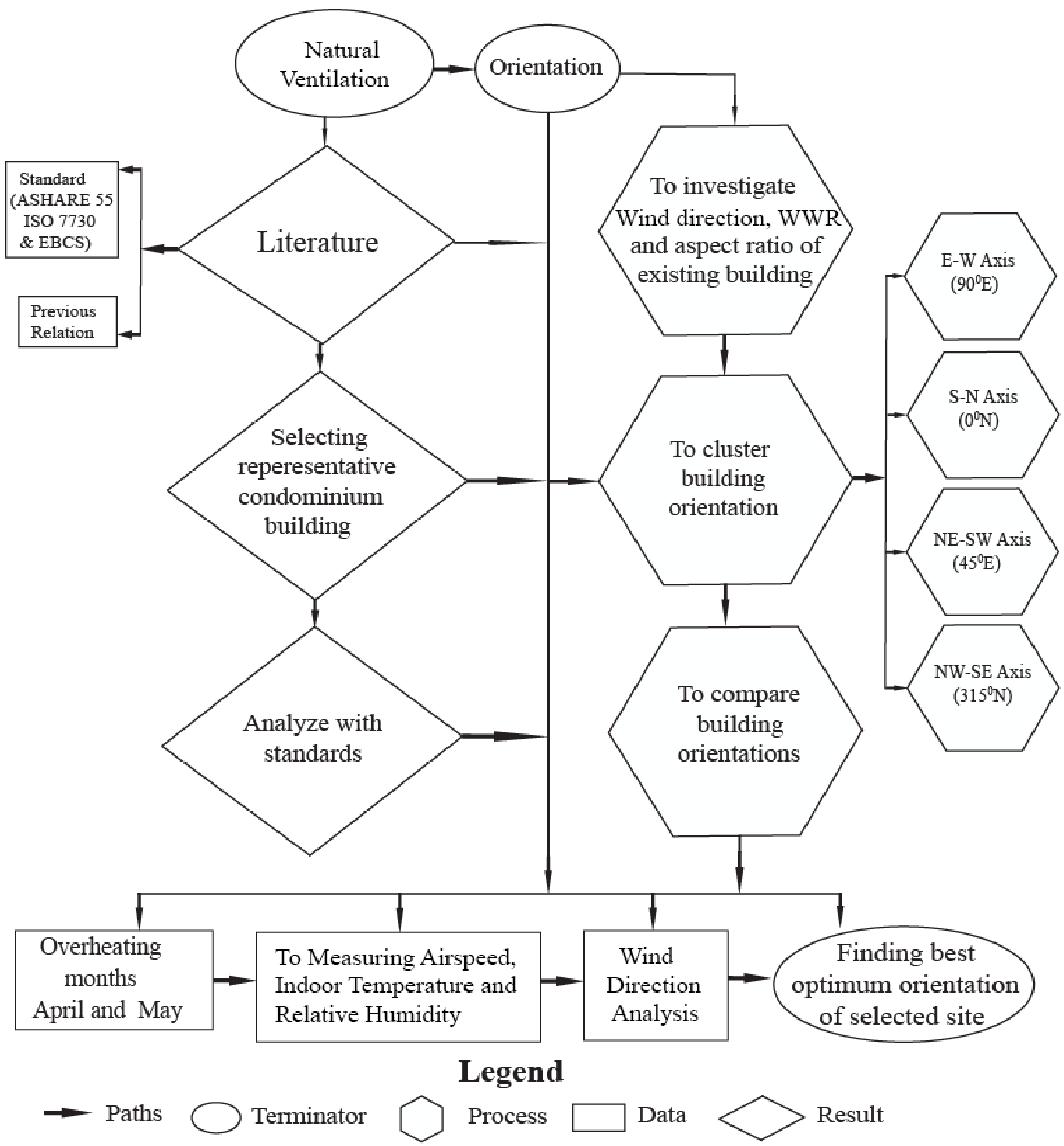


Figure 3: 24 Research Design (Source: own data)

There are 4 types of variables in this study.

(i) Airspeed

(ii) Indoor Temperature

(iii) Relative Humidity, and

(iv) Orientation of the buildings, and WWR.

3.3 Identification of Parameter

i. Weather Data and Location: For this study, weather data of the Adama City has been collected and the research was carried out. All necessary information regarding the air temperature and wind speed with their maximum, minimum, and average for all months of the year was imported from weather data national meteorological agency (NMA) of Adama. This can also be observed in the interpreted data of the weather file by climate Consultant and Ecotect Software.

ii. Building Form: During the measurement, the building form is not changed. The major parameter that impacts the thermal quality and natural ventilation of condominium houses are building orientation and openings on the façade.

iii. Location of Data Logger: The measured data has been taken three times a day a day at 3:00AM, 7:00 PM, and 10:00PM local time from April 15 to May 7, 2024.

iv. Window to wall (WWR) and Aspect Ratio (L/W): In this research, different window to wall ratios were to be examined to understand their exact impact on indoor thermal comfort and natural ventilation. WWR (South: 52.7%, East: 35.5%, West: 41.6%, North: 25.3%) and 57.2%aspect ratio (L/W) were chosen.

v. Natural Ventilation Principles: Most condominium building in Adama city follow cross ventilation principles used in the building to exploit the natural driving forces. Because Cross ventilation can be considered as the most effective technique that can grant a consistent large airflow with deep air penetration across the ventilated space. The airflow in the cross ventilation is a wind driven airflow, unless a difference in height between the inlet and outlet openings within the same wall is provided. According to ASHRAE standard, Cross ventilation is the most suitable technique for ventilating deep plan buildings. The depth of the room can be up to 5 times the height. The identical typologies, building materials, location, climate conditions, and floor level were evaluated in multiple orientations, facing south and north. In each residence, three data loggers were used to capture data from the living room, bedroom, kitchen, and toilet, which are where the tenants spend the majority of their time.

vi. Sample Floor plan

The three-bedroom has 57.9 square meters. The characteristics of the floor plan are almost similar to other sampled of other condominium sites but it has a partition with simple wall material for different activities and stores. This does not influence room temperature levels when compared to those sampled condominium buildings with other condominium buildings. Layout, utility, and service rooms and materials (except those modified) are similar to other rooms. In most cases, these should be located towards the south and north side of the sun path. For the lengthy facades, the building should be oriented south-north. However, it could be slightly rotated in either direction to allow the dominant East-west wind of Adama to improve natural ventilation without compromising the optimal orientation advantages.

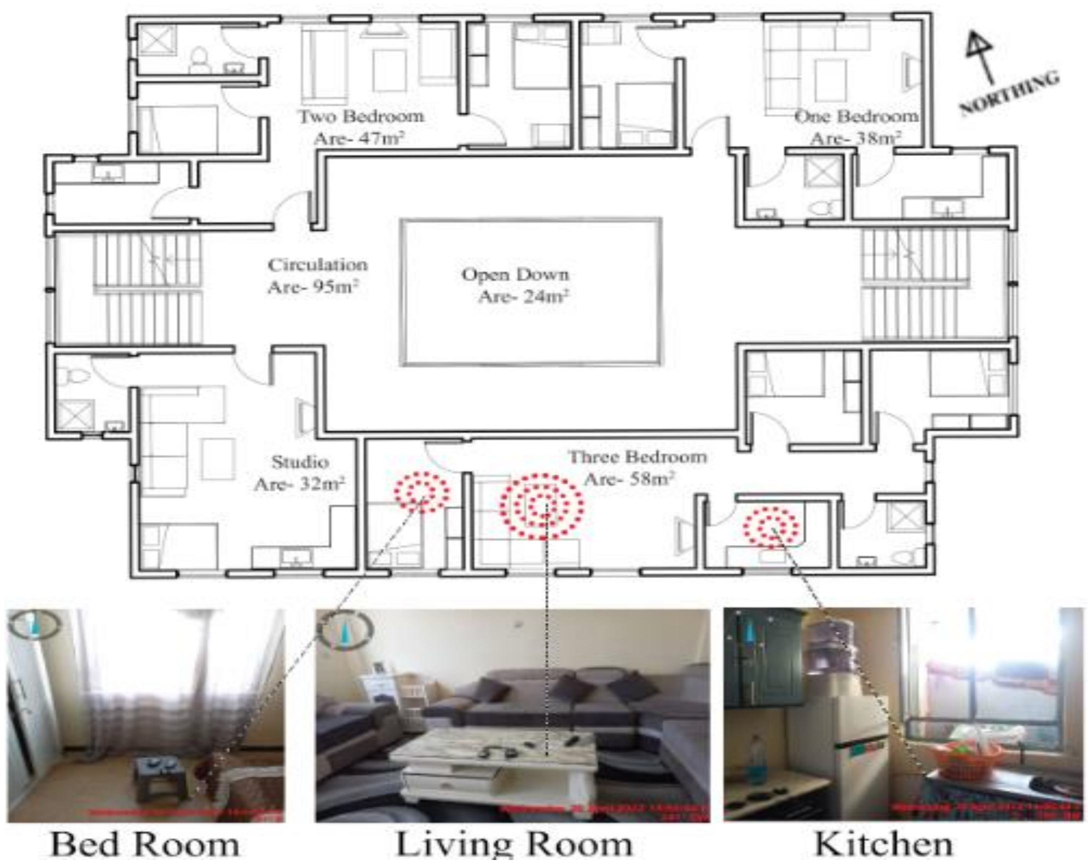


Figure 3: 25 typical sample of north facing room, as well as the placement of the data-loggers

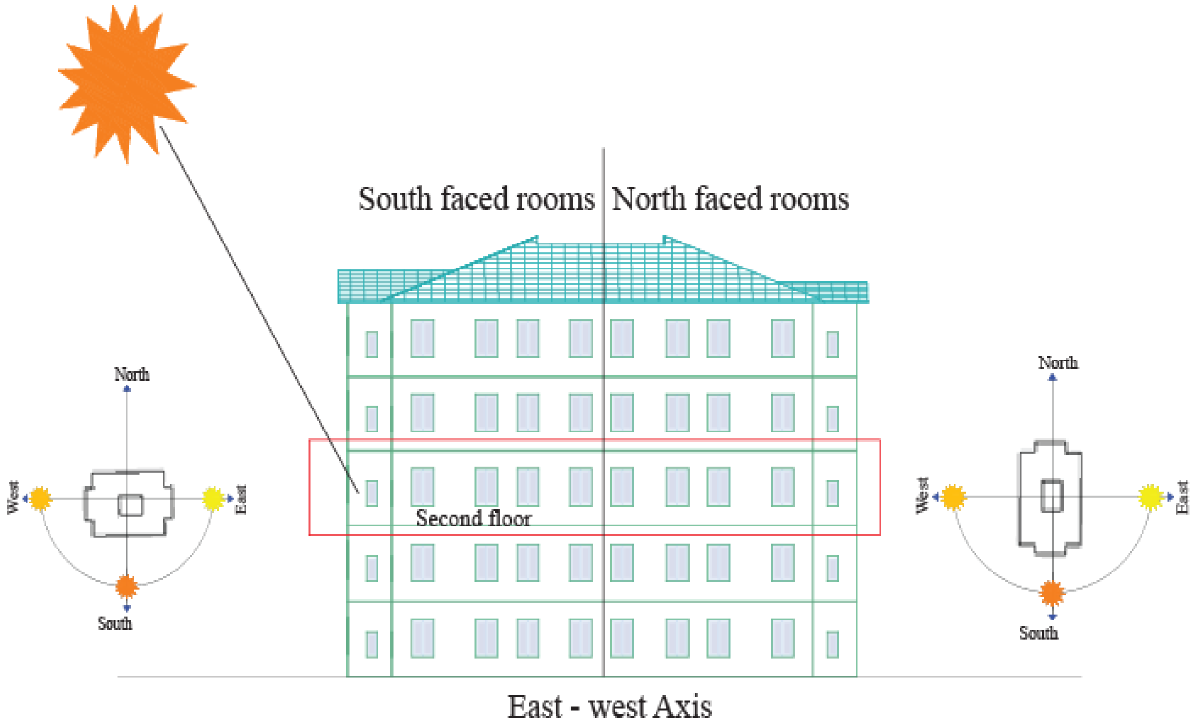


Figure 2: 26 WWR and aspect ratio for sample building (source: own analysis)

vii. Location of data logger: Before measuring, the rooms were split into several equal small sections that should be square, and the centers of each square were marked with a dot on the map (figure 3:27). The measured data has been taken three times a day at 3:00AM, 7:00PM, and 10:00PM local time from April 15 to May 7, 2024. The data loggers were placed in the center of each chamber, around 1.20 meters above the ground level.

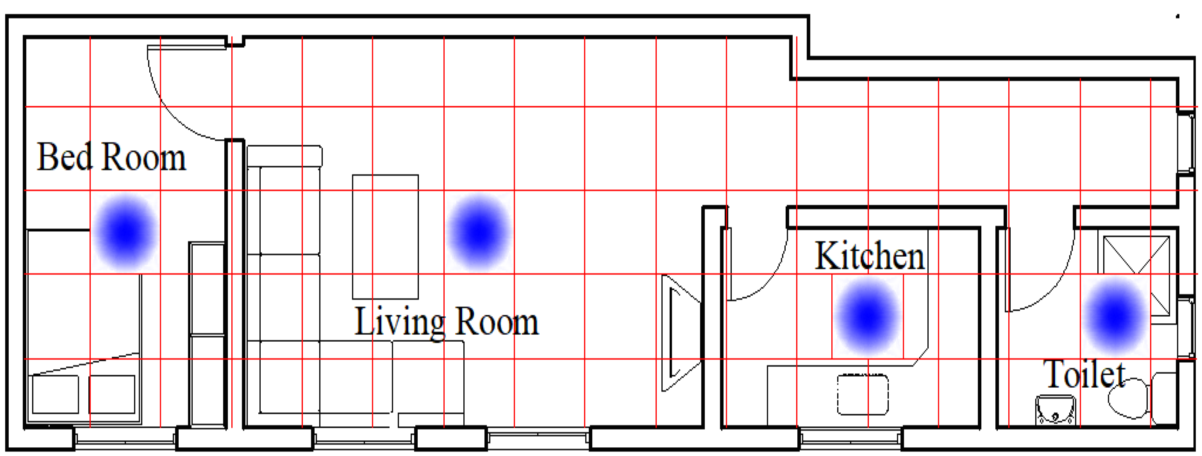


Figure 3: 27 Plan a view of sample rooms

viii. Way of measurements: during measurement, Care was taken to avoid impacts on the measurements Based on consideration of sky condition, temperature, and airspeed, air vents, doors, and windows are closed and internal heat sources such as incandescent lamps, refrigerators, and television offed. (Window closed, artificial light dimmed by sun radiation) Before installing the equipment, the researcher evaluated each residence and determined the best place to collect uniform measurements.

Table 3:4 Physical Characteristics of sample spaces

Zone (E-W axis: three bed room, S-N axis: three bed room)	Length (m)	Width (m)	Area(m^2)	Building material
Living room	E-W: 6.5m S-N: 5m	E-W: 4m S-N: 4m	E-W: $26m^2$ S-N: $20m^2$	HCB wall with cement plaster
Bed room	E-W: 2.5m S-N: 3m	E-W: 4m S-N: 3m	E-W: $10m^2$ S-N: $9m^2$	HCB wall with cement plaster
Kitchen	E-W: 3.5m S-N: 3.5m	E-W: 2m S-N: 2m	E-W: $7m^2$ S-N: $7m^2$	HCB wall with cement plaster
Toilet	E-W: 2m S-N: 2.5	E-W: 1.5m S-N: 1m	E-W: $3m^2$ S-N: $2.5m^2$	HCB wall with ceramics

Roof: The roof is partially covered in CIS, with the rest portion finished with cement and porcelain tiles. Gypsum board ceilings are utilized throughout the interior. The pitch of the roof is 12.5%.

Walls: Fine quartz painted HCB walls cover the majority of the building's south and north facades. The most common type of inside wall is HCB, however, Gypsum can also be found. The walls are plastered and painted yellow and gray on the interior and outside.

Floor: Terrazzo tiles cover the whole interior floor, however, carpets are also typical in most flats.

Pavement: There are also terrazzo and porcelain tiles. From the above assessment, each building block of the condominium site has a significant role in increasing the surface temperature and solar radiation through the wall.

Opening: Doors and single glass windows, aligned E-W, are framed by timber framework and transparent glass.

3.4 Field measurements

A field experiment was carried out in two residential units to measure the airspeed, indoor temperature and humidity of orientation in the condominium house of Adama.

In phase one, the East-West axis (south faced room) condominium building located (Latitude: at (8° 31' 59" N, Longitude: 39° 15' 00" E) and 1611m above sea level, in Duket on the second floor of four stories was selected. The measurement room is the living room, bedroom, kitchen, toilet, and outdoor respectively as shown in figure 4:28. The temperature, humidity, and airspeed, in the room were all measured. For 12 internal days from April 15 to May 7/2024.

In phase two, South- north axis (north faced room) condominium building located (Latitude: 8° 30' 54" N, Longitude: 39° 14' 56" E) and 1610m above sea level, in Duket on the second floor of four stories was selected. The measurement room is the living room, bedroom, kitchen, toilet, and outdoor respectively as shown in figure 4:28. Airspeed, indoor temperature,and humidity in the room were all measured. For 12 internal days from April 15 to May 7/2024. Field experiment was carried out in two residential units to measure the thermal quality of orientation in condominium house of Adama city.

3.5 Variable Parameters

a) Building Orientation: The orientation of the building is the first decision a designer takes throughout the design process. As a consequence, it was picked as the first variable to be examined. Condominium houses with various orientations were to be investigated. To conduct the measurements, a purposeful selection procedure was employed to choose sample residential dwellings of eight condominium sites Duket condominium site located in kebele 09 was selected, based on observation of the building orientation, the building envelope, location, and the massive of blocks in the site are considered which qualify the criteria and can represent the other building typologies. The building was tested from two orientations (east-west and south-north orientation) to investigate how temperature, relative humidity, airspeed, and affect indoor thermal quality.

b) Time of recorded: From April 15 to May 7 was chosen as the hottest day and both months were the hottest day of the year and in the typical winter season. Winter was defined as the months of December 22nd to June 21st. The overheating seasonal of the year, according to climate condition of Adama, are April, and May. As the result, the measurements were conducted during the hottest months and overheating season of the year, from April 15 to May 7, to better understand the impact of orientation on thermal quality. Airspeed, Temperature, and humidity, were all recorded by the data recorder. The measurements were taken for twelve days with one-day intervals from morning to late afternoon, diurnal overheating (3:00 am, 7:00 pm and 5:00 pm). During field measurement Thermo-hygrometer and Anemometer are set in different rooms of the house.

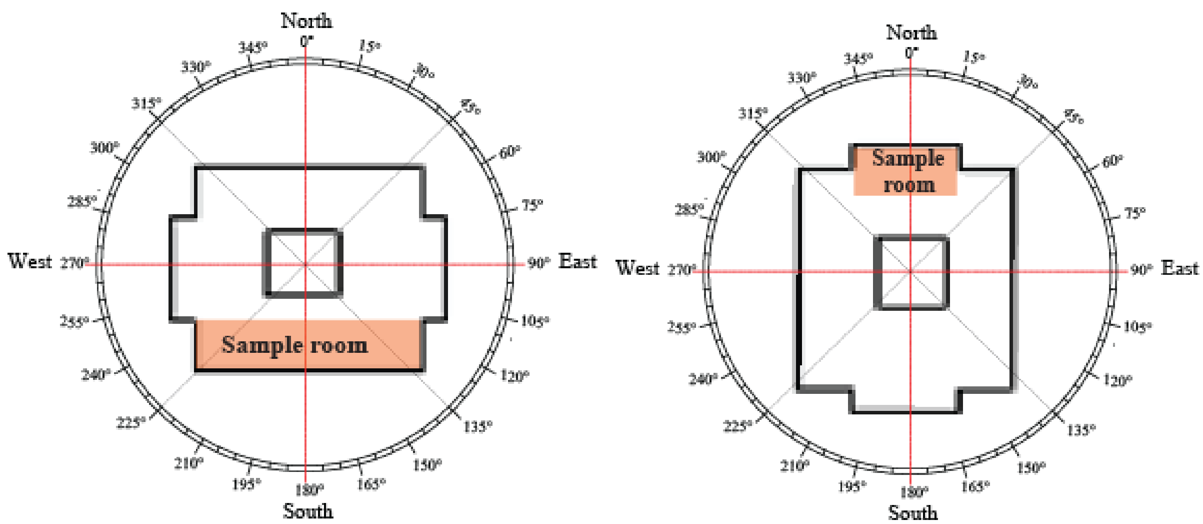


Figure 3: 28 Sample room face and orientation angle for measurements.

3.6 Study Approaches

3.6.1 Quantitative Approach

Involves the generation of data in quantitative data which can be subjected to rigorous quantitative analysis in a formal way. This approach can be further sub classified into inferential, experimental and Simulation approaches to research.

3.6.2 Qualitative Approach

Is concerned with subjective assessment of attitudes, opinion, and behavior.

3.7 Data Types & Source

The research relied on the data collected from Related Literature Reviews, site visits and observations, sample surveys. Throughout the process, in this research, primary data sources are (questioners, observation, interviews and field-survey). Secondary data sources and data gained include research journals, published research, Meteorological data, articles, books and internet websites such as standards like ASHRAE and ISO, video tutorials on natural ventilation.

3.8 Sampling size and Sampling technique

3.8.1 Population

The target population of the study was all the residents found in all building orientation ad building typologies in Adama city (selected building orientation dwellers), management and technical heads of the municipality and kebele officials and experts as their relevance to the study in providing appropriate information.

3.8.2 Sample Size

The sample size is determined according to Singh & Masuku, 2014 (as cited in Gosaye B, 2007), and (Kotari, 2014). The sample size is computed using the method below when the intended research population (N) is less than 10,000. (Total number of households is 2,279).

Formula 1: N_t =n/1+n/N…………… (1) Estimated household size (Singh & Masuku, 2014).

Where: n= the desired sample of household, (when the population is less than 10,000)

N = total households of condominium, is (2,279)

Nt= Estimated household size.

Formula 2: n = (Z2* p*q)/d2 …. (2) The desired sample of households (Singh & Masuku, 2014)

Where: Z= standard normal variable at the required confidence level 90% (Z=1.96),

p= estimated characteristics of target population that is 0.50,

d= level of statistical significance (i.e. 10%),

q= maximum standard deviation.

Formula 3: q= 1-p (3) …………… Maximum standard deviation (Singh & Masuku, 2014).

q=1-0.5=0.5,

$$n = ((1.96)2 * 0.5 * 0.5) / (0.1)2 = 96.04,$$

$$Nt = 96/1 + 2{,}279 / 96$$

$$= 96 + 23.73$$

$$= 119.7 \approx 120 \text{ (household sample size)}$$

A sample of 120 households (n=120) is selected from a total household of N=2,279, within the condominium housing. The sample households are chosen using a purposive sampling method is used to select the sample houses.

Based on this, purposive sampling techniques was used for questionaries' distribution based on:

i). To collect data from selected buildings.

ii). Who would have been the experience of living condominium house, respondents to fill the questionnaires will have drawn?

iii). For the need to reach the target issues of specific objectives.

3.8.3 Sampling Techniques

In this study, condominium buildings are selected purposely from residential buildings. The sample households are chosen using a stratified random sampling method. Then, building selection is depending on the following determinant factors. Most of the time the condominium buildings are built repetitively with the same orientation in different places. Repetitive buildings in the different areas face various problems including unregulated room temperature, natural ventilation, and other orientation constraints. (Kothari, 2004).

There is eight (8) condominiums site in Adama city which are located in different kebele. those are located.

- Duket condominium site, located in kebele 09
- Sodo ber condominium site, located in kebele 09
- Silase condominium site, located in kebele 01
- Atana tera condominium site,located in kebele 01
- Goro timirtbet condominium site, located in kebele 01
- Gende gara condominium site, located in kebele 04

- ✧ Cherkacherk condominium site, located in kebele 04
- ✧ Moenko condominium site, located in kebele 05

From those condominium sites I have chosen 4 sites located in (**Goro timirtbet** condominium site) kebele 01, (**Ganda Gara** condominium site) kebele 04, (**Moenko** condominium site) located in kebele 05, and (**Duket** condominium site) kebele 09 based on:

Selection Criteria of study Buildings

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 airspeed per hour that it receives and also transmit it in to the internal space of the rooms.

- ✓ Based on observation of the building orientation,
- ✓ The building envelope, location, and the massive of blocks in the site are considered which qualify the criteria and can represent the other building typologies.
- ✓ The WWR and location of windows in the site

3.9 Data Collection Tool

Both qualitative and quantitative data types will apply. Regarding this, the study will be used both primary and secondary data sources.

3.9.1 Primary data

3.9.1.1 Questionnaire

Questionnaires will be distributed for purposely selected sample households. The questions will be focused on understanding the satisfaction of the society towards the indoor air quality of buildings, the method that they use to regulate the ventilation system. Survey sample questionnaires will be distributed to 120 households. and the questionnaires from each respondent will be evaluated according to ASHRAE.

3.9.1.2 Observation

The data will be taken depending on parameters like orientation, climate, building mass, WWR, room height, and etc. From all these collected data would be WWR, orientation, Air velocity and relative humidity.

3.9.1.3 Field Survey

The field survey will focus on observation of the lifestyle of Adama society who live in the selected building and how they are challenged by the indoor air quality and also observe the techniques that the people use to inlet and exhaust the air inside the building. The data were taken from East- West Axis (South Facing rooms) and the South-North axis (North facing rooms) in purposely selected buildings: **Goro timirtbet** condominium site, **Ganda Gara** condominium site, **Moenko** condominium site, and **Duket** condominium site depending on parameters like orientation, Sun paths, wind speed and direction, and WWR.

Table 3:5 Instruments used to measure Environmental variables

Environmental Environmental indicator	**Test instrument**	**Specific objective**	**Accuracy**	**Image**
Air Speed	**Anemometer**	To measure the speed or volume of air movement of room.	**Accuracy**±0.05 m/s ± 0.25% of FSR from 50 mV to FSV Range=0.05–9.99 m/s	
Indoor Temperature and Relative humidity	**Thermo hygrometer**	To measures air temperature of room. Hot-Cold (°C). And relative humidity (water vapor in air) of room. Percentage.	Accuracy ±0.2 °C T-98% 10%-99% and 10°C -70°C (14°F -15°F). **Accuracy** ±3% RH - **98%** Range=0–100%	

3.9.2 Secondary data

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

3.10 Data Analysis methods

Triangulation is a technique used for cross-checking the analysis result. And compare the result of environmental variables.

Table 3:6 Summaries of methods

No	Specific objective	Data used	Collection method	Descriptive Analysis
1	To measure air speed, indoor temperature and humidity of selected building orientation.	Field measurement of air speed, indoor temperature, and humidity.	By using a thermo hygrometer, and anemometer,	By using an Excel graph.
2	To examine the relationships of the Wind direction respect to Building orientation, and WWR for natural ventilation of the condominium buildings.	Field survey Ecotect simulation	By measuring building, building, counting window, identify building orientation, and using the Ecotect simulation	By using tables, image and a scatter plot graph.
3	To identify best optimum building orientation based on wind direction and WWR, for natural ventilation of condominium building.	Field measurement of air speed, indoor temperature, humidity. Which building orientation is High and low airspeed, indoor temperature and humidity	By using a thermo hygrometer, and anemometer.	Comparing the measured data like airspeed, heating and loading load incrementing azimuth angle by using an Excel chart, graph, and table

3.10 Simulation analysis

These assessments were evaluated using the Ecotect simulation program's CFD outputs, which were derived from data such as direction (Azimuth angle), and weather data. The model has four stories with a 57.2 aspect ratio, a window-to-wall ratio of 52.7 percent in the south, 35.5 percent in the east, 41.6 percent in the west, and 25.3 percent in the north, and a flat pitched roof. The building has Single-glazed windows and have 120cm x 150cm window size.

3.11 Reliability and Validity

The accuracy of the instruments was checked. The value of measurements has been cross checked with the standard like ASHRAE 55, ISO 7730 and EBCS. To identify the respondent thermal perception and identifying the preference scale, the questionnaires were prepared in English and translated into both Afaan Oromo and Amharic (See Appendix II).

3.12 Ethical Consideration

For quality output the study has given prior concern on awareness creation on purpose and objectives of the study. Consent from each study participants would be obtained, before data collection. The anonymity and confidentiality of information will be secured. Legal permission will be attained from Adama residential building. All material used throughout the study will have acknowledged. The measuring equipment will be located in a way that doesn't disturb households. The researcher will be analyzed the data relative to standards without manipulation.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the result of the data and presents the analyzed data, which is collected during the study to ensure the objectives of the research. Subjective and objective approaches were used, according to environmental variables measured. Airspeed, indoor temperature, relative humidity, of condominium buildings are presented according to the collection of one-month survey in the hottest month and overheating season of April 15 to May 7, 2024.

4.2 To measure Airspeed, Indoor temperature and humidity of selected building typologies

4.2.1 Airspeed, Indoor temperature and Humidity of East-West Axis

According to chart 4:2, At peak times of day, the maximum airspeed 0.5m/s and the lowest 0.1m/s, indoor temperatures of all volumes were 35.1^{0}C maximum and 28^{0}C minimum, and the maximum humidity 32 and the lowest 22. The inside airspeed of the building E-W oriented with open floor plan ranged from 0.5/m/s - 0.1m/s, in contrast the building S-N orientated ranged from 1.94m/s to 1.1m/s.

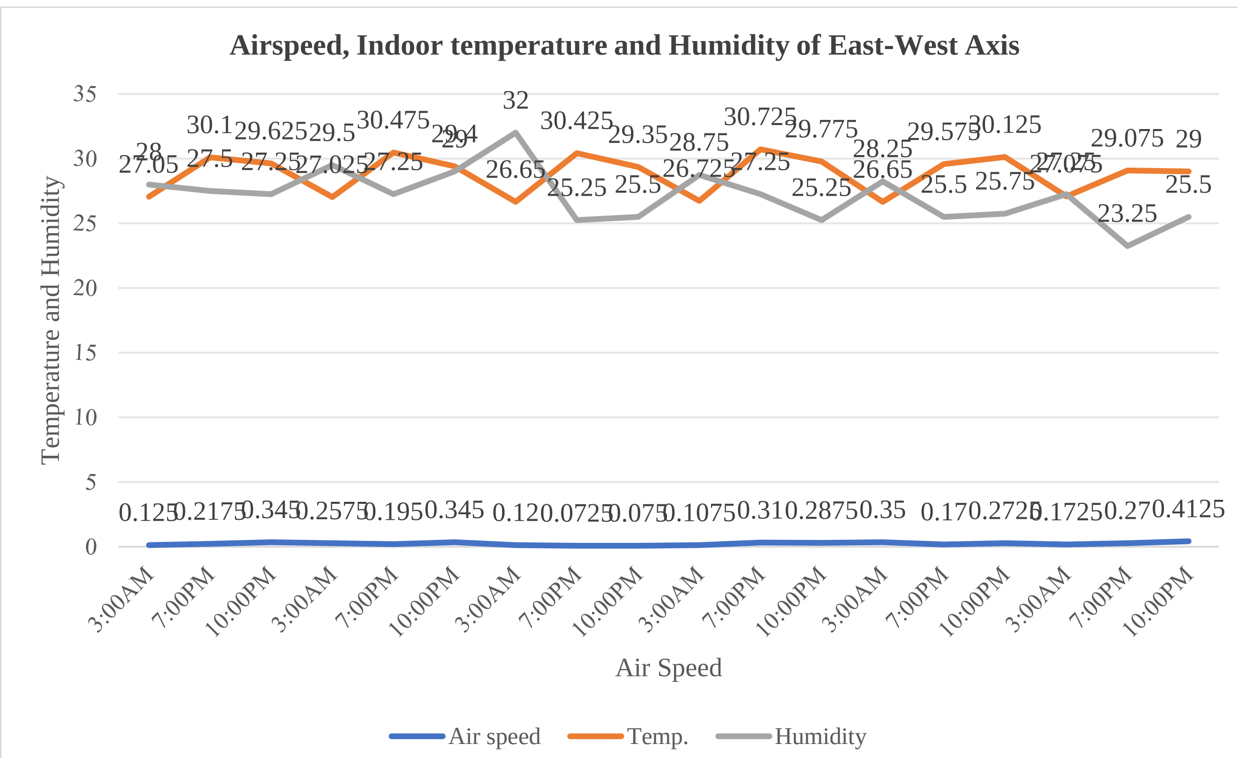


Chart 4:2 Airspeed, Indoor temperature and Humidity East-West Axis (Source: data survey)

4.2.2 Airspeed, Indoor temperature and Humidity of North-South Axis

According to the result which was recorded from April 15 - to - may 7, 2024, At 7:00 pm, the airspeed for the north-south orientation of the building is between 1.94m/s to 1.1m/s (chart 4;3). The air temperature is between 29 and 25 degrees Celsius when the building is orientated North-South Axis. While humidity for north-south building orientation is maximum 76 and minimum 45. The total thermal performance of a building is greatly influenced by the weather (i.e. temperature, humidity, airspeed). Variations in airspeed throughout the day have a direct impact on the thermal behavior of the building.

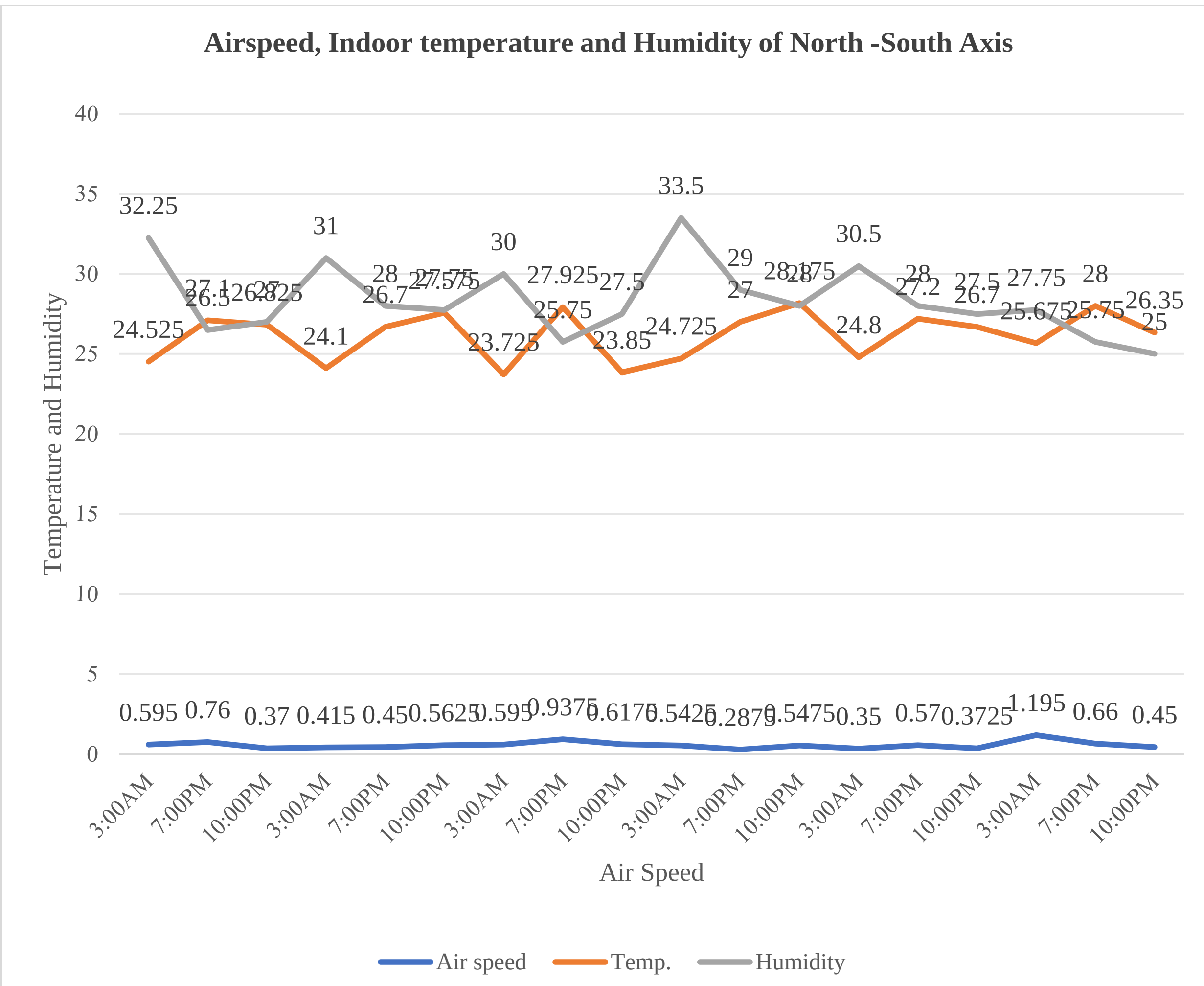


Chart 4:3 Airspeed, Indoor temperature and Humidity of North-South Axis (source: data survey)

4.2.3 Indoor and Outdoor of Airspeed of East-West Axis

Chart 4:4 shows the highest and lowest airspeed measurement results for indoor and outdoor of east-west axis buildings. According to the result which was recorded from April 15 to May 7, 2024, the highest airspeed recorded in indoor that oriented towards east-west direction was 0.5m/s and the lowest airspeed was recorded was 0.1m/s. while outdoor airspeed were 3m/s maximum and 0.4m/s.

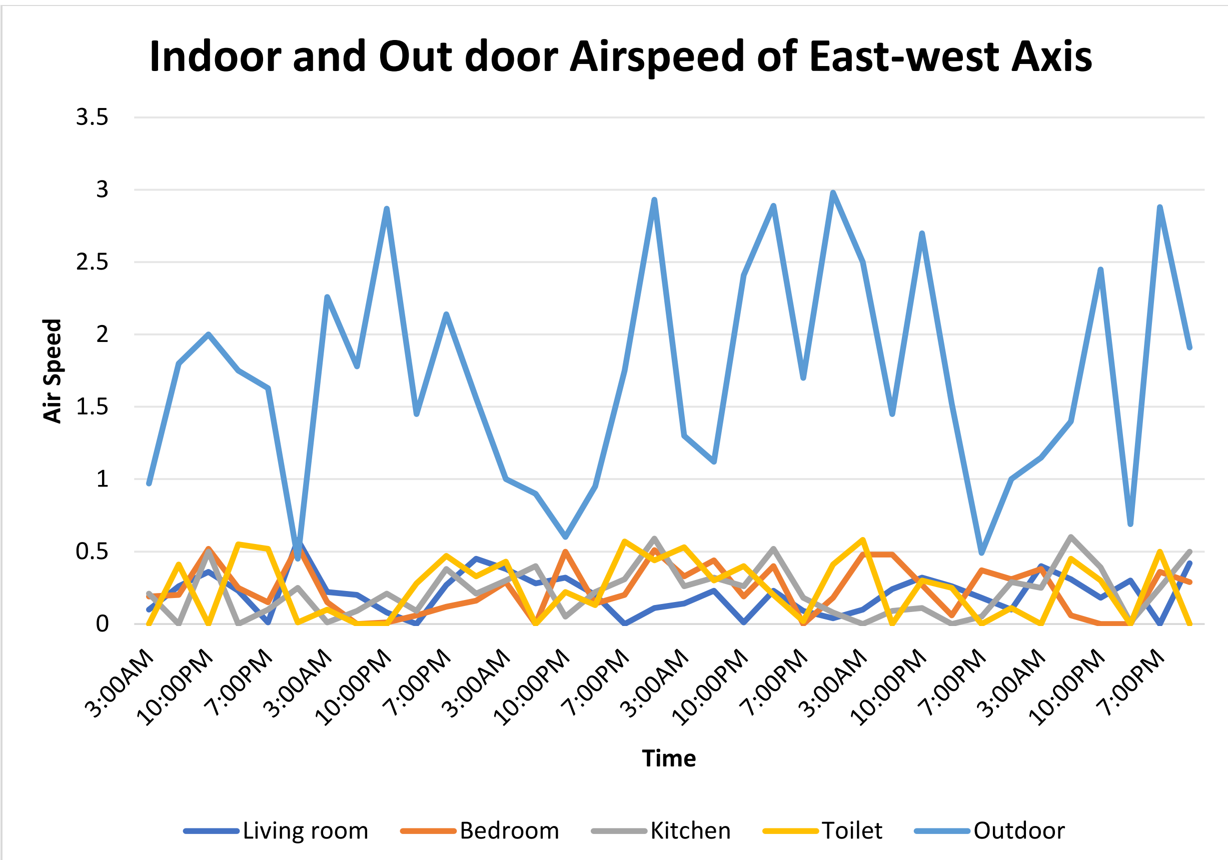


Chart 4:4 Indoor and Outdoor of Airspeed of East-West Axis (source: data survey)

4.2.4 Indoor and Outdoor of Airspeed of North-South Axis

According to the result which was recorded from April 15 - to - may 7, 2024, and Chart 4:5 shows the highest and lowest airspeed measurement result for indoor and outdoor of east-west axis buildings. According to the result which was recorded from April 15 to may 7, 2024, the highest airspeed recorded in indoor that oriented towards east-west direction was 1.94m/s and the lowest airspeed was recorded was 1.1m/s. while outdoor airspeed were 4m/s maximum and 0.5m/s.

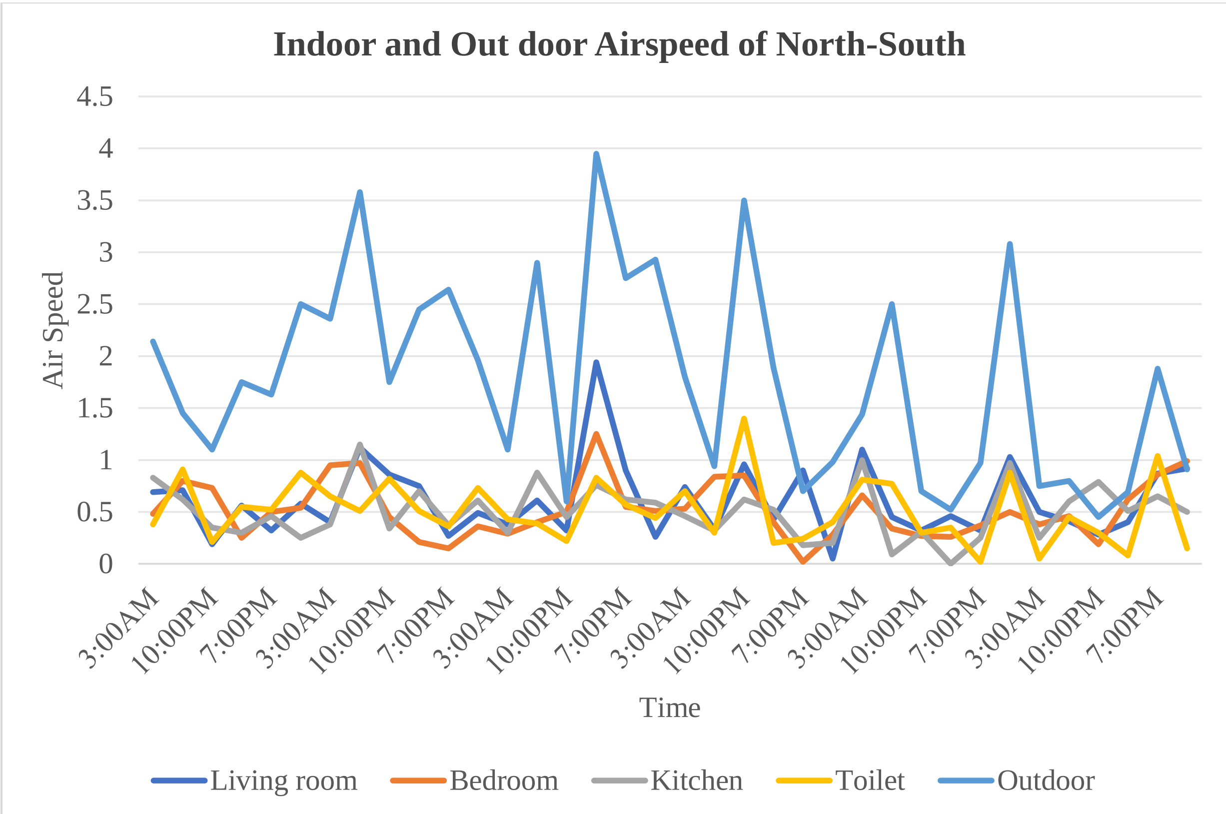


Chart 4:5 Indoor and Outdoor of Airspeed of North-South Axis (Source: data survey)

4.2.5 Indoor Temperature of East-West with North-South Axis

At 6:00 pm, the air temperature for the north-south orientation of the building is between 29 and 26 degrees Celsius (chart 4:6). The air temperature is between 35 and 28 degrees Celsius when the building is orientated east-west. According to the result which was recorded from April 15 - to - may 7, 2024, the highest indoor temperature recorded in buildings that oriented towards southeast direction was 35℃ in 7th March, between 1:00am - 3:00 pm; and the lowest indoor temperature was recorded in 5th of March, which was 25℃ between 9:00am - 11:00am. The average indoor temperature was 28.5℃.

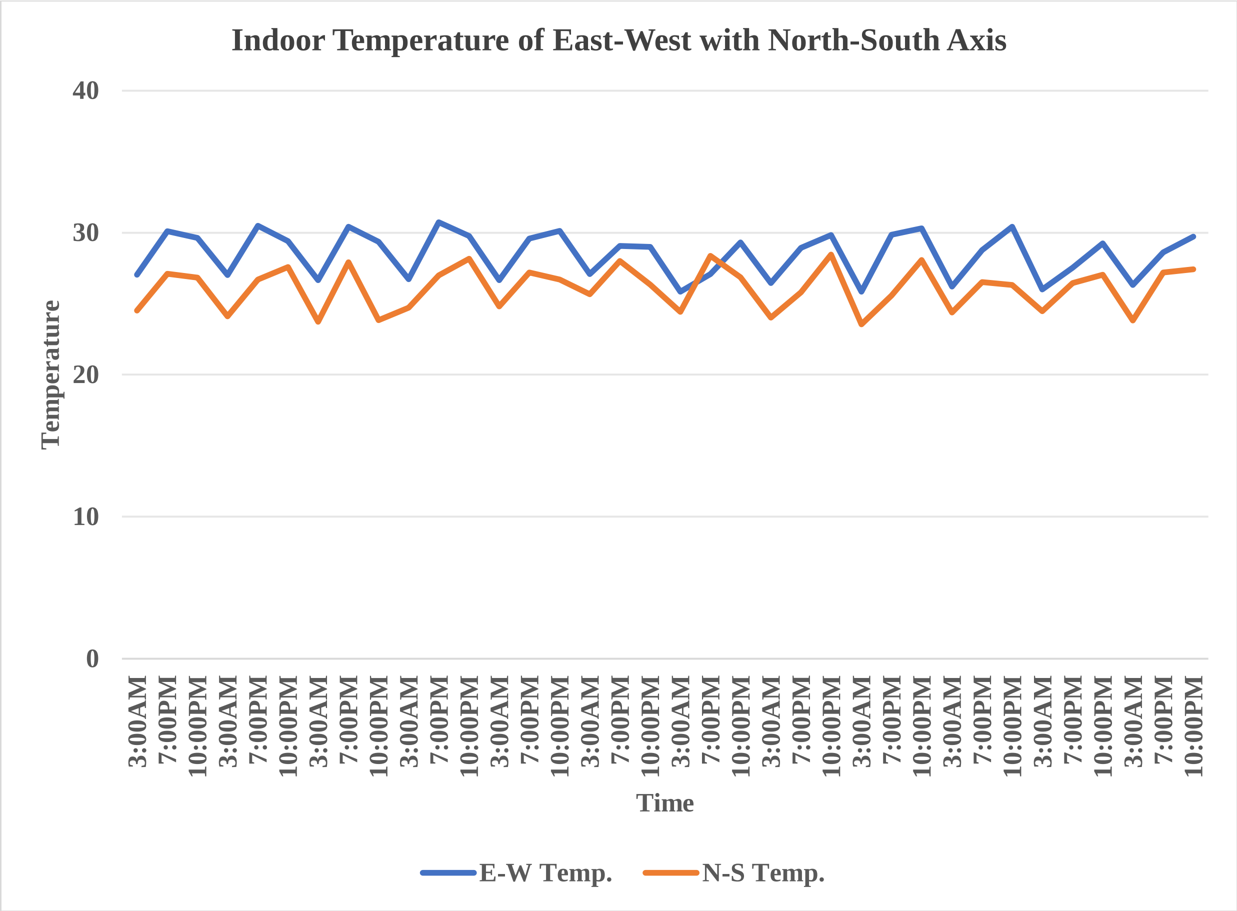


Chart 4:6 Indoor Temperature of East-West with North-South Axis (Source: data survey)

4.2.6 Air Speed of East-West with North-South Axis

The major of the wind speed is occur in North-South orientation (chart 4:7). In that orientation, wind speeds were created is 1.9 m/s - 0.5 m/s. The lowest of the wind speed is 0.2-0.6 m/s that occur in Southwest-Northeast orientation. Based on the above explanation, it is known that the angels of the building influence the wind divert. The principle of movement occurs is the inertia principle, where the existence of obstruction can deflect of airflow and it will influence wind velocity. An average of wind speeds that occur in the room is 0.2 m/s – 0.6 m/s

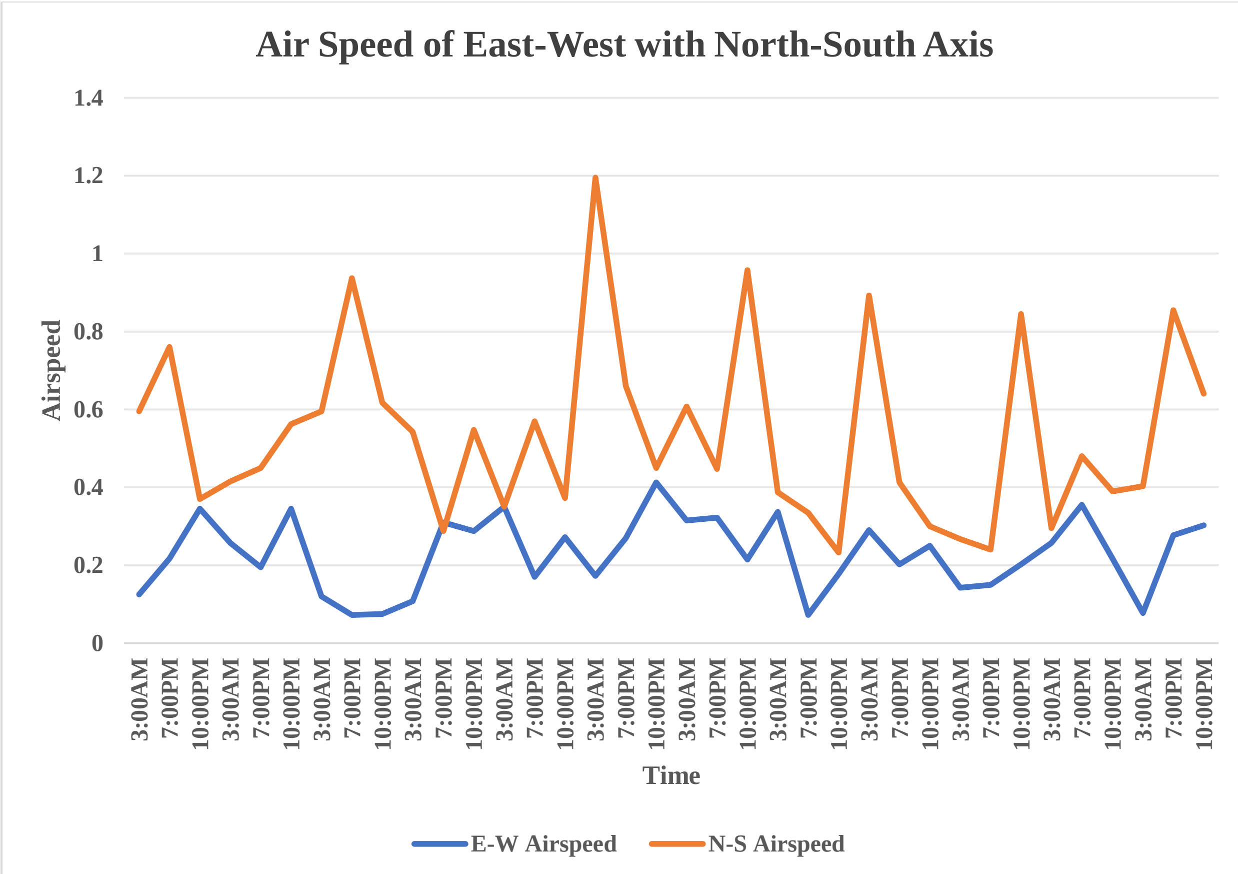


Chart 4:7 Air Speed of East-West with North-South Axis (source: data survey)

4.2.7 Relative Humidity of East-West with North-South Axis

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 room buildings oriented towards east-west, and north-south axis are shown below. According to Chart 4:8, the highest humidity of buildings that oriented towards east-west axis was recorded 32% in 5th March at 9:00am - 11:00am, and the lowest was measured 22% in 30th of April at 1:00pm - 3:00pm. And the highest humidity of buildings that oriented towards north-south axis was recorded 36% in 7th March at 9:00am - 11:00am, and the lowest was measured 23% in 30th of April at 1:00pm - 3:00pm.

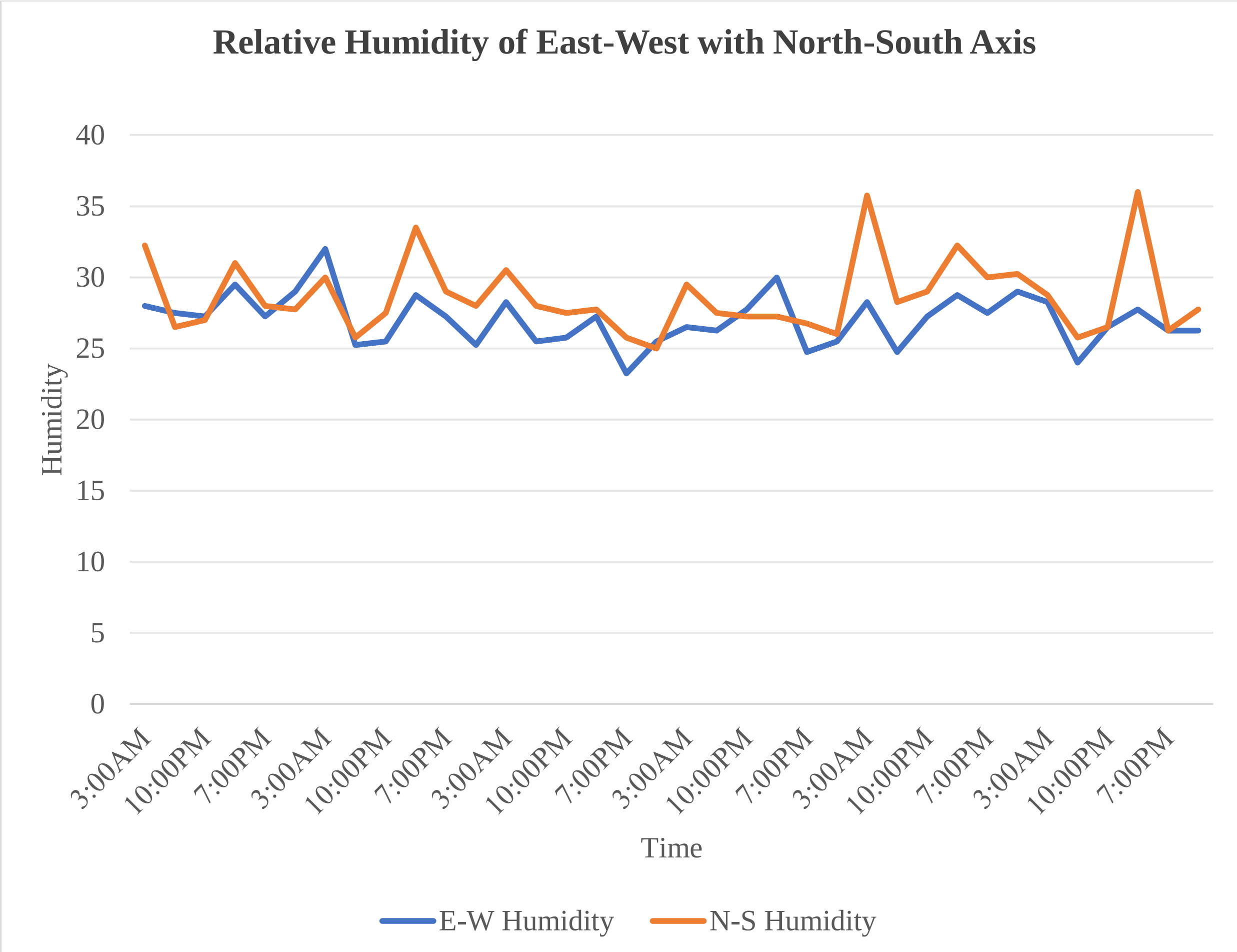


Chart 4:8 Relative Humidity of East-West with North-South Axis (Source: data survey)

The above charts show the highest and lowest humidity of rooms during different hours of the day. The measurement was taken starting from April 15 to May 7. According to the result, the highest and lowest humidity of southwest oriented buildings was recorded 34% measured at 5th March at 9:00am - 11:00am, and 24% in 30th of April at 1:00pm - 3:00pm respectively; for buildings oriented to south-east axis was 36% in 21st April 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 Apirl, 17th April and 2nd of may. 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.

4.3 To examine the relationship of building orientation with wind direction and WWR for natural ventilation of the condominium buildings

4.3.1 Building orientation of Adama condominium

In Adama, proper orientation of most Condominiums is not given due consideration. Buildings that are properly positioned take advantage of the temperature, airspeed, and prevailing wind. During the winter season, overheating from sun radiation is a major issue in Adama.

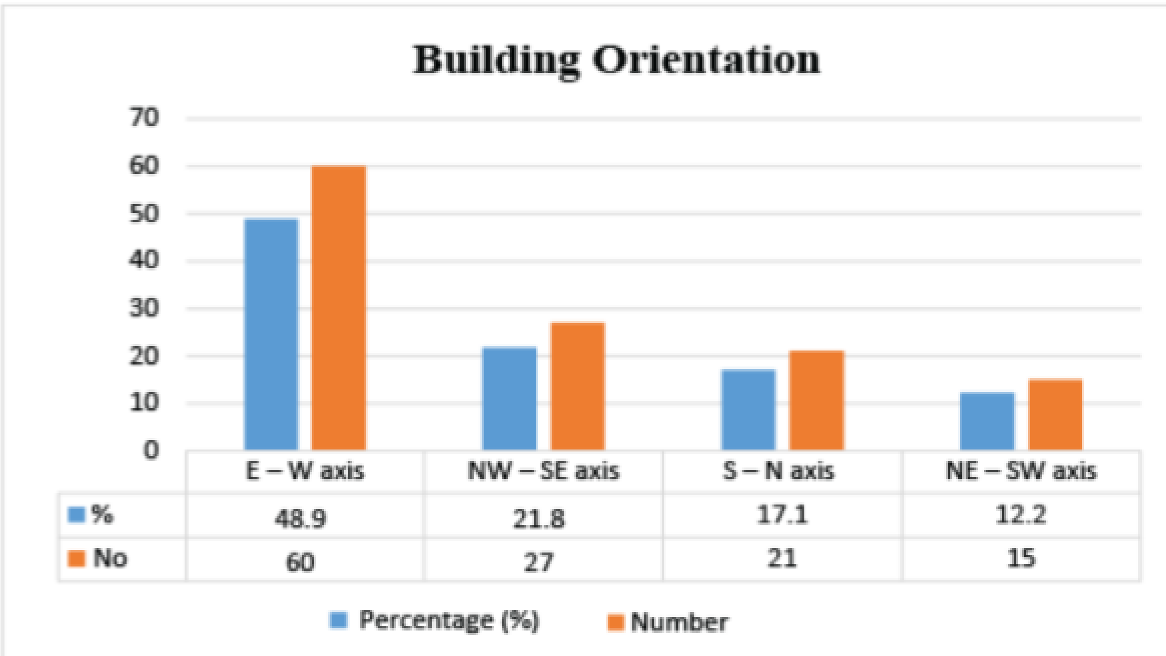


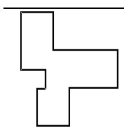
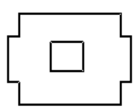
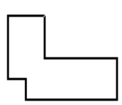
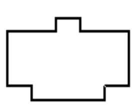
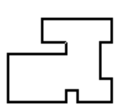
Chart 4:9 Building orientation in Adama (Source: Own analysis)

According to chart 4:9, most existing condominium buildings in Adama are either south faced or east-west faced (48.9%), even if there are also other-faced buildings. In an east-west orientation, the long face is aligned with the south face. North-south faced (17.1%). The envelopes that let the most wind flow through them. The majority of the doors and windows, as well as the long wall, are oriented to the south.

4.3.2 Window to wall ratio and aspect ratio

Changing the aspect ratio leads in different surface areas for an equivalent wall area, according to a geometric study. On smaller building footprints, the influence of the aspect ratio on the outside surface area will be larger. Most of the openings in the building are situated on the two opposite-facing walls on each side of the building. WWR on south faced is the worst ranging between 25 to 53%. But on north faced it ranges 18% to 24.5%. Many wide windows penetrate the direct sun according to observation and survey. Particularly south and west windows are penetrating the sunlight and they are the reason of increase room temperature, however, the buildings are not considered the sun direction and sun path. The other window characteristics are similar to this. According to the visualization of the building, the temperature is optimum from summer to winter except for slight cold during winter and slightly warm during summer.

Table 4:7 Aspect Ratio and WWR

Typologies	(Aspect Ratio) Width to Height	Window to wall ratio (WWR)
	Length: 24m Width: 18m Height: 15m, floor height=3m Aspect Ratio: 20:15 or 1:1.33	South: 30.8% East: 25% West: 25% North: 19.9%
	Length: 28m Width: 22m Height: 15m, floor height=3m Aspect Ratio: 16:15 or 1:1.06	South: 48.97% West: 51.00% North: 20.46% East: 74.41%
	Length:24m Width:16m Height: 9m, floor height=3m Aspect Ratio: 16:9 or 1:1.78	South: 33.3% East: 10.5% West: 14.2% North: 41.7%
	Length: 20m Width: 12m Height: 9m, floor height=3m Aspect Ratio: 12:9 or 1:1.33	South: 41.3% East: 42.4% West: 41.8% North: 19.4%
	Length: 18m Width: 14m Height: 12m, floor height=3m Aspect Ratio: 14:12 or 1:1.17	South: 32.9% East: 19.0% West: 43.1% North: 10.5%

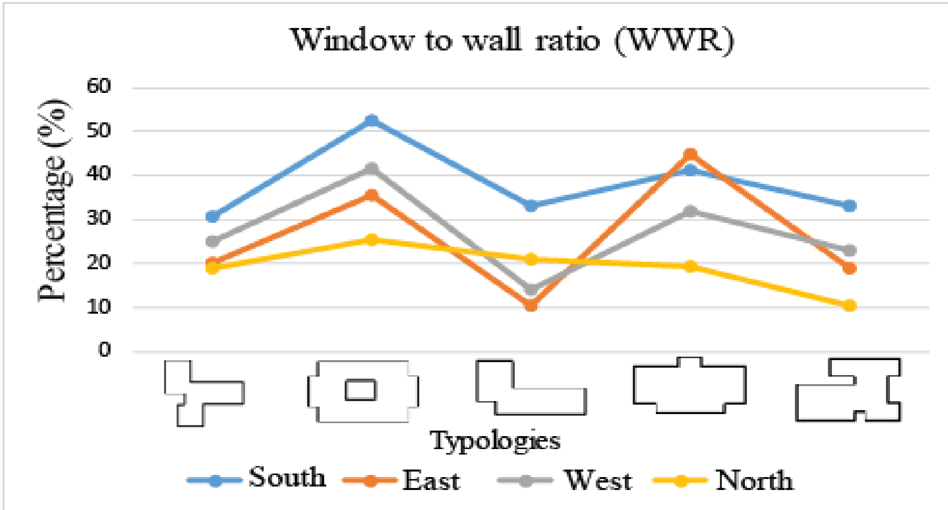


Chart 4:10 Window to wall ratio (source: own analysis)

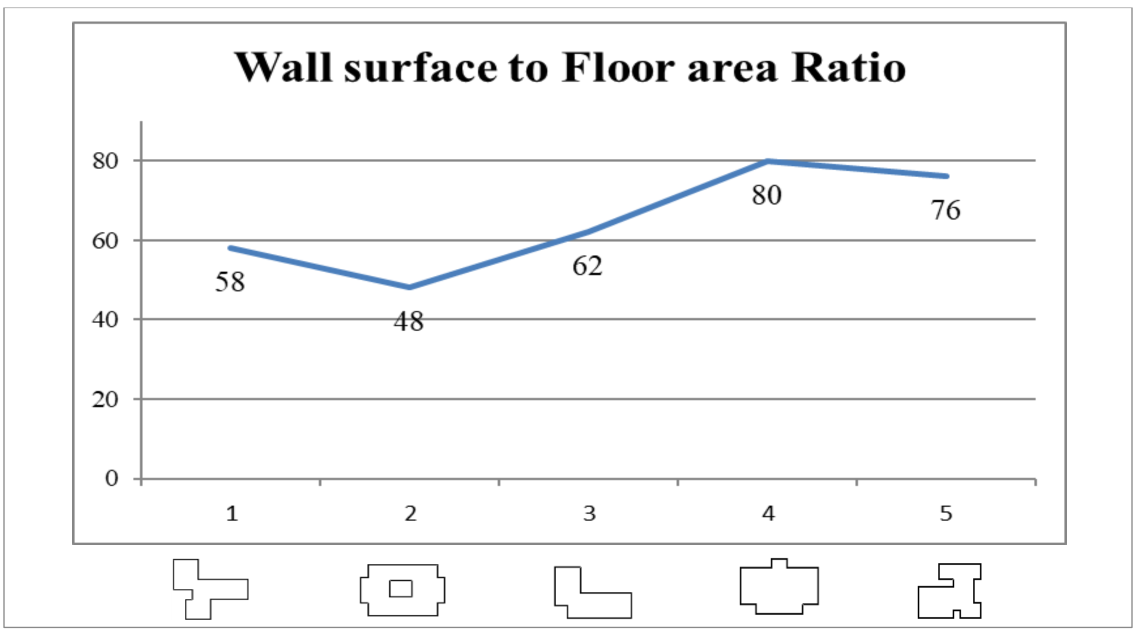
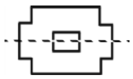
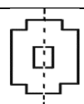
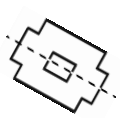
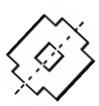


Chart 4:11 Aspect ratio (source: own analysis)

Openings are believed to collect 40 percent of the unwanted heat that accumulates in a structure. The interaction of outside and interior air is influenced by openings, which has an impact on energy consumption, indoor air quality, and thermal performance. The amount of light available in the rooms is influenced by the size of the windows. As a result, windows should account for at least 10% of the room's window-to-wall ratio area, with at least 5% of that space able to be opened for ventilation. When no shading devices are employed, the space depth must be no more than 2.5 times the window head height and no more than 2 times the window head height (when shading devices are used).

Table 4:8 Opening, bare wall area of building typologies

Typologies	Length (L)	Width (W)	Height (H)	Aspect Ratio (W:H)	Window Area	Wall Area	Window to wall ratio (WWR)
 (East-West axis)	28m	16m	15m	16:15 1:1.07	S-120m^2 W-76m^2 N-62m^2 E-96m^2	S-245m^2 W-149m^2 N-303m^2 E-129m^2	South: 48.97% West: 51.00% North: 20.46% East: 74.41%
 (South-North axis)	16m	28m	15m	28:15 1:1.87	S-76m^2 W-62m^2 N-96m^2 E-120m^2	S-149m^2 W-245m^2 N-129m^2 E-303m^2	South: 51.00% West: 25.3% North: 74.41% East: 39.60%
 (NW-SE axis)	28m	16m	15m	16:15 1:1.07	S-120m^2 W-76m^2 N-62m^2 E-96m^2	S-245m^2 W-149m^2 N-303m^2 E-129m^2	South: 48.97% West: 51.00% North: 20.46% East: 74.41%
 (EN-WS axis)	16m	28m	15m	28:15 1:1.87	S-76m^2 W-62m^2 N-96m^2 E-120m^2	S-149m^2 W-245m^2 N-129m^2 E-303m^2	South: 51.00% West: 25.3% North: 74.41% East: 39.60%

The building is aligned in such a manner that just a long portion of the building is exposed to solar radiation. The east-west building orientation is seen in Table 4:8, Buildings are aligned with the long axis and south-north axis is aligned with short portion. The goal of this research is to determine the availability of incident solar radiation on diverse surfaces and locations across the world.

4.3.3 Wind Direction analysis

Natural ventilation can provide building occupants with thermal comfort and a healthy indoor environment. According to survey, Buildings have no enough ventilation and maintain an internal temperature below that of the outside environment. According to the study, single side window openings can breathe a space to a depth of 6 to 7 meters, whereas cross ventilation can ventilate a space to a depth of 15 meters. In hot and dry seasons, increasing the air circulation rate in indoor places improves cooling efficiency. The direction of the wind has an impact on thermal comfort by enhancing evaporation loss via the skin and convectional heat transfer between the body and the environment. To better regulate the temperature environment in hot climates, it is best to prevent wind. North facing windows are the most favorable and south-facing windows cannot get the direction of wind it is opposite to the wind direction. This has an impact on the thermal comfort of rooms facing south.

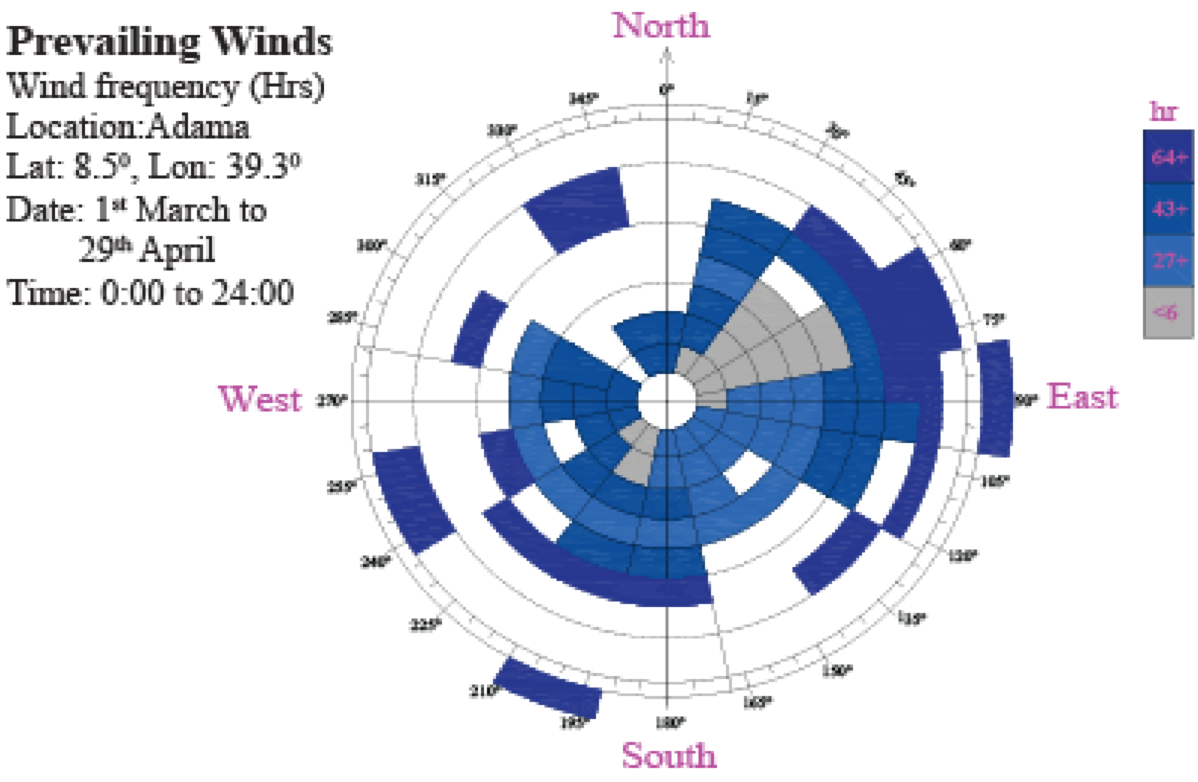


Figure 4: 29 March and April prevailing winds of Adama (source: Author)

When the wind blows directly into the opening, the airflow rate is highest. However, because the rooms are oriented in the opposite direction of the wind, airspeed is low on the east-west axis for south-facing rooms. However, because the rooms are oriented to the wind direction, the airspeed on the south-north axis on the north facing is high, maintaining the thermal quality.

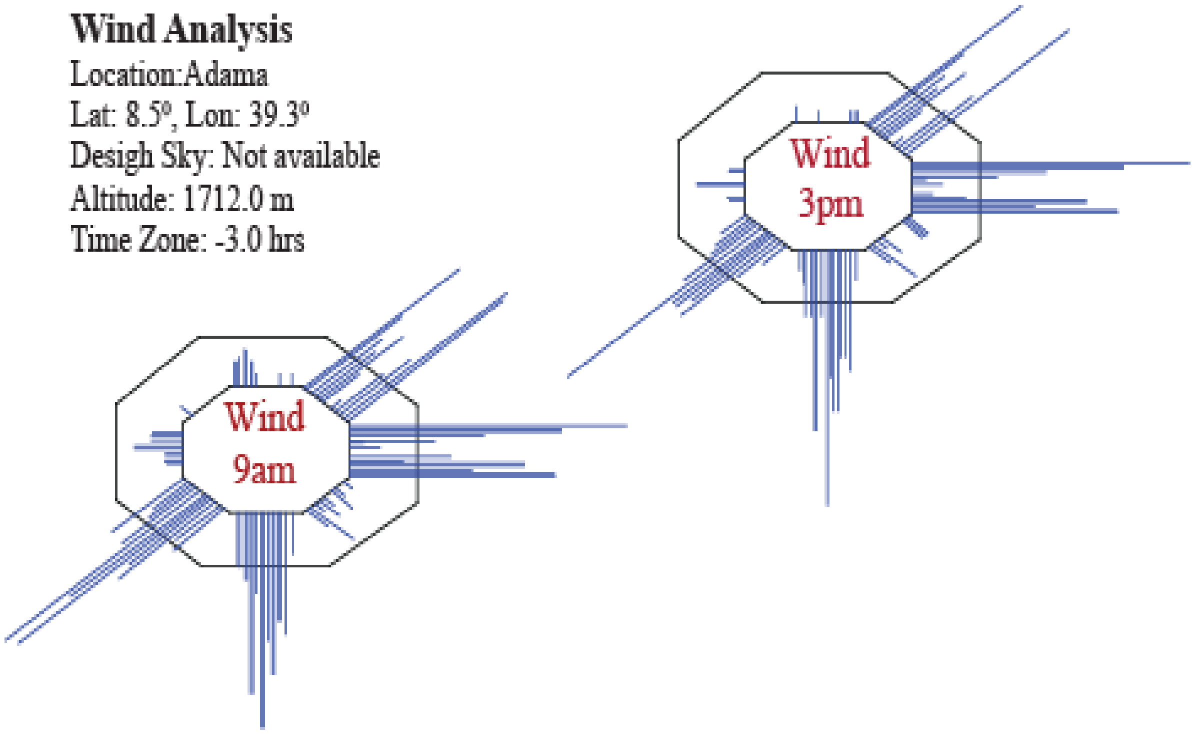
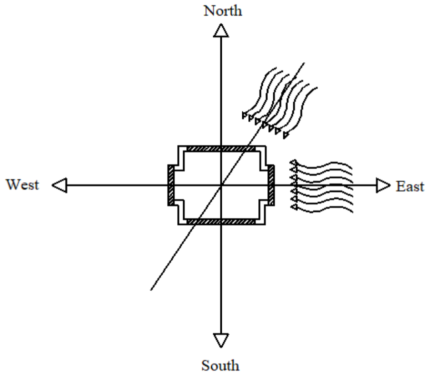
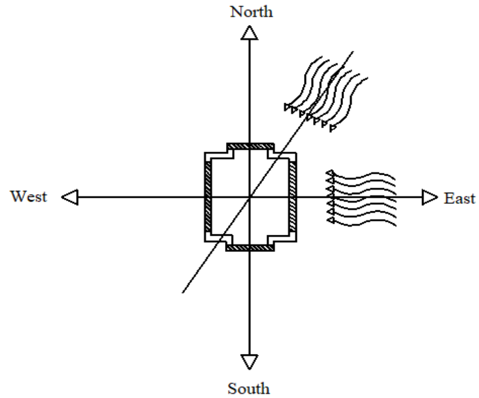


Figure 4: 30 Adama's wind direction in March and April (source: Author)

The airflow rate is greatest when the wind blows straight into the opening. Changes in building orientation to either side have an influence on the value of natural ventilation effectiveness. according to analysis, East and West openings have greater potential for good natural ventilation than North and South openings**.** The natural ventilation of the interior is determined by the direction of the wind in respect to the opening. There are two airflow angles in each cardinal direction, one perpendicular (90^0) to the window and the other with 45^0.

Table 4:9 Opening orientation at different angle with relation to Wind Direction

East-West axis (90^0-180^0) building at 90^0 and 450 to the wind direction	North-South axis (0^0-270^0) building at 90^0 and 450 to the wind direction
	

4.3.4 Opening

In the Adama condominium site, the opening orientation was located in four directions (S, N, E, W) of the building and they have not orientated openings according to the season of the wind and solar radiation. The majority of the openings face the opposite direction of the wind. On south orientated, windows are good to enable excess natural light and ventilation but using these many windows on every side is not good for room temperature and sunlight prevention. Most of the windows are located on the south face, but for Adama climatic conditions such window orientation is not recommended.


A


B


C


D

Figure 4: 31 a) south facing b) north facing c) west south facing d) north east facing

According to survey, the wide wall facade has a thermal quality influence on the inner atmosphere on sunny days. During periods of intense sunlight, high solar radiation in the indoor chamber causes pain. The solar path diagram is well studied to investigate critical hours and days as well as to understand the position of the sun concerning the building orientation. More than 70% of long face of walls are orientated to East-West axis. Each orientation has a different window design. In the south orientation there is 48.97% WWR and 20.46% in the north orientation, where solar radiation is high there is high WWR. South windows, however, need shade from the midday and early afternoon sun. WWR windows should be few and small. Wide sun radiation with low shadow on the challenging east and west faces

Table 4:10 Comparison of building orientation with different WWR

Date	Room Orientation	WWR	Vent. condition	Max /Temp & Airspeed	Min /Temp & Airspeed	Average /Temp & Airspeed	Time of the peak
April 15, 2024 - April 29, 2024	East-West	75%	Natural ventilated	**29.27 0.55**	**26.98 0.35**	**28.12 0.45**	7:00 pm-9:00pm
	East-West	50%	Natural ventilated	**32.20 0.32**	**30.50 0.27**	**31.35 0.29**	7:00 pm-9:00 pm
	East-West	25%	Natural ventilated	**35.70 0.25**	**32.80 0.15**	**34.25 0.20**	7:00 pm-9:00 pm
	North-South	75%	Natural ventilated	**27.25 1.94**	**26.70 1.15**	**26.97 1.54**	7:00 pm-9:00 pm
	North-South	50%	Natural ventilated	**29.60 0.86**	**29.50 0.55**	**29.55 0.70**	7:00 pm-9:00 pm
	North-South	25%	Natural ventilated	**33.10 0.43**	**32.30 0.28**	**32.7 0.35**	7:00 pm-9:00pm
May 1, 2024 - May 7, 2024	East-West	75%	Natural ventilated	**30.10 0.51**	**27.15 0.32**	**28.62 0.41**	7:00 pm-9:00 pm
	East-West	50%	Natural ventilated	**32.20 0.33**	**31.66 0.26**	**31.93 0.29**	7:00 pm-9:00 pm
	East-West	25%	Natural ventilated	**36.70 0.21**	**34.90 0.02**	**35.8 0.11**	7:00 pm-9:00 pm
	North-South	75%	Natural ventilated	**27.89 1.88**	**26.90 1.00**	**27.39 1.44**	7:00 pm-9:00 pm
	North-South	50%	Natural ventilated	**30.40 0.85**	**30.20 0.43**	**30.30 0.64**	7:00 pm-9:00 pm
	North-South	25%	Natural ventilated	**34.18 0.46**	**32.28 0.21**	**33.23 0.33**	7:00 pm-9:00 pm

The existing WWR along East-West orientation of 75% were compared with 50% (i.e. covering up the whole glazed area with no influence of natural ventilation (i.e. windows and doors closed).

For studying the effect of natural ventilation the same E1 and W1 rooms were used and this time all windows and doors were opened. WWR of 50% were compared to WWR of 25%. Data on selected days were taken for graphs and analysis.

4.4 To identify the best optimum building orientation based on wind direction and WWR for natural ventilation of condominium buildings

4.4.1 Environmental measured results

According to field measurement to determine the high natural ventilation building orientation total high ventilated degree between 90° to 180°, and 0° to 90° azimuths in this study. According to the simulation results model, total discomfort degree hours was initially raised at 90° and subsequently dropped between the orientation intervals of 0° azimuth - 90° azimuth. In relation to the other orientations, surfaces facing North received the least discomfort degree hours ranging from 2608.5 to 2609.1hrs too hot and 954.3 to 951.3hrs too cool. The building was rotated by incrementing 10° azimuth angle in 19 various angles (without shading element) in the clockwise direction beginning from the north (azimuth 0°) – south (azimuth 180°) to find the optimal orientation angle. The azimuth building orientation is shown by the minimum discomfort degree hours of the total annual too hot and too cool hours. By increasing a 10° azimuth angle for the identified best orientation region of the smallest total yearly discomfort degree hours, the optimal orientation angle (the minimum annual total too hot and too cool hours) was discovered. The minimal discomfort degree hours were discovered at azimuth 0° to 10^0 north, as a consequence of the model's simulation.

By incrementing a 10° azimuth angle for the identified orientation were considered, namely 0^0E, 10^0E, 20^0E, 30^0E, 40^0E, 50^0E, 60^0E, 70^0E, 80^0E and 90^0E as shown in figure 5:35.

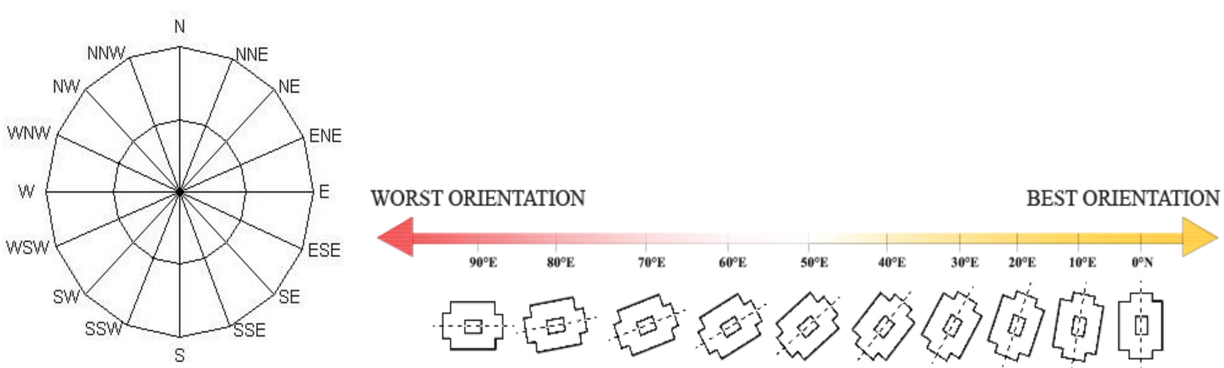


Figure 4: 32 incrementing 10° azimuth angle to find optimum orientation in the study (source, Author)

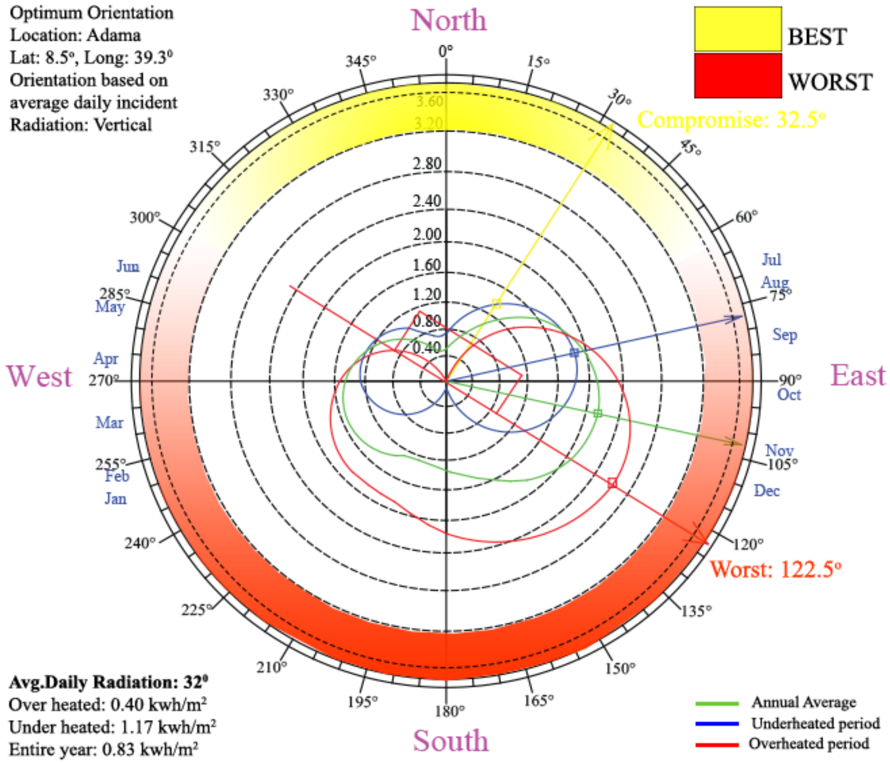


Figure 4: 33 Optimum orientation of Adama (source: own analysis)

4.4.2 Determination of optimum orientation of Natural ventilation in Adama

As shown on the Figure 4:33, 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 connection of a building to the sun's path is determined by its orientation. This, in turn, defines the building's solar gain characteristics. According to Adama's optimum orientation, the sun's apparent course should be carefully investigated in order to identify the most efficient orientation of a given building in a certain area. The best optimum orientation in Adama city has been found at the compromise to be 32.5^0 N, or have to be in the range between 328^0 N-4^{00} E. Depending on this optimum orientation chart, there are solar radiation problems in the south angle from 45^0 E to 315^0 N, and therefore it needs solar radiation control. The worst orientation is found 122.5^0 SE.

Appropriate selection for windows orientation, optimal size of the glass and applying natural ventilation system, can reduce the negative effect of thermal comfort in increasing indoor air temperature. The main findings of this paper are summarized as follows:

According to climate condition and field measurements, the existing scenario for the case study shows in table 4:10 that, east-west orientation is more sensitive to natural ventilation. The east-west rooms are always hotter than those in north-south direction. And even by applying natural ventilation, changing WWR or not, the average differences in in/out door air temperature in east rooms is higher, comparing with west rooms. Unless with WWR=25% they are almost same. More care should be taken in the primary stage of design to avoid any opening in east or west direction, unless there is need for that. Based on the above results, it can be concluded that, in general, thermal comfort can be improved by applying natural ventilation and WWR=75%. Thus, the needs for applying mechanical ventilation is necessary to improve occupiers thermal comfort.

4.5 Discussions

4.5.1 Wind direction and Air 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 figure 4:32 that is used to display the exact orientation of cardinal directions (N, S, E & W), intermediate directions (NW, SW, NE&SE,) and inter cardinal directions (e.g. NNE, ESE, SSW, NNW, WNW, ENE, etc.). The wind rose diagram shown on Figure 4:34 below illustrates the annual wind direction and speed of Adama city. The normal educational Calender 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.

As illustrated on Figure 4:28 and 29 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 Figure below.

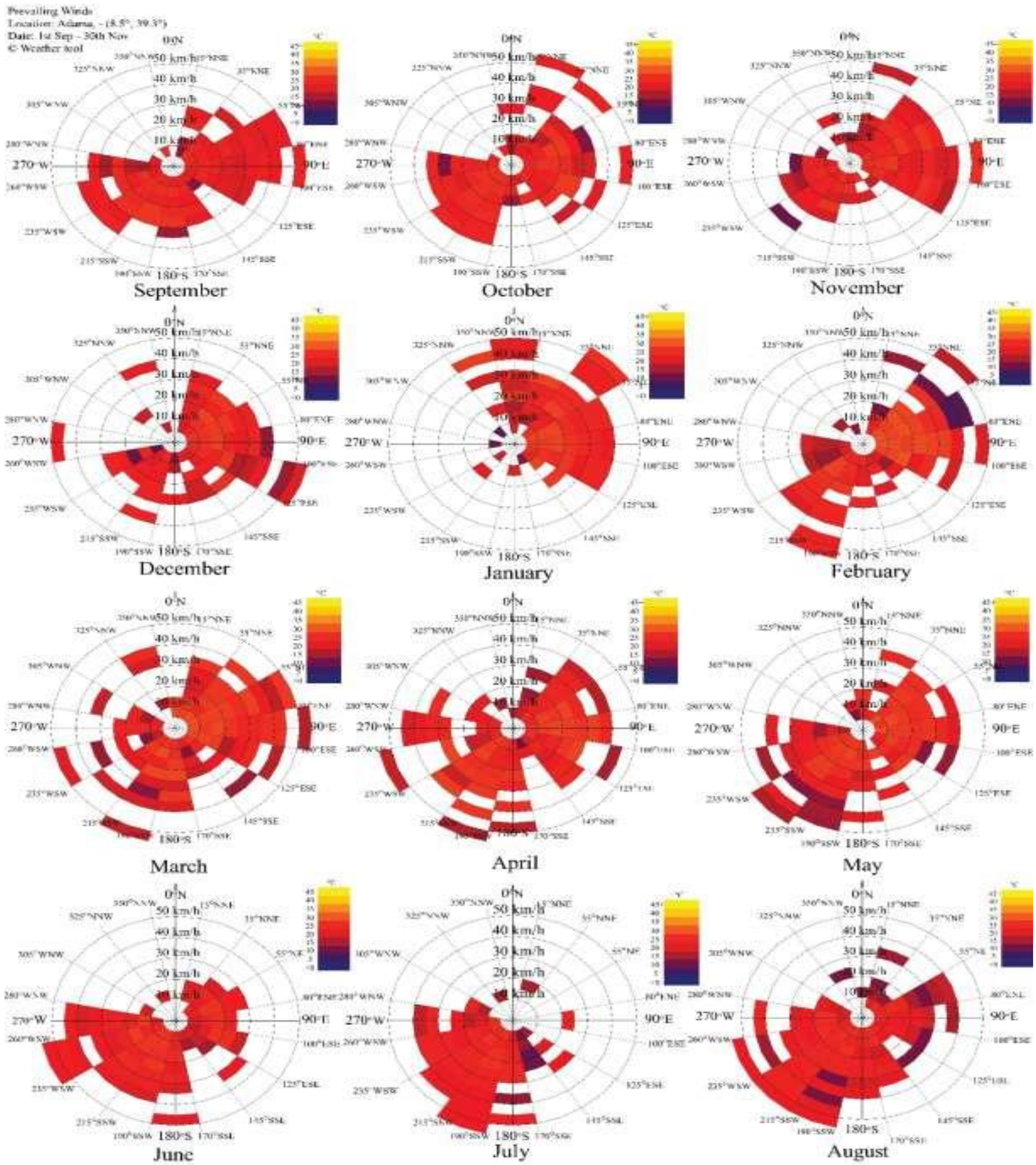


Figure 4: 34 The wind direction and speed of Adama city in each month (Source: own analysis)

4.5.2 Impact of Natural Ventilation

Natural ventilation is the intentional flow of outdoor air through an enclosure under the influence of wind and thermal pressures through controllable openings. It can effectively control temperature particularly in hot and humid climate. Temperature control by natural ventilation is often the only means of providing cooling when mechanical air-conditioning is not available (Tony Rofail, 2006). Natural ventilation in this work defined as the increase in building thermal performance due to an increase in natural air movement as a passive cooling strategy. In a tropical climate the improvements in comfort by NV range between 9% and 41% (Adama in April and May). In a temperate climate the improvements vary between 8% and 56%. The results showed that north-south axis has a good potential in tropical and temperate climates.

4.5.3 Effect of Building orientation and WWR on natural ventilation

Windows, doors, and skylights have a significant impact on the thermal performance of the building envelope. Windows can also have a strong influence on the use, productivity, and comfort of the people who occupy the building. Study reported by Jinghua Yu (2006) showed that heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration. It is up to 40 % (Yang and Yu, 2002) in hot summer and cold winter zone. Glazed windows are becoming an important component of contemporary architecture. They allow natural light, offer a visual communication with outdoors, reduce a structural load and enhance aesthetic appearance of buildings (Datta, 2001; Al-Saadi, 2006). A proper selection for the optimal area of the glass and applying natural ventilation system can reduce the negative effect of solar radiation in increasing the indoor air temperature (Al-Tamimi, N. and Syed Fazil, 2010). Therefore, with many benefits that the glazed windows do offer to the occupants and the designers, they are not free of introducing problems if they are not properly selected. Many parameters in fenestration system are important when thermal performance is evaluated. However, the two parameters evaluated for thermal performance for this study are as follows:

4.5.4 Effect of Natural Ventilation on thermal performance

Natural ventilation is the intentional flow of outdoor air through an enclosure under the influence of wind and thermal pressures through controllable openings. It can effectively control temperature particularly in hot and humid climate. Temperature control by natural ventilation is often the only means of providing cooling when mechanical air-conditioning is not available in a temperate climate the improvements vary between 8% and 56%.

There is two inlets in building with west-east orientation. The wind direction parallel to Opening. Natural ventilation directly creates of openings. In the middle room, the wind speed is declined, and airflow is slow. The wind speed returned increasing in opening to achieve 1 m/s.
The conclusion of the performance of ventilation analyze are:

a. The best Natural ventilation was created in opening that parallel to wind direction. That condition produces the airflow that optimum to cooling space.
b. The building that angled against to wind direction will deflect the flow and the airflow to the building surface. The deflect of airflow that influenced by the obstruction is occurred inertia principle.
c. The factor that influences the performance of ventilation is topography, building orientation to windward, dimension of opening and position of opening.

4.5.5 Effect of windows orientation on thermal performance with consideration to WWR

In considering the orientation of a building, the main issue is the orientation of the windows. The potential of the solar penetration through windows in hot climate, and its effect on the elevation of the indoor temperature, depends greatly on the orientation of the windows (Givoni, 1994). The net effect of the window system in building envelope design depends on the window orientation, window wall ratio WWR and weather conditions.

4.5.5.1 Ventilated Rooms With WWR= 75%

In this analysis, different designs of window system are taken into consideration in order to observe the interaction of the heat gains and/or loss on thermal comfort. The result (Table 4:10) showed that east windows have more obvious effect on increasing indoor air temperature than west windows for the whole time of the day. That is applicable for ventilated rooms. The airspeed and temperature in both rooms slightly decreased, but the east-west room remain hotter than north-south. The maximum airspeed and indoor temperature for east-west room were +1.2m/s and +29^{o} C respectively. The maximum airspeed and indoor temperature for north-south room were +1.9m/s and +26^{o} C respectively.

4.5.5.2 Ventilated Rooms With WWR= 50%

In hot and humid regions where the diurnal temperature range is small, constant daytime ventilation across the skin, either naturally or mechanically, may not provide thermal comfort without additional assistance. In many cases, daytime ventilation alone cannot keep indoor temperatures below those of the outdoors (Givoni, 1981).

The results Table 4:13, showed that with applying natural ventilation NV, the temperature in both rooms slightly decreased and become medium, but the east-west room remain hotter than north-south. The maximum airspeed and indoor temperature for east-west room were +0.9m/s and $+30^{o}$ C respectively. The maximum airspeed and indoor temperature for north-south room were +1.4m/s and $+28^{o}$ C respectively.

4.5.5.3 Ventilated rooms with WWR= 25%

Significant increase in Airspeed and indoor air temperature in both rooms occurred when glazed area ratio of windows were changed from 50% to 25% with applying cross ventilation strategy. That is because of the reduction in the total solar radiation coming through window. The result (Table 4:10) shows that, the peak Airspeed and indoor temperature in east - west room became closer to each other i.e. 0.5m/s and 35^{o}C respectively. While the maximum was 0.9m/s and 29^{0} C airspeed and indoor temperature respectively.

4.6 Summary of discussion

According to the study, there are four (4) different building orientation possibilities employed in Adama condominium houses: East-west, South-North, Northeast-Southwest, and Northwest-Southeast axis. From those orientations, East-West and South-North axis were selected to check the high natural ventilation and to compare the environmental variables of both orientations. Different building orientation options had different takes on comfort within the building during the day; the East-west orientated had the highest percent of discomfort at the same time when compared with north-south orientation. The study found that building orientation affects thermal comfort, and natural ventilation. There is also the variation in Airspeed, indoor temperature, and relative humidity between both orientated rooms. This difference influences the residents and makes their satisfaction also highly different. At 7:00 pm, the Airspeed for the north-south orientation of the building is between 1.94 and 1.15 m/s, indoor temperature for the north-south orientation of the building is between 29 and 25 degrees Celsius. When the building is oriented east-west, Airspeed is between 1.2 and 0.2 m/s, the air temperature is between 35 and 28 degrees Celsius. While relative humidity for north-south building orientation is 76-42, for south-north building orientation is 55-28.

The proportion of walls to windows and the distribution of Airspeed can be affected by larger opening areas. South-facing windows get harsh sun glare, because there are several windows on the south side. Approximately 30% of the unnecessary heat that accumulates in a room enters through windows. The optimal orientation for WWR is south-north axis, whereas the worst direction is East-West axis.

Table 4:11 Compare and contrast different building orientations

parameters	East – west Axis (south facing)	South – north Axis (north facing)	NE - SW Axis (long face oriented East)	NW - SE Axis (long face oriented west)
Airspeed level	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)
Temperature level	Hot (temperature rise in indoor environment)	Neutral (temperature fall in indoor environment)	Neutral (temperature fall in indoor environment)	warm (temperature rise in indoor environment)
Humidity level	Dry	Medium	Medium	Dry
Level of natural ventilation	Low (the wind direction of Adama is from east to west window facing is opposite to wind direction)	Medium (Adama's wind direction is east to west, hence the window facing is not in the opposite direction of the wind.)	Medium (The wind direction in Adama is east to west, hence the window facing does not match the wind direction.)	Medium (the wind direction of Adama is from east to west window facing is not opposite to wind direction))

Level of air speed	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)	Morning (neutral) mid-day (stuffy) afternoon (breezy)
Season when room is too hot (uncomfortable)	Winter (March, April and May)	Winter (March, April and May)	Winter (March, April and May)	Winter (March, April and May)
Source of heat	Direct sun	indirect sun heat	Direct sun	Direct sun

The main findings of this paper are summarized as follows:

- North-South orientation is best for all WWR whereas East-West orientation is worst for all WWR.
- Annual thermal energy consumption decreased by 0.24% for North-South orientation and increased by 1.31% for East-West orientation respectively compared with existing orientation
- Annual thermal energy consumption is minimum when WWR is 0.1. Annual thermal energy consumption is maximum when WWR is 0.9.
- Annual thermal energy consumption decreased by 1.36% for North-South orientation and increased by 0.23% for East-West orientation respectively when WWR is 0.1 compared with existing scenario.

4.6.1 Cross ventilation

In naturally ventilated rooms, 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. 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.

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.

4.6.2 Integration and impact of greenery on natural ventilation

Integrating the green infrastructure is essential as they are productive in the regulation of room temperature, increase productivity and good for health and wellbeing of employee. The above discussed orientation and prototype buildings can be solved through integration of the green infrastructure as much as possible. Green infrastructure can be integrated whether in interior spaces or exterior spaces and building envelope. The most effective green integration for room regulation is using GI for minimizing radiant temperature of the walls and openings in exterior envelope. So integrating GI to reduce high radiant temperature and surface temperature is the greatest possible solution to reduce the climate change and regulate room temperature.

Accordingly there are a lot of types of GI and techniques that can be used for the outside envelope. There also many techniques to integrate these types to the building. That may be by wire, fittings to the building, and some passive elements on the building, on the window sill, rope and other mechanisms.

Interior GI are very effective in using as the temperature regulation, productivity provision and health and wellbeing of occupants in residential building. They increase creativity. Biophilic design can be appreciated in working spaces which encourage using the natural feature, natural surface, natural patterns and natural elements. GI in working space could be appreciated in the provided buffer zone. When the GI provided in buffer zone they can be used as the refreshment of the employee and their thermal feelings of comfort.

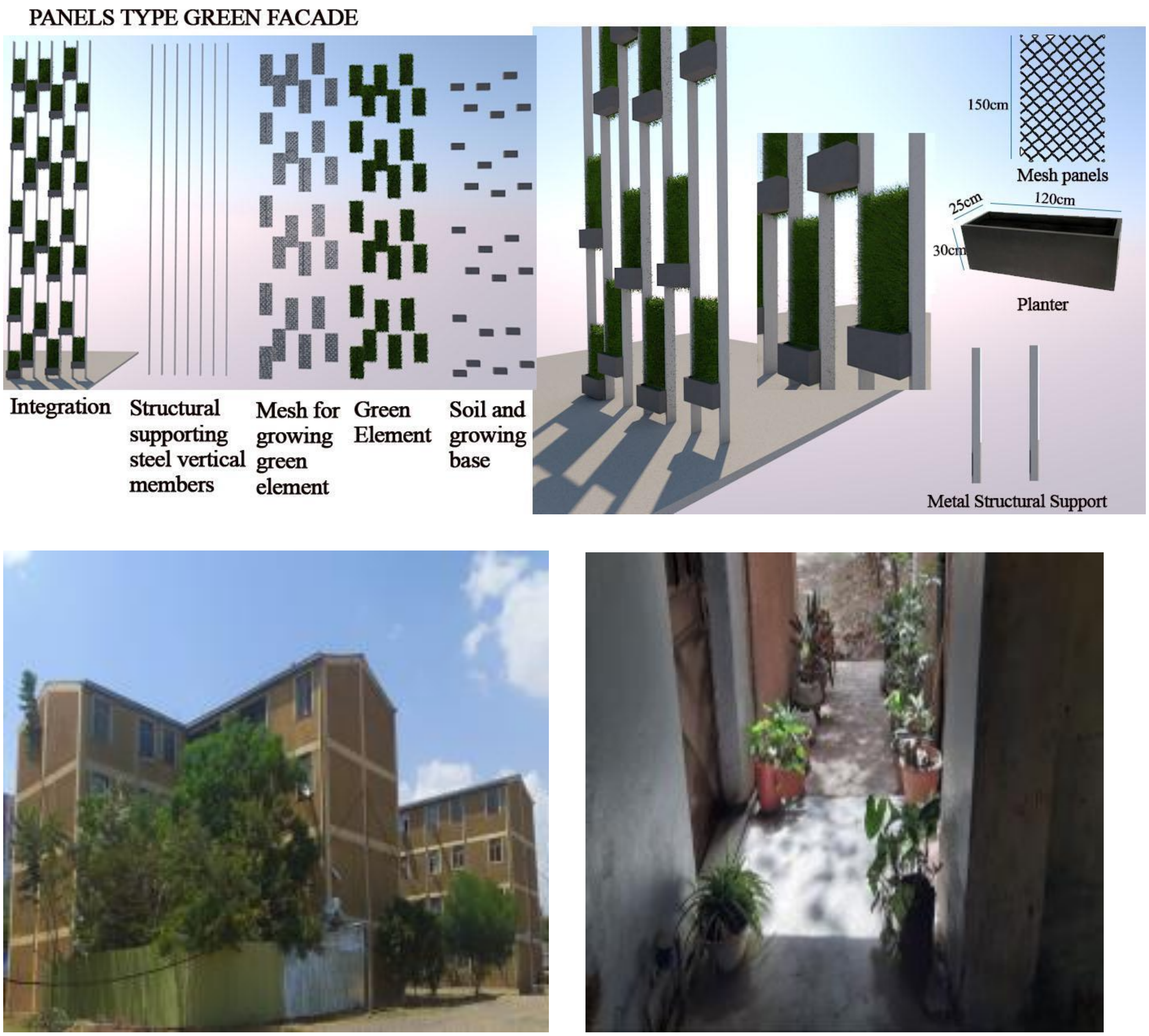


Figure 4: 35 the impact of greenery for natural ventilation

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Natural ventilation through window openings is an inexpensive and effective solution to bring fresh air into internal spaces and improve indoor environmental conditions. In this study, Orientation based adaptive model of naturally ventilated room that enhance thermal comfort was examined. The effect of building orientation on the natural ventilation of condominiums constructed by the government and orientated in different was carried out. The study was conducted using objective evaluation methods and environmental variable measurements (Airspeed, indoor temperature, and relative humidity) were recorded for the hottest months for 12 days by using different data loggers. When we compare the East-west orientated with North-South orientated, the North-South orientated rooms of the natural ventilation is suitable and the residents have a good sensational scale, their preference also good for their dwellings and they have a good satisfaction on the indoor thermal quality. Since in most sites the openings are exposed to harsh sun direction occupants are suffering from different space quality problems. This orientation of untreated building envelope directly affects the comfort of the occupants and productivity.

The south-north orientation recorded the lowest Airspeed and indoor temperature and Relative humidity from April 15 to May 7, 2024, with a range of 23^0C to 35^0C. During daylight afternoons, south-facing rooms are 6-5^oC hotter than north-facing rooms due to the effects of the window-to-wall ratio (WWR) and room orientation on hourly interior air temperature and Airspeed. Because east-west orientation or south faced recorded 35^0C to 28^0C while North-South orientation recorded 29^0C to 23^0C . A building's orientation and exposure to the south can have a big impact on natural ventilation and thermal comfort. The paper concludes that the east-west orientation (90^0E to 180^0W) is the worst orientation in all cases while the North-South orientation from (0^0N) to (270^0S) is considered as the optimum orientation for natural ventilation. 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°.

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5.2 Recommendation

From the results obtained from the research study, the following can be recommended; Before designing any condominium house for any location IDHP should consider the building orientation, and environmental existence of the location. They should incorporate the regulations and monitoring systems regarding building orientation to improve natural ventilation. The long axis of building in hot and dry places like Adama should be South-north axis (north orientated) to increase the natural ventilation to reduce the indoor thermal comfort. The exposed walls of the Adama condominium home should be orientated on the South-North axis, i.e. facing South-North, to minimize indoor heat and increase indoor humidity for cool. In the first instance, window alignment should be used, followed by the use of proper shading systems and glazing treatment. Because the size and location of openings impact the dwellings for internal natural ventilation and thermal comfort. As a result, big openings on the west and south-facing facades should be situated away from direct sunlight due to the building's location in a hot-arid climatic area with high temperatures. Proper arrangement of the windows for cross-ventilation. Buildings that are properly positioned improve indoor thermal comfort significantly. Building orientation should be examined with respect to the sun to decrease facades facing east and west and to accept local prevailing winds. Because of the interaction between building orientation and natural ventilation. The orientation of a building can reduce sun gain while promoting natural ventilation. This is done by using elongated, south-to-north forms with primary apertures pointing north.

- ✓ Wind driven cross ventilation technique plays a significant role in creating a naturally ventilated, thermally comfortable room 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

Questionnaire form for occupants

Dear respondents the purpose of these questioner is to support research on **Effect of orientation and WWR on the natural ventilation for thermal comfort on condominium buildings: In the context of Adama city, Ethiopia**. All responses will be treated in strict confidentiality and will be used for academic research only.Answer the following Questions by putting √ or X for the boxes and fill the blank spaces with your idea.

Questioner N°: ___ Site name: ____________ Building Orientation ___________________

Block no: _______ Story number: _______ Time: ______________ Date: __________

A. Personal information

Sex Male ☐ Female ☐

Age Below 15 ☐ 15-30 ☐ 31-45 ☐ 46-60 ☐ 61 & above ☐

Body Weight below 30kg ☐ 31-60kg ☐ 61-90kg ☐ 91 and above ☐

Activity: Reclining ☐ walking ☐ sitting ☐

Standing ☐ relaxing ☐ Working ☐

Other__________________________________

B. **Level of natural ventilation**

1. 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 ☐

2. Equipment's inside the room

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

3. 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 ☐

4. Are the thermal conditions of this room acceptable to you right now?

Acceptable ☐ Not acceptable ☐

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

Acceptable ☐ Not acceptable ☐

6. What would you prefer right now?

More air movement ☐ Moderate ☐ Less air movement ☐

7.How do you feel about air velocity in the room at this moment?

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

8. How do you feel about humidity in the room at this moment?

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

9.Which of the following mechanism do you use to regulate the room temperature?

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

10. 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 ☐

11.Do you think the orientation of the building affects the temperature of your room?

Yes ☐ No ☐

12. How often are building openings (windows or doors) opened in your room to allow natural airflow?____Hours.

13. Does the temperature in the room affects your concentration on your learning?

Yes ☐ No ☐

14. Do you experience discomfort due to direct sunlight in your room?

Yes ☐ No ☐

15. What changes would you recommend to enhance the thermal comfort in your room?

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APPENDIX- II

የአማርኛ መጠይቅ ቅጽ

ይህ የክነሕንጻ ማስተርስ ድግሪ ጥናት የተፈለገዉ ለአንድ ቦታ የተሰሩ የመንግስት ኮንዶሚኒየም (Condominium) ቤቶዎችን በሌላ ቦታ ያለ በቂ ጥናት በተደጋጋሚ ስለ ተገነቡ ህንጻዎች ላይ የሙቀት ምቾትን ለማሻሻል በተፈጥሮ አየር የተሞላ ለመገምገም (የመኖሪያ ሕንፃ የቤት ውስጥ ሙቀት ጥራት ግምገማ ላይ የተደረገ ጥናት፡ በአዳማ ከተማ የኮንዶሚኒየም ቤት ጉዳይ።) በሚል ርዕስ ለማካሔደው ጥናት የነዋሪዎችና በቀን ተቀን ውሏቸው ላይ በርዕሱ ዙሪያ ያላቸውን ሃሳብ ወይም ስሜት በመጠየቅ፣ ለጥናቱ እንደ ግባት ለመውሰድ የተዘጋጀ ፎርም ነው። ስለሆነም እባክዎትን የተጠየቁ ጥያቄዎችን በአንክሮ በማንበብ፣ ለምርጫ ጥያቄወች መልስ የምትሏቸው ((√ ወይም X) በመምረጥና ዝርዝር ሃሳባችሁን ለሚፈልጉ ጥያቄዎች ደግሞ በተቀመጠው ክፍት ቦታ ገንቢ የሆነ ሃሳባችሁን እንድትሞሉልን በትህትና እንጠይቃለን።

የጠያቂ ቁጥር:____ የጣቢያ ስም:__________የሕንፃ አቀማመጥ ________________________

አግድ ቁጥር:________ የታሪክ ቁጥር:________ ሰዓት:________________ ቀን:__________

ሀ. የግል መረጃ

ጾታ ወንድ ☐ ሴት ☐

እድሜ ከ 15 በታች ☐ 15-30 ☐ 31-45 ☐ 46-60 ☐ 61 ና ከዛ በላይ ☐

የሰዉነት ክብደት (በኪሎ ግራም) ከ 30 በታች ☐ 31-60 ☐ 61-90 ☐ 91 ና ከዛ በላይ ☐

በክፍሎቹ ውስጥ የእንቅስቃሴ ደረ: መራመድ ☐ ተቀምጦ ☐ ቆሞ ☐ ዘና የሚያደርግ ☐

በመስራት ላይ ☐ ሌላ:________________________

ለ. የአየር እንቅስቃሴ

1. **የአልባሳት አይነት፡ የላይኛው፡** ሸሚዝ ☐ ቲሸርት ☐ ሹራብ ☐ ኮት ☐

የታችኛው፡ ሱሪ ☐ ቁምጣ ☐ ቀሚስ ☐

ጫማ፡ ስኒከር ☐ የቆዳ ጫማ ☐ ሌላ ☐

2. በክፍል ውስጥ የሉ መሳሪያዎች፡ የኮምፒውተር ☐ ጣሪያ ማቅዝቀዣ ☐ ፕሪንተር ☐

የእንጨት ጎን ክንድ ወንበር ☐ መብራ ☐

3. 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 ☐

4. የዚህ ክፍል የሙቀት ሁኔታዎች አሁን ለእርስዎ ተቀባይነት አላቸው?

ተቀባይነት አለው ☐ ተቀባይነት የለውም ☐

5. እባኮትን በዚህ ክፍል ውስጥ ስላለው የአየር እንቅስቃሴ በዚህ ጊዜ ምን እንደሚሰማዎት በተሻለ የሚወክል ሳጥን ላይ ምልክትያድርጉ።

ተቀባይነት ያለው ☐ ተቀባይነት የለውም ☐

6. አሁን ምን ይመርጣሉ?

ተጨማሪ የአየር እንቅስቃሴ ☐ መጠነኛ ያነሰ የአየር እንቅስቃሴ ☐

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

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

በጣም ነፋሻማ ☐ እጅግ በጣም ነፋሻማ ☐

8. በዚህ ጊዜ በክፍል ውስጥ ስላለው እርጥበት ምን ይሰማዎታል?

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

ትንሽ እርጥብ ☐ በጣም እርጥብ ☐ እጅግ በጣም እርጥብ ☐

9. የክፍል ሙቀትን ለመቆጣጠር ከሚከተሉት ውስጥ የትኛውን ዘዴ ይጠቀማሉ?

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

10. 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 ☐

11. የሕንፃው አቀጣጫ በክፍልዎ ሙቀት ላይ ተጽዕኖ ያሳድራል ብለው ያስባሉ?

አዎ ☐ አይ ☐

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

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

አዎ ☐ አይ ☐

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

አዎ ☐ አይ ☐

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

____

APPENDIX- III

Afaan Oromo questionary form for occupants

Qorannoon Digirii Maastersii barnoota Invaromental Arkiteekcharii kun kan barbaachiseef condominiemi magalaa Adama keessatti argaman (bakka tokkotti ijaaraman) qorannaa gahaa malee bakka biroo irraa fudhamani yeroo ijaaraman dhiibbaa haala qilleensaa, Argama fi naannoo itti ijaaramu giddu galeessaa kan godhate miti. akkasumas jiraatoota irratti dhiibbaa isaan qaban baruufii adda baasuudhaafi. Isinis kana hubachuudhaan akka nudeeggartan kabajaan isin gaafanna!

Lakk. Gaafi: ___ **Maqaa siyitti condomini'emicha:** _____________ **lakk.Bilooki** ___

Lakk.Gammoo _______ **Sa'aatii** ______________ **Guyyaa** __________

A. Odeeffanno dhunfaa

Gaffille armaan gadiif mallatto (√ yookin X) sanduqa kessatti guutuun deebisi. Akkasuma bakka duwwa isa yaada keettin guutii.

Saala: Dhiiraa ☐ Dhalaa ☐

Umurii: 15 gadi ☐ 15-30 ☐ 31-45☐ 45-60 ☐ 60 ol ☐

Ulfaatina Qaama: 30k.g gadi ☐ 31-60 k.g ☐ 61-90k.g ☐ 91 fi isaa ol ☐

Hoji/Socchi: Ta'umsaa adda ☐ deemsarran jira ☐ ta'een jira ☐

Dhabadhen jira ☐ hojii hojeechan jira ☐

Sochi biroo____

B. Sadarkaa haala qillensaa

1. Gosa Uffataa: **Gubba** sherti ☐ T-sherti ☐ shuraba ☐ kooti ☐

Jalaa suure☐ Quumxa ☐ Qaamisii ☐ Gurdi ☐

Caama snikeeri ☐ caama Qooda ☐ siileeperi ☐ Ergando☐

Kanbiroo____

2. Meeshaaleen kutaa kanaa keessa jiran

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

3.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 ☐

4. Haalli ho'aa kutaa kanaa yeroo ammaa kana siif fudhatama qabaa?

Fudhatama kan qabu dha ☐ Fudhatama hin qabu ☐

5. Sochii Qilleensaa yeroo ammaa kutaa kana keessatti maaltu sitti dhaga'ama?

Mijataa dha ☐ Mijataa miti ☐

6. Yeroo ammaa kana maal filatta?

Sochii qilleensaa baay'ee ☐ Giddugaleessa ☐ Sochii qilleensaa xiqqaa ☐

7.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 ☐

8. Yeroo kanatti jiidhinni daree keessatti maaltu sitti dhagahama?

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

9. Ho'a daree to'achuuf mala armaan gadii keessaa isa kam fayyadamta?

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

10. Guyyaa keessaa yeroo kam keessatti garmalee ho'uun sitti dhaga'amuu jalqaba?

2:00 ☐ 3:0 ☐ 4:00 ☐ 5:00 ☐ 6:00 ☐ 7:00 ☐ 8:00 ☐ 9:00 ☐

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

Eeyyee ☐ Lakki ☐

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

13. Ho'i daree keessatti xiyyeeffannaa barumsa kee irratti qabdu irratti dhiibbaa qabaa?

Eeyyee ☐ Lakki ☐

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

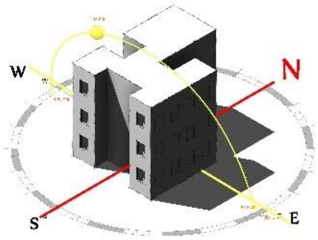
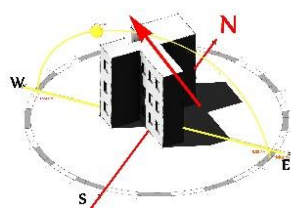
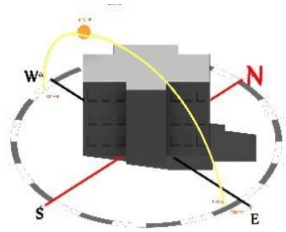
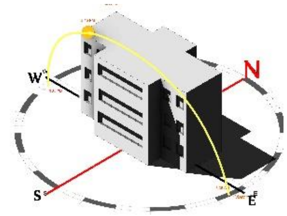
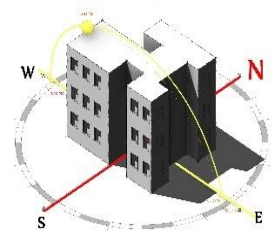
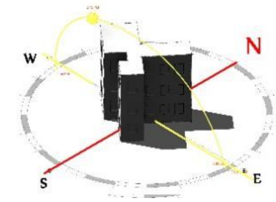
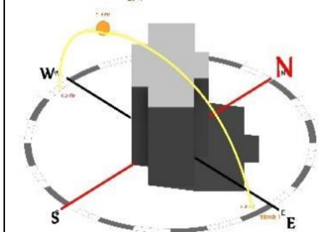
Eeyyee ☐ Lakki ☐

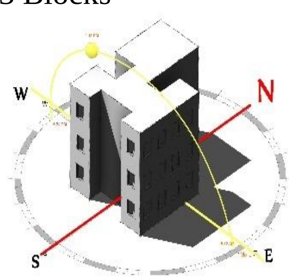
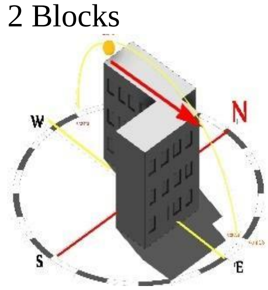
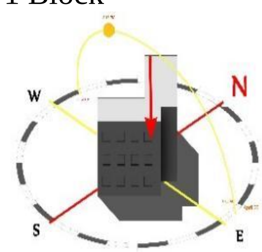
15. Mijataa ho'aa daree keessan keessatti argamu guddisuuf jijjiirama akkamii gorsitu?

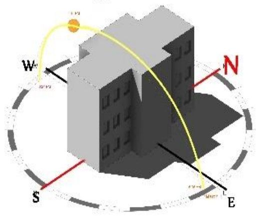
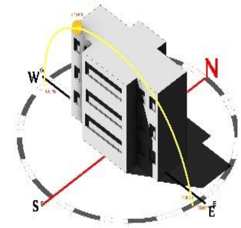
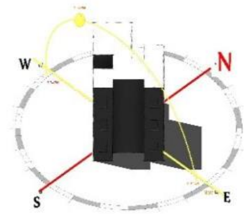
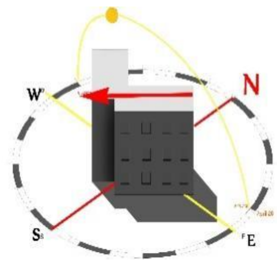
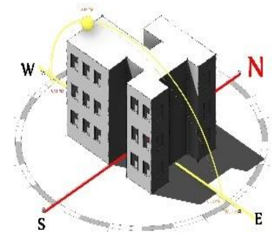
____

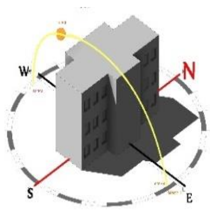
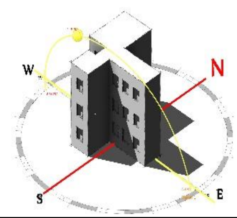
APPENDIX- IV

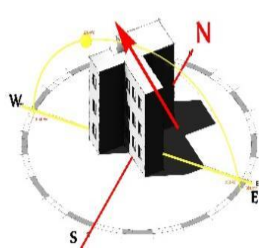
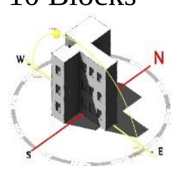
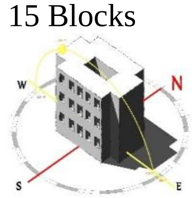
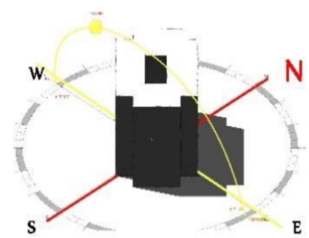
Building orientation of condominium sites in Adama

Site : Goro Condominium site			
Orientation			
S – N axis **(Azimuth angle-0°N)**	**NE – SW axis** **Azimuth angle-45°E**	**E – W axis** **(Azimuth angle-90°E)**	**NW – SE axis** **Azimuth angle- 315° N**
3 Blocks 	3 Blocks  2 Blocks 	5 Blocks  4 Blocks 	3 Blocks  3 Blocks 

Site: Ganda Gara Condominium Site			
Orientation			
S – N axis **(Azimuth angle-0°N)**	**NE – SW axis** **Azimuth angle-45°E**	**E – W axis** **(Azimuth angle-90°E)**	**NW – SE axis** **Azimuth angle- 315° N**
3 Blocks 		2 Blocks 	1 Block 

 1 Block		 4 Blocks	 2 Blocks
	1 Block 	2 Blocks 	

Site : Moenko Condominium Site			
Orientation			
S – N axis (Azimuth angle-0°N)	**NE – SW axis Azimuth angle-45°E**	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle- 315° N**
2 Blocks 	No Blocks	2 Blocks 	No Blocks

Site : Duket Condominium site		
Orientation		
NE – SW axis Azimuth angle-45°E	**E – W axis (Azimuth angle-90°E)**	**NW – SE axis Azimuth angle- 315° N**
2 Blocks 	10 Blocks  15 Blocks 	1 Blocks 

APPENDIX-V

Environmental variables measurements

Axis: - East - West

1. **Air Speed**

Site name: - Duket condominium site **Axis: -** East - West **Room Orientated: -** South

Floors:- Second floor **Room type:-** Three bed room

Air Speed data (m/s)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2024	3:00AM	0.10	0.19	0.21	0.00	0.97
	7:00PM	0.26	0.20	0.00	0.41	1.80
	10:00PM	0.36	0.52	0.50	0.00	2.00
Sunday, April, 17/2024	3:00AM	0.23	0.25	0.00	0.55	1.75
	7:00PM	0.01	0.15	0.10	0.52	1.63
	10:00PM	0.58	0.54	0.25	0.01	0.45
Tuesday, April, 19/2024	3:00AM	0.22	0.15	0.01	0.10	2.26
	7:00PM	0.20	0.00	0.09	0.00	1.78
	10:00PM	0.08	0.01	0.21	0.00	2.87
Thursday, April, 21/2024	3:00AM	0.00	0.06	0.09	0.28	1.45
	7:00PM	0.27	0.12	0.38	0.47	2.14
	10:00PM	0.45	0.16	0.21	0.33	1.56
Saturday, April, 23/2024	3:00AM	0.38	0.29	0.30	0.43	1.00
	7:00PM	0.28	0.00	0.40	0.00	0.90
	10:00PM	0.32	0.50	0.05	0.22	0.60
Monday, April, 25/2024	3:00AM	0.20	0.14	0.22	0.13	0.95
	7:00PM	0.00	0.20	0.31	0.57	1.75
	10:00PM	0.11	0.51	0.59	0.44	2.93

Wednesday, April, 27/2024	3:00AM	0.14	0.33	0.26	0.53	1.30
	7:00PM	0.23	0.44	0.32	0.30	1.12
	10:00PM	0.01	0.19	0.26	0.40	2.41
Friday, April, 29/2024	3:00AM	0.23	0.40	0.52	0.20	2.89
	7:00PM	0.09	0.00	0.18	0.02	1.70
	10:00PM	0.04	0.18	0.08	0.41	2.98
Sunday, May, 1/2024	3:00AM	0.10	0.48	0.00	0.58	2.50
	7:00PM	0.24	0.48	0.09	0.00	1.45
	10:00PM	0.32	0.27	0.11	0.30	2.70
Tuesday, May, 3/2024	3:00AM	0.26	0.06	0.00	0.25	1.52
	7:00PM	0.18	0.37	0.05	0.00	0.49
	10:00PM	0.10	0.31	0.29	0.11	1.00
Thursday, May, 5/2024	3:00AM	0.40	0.38	0.25	0.00	1.15
	7:00PM	0.31	0.06	0.60	0.45	1.40
	10:00PM	0.18	0.00	0.39	0.30	2.45
Saturday, May, 7/2024	3:00AM	0.30	0.00	0.01	0.00	0.69
	7:00PM	0.00	0.36	0.25	0.50	2.88
	10:00PM	0.42	0.29	0.50	000	1.91

2. Air temperatures

Site name: - Duket condominium site **Axis:-** East - West **Room Orientated:-** South

Floors:- Second floor **Room type:-** Three bed room

Temperature data (^{0}C)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April,	3:00AM	27.4	26.6	27.7	26.5	28.1
	7:00PM	30.5	31.4	28.8	29.7	32.5

15/2024	10:00PM	29.2	30.6	29.7	29.0	33.1
Sunday, April, 17/2024	3:00AM	26.7	27.0	27.5	26.9	28.3
	7:00PM	30.9	30.1	31.4	29.5	31.9
	10:00PM	29.3	28.8	29.4	30.1	31.6
Tuesday, April, 19/2024	3:00AM	26.1	27.6	26.6	26.3	28.4
	7:00PM	30.0	29.8	30.9	31.0	32.9
	10:00PM	29.3	29.5	28.7	29.9	32.0
Thursday, April, 21/2024	3:00AM	26.8	26.6	26.0	27.5	28.5
	7:00PM	32.1	30.3	29.5	31.0	33.7
	10:00PM	30.4	29.2	28.5	31.0	32.3
Saturday, April, 23/2024	3:00AM	26.7	26.4	27.3	26.2	27.5
	7:00PM	30.0	29.1	30.8	28.4	29.4
	10:00PM	30.5	29.6	30.5	29.9	32.9
Monday, April, 25/2024	3:00AM	26.9	27.1	26.5	27.8	27.9
	7:00PM	28.9	28.7	29.5	29.2	32.2
	10:00PM	29.8	28.5	30.3	27.4	33.4
Wednesday, April, 27/2024	3:00AM	26.0	25.5	26.1	25.8	26.4
	7:00PM	28.5	26.0	26.2	27.6	30.2
	10:00PM	29.6	28.7	30.3	28.7	32.5
Friday, April, 29/2024	3:00AM	26.8	25.5	27.0	26.5	27.7
	7:00PM	28.4	27.1	31.2	29.0	31.4
	10:00PM	29.6	28.3	30.9	30.5	31.9
Sunday, May, 1/2024	3:00AM	25.9	26.7	25.8	25.0	26.3
	7:00PM	30.5	30.5	30.0	28.4	29.0
	10:00PM	30.0	31.8	29.7	29.7	31.4
Tuesday,	3:00AM	26.1	26.3	25.3	27.1	28.2

May, 3/2024	7:00PM	28.9	29.3	28.4	28.5	29.1
	10:00PM	31.3	30.5	29.9	30.0	30.8
Thursday, May, 5/2024	3:00AM	26.4	25.8	26.0	25.8	27.9
	7:00PM	30.9	26.1	26.5	26.6	31.2
	10:00PM	31.2	29.8	27.4	28.6	32.8
Saturday, May, 7/2024	3:00AM	26.1	25.4	25.8	28.0	29.6
	7:00PM	29.1	29.9	26.0	29.5	32.2
	10:00PM	30.5	29.0	29.9	29.5	33.6

3. Relative Humidity

Site name: - Duket condominium site **Axis: -** East - West **Room Orientated: -** South

Floors:- Second floor **Room type:-** Three bed room

Relative Humidity data (%)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2024	3:00AM	29	27	28	28	28
	7:00PM	28	26	27	29	29
	10:00PM	28	27	26	28	28
Sunday, April, 17/2024	3:00AM	31	29	30	28	29
	7:00PM	28	26	27	28	27
	10:00PM	27	29	30	30	26
Tuesday, April, 19/2024	3:00AM	32	32	30	34	28
	7:00PM	25	26	26	24	25
	10:00PM	24	27	26	25	24
Thursday, April, 21/2024	3:00AM	27	29	29	30	30
	7:00PM	26	27	28	28	25
	10:00PM	25	24	26	26	22

Saturday, April, 23/2024	3:00AM	30	28	27	28	25
	7:00PM	24	25	26	27	26
	10:00PM	25	27	25	26	24
Monday, April, 25/2024	3:00AM	27	27	28	27	26
	7:00PM	24	23	22	24	20
	10:00PM	26	25	24	27	26
Wednesday, April, 27/2024	3:00AM	28	25	26	27	29
	7:00PM	25	26	25	29	28
	10:00PM	28	28	26	29	26
Friday, April, 29/2024	3:00AM	29	29	28	34	27
	7:00PM	25	26	24	24	25
	10:00PM	26	25	25	26	21
Sunday, May, 1/2024	3:00AM	28	29	28	28	25
	7:00PM	24	26	25	24	29
	10:00PM	27	28	27	27	26
Tuesday, May, 3/2024	3:00AM	30	28	28	29	29
	7:00PM	28	28	27	27	26
	10:00PM	29	29	29	29	29
Thursday, May, 5/2024	3:00AM	29	26	28	30	27
	7:00PM	23	24	25	24	21
	10:00PM	26	27	25	28	24
Saturday, May, 7/2024	3:00AM	26	27	28	30	24
	7:00PM	24	25	27	29	24
	10:00PM	25	26	26	28	29

Axis:- North - South

1. **Air Speed**

Site name: - Duket condominium site **Axis:-** North - South **Room Orientated:-** North

Floors:- Second floor **Room type:-** Two bed room

Air Speed data (m/s)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2024	3:00AM	0.69	0.48	0.83	0.38	2.14
	7:00PM	0.71	0.80	0.62	0.91	1.45
	10:00PM	0.19	0.73	0.35	0.21	1.10
Sunday, April, 17/2024	3:00AM	0.56	0.25	0.30	0.55	1.75
	7:00PM	0.32	0.50	0.46	0.52	1.63
	10:00PM	0.58	0.54	0.25	0.88	2.50
Tuesday, April, 19/2024	3:00AM	0.40	0.95	0.38	0.65	2.36
	7:00PM	1.12	0.97	1.15	0.51	3.58
	10:00PM	0.86	0.45	0.34	0.82	1.75
Thursday, April, 21/2024	3:00AM	0.75	0.21	0.70	0.51	2.45
	7:00PM	0.27	0.15	0.37	0.36	2.64
	10:00PM	0.49	0.36	0.61	0.73	1.96
Saturday, April, 23/2024	3:00AM	0.38	0.29	0.30	0.43	1.10
	7:00PM	0.61	0.40	0.88	0.39	2.90
	10:00PM	0.32	0.50	0.45	0.22	0.60
Monday, April, 25/2024	3:00AM	1.94	1.25	0.76	0.83	3.95
	7:00PM	0.90	0.55	0.62	0.57	2.75
	10:00PM	0.26	0.51	0.59	0.44	2.93
Wednesday, April,	3:00AM	0.74	0.53	0.46	0.70	1.80
	7:00PM	0.33	0.84	0.32	0.30	0.94

27/2024	10:00PM	0.96	0.85	0.62	1.40	3.50
Friday, April, 29/2024	3:00AM	0.43	0.40	0.52	0.20	1.89
	7:00PM	0.90	0.02	0.18	0.24	0.70
	10:00PM	0.05	0.28	0.20	0.40	0.98
Sunday, May, 1/2024	3:00AM	1.10	0.66	1.00	0.81	1.44
	7:00PM	0.45	0.34	0.09	0.77	2.50
	10:00PM	0.32	0.27	0.31	0.30	0.70
Tuesday, May, 3/2024	3:00AM	0.46	0.26	0.00	0.35	0.52
	7:00PM	0.32	0.37	0.25	0.02	0.97
	10:00PM	1.03	0.50	0.97	0.88	3.08
Thursday, May, 5/2024	3:00AM	0.50	0.38	0.25	0.05	0.75
	7:00PM	0.41	0.46	0.60	0.45	0.80
	10:00PM	0.28	0.19	0.79	0.30	0.45
Saturday, May, 7/2024	3:00AM	0.40	0.62	0.51	0.08	0.69
	7:00PM	0.87	0.86	0.65	1.04	1.88
	10:00PM	0.92	0.99	0.50	0.15	0.91

2. **Air temperature**

Site name: - Duket condominium site **Axis:-**North - South **Room Orientated:-** North

Floors:- Second floor **Room type:-** Two bed room

Temperature data (^{0}C)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2024	3:00AM	24.9	24.8	24.5	23.9	24.6
	7:00PM	27.5	26.9	26.3	27.7	29.0
	10:00PM	26.8	26.5	27.4	26.6	27.5
Sunday, April,	3:00AM	24.6	23.5	24.1	24.2	25.0
	7:00PM	26.8	26.9	26.0	27.1	28.7

17/2024	10:00PM	27.7	27.2	27.4	28.0	28.5
Tuesday, April, 19/2024	3:00AM	24.5	23.7	22.8	23.9	24.8
	7:00PM	28.2	28.8	28.7	26.0	29.4
	10:00PM	24.0	23.8	24.2	23.4	26.0
Thursday, April, 21/2024	3:00AM	25.1	24.0	24.9	24.9	25.5
	7:00PM	26.6	26.7	26.8	27.9	28.1
	10:00PM	28.7	26.3	28.8	28.9	29.1
Saturday, April, 23/2024	3:00AM	25.8	24.1	24.6	24.7	25.0
	7:00PM	28.3	27.6	26.2	26.7	28.8
	10:00PM	26.0	27.0	26.4	27.4	28.5
Monday, April, 25/2024	3:00AM	25.6	24.9	25.5	26.7	26.7
	7:00PM	27.9	28.5	28.1	27.5	29.8
	10:00PM	26.1	26.6	26.4	26.3	27.5
Wednesday, April, 27/2024	3:00AM	23.9	23.8	24.8	25.2	25.3
	7:00PM	29.1	28.3	27.4	28.7	30.4
	10:00PM	27.0	27.5	26.5	26.4	27.8
Friday, April, 29/2024	3:00AM	24.5	24.9	22.8	23.9	25.2
	7:00PM	26.4	25.5	24.6	26.7	28.1
	10:00PM	28.5	28.4	28.7	28.2	30.0
Sunday, May, 1/2024	3:00AM	23.8	24.4	23.5	22.5	24.4
	7:00PM	26.0	25.3	25.6	25.4	28.4
	10:00PM	27.3	27.2	29.8	28.0	29.0
Tuesday, May, 3/2024	3:00AM	25.9	24.8	23.0	23.8	25.7
	7:00PM	26.2	26.8	26.3	26.8	27.9
	10:00PM	26.1	25.5	26.3	27.4	28.5
Thursday,	3:00AM	25.2	23.3	24.5	24.9	25.1

May, 5/2024	7:00PM	26.5	26.0	26.0	27.3	27.5
	10:00PM	26.8	26.9	27.1	27.4	28.5
Saturday, May, 7/2024	3:00AM	22.9	24.4	23.8	24.2	25.5
	7:00PM	26.4	28.7	26.8	26.9	28.2
	10:00PM	26.8	27.2	26.9	28.8	29.0

3. Relative Humidity

Site name: - Duket condominium site **Axis:-** North - South **Room Orientated:-** North **Floors:-** Second floor **Room type:-** Two bed room

Relative Humidity data (%)						
Date	**Time**	**Living room**	**Bedroom**	**Kitchen**	**Toilet**	**Outdoor**
Friday, April, 15/2024	3:00AM	33	32	30	34	29
	7:00PM	27	26	27	26	25
	10:00PM	28	27	25	28	27
Sunday, April, 17/2024	3:00AM	31	37	30	26	31
	7:00PM	29	28	27	28	26
	10:00PM	28	28	26	29	27
Tuesday, April, 19/2024	3:00AM	29	30	32	29	28
	7:00PM	25	24	26	28	24
	10:00PM	26	27	28	29	25
Thursday, April, 21/2024	3:00AM	37	32	32	33	30
	7:00PM	29	28	29	30	28
	10:00PM	27	28	28	29	26
Saturday, April, 23/2024	3:00AM	32	29	31	30	28
	7:00PM	28	27	29	28	26
	10:00PM	27	26	28	29	25

Monday, April, 25/2024	3:00AM	28	29	27	27	26
	7:00PM	26	27	25	25	24
	10:00PM	26	25	24	25	24
Wednesday, April, 27/2024	3:00AM	29	28	30	31	29
	7:00PM	25	27	29	29	25
	10:00PM	27	26	28	28	27
Friday, April, 29/2024	3:00AM	27	26	28	28	27
	7:00PM	26	26	27	28	26
	10:00PM	26	25	26	27	25
Sunday, May, 1/2024	3:00AM	38	36	35	34	32
	7:00PM	28	28	29	28	28
	10:00PM	29	28	30	29	29
Tuesday, May, 3/2024	3:00AM	32	30	34	33	32
	7:00PM	30	29	30	31	29
	10:00PM	29	30	29	33	29
Thursday, May, 5/2024	3:00AM	29	28	28	30	29
	7:00PM	27	26	25	25	24
	10:00PM	28	27	26	25	25
Saturday, May, 7/2024	3:00AM	33	38	36	37	34
	7:00PM	24	25	27	29	24
	10:00PM	27	26	28	30	25