EVALUATING INDOOR THERMAL COMFORT IN DIRE DAWA CITY ETHIOPIA: A COMPARATIVE STUDY OF MODERN AND TRADITIONAL RESIDENTIAL HOUSES.

Yoseph Haileyesus Haileselasie

A thesis submitted to the Department of Architecture
College of Civil Engineering & Architecture, Urban Planning and Design

Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Architecture

Office of Graduate Studies Adama Science

And

Technology University

Adama

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ASSESSING INDOOR THERMAL COMFORT IN DIRE DAWA CITY ETHIOPIA: A CASE STUDY OF MODERN AND TRADITIONAL RESIDENTIAL HOUSES.

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Advisor: Belay Zeleke (PhD)

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Declaration

I declare that this thesis proposal entitled "**Evaluating Indoor Thermal Comfort in Dire Dawa city Ethiopia: A Comparative Study of Modern and Traditional Residential Houses**." is my own work and has not been submitted to any university for similar purpose. The references used in this proposal are duly recognized by proper citations.

Yoseph Haileyesus haileselasie	____________________	_______________
Name of student	Signature	Date

Recommendation of Advisors/ Supervisors

I, the major advisor/supervisor of this research proposal, hereby certify that I have closely advised/supervised the student while developing this proposal and read the draft thesis/dissertation proposal entitled **"Evaluating Indoor Thermal Comfort in Dire Dawa city Ethiopia: A Comparative Study of Modern and Traditional Residential Houses"** prepared under my guidance by Yoseph Haileyesus Haileselasie. Therefore, I recommend the submission of the proposal to the department for further review and evaluation.

Belay Zeleke (PhD)	______________________	________________
Major Advisor/Supervisor	Signature	Date
___________________________	________________________	________________
Co-advisor/Co-supervisor	Signature	Date

Approval Page Thesis Proposal

I hereby certify that the recommendation and suggestion given by the proposal review the committee are appropriately incorporated into the final thesis/dissertation proposal entitled **"Evaluating Indoor Thermal Comfort in Dire Dawa city Ethiopia: A Comparative Study of Modern and Traditional Residential Houses"** by Yoseph Haileyesus Hailesilasie.

Belay Zeleke (PhD)	____________________	__________________
Major Advisor/Supervisor	Signature	Date
______________________________	__________________	__________________
Co-advisor/ Co-supervisor	Signature	Date

Approval Board of Reviewers

We, the undersigned, members of the Board of Reviewers of the proposal open defense by Yoseph Haileyesus Haileselasie have read and evaluated the thesis/dissertation proposal entitled **"Evaluating Indoor Thermal Comfort in Dire Dawa city Ethiopia: A Comparative Study of Modern and Traditional Residential Houses"** and assessed the understanding of the candidate about the proposed research. This is, therefore, to certify that the thesis/dissertation proposal is accepted and we recommend the implementation of the proposal. -------------------------------- ---- -----------------------------.

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Chairperson	Signature	Date
______________________	______________	________________
Internal examiner	Signature	Date
Mekonnen Abebe (PhD)	______________	________________
External examiner	Signature	Date

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

______________________	______________	________________
Department Head	Signature	Date
______________________	______________	________________
College Dean	Signature	Date
______________________	______________	________________
Office of Postgraduate Studies, Dean	Signature	Date

Motivation

My master's design studio project for the second half of the first year, focused on a case study and workshop of the thermal comfort of buildings. In particular, the focus of my work has been to investigate the interrelationship between the building design, climate, and thermal comfort. Finally, after completing my postgraduate study, I went on a professional field trip to explore Dire Dawa. As I spent more time there, I observed the living and noticed that comfort wise, the temperature range was not up to modern accommodation standards. While looking, I found an article about modern housing being utilized in the extreme weather models in my location. This is because most modern homes are dependent on the weather conditions elsewhere. Most of the time is usually given to people living in traditional mud houses. Because of the above reasons, my study has provided a good avenue for identifying building types that are thermally thermal and correspond to the specific climatic condition of the area.

ACKNOWLEDGMENT

I would like to express my deep appreciation for the continued guidance, advice, and invaluable insight from my advisor, Dr. Belay Zeleke, during my research. This has been greatly reshaped by his sharp, constructive comments; something that bears witness to the value of such close supervision, backstopped by the patience in academic.

I am very much appreciative of the cooperation and support from the residents of Dire Dawa City, Ethiopia, without whose participation this research would not have been possible. Their willingness to share their experiences and perceptions has been greatly important in exploring the thermal comfort conditions of modern and traditional residential houses.

I would also like to extend my appreciation for the support and facilities provided by the Adama Science and Technology University and Department of architecture throughout the duration of this research. Indeed, the availability of research facilities, literature, and funding has been very instrumental in the successful completion of this study.

Lastly, I would also like to thank my family and friends for their untiring encouragement and moral support throughout this research. Their understanding and motivation have been a constant source of inspiration.

This research was made possible by the joint efforts and contributions of all the persons and organizations cited above. I am indeed grateful for their valuable assistance and support.

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List of abbreviation

AAC : Autoclaved aerated concrete

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

CFM : cubic feet per minutes

CIS : Construction Specifications Institute

E.c. Ethiopian calendar

HCB : hollow concrete block

MS : micro soft

PMV : predicted mean vote

PPD : Predicted Percentage of Dissatisfied (PPD)

RC : reinforced concrete

RH : relative humidity

WBGT: Wet Bulb Globe Temperature

ABSTRACT

This paper investigates indoor thermal comfort conditions in modern and traditional residential houses in Dire Dawa City, Ethiopia. The aims are to identify factors that affect the indoor thermal environment and their contribution to discomfort, assess users' thermal comfort preferences between traditional and modern residential houses, and explore possible improvements to increase occupants' satisfaction. It also compares the results between the two housing types for any differences that may be ascribed to the design, construction, and the climatic condition in the area of the other region. On-site surveys and measurement of indoor and outdoor temperature, relative humidity, and air speed are measured while occupants' perceptions and their satisfaction levels of indoor environment conditions were obtained by questionnaire. For the survey, a total of 116 targeted groups of respondents were purposively chosen from the population who had experience in living in both types of houses. Results: 88.8% of the respondents felt that the thermal sensation scale of traditional houses was better than that of modern houses; 87.1% preferred the thermal environment of traditional houses, and 87.1% were more satisfied with traditional houses than with modern houses. The recorded data's also show that, in all four consecutive months, the traditional houses performed better than the modern houses. This paper provides useful knowledge on how design, construction, and selection of residential buildings in Dire Dawa City can be upgraded to achieve better indoor thermal comfort. The results can contribute to policy recommendations for local governments, building regulations, and guidelines for future construction projects. This paper can become a reference point for similar studies that other regions may conduct due to similar challenges arising from urbanization and climate change impacts on housing conditions.

Key words: indoor thermal comfort, micro(local) climate ,environmental variables,level of comfort

CHAPTER ONE

1. INTRODUCTION

This paper aims at meeting requirements for the Master's program in Environmental Architecture of Adama Science and Technology University. The research took place in Dire Dawa municipality, Ethiopia. The major objectives of this study were to assess the physical and environmental aspects of thermal comfort in modern and traditional houses, and develop suitable housing design strategies that would fit the existing climate condition within the city. In designing buildings, sustainability emanates from following the climatic conditions optimally for comfort. This is a major contributor to the degree of comfort within an indoor environment for its occupants. Such designers are generally mindful about taking care of the environment issues in their work. However, the situation in Dire Dawa, Ethiopia, among other similar areas found in hot semi arid climatic zones is different greatly from this rule. Exposure to extreme temperatures results in a drop in productivity or deteriorating health of the subjects involved.

A resident from Dire Dawa city who understands various dimensions on several levels, makes this researcher competent enough. With that in mind, this analysis examines thermal comfort situations both in modern houses and traditional ones so that they could get more insight into it.

This chapter deals with the background of the study, statement of the problem, objectives of the study, research questions, scope of the study, the significance of the study, limitation of the study and description of the study area.

1.1. Background of the study

Thermal comfort is one of the important factors in human well-being, health, and productivity, especially within residential environments. It is defined as the condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 2017). Indoor thermal comfort, at optimum levels, is imperative in residential buildings to improve quality among the occupants.

The thermal comfort depends upon the parameters including air temperature, relative humidity, air movement, and the properties of building materials (Fanger, 1970). Of course, the most critical parameter is the air temperature: this factor results in a direct influence on the heat exchange between the human body and the environment. On the other hand, relative humidity contributes mainly to evaporative cooling through the process that is, evaporative cooling is considered a primary route of heat dissipation from the human body. On the other hand, air movement can affect the loss of heat from the body and affecting overall thermal sensation (Auliciems & Szokolay, 1997).

The design of residential buildings is one of the major factors in achieving thermal comfort, especially in regions with diverse climatic conditions. Dire Dawa, Ethiopia, is located in a subtropical highland and hot semi-arid climate characterized by warm temperatures and some precipitation throughout the year (Woldeamlak, 2009). The unique geographical location and climatic condition of the city make it very challenging to maintain indoor thermal comfort, especially in traditional and modern residential buildings.

Traditional residential buildings in Dire Dawa have design elements and construction materials that are well suited to the local climate, such as thick walls, small windows, and natural ventilation systems. With these features, buildings could regulate indoor temperatures and promote thermal comfort. On the other hand, modern residential buildings emphasize more aesthetics and functionality rather than thermal performance, which might lead to potential issues of indoor thermal comfort.

Understanding the thermal performance of both traditional and modern residential buildings in Dire Dawa is very important for the development of strategies to improve indoor thermal comfort, since it might have important implications in the health, well-being, and productivity of the inhabitants. This study tries to compare the indoor thermal comfort of modern and traditional residential houses in Dire Dawa, Ethiopia, so as to provide insights that will be useful for future building design and construction practices in the region.

1.2. Statement of the problem

The issue of indoor thermal comfort in Dire Dawa City, Ethiopia, is increasingly pressing due to rising temperatures and inadequate building designs that fail to account for local climatic conditions. As urbanization accelerates, the demand for housing has led to a proliferation of both modern and traditional residential structures. However, many of these buildings do not incorporate essential passive design strategies that could mitigate heat gain and enhance thermal comfort for occupants. The lack of consideration for the region's climate in construction practices results in environments that are often uncomfortably hot, negatively impacting the health and well-being of residents.

Furthermore, the existing body of research on indoor thermal comfort in Ethiopia is limited, particularly in the context of Dire Dawa. While some studies have addressed thermal comfort, they often overlook the unique climatic challenges faced by the city. The dearth of comprehensive research hinders the development of effective strategies for improving indoor conditions. Additionally, many studies that do exist rely on unsuitable methods for data collection, leading to unreliable conclusions that fail to accurately reflect the thermal comfort levels experienced by occupants in both modern and traditional homes.

To address these gaps, it is essential to undertake a thorough assessment of indoor thermal comfort in Dire Dawa. This study aims to evaluate the thermal performance of various residential building types, considering local climate data and occupant experiences. By employing appropriate data collection methods and focusing on the specific characteristics of the buildings, the research will provide valuable insights that can inform future architectural practices and policies, ultimately enhancing the quality of life for residents in the region.

1.3. Research Objective

1.3.1. General objective

The study's main goal is to compare the bioclimatic thermal comfort of modern houses to that of traditional one in Dire Dawa city.

1.3.2. Specific objectives

The specific objectives of the study are

- To evaluate the various environmental and physical factors that effects on the thermal comfort levels of both modern and traditional buildings.
- To evaluate the thermal comfort choices of users between traditional and modern residential houses.
- To compare the level of comfort provided by traditional houses in comparison to modern ones.
- To develop the design strategies to enhance the indoor thermal comfort building occupants.

1.4. Research Questions

The following research questions are formulated based on the specific objective of the study.

1. What is the current state of the thermal comfort of the modern and the traditional house?
2. What are the perceptions of the society towards preference of living in a modern and traditional house with respect to thermal comfort?
3. Which building type building is comfortable for residents concerning to thermal comfort?
4. What design strategies can be developed to effectively enhance indoor thermal comfort for building occupants?

1.5. Significance of the study

The importance of the study will be very high in enhancing thermal comfort in dwellings in various ways, including:

By improving comfort in houses and protecting the occupants from potential health problems such as pain, headache, stress, dizziness, asthma, and asthma-like conditions caused by inadequate indoor temperatures, the research will impact positively on education, transform society for the better, boost the economy, and accelerate technological development.

The present comparison would be important in learning how buildings designed in very different ways, in terms of construction materials, are affecting the thermal environment for their occupants in both modern and traditional residential houses in Dire Dawa city, Ethiopia.

Such an evaluation of thermal comfort in both modern and traditional residential houses can enable the researcher to identify all the factors responsible for better or worse thermal comfort. This information could direct future building designs and construction practices on how to improve indoor thermal conditions.

The study will help preserve and document traditional building knowledge and construction techniques likely to be useful for achieving thermal comfort in this local context through the inclusion of traditional residential houses.Such will be useful in developing building codes, standards, and policies that are aimed at improving thermal comfort while enhancing energy efficiency in the residential sector, particularly for Dire Dawa and similar climates.

1.6. The scope of the research

Thematic scope

The main objective of the study is to investigate and evaluate the traditional and contemporary structures of Dire Dawa. The study focuses on the sustainability of traditional buildings and their ability to provide cooling heat. The main objective of the study is to investigate the characteristics of indoor thermal satisfaction in traditional and modern buildings

Spatial scope

The study mainly focuses on Kebele 02 and Kebele 08 of Dire Dawa City, though modern and traditional architecture is seen all over the city. The above two Kebeles were chosen because they show most of the variety in modern and traditional housing. This diversity allows for a thorough comparison of thermal performance across building types and valuable lessons on how architectural design influences indoor climate. The architectural diversity aside, the socio-economic diversity represented within Kebele 02 and Kebele 08 offers a unique perspective to thermal comfort. The variations in income levels and living conditions prevailing in these areas allow an investigation into how socio-economic parameters influence residents' experience of thermal comfort. This aspect of the research aims to emphasize the link between economic status and the efficiency of various architectural styles in terms of creating a comfortable environment for living.

Furthermore, the microclimatic conditions of each kebele make them suitable for analyzing the impact of local environmental factors on indoor comfort.

1.7. Limitation of the research

Research is an important tool for gathering knowledge and information to help communities solve a variety of challenges. However, research is not always accurate, introducing limitations that can affect the accuracy, validity, and validity of results. This section focuses on the discussion of limitations that arise during the analysis. An important limitation of this study is the availability of measurement instruments for measuring environmental variables. Sensors and instruments are often used to analyze and measure indoor temperatures. These instruments typically have specific calibration requirements that must be followed exactly. Another is that this research is likely to require significant resources, both in terms of time and funding, which limits the capacity for more comprehensive research. And the study focused on specific environmental variables, such as room temperature, humidity & wind velocity, without considering other factors affecting thermal comfort, such as physiological variables or demographics they stay in because of the resources available that measure those things.

1.8. Thesis structure

This thesis present in five parts: the first part of the title is represented by the "General Introduction," describing the main area of research and the problem that the research tries to solve; in this chapter, the aims, objectives, and scope of the research are outlined, and each further chapter is introduced. Chapter 2 is entitled "Literature review" and covers the critical literature review in view of past research into the research topic. The second chapter will critically examine and analyze previous research in the area and outline any omissions or defects that this research tries to address. Chapter 3 entitled "Research Methods" outlines the research methods and procedures applied in the study. This chapter gives a general description of the methodology adopted for the study, followed by the target population and sampling design. The last part of this chapter introduces in-depth the instruments and methods applied for data collection, analysis, and presentation. The research effort has been designed and organized in detail. Chapter 4 covers the results from the data collection. Summary of Data Analysis This section discusses the findings and the results of the study. It includes tables of data, graphs, figures, and statistical analysis which may be used in interpreting findings and results. The last part of the title is the "conclusion", which summarizes the research findings, implications, recommended actions and also the strategies to solve the discomfort of occupants. This chapter synthesizes the research findings and discusses their theoretical and practical implications use of the character. It also indicates areas that have to be researched further and goes ahead to make recommendations.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This literature narrative review contains information gathered concerning the architecture of buildings envelope in response to the thermal comfort zone of the occupants. This review contains descriptions and knowledge that have been grasped in the means to attain thermal comfort in building through the building envelope. In addition, there is a review of different scholars' findings and works. In recognition of the study title.

2.2. Theoretical review

2.2.1 Thermal comfort and its importance

According to ASHRAE 55-2010, thermal comfort is the state of mind which is expressed in the level of satisfaction regarding the thermal environment and requires subjective evaluation (ASHRAE, 55-2010, 2017). Understanding thermal comfort as the state of mind also correctly highlights the fact that, the evaluation of comfort is a task of the brain which can be described as multi input and multi output, and is in turn influenced by physical, physiological and other aspects (Lin, 2008). Such factors, especially personal factors include differences in mood or cultures, as well as any individual, organizational or social factors. In this way, the concept of thermal comfort is not only a condition but a more to do with the psychology of the human beings (Noel et al., 2010).Furthermore, taking into consideration the behavior of occupants, Hensen (1991) defines thermal comfort as a state in which there are no driving impulses to correct the environment by the behavior. This definition has similarities with Givoni‘s definition (1976), that it is the absence of irritation and discomfort due to heat or cold, and as a state involving pleasantness. This can also depict the state where the person is entirely unaware of the thermal condition around them, without considering whether the space is too hot or too cold. In this state, the body temperatures are expected to remain within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized. Fanger (1973) defined thermal comfort as the subjective feeling of being neither too cold nor too warm under the provided clothing level. Accordingly, it is possible to say that thermal comfort is a mental condition where an individual is content with the thermal environment in which he is and does not feel the need to change the surrounding conditions or his or her physical and mental activities for a certain period of time.

Enhancing thermal comfort is important since it improves the health and productivity of the occupants, while also facilitating the enjoyment and protection of the indoor environment. Thermal comfort standards and evaluations developed from understanding the characteristics, behavior and impacts as well as the numerous factors that affect the thermal sensation and perception of the occupants. Therefore, the understanding of the characteristics and functions of these factors is also the defining feature of development of thermal comfort evaluation procedure.

2.2.2. Thermal comfort in outdoor spaces

The concept of thermal comfort is not limited to indoor spaces. It is equally important in outdoor areas. In recent years, there has been an increased interest in studying thermal comfort in outdoor environments, especially in urban areas, where the built environment can significantly affect thermal conditions.

According to Njomo's (2010) concept of thermal comfort in the outdoors, thermal comfort is defined as a state of mind that reflects satisfaction with the environment in a thermal environment.

Ambient temperature can be affected by many factors, including air temperature, radiant temperature, humidity, and wind speed. Njomo argues that the effects of these factors on thermal comfort are not independent, but interdependent. The thermal comfort of outdoor spaces is therefore best explained by considering climatic variables. To ensure thermal comfort in outdoor spaces, Njomo suggests that designers and planners should consider shade, ventilation, materials that capture the microclimate of the site Functions and the duration of the space, and the clothing of individuals the use of which forces the space.

In addition, Njomo suggests that individual users of outdoor spaces should be taught strategies to adapt to changing circumstances, such as removing or adding clothing, seeking shade, using apple understanding and managing increased heat or external temperature conditions can reduce the risk of health problems.

2.2.3. Thermal comfort zone

Thermal comfort is a well-researched concept in environmental psychology over the past decades. It refers to the state of satisfaction or comfort that individuals experience with the environment. The thermal comfort zone is the temperature where most people feel comfortable Neither too hot nor too cold. The concept of thermal comfort is important for the sake of energy conservation and its sustainability implications, as it relates to energy consumption and temperature and to air conditioning in buildings and (HVAC) system design (Njomo, 2010).

The graph below indicates that the temperature and humidity level of comfort. And according to ASHARE and as the figure indicates that temperature between 23^{0}C & 27^{0}C and Humidity from 30RH – 60RH refers to comfort zone (ASHRAE, 55, 2010).

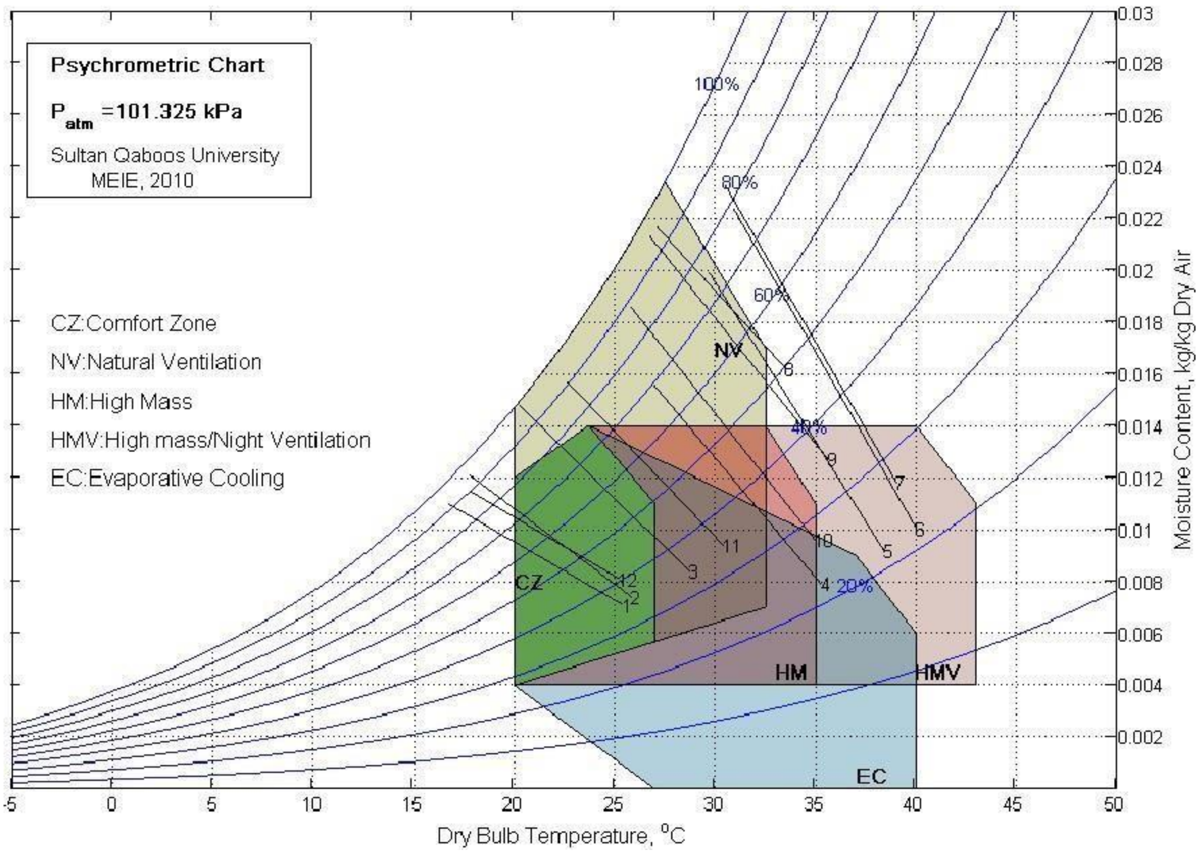

Figure 1: Thermal comfort zone source (Njomo, 2010)

2.2.4. Bio-climatic thermal comfort

The concept of bioclimatic thermal comfort relates to the ability of individuals to maintain a state of comfort within a built environment, taking into account the interaction of various microclimates. These factors include temperature, humidity, ventilation and radiation, etc. play an important role in achieving overall thermal comfort (Akande 2010).Proper consideration of bio-climate can inform the design of energy efficient buildings for the benefit of occupants comfort and well-being have improved. Thus, the study and application of this concept is important in promoting a sustainable and eco-friendly built environment.

Bioclimatic zone

Bioclimatic zones refer to regions of the world with similar climatic conditions such as temperature, humidity, and rainfall. These areas are determined by a combination of natural and anthropogenic factors, such as elevation, latitude, topography and land use. Understanding bio-climatic zones is important for fields such as architecture, urban planning and agriculture, as they enable the design of buildings and infrastructure suitable for the specific environmental conditions of a particular location.

Olgyay (1963) proposed a method for identifying bioclimatic zones by analyzing the annual temperature and relative humidity trends in an area. His method was to record monthly dry bulb temperatures in comparison to monthly wet bulb temperatures on a mental analytical chart, which could then be used to determine thermal comfort limits for a region of the country.

Temperate and semi-arid climates have absolute temperatures (vapor pressure) below 2.5 k Pa, and very high daily temperatures that rarely exceed 50ºC, with significant differences in summer and winter between which there is plenty of bright sunlight. In winter, temperatures fluctuate widely between daily and nighttime hours, varying by about 20ºC. Countries included within this zone are characterized by strong direct winds from the Earth’s surface, rainfall and runoff, frequent dust and sand storms, and large daily temperature fluctuations (Nicol & Humphreys, 2002).

Figure 2: Climatic zone source (Carmona, 2018)

2.2.5. Factors of thermal comfort

Thermal comfort factors (physical and non-physical) influence the thermal perception of a person in given space and time, due to its intrinsic characteristics, weight and potentials. These factors can be grouped into objective and subjective factors. Objective factors can be further divided into physical and physiological factors while subjective factors can be divided into psychological and socio-cultural factors.

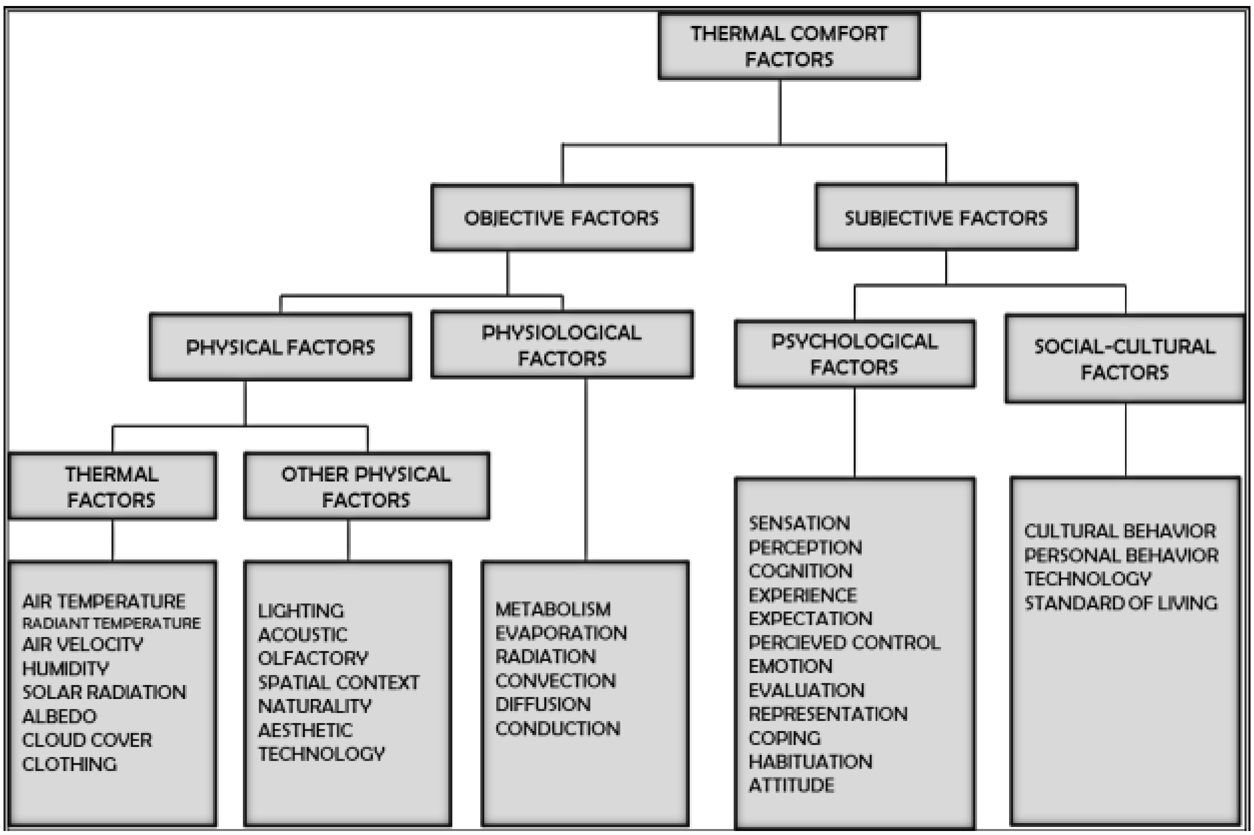

Figure 3: factors of thermal comfort (Fanger 1970)

Objective factors

They are factors that relates to some inherent characteristics of objects, elements, entity, or systems which are not influenced by a person‘s feelings or opinions in considering and representing the facts or value of its characters.

A. <u>Physical factors</u>

These are thermal comfort factors that relates to some inherent characteristics of objects or elements that are available and can be sensed from our environment, but are not influenced by a person‘s feelings or opinions in considering the value or quantity of such characters. These factors can be further divided into thermal factors and other physical factors such as acoustics, visual aspects, and olfactory influences. Only the thermal factors will be detailed in this study because of its relevance to this research.

Air temperature: The air temperature is the average temperature of the air surrounding the occupant, with respect to location and time. According to ASHRAE 55 standard, the spatial average takes into account the ankle, waist and head levels, which vary for seated or standing occupants. The temporal average is based on three-minute intervals with at least 18 equally spaced points in time. Air temperature is measured with a dry-bulb thermometer and for this reason it is also known as dry-bulb temperature. (ASHRAE, 2020)

Mean radiant temperature: The radiant temperature is related to the amount of radiant heat transferred from a surface, and it depends on the material's ability to absorb or emit heat, or its emissivity. The mean radiant temperature depends on the temperatures and emissivity's of the surrounding surfaces as well as the view factor, or the amount of the surface that is "seen" by the object. So the mean radiant temperature experienced by a person in a room with the sunlight streaming in varies based on how much of their body is in the sun. (ASHRAE, 2020)

Air speed: is defined as the rate of air movement at a point, without regard to direction. According to ASHRAE Standard 55, it is the average speed of the air surrounding a representative occupant, with respect to location and time. The spatial average is for three heights as defined for average air temperature. For an occupant moving in a space the sensors shall follow the movements of the occupant. The air speed is averaged over an interval not less than one and not greater than three minutes. Variations that occur over a period greater than three minutes shall be treated as multiple different air speeds. (ASHRAE, 2020)

Relative humidity (RH): is the ratio of the amount of water vapor in the air to the amount of water vapor that the air could hold at the specific temperature and pressure. While the human body has thermoreceptors in the skin that enable perception of temperature, relative humidity is detected indirectly. Sweating is an effective heat loss mechanism that relies on evaporation from the skin. However at high RH, the air has close to the maximum water vapor that it can hold, so evaporation, and therefore heat loss, is decreased. On the other hand, very dry environments (RH < 20–30%) are also uncomfortable because of their effect on the mucous membranes. The recommended level of indoor humidity is in the range of 30–60% in air conditioned buildings, (Aronoff & Kaplan,

1995) but new standards such as the adaptive model allow lower and higher humidity, depending on the other factors involved in thermal comfort.

Recently, the effects of low relative humidity and high air velocity were tested on humans after bathing. Researchers found that low relative humidity engendered thermal discomfort as well as the sensation of dryness and itching. It is recommended to keep relative humidity levels higher in a bathroom than other rooms in the house for optimal conditions. (Hashiguchi, Nobuko; Tochihara, Yutaka,2009)

Various types of apparent temperature have been developed to combine air temperature and air humidity. For higher temperatures, there are quantitative scales, such as the heat index. For lower temperatures, a related interplay was identified only qualitatively:

- High humidity and low temperatures cause the air to feel chilly. (McMullan, Randall, 2012).
- Cold air with high relative humidity "feels" colder than dry air of the same temperature because high humidity in cold weather increases the conduction of heat from the body. (Humidity ,2012)

Clothing insulation: According to the ASHRAE definition, clothing insulation is the resistance to sensible heat transfer provided by a clothing ensemble‖ (ASHRAE, 2017). It is usually expressed in clo units and 1 clo is equal to 0.155 m^2C/W.

b. Physiological factors

They factors are related with the functioning of body‘ system which regulate the body‘s thermal balance. These factors are based on the situation and body‘s need at a particular space in time. They include, but not limited to, heat transfer through the human metabolism, evaporation, convection, radiation and conduction.

Metabolic rate: People have different metabolic rates that can fluctuate due to activity level and environmental conditions (Toftum, J. 2005). ASHRAE 55-2017 defines metabolic rate as the rate of transformation of chemical energy into heat and mechanical work by metabolic activities of an individual, per unit of skin surface area. Metabolic rate is expressed in units of met, equal to 58.2 W/m^2 (18.4 $Btu/h{\cdot}ft^2$). One met is equal to the energy produced per unit surface area of an average person seated at rest.

ASHRAE 55 provides a table of metabolic rates for a variety of activities. Some common values are 0.7 met for sleeping, 1.0 met for a seated and quiet position, 1.2–1.4 met for light activities standing, 2.0 met or more for activities that involve movement, walking, lifting heavy loads or operating machinery. For intermittent activity, the standard states that it is permissible to use a time-weighted average metabolic rate if individuals are performing activities that vary over a period of one hour or less. For longer periods, different metabolic rates must be considered.

According to ASHRAE Handbook of Fundamentals, estimating metabolic rates is complex, and for levels above 2 or 3 met – especially if there are various ways of performing such activities – the accuracy is low. Therefore, the standard is not applicable for activities with an average level higher than 2 met. Met values can also be determined more accurately than the tabulated ones, using an empirical equation that takes into account the rate of respiratory oxygen consumption and carbon dioxide production. Another physiological yet less accurate method is related to the heart rate, since there is a relationship between the latter and oxygen consumption. (ASHRAE, 2005)

The Compendium of Physical Activities is used by physicians to record physical activities. It has a different definition of met that is the ratio of the metabolic rate of the activity in question to a resting metabolic rate (Ainsworth, 2000). As the formulation of the concept is different from the one that ASHRAE uses, these met values cannot be used directly in predicted mean vote (PMV) calculations, but it opens up a new way of quantifying physical activities.

Food and drink habits may have an influence on metabolic rates, which indirectly influences thermal preferences. These effects may change depending on food and drink intake. (Szokolay, Steven V, 2010)

According to ASHRAE the body shape is another factor that affects metabolic rate and hence thermal comfort. Heat dissipation depends on body surface area. The surface area of an average person is 1.8 m^2 (19 ft^2).

A tall and skinny person has a larger surface-to-volume ratio, can dissipate heat more easily, and can tolerate higher temperatures more than a person with a rounded body shape. (Szokolay, Steven V, 2010)

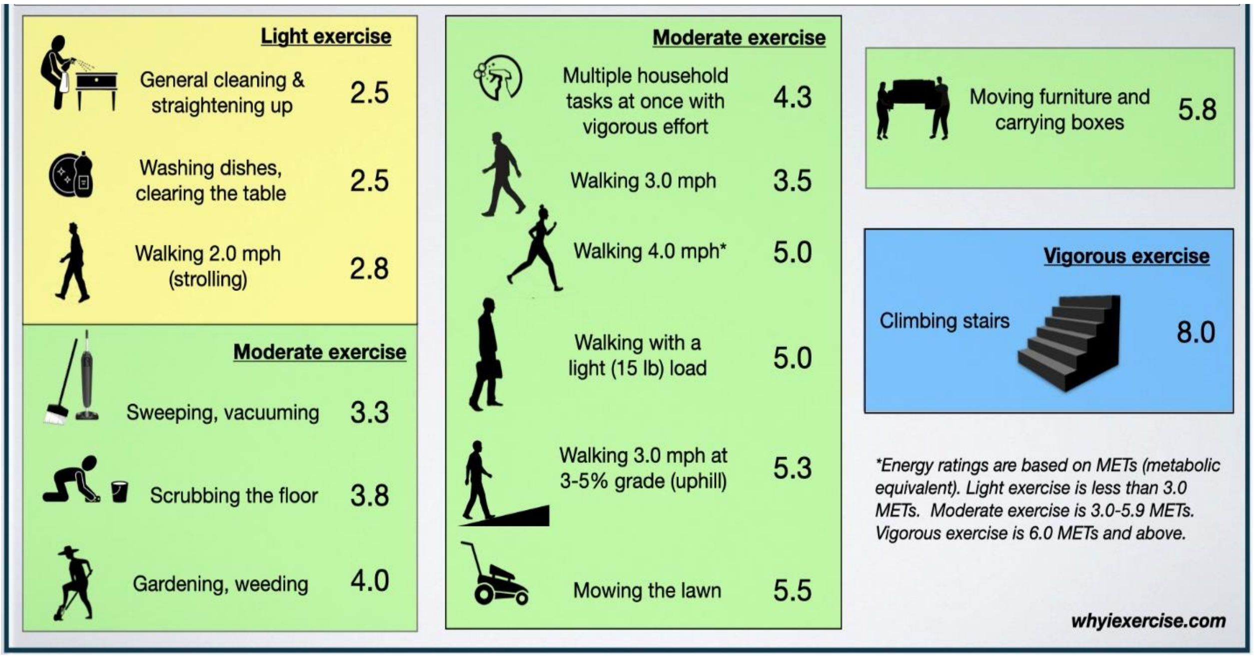

Figure 4: Metabolic rates for typical tasks (ASHRAE Standard)

Evaporation: is the process through which a liquid turns into gas. The human body utilizes by perspiration and diffusion from the skin and respiratory track to release energy to their surroundings, even in conditions when the surrounding temperature is higher than the body temperature.

Convection: is the transfer of heat by gas or liquid, where the amount of heat transferred depends on the temperature differences between the two mediums and the velocity of the fluid. Three different processes exist: free, mixed and forced convection.

Thermal radiation: refers to the emission of electromagnetic waves from any matter with a temperature above absolute zero (Howell, John R. 2016). The characteristics of thermal radiation depend on various properties of the surface, such as temperature, emissivity, absorptivity, reflectivity, and the view factor or geometric factor of the surfaces.

Heat conduction: occurs between two objects in contact, and heat energy transfers from one object to another. This usually occurs between the clothing and skin surfaces and the amount of heat transfer is determined by factors such as the clothing material conductivity or resistance.

Subjective factors

They are factors related to feelings or opinions in considering the facts or value of an entity, objects, elements or system. In thermal comfort evaluation, the subjective factors can be grouped into psychological and socio-cultural factors.

A. <u>PSYCHOLOGICAL FACTORS</u>

They are thermal comfort factors that are related to the human mind and behavior. This includes conscious and unconscious phenomena such as feelings and thoughts that can directly affect the behavior of individuals and groups. Psychological processes affecting thermal comfort includes sensation, environmental cognition (perception, representation, evaluation), Emotions, experiences, expectation, attitude, coping, habituation, based on past researchers especially Knez et al (2009).

Sensation: is the initial detection of a stimulus resulting from the stimulation of a receptor in a sense organ. Our sense organs are engaging in transduction, and sensation is possible if the stimulus is strong enough to excite sensory receptors and send nerve impulses to the brain.

Environmental cognition: refers to the mental process of acquiring knowledge and understanding our surroundings through thought, experience, and the senses. It is how we learn, remember, and think about information (Knez et al. 2009). Cognition includes perception, representation and evaluation.

Perception: was defined by Knez et al. 2009 as the conscious interpretation and elaboration of sensory data. In order for sensations to be useful, we must add meaning to those sensations, which create our perceptions.

Representation: is a hypothetical internal cognitive code that represents external reality (M. Nikolopoulou (2003). It can be referred to as the internal image of one‘s environment that constitutes a functional means of organizing information. Thus, people can codes and stores information relating to the positions and qualities of phenomena taking place in his or her environment.

Emotions: are mental states brought on by neurophysiological changes, variously associated with feelings, behavioral responses, and a degree of pleasure or displeasure (Cabanac Michel, 2002; Damasio, 1998).

Experience: refers to conscious events and the practical knowledge and familiarity that are produced by these conscious processes. It is associated with recurrent past acquaintance and the present contents of consciousness, as well as the stimulus that has resulted from its learning. **Expectation:** is a perceptual state of anticipation of an event or occurrence. They are personal beliefs about occurrences that may occur in the future, which are usually developed from a combination of individuals experiences and knowledge. Therefore, they serve a basic function to prepare humans for future action.

Attitude : can be defined as the readiness of the psyche to act or react in a certain way (Main, 2004). It can also refer to a mental and neurophysiological state, determined by experience that exerts a dynamic influence on the individual by preparing him to act in a particular way towards a number of objects or events.

Coping: refers to a complex set of behaviors and cognitions that individuals uses to deal with stress and adversity. Hence, in thermal comfort, coping is psychological regulation and strategic ways for dealing with some place-related stimulation and surpassing environmental situations (Knez et al. 2009)

Habituation: is a form of non-associative learning in which an innate (non-reinforced) response to a stimulus decreases after repeated or prolonged presentations of that stimulus (Bouton, 2007).

B. <u>Socio-cultural factors</u>

Culture is shared behaviors and ideas that are passed down through generations; this includes shared values, beliefs, norms, language, and even geography. Socio-cultural factors focus on how situations and cultural factors affect a person's behavior and thinking. It emphasizes that understanding a person's behavior requires knowing about the cultural context in which the behavior occurs (Matsumoto & Juang, 2013). It also submits that human learning is largely a social process, and that our cognitive functions are formed based on our interactions with those around us who are more skilled‖. Here are some of the socio-cultural factor that can influence the behavior of individuals: Culture and cultural expectations, Parental and peer influences, Community influences, Gender norms, Societal norms, Family, personal, and/or religious values, standard of living, mainstream media and social media, technological advancement.

Cultural behavior: depicts how culture reflects and shapes the mind and behavior of its members (Heine, 2015). The culture cycle consists of four layers; this includes individuals, interactions, institutions, and ideas. (Markus, & Conner, 2013)

Standard of living: implies the level of welfare provided to the residents of a country. Practically, it is reflected in the way in which people live, such as how much money they have to spend, how their houses are constructed, how educated they are, what facilities are available to them, etc.

Technological advancement: refers to the making, modification, usage, and knowledge of tools, machines, techniques, crafts, systems. Technological advancement equips individual with advanced devices and systems that enable him to live a more comfortable life.

2.2.6. Design factors affecting the level of thermal comfort

To the enhancement of indoor thermal comfort of housing, it is better to protect the buildings from different obstacles that directly affect the thermal comfort during design. It has been found that many factors affect the level of this comfort; major effects are such as urban design, the architectural design of the house, and material selection for the buildings, united with minor ones, such as economy, quality, etc. (ASHRAE 55, 1992).

Architectural design factor

The temperature inside a house affects the way it is built. The courtyard is an architectural feature that adds a great sense of warm home comfort. Several research efforts in the field of residential courtyards have highlighted its versatility, as it can be a useful method for controlling the natural environment within a household courtyards therefore represent an ideal architectural solution for tropical climates.

Appropriate design is an economically viable solution to enhance the residents' thermal comfort and reduce energy consumption in heating and cooling. Positioning the building can ensure that beneficial winter sunlight illuminates the interior, as well as providing natural ventilation during the summer months by controlling the direction of the summer winds so (Mirrahimi, 2014).

Wall construction mainly focuses on thermal comfort, so a huge amount of energy is used for that purpose. Proper design of walls in a building can save energy. Barrier construction uses specific materials to create walls with unique thermophysical properties that determine how walls respond to different climatic conditions In order to reduce energy consumption in buildings, it is important to understand how building envelope thermal performance affects the indoor environment.

Opening a building is a significant factor that can affect the comfort of its occupants. With increasing construction activity, people have turned to improved mechanical solutions such as air conditioning to provide thermal comfort in modern buildings but this has led to the introduction of increased energy efficiency.

One of the sources of heat for buildings is the movement of air between the roof and the interior. The roof of a building is involved in thermal gain generation. A roof with abundant and frequent sun exposure contributes greatly to the overall temperature of a building.

The purpose and use of a building are important factors that greatly affect the likelihood of occupants achieving optimal thermal comfort. The style of a building varies depending on the type of function. In residential apartments, the difference in room temperature is more tolerable compared to a hotel or hospital. (Mirrahimi, 2014).

Construction Materials

Building materials have also been reported to influence the comfort temperature in buildings. Locally sourced materials are often adapted to the local climate and therefore can contribute to creating a comfortable interior. For example, buildings constructed of high-temperature locally sourced materials such as adobe or rammed earth can help regulate indoor temperatures by slowly absorbing and releasing heat over time This can help hold comfortable room temperature, reducing the need for heating and cooling systems and energy storage.

Furthermore, locally sourced products can also be more sustainable and environmentally friendly compared to imported or distant products. The production and transportation of building materials over long distances can increase carbon emissions and contribute to global climate change, including by affecting local climate Local utilities can help reduce the environmental impact of construction and contribute to the sustainability of the built environment.

In addition, the use of local resources in construction can help support local economies by providing jobs and supporting local businesses. Traditional architecture often uses this approach, using local materials and construction methods to build buildings that are suited to the local climate and environment Using locally sourced materials does not necessarily provide they have not only achieved a sustainable and aesthetically pleasing interior, but also create a connection between architecture and ongoing communities .

In conclusion, using locally sourced materials in construction has many advantages associated with thermal comfort, sustainability, and local economy etc. Building design and material selection should take into account local climate and environmental factors to achieve a comfortable indoor environment. This approach can also help reduce our impact on the environment and ensure that construction practices are sustainable and helpful to local communities. The use of local materials in construction is an effective solution to many problems such as pollution, economy and complexity of construction.

2.3. Empirical literature review

2.3.1. Methods for evaluating indoor thermal comfort

There are several different models or indices that can be used to assess thermal comfort conditions indoors as described below.

PMV/PPD method

The PMV/PPD model was developed by P.O. Fanger using heat-balance equations and empirical studies about skin temperature to define comfort. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale from cold (−3) to hot (+3). Fanger's equations are used to calculate the predicted mean vote (PMV) of a group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation. (Fanger, P Ole 1970). PMV equal to zero is representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits ($-0.5 < PMV < +0.5$). (ASHRAE Standard 55-2017).Although predicting the thermal sensation of a population is an important step in determining what conditions are comfortable, it is more useful to consider whether or not people will be satisfied. Fanger developed another equation to relate the PMV to the Predicted Percentage of Dissatisfied (PPD). This relation was based on studies that surveyed subjects in a chamber where the indoor conditions could be precisely controlled. (Fanger, P Ole 1970).

The PMV/PPD model is applied globally but does not directly take into account the adaptation mechanisms and outdoor thermal conditions. Gail (1998)

ASHRAE Standard 55-2017 uses the PMV model to set the requirements for indoor thermal conditions. It requires that at least 80% of the occupants be satisfied. (ASHRAE Standard 55-2017)

The PMV/PPD model has a low prediction accuracy. Using the world largest thermal comfort field survey database, the accuracy of PMV in predicting occupant's thermal sensation was only 34%, meaning that the thermal sensation is correctly predicted one out of three times. The PPD was overestimating subject's thermal unacceptability outside the thermal neutrality ranges (-1≤PMV≤1). The PMV/PPD accuracy varies strongly between ventilation strategies, building types and climates. Gail (1998)

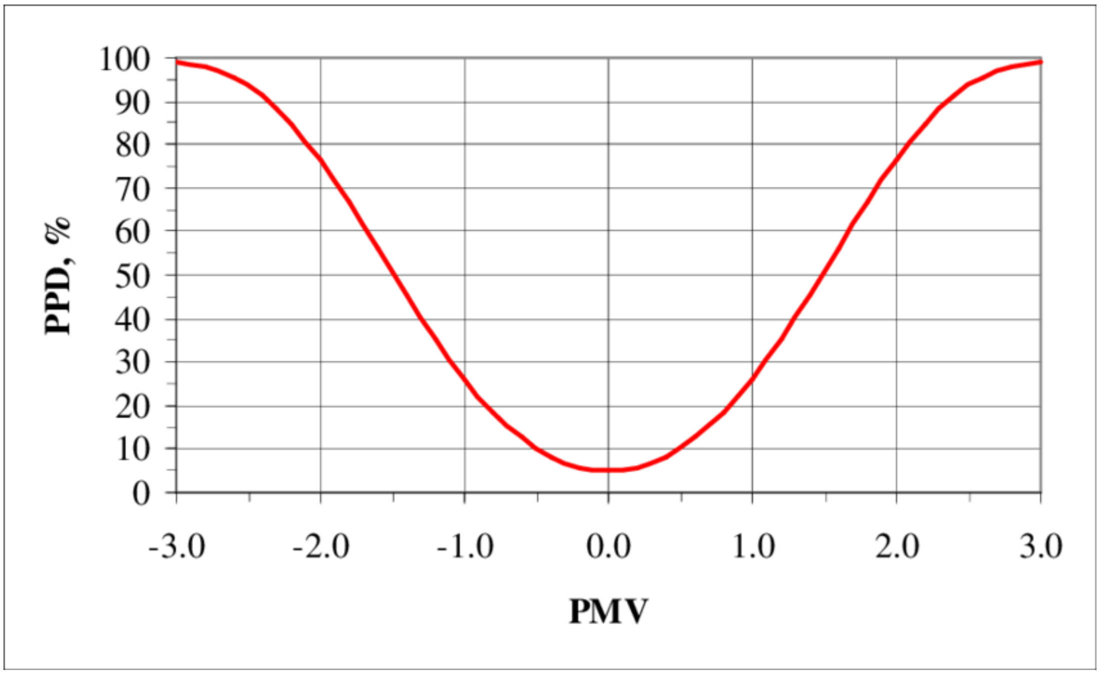

Figure 5: PMV/PPD model (Fanger, P Ole 1970)

The adaptive model

The adaptive model is based on the idea that outdoor climate influences indoor comfort because humans can adapt to different temperatures during different times of the year. The adaptive hypothesis predicts that contextual factors, such as having access to environmental controls, and past thermal history influence building occupants' thermal expectations and preferences (Gail ,1998).Numerous researchers have conducted field studies worldwide in which they survey building occupants about their thermal comfort while taking simultaneous environmental measurements. Analyzing a database of results from 160 of these buildings revealed that occupants of naturally ventilated buildings accept and even prefer a wider range of temperatures than their counterparts in sealed, air conditioned buildings because their preferred temperature depends on outdoor conditions(Gail ,1998).These results were incorporated in the ASHRAE 55-2004 standard as the adaptive comfort model. The adaptive chart relates indoor comfort temperature to prevailing outdoor temperature and defines zones of 80% and 90% satisfaction (ASHRAE Standard 55-2017).

The ASHRAE-55 2010 Standard has introduced the prevailing mean outdoor temperature as the input variable for the adaptive model. It is based on the arithmetic average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question(ASHRAE Standard 55-2017).It can also be calculated by weighting the temperatures with different coefficients, assigning increasing importance to the most recent temperatures. In case this weighting is used, there is no need to respect the upper limit for the subsequent days. In order to apply the adaptive model, there should be no mechanical cooling system for the space, occupants should be engaged in sedentary activities with metabolic rates of 1-1.3 met, and a prevailing mean temperature greater than 10 °C (50 °F) and less than 33.5 °C (92.3 °F) (ASHRAE Standard 55-2017).

This model applies especially to occupant-controlled, natural conditioned spaces, where the outdoor climate can actually affect the indoor conditions and so the comfort zone. In fact, studies by de Dear and Brager(1998) showed that occupants in naturally ventilated buildings were tolerant of a wider range of temperatures. This is due to both behavioral and physiological adjustments, since there are different types of adaptive processes. ASHRAE Standard 55-2010 states that differences in recent thermal experiences, changes in clothing, availability of control options and shifts in occupant expectations can change people thermal responses.

According to ASHRAE (55, 1992) for indoor thermal comfort can be assessed using subjective and objective assessment methods. Subjective assessment involves the use of the ASHRAE thermal sensitivity scale, structured surveys, and interviews and examines resident attitudes. When using the objective assessment method, factors that contribute to indoor thermal comfort are measured including air temperature, humidity, wind speed, and average radiant temperature and these values are then compared to specified values in ASHRAE 55. Both methods are very important the desired results.

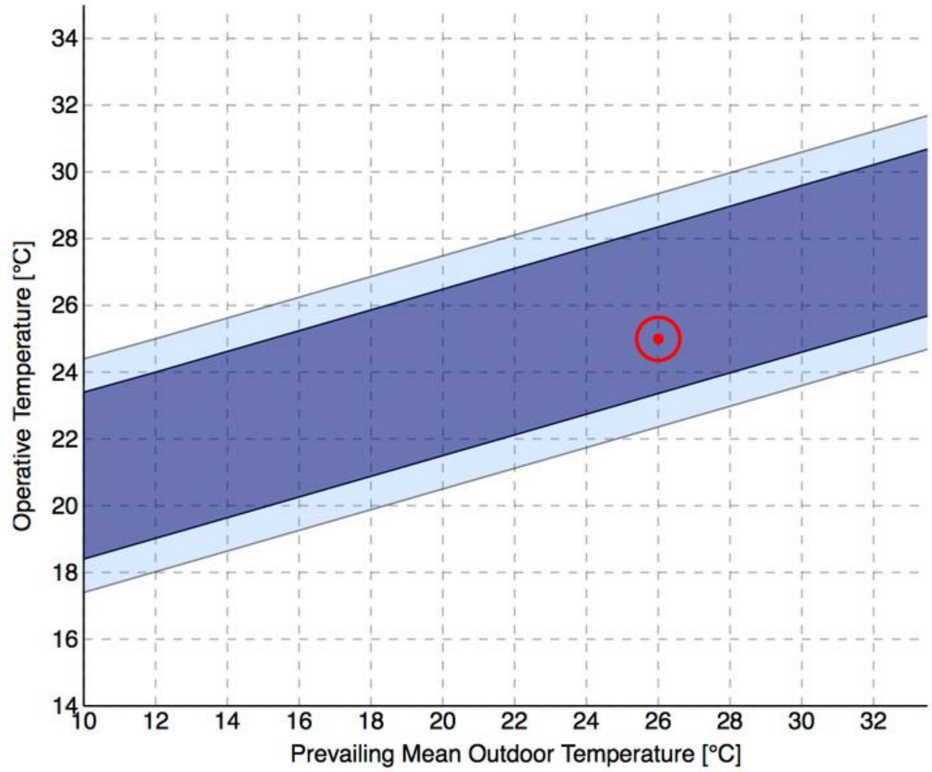

Figure 6: adaptive model

2.3.2. Indoor thermal comfort comparison between modern and traditional buildings in different countries.

Indoor thermal comfort is important aspects of building design and occupant satisfaction, which is strongly determined by climatic conditions, human practices on the buildings, and economic factors. Most buildings in developed countries are of the modern type; early studies, such as those by Fanger, 1970, and by de Dear & Brager, 2002, developed basic models of thermal comfort, placing into focus the importance of air temperature, humidity, and air velocity. The models have since been adopted globally in many countries, resulting in standards such as ASHRAE 55 to guide the design of HVAC systems to optimize comfort. They have more consideration for the thermal comfort of indoor activities in the modern houses and try to adjust the thermal comfort using various techniques, including the use of clothing and mechanical cooling and heating technologies that could control the thermal comfort.

On the other hand, most buildings in developing countries are of the traditional type. In the works of Auliciems 1996 and Khedari et al. 2000, occupants in most traditional houses around the world depend on natural ventilation and passive cooling strategies since they do not have access to advanced HVAC systems due to their high cost.

In Thailand, for instance, the study by Khedari et al., 2000, a conclusion was reached that thermal comfort can considerably be enhanced using standard building materials and designs like earth and bamboo. Similarly, Aye et al. (2012) through comparative research of buildings in Australia and India, affirmed that appropriate building design cannot effectively be applied without an assurance that it will not only be culturally appropriate but also acceptable to the people of developing countries. These disparities of indoor thermal comfort between developed and developing countries reveal the necessity for context-specific approaches. Conclusions from recent publications by Al-Horr et al. (2016) and others support this integration into building design of local climate data and cultural practices toward improving or enhancing indoor thermal comfort quality.

This is further underlined in an article by Ghaffarianhoseini et al. (2017) to reach a "balance between modern technologies and traditional practices to create sustainable environment." As urbanization is increasing in the developing countries, improvement and understanding of indoor thermal comfort will be good for health, productivity, and general well-being.

2.4. Summary and gaps of the literature review

In the earlier studies, attention is paid to its various applications in buildings and various results in terms of thermal comfort are studied but some studies have revealed some shortcomings which can be briefly summarized as follows:

The study paper titled "Human Thermal Comfort and Its Analysis by Computational Fluid Dynamics for Naturally Ventilated Residential Buildings of Jimma Town, South West Ethiopia" and the case study Yadeta (2019) aimed to investigate various aspects of indoor environmental thermal comfort properties to improve and increase the welfare of residents. Studies use questionnaires to collect information from people, but their responses may be influenced by factors such as their background and adaptability, and use less accurate and less effective, which can affect the reliability of the results.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Overview

The present section describes the design of the research. A study was conducted on buildings in Dire Dawa City, which included both traditional and modern architecture. Three random interviews were conducted. The inquirer was well prepared to interact with residents and subsequently surveyed them. Temperature, humidity and wind speed data were collected for both types of homes using Holdpeak brand digital thermometers and humidity meters.

The study delved into comparing the warm comfort of houses where residents rated traditional construction methods with modern houses in Diredawa. The modern house was chosen randomly because of its comparable characteristics, while the traditional house was based on factors such as building materials, availability of traditional cooling fans and location.

3.2. Description of the study area

3.2.1. The geographical location of the study area

Dire Dawa lies in the eastern part of the nation, on the Dechatu River, at the foot of a ring of cliffs. The western outskirts of the city lie on the Gorro River, a tributary of the Dechatu River. It is located at the latitude and longitude of 9°36′N 41°52′E. The city is an industrial center, home to several markets and the Dire Dawa Airport.

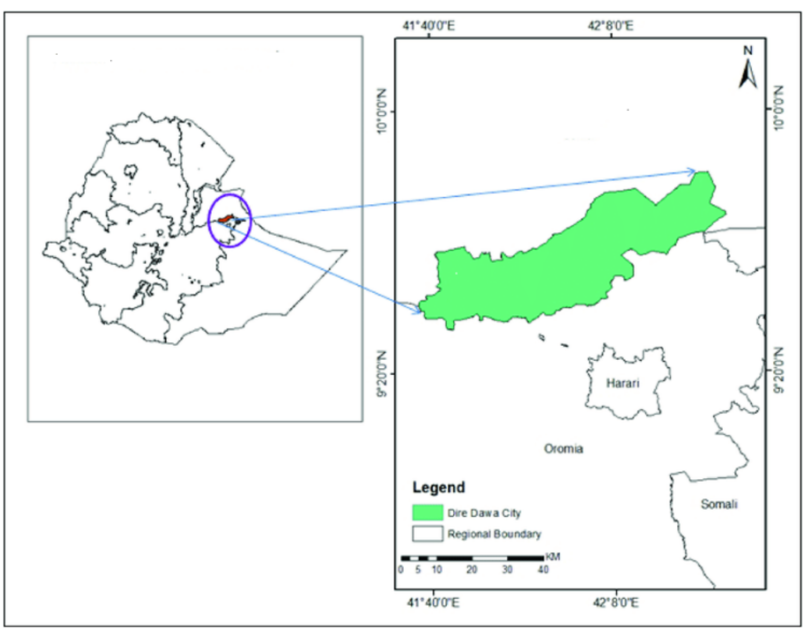

Figure 7: location of Dire Dawa, Ethiopia(Dire Dawa city administration)

3.2.2. The climatic condition of the study area

Dire Dawa has a borderline tropical savanna climate (Köppen) just it's most part under a hot semi-arid climate . The mean annual temperature of Dire Dawa is about 37.9 °C or 100.22 °F. The average maximum temperature of Dire Dawa is 41.8 °C or 107.24°F, while its average minimum temperature is about 28.0 °C or 82.4 °F. The region has rain season; that is, more pronounced rain season that extends from July to August. The aggregate average annual rainfall that the region gets from this seasons is about 670 millimetres or 26 inches.

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average High °C (°F)	28.3 (82.9)	29.5 (85.1)	36.0 (96.8)	36.8 (98.4)	37.8 (100.0)	33.7 (92.7)	32.3 (90.1)	31.0 (87.8)	32.3 (90.1)	32.1 (89.8)	29.9 (85.8)	28.3 (82.9)
Average low °C (°F)	14.8 (58.6)	15.5 (59.9)	18.2 (64.8)	19.6 (67.3)	20.7 (69.3)	21.6 (70.9)	20.4 (68.7)	19.2 (66.6)	19.6 (67.3)	18.1 (64.6)	15.6 (60.1)	14.4 (57.9)
Daily mean °C (°F)	22.1 (71.8)	23.2 (73.8)	25.2 (77.4)	26.0 (78.8)	27.8 (82.0)	28.5 (83.3)	27.0 (80.6)	26.3 (79.3)	26.6 (79.9)	25.9 (78.6)	23.5 (74.3)	22.3 (72.1)
Average rainfall mm (inches)	15 (0.6)	27 (1.1)	74 (2.9)	113 (4.4)	78 (3.1)	42 (1.7)	115 (4.5)	158 (6.2)	105 (4.1)	36 (1.4)	16 (0.6)	13 (0.5)
Average Dew point °C (°F)	1 (52)	12 (54)	12 (54)	15 (59)	15 (59)	14 (57)	15 (59)	16 (61)	15 (59)	12 (54)	12 (54)	11 (52)

Table 1: climatic data of dire dawa city. Source- (*"Station Diredawa" (in French). Météo Climat.).*

3.3. Research design

This study uses both descriptive and qualitative research methods and has been designed accordingly. A combination of qualitative and quantitative data methods were used. Quantitative methods involve taking physical measurements while qualitative methods use questionnaire, interview and field survey. This study provides a comparative analysis of thermal comfort in contemporary and traditional dwellings, as well as an examination of several factors affecting optimal thermal comfort in buildings in Dire Dawa. Furthermore, the study examines public preferences and determinants.

3.4. Type and source of data

To achieve the objectives of this study, first, data have been collected from two existing sources. Regarding secondary sources, sources such as books, journal articles, official documents and official reports were used. The relevant literature was thoroughly searched for the importance of indoor thermal comfort, as valued in other countries as questionnaire delivery day besides, primary data were obtained by conducting interviews with respondents experienced in both types of households. Furthermore, measurements of temperature, humidity and air velocity made by individuals in buildings have been treated as primary data and have been shown to be inaccurate.

3.5. Population and target population

The population of this research study encompasses the residential houses in Dire Dawa city. The city has a mixed population and is a blend of modern and traditional residential houses.

The target population for this study is a subset of the residential houses in Dire Dawa city, specifically focusing on modern and traditional houses. Most of the modern houses in Dire Dawa city are made with modern building materials and technologies like concrete, steel of stairs construction, and glass, and are equipped with amenities such as sanitary, electrical, and sometimes manual ventilation system hold by hands. On the other hand, most of the traditional houses in Dire Dawa are made of local materials such as mud, straw, and wood, relying heavily on natural ventilation and passive cooling. The target population include a representative sample of both modern and traditional residential houses and occupants. The sample size and the selection criteria shall be determined with considerations that include the total number of modern and traditional houses in the city, the geographic distribution of these houses, the feasibility of data collection and the occupants who live in both house type.

The target population is selected by using of purposive sampling techniques. The purposive sampling techniques try to make the cases picked representative of the whole modern and traditional houses population and also the occupants of Kebele 02 and Kebele 08 of Dire Dawa city. This selection is carried out based on specific characteristics meant for the investigation: the building material used for construction, time since construction, and occupancy pattern differ from the other target population.

This is used to compare the indoor thermal comfort of modern and traditional residential houses in the city and identify factors that contribute to the differences in thermal comfort between the two types of houses from the collected data from the target population.

3.6. Sampling technique and sample size

Respondents were drawn to complete a questionnaire from those individuals who lived in kebele 02 and 08, and had experienced living in traditional houses and modern houses. Sample size was determined using the procedure developed by Singh & Masuku, (2014). The sample size is calculated using the method described below when the number of candidates (N) is less than 10,000. The total population size of Kebele 02 and Kebele 08 is 1930 from the information of Dire Dawa city urban profile on the year of 2013 E.c.

$$Nt = n/1+n/N$$

Where: n= the desired sample of household

N = total households of houses, is (1930)

Nt= Estimated sample size.

$$n = (Z^2 * p*q)/d^2$$

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

For Maximum standard deviation

q= 1-p

q=1-0.5=0.5,

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

Nt= 96/1+1930/96

=96+20.10

=116.1≈116 (sample size)

Accordingly, out of 1930 households, 116 sample Informants were selected for household surveys. The sample informants were selected using a purposive sampling method from the total household. Those purposive samples selected base on the criteria of almost the same working environment and activities, and also they have almost the same working hours per day.

And also Out of 1930 houses 1260 houses are the traditional houses and also the remaining 670 houses are the modern one. By using the above sample size calculation method the sample size of the traditional house is 109 and the sample size of the modern house to measure environmental variables is 103, but this study takes the maximum sample size which is 116 sample size for households and both type of houses because to balance and avoid to biased the results from the measurement of the variables, manage the given time and its easier to collect the data from the same number of participants.

3.7. Data Collection

3.7.1. Temperature, humidity and wind velocity data collection

Accurate readings of indoor and outdoor temperature, humidity & wind velocity were obtained through the utilization of HOLDPEAK Digital Anemometer, a handheld measuring device that also tracks wind speed, heat stress, and CFM. The data was recorded in both a traditional and modern home setting, without any mechanical cooling or ventilation system in place. The record stayed for the consecutive four months in a gap of three days. And the data was recorded with a three-hour interval starting from 1:00 pm – 12:00am because of the inclination of the sunlight. The recording process started from 12th February 2023 to 29th may 2023. Those data are recorded inside the living rooms of both type of the houses because most of the occupants who lived in both house they spent most of their time in living room.

HOLDPEAK DIGITAL HEAT STRESS METER

Wind Speed Range: 0.0~30m/s (Accuracy: ±5%Digit),

Resolution: 0.1m/s Accuracy: ± 1.5o C/ ±1.5%

Temperature Range: 0~50℃ (Accuracy: ±0.6℃)

Distance spot ratio: 12: 1

Humidity range: 0.1%~99.9%RH; Resolution: 0.1%RH

Figure 8: environmental variables measurement tool

3.7.2. Questionnaire survey

Residents' perceptions of heat were assessed by questionnaire. A randomly selected group of people living in both housing types were randomly selected and given a survey to complete. The questionnaire focused primarily on comparing two types of buildings to explore residents' perceptions of comfort and thermal management strategies Comfort levels, energy consumption, building materials, cooling and heating strategies, strategies a the opening, electrical and other utilities tested were randomly allocated to different types. Participants' thermal sensations were assessed using the ASHRAE 7-point scale, which is presented in the table below.

Thermal sensation scale						
Cold	cool	Slightly cool	Neutral	Slightly Warm	Warm	Hot
-3.0	-2.0	-1.0	0.0	1.0	2.0	3.0
Thermal preference scale						
Cold	cool	slightly cool	Neutral	Slightly Warm	Warm	Hot
-3.0	-2.0	-1.0	0.0	1.0	2.0	3.0
Satisfaction scale						
Very dissatisfied	dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	satisfied	Very satisfied
-3.0	-2.0	-1.0	0.0	1.0	2.0	3.0

Table 2: Thermal sensation scale source (ASHRAE 2017)

3.8. Field survey

The study in Dire Dawa aimed to assess the livelihood of the community in dealing with the challenges posed by temperature fluctuations. The study specifically looked at indoor temperature control techniques, as well as construction methods, materials used, opening spacing and size, and overall function to ensure thermal comfort.

3.9. Data processing and analyses

Data were analyzed using MS Excel, a software package specially designed for handling spreadsheets. With a spreadsheet showing the mean environmental variables, tables are developed to show percentages of temperature, humidity and wind speed. The first part of the experiment focused on information assessment of the collected temperature, humidity data and wind velocity.

Data were presented as linear graphs contrasting the condition of traditional habitat with that of current habitat. In the second stage of data analysis, descriptive statistics were used to analyze experimental findings, presented in visual formats such as charts and tables. These data summarize the robustness of the two types of structures.

3.10. Ethical consideration

This thesis is the culmination of the author's own efforts and all the resources used in the research are cited accordingly. The researcher was given detailed information about the nature and objectives of the study, and confidentiality and sensitivity of their responses were fully assured. The researcher obtained consent from the participants before collecting their responses. Researchers obtained permission from building occupants or owners to measure air velocity, humidity and heat levels entering their buildings, and assured that all data collected were obtained in a manner that respected individual contributions the participant's privacy rights were highly prized, in order to avoid any possible influence resulting from researcher bias or own experience.

3.11. Data quality and control

The researcher aims to achieve superior results in their research by implementing techniques that improve the caliber of the outcomes. Thus, the researcher distributed a limited number of questionnaires and aimed to gauge the accuracy of the instruments by assessing their performance against established temperature standards.

CHAPTER FOUR

4. RESULT AND FINDINGS

This section provides a detailed analysis of the collected data, focusing on important factors including temperature, humidity and wind speed that influence comfort levels in urban areas in Dire Dawa. Study presents numerical data and visual representations. The findings from this study can be used by powerful people in the fields of architecture, planning and construction design This will help them to identify the most effective ways to build heat-generating buildings optimal comfort for the occupants.

4.1. The result form sample population

4.1.1. Age of the respondents

All the 116 people who formed the total population were of various ages from 20 years to 60 years Of all the respondents, 53 people (approximately 45.7%) were in the age group of 20-40 years, while 40 people (approximately 34.5%) part of the same age. Among the participants, those in the age group of 41-50 years constituted the majority, followed by those aged 51-60 years, with 16 (13.8%) Respondents only a small percentage, seven (6.0%) were over 61 years of age.

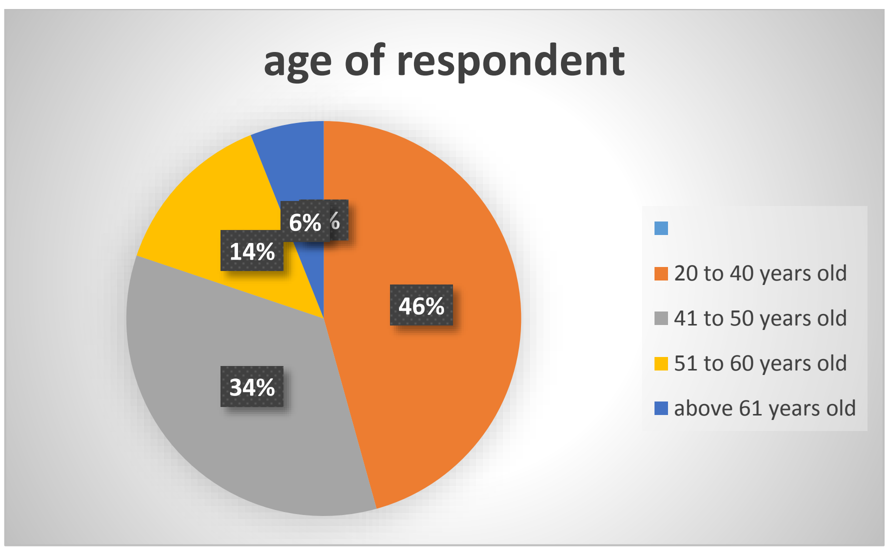

Figure 9: age of respondents

4.1.2. Level of education

According to the results of the study, most of the participants were identified. All (100%) completed primary school, 42.2% completed secondary school, 35.3% had a university degree, and a minority of respondents (9.5%) had no formal education.

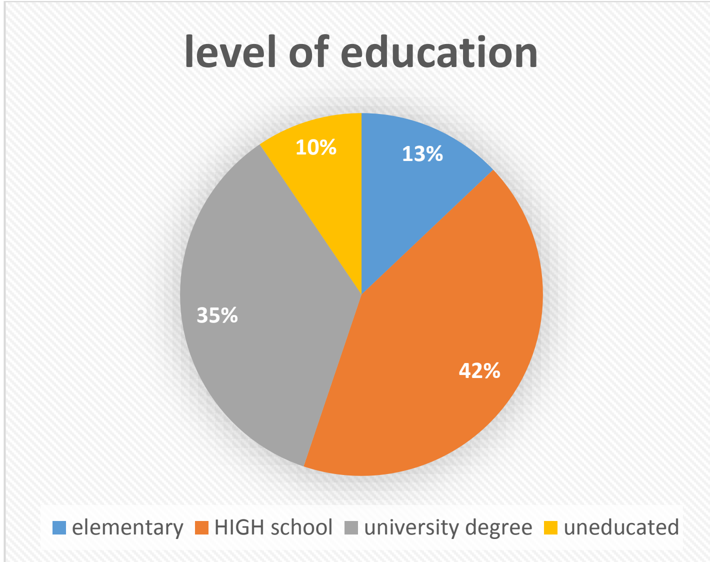

Figure 10: level of education

4.1.3. Family size of the respondent

Regarding family size, the survey data indicated that about 57.8% of the 116 participants or all 67 individuals had families of four to seven members, while about 22.4% or 26 had families of four members two or less in and also, about 11.2% or 13 respondents reported having families of eight to ten members, about 8.5% or 10 participants reported having eleven or more members in in their families.

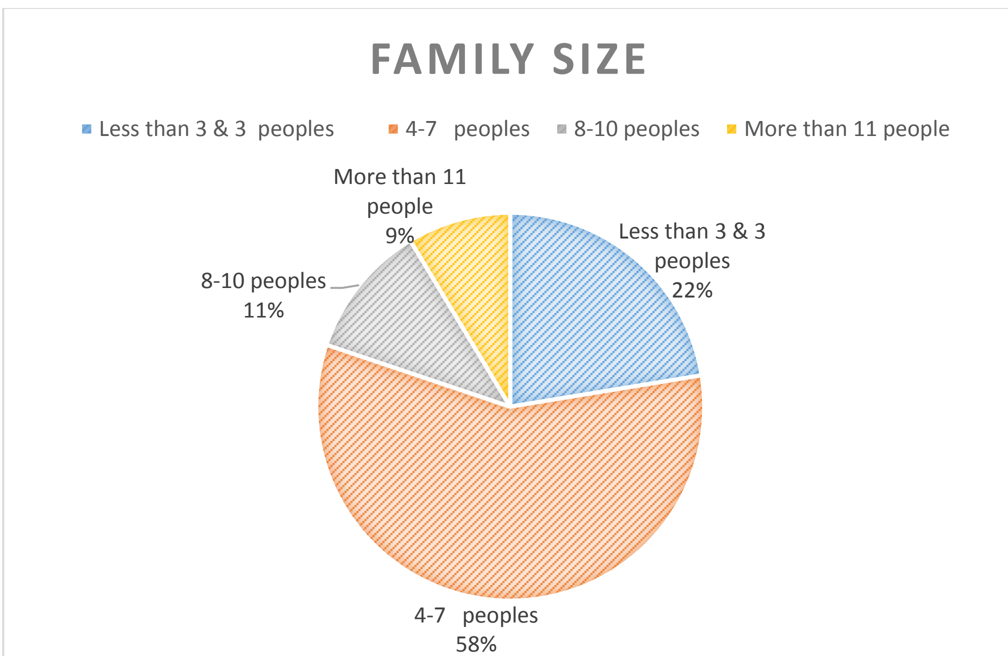

Figure 11: Family size of the respondent

4.1.4. Housing Type of respondent from traditional housing type

In terms of the residents housing preferences; 58 houses (50%) were classified as row houses; 25 houses (21%) were semidetached; A smaller number of houses (33 houses or 28%) were detached homes. Suggesting that row houses are the favored choice, among the respondents. Make sure to have openings in every direction windows, for good cross ventilation.

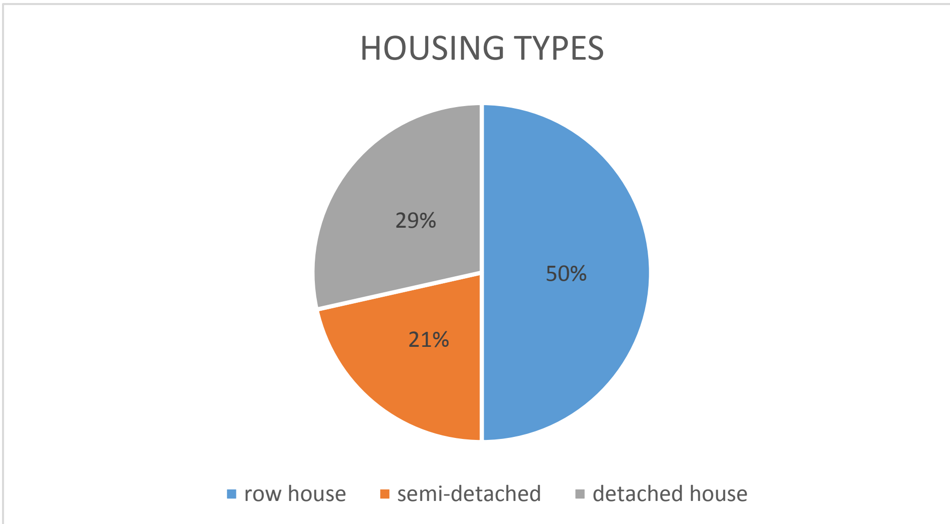

Figure 12: Housing Type of respondent

4.1.5. Experiences of respondents living in the traditional house

Regarding family size, the survey data indicated that about 57.8% of the 116 participants or all 67 individuals had families of four to seven members, while about 22.4% or 26 had families of four members two or less in and also, about 11.2% or 13 respondents reported having families of eight to ten members, about 8.5% or 10 participants reported having eleven or more members in in their families.

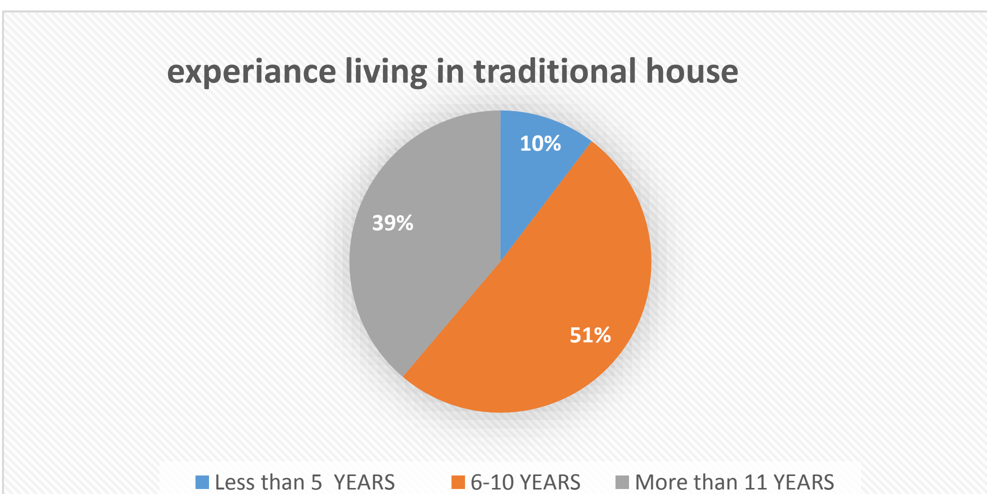

Figure 13: Experiences of respondents living in the traditional house

4.1.6. Experiences of respondents related to living in modern houses

The results of the survey showed that of the 116 people living in modern houses, 56% (n=65) had lived in such houses for five years; 33.65% (n=39) had a life experience of 6-10 years, and a minority of respondents, roughly equivalent to 10.4% (n=12), had lived in modern households for 11 years or more than that.

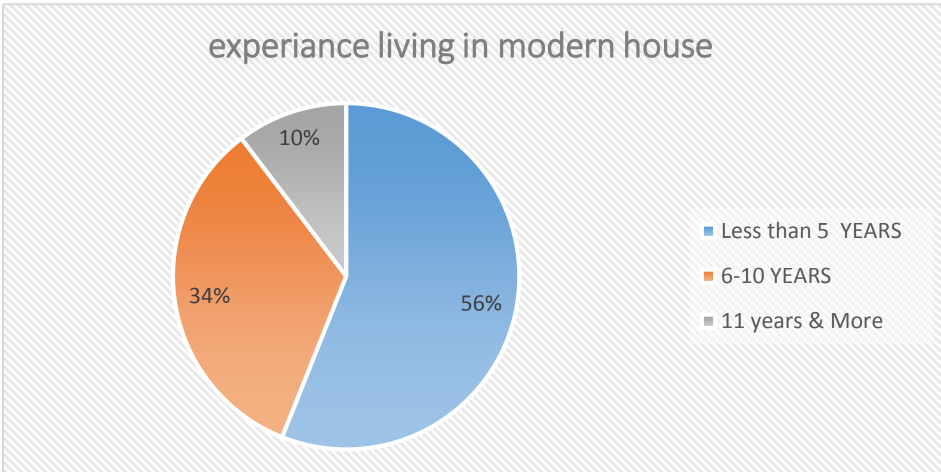

Figure 14: Experiences of respondents living in the modern house

4.2. Characteristics of the existing buildings

The house of all the respondents who living in modern houses have similar physical feature since the house is standard condominium having a concrete floor with marble and ceramic floor finishes, the wall is constructed hollow concrete block and plastered and painted the ceiling have a clear height of 280 cm. The buildings are covered by CIS (Construction Specifications Institute) roofing material and they used windows for every rooms exposed to external wall of the building but the opening is not compatable with room size &climatic condition of the city.

According to information from the field survey, the traditional house of the respondent has common physical character. All traditional houses use mud blocks for constructing both internal & external walls, and use cement screed and sand flooring material and also metal and plastics for roof cover. They have no ceiling at all and the roof of the house. This all materials and construction method were used in order to regulate the thermal comfort of the indoor environment by using those locally available materials.

4.2.1. Common characteristics of local houses

Houses constructed of locally manufactured mud block walls, sand (soil) flooring material, and those that are built with cis roofs, have a range of common characteristics in addressing the hot climate of the town of Dire Dawa. The flooring materials (i.e. sand or soil) are also common for most housing types, and serve as an enhancement to the efficacy of evaporative cooling. Both mud blocks & sand flooring materials have a high thermal mass to resists the hot climatic seasons (refer to table 5).

Material	Density (kg/m3)	Specific heat capacity (kJ/kg.K)	Volumetric heat capacity (kJ/m3.K)
Water	1000	4.186	4186
Concrete	2240	0.920	2060
Stone (sandstone)	2000	0.900	1800
Compressed earth blocks	2080	0.837	1740
Rammed earth	2000	0.837	1673
Fibre cement sheet (compressed)	1700	0.900	1530
Brick	1700	0.920	1360
Earth wall (adobe)	1550	0.837	1300
Autoclaved aerated concrete (AAC)	500	1.100	550

Table 3: thermal mass of materials (Source: Baggs and Mortensen 2006)

Traditional dwellings from the city of Dire Dewa are designed to be a good representation of hot climatic conditions, that are both suitable with local climates and harmoniously combined with local belief and traditions while using local materials. The houses are built from mud walls and soil floors, employ natural air conditioning techniques and provide adequate thermal comfort at all times of the day and night. The semi-arid conditions encourage reliance on the use of hot air at night while controlling hot air, as well, when used in the appropriate time of day because of their thermal mass.

Figure 15. Mud block construction for external walls

Figure 16. Narrow window opening

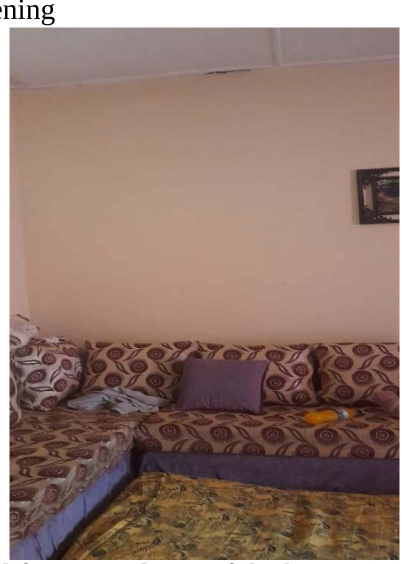

Figure 17: construction material for internal part of the houses

Construction features of the Traditional house

During the study, the researcher tried to identify the layout of houses, opening, structures and their overall feature including their construction materials. From their layout and characteristics, the study able to detect the construction of the housings over time.

A; building layout

Room shape: most of the buildings are rectangular shapes with mud block partition walls with mud plastering materials used for bed room & kitchen areas.

Opening orientation: The opening orientation was located mostly on front side of the building and the other side of the building openings are too small and fixed windows used for light and ventilation.

Opening size and materials: The size of the openings is to small that compared to room size.it used to control the amount of hot air entering in to each rooms.

B; construction material of structures

Floor material: they used mud and cement plastered floor for the construction of floor.

Walls material: mud blocks used as a main material to construct the internal partition wall and exterior wall.

Ceiling: most of the houses are there are no ceiling but some of them used woolen fiber material as with white paints.

Roofing: all of the traditional buildings covered by metal roofing's.

4.2.2. Common characteristics of modern houses

The newly constructed houses are not suitable with the typical biopsychosocial behaviors of the people and the hot climate of Dire Dawa city, its 'hot the whole day and the whole night'. The structure of the houses are formed of a hollow concrete block (HCB) wall followed by a large glass window, a reinforced concrete (RC) slab, and a suspended ceiling (in many cases), and also, a small balcony is attached to the houses. These essentially make the houses hot, especially during the Monsoon, when they trap the hot air inside. In fact, most of houses consider enclosing their balcony with glass and metal material (see figure 17), so this puts the effort of air circulation back. Therefore, the buildings are hotter than the air outside, and it takes time for the air inside to exit the house; now, the time is the reason why the air stayed inside.

Figure 18: Balcony’s used as a room

The openings' orientation has not been thoroughly explored as part of investigation of how they affect the inside environment. The openings do not promote natural ventilation, although, and they are too large, because the larger part is the non-operable part, while the operable part is a narrow piece compared to the size of the opening and size of the room’s. Even the worst sun will push through the larger fixed glass but very little wind, or little air will come through the smaller operable opening, contributing to the heat in the room. (See figure 18)

Figure 19: The operable part of the window compared to the size of the opening and size of the room’s

Construction features of the modern house

A; Building layout

Room shape: all of the modern buildings are rectangular shapes with typology of studio, one, two & three bed rooms.

Opening orientation: The opening orientation was located mostly on front side and rear of the building and the other side of the building openings are too large comparable with surface of the wall used for light and ventilation. (See figure 19)

Opening size and materials: The size of the openings is to large that compared to room size. but The openable part is too small that in a ratio of opening size, and those openings are constructed with 4mm glass on most of the time aluminum framing.

B; construction material of structures

Floor material: they used concert for floor construction and ceramic tile as floor finishing material.

Walls material: The wall of the buildings constructed from 20cm plastered and painted HCB and also using 15cm HCB for partitions.

Ceiling: All rooms have a ceiling made from gypsum and the height of the celling is 280cm.

Roofing: all buildings use iron sheet metal to cover the roof.

Figure 20: the area covered by opening comparable with walls.

4.3 comparable analysis on cooling methods of traditional and modern houses

Both buildings have their own method cooling the hot air but differ in their degree of cooling, mostly the traditional houses the consideration of local climatic condition by using different traditional methods before construction but the modern house tries to cool the hot air after construction is finished. There is no consideration of the local temperature during the construction of the modern house but the residents take their measures to cool down the temperature. The table below compares and contrasts the common cooling methods of old traditional houses with the modern houses in their response to the hot climatic conditions.

cooling methods	Traditional houses	modern houses
High Thermal mass materials	Used high thermal mass materials such as mud blocks, grass fiber materials on mud blocks manufacturing	High thermal mass HCB walls,
Natural ventilation	Use natural ventilation in proper ways which is the openable part suitable for room size	Use natural ventilation in affecting the indoor environment because the openable part of the window out of the proportion of room size & opening size.
Outdoor cooling methods	The green elements almost fully covered the surface of the buildings.(see fig)	They closed the balconies by glass material and used as a room. And also plantation size is not suitable to covers the building height
Building orientation	The green elements & opening size that can compensate the building orientation that exposed to harsh sun	Constructing the houses with out considering building orientation and face of the building exposed to harsh sun
Floor height	330cm to 400 cm	280cm ,that affects the circulation of the air inside the room
Cross ventilation	Highly used cross ventilation	Less use of cross ventilation

Table 4: cooling methods inside traditional and modern houses

Figure 21: The effect of green elements on traditional buildings

4.3.1. Level of natural ventilation & light in both types of House resulted from sample

A-Level of natural ventilation in both house

According to the survey data, it was found that out of 116 (100%) residents living in a typical home with natural ventilation, 46 (39.7%) said there was plenty of natural light, 42 (36.2%) said it was adequate and 28 people (24.1%) considered it inadequate We do.

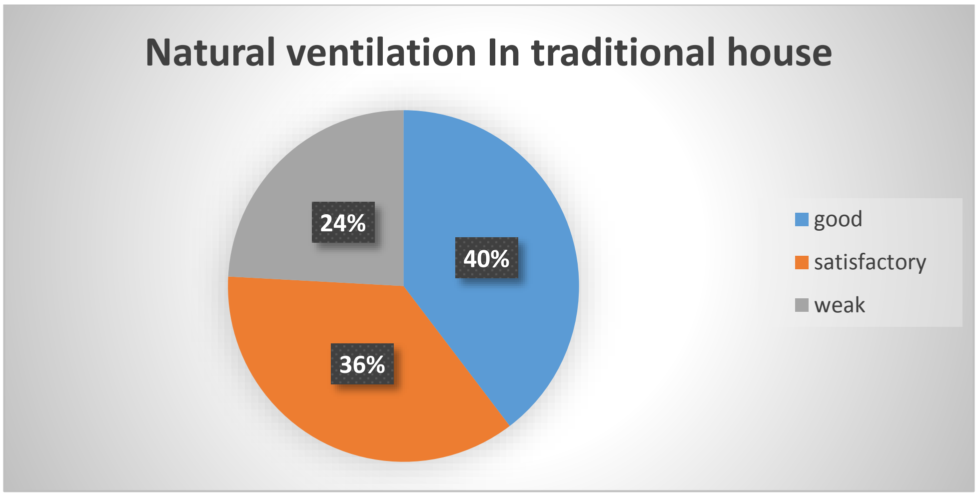

Figure 22: Level of natural ventilation inside traditional houses

Out of the 116 residents in modern houses, 32.8% reported good air quality, 26.7% reported good and the remaining 27.4% reported poor These results indicate that the respondents most of us are not happy with the air quality in modern buildings.

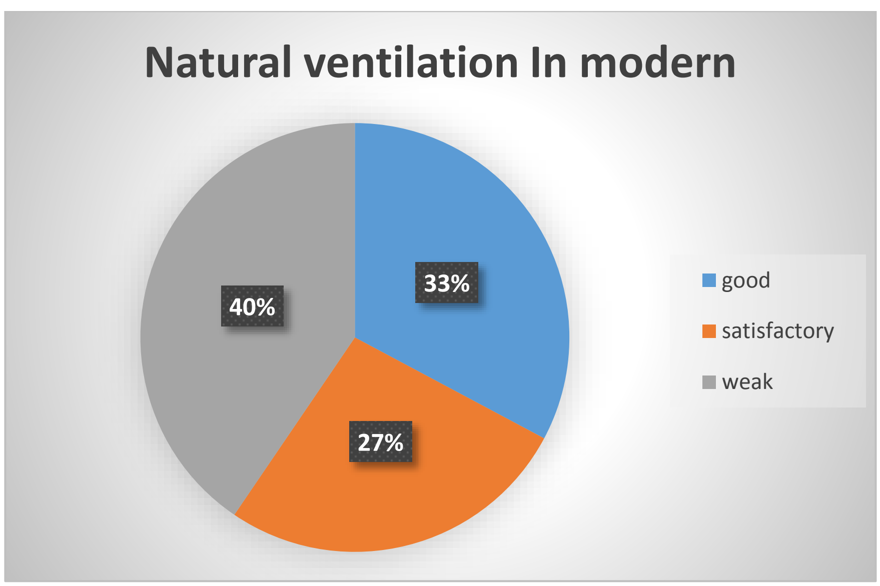

Figure 23: Level of natural ventilation inside modern houses

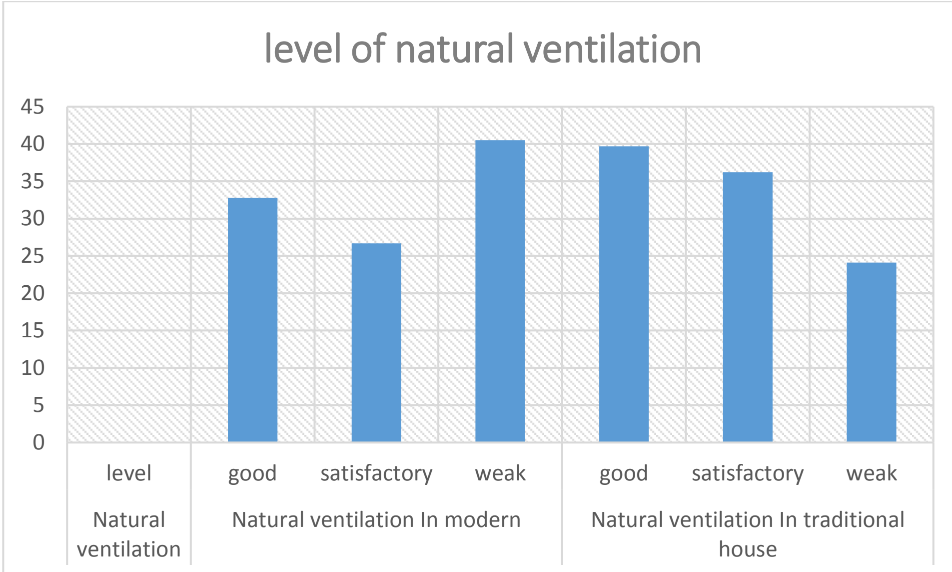

Figure 24: Level of natural ventilation inside both houses

B-Level of natural light in both house

The survey results show that of the 116 respondents in traditional houses, 54.3% said the natural light was good, 24.1% said it was satisfactory and 21.6% said it was poor.

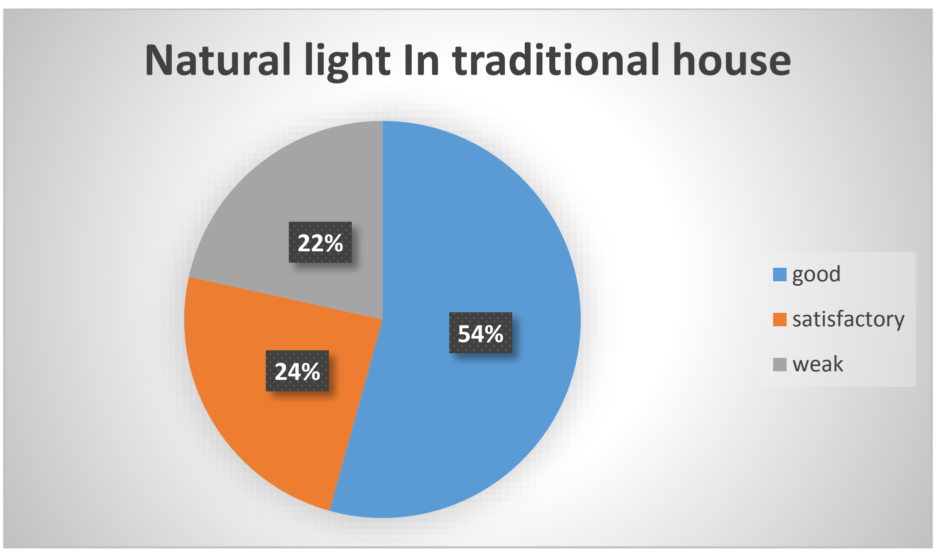

Figure 25: Level of natural light inside traditional houses

A total of 116 individuals were studied in a modern home. Of these, 65 (54.3%) saw it correctly, 38 (32.7%) thought it was acceptable, and the remaining 13 (13%) considered it below average. Based on the findings, most respondents seem to indicate satisfaction with the appearance of modern buildings. But this natural light creates the hot air circulating the houses.

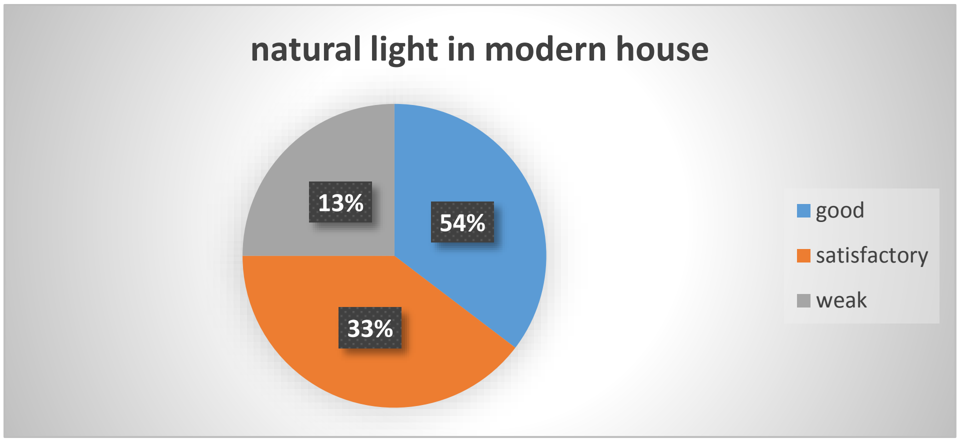

Figure 26 : Level of natural light inside modern houses

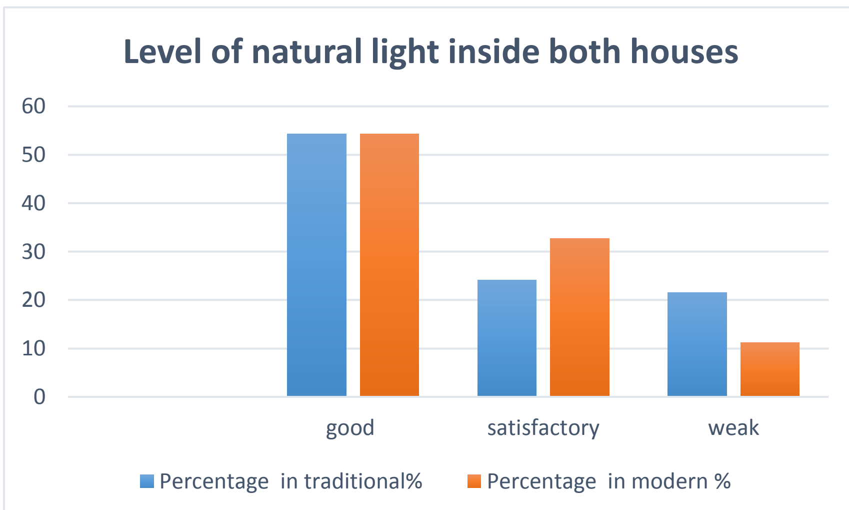

Figure 27 : Level of natural light inside both houses

4.4. Climatic comfort for both houses

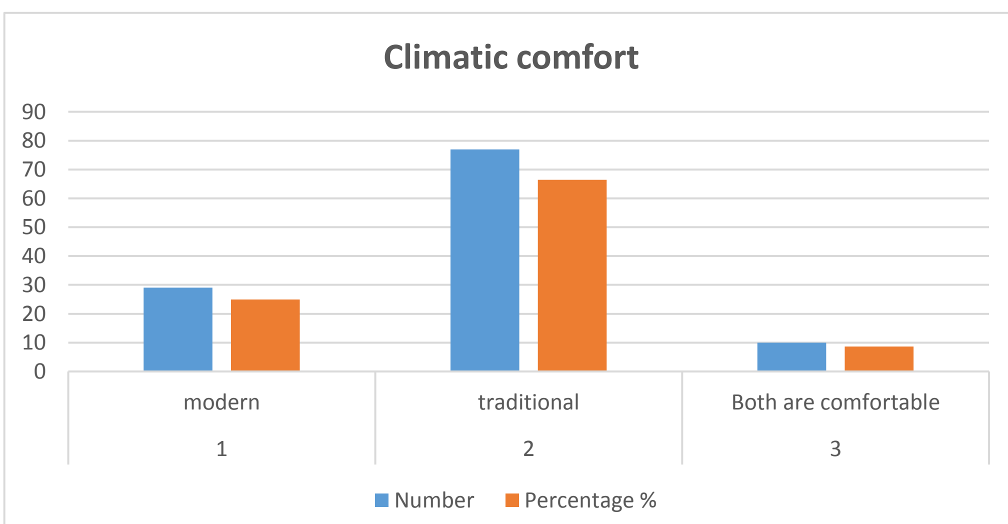

Figure 28: climatic comfort of both houses

Regarding the comfort experienced in traditional and modern houses, most of the respondents especially n = 77 (66. 4%) expressed that traditional houses provide high level of comfort compared to modern houses , On the other hand, a small percentage of the respondents, ie. n = 10 (8. 6%), had the opinion that both types of houses provide the same comfort. This climatic comfort in traditional homes is further achieved through the use of local materials and construction techniques suitable for the extreme climate said to be hot with little rain Mud walls help to keep the interior cooling during the day and warmed at night.

At the same time, modern buildings in Dire Dawa tend to use materials unsuitable for the local climate; examples are HCB walls and glass. Such materials absorb and store heat and radiate it. Modern buildings are brighter and less glamorous than the traditional one. Traditional houses are designed in such a way that they encourage natural ventilation by using openings. Openings used are suitable for the room size. In condominium houses, perhaps with very big opening sizes, the openable part is very small compared to room size and opening size; hence, it is difficult to ventilate and comfortably warm.

4.5. Indoor thermal comfort in modern & traditional house

The thermal sensation, preference, and satisfaction of both houses were summarized based on seven points according to the ASHRAE 55 standard.

THERMAL SENSATIONAL COMFORT OF both HOUSE

	Thermal sensational Comfort	Thermal Sensation Scale	Number out of 116	Percentage %
1	Hot	+ 3	3	2.60
2	Warm	+ 2	10	8.6
3	Slightly Warm	+ 1	50	43.1
4	Neutral	0	40	34.5
5	Slightly Cool	– 1	13	11.2
6	Cool	– 2	-	-
7	Cold	– 3	-	-

Table 5: Thermal sensational Comfort inside traditional house

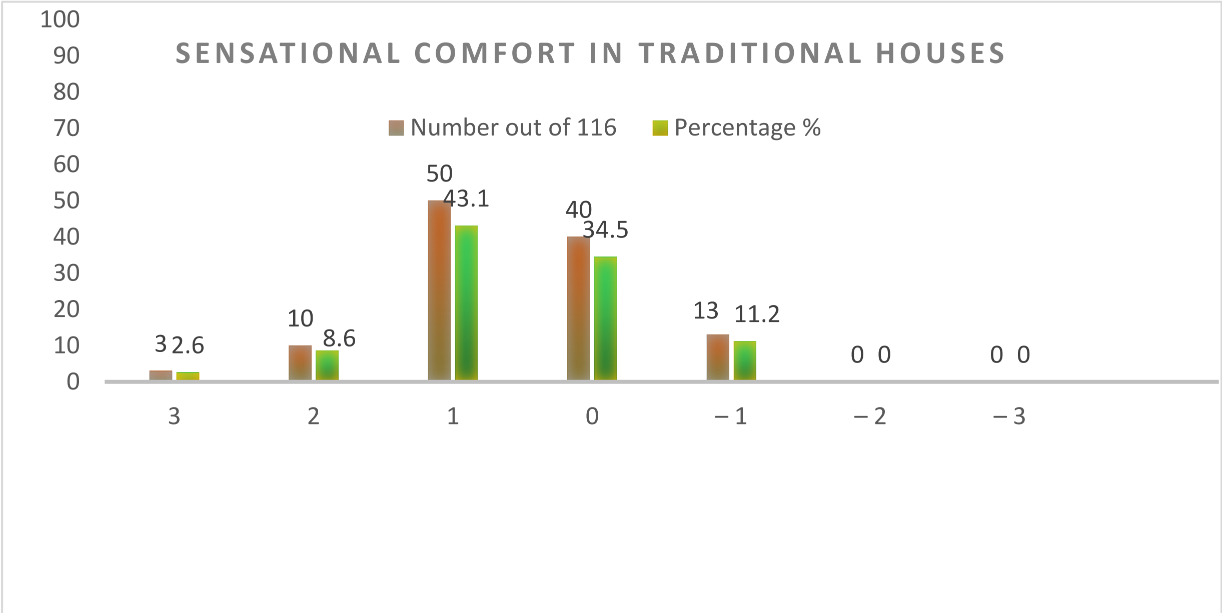

Figure 29: Thermal sensational Comfort inside traditional house

The result of traditional home temperature sensitivity scale data from respondents shows that 50(43.10%) respondents answered slightly warm,40(34.5%) respondents because temperature sensitivity scale is neutral,13(11.2%) answered that slightly cold in 10 (8.60%)and 3 (2. 60) Respondents respond to temperature and humidity, respectively. According to ASHRAE criteria, 103 (88.80%) were inside the comfort zone because they are at +1, 0, -1, and the remaining 13(11.20%) were outside the comfort zone.

	Thermal sensational Comfort	Thermal Sensation Scale	Number out of 116	Percentage %
1	Hot	+ 3	16	13.8
2	Warm	+ 2	54	46.5
3	Slightly Warm	+ 1	29	25.0
4	Neutral	0	11	9.6
5	Slightly Cool	– 1	4	3.4
6	Cool	– 2	2	1.7
7	Cold	– 3		

Table 6 : Thermal sensational Comfort inside modern houses

Studies have examined the perception of heat by people living in modern houses. Data collected from the respondents, n=16 (13.8%) reported feeling warm, while n=54 (46.5%) reported warm sensation. Additionally, n=29 (25%) of the respondents stated that they felt somewhat dizzy, n=11

(9.6%) stated that the sensation was natural, n=4 (3.4%) and n=2 (1.7%). Respondents reported feeling slightly cold and cold.

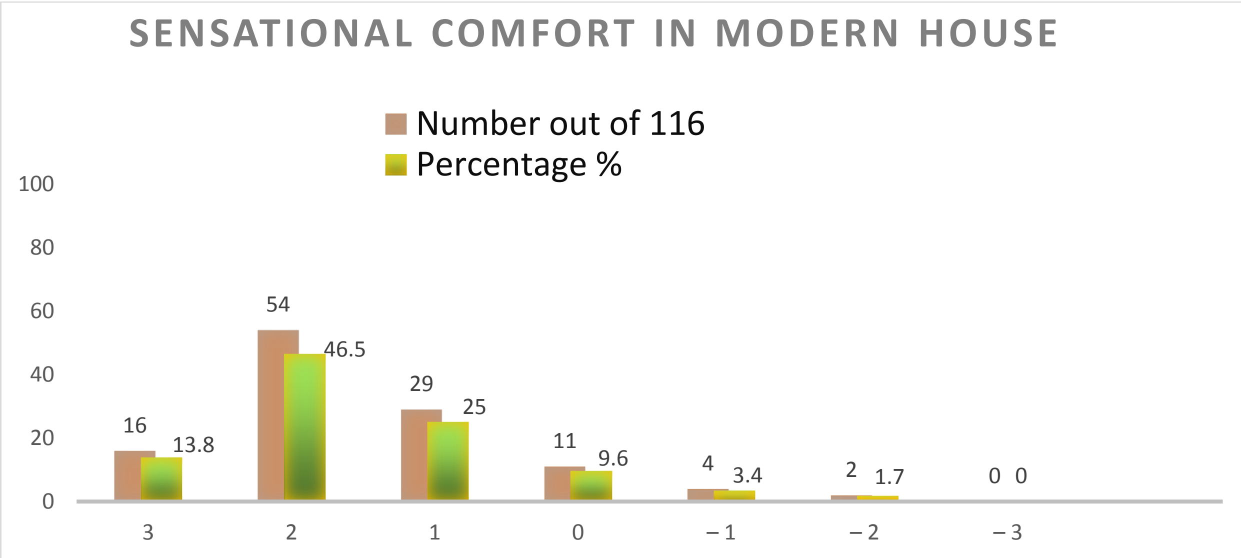

Figure 30: Thermal sensational Comfort inside modern house

In accordance with established ASHRAE guidelines, it was determined that a total of n=44 individuals, comprising 38. 00% of the study population, were within the comfort zone, particularly at temperatures of +1, 0, and -1. In contrast, the majority of the n=72 individuals, constituting 62% of the study population, were found to lie outside the aforementioned range. Based on the data collected, we can conclude that traditional homes are more adept at providing thermal comfort than their modern counterparts.

THERMAL PREFERENCE SCALE FOR BOTH HOUSES

	Thermal preference Comfort	Thermal preference Scale	Number out of 116	Percentage %
1	Hot	+ 3	2	1.7
2	Warm	+ 2	13	11.2
3	Slightly Warm	+ 1	51	44.0
4	Neutral	0	42	36.2
5	Slightly Cool	– 1	8	6.9
6	Cool	– 2	-	-
7	Cold	– 3	-	-

Table 7 : Thermal preference Comfort for traditional houses

Analysis of the surveyed warmth preference scale for traditional houses, as reported by the respondents shows that 51 individuals (44%) expressed some warmth preference, while respondents 42 of the cases (36.2%) had preferential temperature neutral scale responses. In addition, 8 (6.9%) of the respondents reported a preference for some cold weather, whereas 13 (11.2%) and 2 (1.7%) indicated a preference for warm temperatures According to ASHRAE criteria, the findings showed a total of 101 individuals (or 87. 0 % of the sample) within the comfort zone, defined by temperature levels of +1, 0, and -1 The remaining 15 individuals (or 13. 0% of the sample) were outside the specified comfort zone.

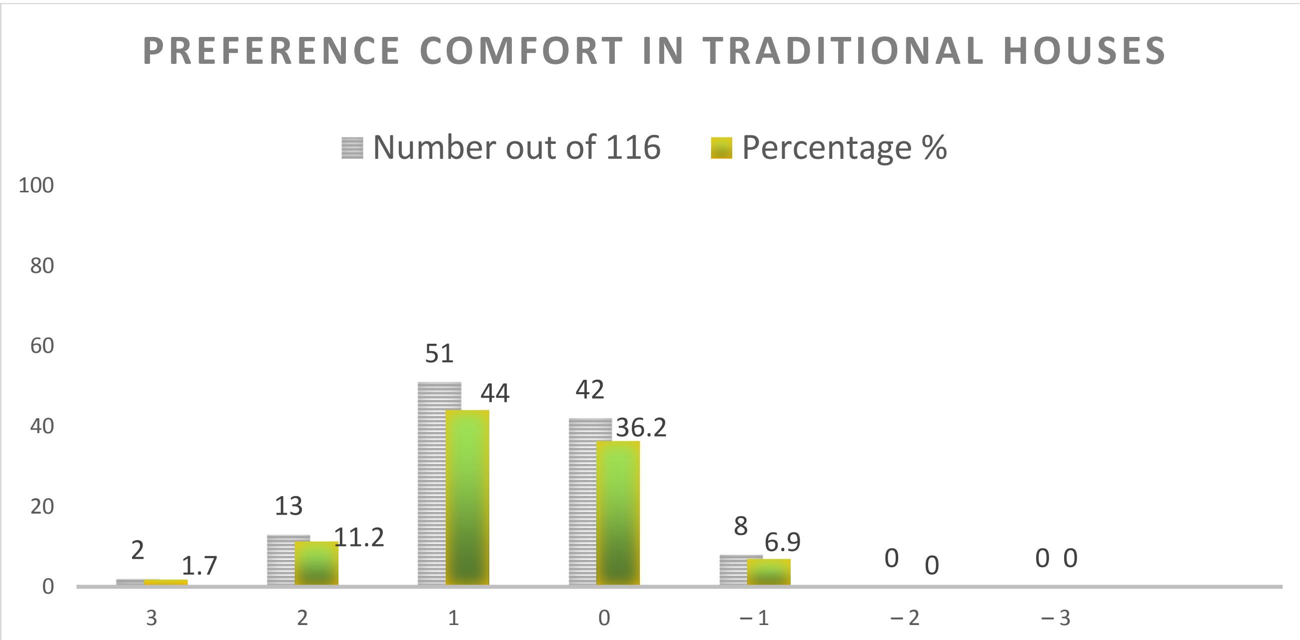

Figure 31: Thermal preference Comfort for traditional houses

	Thermal preference Comfort	Thermal preference Scale	Number out of 116	Percentage %
1	Hot	+ 3	14	12.0
2	Warm	+ 2	47	40.5
3	Slightly Warm	+ 1	28	24.2
4	Neutral	0	25	21.5
5	Slightly Cool	– 1	2	1.8
6	Cool	– 2	-	-
7	Cold	– 3	-	-

Table 8 : Thermal preference Comfort for modern houses

Studies have examined the warmth preferences of occupants of modern homes. Data collected from the respondents, n=14 (12.0%) reported feeling hot, while n=47 (40.5%) reported warm preferred temperature. In addition, n=28 (24.2%) respondents felt somewhat warm, n=25(21.5%) described the preference as natural, and n=2 (1.8%) respondents respondents reported feeling slightly cold. According to ASHRAE criteria, the findings indicated that 55 individuals (or 47.4% of the sample) were within the comfort zone, defined by temperature levels of +1, 0, and -1 while 61 individuals the remainder (or 52.6 % of the sample) were outside the specified comfort zone.

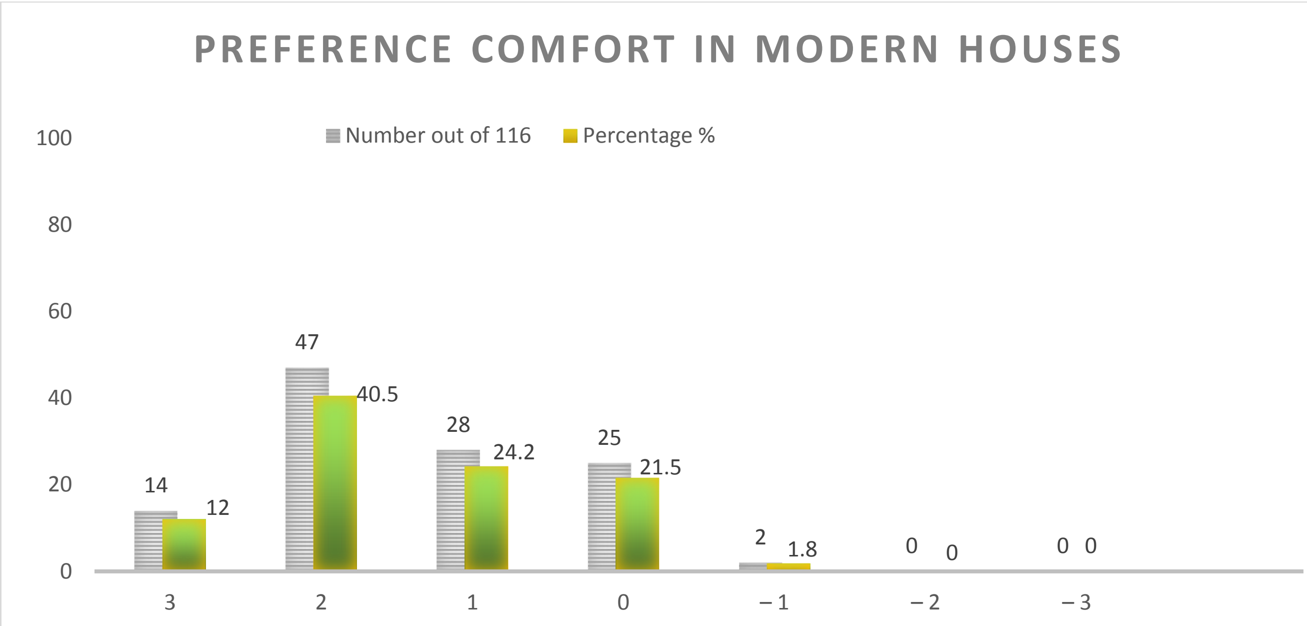

Figure 32: Thermal preference Comfort for modern houses

Based on the data collected, it can be argued that traditional houses are providing more thermal preference scale than the modern house.

Thermal satisfaction scale for both houses

	Thermal satisfaction Comfort	Thermal satisfaction Scale	Number out of 116	Percentage %
1	very dissatisfied	+ 3	-	-
2	dissatisfied	+ 2	3	2.6
3	Slightly dissatisfied	+ 1	12	10.3
4	comfortable	0	23	19.8
5	Slightly satisfied	– 1	53	45.7
6	satisfied	– 2	21	18.1
7	very satisfied	– 3	4	3.5

Table 9: Thermal satisfaction Comfort of traditional home

The result of traditional home thermal satisfaction scale data from the respondents shows that 3 respondents(2.6%) were dissatisfied,12(10.3%) respondents were somewhat dissatisfied, 23 respondents(19.8%) according to thermal satisfaction scale was neutral,53(45.7 %) answered slightly satisfied and 21(18.1%) and 4(3.5%) respondents answered satisfied and very satisfied respectively.

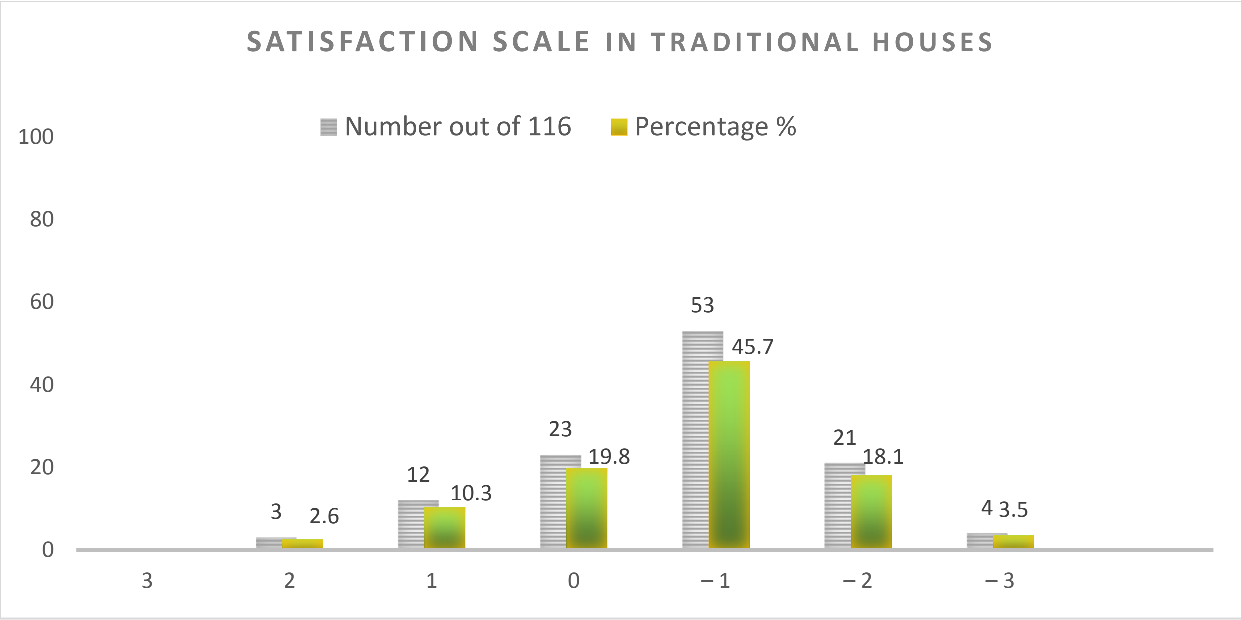

Figure 33: Thermal satisfaction Comfort of traditional home

According to the standard of ASHRAE, 88 (75.80%) were under the comfort zone because it locates in +1, 0, -1, and the rest 28(24.2%) were located out of comfort zone.

	Thermal satisfaction Comfort	Thermal satisfaction Scale	Number out of 116	Percentage %
1	very dissatisfied	+ 3	18	15.5
2	dissatisfied	+ 2	41	35.3
3	Slightly dissatisfied	+ 1	22	19.0
4	comfortable	0	15	12.9
5	Slightly satisfied	– 1	11	9.5
6	satisfied	– 2	9	7.8
7	very satisfied	– 3	-	-

Table 10 : Thermal satisfaction Comfort of modern houses

Data collected from the respondents regarding modern housing satisfaction scale shows that n=18(15.5%) are very dissatisfied, n=41(35.3%) respondents are not satisfied, n= 22(19%) somewhat dissatisfied, n =15(12.9%) respondents were comfortable with modern housing, n= 11(9.5%) somewhat satisfied, n=9(7.8%) respondents their statements were satisfactory.

According to ASHRAE criteria, findings indicated that 48 individuals (or 41.4% of the sample) were within the comfort zone of the thermal satisfaction scale, defined by burn levels of +1, 0, and -1 in. Comparatively, the traditional house was more comfortable than the modern house due to the satisfaction scale with reserved space.

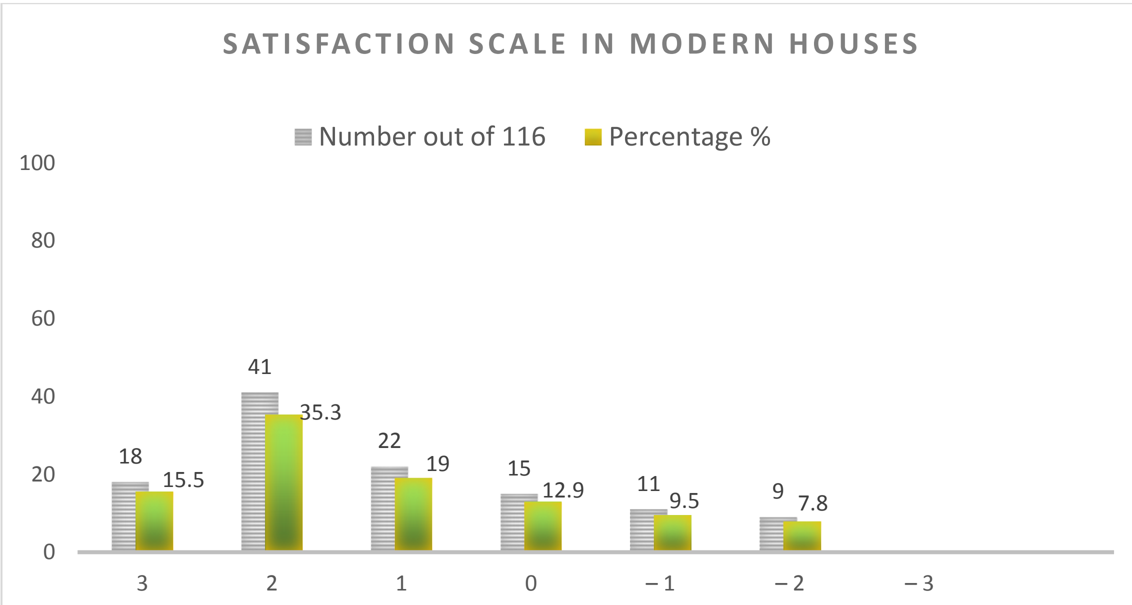

Figure 34: Thermal satisfaction Comfort of modern houses

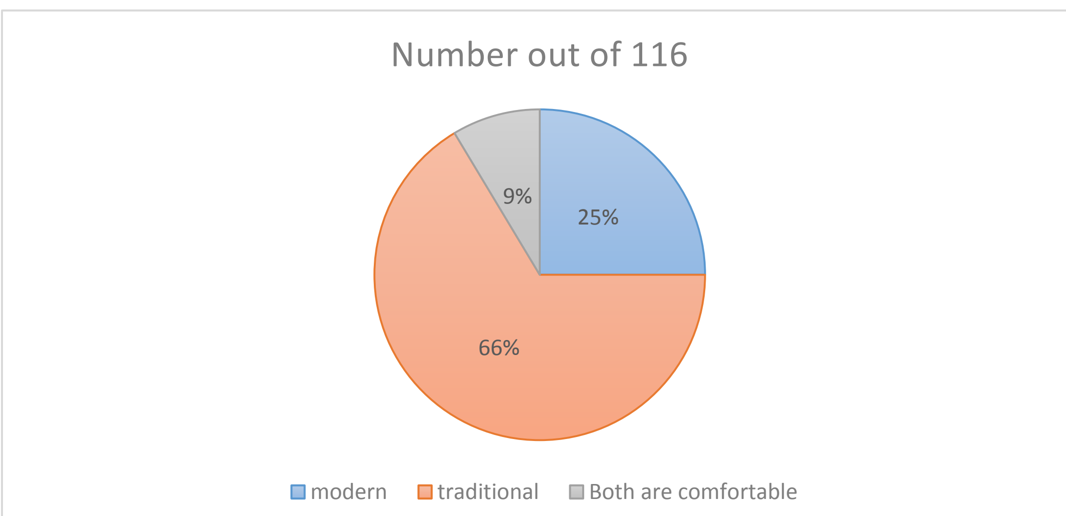

Figure 35: climatic comfort of both houses

4.6. The analyses of thermal environments variables in both traditional and modern Houses

During the survey, environmental variables such as air temperature, humidity & wind velocity, affecting thermal comfort have been collected from the interior of traditional house and modern house and the outside of the building during several days and times in four months at a certain assigned spot by using Holdpeak digital heat stress meter.

A. environmental variables data analysis in February month

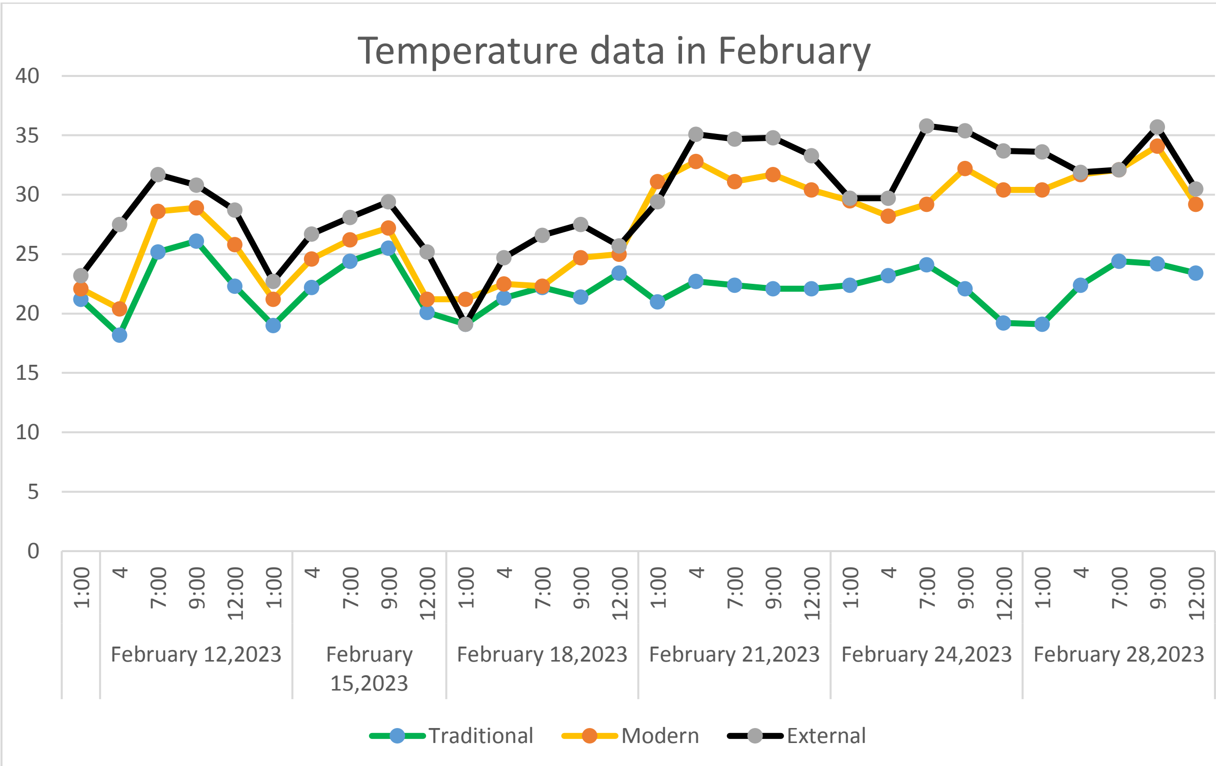

Figure 36: Temperature data in February 2023 (field survey)

Measurements in February showed a maximum temperature of 35. 8^0C and a minimum of 18. 2^0C.It was observed that most temperature readings were obtained from outside, while the lowest number of temperature readings were recorded there in a typical house.

According to the established ASHRAE standards, 22. 2^0C to 26. 6^0C (72°F to 80°F) is considered the desired comfort zone in winter in terms of thermal comfort and it was surprising that in February in the latter half, it is so modern houses seem uncomfortable. The sequence of numbers 21, 24, 28, 2023 is based on recorded data. As for traditional households, temperature measurements showed a maximum of 26.1^0C and a minimum of 18.2^0C.However, with respect to thermal comfort, the observed temperature in February was found to be 21.480C, and fell below the standard comfort level.

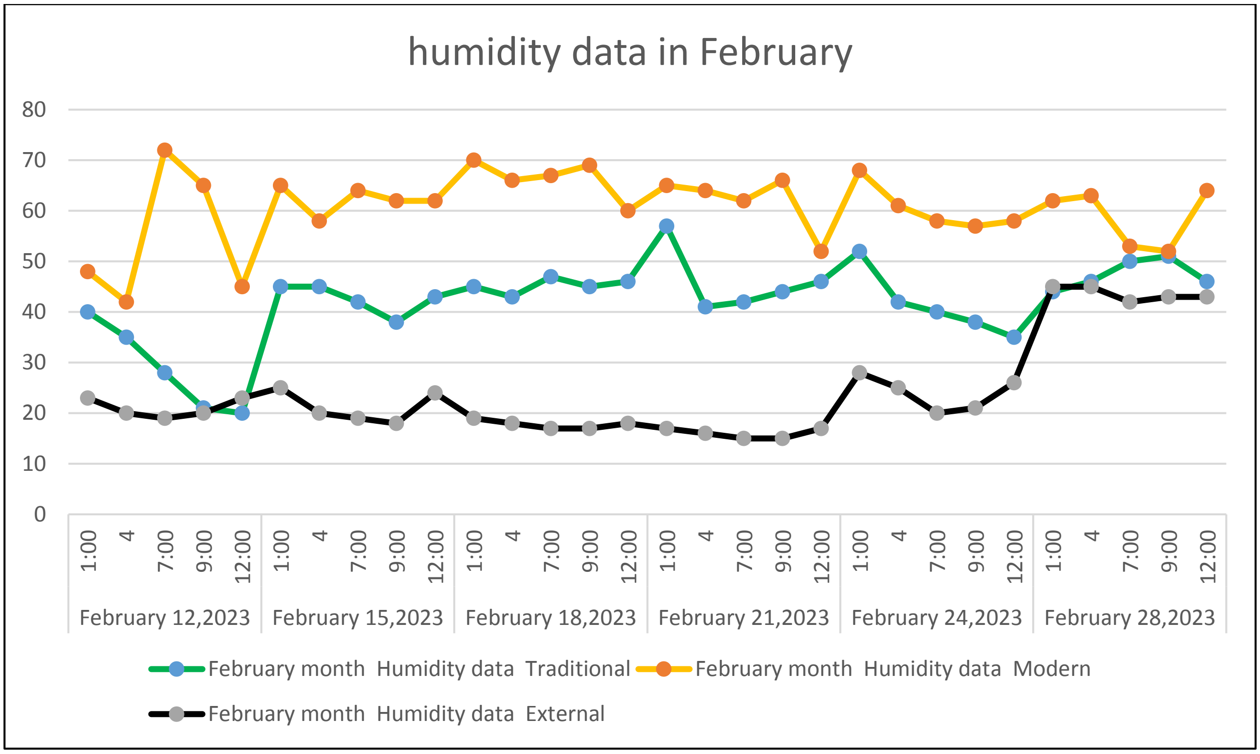

Figure 37: humidity data in February 2023 (field survey)

Regarding modern houses all scenarios except 28 February 2023 were found to be below the thermal comfort limit set by ASHRE (30 RH - 60 RH) In contrast, analysis of traditional houses revealed that with thermal relief coefficients match exactly, according to all recorded measurements obtained in the specified range.

One reason modern homes are not simple is their design. The houses have been designed out of harmony with the environment of Dire Dawa, resulting in unhealthy living conditions. Apart from design, another reason for the lack of taste in contemporary homes is the building materials. Many modern homes in Dire Dawa are built with building materials that have proven unsuitable in tropical and semi-arid regions. For example, concrete walls and a thin roof retain heat and create an uncomfortable indoor temperature.

Traditional home design in Dire Dawa can be ideal. Traditional homes are built with materials suitable for hot semi-arid climates, thus providing the same luxurious living conditions as traditional homes above it sinks to the floor allowing warm air to escape quickly, cooling the house.

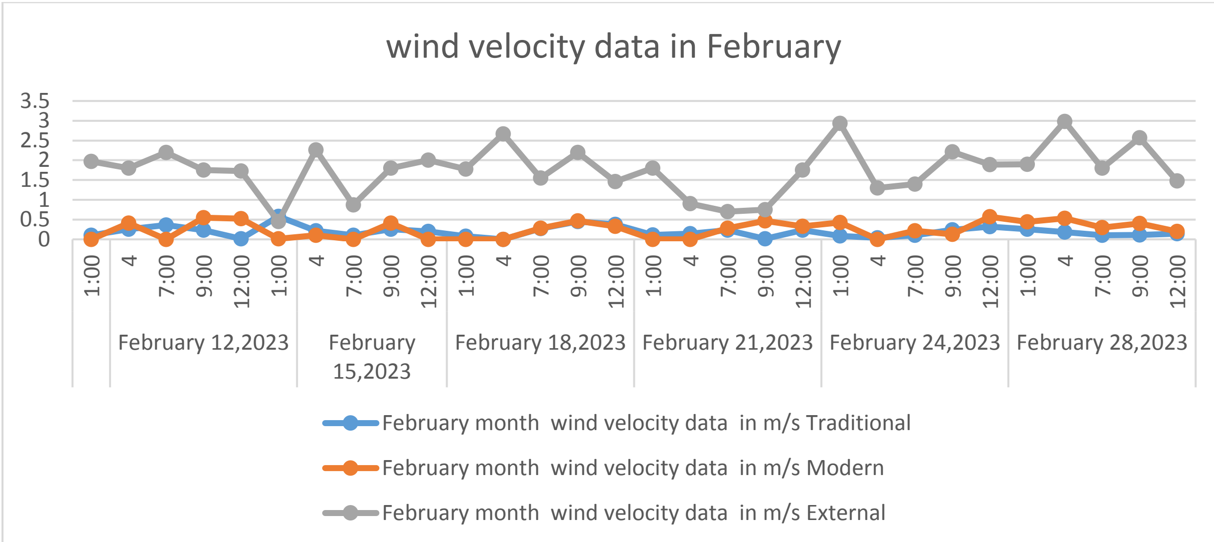

Figure 38: wind velocity data in February 2023 (field survey)

In February, wind speeds in modern and traditional houses are almost similar but much lower than outdoors because various building materials, building parts such as walls and windows, green vegetation or wind barriers block outdoor air approach.

b. environmental variables data analysis in march month

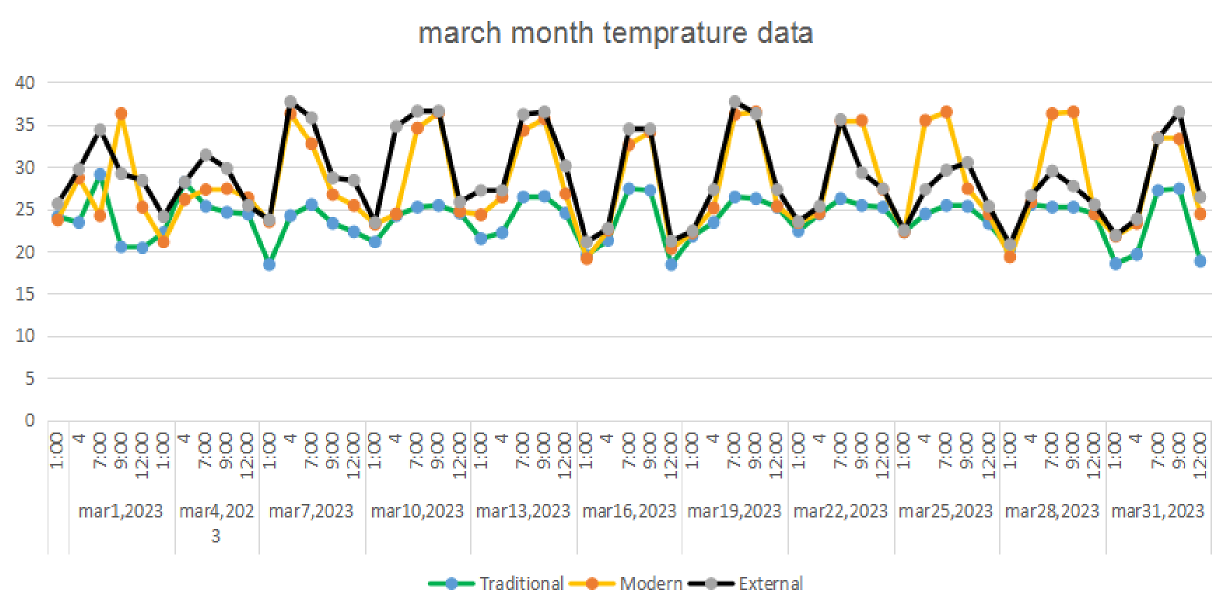

Figure 39: Temperature data in March 2023 (field survey)

Accordingly, the maximum temperature in March is 37.70°C in the outdoor climate. For modern house all recorded temperatures were above 26^{0}C not March 04, 2023 (average 25.64^{0}C) and March 16, 2023 (average 25.72^{0}C). This means that modern house is above comfort zone with remaining days in March. As for the traditional house, there are some points which show in thermal comfort zone but the average traditional house was in comfort zone. The traditional house is better compared to the modern house because the temperature recorded in the traditional house was in the comfort zone and the stability of the reading is better than the modern house.

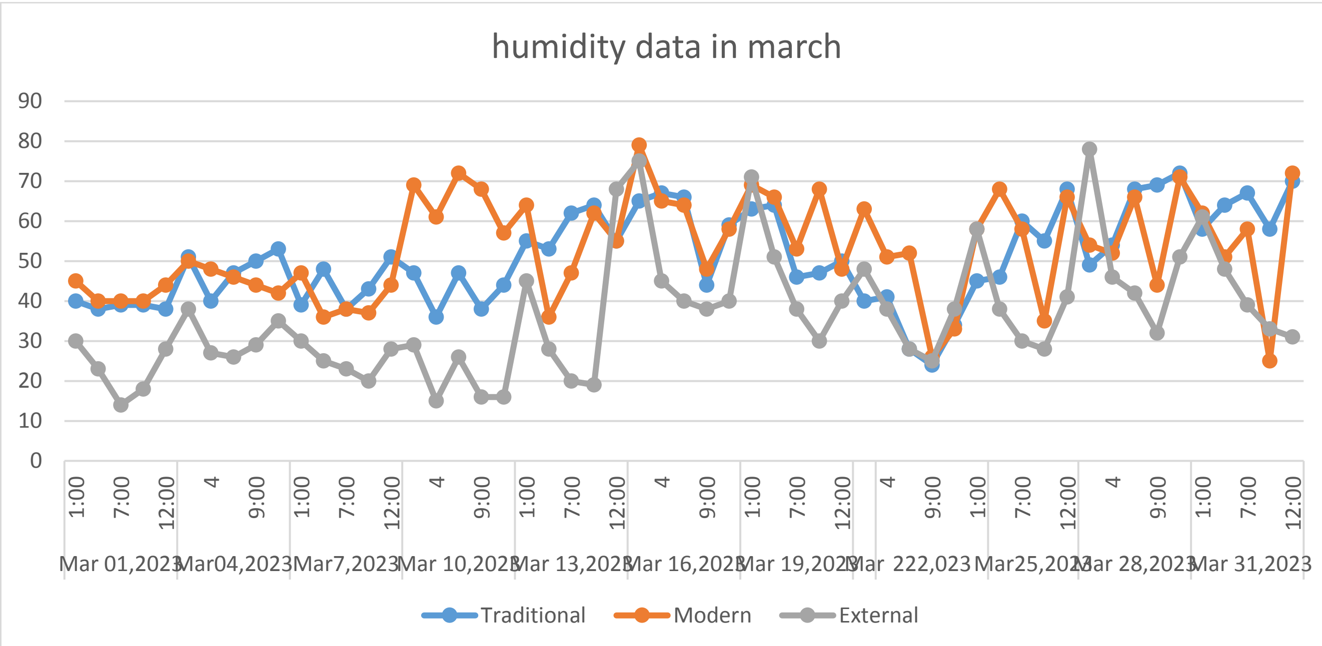

Figure 40: humidity data in March 2023 (field survey)

The figure above show that the humidity recorded shows that on average both buildings have almost a basic comfort zone for traditional houses but the range was very high in terms of interior and exterior features a around us in the modern home, it doesn't have regular consistency. This section creates an uncomfortable environment in modern homes & low level of comfort .This uncomfortable house environment is due to careful choice of materials & drafts in building walls.

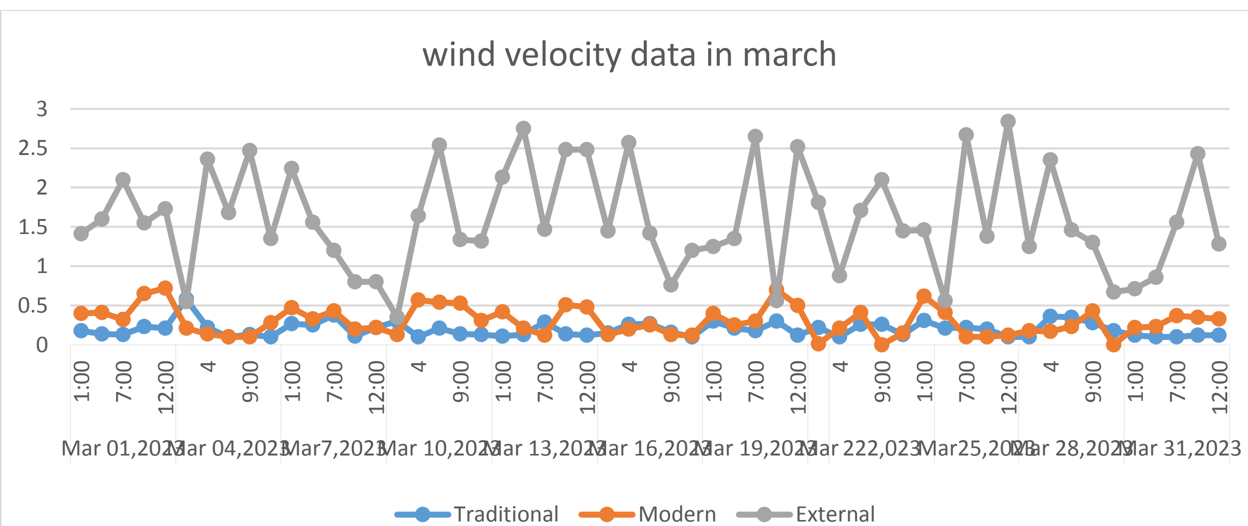

Figure 41: humidity data in March 2023 (field survey)

On March, the wind velocity inside a modern home is higer than that of traditional homes but is almost the same throughout and much lower than the wind outside. This means that wind speed is constrained by the structure.

c. environmental variables data analysis in April month

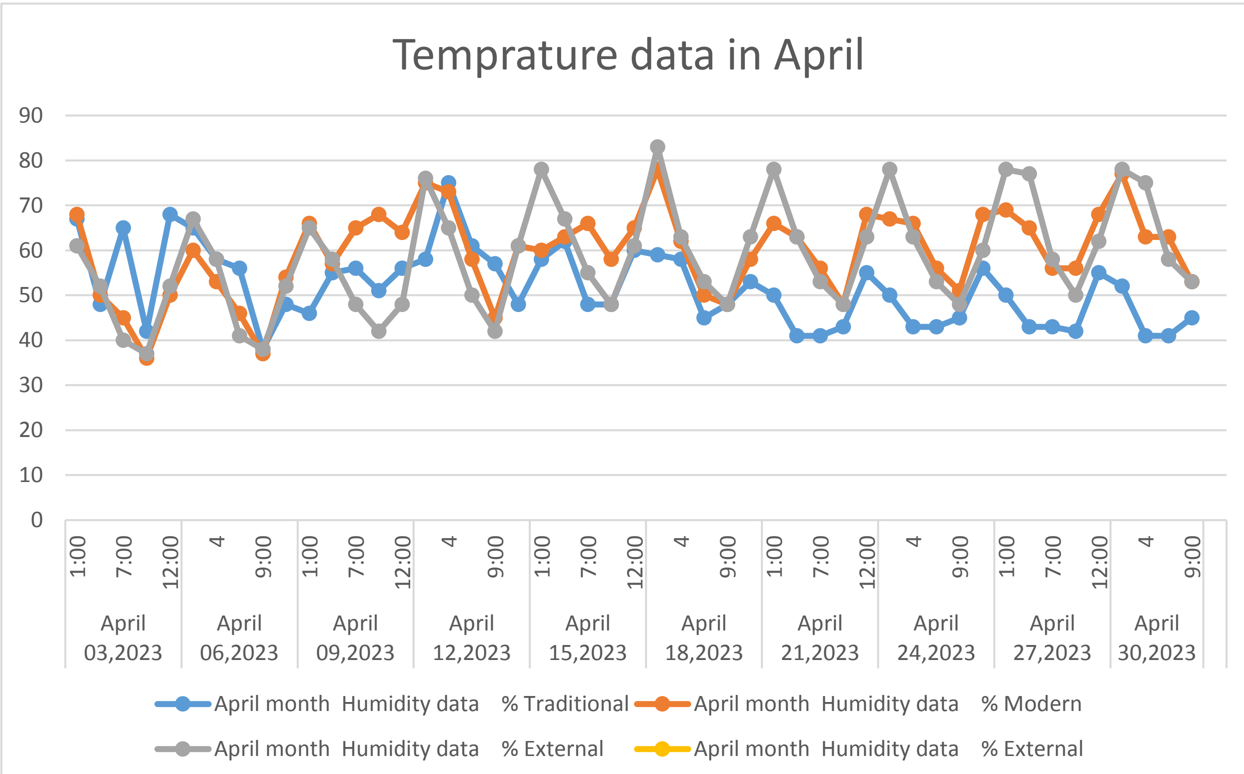

Figure 42: Temperature data in April 2023 (field survey)

Thus, the maximum April weather temperature was 38.4°C. For the modern house all recorded temperatures were over 26°C except for that analyzed on April 3, 2023 (average 24.3°C). This indicates that the modern house will be above the comfort range for the remaining days in April. The traditional house exhibited some periods suggesting a thermal comfort zone but certainly the average traditional house was in a comfort zone for April. The traditional house is better compared to the modern house because the temperature reading were in comfort zone and overall stability of temperature readings were better for the traditional house.

The figure below show that the average humidity recorded on April month of both buildings and the external environment. Both building are almost the same level of humidity but the traditional houses much lower level of humidity that compared to the modern houses and the external one.

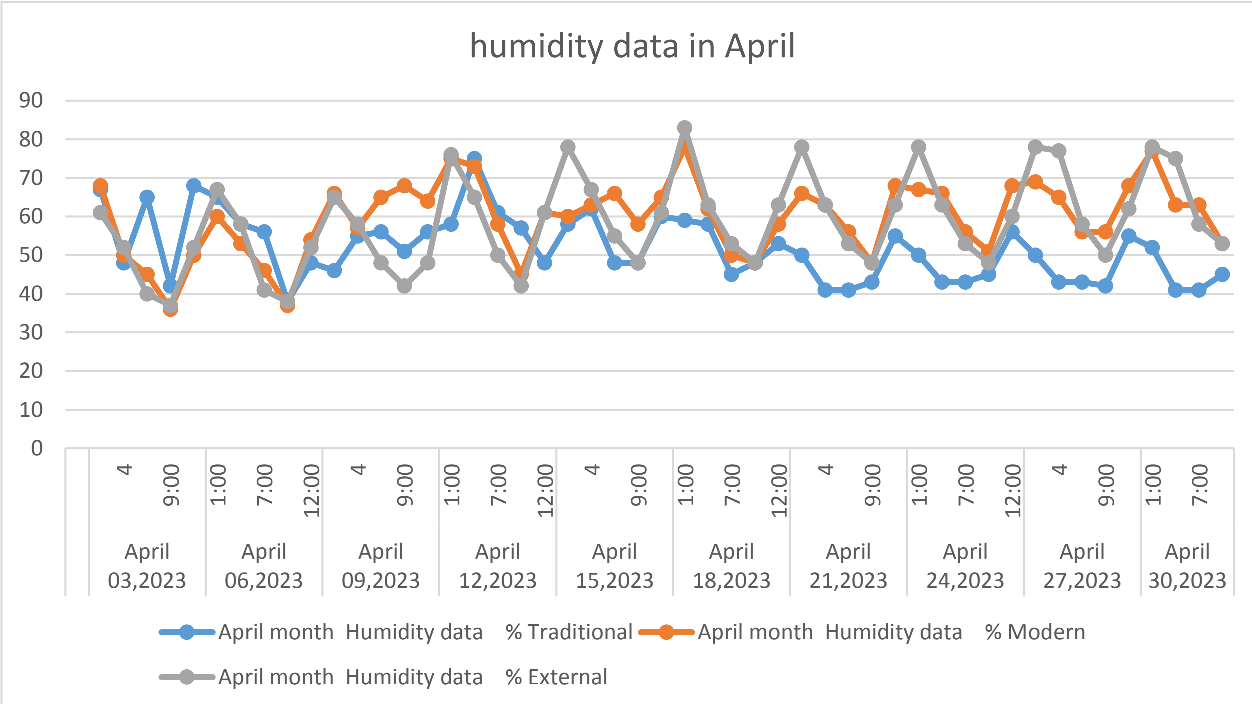

Figure 43: Humidity data in April 2023 (field survey)

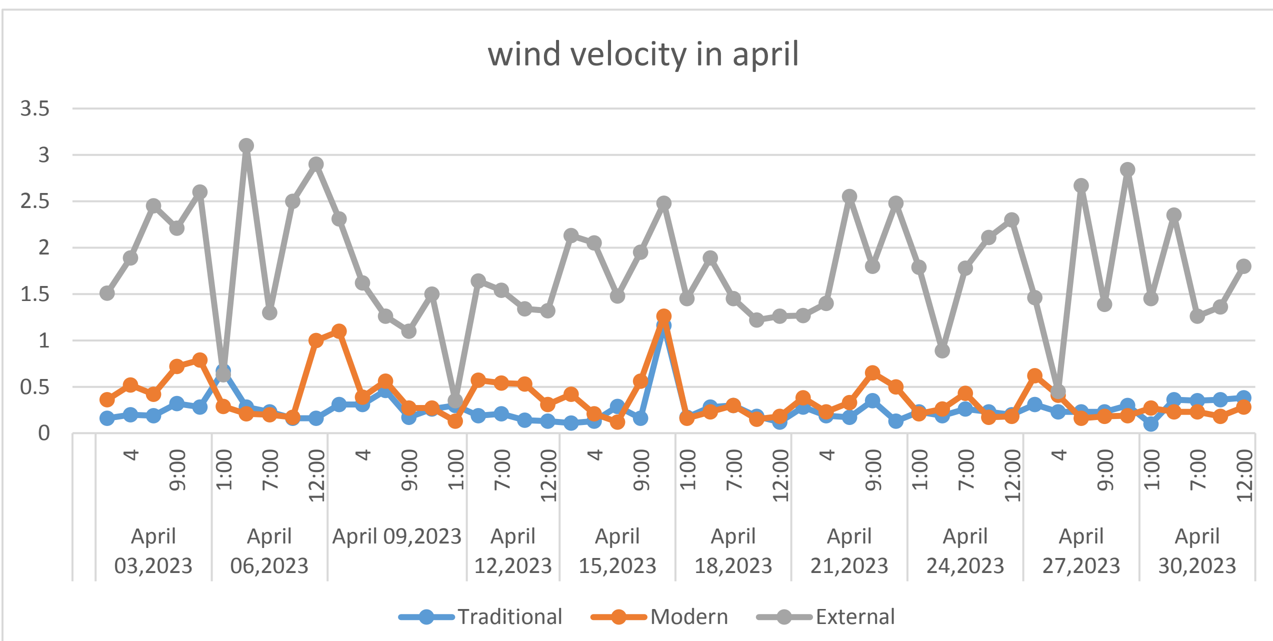

Figure 44: wind velocity data in April 2023 (field survey)

Within the month of April, the indoor wind velocity of a modern house is greater than indoor wind collection data of traditional houses, while both house types would have much lower velocities than the wind collected data of outside. The main reason for the lower wind velocities indoors of traditional house is due to the fact that their green elements are able to block wind velocity because the heights of the buildings were are similar to height of the green elements. The openings of traditional houses are also less in size therefore also contributing to the lower wind velocity.

d. environmental variables data analysis in may month

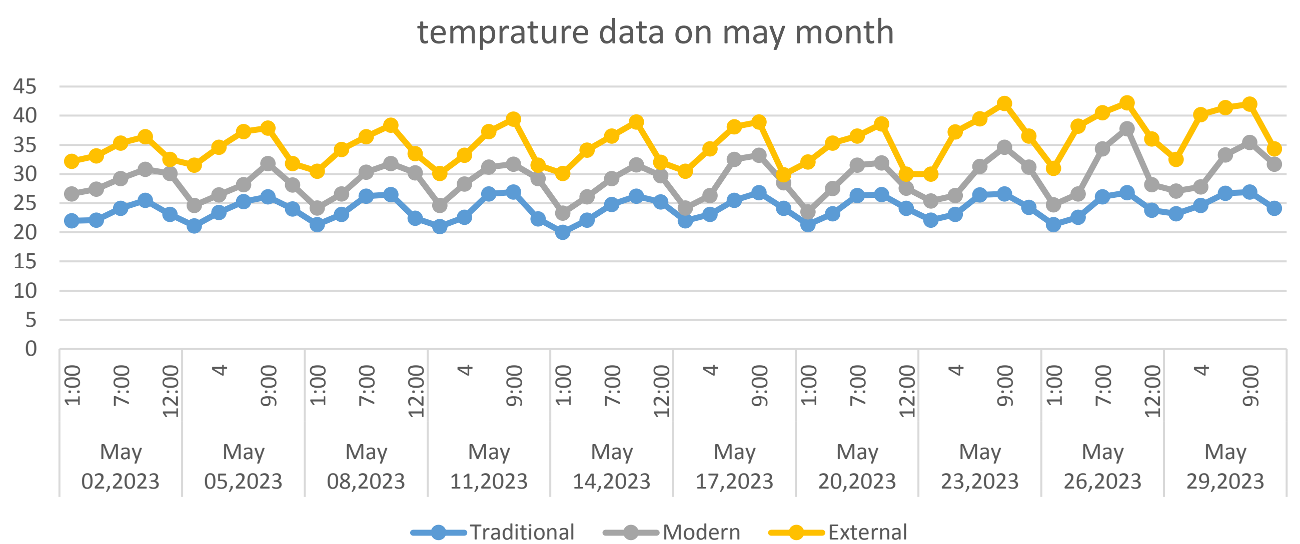

Figure 45: Temperature data in May 2023 (field survey)

The temperature recorded in May is much higher compared to other months. The average temperatures recorded at each day of the May month are all over 26°C in the modern house. This is an indication that the modern house for every day will be over the comfort range, which is within a temperature of 22. 20C - 26. 60C or 72°F - 80°F. The traditional house presented some periods that were in a thermal comfort zone; definitely, the mean traditional house was within the comfort zone for May.

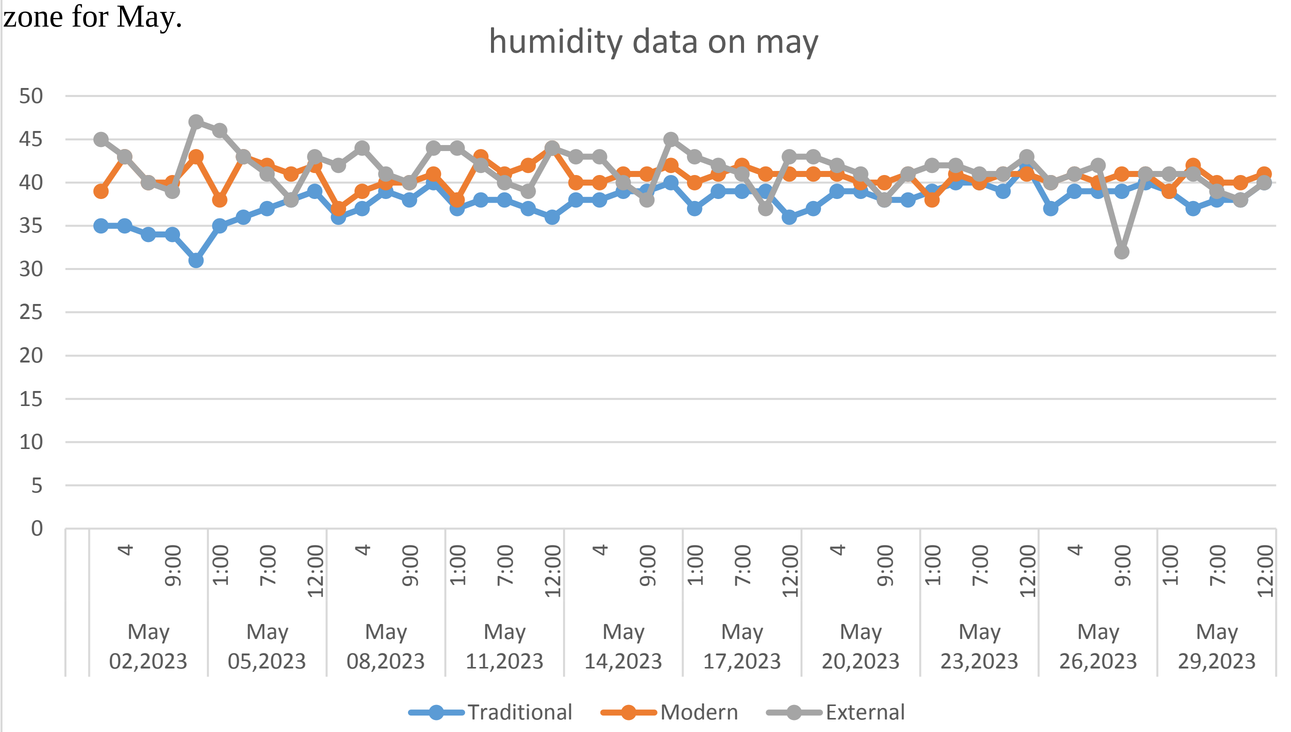

Figure 46: humidity data in May 2023 (field survey)

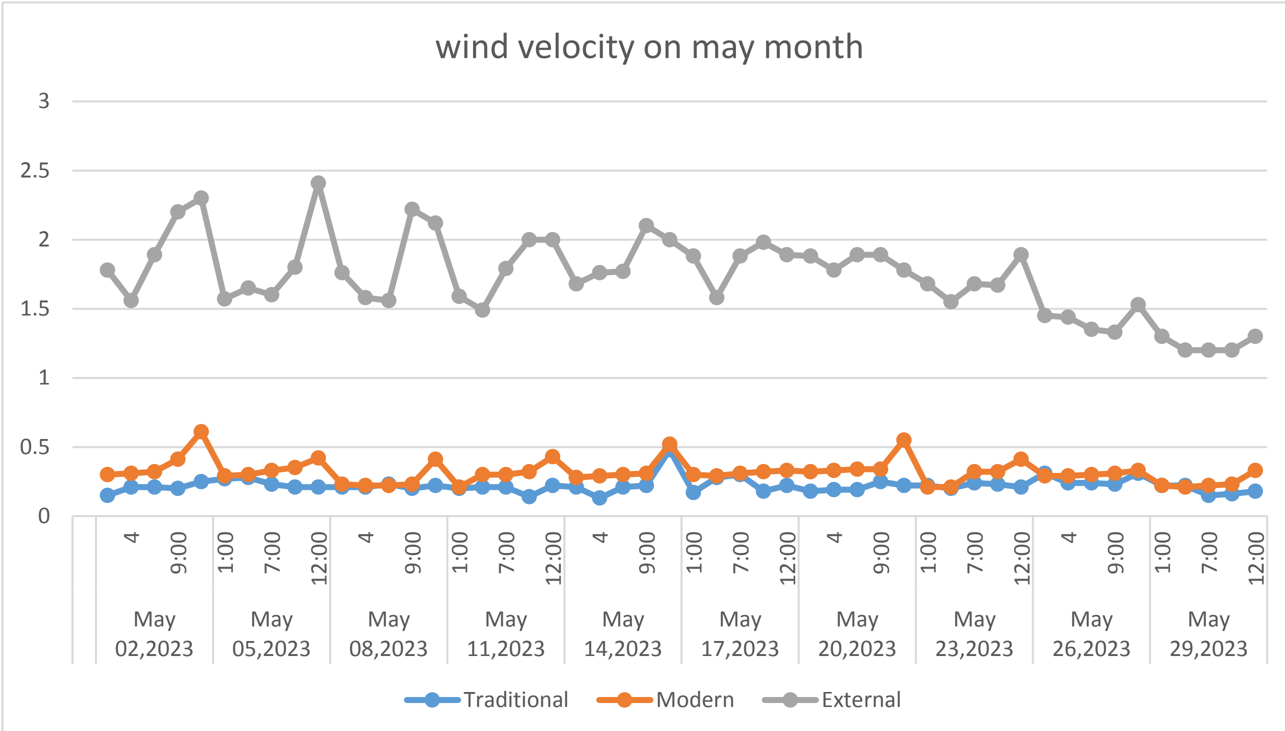

Figure 47: wind velocity data in May 2023 (field survey)

The above figures show that the average humidity and wind velocity recorded on May month of both buildings and the external environment. Both building are almost the same level of humidity and wind velocity but the traditional houses much lower level of humidity and wind velocity that compared to the modern houses and the external one this is due to the opening sizes.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study assess the indoor thermal comfort of the traditional houses and condominium (modern house). The study was conducted using both subjective and objective evaluation methods such as structured questionnaires and environmental variable measurements (temperature, humidity, airspeed) were recorded for the four months from February to May by using HOLDPEAK DIGITAL HEAT STRESS METER, ASHRAE 55 7-points of sensational scale and the questionnaires distributed to 116 samples. The results were summarized as follows.

Regarding to the traditional houses indoor thermal comfort, those houses are suitable for residents with a good sensational scale, preference and good satisfaction on the houses and also the recorded variables. Because the materials used for constructing those houses are resisting the harsh bio climatic environment of the Dire Dawa city. And the other main reason is the opening size much suitable to give the natural ventilation that compared to room sizes of the houses.

When we see the result from the modern houses they have negative results on the indoor thermal comfort. The residents have faced a lot of challenges even they spent their more time in outdoor due to the balconies covered by another non hot air resistant materials like glass and HCB walls and the openable size of window are not suitable for the window and room size. From this the amount of hot air entering in to the rooms much higher than the air circulating inside rooms from out sides of rooms. And concerning to thermal sensation, preference and comfort the residents were in a huge challenges and some residents also wants to live in the traditional house.

5.2. Recommendations

The following are recommendations for improving the indoor thermal performance for occupants' comfort of future projects that seek to compete with the buildings evaluated in this study.

For Architects and planners:

1. Integrate passive design strategies that leverage the local climate and traditional building practices in enhancing indoor thermal comfort, including natural ventilation, shading, and the use of locally sourced materials.

2. Conduct Detailed thermal comfort investigations in modern and traditional residential homes to identify design features and building characteristics that both provide and prevent the delivery of indoor thermal comfort.

3. Establish design guidelines and standards that are sensitive to the unique climate and cultural context of a given locale, ensuring new residential developments prioritize occupant comfort.

4. Investigate how sustainable and innovative technologies, such as renewable energy systems and advanced insulation materials, can be integrated to enhance thermal comfort while reducing environmental impact.

For Municipal Organizations and Policymakers:

1. Develop and implement building energy codes and standards that prioritize indoor thermal comfort, incorporating the findings from this research to ensure regulations are tailored to the local climate and building practices.

2. Provide incentives and support programs to encourage the adoption of sustainable and energy-efficient design solutions in both new construction and retrofits of existing residential buildings.

3. Collaborate with local research institutions and community stakeholders to continuously monitor and update thermal comfort guidelines and policies, ensuring they remain responsive to changing climate conditions and evolving occupant needs.

4. Integrate thermal comfort considerations into urban planning and development strategies, promoting the integration of green infrastructure and sustainable neighborhood design.

For Researchers:

1. Longitudinal studies: Measure and survey the buildings for a longer period of time, under different seasons and climatic conditions, to understand the seasonal variations in thermal comfort.

2. Analysis of occupant behavior: Look into how the occupants, by their behaviors—like opening windows, using fans or air conditioners, and changing clothes—reach the appropriate level of thermal comfort within the studied houses.

3. Analyze the Building Design and Materials Effect: Compare the architectural design and the building materials being used with how the traditional houses and modern perform thermally.

5.3. Strategies to achieving thermal comfort in Dire Dawa city

Achieving thermal comfort of the building has become the key to improving life quality both in indoors and outdoors. It expresses a situation in which occupants do not feel either too hot or too cold, and hence, this allows maximum productivity with a feeling of well-being. The contributory factors towards thermal comfort include air temperature, humidity, air movement, and personal attitude. These factors are of prime importance to enable the adoption of appropriate methods to sustain a comfortable indoor climate.

The thermal comfort can be addressed by considering different strategies in the design and selection of building material.

A. building design strategies

Building design strategies can be used to improve modern buildings' indoor comfort, enhance their energy efficiency, and minimize energy use. More importantly, incorporating these Strategies in the construction of buildings can directly and indirectly benefit the environment.

There are two type of design strategies, Passive strategies, by their very nature, involve architectural design and materials in the facilitation of natural temperature regulation, including proper insulation, shading, and ventilation. And also Active strategies are related to heating, ventilation, and air conditioning systems that may be adjusted based on the need for comfort. By combining such approaches, individuals can produce a more stable and pleasant indoor environment. But active design strategies are not suggested for developing countries like Ethiopia because most of them use high electric and energy consumption, so this research only focuses on passive design strategies.

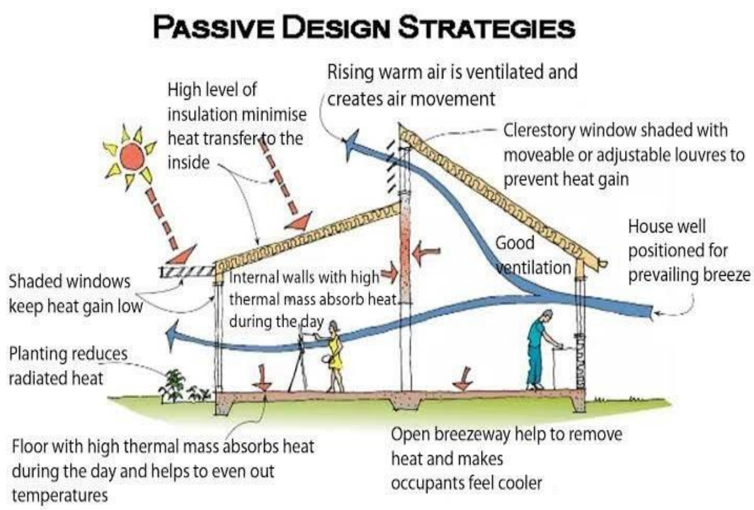

Figure 48: passive design strategies

Passive design strategies

To regulate the indoor thermal comfort in hot arid areas like Dire Dawa, Ethiopia, several strategies can be implemented. Here are a few recommendations:

1. Insulation and shading: Improve insulation on exterior walls, roofs, and windows to reduce heat gain. This can help maintain a more comfortable indoor temperature, especially during the hottest hours of the day.

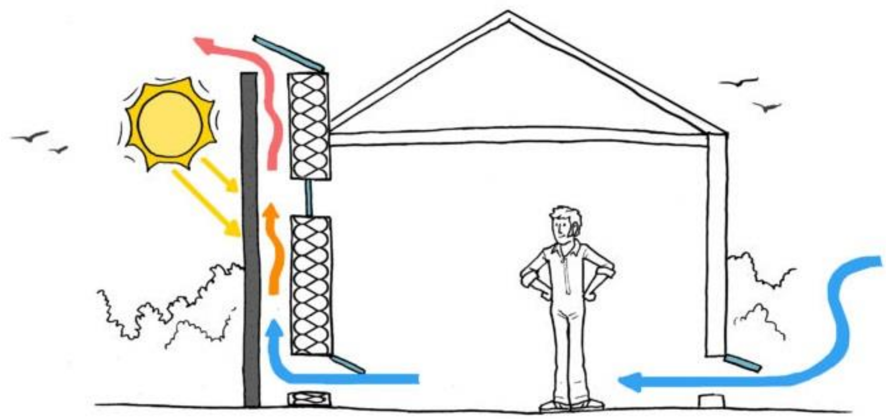

Figure 49: the effect of insulation material (source: Biggs (1987)

2. Cross-ventilation: Design the building with open spaces that promote natural cross-ventilation. Opening windows and doors on opposite sides of the building will create a flow of fresh air, which can help dissipate heat.

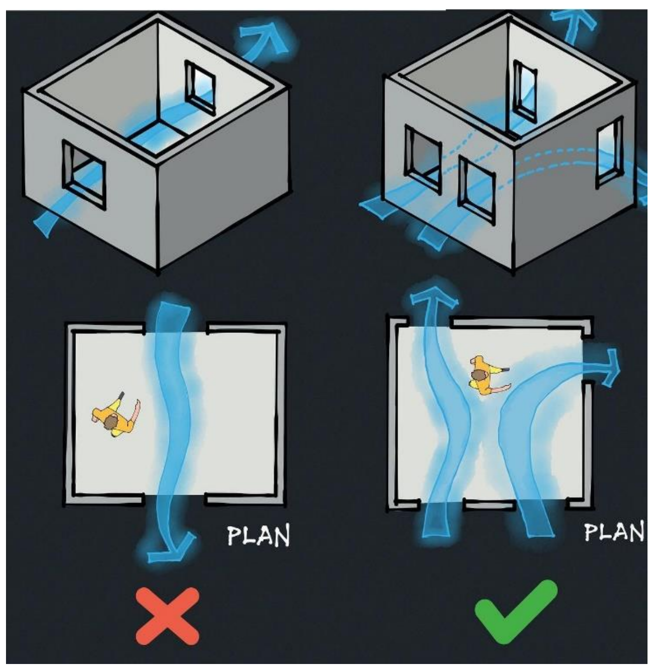

Figure 50: the effect of cross ventilation (source: Gautam (2019).

3. Green roofs: Install green roofs, which have vegetation on top of the building's surface area, to provide insulation and cooling effect due to evapotranspiration. They also help reduce the heat island effect in urban areas.

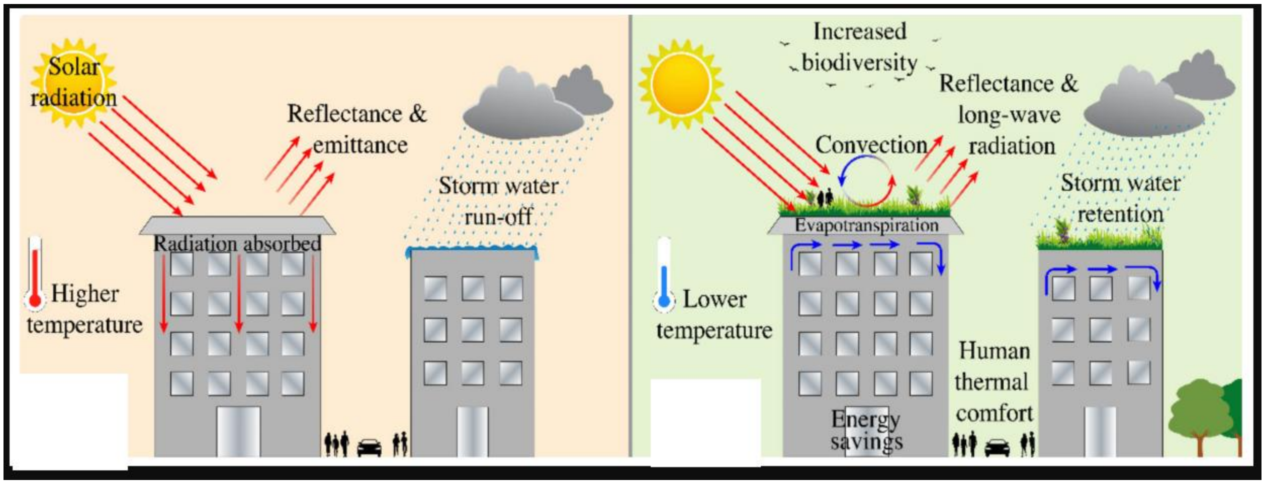

Figure 51: the effect of green roofs (source: Rowe (2011).

4. Shading devices: Incorporate shading devices such as external blinds, curtains, or awnings on windows and openings to block out direct sunlight and prevent heat from entering the building.

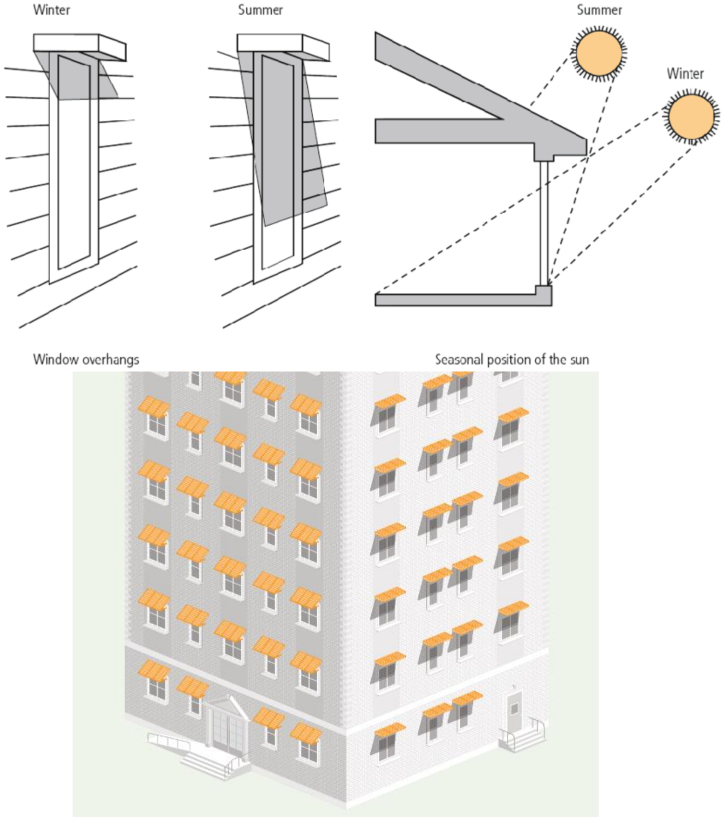

Figure 52: the effect of external shading device (source: Rosencrantz (2005).

5. Nighttime cooling: Open windows and doors at night to allow cooler outside air to enter the building, replacing the warmer indoor air. Close them again in the morning when temperatures start to rise.

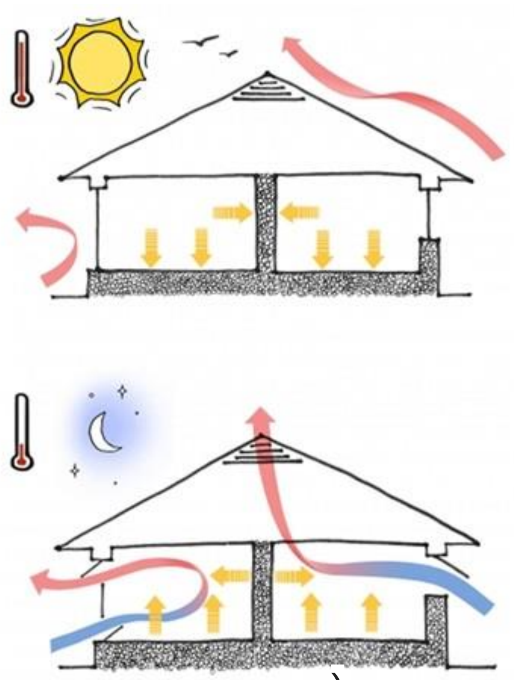

Figure 53: the nighttime cooling (source: Tahbaz . (2008)

6. Building orientation: Orient the building in such a way that it takes advantage of prevailing winds and natural shade. For example, positioning windows and openings facing north or south can help reduce solar heat gain while still allowing for natural light.

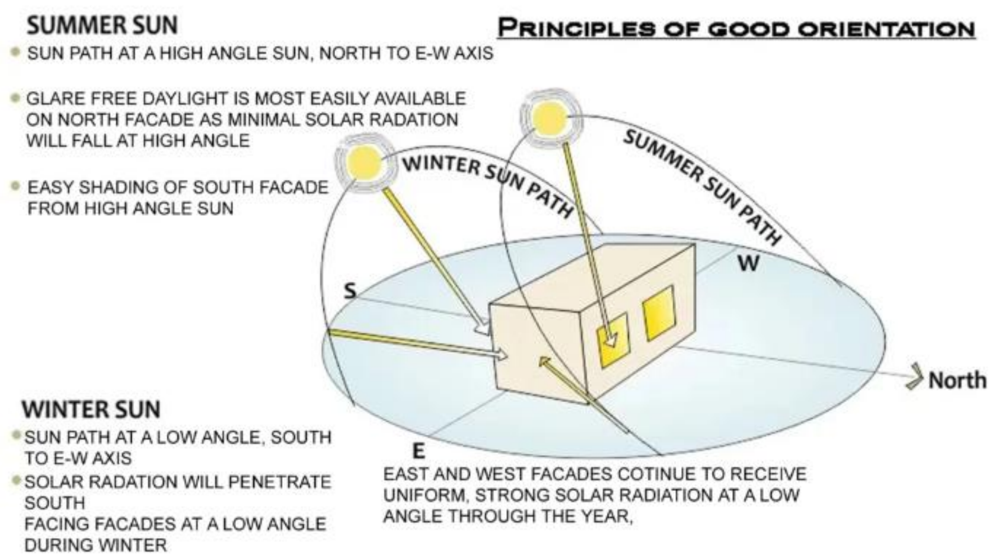

Figure 54: openings on north and south face the building (source: Fallahtafti (2015)

7. Landscaping and urban greening: Plant trees and vegetation around the building to create shade and reduce the urban heat island effect. This can provide a more comfortable environment outside as well as inside the building.

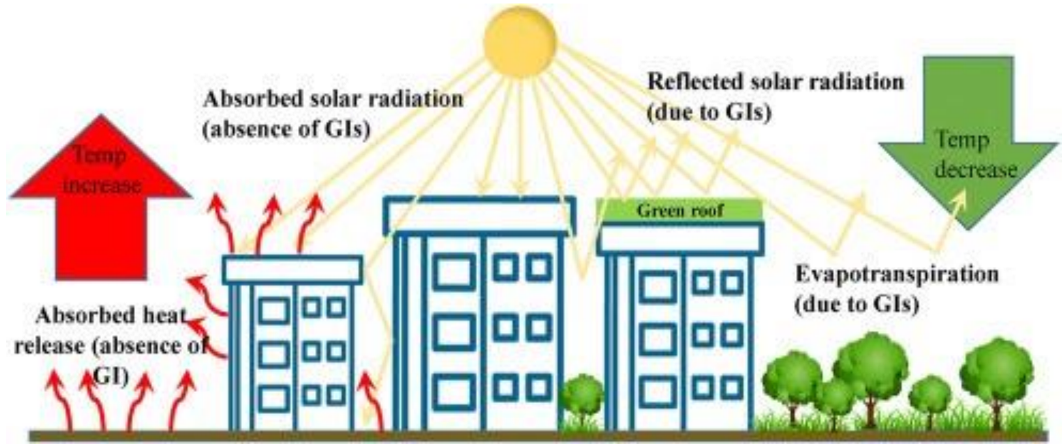

Figure 55: the effect of urban green area (source: Francisco Gómez (2010)

8. Use courtyard shape buildings: courtyard buildings, also known as peristyle or atrium architecture, are designed with an open central space or courtyard, which allows for natural light and ventilation. This architectural style has several effects on improving indoor thermal comfort:

A. the presence of a courtyard creates a cooling effect due to the stack effect, where cooler air sinks and warmer air rises. As hot air rises, it is replaced by cooler air from the ground level, effectively creating a natural circulation that helps maintain a comfortable temperature inside the building.

B. The open central space of a courtyard allows for better air circulation throughout the building. This ventilation can help dissipate heat and humidity, reducing indoor temperatures during warm months and improving overall thermal comfort.

C. Shading and daylighting: Courtyard buildings often incorporate shaded outdoor spaces that provide protection from direct sunlight, which helps to regulate indoor temperatures and prevent overheating. Additionally, the open central area allows for natural light to penetrate deep into the building, reducing the need for artificial lighting and contributing to a more comfortable environment for occupants.

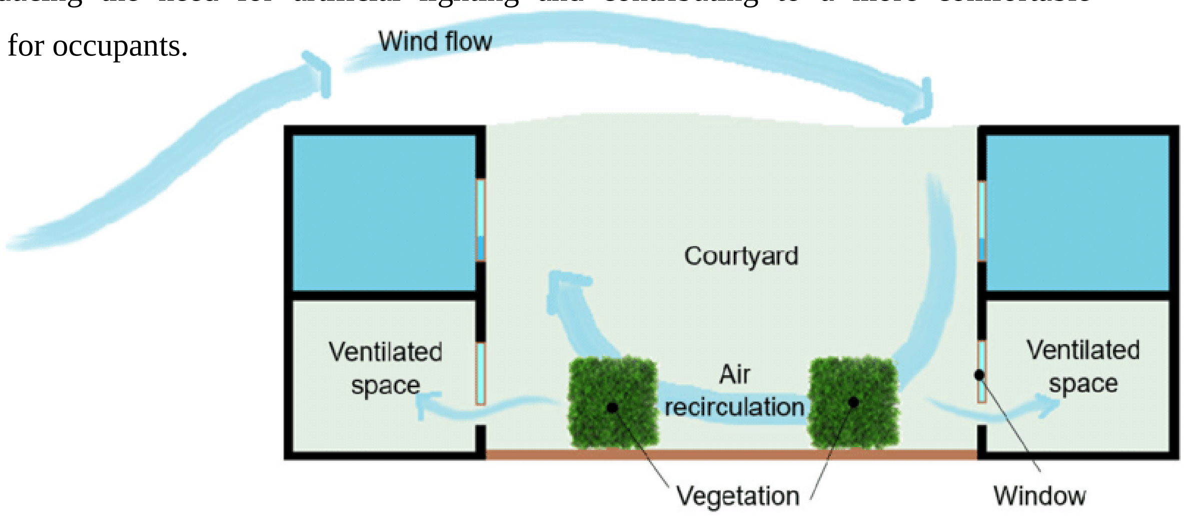

Figure 56: use of courtyard building shape on cooling air (source: Abdelsalam(2008)

By implementing these building design strategies, we can improve indoor thermal comfort in hot arid areas like Dire Dawa, Ethiopia.

B. Building material selection strategies

Selecting suitable building materials to provide thermal comfort depends on various considerations, such as climate, building design and budget. Common materials used are:

1. Insulation material: Insulation is a material that acts as a thermal barrier between the interior and exterior of a building .it is used to reduce heat transfer, keeping the indoor temperature consistent and comfortable. Those materials plays a crucial role in improving indoor comfort levels, especially during extreme weather conditions. It can help maintain a comfortable temperature inside a building by reducing heat transfer from outside during summer and retaining warmth during winter.

Like Fiberglass, foam boards and cellulose insulation offer better thermal resistance by limiting heat transfer between areas, thus improving heat insulation properties and resistance against temperature swings.

2. High Performance Windows materials: High performance window materials significantly enhance thermal comfort in hot arid regions like dire dawa by minimizing heat gain and loss. These materials typically feature low-emissivity (Low-E) coatings, which reflect infrared radiation while allowing visible light to pass through. Additionally, double or triple glazing creates an insulating barrier, reducing thermal transfer. The use of argon or krypton gas between panes further improves insulation. By effectively managing solar heat gain and maintaining interior temperatures, these windows contribute to energy efficiency and occupant comfort in extreme climates.

3. Thermal Mass Materials: In hot arid regions, there are a few materials, such as concrete, stone, and adobe that can be used in the regulation of thermal comfort by using their characteristic properties in storing and releasing heat. Here's how it works:

A. Heat absorption: These materials absorb heat when exposed to sunlight and convert it into potential energy stored in the material. Therefore, they are best suited for warmer climates with large temperature variations during the day.

B. Slow heat transfer: High thermal mass materials have great thermal capacity; thus, they can absorb and store much heat without changing the temperature by a large margin. This reduces the speed of heat going into or out of the building and provides a buffer against extreme temperatures.

C. Cooling effect: It will slowly emit the absorbed heat as the sun goes down and outdoor temperatures drop. This will help maintain indoor temperatures at comfortable levels during cooler hours, thereby cutting down on mechanical cooling systems and energy consumption.

D. Radiant cooling: Some buildings have a radiant cooling system to further increase the thermal comfort level. Those are systems that circulate chilled water through pipes in concrete slabs or stone walls, creating a cool surface that radiates the heat away from the interior of the building and, therefore, reduces indoor temperatures without mechanical systems.

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APPENDIX
A. Questionaries

Please every one of you helps me by giving the correct answer to the questions and play your great role in this research (mark /x).

1. General Information:

1.1. Woreda : ____________________

1.2. Age group:

A. 20-40 B.41-50 C.51-60 D. Over 61

1.3. Level of education:

A. Elementary B. High School C. University D. Uneducated

1.4 family size:

A. Less than 3 & 3 peoples B. 4-7 peoples C. 8-10 peoples D. More than 11 people

2. Information on type of house:

A. traditional houses B. modern house

2.1. Housing type of tradional houses:

A. semi- detached B. detached C. row D. other types

2.2 For how long you lived in the traditional house/modern house:

A. Less than 5 years B. 5-10 years C. More than 10 years

2.3 What is the total number of occupants in the house?

A. Less than 5 B. 5-10 C. More than 10 people (please mention the number of families)

3. Utilities in the Traditional/modern House:

3.1 Level of natural lighting:

A. Weak B. Fair C. Good

3.2 Level of natural ventilation:

A. Weak B. Fair C. Good

4. Environmental Comfort Level both House:

4.1. Thermal Sensation for both houses. (ASHRAE thermal sensational scale)

	Thermal Sensation Comfort	Thermal Sensation Scale	Make x on your scale
1	Hot	+ 3	
2	Warm	+ 2	
3	Slightly Warm	+ 1	
4	Neutral	0	
5	Slightly Cool	– 1	
6	Cool	– 2	
7	Cold	– 3	

4.2. Thermal preference for both houses. (ASHRAE thermal preference scale)

	Thermal preference Comfort	Thermal preference Scale	Make x on your scale
1	Hot	+ 3	
2	Warm	+ 2	
3	Slightly Warm	+ 1	
4	Neutral	0	
5	Slightly Cool	– 1	
6	Cool	– 2	
7	Cold	– 3	

4.3. Thermal satisfaction for both houses. (ASHRAE thermal preference scale)

	Thermal satisfaction Comfort	Thermal satisfaction Scale	Make x on your scale
1	very dissatisfied	+ 3	
2	dissatisfied	+ 2	
3	Slightly dissatisfied	+ 1	
4	comfortable	0	
5	Slightly satisfied	– 1	
6	satisfied	– 2	
7	very satisfied	– 3	

4.4 What are the reasons for differences between traditional and modern houses concerning climatic comfort?

A. Building design B. Construction materials C. construction techniques

D. type and size of openings in the house E. Other …………………………

4.5. What was the system used for cooling during the Hot seasons:

…………………………. …………………………………………………………………

4.6. What was the system used for heating during the cold season:

…………………………. …………………………………………………………………

4.7. What are the benefits of the traditional house are that:

A. Provide climatic comfort B. Low cost C. Use local construction material
D. Provide strong social relationships E. Other ……………………………

4.8. What are the disadvantages of the traditional house are that they have:

A. Problems with sanitary utilities. B. Lack of prestige value (not fashionable)

C. Less privacy since most families stay in a single house.

D. Other ……………

4.9. What are the benefits of the modern house.

…………………………. …………………………………………………………………

5. What are the disadvantages of the modern house.

…………………………. …………………………………………………………………

B. General information about HOLDPEAK Wind Speed & Heat Stress WBGT Meter

The importance of the device

HP-881W handheld anemometer can measures wind speed, WBGT temperature, temperature and humidity. It used to prevent injuries associated with hot and humid hazardous environments by controlling operational activities in hot environments.

- WBGT Alarm be used to remind whether the current working environment temperature is too high to reduce the harm caused by high temperature environment to people. Suitable for buildings, iron and steel foundries, brick factories, glass facilities, boiler rooms and so on.

Accuracy of the device

- Wind Speed Range: 0.7~30m/s(Accuracy:±5%Digit), Resolution:0.1m/s.
- Temperature Range: 0~50℃(Accuracy:±0.6℃).
- Humidity range: 0.1%~99.9%RH; Resolution:0.1%RH.
- The Anemometer weather station can accurately measure wind speed in 5 units: m/s, km/h, Ft/min, Knots, Mph. Wind temp in ℃/°F.

In/out function

It has Switchable IN/OUT function displays the WBGT value with or without direct sun exposure. Suitable for all indoor and outdoor scenes.

Product specification

Hazard level	WBGT
Caution	26.7~29.4℃ / (80~84.9°F)
Extreme caution	29.4~31℃ / (85~87.9°F)
Danger	31~32.2℃ / (88~89.9°F)
Extreme Danger	>32.2℃ / (>90°F)

unit	Range	Resolution	Accuracy
M/s	0~30	0.1	±5%
Ft/min	0~5860	19	
Knots	0~55	0.2	
Km/h	0~90	0.3	
Mph	0~65	0.2	
Temp.range		0~50℃	
Temp..resolution		0.1℃/℉	
Temp.accuracy		+/-0.6℃	
Humidity.range		0.1%~99.9%RH	
Humidity.resolution		0.1%RH	
Humidity accuracy		10.0%~90.0%@25℃: Typical 5%.Others 7%	
WBGT temp.range		0~50℃	
WBGT Alarm Range		20~50℃	
Stabilization time		15~25minutes typical	
Operation temp.		0~50℃	
Operation RH%		Humidity<80%	
Storage temp.		-20~50℃	
Storage RH%		Humidity<90%	
Dimension(mm)		208.33×52×40mm	
Weight		137.3g	

Displays and buttons

THIS heat stress meter anemometer is designed with large LCD display with backlight, which can quickly show the measurement, clearly and easy to read.

Figure 57: data Measuring device

C. **Environmental variable measured data by HOLDPEAK wind speed & heat stress WBGT meter inside the living room of both type of houses.**

February month Temperature data in ^{o}C				
Date	day Time	Traditional	Modern	External
February 12,2023	1:00	21.2	22.1	23.2
	4.00	18.2	20.4	27.5
	7:00	25.2	28.6	31.7
	9:00	26.1	28.9	30.8
	12:00	22.3	25.8	28.7
February 15,2023	1:00	19.0	21.2	22.7
	4.00	22.2	24.6	26.7
	7:00	24.4	26.2	28.1
	9:00	25.5	27.2	29.4
	12:00	20.1	21.2	25.2
February 18,2023	1:00	19.1	21.2	19.1
	4.00	21.3	22.5	24.7
	7:00	22.2	22.3	26.6
	9:00	21.4	24.7	27.5
	12:00	23.4	25.0	25.7
February 21,2023	1:00	21.0	31.1	29.4
	4.00	22.7	32.8	35.1
	7:00	22.4	31.1	34.7
	9:00	22.1	31.7	34.8
	12:00	22.1	30.4	33.3
February 24,2023	1:00	22.4	29.5	29.7
	4.00	23.2	28.2	29.7
	7:00	24.1	29.2	35.8
	9:00	22.1	32.2	35.4
	12:00	19.2	30.4	33.7
February 28,2023	1:00	19.1	30.4	33.6
	4.00	22.4	31.7	31.9
	7:00	24.4	32.1	32.1
	9:00	24.2	34.1	35.7
	12:00	23.4	29.2	30.5

March Month Temperature data in ^{o}C				
Date	Time	Traditional	Modern	External
01,2023	1:00	24.1	23.7	25.6
	4.00	23.4	28.7	29.7
	7:00	29.1	24.2	34.4
	9:00	20.5	36.3	29.2
	12:00	20.4	25.2	28.4
04,2023	1:00	22.2	21.1	24.1
	4.00	28.2	26.1	28.2
	7:00	25.3	27.3	31.4
	9:00	24.6	27.4	29.8
	12:00	24.4	26.3	25.4
7,2023	1:00	18.4	23.5	23.7
	4.00	24.2	36.3	37.7
	7:00	25.5	32.7	35.8
	9:00	23.3	26.7	28.7
	12:00	22.3	25.4	28.4
10,2023	1:00	21.1	23.2	23.4
	4.00	24.2	24.4	34.8
	7:00	25.2	34.6	36.6
	9:00	25.4	36.4	36.6
	12:00	24.5	24.7	25.8
13,2023	1:00	21.5	24.3	27.2
	4.00	22.2	26.4	27.2
	7:00	26.4	34.3	36.2
	9:00	26.5	35.7	36.5
	12:00	24.5	26.8	30.1
16,2023	1:00	19.5	19.1	21.1
	4.00	21.3	22.5	22.7
	7:00	27.4	32.6	34.5
	9:00	27.2	34.1	34.5
	12:00	18.4	20.3	21.2
19,2023	1:00	21.8	22.2	22.4
	4.00	23.4	25.1	27 .3
	7:00	26.4	36.2	37.7
	9:00	26.2	36.5	36.3
	12:00	25.2	25.3	27.3
22,2023	1:00	22.4	23.4	23.5
	4.00	24.4	24.5	25.3

	7:00	26.2	35.4	35.6
	9:00	25.4	35.5	29.3
	12:00	25.2	27.3	27.4
25,2023	1:00	22.3	22.3	22.5
	4.00	24.4	35.5	27.3
	7:00	25.4	36.5	29.6
	9:00	25.3	27.4	30.5
	12:00	23.3	24.4	25.3
28,2023	1:00	20.2	19.3	20.8
	4.00	25.5	25.8	26.6
	7:00	25.2	36.3	29.5
	9:00	25.2	36.5	27.7
	12:00	24.4	24.4	25.5
31,2023	1:00	18.5	21.8	21.9
	4.00	19.6	23.3	23.8
	7:00	27.2	33.4	33.4
	9:00	27.4	33.3	36.5
	12:00	18.8	24.4	26.4

April Month Temperature data in ^{o}C

Date	Time	Traditional	Modern	External
April 03,2023	1:00	18.5	21.3	21.4
	4.00	19.2	21.2	24.5
	7:00	23.1	28.2	37.4
	9:00	23.4	28.6	37.7
	12:00	23.4	22.3	30.5
April 06,2023	1:00	19.1	23.3	23.2
	4.00	20.7	25.3	27.6
	7:00	25.3	28.2	31.8
	9:00	25.2	29.7	36.8
	12:00	23.5	27.4	27.4
April 09,2023	1:00	20.2	24.6	24.6
	4.00	20.2	26.3	27.5
	7:00	24.2	28.4	30.3
	9:00	25.4	29.3	33.4
	12:00	24.2	26.5	28.8
April 12,2023	1:00	20.2	23.2	26.3
	4.00	22.4	26.4	32.3

	7:00	24.5	30.5	34.6
	9:00	27.4	30.5	36.6
	12:00	27.7	27.5	29.6
April 15,2023	1:00	20.2	22.4	23.3
	4.00	19.2	27.1	29.2
	7:00	19.4	32.9	37.8
	9:00	20.3	34.3	38.4
	12:00	21.2	29.2	27.2
April 18,2023	1:00	22.1	23.5	28.4
	4.00	22.4	29.3	27.4
	7:00	26.2	34.7	34.8
	9:00	25.4	36.3	36.7
	12:00	25.7	31.5	27.4
April 21,2023	1:00	22.4	22.5	26.4
	4.00	22.3	25.4	27.5
	7:00	22.3	32.4	33.5
	9:00	23.2	35.4	35.3
	12:00	20.3	30.2	27.4
April 24,2023	1:00	20.2	24.4	24.3
	4.00	22.1	29.0	29.2
	7:00	28.8	32.4	32.9
	9:00	28.7	34.6	35.8
	12:00	26.0	32.2	29.7
April 27,2023	1:00	20.1	22.4	22.5
	4.00	21.4	28.5	32.7
	7:00	26.5	33.4	35.3
	9:00	25.5	33.5	34.6
	12:00	25.4	28.5	29.3
April 30,2023	1:00	20.2	26.4	33.7
	4.00	20.2	29.7	36.8
	7:00	23.7	36.9	37.8
	9:00	24.4	38.3	29.4
	12:00	23.1	26.0	26.2

May Month average Temperature data in ^{o}C				
Date	Time	Traditional	Modern	External
May 02,2023	1:00	22.0	26.6	32.2
	4.00	22.1	27.4	33.1

	7:00	24.1	29.2	35.3
	9:00	25.5	30.8	36.4
	12:00	23.1	30.1	32.5
May 05,2023	1:00	21.1	24.6	31.5
	4.00	23.4	26.4	34.6
	7:00	25.3	28.2	37.3
	9:00	26.1	31.8	37.9
	12:00	24.0	28.1	31.8
May 08,2023	1:00	21.3	24.2	30.5
	4.00	23.1	26.6	34.2
	7:00	26.2	30.3	36.4
	9:00	26.5	31.8	38.4
	12:00	22.4	30.2	33.5
May 11,2023	1:00	21.0	24.6	30.1
	4.00	22.6	28.3	33.2
	7:00	26.6	31.2	37.3
	9:00	26.9	31.7	39.4
	12:00	22.3	29.2	31.5
May 14,2023	1:00	20.0	23.3	30.1
	4.00	22.1	26.1	34.1
	7:00	24.8	29.2	36.5
	9:00	26.2	31.6	38.9
	12:00	25.2	29.7	32.0
May 17,2023	1:00	22.0	24.2	30.5
	4.00	23.1	26.3	34.3
	7:00	25.5	32.5	38.1
	9:00	26.8	33.2	38.9
	12:00	24.1	28.5	29.9
May 20,2023	1:00	21.3	23.5	32.1
	4.00	23.2	27.5	35.3
	7:00	26.3	31.5	36.5
	9:00	26.5	31.9	38.6
	12:00	24.1	27.6	30.0
May 23,2023	1:00	22.1	25.4	30.0
	4.00	23.1	26.3	37.2
	7:00	26.4	31.3	39.5
	9:00	26.6	34.6	42.1
	12:00	24.3	31.2	36.5
May 26,2023	1:00	21.3	24.7	31.0
	4.00	22.6	26.6	38.2

	7:00	26.1	34.3	40.5
	9:00	26.8	37.8	42.2
	12:00	23.8	28.2	36.0
May 29,2023	1:00	23.2	27.1	32.5
	4.00	24.6	27.8	40.2
	7:00	26.7	33.3	41.4
	9:00	26.9	35.4	42.0
	12:00	24.1	31.7	34.3

HUMIDITY

February month Humidity data				
Date	Day Time	Traditional	Modern	External
February 12,2023	1:00	40	48	23
	4.00	35	42	20
	7:00	28	72	19
	9:00	21	65	20
	12:00	20	45	23
February 15,2023	1:00	45	65	25
	4.00	45	58	20
	7:00	42	53	19
	9:00	38	58	18
	12:00	43	62	24
February 18,2023	1:00	45	70	19
	4.00	43	66	18
	7:00	47	67	17
	9:00	45	69	17
	12:00	46	60	18
February 21,2023	1:00	57	65	17
	4.00	41	64	16
	7:00	42	62	15
	9:00	44	66	15
	12:00	46	52	17
February 24,2023	1:00	52	68	28
	4.00	42	60	25
	7:00	40	58	20
	9:00	38	48	21
	12:00	35	38	26
	1:00	44	62	45

February 28,2023	4.00	46	63	45
	7:00	50	53	42
	9:00	51	52	43
	12:00	46	64	43

march month Humidity data %				
Date	Day Time	Traditional	Modern	External
March 01,2023	1:00	40	45	30
	4.00	38	40	23
	7:00	39	40	14
	9:00	39	40	18
	12:00	38	44	28
March 04,2023	1:00	51	50	38
	4.00	40	48	27
	7:00	47	46	26
	9:00	50	44	29
	12:00	53	42	35
March 7,2023	1:00	39	47	30
	4.00	48	36	25
	7:00	38	38	23
	9:00	43	37	20
	12:00	51	44	28
March 10,2023	1:00	47	69	29
	4.00	36	61	15
	7:00	47	72	26
	9:00	38	68	16
	12:00	44	57	16
March 13,2023	1:00	55	64	45
	4.00	53	36	28
	7:00	62	47	20
	9:00	64	62	19
	12:00	55	55	68
March 16,2023	1:00	65	79	75
	4.00	67	65	45
	7:00	66	64	40
	9:00	44	48	38
	12:00	59	58	40
March 19,2023	1:00	63	69	71
	4.00	64	66	51

	7:00	46	53	38
	9:00	47	68	30
	12:00	50	48	40
March 22,2023	1:00	40	63	48
	4.00	41	51	38
	7:00	28	52	28
	9:00	24	26	25
	12:00	34	33	38
March 25,2023	1:00	45	58	58
	4.00	46	68	38
	7:00	60	58	30
	9:00	55	35	28
	12:00	68	66	41
March 28,2023	1:00	49	54	78
	4.00	54	52	46
	7:00	68	66	42
	9:00	69	44	32
	12:00	72	71	51
March 31,2023	1:00	58	62	61
	4.00	64	51	48
	7:00	67	58	39
	9:00	58	25	33
	12:00	70	72	31

April month Humidity data %				
Date	Day Time	Traditional	Modern	External
April 03,2023	1:00	67	68	61
	4.00	48	50	52
	7:00	65	45	40
	9:00	42	36	37
	12:00	68	50	52
April 06,2023	1:00	65	60	67
	4.00	58	53	58
	7:00	56	46	41
	9:00	38	37	38
	12:00	48	54	52
April 09,2023	1:00	46	66	65

	4.00	55	57	58
	7:00	56	65	48
	9:00	51	68	42
	12:00	56	64	48
April 12,2023	1:00	58	75	76
	4.00	75	73	65
	7:00	61	58	50
	9:00	57	45	42
	12:00	48	61	61
April 15,2023	1:00	58	60	78
	4.00	62	63	67
	7:00	48	66	55
	9:00	48	58	48
	12:00	60	65	61
April 18,2023	1:00	59	78	83
	4.00	58	62	63
	7:00	45	50	53
	9:00	48	48	48
	12:00	53	58	63
April 21,2023	1:00	50	66	78
	4.00	41	63	63
	7:00	41	56	53
	9:00	43	48	48
	12:00	55	68	63
April 24,2023	1:00	50	67	78
	4.00	43	66	63
	7:00	43	56	53
	9:00	45	51	48
	12:00	56	68	60
April 27,2023	1:00	50	69	78
	4.00	43	65	77
	7:00	43	56	58
	9:00	42	56	50
	12:00	55	68	62
April 30,2023	1:00	52	77	78
	4.00	41	63	75
	7:00	41	63	58
	9:00	45	53	53
	12:00	56	68	71

may month average Humidity data %				
Date	Day Time	Traditional	Modern	External
May 02,2023	1:00	35	39	45
	4.00	35	43	43
	7:00	34	40	40
	9:00	34	40	39
	12:00	31	43	47
May 05,2023	1:00	35	38	46
	4.00	36	43	43
	7:00	37	42	41
	9:00	38	41	38
	12:00	39	42	43
May 08,2023	1:00	36	37	42
	4.00	37	39	44
	7:00	39	40	41
	9:00	38	40	40
	12:00	40	41	44
May 11,2023	1:00	37	38	44
	4.00	38	43	42
	7:00	38	41	40
	9:00	37	42	39
	12:00	36	44	44
May 14,2023	1:00	38	40	43
	4.00	38	40	43
	7:00	39	41	40
	9:00	39	41	38
	12:00	40	42	45
May 17,2023	1:00	37	40	43
	4.00	39	41	42
	7:00	39	42	41
	9:00	39	41	37
	12:00	36	41	43
May 20,2023	1:00	37	41	43
	4.00	39	41	42
	7:00	39	40	41
	9:00	38	40	38
	12:00	38	41	41
May 23,2023	1:00	39	38	42

	4.00	40	41	42
	7:00	40	40	41
	9:00	39	41	41
	12:00	42	41	43
May 26,2023	1:00	37	40	40
	4.00	39	41	41
	7:00	39	40	42
	9:00	39	41	32
	12:00	40	41	41
May 29,2023	1:00	39	39	41
	4.00	37	42	41
	7:00	38	40	39
	9:00	38	40	38
	12:00	40	41	40

Wind velocity

February month wind velocity data in m/s				
Date	Day Time	Traditional	Modern	External
February 12,2023	1:00	0.10	0.00	1.97
	4.00	0.26	0.41	1.80
	7:00	0.36	0.00	2.20
	9:00	0.23	0.55	1.75
	12:00	0.01	0.52	1.73
February 15,2023	1:00	0.58	0.01	0.45
	4.00	0.22	0.10	2.26
	7:00	0.10	0.00	0.87
	9:00	0.26	0.41	1.80
	12:00	0.20	0.00	2.00
February 18,2023	1:00	0.08	0.00	1.78
	4.00	0.00	0.00	2.67
	7:00	0.27	0.28	1.55
	9:00	0.45	0.47	2.20
	12:00	0.38	0.33	1.46
February 21,2023	1:00	0.11	0.00	1.80
	4.00	0.14	0.00	0.90
	7:00	0.23	0.28	0.70
	9:00	0.01	0.47	0.75
	12:00	0.23	0.33	1.75
February 24,2023	1:00	0.09	0.43	2.93
	4.00	0.04	0.00	1.30

	7:00	0.10	0.22	1.40
	9:00	0.24	0.13	2.21
	12:00	0.32	0.57	1.89
February 28,2023	1:00	0.26	0.44	1.90
	4.00	0.18	0.53	2.98
	7:00	0.10	0.30	1.80
	9:00	0.11	0.40	2.57
	12:00	0.14	0.20	1.48

march month wind velocity data in m/s				
Date	Day Time	Traditional	Modern	External
March 01,2023	1:00	0.18	0.40	1.41
	4.00	0.14	0.41	1.60
	7:00	0.13	0.32	2.10
	9:00	0.23	0.65	1.55
	12:00	0.21	0.72	1.73
March 04,2023	1:00	0.58	0.21	0.55
	4.00	0.22	0.14	2.36
	7:00	0.10	0.10	1.68
	9:00	0.13	0.10	2.47
	12:00	0.10	0.28	1.35
March 7,2023	1:00	0.27	0.47	2.24
	4.00	0.25	0.33	1.56
	7:00	0.38	0.43	1.20
	9:00	0.11	0.20	0.80
	12:00	0.22	0.22	0.80
March 10,2023	1:00	0.30	0.13	0.35
	4.00	0.10	0.57	1.64
	7:00	0.21	0.54	2.54
	9:00	0.14	0.53	1.34
	12:00	0.13	0.31	1.32
March 13,2023	1:00	0.11	0.42	2.13
	4.00	0.13	0.21	2.75
	7:00	0.29	0.12	1.47
	9:00	0.14	0.51	2.48
	12:00	0.12	0.48	2.48
March 16,2023	1:00	0.15	0.13	1.45
	4.00	0.26	0.20	2.57
	7:00	0.27	0.25	1.42

	9:00	0.16	0.13	0.76
	12:00	0.10	0.12	1.20
March 19,2023	1:00	0.30	0.40	1.25
	4.00	0.21	0.25	1.35
	7:00	0.18	0.30	2.65
	9:00	0.30	0.70	0.56
	12:00	0.12	0.50	2.52
March 22,2023	1:00	0.22	0.01	1.81
	4.00	0.10	0.21	0.88
	7:00	0.26	0.41	1.71
	9:00	0.26	0.00	2.10
	12:00	0.13	0.15	1.45
March 25,2023	1:00	0.31	0.62	1.46
	4.00	0.21	0.41	0.56
	7:00	0.22	0.10	2.67
	9:00	0.20	0.10	1.38
	12:00	0.10	0.12	2.84
March 28,2023	1:00	0.10	0.18	1.25
	4.00	0.36	0.17	2.35
	7:00	0.35	0.23	1.46
	9:00	0.28	0.43	1.30
	12:00	0.18	0.00	0.67
March 31,2023	1:00	0.12	0.22	0.71
	4.00	0.10	0.23	0.86
	7:00	0.10	0.37	1.56
	9:00	0.12	0.35	2.43
	12:00	0.12	0.33	1.28

April month average wind velocity data in m/s				
Date	day Time	Traditional	Modern	External
April 03,2023	1:00	0.16	0.36	1.51
	4.00	0.20	0.52	1.89
	7:00	0.19	0.42	2.45
	9:00	0.32	0.72	2.21
	12:00	0.28	0.79	2.60
April 06,2023	1:00	0.67	0.29	0.63
	4.00	0.28	0.21	3.10
	7:00	0.23	0.2	1.30
	9:00	0.16	0.17	2.50
	12:00	0.16	1.00	2.90
April 09,2023	1:00	0.31	1.10	2.31
	4.00	0.31	0.39	1.62
	7:00	0.46	0.56	1.26
	9:00	0.17	0.27	1.10
	12:00	0.26	0.27	1.50
April 12,2023	1:00	0.30	0.13	0.35
	4.00	0.19	0.57	1.64
	7:00	0.21	0.54	1.54
	9:00	0.14	0.53	1.34
	12:00	0.13	0.31	1.32
April 15,2023	1:00	0.11	0.42	2.13
	4.00	0.13	0.21	2.05
	7:00	0.29	0.12	1.48
	9:00	0.16	0.56	1.95
	12:00	1.16	1.26	2.48
April 18,2023	1:00	0.17	0.16	1.45
	4.00	0.28	0.23	1.89
	7:00	0.30	0.30	1.45
	9:00	0.18	0.15	1.22
	12:00	0.12	0.18	1.26
April 21,2023	1:00	0.28	0.38	1.27
	4.00	0.19	0.23	1.40
	7:00	0.17	0.33	2.55
	9:00	0.35	0.65	1.80
	12:00	0.13	0.50	2.48
April 24,2023	1:00	0.23	0.21	1.79

	4.00	0.19	0.26	0.89
	7:00	0.26	0.43	1.78
	9:00	0.23	0.17	2.11
	12:00	0.20	0.18	2.30
April 27,2023	1:00	0.31	0.62	1.46
	4.00	0.23	0.41	0.45
	7:00	0.23	0.16	2.67
	9:00	0.23	0.18	1.39
	12:00	0.30	0.19	2.84
April 30,2023	1:00	0.10	0.27	1.45
	4.00	0.36	0.23	2.35
	7:00	0.35	0.23	1.26
	9:00	0.36	0.18	1.36
	12:00	0.38	0.28	1.80

may month average wind velocity data in m/s				
Date	day Time	Traditional	Modern	External
May 02,2023	1:00	0.15	0.30	1.78
	4.00	0.21	0.31	1.56
	7:00	0.21	0.32	1.89
	9:00	0.20	0.41	2.20
	12:00	0.25	0.61	2.30
May 05,2023	1:00	0.27	0.29	1.57
	4.00	0.28	0.30	1.65
	7:00	0.23	0.33	1.60
	9:00	0.21	0.35	1.80
	12:00	0.21	0.42	2.41
May 08,2023	1:00	0.21	0.23	1.76
	4.00	0.21	0.22	1.58
	7:00	0.23	0.22	1.56
	9:00	0.20	0.23	2.22
	12:00	0.22	0.41	2.12
May 11,2023	1:00	0.20	0.21	1.59
	4.00	0.21	0.30	1.49
	7:00	0.21	0.30	1.79
	9:00	0.14	0.32	2.00
	12:00	0.22	0.43	2.00

May 14,2023	1:00	0.21	0.28	1.68
	4.00	0.13	0.29	1.76
	7:00	0.21	0.30	1.77
	9:00	0.22	0.31	2.10
	12:00	0.48	0.52	2.00
May 17,2023	1:00	0.17	0.30	1.88
	4.00	0.28	0.29	1.58
	7:00	0.30	0.31	1.88
	9:00	0.18	0.32	1.98
	12:00	0.22	0.33	1.89
May 20,2023	1:00	0.18	0.32	1.88
	4.00	0.19	0.33	1.78
	7:00	0.19	0.34	1.89
	9:00	0.25	0.34	1.89
	12:00	0.22	0.55	1.78
May 23,2023	1:00	0.22	0.21	1.68
	4.00	0.20	0.21	1.55
	7:00	0.24	0.32	1.68
	9:00	0.23	0.32	1.67
	12:00	0.21	0.41	1.89
May 26,2023	1:00	0.31	0.29	1.45
	4.00	0.24	0.29	1.44
	7:00	0.24	0.30	1.35
	9:00	0.23	0.31	1.33
	12:00	0.31	0.33	1.53
May 29,2023	1:00	0.22	0.22	1.30
	4.00	0.22	0.21	1.20
	7:00	0.15	0.22	1.20
	9:00	0.16	0.23	1.20
	12:00	0.18	0.33	1.30