# The Effect of Floor Height on Indoor Thermal Comfort in Case of Municipal Residential Buildings: Case of Hawassa City, Ethiopia

Tamirat Takele

A Research Submitted to the Department of Architecture,

College of Civil Engineering and
Architecture

Office of Graduate Studies

Adama Science and Technology
University

January, 2025

Adama, Ethiopia

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# Declaration

Declaration I declare that this thesis entitled "The Effect of Floor Height on Indoor Thermal Comfort in Case of Municipal Residential Buildings: The case of Hawassa City, Ethiopia"is my own work and has not been submitted to any university for similar purpose. The references used in this thesis are duly recognized by proper citations.

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Name of student Signature Date

## Approval of Board of Reviewers

I, the advisor of the thesis entitled ’The Effect of Floor Height on Indoor Thermal Comfort in Case of Municipal Residential Buildings: The case of Hawassa City, Ethiopia” and developed by Tamirat Takele Adie, hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis. Belay Zeleke (Ph.D.)

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Major Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Tamirat Takele, have read and evaluated the thesis ’The Effect of Floor Height on Indoor Thermal Comfort in Case of Municipal Residential Buildings: The Case of Hawassa City, Ethiopia” and examined the candidate during open defence. This certifies that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Environmental Architecture.

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

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## List of Abbreviations

| | |
|---|---|
| PMV | Predictive mean vote |
| PPD | Predicted percentage of dissatisfied |
| SPSS | Statistical Package for the Social Sciences |
| IAQ | Indoor air Quality |
| CFD | Computational fluid dynamics |
| UFAD | Under-floor Air Distribution |
| CBAD | Ceiling-based Air distribution |
| THI | Temperature Humidity Index |

# Abstract

*This study investigates the impact of floor height on indoor thermal comfort in municipal residential buildings in Hawassa, Ethiopia. The research underscores the critical role of architectural design—specifically, floor height—in influencing thermal performance, energy efficiency, and occupant well-being. A mixed-methods approach was employed, incorporating Design Builder simulations, occupant surveys, field measurements, and behavioral observations through hidden cameras to analyze these effects. Findings reveal that lower floor heights (below 2.5 meters) contribute to increased thermal discomfort due to poor ventilation, heat accumulation, and a heightened sense of confinement. In contrast, higher floor heights (above 2.65 meters) improve natural ventilation, reduce heat retention, and enhance perceptions of spatial comfort. Hidden camera footage further highlights behavioral adaptations, such as increased use of cooling devices and residents seeking outdoor shaded areas to mitigate discomfort. Additionally, government-constructed residential buildings often prioritize cost efficiency at the expense of thermal comfort, exacerbating these challenges. Based on the findings, the study recommends a minimum floor height of 2.65 meters for new residential developments, alongside passive cooling strategies and retrofitting solutions to enhance thermal conditions in existing structures. These insights provide valuable guidance for architects, urban planners, and policymakers seeking to design sustainable, thermally comfortable, and psychologically supportive residential environments in Ethiopia and other tropical regions.*

**Keywords: Thermal Comfort, Floor Height, Indoor Environment, Design Builder, Hidden Camera, THI, PMV/PPD, Hawassa City.**

# CHAPTER ONE

# 1. INTRODUCTION

## 1.1. Background of the study

The mental state that reflects satisfaction with the environment is known as Thermal comfort. Researchers examine Thermal comfort levels in a variety of settings. Research indicates that a few elements can alter people's comfort in a building. Understanding these elements may aid designers in creating comfortable environments. One of the elements that impact thermal comfort is the building Floor height. Thermal comfort is a critical factor in building design, particularly in hot climates. Research indicates that floor height plays a significant role in influencing indoor temperature, air circulation, and occupant well-being. According to Nicol et al. (2017), higher ceiling heights allow better air stratification, reducing heat buildup and improving overall thermal conditions. In contrast, low ceiling heights tend to trap heat, increasing reliance on mechanical cooling (Nicol & Roaf, 2017). Despite having different characters and personalities, people exhibit the same emotions in similar Thermal comfort situations, according to research on the commonalities betw een people's comfort-related feelings. When the heat condition is taken into account, this is much more obvious (Mofrad, n.d.).

Early humans first used campfires 1.5 million years ago, which marks the beginning of indoor environments. The campfire was eventually brought inside huts and caves. The invention of air conditioning, which had a significant influence on the indoor environment, also occurred at the start of the 20th century. The Stock Exchange building in New York, USA, designed the cooling system that used three ammonia absorption chillers, with a cooling capacity of 1,582 kW, is likely the first structure with cooling (without using ice). Willis Haviland carrier (The father of modern air conditioning) did not, however, become the most well-known HVAC engineer (Centnerova, 2018).

Thermal comfort has evolved as a critical aspect of indoor environments, particularly in hot climates where ventilation and heat management play a significant role. Several studies have highlighted key architectural factors that influence indoor comfort, among which floor height remains an understudied variable in the Ethiopian housing sector (Hailu et al., 2021).

90% of the average American's time is spent indoors (Fisk & Rosenfeld, 1997), and a large portion of that time is spent at work in commercial office buildings. A growing body of research demonstrates that happy residents are more alert, have more energy, and take fewer sick days, all of which translate to happier, more productive workers. Despite the fact that comfort is unquestionably vital, the traditional air temperature-centric design strategy has been ineffective and expensive in buildings for decades. Wall thermostat readout of 72 degrees does not even begin to tell the whole story, as anyone who has ever sat next to a single pane window in the winter knows. The comfort of a person is influenced by a wide range of additional factors, including radiant temperature and air speed. A design strategy can become more targeted and concentrated the building energy where it had the biggest impact on occupant comfort by paying close attention to every variable. This helped it move away from a one-size-fits-all approach and toward directly addressing the needs of each individual occupant (Rawal et al., 2019).

The conditions for comfort were displayed on a psychometric diagram in the 1923 article "Determination of the comfort zone" (Houghten & Yaglou) from the ASHRAE Journal. They made use of the "Effective Temperature" (ET) index, which was widely used over the ensuing 50 years. The dry bulb temperature (DBT) of a uniform environment with relative air humidity of 50% is referred to as ET (Houghten, F.C., & Yaglou, C. P. 1923). This environment would have the same heat exchange processes of radiation, convection, and evaporation as the environment under consideration. In 1936, Adolf P. Gagge (1908-1993) unveiled his "Two-node model." Two energy balan ce equations—one for the core node and one for the skin node—are used to calculate the thermal response. This model (sometimes referred to as the Pierce model) makes the assumption that the total heat exchange between people and their environment through metabolism, activity, evaporation, radiation, and conduction is zero. Gagge developed the model with his colleagues at the JB Pierce Laboratories of Yale University. Gagge used his model to apply the first law of thermodynamics (energy conservation) to people and their surroundings. Later, this model was expanded (after World War II) (Centnerova, 2018). The thermal behavior of the environment has been the subject of numerous intricate studies in a variety of climates. According to Hashimoto, K., & Yoneda, H. (2009), the height of the room has a significant impact on thermal comfort. One of the core components of indoor environmental quality is thermal comfort, which has a direct impact on both occupant satisfaction and building energy consumption. Using CFD software to monitor buildings, Hashimoto and Yoneda (2009) studied the variation of floor heights and their effects on thermal load and ventilation and elaborated the findings. There are some design elements that have an impact on how much energy is used in buildings, including the thickness of insulation, the materials used, the use of passive and active solar design elements, shadings, the size of opening areas, colors, the reflectivity of the materials, and others. The goal of this study is to determine how floor height affects heating energy usage, which can both increase thermal comfort and lower heating energy costs. Due to unique regional characteristics like climates and building types, these results vary greatly (whether be residential or non-residential).The investigational classroom was designed using Neufert standards. The secondary school special courses classroom is estimated to be 40–45 m2 (The Area of a classroom specifically designed for special courses In a secondary school and the size range represents the approximate floor space of the classroom as per the design standards mentioned in the study, such as Neufert standards) (Ghafari & Heidari, 2018).

According to ANSI/ASHRAE Standard 55(Schiavon et al., 2014), thermal comfort is a subjectively assessed mental state that shows satisfaction with the thermal environment. The heat engine in the human body is powered by food. The human body release additional heat into the environment in order to continue functioning. Both the hot and cold conditions are uncomfortable. Maintaining this level of thermal comfort for people inside of buildings or other enclosures is one of the main goals of HVAC (heating, ventilation, and air conditioning) design engineers (Sansaniwal et al., 2022).

Investigational studies conducted over a long period of time in different countries defined a number of thermal comfort levels(Mishra & Ramgopal, 2013). The studies, however, by Meshal AlOtaibi and Nikravan Mofrad Mojgan, which were more pertinent to my field of study, are titled "The Effect of Ceiling Height on Thermal Comfort for Ceiling-Based Air Distribution Systems Vs Underfloor Air Distribution Systems in an Office Space(AlOtaibi, 2018)" and "The Impact of Floor-to-Ceiling Height on Human Comfort (Nikravan Mofrad, 2014)," respectively.

According to (AlOtaibi, 2018), the study focused on the contribution of CBAD and UFAD systems to improve the thermal comfort of the occupants. The primary data used in this study is the thermal comfort ratings of the rooms that were chosen for the investigation using only simulation software. This was done to analyze how the rooms are air-conditioned using CBAD and UFAD systems, and only the FloVent simulation program was used to move air and heat in the office rooms (Alotaibi, 2018).

According to (Nikravan Mofrad, 2014), the study examines how a residential unit's floor to ceiling height affects people's comfort levels. In order to confirm the existence of the desired comfort conditions, only the comfort measuring device is used. The unit also serves to monitor consistency of internal conditions during changes in height. Comfort levels stay within a predetermined range. The tests were conducted in the same location, in a lab with a height-adjustable roof. The Simulation software were not taken as a data measuring tool and not yet proposed model (Nikravan Mofrad, 2014).

This research was carried out to fill any research gaps left by earlier studies on the thermal comfort issue as it is related to low floor heights and residential housing in Hawassa, Ethiopia. However, conducting this research helped for better understanding of how the independent variables; floor height, Temperature, and Humidity conditions affect dependent variable; indoor thermal comfort. Determining how the Floor height condition was used to address some of the problems that had a negative impact on human life while also promoting indoor thermal comfort, human health, and well-being is the main aim of the study.

It is clear that people are the primary cause of indoor thermal comfort, despite the fact that they are shielded from the environment's hot climate, people ought to be aware of how the size of their homes' enclosures affect their health. According to the research, low floor height increases will lead to greater indoor thermal discomfort in Hawassa, Ethiopia, which has a tropical climate. To fill the research gap, research was done using questionnaires, portable instruments, and software techniques. The gap's general foundation is outlined in the gaps identified section; furthermore, floor height is not considered to have a direct impact on thermal comfort, and measurement and questionnaires are not used in the study's methods.
Motivation of he study; I have noted February 10 to March 05 is experienced overheated periods; this is also the hot and warm season of Hawassa where I was born and raised. Yet, the residents of the kebele houses in Hawassa continue to face the same complications in terms of thermal comfort. What is the advantage of floor height levels to satisfy the needs of inhabitants for human comfort, I have been wondering myself for a while. Because research starts with recognizing a problem, I took this opportunity to study this issue. Following that, this study recommended the ideal floor heights for thermally enjoyable residential homes for both owners

and the government to utilize as a guide when constructing a structure. The lack of participation from residents during the design development phase makes it difficult to improve the height condition while the government (kebele) has been constructing its own non economical housing. These therefore had an impact on the building's floor height, with lower floor heights deserving less expenditure.

## 1.2. Statement of the Problem

To determine the extent to which thermal variables affect human thermal comfort under particular climatic conditions, many nations conducted a number of thermal comfort studies. The majority of thermal comfort research was carried out in developed nations, In Ethiopia, limited research has explored the role of floor height in indoor thermal comfort, particularly in government-constructed housing. Studies by Yadeta et al. (2019) highlight that inadequate ventilation in low-cost housing exacerbates thermal discomfort, often leading to increased health risks such as heat stress and respiratory illnesses (Yadeta, Mekonnen, & Kumie, 2019). However in developing nations; the studies are still in the awareness-raising phase. There aren't any researches on thermal comfort that address climate change, and how it affects human health and well-being in the majority of developing nations, including Ethiopia. Citizens can identify setups that could make them thermally comfortable, happy, and productive indoors through studies of indoor thermal comfort in a variety of climate conditions (Yadeta et al., 2019).
From the Literature review, on most of the studies, thermal comfort is surveyed for different floor height experimentally. In the example of Ethiopia, the "numerical study on the effects of a floor height for displacement ventilation" was carried out to investigate the thermal effect of ceiling height for a small office space for a displacement ventilation system using computational fluid dynamics analysis (Hashimoto & Yoneda, 2009). It is challenging to use an experimental approach to investigate the effects of a ceiling height. Therefore, computational fluid dynamics is used to investigate the impact of a ceiling height. Thermal comfort in the test room is assessed according to ISO7730-1994 recommendations for the test room of a different ceiling height (Hashimoto & Yoneda, 2009).

Even though there have been numerous researches on thermal comfort recently, there are few researches on floor height as a factor of indoor thermal comfort of residential building, and the problem is still present in many regions of the world. In Ethiopia, there is a huge knowledge gap when it comes to residences and thermal comfort. I looked into the indoor thermal comfort of residential houses in Hawassa, Ethiopia, for my study. The purpose of my study was to examine the thermal comfort of residents of low-floor government buildings, where the issue of discomfort is obvious. In order to address the issue of discomfort for people in residential buildings, I described floor height as important factor to affect thermal comfort in my paper. Specifically my study has understood the dweller's perceptions of satisfaction and thermal comfort, as well as their satisfaction with the current floor height condition and outdoor temperature to know how much heat the floor height allowed. Evaluated floor height's effect on the thermal comfort of residential buildings was the study's overall objective. Laterally, research was done to demonstrate floor height level for the affordable thermal comfort to overcome the challenge of Africa, Ethiopia, Hawassa, Governmental residential building.

## 1.3. Research Objectives

Previous studies suggest that a minimum floor height of 2.65m significantly enhances natural ventilation and reduces indoor heat accumulation (Alfano et al., 2019). The current study aims to validate this finding within the context of Hawassa's municipal residential buildings.

### 1.3.1. General Objective

- To evaluate floor height's effects on the Indoor thermal comfort of residential buildings and to provides strategies and design solutions.

### 1.3.2. Specific objectives

- To assess the impact of Floor Height on indoor thermal conditions.
- To identify the Dwellers floor height perceptions, satisfaction and thermal comfort.
- To provide strategies and design solutions for planners and Stakeholders.
- To measure the outdoor temperature allowed by the floor height.

## 1.4. Research Questions

This study aims to address the following research questions.

- Research Question 1: How does floor height affect indoor thermal conditions?

- Research Question 2: What are the perceptions of dwellers regarding satisfaction and thermal comfort in low floor height conditions?
- Research Question 3: What strategies and Design solution can be implemented to improve dwellers' satisfaction with the current floor height condition?
- Research Question 4: What is the relationship between outdoor temperature and the heat transfer allowed by floor height?

## 1.5. Scope of the Study

This study examines the impact of floor height on indoor thermal comfort in municipal residential buildings in Hawassa City, Ethiopia, the capital of Sidama Region, covers 157.2 square kilometers in the Great Rift Valley, bordered by Lake Hawassa, Oromia Region, Wondogenet Woreda, and Shebedino Woreda.The focus is specifically on government-owned, low-floor residential units where thermal discomfort is a prevalent concern. Data was collected from selected residential units within a 6-kilometer radius of the city's municipal government housing, ensuring a targeted analysis of indoor thermal comfort under local climatic conditions. Hawassa experiences a tropical climate with an average annual temperature of 19.8°C and significant seasonal variations. Peak summer temperatures can exceed 30°C, making indoor thermal comfort a critical issue (Kassahun, 2020). The study utilized accessible tools such as questionnaires, portable thermal comfort measurement devices, and simulation software. Due to technological limitations, laboratory experiments involving adjustable floor heights were not conducted. The research is limited to exploring thermal comfort in low-floor residential spaces typical of government housing in Hawassa City.

## 1.6. Significance of the Study

This study addresses critical gaps in understanding the impact of floor height on indoor thermal comfort in residential buildings, with a focus on government-constructed low-cost housing in Hawassa, Ethiopia. Its significance lies in the following key areas:

1. Advancement of Architectural Design Standards:

Government-constructed housing in Ethiopia typically prioritizes cost efficiency over thermal comfort. Studies have shown that minor design modifications, such as increasing floor height, can significantly improve energy efficiency and occupant satisfaction without substantially raising construction costs (Mengistu & Tadesse, 2021).

The research provides empirical evidence to guide the design of thermally comfortable residential buildings in tropical climates. By recommending a minimum floor height of 2.65m, the study establishes a baseline for future housing projects, ensuring improved thermal performance and occupant satisfaction.

2. Policy Implications:

Insights from this study inform policymakers and urban planners on the importance of incorporating thermal comfort considerations into housing policies. These recommendations aim to enhance living conditions for low-income residents while promoting sustainability in construction practices.

3. Integration of Multi-Method Approaches:

This research uniquely combines field measurements, occupant surveys, and simulation tools to deliver a holistic understanding of thermal comfort. The comprehensive methodology bridges the gap between theoretical models and real-world applications, setting a precedent for future studies in similar contexts.

4. Enhancement of Resident Well-being:

By addressing thermal discomfort in government-constructed housing, the study highlights the psychological and physiological effects of low floor heights on occupants. Proposed solutions, such as retrofitting and passive cooling techniques, aim to improve quality of life for residents.

#### 1.6.1. Study Limitations

While this study offers valuable contributions, it is essential to acknowledge its limitations:

Technological Constraints: Due to limited resources, laboratory experiments with adjustable floor heights were not conducted. Instead, the study relied on simulation tools and field data.

Geographic Scope: The study focuses on municipal residential buildings in Hawassa, which may limit the generalizability of findings to other regions with different climatic or socioeconomic conditions.

Behavioral Analysis Limitations: Though hidden cameras were used to observe behavioral patterns, ethical considerations may have constrained a deeper exploration of occupant adaptation strategies.

### 1.6.2. Organization of the Thesis

This thesis is organized into five chapters:

Chapter One introduces the background, statement of the problem, objectives, and significance of the study.
Chapter Two presents a detailed review of theoretical, empirical, and methodological literature, identifying gaps and outlining the conceptual framework.
Chapter Three explains the research design, study area, sampling techniques, data collection tools, and analytical methods used.
Chapter Four discusses the results, including quantitative and qualitative analyses, and correlates them with design implications and policy recommendations.
Chapter Five concludes the study with key findings, practical recommendations, and suggestions for future research.

## 1.7. Operational Definitions

1. Thermal Comfort: A state of mind expressing satisfaction with the thermal environment, determined by factors such as air temperature, humidity, air velocity, and clothing insulation. Quantified using indices like Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD).
2. Floor Height: The vertical distance between the finished floor and the ceiling in a residential building. In this study, floor heights below 2.5m are classified as low, and heights above 2.65m are considered optimal for thermal comfort.
3. Indoor Thermal Comfort: The quality of the indoor environment ensuring that occupants feel neither too warm nor too cold, measured using air temperature, humidity, and air velocity data collected through thermal comfort devices and simulations.
4. Temperature Humidity Index (THI): An index combining air temperature and relative humidity to assess human discomfort. For this study:

$21 \leq THI \leq 24$: Comfortable

$24 < THI \leq 26$: Moderately uncomfortable

$THI > 26$: Uncomfortable

5. Design Builder Software: A simulation tool used to model the thermal performance of

residential buildings, providing insights into comfort indices like PMV and PPD.

6. Low-Floor-Height Residences: Government-constructed residential buildings in Hawassa City with floor heights less than 2.5m. These are studied for their thermal comfort implications.

7. Predicted Mean Vote (PMV): A numerical scale predicting the average thermal sensation of occupants on a scale from -3 (cold) to +3 (hot), based on environmental and behavioral parameters.

8. Predicted Percentage of Dissatisfied (PPD): An index predicting the percentage of people dissatisfied with the thermal environment. It complements PMV to evaluate thermal comfort comprehensively.

9. Hidden Camera:

A tool used in this study to observe behavioral patterns and occupant adaptation in low-floor-height residences, ensuring ethical considerations.

10. Low-cost housing:

Low-cost housing refers to government- or privately funded residential units designed for low-income households, typically characterized by simplified construction, minimal design features, and affordability-driven spatial constraints. In the Ethiopian context, these units generally have floor heights below 2.5 meters, affecting indoor thermal comfort (Mengistu & Tadesse, 2021).

# CHAPTER TWO

# 2. LITERATURE REVIEW

## 2.1. Theoretical reviews

### 2.1.1. Building Challenges in Hot Climates

"The primary purpose of a building is to shelter the occupants from unfavorable outdoor conditions such as heat, cold, wind and rain. Thus, the building should be designed to provide a desirable indoor climate." By worldwide concern on sources of energy and environmental issues, many factors should be considered altered at the design stage of buildings. Through those issues to be considered at is the suitability of the building design and materials in terms of climate properties. According to a large number of research works in order to indicate the climatic suitability of the building design and building materials, designers and/or architects have to be aware of the climatic characteristics of their working environment. Moreover, based on the related climatic elements, they will be able to categorize the building problems and apply or suggest their solutions to avoid them. This progress is defined as climatic design, having taken into consideration the climatic parameters of the area. In order to have successful climatic design in hot climates, which is the main focus in this study, first of all, the resources of the building problems have to be known in advance. Five factors have been commonly referenced in many studies

These resources include:

• High temperature,
• High solar radiation or high UV level,
• Moisture or high RH level,
• Excessive heat gain in summer
• Heat loss during winter

(Divsalar, 2010)

In regions with prolonged warm seasons, buildings with low ceiling heights are more likely to experience thermal discomfort due to inadequate airflow. Studies by Holopainen et al. (2018) emphasize that increasing ceiling height by even 0.3 meters can reduce indoor temperature by 1-2°C under natural ventilation conditions (Holopainen, 2018).

### 2.1.2. Thermal Comfort Issues in Hot Climates

Climate change adaptation in cities is now an important challenge for European cities, and is becoming part of urban policies. The urban heat island (UHI) is a phenomenon that further amplifies the negative effects of climate change. Densely built-up areas of development absorb and then radiate heat from the sun's rays, which, with the additional heat gained from anthropogenic activities, causes a local increase in temperature relative to neighboring undeveloped areas. This problem is being researched in many areas, and ways of mitigating this phenomenon are currently the most important challenge. Designing public spaces for the comfort of older people should combine spatial temporal distribution with functional needs. In the analyzed public space, the new compensatory plantings will have little impact on the advancement of thermal comfort due to inadequate, random species selection (small ornamental trees) and location, as confirmed in the article, "Effects of tree seasonal characteristics on thermal-visual perception and thermal comfort" (Przesmycka et al., 2022).

### 2.1.3. Fundamentals of Comfort

Latin defined comfort as assistance or a boost in power. In the last 200 years, the meaning of the word in English has evolved to mean "ease; freedom from pain or trouble; that which inserts to content." Comfort, as a notion pertaining to inhabited spaces, is an affective state, subjective and unique like hunger or fatigue (Mafarlane, 1958). The subject weighs a variety of factors to determine their level of comfort, and each person is their own expert (Gubbels, n.d.).

The standard air temperature-centric design strategy that has been employed in buildings for decades is unproductive, inefficient, and expensive, despite the fact that comfort is extremely essential to building occupants.

By concentrating on six factors that influence a person's comfort, a design plan can be made more focused and direct, shifting from a one-size-fits-all approach to specifically matching the demands of each particular passenger. Because it was a key component of a whole-systems, passive design that allowed us to cost-effectively achieve our lofty net-zero energy targets for the Innovation Center, RMI chose to adopt this novel approach to thermal comfort (Rawal et al., 2019).

### 2.1.4. Concept of Thermal Comfort

According to ANSI/ASHRAE Standard 55(Schiavon et al., 2014), thermal comfort is a mental state that indicates contentment with the thermal environment and is evaluated subjectively (Mofrad, n.d.) and (Ferrari & Zanotto, 2016). The heat engine in the human body is powered by food. The human body will release additional heat into the environment in order to continue functioning. Heat transport is directly impacted by temperature differences. While the body loses more heat to the environment in cold environments than it does in hot ones, the body does not release enough heat in hot conditions. Both the hot and cold conditions are uncomfortable. To keep people at this level of thermal comfort inside of buildings or other enclosures is one of the main goals of HVAC (heating, ventilation, and air conditioning) design engineers (Sansaniwal et al., 2022).

According to Hensen, "a state in which there are no driving impulses to correct the environment by the behavior" is what thermal comfort is. It is described as "the condition of the mind in which satisfaction is expressed with the thermal environment" by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). As a result, it will be impacted by individual, organizational, and social factors such as cultural differences, mood, and personality. According to the aforementioned definitions, comfort is a mental state rather than a physical one. Though it correctly emphasizes that the assessment of comfort is a cognitive process involving many inputs influenced by physical, physiological, psychological, and other factors, the definition of thermal comfort leaves unclear what is meant by "condition of mind" or "satisfaction" and other factors (Sansaniwal et al., 2022).

According to conventional wisdom, thermal sensation is an objective sensation, whereas thermal discomfort is treated as a subjective condition. Satisfaction with the thermal environment is a complicated subjective reaction to many interdependent and intangible factors. To put it another way, there really isn't an absolute standard for thermal comfort. In general, comfort occurs when skin moisture is low, body temperatures are maintained within specific ranges, and the physiological effort required to maintain those conditions is reduced. Comfort also depends on behavioral choices like changing one's behavior, posture, or location, adjusting the thermostat, opening a window, complaining, or vacating a space (Sansaniwal et al., 2022). The psychological state of thermal comfort denotes satisfaction with the Because it can be fatal for people if their core body temperatures increase to those of hyperthermia (above 37.5-38.3

°C; 99.5-100.9 °F) or hypothermia (below 35.0 °C; 95.0 °F), respectively, it is important that the thermal environment be comfortable. Buildings alter the surrounding environment and reduce the amount of energy the body must expend to maintain a normal body temperature, which is necessary for the smooth operation of all physiological processes in humans. Various countries have developed standards of practice for the thermal behavior of buildings based on these principles, allowing for the reduction of ceiling heights while influencing the temperature of the interior air and reducing the thermal inertia of the interior environment. For hot weather areas, like those in tropical countries, a reduction in ceiling height causes a slight increase in indoor temperature for the majority of the year. The temperature difference between the top and bottom layers of an interior environment can be as much as 4 °C, according to laboratory and mathematical model research. Another thing to keep in mind is the necessity of ventilation apertures in enclosed spaces because they serve as a mechanism for controlling air temperature and how hot it feels to people.

2.1.4.1. Key Variables Influencing Thermal Comfort

Extensive research by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and University of California Berkeley Center for the Built Environment (CBE) has found six variables that predict a person's thermal comfort.

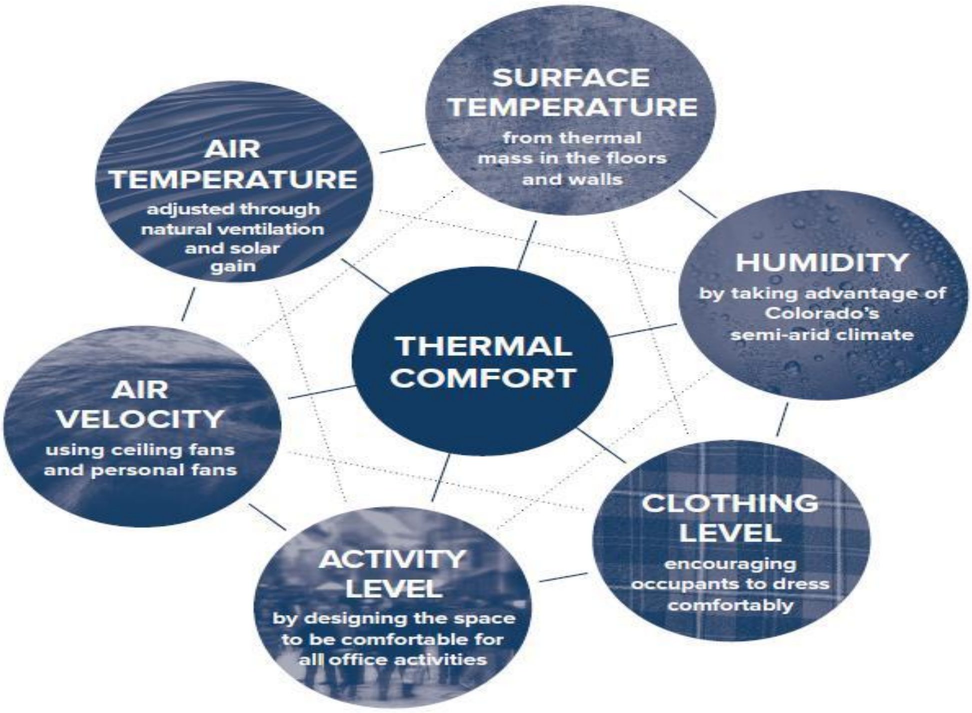



Figure 1: Six Variables in Thermal Comfort (Rawal et al., 2019).

2.1.4.2. Indoor vs. Outdoor Thermal Comfort

Stable state models may be effective for thermal comfort assessments inside, where people spend the majority of their time, however those models tend to overstate discomfort for the comparatively brief periods spent outside (often less than 1 hour). This difference is more pronounced in cool outdoor situations compared to warm ones. For instance, a person entering frigid winter outside conditions (Ta=Tmrt=0 °C, VP=5 hPa, v=1 m/s) while in thermal comfort (Tsk=33.5 °C, Tcore=37 °C) will take many hours to reach steady state, whereas a person entering hot conditions (Ta=30 °C, Tmrt=60 °C, VP=15 hPa, v Therefore, non-steady state models should be used, particularly for outdoor thermal comfort assessments in cold temperatures. A working group of the International Society of Biometeorology is now developing a new, globally standardized Universal Thermal Climate Index (UTCI), which will take into account this and other novel elements. Along with such physical/physiological measures, psychological aspects such different thermal expectations indoors and outdoors must also be taken into account. As a result, various methods are required to evaluate thermal comfort indoors versus outside (PeterHöppe (2002), n.d.).

2.1.4.3. Approaches to Indoor Thermal comfort

Both subjective and objective methods can be used to measure the indoor thermal comfort. The ASHRAE seven-point thermal sensational scale, thermal preference, standardized questioners, and interviews are examples of subjective approaches used to gauge inhabitants' emotions. This approach will be affected by how effectively the inhabitants adapt and by how they feel. The objective measurement approach is centered on measuring the indoor thermal comfort parameters of the indoor environment, such as air temperature, relative humidity, air velocity, and mean radiant temperature, and comparing these results to norms like the ASHRAE 55 and others. Both techniques were used in this study to assess the indoor thermal comfort of traditional homes and condominium homes (Hailu et al., 2021).

The rational or heat-balance approach and the adaptive approach are the two current approaches for defining thermal comfort, each with their own potentials and limitations. The works of Fanger are the best representations of the rational approach, which uses data from climate chamber studies to support its theory, while the adaptive approach uses data from field studies of people in building (Sansaniwal et al., 2022).

2.1.4.4. Heat-Balance Approach to Thermal Comfort

Warmth discomfort is strongly correlated with skin wittedness brought on by sweat secretion, while cold discomfort is strongly correlated with the mean skin temperature. Unwanted heating or cooling of a specific body part can also leave one unsatisfied if the body as a whole is too warm or cold (local discomfort) (Sansaniwal et al., 2022).

In order to expand the equation, 1296 participants' data were used. The equation that resulted defined thermal comfort as the discrepancy between the body's actual heat output in a particular thermal environment and the heat output necessary for optimal (i.e., neutral) comfort during a particular activity. The seven-point ASHRAE was related to thermal conditions using this expanded equation. (Ferrari & Zanotto, 2016), The "Predicted Mean Vote" (PMV) index was created using the thermal sensation scale. The "Predicted Percentage of Dissatisfied" (PPD) index was created after the PMV was taken into consideration. The evaluation of indoor thermal environments in buildings and the theory of thermal comfort have both benefited greatly from Fanger's PMV-PPD model on thermal comfort. It is widely used and accepted for designing and evaluating thermal comfort in the field (Sansaniwal et al., 2022).

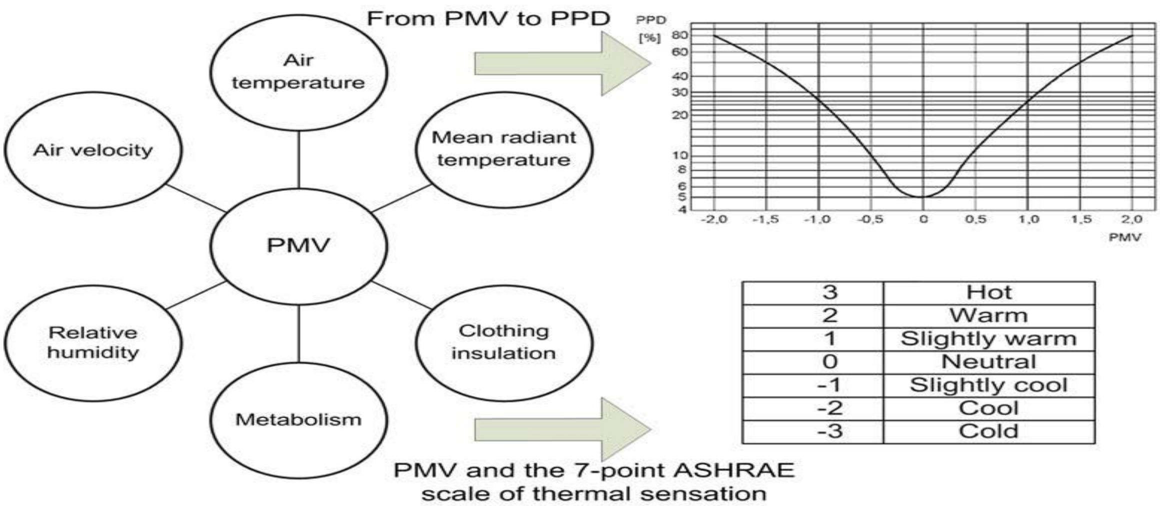



Figure 2 PMV, its input parameters, its relation to PPD, and its expression on the ASHRAE 7-point scale of thermal sensation(Basis, 2005).

2.1.4.5. Physiological Responses to Heat and Cold

In a thermal context, comfort is typically attained with the least amount of physiological adjustment to control heat flow, and discomfort is felt when the equilibrium between heat gain and loss is upset. Therefore, discomfort is linked to the sweating, shivering, and vasomotor adjustments made to offset thermal imbalance. Heat exchange occurs at the surface, and insulation, in the form of clothing, is used to change the heat exchange (Mafarlane, 1958).

2.1.4.6. Thermal Control Mechanisms

The brain stem, specifically the medulla and hypothalamus, is where human functions are organized to adjust to temperatures that are higher or lower than the comfort range. Finer than most nerve fibers, less than 6 microns in diameter, carry heat balance information from the skin to the hypothalamus. Heat-sensitive and cold-sensitive nerves have both been discovered. Human judgments of hot and cold exist. Since heat and cold are components of an energy continuum in physics, different parts of the temperature scale affect receptor responses, and those that are affected by low temperatures transmit signals that are perceived as cold, whereas those that are affected by temperatures above 70°F are perceived as warm. The heat sensitive nerves react to a rise in temperature over a broad temperature range, from approximately 60" to 100°F. Similar to this, the cold-sensitive nerves react to a drop in temperature, and each nerve has a response threshold. Some people respond to cooling from 100° to 90°, while others do so from 40° to 30° (Mafarlane, 1958).

2.1.4.7. Adaptive Thermal Comfort Model

The adaptive approach was developed from field studies with the aim of analyzing the actual acceptability of the thermal environment, which is highly dependent on the environment, occupant behavior, and expectations. Three categories—behavioral adaptation, physiological adaptation, and psychological adaptation—have been used to summarize the changes. Several authors have advocated field studies in place of laboratory experiments in recent years in order to obtain more accurate data regarding the actual workplace comfort and the pertinent (interacting) parameters (Makvandi et al., 2021).

As the subjects respond in their natural environments, dressed as they normally would, and acting naturally, field studies also enable the analysis of factors that cannot be replicated in chambers. The adaptive approach to thermal comfort studies' theoretical foundation is based on the subjectivity of thermal experience and the interpretations that result from a very complex interaction between the occupants and their environment. The literature contains a number of adaptive studies, including those on: I thermal comfort models and techniques; (ii) comparisons of traditional and modern living spaces; (iii) building performance assessment techniques; (iv) low energy consumption systems; (v) comparative studies of sex; and (vi) effects of indoor climates on thermal perceptions, (vii) thermal comfort in classrooms, (viii) adaptive algorithms, (ix) patients' thermal comfort in hospitals, and (x) thermal comfort in outdoor environments (Djongyang et al., 2010).

## 2.2. Empirical Studies

### 2.2.1. Impact of Floor Height on Thermal Comfort

#### 2.2.1.1. Perceptions of Floor Height in Architecture

##### 2.2.1.1.1. Architectural design behavior

People in materially developed cultures spend over 90% of their lives in buildings every day, the architecture we inhabit envelopes our mind and body and influences how we feel and behave. The design of our built environment can modulate how comfortable, or focused, we feel in a given moment and can influence hormonal patterns, speed of recovery from surgery, and long-term cardiac health (Coburn, Vartanian, Kenett, Nadal, Hayn-leichsenring, et al., 2020) Today's architectural design approaches do not adequately address the relationship between users' spatial, environmental and psychological experiences. Domestic environmental experience generally indicates users' cognitive perceptions and physical responses within dwelling spaces. Therefore, without a clear perception of occupants' experiences, it is difficult to identify proper architectural solutions for a domestic environment. To understand notions of these domestic experiences, the current study explores the theoretical relationship between spatial and environmental design factors within domestic settings which led to the concept of "Environmental Experience Design (EXD)".

##### 2.2.1.1.2. Behavior of building occupants

The behavior of building occupants can have large effects on building energy use, and it results in huge gaps between real and predicted energy performance of buildings. The differences between real and predicted energy use depends on differences between the predicted and actual final realization of the construction, technical installations, and the real use of the built systems operated by occupants. Recently, it has been shown that occupant behavior plays a fundamental role on the amount of energy used in buildings, e.g., by the time and type of window opening, the use of air-conditioning (AC) units or the choice of indoor temperature set point So in the challenge of reducing the environmental impact, it is important to understand the occupant interactions with the indoor environment in order to provide comfortable conditions in the most efficient ways (Fabi et al., 2012).

The drivers influencing occupant behavior have been divided into five groups:

- Physical environmental: Examples of physical environment aspects that drive occupant behavior with an effect on energy consumption are temperature, humidity, air velocity, noise, illumination, and odour.
- Contextual: Contextual drivers are factors that have an indirect influence on the human being. They are determined by the context. The insulation of buildings, orientation of façades, heating system type, thermostat typ e (e.g., manual or programmable), etc. are examples of contextual drivers.
- Psychological: Occupants tend to satisfy their needs concerning thermal comfort, visual comfort, acoustical comfort, health, safety, etc.

Furthermore, occupants have certain expectations of e.g., the indoor environmental quality (temperature, etc.). Other examples of psychological driving forces are awareness (e.g., financial concern, environmental concern), cognitive resources (e.g., knowledge), habit, lifestyle and perception.

- Physiological: Examples of physiological driving forces are age, gender, health situation, clothing, activity level, and intake of food and beverages.

These factors together determine the physiological condition of the occupant.

- Social: Social driving forces refer to the interaction between occupants. For residential buildings this depends of the household composition (e.g., which household member determines the thermostat set point or the opening/closing of windows).

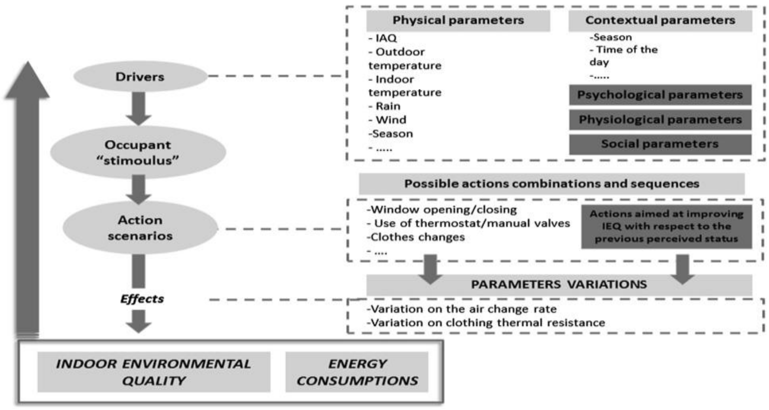



Figure 3 Flux diagram: from drivers to energy consumption and indoor environment

2.2.1.1.3. Cognitive judgments of Interior architecture

When people enter buildings, they often make cognitive judgments about the spaces around them. We define cognitive judgments as informed by top-down knowledge people bring to evaluations made about external qualities of their surroundings, rather than self-reflective evaluations of their own inner states of being. This distinction is based on past research suggesting that extrospective and introspective evaluations likely involve dissociable neural circuitry Here, we discuss five key measures of cognitive judgment in the built environment: complexity, organization, modernity, naturalness, and beauty (Coburn, Vartanian, Kenett, Nadal, Hayn-leichsenring, et al., 2020).
When judging interior space or roominess, a dark ceiling is judged to be lower than a light ceiling. The method of metric judgments (e.g., on a centimeter scale) that has typically been used in such tasks may reflect a genuine perceptual effect or it may reflect a cognitively mediated impression. We employed a height-matching method in which perceived ceiling height had to be matched with an adjustable pillar, thus obtaining psychometric functions that allowed for an estimation of the point of subjective equality (PSE) and the difference limen (DL) (Castell et al., 2016)

2.2.1.1.4. Emotional responses to architecture

In addition to eliciting external judgments, architectural spaces modulate affect, emotions, and other inner states of being. The importance of judging a building not only via detached observation of its appearance, but also by examining the degree to which it "touches us in our humanity" and "stirs our feelings, our passion". Several other writers have also highlighted the introspective dimension of architectural experience. Eight measures of emotional experience in the built environment are outlined below: personalness, hominess, relaxation, comfort, stimulation, uplift, vitality, and valence. The degree of personal feeling that a building generates is an important consideration in architectural design (Coburn, Vartanian, Kenett, Nadal, Hayn-leichsenring, et al., 2020).

2.2.1.1.5. Behavioral-motivational responses to architecture

The final class of aesthetic response scales encompasses the psychological measures of behavior, movement, and motivation, which may be to a first approximation linked to sensorimotor processing in the brain. Here, we focus on three behavioral measures: interest, approachability, and explorability. Interest, an important response measure in empirical aesthetics and environmental psychology is closely linked to sensory perception and motivation.

2.2.1.1.6. Architectural Variable; Floor Heights

There appears to be widespread belief that Floor height can affect the quality of indoor consumption experiences. Floor height ranked among the top three architectural details that influenced consumers' psychological well-being. A home development company that uses design ideas inspired by the guru of transcendental meditation maintains that homes with higher rooms induce clearer and improved thinking, more energy, and better health among residents. Airplane manufacturers seem to concur those higher ceilings can enhance consumers' consumption experience, even if the increased height is only illusory (Meyers-levy & Zhu, 2012). According to Psychology Today, a study from the University of Minnesota reported that people in 8-foot-high rooms feel confined, while those in 10-foot rooms feel freer, even if they didn't actually use the vertical height. While there are no official Ethiopian building regulations that mandate minimum floor heights for residential buildings, neighboring countries such as Kenya and Tanzania have established guidelines recommending a minimum of 2.7 meters for low-income housing (Kamau & Otieno, 2020). These standards aim to improve indoor air circulation and reduce reliance on mechanical cooling. The lower the floor height, the more personal space we need from others. Higher ceilings also evoke formality, whereas lower ceilings create more intimate spaces. Oddly enough, lofts are historically thought of as spaces for artist-types. Another consideration is that ceiling heights affect our thought processes. Those in rooms with lower ceilings tend to become more detail-oriented, compared to their counterparts in larger rooms, who tended to overlook details. A variety of ceiling heights within a home is ideal, but a hot fix is changing the color. Studies show that we perceive light-colored ceilings as higher (Environmental Psychology, n.d.).

Figure 4: psychological responses to architectural interiors

Research suggests that ceiling height can affect psychological responses to architectural interiors. On average, preferences for ceiling height peak around 10 feet across a range of spatial functions. In a recent study investigating the effect of Floor height on aesthetic perceptions and neural activity, spaces with high ceilings received higher beauty ratings than those with low spaces. Functional magnetic resonance imaging (FMRI) results showed that rooms with high ceilings differentially activated neural structures involved in visual spatial attention and exploration, such as the left middle frontal gyrus and left precuneus. These findings were consistent with previous research indicating that high ceilings increase perceptions of spaciousness and prime thoughts of freedom, whereas low ceilings are more likely to prime thoughts of confinement (Coburn, Vartanian, Kenett, Nadal, Hayn-leichsenring, et al., 2020). According to (Meyers-levy & Zhu, 2012) relatively high floor heights may prime thoughts related to freedom, whereas lower floor height may prompt those that pertain to confinement. We suggest that, in turn, these alternative concepts may affect the particular manner in which consumer's process information, namely, whether they rely on relational or item-specific processing. Finally, the type of processing that is used could alter how consumers elaborate and ultimately evaluate the table's features. The preceding notion that floor height might prime certain concepts or networks of associations that then affect how people process product information is quite novel (Meyers-levy & Zhu, 2012). Clearly, it is well established that exposure to particular objects can prime concepts that are related to them and that the heightened accessibility of such primed concepts can spill over and affect people's perceptions or even their overt behaviors. However, it is typically assumed that such effects occur because of associations to the primed concept spill over and affect perceptions or behavioral representations. In contrast, the paper proposes that, in certain instances, effects on perceptions or behavior may occur because the primed concepts actually affect the very type of processing that people use. That this possibility is novel is suggested by the fact that we could identify only one developed body of research, which posits that this alternative mechanism can occur. Moreover, even in that case, both the semantic content of the primed concepts and the types of processing that are claimed to be stimulated differ from the ones that we propose are activated by a high versus low ceiling (Coburn, Vartanian, Kenett, Nadal, Hayn-leichsenring, et al., 2020).

2.2.1.2. *H/W* (Height-to-Width) Ratio and Thermal Dynamics

The *H/W* ratio is calculated as the ratio of a building height to the width of the street abutting the building. The problem is to identify streets between buildings, which is not easy because of lack of street information and irregular street patterns (Chun & Guldmann, 2012).

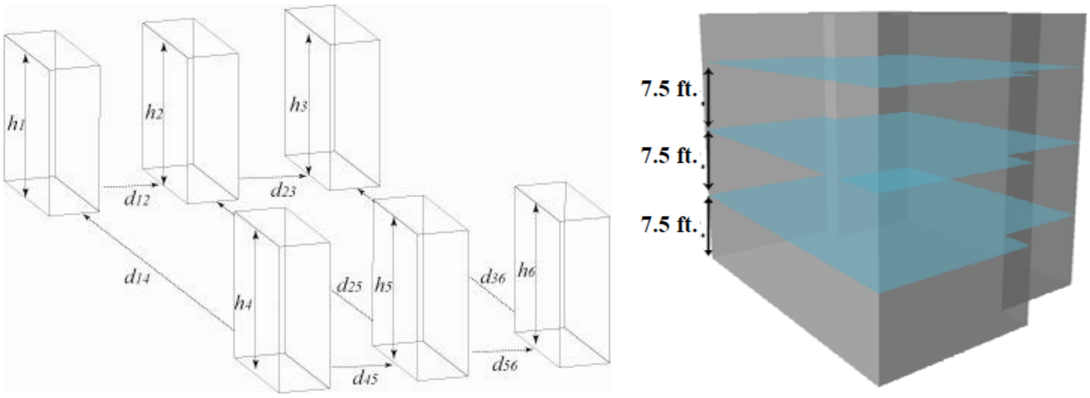



Figure 5: H/W (height-to-width) ratio and Residential Floor to Floor height(Chun & Guldmann, 2012).

Floor height's impact on vertical temperature profiles In accordance with the CFD findings, the vertical temperature profiles at the horizontal point of d for cases with CH=2.5, 3.0, and 3.5m in the case of 1.25kW and 2.5kW heater load with a variety of supply air velocity. A greater supply air velocity is required to achieve lower vertical temperature variations. This trend is more pronounced for internal loads of 2.5kW. If the overall tendency is roughly estimated, vertical temperature differences in the occupied zone decrease as supply air velocity increases. When the supply of air velocity changes, vertical temperature profiles are more different when a heat source has a larger capacity. Vertical temperature differences for similar heat source capacity and equal supply air velocity diminish as the room's ceiling height increases. This indicates that displacement ventilation is better suited to a room with a higher ceiling height. Any other horizontal locations have a similar trend. As previously stated, if a VAV system is used and in response by a measured temperature in an occupied zone, vertical temperature profiles will be controlled. The vertical temperature profile is improved and the measured temperature in the occupied area feeds back to supply air volume (Hashimoto & Yoneda, 2009).

#### 2.2.1.3. Floor Height and Thermal Comfort Systems

There is a lab at Tianjin University where the available space, including the floor size and height, can be altered via an automatic control system, as seen in and as shown in and, the laboratory has two sets of air conditioning systems: a fan coil system and a radiant floor system. In August and September 2017, experiments on thermal comfort conditions with these two systems under cooling conditions in a space with varying heights were carried out. Space's effects were the main subject of this study. The floor area was fixed at 99 meters, and the space heights were 3, 5, 7, and 9 meters for two different types of systems. Because Franklin County does not publicly disclose the total floor space and the number of stories for buildings, it is challenging to determine the actual floor space of structures. Therefore, in order to estimate energy consumption, the total building floor space must be estimated (Cen et al., 2018). The use of radiant heating systems for indoor heating is not new. In a laboratory measuring 17 x 24 x 14 ft (5.18 x 7.32 x 4.27 m), F.A. Chrenko conducted experimental studies on thermal comfort using a radiant floor system in 1957. He found that the radiant floor system had the significant advantage of creating a lot of space in the room and having an invisible heating system. Radiant floor systems, however, have the potential to cause local discomfort, according to tests on the temperature of subject feet. Research conducted later on radiant systems suggested that they had many advantages over convective systems in terms of thermal comfort (Cen et al., 2018).

#### 2.2.1.4. Assessment Techniques for Thermal comfort

##### 2.2.1.4.1. Early Investigations

According to “The Effect of Ceiling Height on Thermal Comfort” study (AlOtaibi, 2018), these factors lead to decreased energy use by mechanical heating and cooling systems, improved indoor air quality and ventilation efficiency, decreased building costs over the course of their entire lives, decreased floor-to-floor height of new buildings, improved thermal comfort for occupants of the building, and increased productivity and occupant satisfaction. CBAD and

UFAD systems are therefore anticipated to enhance thermal comfort in buildings (Alotaibi, 2018).

According to "Impact of Floor-to-Ceiling Height on Human Comfort" study (Nikravan Mofrad, 2014), human comfort is typically studied by taking into account environmental factors and how they affect people's thermal comfort, as well as by adjusting the variables in thermal comfort equations and computing interactive relations. As a result, changes in height have influenced people's responses if comfort levels remain within a predetermined range but people still express satisfaction or dissatisfaction in their responses. The impact of a residential unit's floor to ceiling height on people's comfort levels is examined in this study. 39 people's levels of satisfaction with the tests, which were carried out in a lab with an adjustable roof height, were tallied. For the test, four roof heights between 2100mm and 4000mm are taken into consideration. The best floor-to-ceiling height for typical residential urban units, according to the findings, is between 2700mm and 2800mm. The arguments made in this paper are the outcomes of studies and tests conducted at BHRC (Nikravan Mofrad, 2014).

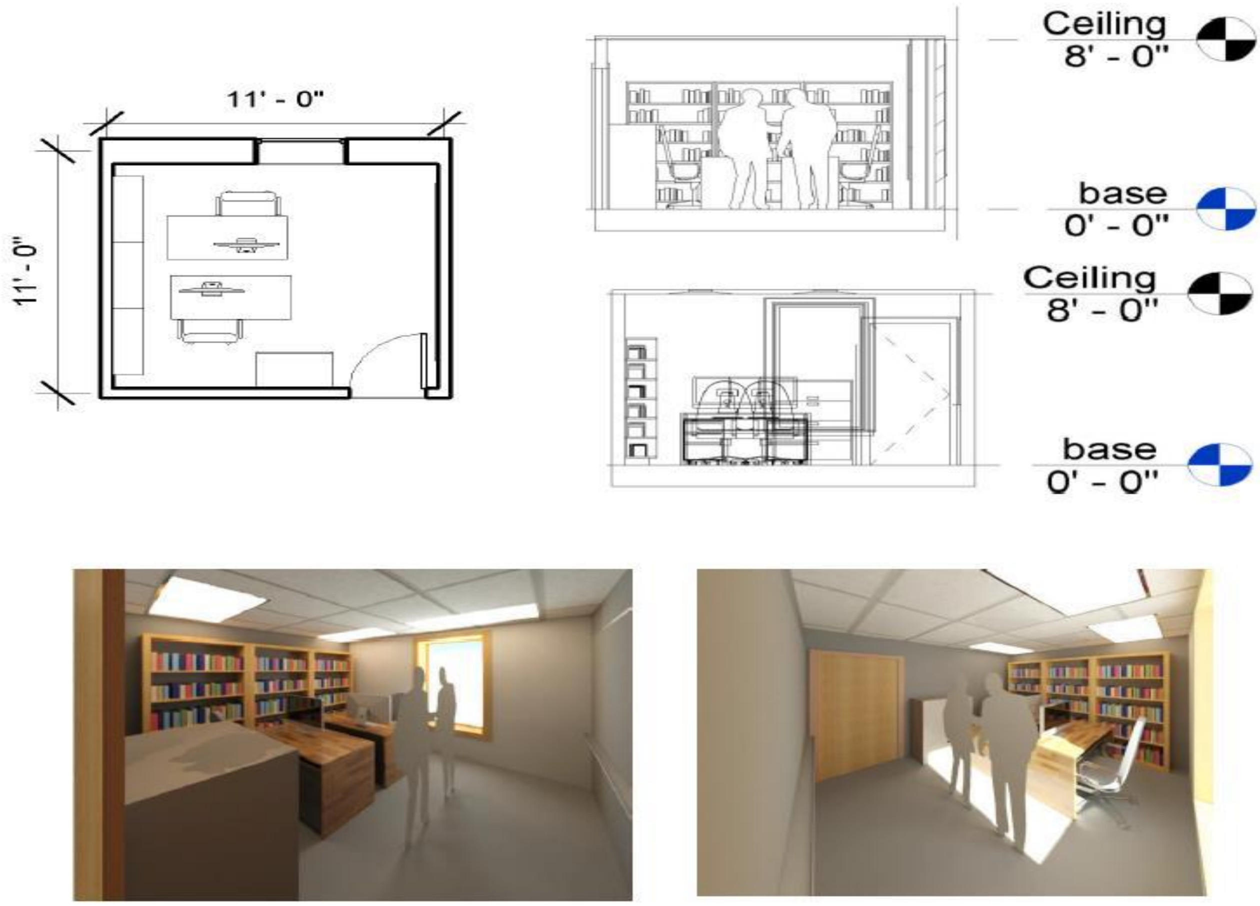



Figure 6: Virtual model of the interior space of an office (Alotaibi, 2018).

2.2.1.4.2. Temperature Humidity Index (THI) or Discomfort index (DI)

According to (Mishima et al., 2010), A field survey and measurement report titled "Field survey and measurement: In April 2009, a thorough field survey of the research region was carried out to look at certain building data, such as layout, height, and material. Thermo Recorder TR-72U was once more used to measure the air temperature Ta and relative humidity RH in the research region from April 10–20. Data was gathered between 7:30 am and 18:30 pm. There have been several attempts to create an index that would combine all of the variables that define the limits of thermal comfort. More than 60 years ago, efforts to measure thermal comfort in the tropics were made. Ellis, who measured "comfort" (or neutral) temperature as 26.1-26.7°C in Singapore (Kakon et al., 2010), Webb, who measured 27.2°C in Singapore (Wong & Khoo, 2003), Rao, who measured 26.0°C in Calcutta (Ratnam et al., 2013), and Nicol, who measured 31.1°C in Roorkee (Emmanuel, 2005), India, are some of these. In fact, rather than using a single value, the outdoor thermal comfort condition should be defined in terms of a combination of the following variables: air temperature, relative humidity, air velocity, and radiation. Temperature Humidity Index has been chosen as the indicator for this study's thermal comfort evaluation (THI) (McGregor & Nieuwolt, 1998).

Table 1 THI Indicator of thermal comfort Evaluation

| | |
|---|---|
| Location | Dhaka, Bangladesh, 23.24°N, 90.23°E, 8.8 m a.s.l. |
| Simulation day | Typical summer day, 13th April |
| Simulation duration | From 7:30-18:30 (11 h) |
| Spatial resolution | 110x80x25 grids, grid size: 2x2x3 m |
| Wind speed and direction | 2 m sec-1 a.g.l. from 180° (south) |
| Initial temperature | 293 K |
| Relative humidity | 40% |
| Heat transmission | Walls: 1.7 W m-2 K<br>Roofs: 2.2 W m-2 K |
| Albedo | Walls: 0.3<br>Roofs: 0.15 |

THI is one of the variants of Effective Temperature (ET), developed by Thom (1959). It combines the wet and dry bulb temperatures into a scale that imitates the thermal sensation of a human being (Thom, 1959). Later Nieuwolt (1998) modified the index using air temperature and relative humidity. Especially in a case where relative humidity data is more frequently available than the wet bulb temperature, then the following equation can be used (McGregor & Nieuwolt, 1998):

$$THI = 0.8T_a + \frac{RH \times T_a}{500}$$

Where:

Ta = the air temperature (°C)

RH = the relative humidity (%)

By empirically testing the THI values on human objects, the comfort limits are defined as:

$21 \leq THI \leq 24$ = 100% of the subjects felt comfortable

$24 < THI \leq 26$ = 50% of the subjects felt comfortable

$THI > 26$ = 100% of the subjects felt uncomfortably hot

However, it must be mentioned that the above ranges were developed in the mid-latitudes Tropical residents are likely to tolerate higher levels of THI due to acclimatization as well as variations in food habitats and clothing (Mishima et al., 2010).

## 2.3. Methodological Approaches in Thermal Comfort Research

### 2.3.1. Simulation Tools

Previous studies used various methods to investigate thermal comfort, including: Simulation Tools: Software like FloVent and Design Builder has been used to model airflow, temperature variations, and comfort indices like PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied). These tools offer insights into the effects of floor height but often lack integration with real-world observations.

The thermal comfort ratings of the rooms used in this study entitled “The Effect of Ceiling Height on Thermal Comfort” serve as the primary source of information. The air temperature, surface temperature, air velocity, relative humidity, clothing thermal insulation, and metabolic rates of the occupants are measured in order to determine the room's overall thermal comfort values (Alotaibi, 2018).This will be achieved by analyzing the CBAD and UFAD systems that are used to cool the rooms, as well as the movement of air and heat in the rooms, using the FloVent simulation program. FloVent is primarily used to investigate how conditioned air enters, circulates through, and exits a room. Two specific tools, predicted-mean-vote (PMV) and predicted percentage of dissatisfaction (PPD), will be used from this analysis to assess the room's thermal comfort. The number of passengers who are at ease in a specific thermal comfort condition will be determined using PMV, while the number of passengers who are dissatisfied with a specific level of comfort will be determined using PPD. It will be possible to establish these values and the impact that CBAD and UFAD have on thermal comfort in a building or room. As previously mentioned, this study will be carried out by gathering data using the FloVENT program, PMV, and PPD techniques. Here are some specifics about these techniques: Predicted Mean Vote (PMV) is a variable obtained using the ASHRAE 55 thermal tool, developed by the American Society of Heating, Refrigeration, and Air Conditioning Engineers. Using this method, it will be possible to identify the six variables that affect occupants' thermal comfort and result in the variable known as PMV: ambient air temperature, mean radiant or surface temperature, air velocity, relative humidity (RH), activity level or metabolic rate (M), and clothing level or thermal insulation (Alotaibi, 2018).

Based on the design methods of the research entitled "Impact of Floor-to-Ceiling Height on Human Comfort" in the consistent climatic conditions of the laboratory environment, feedback from participants regarding changes in floor-to-ceiling height is gathered (Nikravan Mofrad, 2014). It is important to note that the data logger-thermal comfort unit measures the comfort level and thermal conditions of the lab room. Through the calculation of (PMV-PPD), using the international standards specified for thermal comfort and taking into account the level of physical activity and clothing considered for the device, the device is equipped with sensors that receive the climatic conditions of the laboratory environment and it measures the rate of satisfaction and dissatisfaction of the people in the room in which they are located (Nikravan Mofrad, 2014).

### 2.3.2. Experimental Setups

Adjustable-height rooms in laboratory settings have been used to assess how floor height impacts comfort. While controlled, these studies lack generalizability to real-world housing conditions.

Based on the design methods of the research entitled "Impact of Floor-to-Ceiling Height on Human Comfort" To assess people's perceptions of an appropriate floor-to-ceiling height in the current study, a novel, and innovative methodology was used (Nikravan Mofrad, 2014). The research was carried out in a laboratory with an adjustable roof height, where constant climatic conditions were provided solely on the basis of test requirements. The test laboratory's desired thermal comfort condition is then taken into consideration. The study's failure to use simulation software as a method of measuring the thermal comfort parameters and its failure to contribute to the development of new energy-efficient technologies are both drawbacks (Nikravan Mofrad, 2014).

### 2.3.3. Field Measurements and Surveys

The integration of portable thermal comfort measurement devices and occupant surveys provides a holistic understanding of thermal comfort. Combining quantitative data with qualitative insights addresses gaps in existing methodologies (Nikravan Mofrad, 2014).

## 2.4. Identified Research Gaps

Despite extensive research conducted globally on thermal comfort, significant gaps remain, particularly concerning the role of floor height in residential buildings. Most thermal comfort studies have been conducted in developed countries, with limited focus on developing nations like Ethiopia. This creates a critical knowledge gap in understanding the unique challenges faced in low-cost housing in tropical climates.

In Ethiopia, there is a notable absence of research addressing the direct impact of floor height on indoor thermal comfort in residential settings. Previous studies, such as those by Meshal AlOtaibi and Nikravan Mofrad Mojgan, have explored thermal comfort under specific conditions, such as ceiling-based air distribution (CBAD) systems or laboratory settings with adjustable floor heights. However, these studies relied heavily on either simulation tools or experimental setups, neglecting the integration of multiple data collection methods and real-world applications.

Furthermore, existing research has not sufficiently combined field measurements, simulation software, and surveys to comprehensively analyze thermal comfort. Most studies have overlooked the contribution of outdoor temperature and its interaction with floor height on indoor environments. For example, portable thermal comfort measurement devices and people's lived experiences, critical in understanding context-specific issues, are rarely employed in tandem. This research addresses these gaps by integrating advanced simulation tools, portable measurement devices, and qualitative surveys to evaluate the effect of floor height on indoor thermal comfort and behavioral observations captured through hidden cameras to provide a deeper understanding of how residents adapt to low-floor-height homes in Hawassa, Ethiopia. It uniquely incorporates outdoor temperature data to assess its influence on indoor thermal conditions, bridging the gap between theoretical models and real-world challenges. Additionally, this study explores government-constructed low-cost housing, where thermal discomfort is a persistent issue, providing practical insights for future architectural and policy interventions.

## 2.5. Summary of Literature Review

- Theoretical Review

Building Problems in Hot Climates:

Buildings in hot climates face challenges like high temperatures, solar radiation, and inadequate ventilation.
Effective architectural design, including materials and climatic suitability, is crucial to address these issues.

Thermal Comfort:

Defined as a state of mind expressing satisfaction with the thermal environment, influenced by physical, physiological, and psychological factors.
Two main approaches:
Heat-Balance Approach: Uses energy balance equations to predict thermal comfort.
Adaptive Approach: Based on field studies, considers behavioral, physiological, and psychological adjustments of occupants.

Indoor and Outdoor Thermal Comfort:

Indoor comfort is often evaluated using steady-state models like the PMV-PPD indices.
Outdoor comfort requires dynamic models, considering variables such as air velocity and

radiant temperature.

Six Variables Influencing Thermal Comfort:

Air temperature, humidity, air velocity, mean radiant temperature, clothing insulation, and metabolic rate are key determinants of comfort.

Floor Height and Thermal Comfort:

Higher ceilings enhance ventilation, reduce heat accumulation, and evoke a sense of freedom.
Lower ceilings lead to poor air circulation, increased heat retention, and feelings of confinement.

- Empirical Review

Floor Height's Impact:

Empirical studies show that optimal floor-to-ceiling heights (2.7–2.8m) provide better thermal comfort.
Higher ceilings improve airflow patterns and reduce vertical temperature gradients, especially in displacement ventilation systems.

Behavioral and Psychological Responses:

High ceilings promote abstract thinking, creativity, and a sense of spaciousness.
Low ceilings are associated with detail-oriented thinking, confinement, and dissatisfaction.

Thermal Comfort Indices:

PMV and PPD: Predict occupants' thermal sensations and dissatisfaction levels.
Temperature-Humidity Index (THI): Quantifies thermal comfort using air temperature and relative humidity.

Research Gaps:

Lack of studies focusing on floor height and thermal comfort in low-cost housing in developing countries like Ethiopia.
Limited integration of field measurements, simulations, and qualitative surveys in previous

research.

- Methodological Review

Methods Used in Previous Studies:

Field Measurements: Portable devices to assess indoor temperature, humidity, and airflow.
Simulation Tools: Tools like Design Builder and FloVent simulate airflow and thermal performance.
Laboratory Experiments: Adjustable ceiling-height laboratories for real-time thermal comfort testing.
Behavioral Studies: Surveys and observations to assess occupants' perceptions and satisfaction.

Integration of Methods:

Advanced studies combined multiple approaches, such as field measurements, simulations, and behavioral data, for comprehensive analysis.

Limitations in Prior Studies:

Over-reliance on simulation tools or laboratory setups, lacking real-world applicability.
Few studies addressed tropical climates or low-cost housing challenges.
Limited use of outdoor temperature data and its interaction with indoor thermal comfort.

The Literature review provides a detailed review of theoretical foundations, empirical findings, and methodologies related to thermal comfort and floor height. It highlights the importance of integrating multiple approaches to address research gaps, particularly in the context of developing countries and low-cost housing. This sets the foundation for the study to explore the role of floor height in improving indoor thermal comfort in Hawassa, Ethiopia.

## 2.6. Conceptual Framework

The conceptual framework of this study illustrates the relationships between the independent variables (e.g., floor height, air temperature, humidity) and the dependent variable (indoor thermal comfort). It integrates theoretical principles, empirical findings, and methodological approaches to address the research objectives.

### 2.6.1. Independent Variables

1. Floor Height:

Defined as the vertical distance between the floor and ceiling, this architectural variable significantly influences airflow, heat retention, and occupants' psychological perceptions.

Higher floor heights are associated with improved ventilation and reduced thermal discomfort, while lower floor heights often lead to confined and thermally uncomfortable environments.

2. Environmental Factors:

Temperature: Both indoor and outdoor temperatures affect heat transfer and occupant comfort.

Humidity: Relative humidity amplifies the perception of heat, particularly in tropical climates like Hawassa.

3. Behavioral Adaptations:

Occupants' clothing, activities, and use of ventilation systems or fans affect their thermal comfort levels.

### 2.6.2. Dependent Variable

Indoor Thermal Comfort

Measured using indices such as Predicted Mean Vote (PMV), Predicted Percentage of Dissatisfied (PPD), and Temperature Humidity Index (THI).

Combines physical conditions (e.g., temperature, humidity) and psychological satisfaction (e.g., perceived freedom or confinement due to floor height).

Conceptual Flow: The framework draws from both theoretical and empirical literature to establish that:

1. Floor height affects thermal conditions by altering airflow patterns, heat dissipation, and occupant behavior.
2. Environmental factors, such as temperature and humidity, interact with architectural variables to influence comfort.
3. Occupant perceptions mediate the relationship between physical conditions and satisfaction with the thermal environment.

Visual Representation:

Referencing Figure 9 (page 43) in this thesis, the conceptual model visually connects these variables, illustrating how floor height impacts indoor thermal comfort directly and indirectly through environmental factors and behavioral adaptations. Here is also the visual representation of the conceptual framework. It illustrates the relationships between the Independent variables (Floor height, Environmental factors like Temperature and Humidity, and Behavioral adaptations) and the dependent variables (Indoor Thermal comfort)

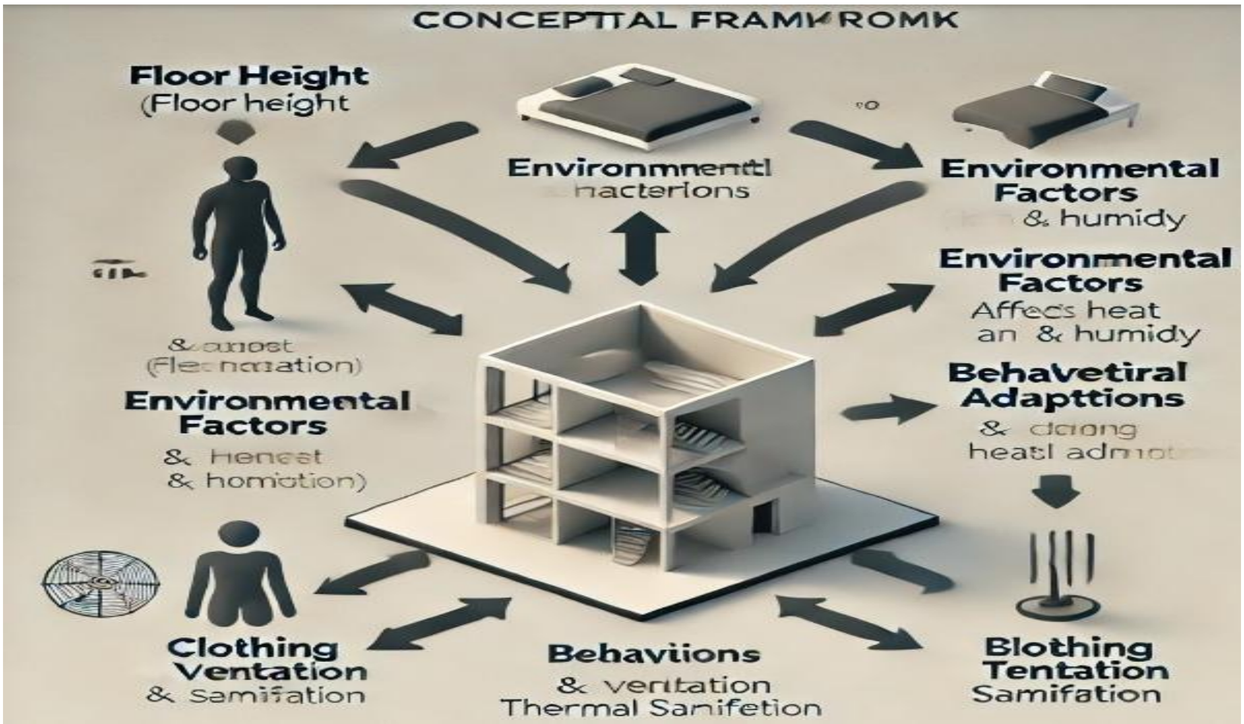



Figure 7: Visual representation of the Conceptual framework

# CHAPTER THREE

# 3. METHODS AND MATERIAL

This research followed clear and credible procedures to achieve its objectives. Some of the details of these methods are as follows: Description of the study area, Study design, Study approaches, Data Type and Sources, Study Population, Sample size, Sampling techniques, Data collection tools, Data analysis and interpretation and Ethical Consideration.

## 3.1. Description of the study area

Hawassa city is one of agglomerating urban centers in the Sidama Regional State established on the shore of Lake Hawassa. It is located in the Great Rift Valley region; 275 km south of Addis Ababa via DebreZeit and 1125 km north of Nairobi. The city serves as the capital of the Southern Nations Nationalities & Peoples Regional State and Sidama Zone. Geographically it lays between 7 03' latitude North and 380 28' longitudes east. It is bounded by the lake in the West, Oromia Region in the North, Wondogenet woreda in the East and ShebedinoWoreda in the south. Hawassa has a total area of 157.2 sq.km divided into Eight (8) sub cities divided into 32 Kebeles. These Eight sub cities are Hayek Dare, Menehariya, Tabore, Misrak, Bahile Adarash, Addis Ketema, Hawela Tula and Mehalketema sub city.

Temperatures in Hawassa range from 5°C in winter to 34°C in summer. The city experiences sub humid-called 'Woyina Dega' type of climate. It has the highest and lowest temperature of $34^{0C}$. The average annual temperature is $20.3^{OC}$. The investigation focused on particular government low floor height residences where the discomfort issue is evident. The study thus ascertains how the indoor thermal comfort of residential units in Hawassa city, Ethiopia, is impacted by floor heights (Brier & lia dwi jayanti, 2020).

Hawassa experiences a tropical climate with high temperatures and humidity, which significantly affects indoor thermal comfort. Government-built residences in the city have low floor heights, leading to poor ventilation and increased heat retention.

The study focuses on municipal housing units characterized by low floor heights (≤2.5m), poor ventilation, and high indoor temperatures, affecting residents' comfort.

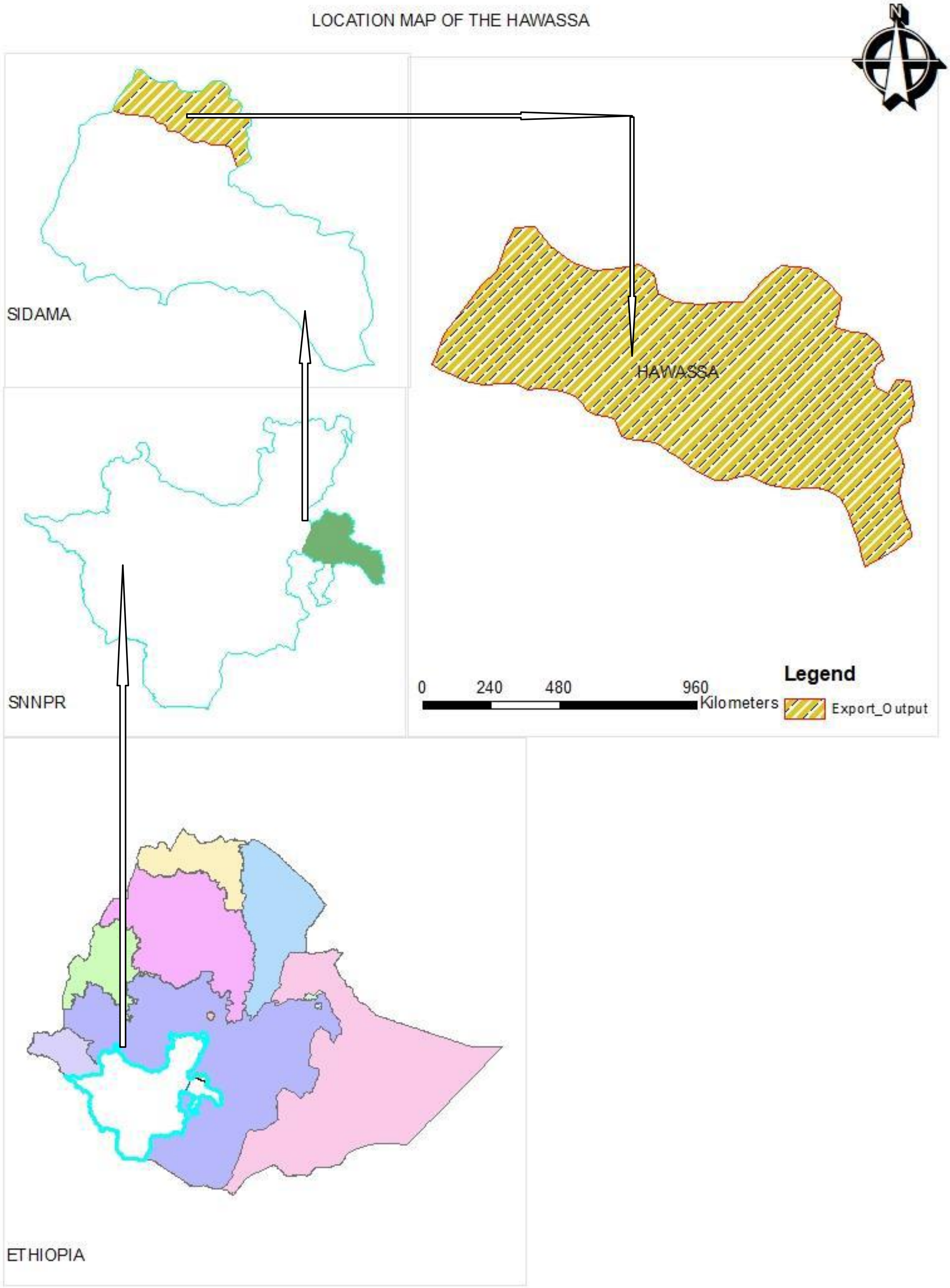



Figure 8: Hawassa city land use site (GIS)

## 3.2. Research design

The research design serves as the master plan of this study, providing a structured framework to achieve the research objectives. This study employs a mixed-methods approach, integrating quantitative and qualitative data collection techniques, along with computational simulations. The mixed-methods approach was chosen to correlate measurable environmental conditions (temperature, humidity, and airflow) with subjective occupant perceptions (thermal comfort, satisfaction, and psychological responses). This approach ensures a holistic analysis of the effect of floor height on indoor thermal comfort.

### 3.2.1. Core Elements of the Research Design

1. Descriptive Design:
The study describes the current state of thermal comfort in residential buildings, focusing on how floor height influences temperature, humidity, and ventilation.

2. Correlational Design:
To analyze the relationships between variables, such as floor height, indoor thermal conditions, and occupant satisfaction, the study utilizes statistical tools, including correlation and regression analysis.

3. Experimental Design (Simulation):
The research incorporates simulations using Design Builder software to model and predict the thermal performance of buildings with varying floor heights.

4. Survey Design:
Questionnaires were used to gather data on residents' perceptions of thermal comfort and satisfaction with their living environments. This complements quantitative measurements by providing qualitative insights.

5. Case Study Approach:
The research focuses on government-constructed low-floor-height residences within a 6-kilometer radius of the Hawassa municipal government housing area. This localized case study provides context-specific insights into thermal comfort challenges in tropical climates.

6. Integration of Methods:

By combining descriptive, correlational, simulation, and survey designs, the study design ensures that both objective measurements (e.g., temperature and humidity) and subjective feedback (e.g., occupant perceptions) are analyzed in tandem. This integration enhances the reliability and applicability of the findings.

This study employed a descriptive research design to explore the impact of floor height on indoor thermal comfort in residential buildings within Hawassa city, Ethiopia. The design was selected to comprehensively assess and document the relationships between independent variables (floor height, indoor temperature, and relative humidity) and the dependent variable (thermal comfort).

To ensure robust findings, both quantitative and qualitative methods were integrated into the study. This mixed-methods approach provided a holistic understanding of the issue by combining objective measurements with residents' subjective experiences.

Temporal Scope: Data collection was conducted during the warmest period of the year (February 10 to March 5) to capture thermal conditions when discomfort is most likely to occur. Measurements and observations were carried out between 2:00 AM and 6:00 PM to account for variations in indoor thermal conditions throughout the day.

This study design provided a structured, systematic, and in-depth approach to investigating the effect of floor height on thermal comfort, addressing gaps in existing literature and offering actionable insights for improving residential building designs.

### 3.2.2. Quantitative Research Approach

Real-time thermal comfort measurements were taken using portable temperature and humidity sensors, analyzed using SPSS to determine statistical relationships.

The quantitative approach involves direct measurements of indoor environmental variables and statistical analysis of the data.

Data Collection Methods:

1. Portable Thermal Comfort Measurement Devices:

Temperature and humidity were recorded using thermo device at hourly intervals.

Data was collected in 30 municipal residences with varying floor heights.

2. Questionnaire Surveys:

Residents were asked to rate their thermal comfort on a 7-point ASHRAE scale (ranging from -3 = cold to +3 = hot).

Additional questions assessed perceived confinement, ventilation, and satisfaction with current floor height conditions.

3. Statistical Analysis (SPSS):

Descriptive statistics summarized thermal comfort levels.

Correlation analysis identified relationships between floor height, indoor temperature, and occupant satisfaction.

Regression models predicted temperature changes based on floor height variations.

### 3.2.3. Qualitative Research Approach

Surveys and interviews were conducted to understand residents' perceptions of thermal comfort and psychological responses to different floor heights. The qualitative approach complements quantitative findings by capturing resident experiences and behavioral patterns related to indoor thermal comfort.

Methods of Data Collection:

1. Resident Interviews & Open-Ended Surveys:

Semi-structured interviews were conducted to understand residents' perceptions of thermal comfort and psychological effects of different floor heights.

Participants were asked to describe their daily adaptations to uncomfortable indoor temperatures.

2. Hidden Camera Observations:

Cameras were discreetly installed (with consent) in shared living spaces to observe adaptive behaviors, such as:

Opening/closing windows

Use of fans and cooling devices

Clothing adjustments

Ethical measures ensured anonymity and privacy protection.

3. Content Analysis:

Qualitative data was coded to identify common themes, such as perceived air stagnation, feelings of confinement, and ventilation strategies used by residents.

### 3.2.4. Simulation Techniques

Computational simulations were conducted to validate field measurements and explore how different floor heights influence airflow and temperature distribution.

Simulation Methods:

1. Computational Fluid Dynamics (CFD) Modeling:

CFD simulations (using ANSYS Fluent or Design Builder) analyzed air circulation, temperature gradients, and heat retention in rooms with varying floor heights.

Simulations compared 2.5m, 2.65m, and 3.0m ceiling heights.

2. Thermal Comfort Indices (PMV & PPD):

PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) models were applied to estimate comfort levels across different floor heights.

3. Temperature-Humidity Index (THI) Analysis:

THI values were calculated using the standard comfort classification system:

$21 \leq THI \leq 24$ → Comfortable

$24 < THI \leq 26$ → Moderately uncomfortable

$THI > 26$ → Uncomfortable

### 3.2.5. Justification of Research Design

This study design was selected based on the need for a comprehensive understanding of indoor thermal comfort.

Why use field measurements?

Real-world conditions provide more accurate data than lab-based experiments.

Why include qualitative insights?

Thermal comfort is not just a physical condition but also a psychological experience.

Why use simulations?

CFD and PMV models allow us to predict airflow and thermal behavior across different floor heights, which would be impractical to measure in every household.

### 3.2.6. Study Design Limitations

While this study provides valuable insights, it has some limitations:

1. Technological Constraints:

Due to resource limitations, adjustable-height laboratory experiments were not conducted.

Instead, real-world residential units were used for field measurements.

2. Generalizability:

The study focuses only on Hawassa municipal housing, which may limit its applicability to other regions with different construction materials and ventilation design

3. Ethical Constraints:

Hidden camera observations were limited to public spaces within residences, avoiding bedrooms and private areas.

Some residents were hesitant to participate in surveys due to privacy concerns.

## 3.3. Study Population and Sampling

The study population includes residents of Hawassa City, Ethiopia, with a total population of approximately 578,000. The focus is on kebele houses, which are low-cost residential units constructed by the government. There are 2,520 kebele houses in Hawassa, with an average of 3 occupants per house, resulting in a total kebele house population of 7,560 individuals. These houses, characterized by low floor heights, often face challenges related to indoor thermal comfort, making their residents the primary focus of this study.

### 3.3.1. Sample size and Justification

The sample size for the study was determined using the Yamane (1967) formula for sample size calculation (Umar & Wachiko, 2021):

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

Where:

(total number of kebele houses),

(margin of error at a 95% confidence level).

Substituting the values:

$$n = \frac{2,520}{1 + 2,520(0.05)^2} = \frac{2,520}{1 + 6.3} = \frac{2,520}{7.3} \approx 345$$

Thus, the required sample size is approximately 345 houses.

However, for this study, 2 houses from each of the 15 kebeles were purposively selected, resulting in a final sample size of 30 houses. This selection ensures representation across all kebeles in Hawassa.

Justification for Sample Size:

The calculated sample size of 345 houses would provide statistical significance; however, due to logistical and resource constraints, the study opted to select 30 houses, focusing on 2 houses per kebele which are government-built units with low floor heights. The selection was based on Yamane 1967 Formula (Umar & Wachiko, 2021) to ensure statistical relevance.

This smaller, purposive sample provides meaningful insights into the thermal comfort challenges of government-constructed housing while ensuring geographic representation.

## 3.3.2. Sampling Techniques and Rationale

A purposive sampling technique was employed for this study, guided by the following steps:

### 3.3.2.1. Stratified Sampling

The total kebele house population was stratified into 15 kebeles (sub-cities) to ensure representation across all administrative divisions of Hawassa City.

Why stratified sampling? Residences were categorized into low-floor (≤2.5m) and high-floor (>2.65m) groups to analyze differences in thermal comfort.

### 3.3.2.2. Purposive Sampling:

Within each kebele, 2 houses were selected based on their accessibility and representation of typical kebele housing characteristics, particularly low floor height.

Houses were selected to ensure they reflected the conditions targeted in the study, focusing on thermal discomfort challenges associated with low-cost construction.

Why purposive sampling? Only municipal housing was considered due to its uniform construction characteristics and the high prevalence of thermal discomfort.

### 3.3.2.3. Justification for Sampling Technique

Stratified Sampling ensures geographic and demographic diversity, capturing variations across kebeles. Purposive Sampling is appropriate for this study as it targets houses with specific characteristics relevant to the research objectives (e.g., low floor height, government-constructed housing). This combination allows for a focused analysis while maintaining practical feasibility within the available resources.

## 3.4. Data Collection Methods

### 3.4.1. Thermal Comfort Measurement Device

To measure indoor thermal comfort parameters, the study utilized a Thermo Recorder device. This instrument measured air Indoor and outdoor temperature (Ta) and relative humidity (RH) in selected municipal residential units. The device not only assisted in regulating and monitoring indoor environmental conditions but also allowed for the comparison of subjective responses with objective thermal comfort data. It was instrumental in ensuring consistency and accuracy during floor height variations.

### 3.4.2. Surveys and Interviews

The data collection process included a survey using structured questionnaires designed to capture residents' perceptions of indoor thermal comfort and satisfaction with current floor-height conditions. These surveys were conducted in 30 selected residential units, allowing respondents to express their subjective experiences and satisfaction levels.

### 3.4.3. Observational Techniques

To complement the survey and instrumental measurements, hidden cameras were discreetly installed in selected residential units to observe occupants' behaviors and interactions with their indoor environment. The use of hidden cameras provided valuable insights into real-time behavioral patterns, such as adjustments to ventilation, use of personal cooling mechanisms, or changes in activity levels. This method enabled the study to capture data that might not be reported through self-assessments due to recall bias or social desirability. The placement of hidden cameras was conducted with strict adherence to ethical guidelines. Participants were informed about the purpose of the observation and their consent was obtained prior to installation. The data collected was anonymized and used exclusively for the study's objectives to maintain privacy and confidentiality. To ensure ethical compliance, all observational studies using hidden cameras were conducted with prior consent from participants. Ethical approval was obtained from the Adama Science and Technology University Research Ethics Committee (Ref: ASTU/2025/021) before data collection.

### 3.4.4. Simulation Software Tools

Simulation tools, including the Design Builder software, were used to model the indoor thermal environment of selected residences. These simulations analyzed variables such as airflow, heat transfer, and predicted thermal comfort indices (e.g., PMV and PPD).

## 3.5. Data analysis Procedures

The analysis of data collected through surveys, instrumental measurements, and simulations was conducted using a structured approach to ensure accurate and actionable insights. A combination of statistical techniques and visual representations was employed to interpret the relationships between floor height and indoor thermal comfort.

### 3.5.1. Quantitative Data Analysis (SPSS)

Quantitative data were analyzed using SPSS to identify patterns and relationships between variables. Statistical techniques included:

Descriptive Statistics: Mean, median, standard deviation

Correlation Analysis: To identify relationships between floor height and thermal variables

Linear Regression: To determine the predictive power of floor height on thermal comfort indices.

Table 2 below presents data on how floor height influences psychological and Thermal comforts as well as associated concepts like freedom and confinement.

The average amounts are calculated through:

Mean

$$\text{Y-bar} = \frac{(Y1 + Y2 + \ldots + Yn)}{n} \quad , \quad \text{Y-bar} = \frac{\Sigma Yi}{n}$$

Where :

(y-bar) = The mean or average of the values. It represents the central value of the dataset.

Yi = .The individual data points or observations in the dataset.

n = The total number of observations or data points in the dataset.

The Analysis examined initially: provided that floor height is reasonably salient, can low floor rooms prime confinement-related concepts? Borrowing a method used by Aarts and Dijk (Assouly et al., 2022)- Questionnaires' form is manipulated as follow:

Table 2 Questionnaires' form of how floor height can affect type of processing

| House No | Kebele | Floor Height (m) | Association to Activated concepts | | Type of processing brought | | Suggested related concepts (Questionnaires answers) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 | | Item specific | Relational | 1 | 2 | 4 | 5 | 6 | 7 | | 8 |
| | | | Confinement | Freedom | | | | | | | | Thermal | Others | |
| 1 | 01 | 2.4 | a | | a | | b | b | d | a | b | | ✓ | a |
| 2 | | 2.34 | a | | a | | b | b | b | a | b | | ✓ | a |
| 3 | 02 | 2.5 | a | | a | | b | b | b | a | b | ✓ | | a |
| 4 | | 2.6 | | b | a | | a | a | c | b | a | ✓ | | b |
| 5 | 03 | 2.5 | a | | a | | b | b | c | a | b | ✓ | | b |
| 6 | | 2.5 | a | | a | | b | b | d | a | b | ✓ | | a |
| 7 | 04 | 2.56 | a | | a | | a | b | d | a | a | ✓ | | b |
| 8 | | 2.75 | | b | a | | a | a | b | b | a | ✓ | | b |
| 9 | 05 | 2.35 | a | | a | | b | b | a | a | b | ✓ | | a |
| 10 | | 2.56 | | b | a | | a | b | b | b | b | ✓ | | a |
| 11 | 06 | 2.3 | a | | a | | a | b | d | a | b | ✓ | | a |
| 12 | | 2.5 | a | | a | | a | b | b | a | b | | ✓ | a |
| 13 | 07 | 2.45 | a | | a | | b | b | c | a | b | ✓ | | a |
| 14 | | 2.5 | | b | a | | b | b | b | b | a | ✓ | | b |
| 15 | 08 | 2.65 | | b | a | | b | a | b | b | a | | ✓ | a |
| 16 | | 2.25 | a | | a | | b | b | d | a | b | ✓ | | b |
| 17 | 09 | 2.35 | a | | a | | b | b | d | a | b | ✓ | | b |
| 18 | | 2.4 | a | | a | | b | b | a | a | b | ✓ | | b |
| 19 | 10 | 2.45 | a | | a | | b | b | d | a | b | ✓ | | b |
| 20 | | 2.65 | a | | a | | b | a | b | a | a | ✓ | | a |
| 21 | 11 | 2.55 | a | | a | | b | a | b | a | b | ✓ | | b |
| 22 | | 2.6 | a | | a | | a | b | b | a | a | ✓ | | b |
| 23 | 12 | 2.6 | | b | a | | a | a | b | a | a | | ✓ | b |
| 24 | | 2.75 | a | | a | | a | a | b | a | a | ✓ | | b |
| 25 | 13 | 2.35 | a | | a | | b | b | d | a | b | ✓ | | a |
| 26 | | 2.5 | a | | a | | b | b | d | a | b | ✓ | | a |
| 27 | 14 | 2.4 | a | | a | | a | b | d | a | b | ✓ | | a |
| 28 | | 2.35 | a | | a | | a | b | d | a | b | | ✓ | a |
| 29 | 15 | 2.75 | | b | a | | b | a | b | b | a | | ✓ | b |
| 30 | | 2.65 | | b | a | | b | a | b | b | a | | ✓ | b |

Note: numbers 1, 2,3,4,5,6,7,8 and 9 correspond to specific question numbers in the questionnaire form of Appendix 1, whereas the letters a, b, c, and d represent the answer choices for each question. Additionally, in Table 2, these answer choices are used to indicate associations with psychological concepts (e.g., confinement or freedom), types of processing (item-specific or relational), and suggested related concepts such as thermal comfort and other influencing factors.

According to the analysis of number of families per a single room, Out of the target residences, 11 homes or 36.6% has accounted less than 5 numbers of occupants within, whereas the rest 63.3% accounted for more than 5 numbers of occupants.

According to Quantitative Analysis of Indoor Thermal Conditions, out of the overall sample frame, nine different homes (which means 30% of the respondents) tend to think more freely, more abstractly, when they are in a setting with a mean range of 2.65m floor height, In contrast in a room with a mean 2.43m foot floor Height, 70% are tending to concentrate on details that they process less abstract, less freely relationships in rooms.

From the Residence of Hawassa 46% are Municipal house. According to this study's questionnaire survey reaction of question number 3, on low floor Dwellings, 22 home owners (73.3%) of the sample frame feels Confinement related concepts which has an mean for those twenty two floor heights 2.45m while 8 home owners (26.7%) had a Freedom related concepts which has an mean for those twenty two floor heights 2.63m. The results showed that a large proportion of occupants use are think feel and behave frustrated. Therefore based on these, the study can conclude that the higher the floor height the higher freedom related concepts where occupants thinks, feels and behave without restrictions. In opposition the lower the height of the room the more restrictions to think, feel, and behave.

According to the analysis of the occupants who felt confined and which time of the day they experience confined related issues; out of the overall sample frame In the morning 6.6% of the sample frame feels confinement related concepts, in the afternoon/midday 46.6% of the sample frame feels confinement related concepts, in the evening 10% of the sample frame feels confinement related concepts, and throughout the day 36.6% of the sample frame feels confinement related concepts

According to the analysis of the possibility of the occupants to modify their house, 76.6% assured that they have no the possibilities to higher the existing room height of their home by their own, whereas others account 23.4% who argued that it is possible to let the municipalities to construct under urgent and acute cases like complaints.

According to analysis to determine the social interaction of the occupants with, 36.6% of the sample frame has an interaction with their neighborhoods. Although different findings suggest that high floor heights are a useful characteristic in spaces intended for social interaction, 63.4% of the sample frame has no any social interaction with their neighborhoods.

Floor height exerts an effect: As explained in above, the highest confinement level was achieved in the afternoon/midday. From these 73.3% of the respondents confirmed that the reason for their confinement related concept is the Thermal comfort caused by the midday harsh sun hitting the low roof. This climatic issue influence mood and building and directly or indirectly determines the behavior. The rest 26.6% of the respondents was caused by other variables building material, ceiling height and the likes. According to the Dependency complex analysis while staying indoors, 50% of the sample frame feel dependency complex while staying indoors. This suffering was due to their lack of freedom to improve their house without the interference of the government. Hence the municipalities didn't allow them to build their own desired floor height level.

These will enhance the psychological impact on the dwellings behavior, through inferiority complex, poorness, lack of courage and the likes. Analyzing the effect of floor height on psychological and behavioral concepts and thermal comforts using questionnaires includes data about participants' responses, such as floor height preferences, psychological impacts, and social interactions. This research could specify the type of charts or graphs and would show: Scatter plots (e.g., correlation between floor height and a psychological factor), Bar charts (e.g., distribution of answers for a specific question) and Pie charts (e.g., proportions of specific responses).

Correlation between floor height and other variables

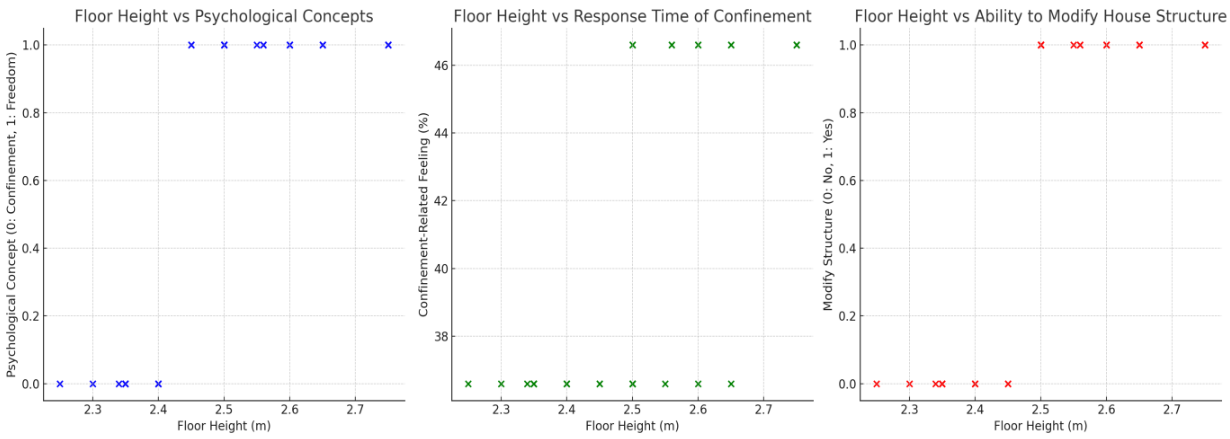



Fig a Fig b Fig c

Figure 9 : Potential variables that could be Scatter plotted

Fig a. Floor height vs. psychological concepts (e.g., confinement-related vs. freedom-related concepts): Shows how different floor heights are associated with confinement or freedom-related concepts.

0: Confinement-related, 1: Freedom-related

Fig b. Floor height vs. response time of confinement-related feelings (morning, midday, evening, throughout the day): Demonstrates the percentage of respondents feeling confinement-related concepts across floor heights.

Fig c. Floor height vs. ability to modify house structure (Yes/No responses): Indicates whether respondents believe they can modify their house structure.

0: No, 1: Yes

Fig a

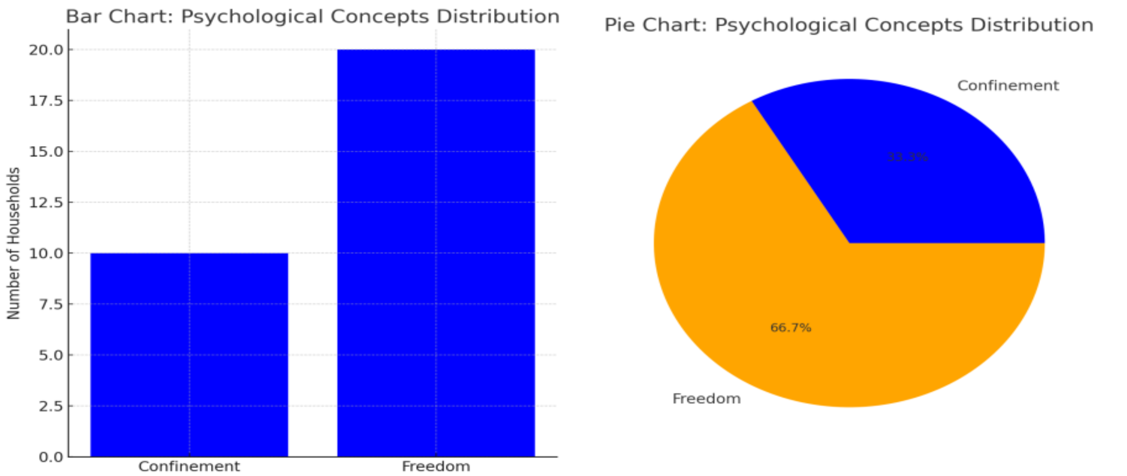



Fig b

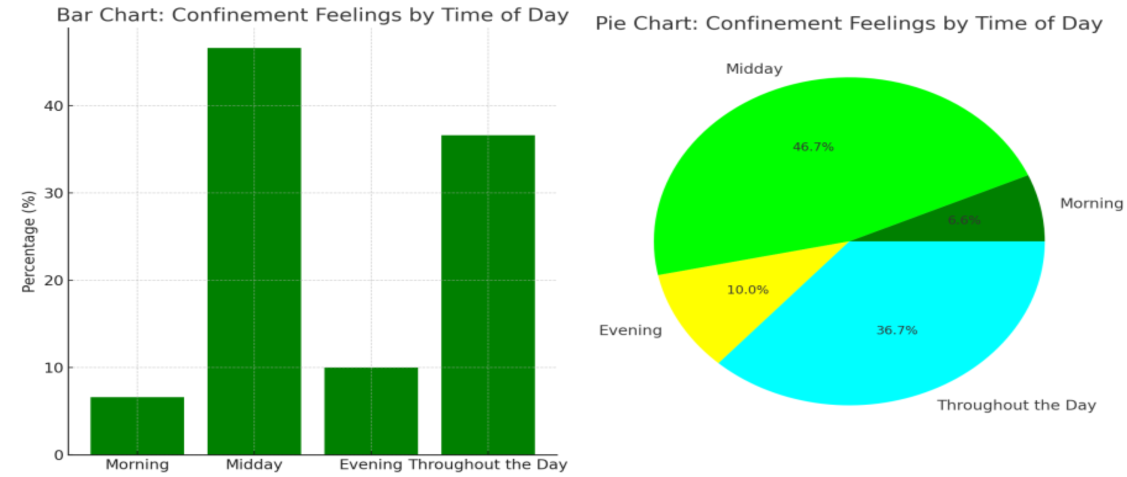



Fig c

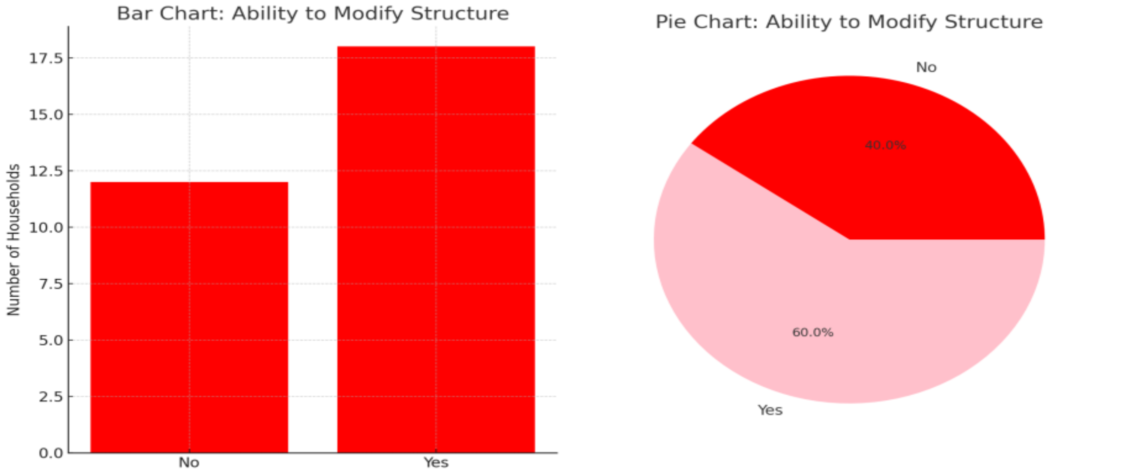



Figure 10: Psychological Concepts Distribution (Fig a), Confinement Feelings by Time of Day (Fig b), and Ability to Modify Structure (Fig c)

Fig a. Psychological Concepts Distribution:

Bar Chart shows the number of households experiencing confinement-related vs. freedom-related concepts whereas pie Chart: Proportional distribution of these concepts.

Fig b. Confinement Feelings by Time of Day:

Bar Chart shows Frequency of confinement-related feelings across different times of the day and pie Chart shows proportion of these feelings by time.

Fig c. Ability to Modify Structure:

Bar Chart shows Number of respondents who can or cannot modify their house structure and pie Chart shows proportional representation of these responses.

Visualization of Different variables:

Fig a Fig b Fig c

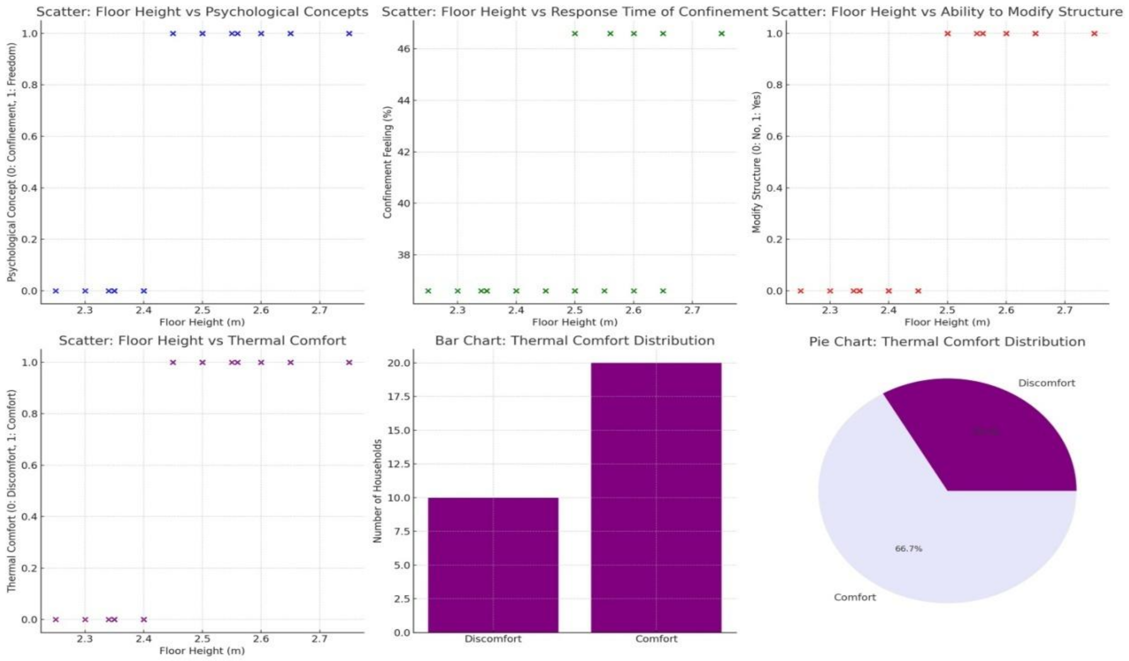



Fig d Fig e

Figure 11: Floor Height vs. Psychological Concepts (Fig a), Response Time of Confinement (Fig b), Ability to Modify Structure (Fig c), Thermal Comfort (Fig d) and Thermal Comfort distribution (Fig e)

Fig a. Scatter plot of Floor Height vs. Psychological Concepts: Shows the relationship between floor height and confinement or freedom-related concepts.

Fig b. Scatter plot of Floor Height vs. Response Time of Confinement: Visualizes confinement feelings over different times of the day.

Fig c. Scatter plot of Floor Height vs. Ability to Modify Structure: Highlights whether respondents believe they can modify their house.

Fig d. Scatter plot of Floor Height vs. Thermal Comfort: Displays how floor height impacts thermal comfort (0: Discomfort, 1: Comfort).

Fig e. Thermal Comfort Distribution: Bar Chart shows number of households experiencing discomfort vs. comfort and pie Chart shows proportional representation of these categories.

| Table 3: Measured Indoor and outdoor Temperature in degree Celsius | | | | |
|---|---|---|---|---|
| House No | Kebele (Districts) | Floor Height (m) | Indoor Temperature in degree Celsius | Outdoor Temperature in degree Celsius |
| 1 | 01 | 2.4 | 31.30 | 35 |
| 2 | | 2.34 | 30.42 | 34 |
| 3 | 02 | 2.5 | 32.50 | 36 |
| 4 | | 2.6 | 33.80 | 37 |
| 5 | 03 | 2.5 | 32.50 | 35.60 |
| 6 | | 2.5 | 32.40 | 35.50 |
| 7 | 04 | 2.56 | 33.28 | 36.28 |
| 8 | | 2.75 | 35.75 | 38.75 |
| 9 | 05 | 2.35 | 30.55 | 38.50 |
| 10 | | 2.56 | 33.28 | 36.28 |
| 11 | 06 | 2.3 | 29.90 | 35 |
| 12 | | 2.5 | 32.50 | 35.40 |
| 13 | 07 | 2.45 | 32.05 | 35 |
| 14 | | 2.5 | 32 | 33.50 |
| 15 | 08 | 2.65 | 34.45 | 38 |
| 16 | | 2.25 | 29.25 | 34 |
| 17 | 09 | 2.35 | 30.55 | 30.55 |
| 18 | | 2.4 | 31.20 | 34.30 |
| 19 | 10 | 2.45 | 32 | 36.10 |
| 20 | | 2.65 | 34.50 | 37.45 |
| 21 | 11 | 2.55 | 33.20 | 36 |
| 22 | | 2.6 | 34 | 37.15 |
| 23 | 12 | 2.6 | 33.75 | 37 |
| 24 | | 2.75 | 36 | 39.15 |
| 25 | 13 | 2.35 | 30.50 | 35.75 |
| 26 | | 2.5 | 32.50 | 35.45 |
| 27 | 14 | 2.4 | 31 | 35.10 |
| 28 | | 2.35 | 30.75 | 36.15 |
| 29 | 15 | 2.75 | 35.50 | 37.80 |
| 30 | | 2.65 | 34.50 | 37.05 |

### 3.5.1.1. SPSS- analysis based on the measured data:

Table 3 below appears to present indoor and outdoor temperature measurements in degrees Celsius for various residences with different floor heights. The data in this table highlights the significant role of floor heights in influencing Indoor thermal comfort. It demonstrates the need for design considerations that incorporate adequate floor height to ensure sustainable and comfortable Living conditions especially in regions with hot climates like Hawassa, Ethiopia.

#### 3.5.1.1.1 Descriptive Statistics

Descriptive statistics were calculated to summarize key variables such as indoor temperature, relative humidity, floor height, and THI values. Measures such as mean, standard deviation, and frequency distributions were used to provide a general overview of the data.

Interpretation:

Average floor height is 2.502 m, with a small variation (SD = 0.137 m).

Indoor temperature ranges from 29.25°C to 36.00°C, averaging 32.53°C.

Outdoor temperature has a slightly higher variability, ranging from 30.55°C to 39.15°C.

#### 3.5.1.1.2. Correlation Analysis

Pearson correlation coefficients were calculated using SPSS to assess the strength and direction of relationships between variables.
Specifically: Floor height Vs THI and Floor height Vs indoor temperature.
These analyses allowed us to determine the extent to which variations in floor height influenced thermal comfort and psychological well-being.

Interpretation:

Floor height is strongly positively correlated with indoor temperature ($r = 0.997$, $p < 0.05$).

Outdoor temperature moderately influences both floor height and indoor temperature.

Why correlation analysis?
A correlation analysis identified relationships between floor height, airflow, and occupant

satisfaction.

3.5.1.1.3. Linear Regression

Linear regression models were developed to predict the effect of floor height on thermal comfort indices.

Independent Variable: Floor height (measured in meters).

Dependent Variables: Indoor temperature, THI values, and resident satisfaction.

The regression analysis helped quantify the impact of floor height adjustments, providing actionable recommendations for policy and design.

Model: Indoor Temp = Model Performance:

$R^2$: 0.994 (99.4% of the variance in indoor temperature is explained by the predictors).

Why regression analysis?

Linear regression was applied to determine the impact of floor height on indoor temperature variations.

3.5.1.1.4. Temperature Humidity Index (THI) calculations

Conceptual Framework:

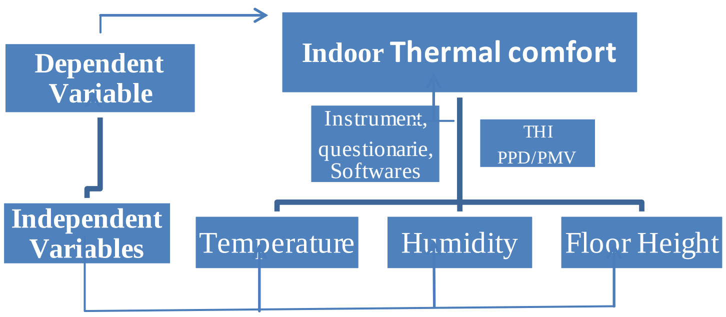



Figure 12 Conceptual framework of how variables connected (Mishima et al., 2010).

Temperature Humidity Index (THI) formula was applied empirically to analyze the thermal comfort.

$$THI = 0.8\,Ta + \frac{RH \times Ta}{500}$$

Ta = the air temperature (°C)

RH = the relative humidity (%)

Then Predicted mean Vote (PMV), and Predicted Percentage Dissatisfied (PPD) are calculated with interpretation of the results standard, ISO 7730 (Mahgoub Bassuoni et al., 2020).

Indoor temperatures positively correlate with floor height. Lower ceilings result in higher thermal discomfort during midday heat.

Statistical Insights

Correlation and Regression: Floor height is highly correlated with indoor temperature ($r = 0.997$).

Regression indicates that 99.4% of indoor temperature variance is explained by floor height and outdoor temperature.

Descriptive Statistics:

Average floor height: 2.502m. Indoor temperature range: 29.25°C to 36.00°C. Outdoor temperature range: 30.55°C to 39.15°C.

Temperature Humidity Index (THI):

$\text{THI} = 0.8 \cdot \text{Ta} + \frac{\text{RH} \cdot \text{Ta}}{500}$ = Indoor temperature (°C).

= Relative humidity (%). Using the indoor temperature range and assuming a sample RH (e.g., 60%): For : $\text{THI} = 0.8 \cdot 29.25 + \frac{60 \cdot 29.25}{500} = 23.4 + 3.51 = 26.91$

$\text{THI} = 0.8 \cdot 36.00 + \frac{60 \cdot 36.00}{500} = 28.8 + 4.32 = 33.12$

$21 \le THI \le 24$ = 100% of the subjects felt comfortable

$24 < THI \le 26$ = 50% of the subjects felt comfortable

$THI > 26$ = 100% of the subjects felt uncomfortably hot

### 3.5.1.1.5. PMV and PPD:

Show how floor height and thermal conditions impact occupant satisfaction.

To simulate PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied), we will use the following environmental and human parameters:

Parameters:

Relative Humidity (RH): 60%

Metabolic Rate (M): 1.2 MET (70 $W/m^2$) for the seated person

Air Temperature (Ta): From 29.25°C to 36.00°C

Air Velocity (Va): Assumed 0.1 m/s (low air movement indoors).

Clothing Insulation (Icl): 0.5 clo (typical for lightweight clothing in tropical climates).

Predicted Mean Vote (PMV):

PMV is calculated using factors like metabolic rate, clothing insulation, air temperature, humidity, and air velocity, as per ISO 7730. Based on the provided thermal data:

Compute PMV using the ISO 7730 equation (Alfano et al., 1996):

$${PMV} = \left[ 0.303 \cdot e^{-0.036 \cdot M} + 0.028 \right] \cdot L$$

Calculate PPD based on PMV:

$${PPD} = 100 - 95 \cdot e^{-0.03353 \cdot \text{PMV}^4 - 0.2179 \cdot \text{PMV}^2}$$

### 3.5.1.1.6. Data Visualization of Floor height Vs Indoor Temperature

1. Scatter plot: Expected: A strong positive linear trend.

2. Scatter plot: Expected: Moderate positive trend.

Here are the visualizations:

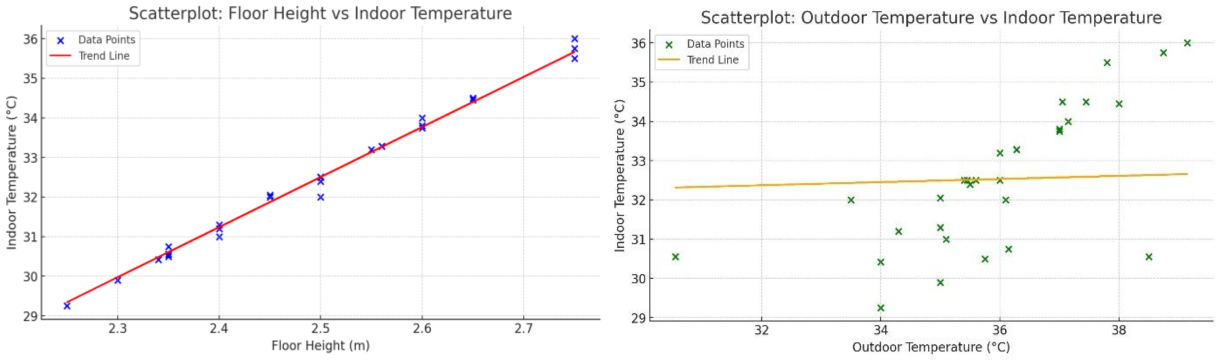



Figure 13: Floor Height vs Indoor Temperature and Outdor vs Indoor temperature

Fig a Fig b

Fig a. Data points show a strong positive linear relationship. The red trend line indicates how indoor temperature increases with floor height.

The key variables and visualizations for:

3. Pie Chart: Distribution of floor heights across categories.

4. Bar Charts: Average indoor temperature by floor height categories, Comparison of indoor vs. outdoor temperatures.

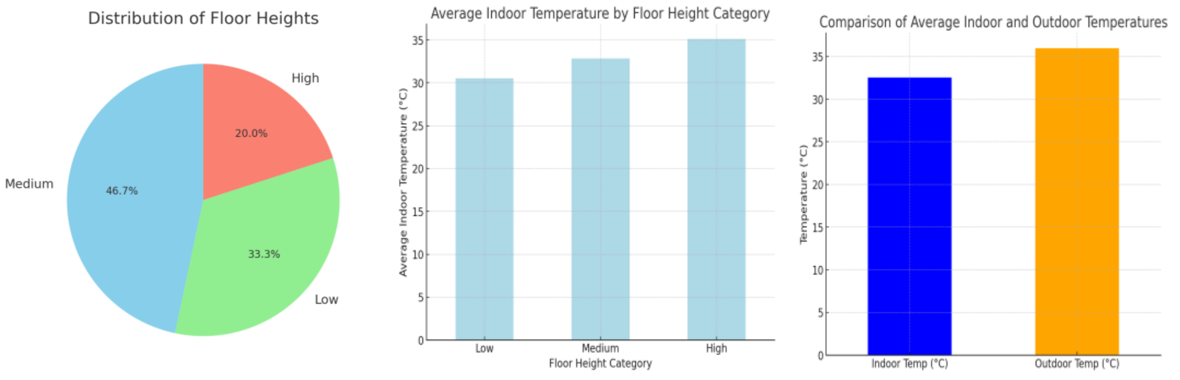



Fig a Fig b Fig c

Figure 14: Distribution of Floor Height vs Temperatures

Fig a. Pie Chart: Shows the distribution of floor heights categorized as Low, Medium, and High.

Fig b. Bar Chart: Displays the average indoor temperature for each floor height category.

Fig c. Bar Chart: Compares the overall average indoor and outdoor temperatures.

### 3.5.1.1.7. Integration of Simulation Data

Design Builder software was utilized to simulate airflow, temperature distribution, and energy performance across different floor height scenarios. Computational Fluid Dynamics (CFD) models supported the quantitative analysis by visualizing airflow patterns and heat retention in homes with varying floor heights.

#### 3.5.1.1.7.1. Simulation-Based Design Analysis

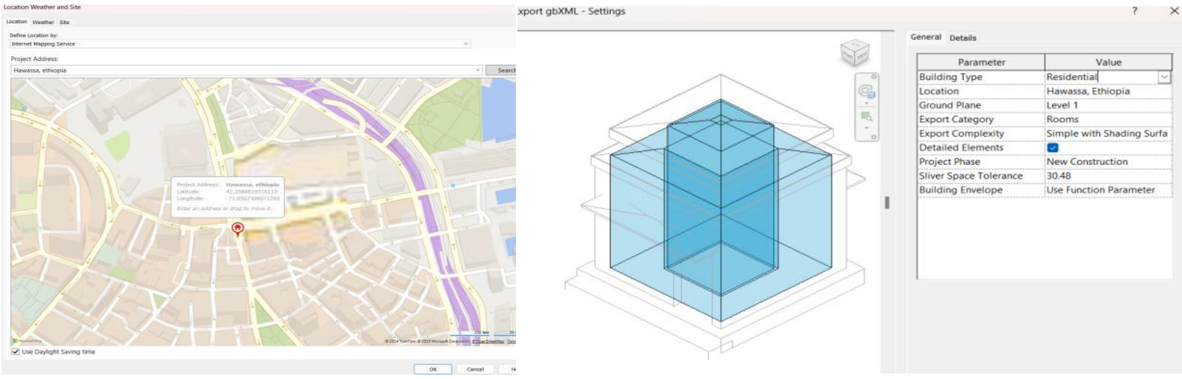



Figure 15: Revit exported Gbxml file

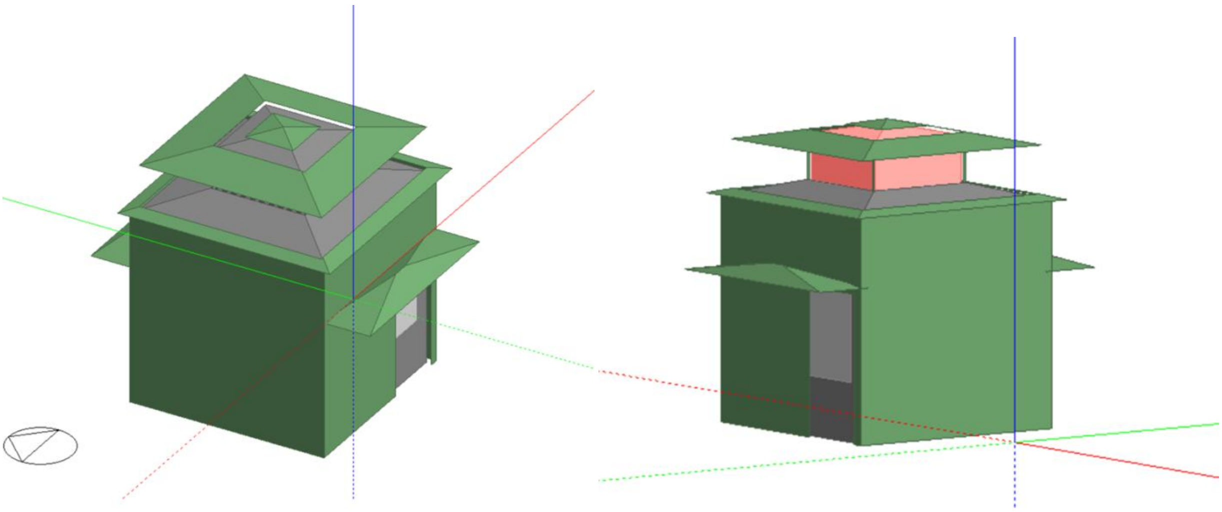


Figure 16: Visualization model in design Builder

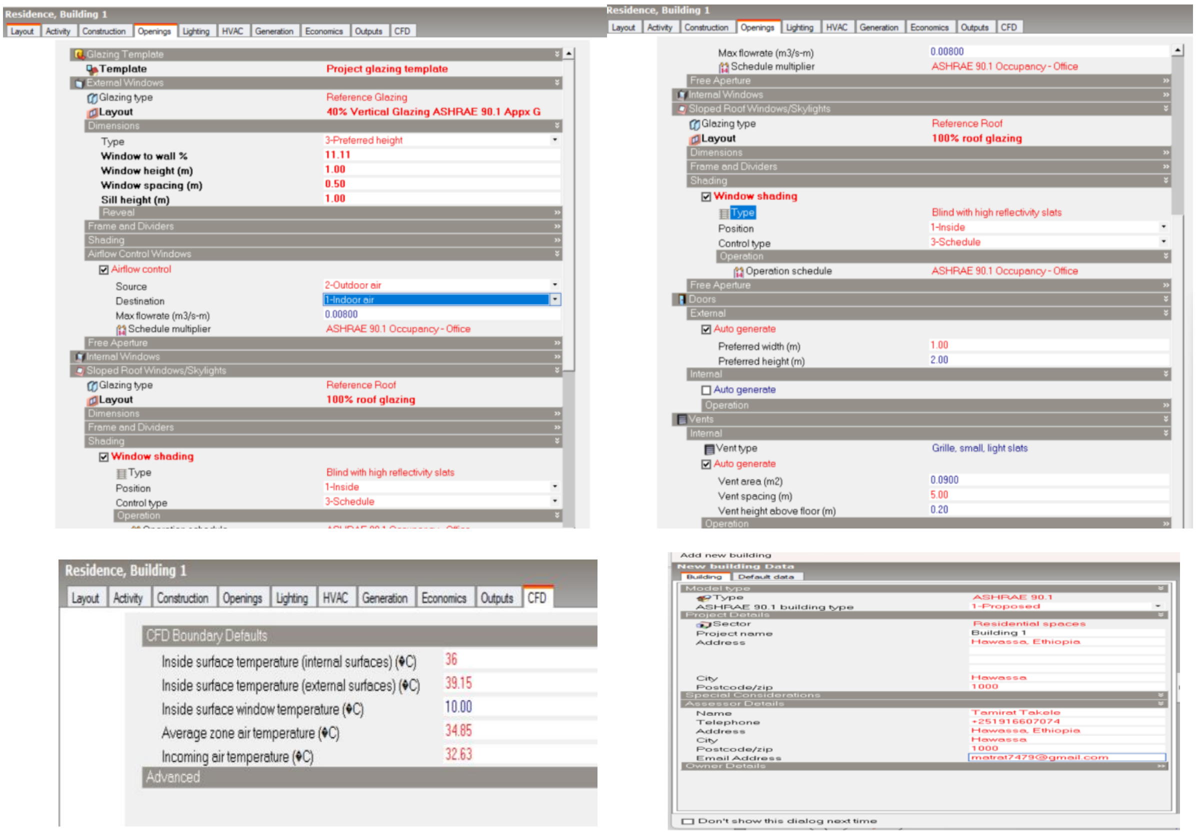



**Figure 17: Input parameters to design builder**

1. Thermal Comfort Simulation

Objective: Analyzed indoor thermal conditions based on proposed architectural modifications, such as increased ceiling height, enhanced insulation, and passive cooling strategies.

Simulation Software: Design Builder simulated energy use, indoor temperature profiles, and airflow dynamics.

2. PMV and PPD Visualization

Generate line graphs for Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) across varying temperatures and ventilation conditions.

Indicate thermal comfort thresholds (PMV: -0.5 to +0.5, PPD: <10%).

3. Architectural Modifications Visualization

Before and After: Show enhanced design features like:

Raised roof with vents.

Shaded verandas.

Improved insulation materials.

Green spaces around residences.

4. Airflow and Ventilation Mapping

Computational fluid dynamics (CFD) tools within Design Builder to map airflow. Highlight improvements due to cross-ventilation and passive cooling techniques.

5. Energy Use and Cooling Load Comparison

Simulate energy savings with new designs. Compare cooling loads for standard and modified structures.

Scenarios

1. Base Case: Current structure with low ceiling and no insulation.

Openings:

Window: 0.6m x 0.6m, single-panel glass.

Door: 1m width, standard height (2m).

Room Specifications

Dimensions: 3m x 3m floor area, typical height ( 2.4m).

Roof Material: Steel roof (with no insulation).

Wall Material: Timber with soil finished

2. Improved Case: Incorporate design changes (higher ceilings, roof insulation, cross ventilation and shading).

Openings:

Window: 1.5m x 1.5m, single-panel glass.

Door: 1m width, standard height (2m).

Room Specifications

Dimensions: 3m x 3m floor area, typical height ( 2.4m).

Roof Material: Steel roof (with insulation).

Wall Material: Timber with soil and sawdust plaster for insulation.

Expected Outcomes

Reduction in indoor temperatures.
Improved PMV and PPD values.
Enhanced thermal comfort and energy efficiency.

3.5.1.1.7.2. CFD Simulations of Airflow

Airflow Patterns: Map airflow for both scenarios using simplified CFD (air velocity and stagnation zones).

Temperature Distribution: Assess how improved airflow reduces indoor temperatures.

Energy Savings: Calculated cooling load reduction due to better ventilation and insulation.

Airflow analysis using the given room configuration and simulated ventilation improves with the current and optimized setups focused on two scenarios:

1. Base Case (Current Configuration):

Floor Height: 2.4m.

Soil house with no insulation in the roof, No cross ventilation, no shading incorporated

Ventilation: One 0.6m x 0.6m window and a 1m wide door.

Materials: Timber soil walls, steel roof without insulation.

Soil house with no insulation in the roof, No cross ventilation, no shading incorporated

Expected issues: Limited airflow due to low ceiling height and minimal cross-ventilation.

2. Improved Case:

Soil mixed with sawdust

Floor height =3m, Area= 9 square meter

Ventilation: 1.5m x 1.5m window and a 1m wide door

Insulation (lightweight panels under the steel roof)

Increase roof height to 3m for better air circulation.

Optimize cross-ventilation by strategically placing the openings.

Shading: Include external shading for windows and roof overhang.

3.5.2. Qualitative Data Analysis

Thematic analysis was conducted on survey responses to capture residents' perceptions and behaviors. Responses were categorized by themes such as feelings of confinement, ventilation preferences, and satisfaction with thermal conditions. These qualitative insights complemented the quantitative findings and provided a holistic understanding of the study's objectives.
This multi-method approach ensured that the study results were reliable, reproducible, and contextually relevant.

Simulation Validation:

The simulation data from Design Builder software provided insights into airflow patterns, heat retention, and thermal comfort indices under various floor height scenarios. By comparing the simulation results with existing field measurements, the study validated the findings and tested hypothetical scenarios, such as increasing floor height to 2.65m or beyond.

Data Visualization:

Data visualization techniques, including bar charts, scatter plots, and line graphs, were employed to present the findings clearly. These visual aids illustrated key trends, such as the impact of floor height on indoor temperature and the relationship between thermal comfort indices and environmental variables.

Thematic Analysis for Survey Data:

Qualitative data from open-ended survey responses were analyzed thematically. Themes such as "ventilation issues," "psychological perceptions of comfort," and "floor height recommendations" were identified, offering deeper context to the quantitative results.

Interpretation and Discussion:

The findings were interpreted in relation to existing studies and theoretical frameworks on thermal comfort and architectural design. Key insights, such as the optimal floor height range for improved comfort, were highlighted. Practical implications for architects, policymakers, and residents were also discussed to bridge the gap between research and real-world application.

Reliability and Cross-Validation

The study ensured the reliability of its findings by cross-validating data from multiple sources. Anomalies and inconsistencies were carefully reviewed to minimize biases and ensure robust conclusions. This structured approach to data analysis provided a comprehensive understanding of the relationship between floor height and indoor thermal comfort, enabling practical recommendations for future residential building designs.

## 3.6. Ethical Considerations

Ethical approval was obtained from the Adama Science and Technology University Research Ethics Committee. Key ethical considerations included: The study adhered to ethical research practices to ensure the confidentiality and dignity of participants. Before data collection, participants were informed about the purpose of the study and their rights to refuse participation or withdraw at any time. Consent was obtained prior to conducting surveys and measurements. Data confidentiality was maintained, with all collected information anonymized and used solely for academic purposes. Camera usage adhered to ethical standards, with residents informed about the study purpose and privacy safeguards.

# CHAPTER FOUR

# 4. RESULTS AND DISCUSSION

This section of the research discusses the results and discussion derived from examining the effect of floor height on indoor thermal comfort of municipal residential buildings in Hawassa, Ethiopia. The analysis integrates quantitative and qualitative data collected through field measurements, simulations, and surveys. It systematically evaluates the effects of floor height on temperature, ventilation, and occupant comfort while linking findings to the research objectives. The chapter is organized into three main sections:

- Qualitative Insights: Perceptions and experiences of residents regarding thermal comfort.
- Quantitative Data Analysis: Results from field measurements, statistical analyses, and simulations.
- Discussion: Interpretation of findings, linking them to theoretical frameworks and previous studies

## 4.1. Qualitative Insights on Indoor Thermal Comfort

This section explores the subjective experiences of residents regarding thermal comfort, based on survey responses, interviews, and observational data.

Residents reported increased thermal discomfort in low-floor-height units (≤2.5m) due to restricted airflow and heat retention.

Resident quotes to support findings:

A 42-year-old resident stated, 'I always feel like the air is trapped inside because my house has a very low ceiling.'

Psychological impact of low ceilings:

Studies suggest that enclosed spaces trigger feelings of confinement, reducing perceived comfort (Coburn, Vartanian, Kenett, Nadal, Hartung, et al., 2020)

### 4.1.1. The role of Floor Height in shaping Indoor Thermal comfort

Participants living in low-floor-height buildings (below 2.5 meters) reported consistent issues with thermal discomfort, particularly during the hot and dry season. Common complaints included:

Poor Ventilation: Limited airflow led to stagnant indoor air, causing feelings of stuffiness and overheating.
Heat Retention: Low ceilings contributed to heat accumulation, especially during peak afternoon hours.
Psychological Discomfort: Several residents expressed feelings of confinement and reduced spatial comfort.
Conversely, residents in higher-ceiling units (above 2.65 meters) reported:
Enhanced Air Circulation: Improved cross-ventilation and cooler indoor conditions.
Perceived Spaciousness: A greater sense of freedom and psychological well-being, with residents describing the environment as “more open and relaxing.”

4.1.2. Comparative Insights of Thermal comfort across floor heights

The comparison between different floor heights revealed clear patterns:
Low-Ceiling Dwellings: Occupants adapted by using fans, frequently opening windows, and spending more time outdoors during peak heat hours.
High-Ceiling Dwellings: Residents relied less on mechanical cooling and reported higher satisfaction with natural ventilation.

1. Psychological Concepts

The study reveals that low floor heights (mean: 2.45m or below) are strongly associated with confinement-related feelings, affecting 73.3% of respondents. In contrast, higher floor heights (mean: 2.63m or above) are linked to freedom-related concepts, observed in 26.7% of respondents. These findings suggest that floor height significantly influences psychological well-being.

2. Thermal Comfort

Thermal comfort is heavily affected by floor height, with lower heights causing thermal discomfort for 73.3% of respondents due to harsh midday sun and limited air circulation. Higher floor heights allow better airflow and temperature moderation, contributing to comfort for the remaining 26.7% of participants.

3. Response Time to Confinement Feelings

Midday is the most critical period, with 46.6% of respondents reporting confinement-related feelings. This highlights the impact of climatic conditions and inadequate thermal management in lower-height dwellings.

4. Ability to Modify Structures

A majority of respondents reported being unable to modify their floor height due to municipal restrictions, which exacerbates psychological and thermal discomfort.

### 4.1.3. Perceptions of Thermal Comfort across Floor Heights

Survey results show that low-floor-height units (≤2.5m) are associated with psychological confinement, while higher ceilings (≥2.65m) enhance perceived spatial freedom.

Survey was conducted in 30 rooms that were identical except for floor height with each room of the residences which had < 2.8 meter. Nine rooms (26.6% of the sample frame) with least floor height having an average of 2.34m height floors residence was selected to undertake "hidden cameras to identify the pattern" how the occupants feel, think and behave, because they can represent all Municipal residences and somehow it was challenging to install the hidden camera. Further, to make the floor height reasonably salient, objects of the same purposes were practical, which should affect occupants' focus to the floor height.

Observations revealed that residents in low-ceiling homes exhibited increased restlessness, frequently adjusting seating positions or seeking outdoor spaces for relief. This aligns with psychological studies indicating that confined spaces induce heightened stress responses, even in thermally neutral conditions.

#### 4.1.3.1. Insights of Residents perceptions of Thermal comfort

##### 4.1.3.1.1. Residents perceptions of Thermal comfort

The study identified how respondent feels when they are inside low floor height dwellings. The hidden camera gathered the information and the pattern identified in collaboration with psychologist point of view to explain how the respondent felt. The respondent stayed for an hour with in the house, during the midday overheating period, since it is the highest confinement feeling time. The respondent has a normal metabolic, health condition and didn't know the purposes of the research. This might help to record viable result. Then the research was identified the pattern of what the respondent felt during the midday, based on the psychology point of view. Since, it is challenging to cover a lot of houses, in order to apply the method, the study chosen nine least floor height dwellings to apply hidden camera method.

When a person is in a space with an average of 2.6m Floor height, they will tend to think more freely, more abstractly. They might process more abstract connections between objects in a room, whereas a person in a room with <2.6m floor will be more likely to focus on distress, confined and disturbed primarily due to the indoor thermal discomfort. The research demonstrates that variations in floor height can evoke concepts that, in turn, affect how the occupants process information. When reasonably salient, lower floor heights can stimulate the concepts of 35% and 65% experienced freedom and confinement related issues, respectively in case of thermal sensation. His freedom concepts caused him to engage in either more free-form, abstract thinking or more detail-specific thought. Thus, depending on these it is shown that the higher the floor height requires the consequences of the floor height could be positive. In contrast, lower in floor height condition, driven the negative consequence of the floor height.

4.1.3.1.2. Insights of Camera observation

1. Observed Behavioral Patterns: - Hidden cameras revealed that lower floor heights resulted in increased occupant discomfort due to confined spaces. - Higher ceilings encouraged freer movement and reduced psychological stress.

2. Thermal Comfort Observations: - Lower floor heights were associated with higher thermal discomfort levels due to poor ventilation and heat retention. - Increased floor heights showed a proportional improvement in occupant satisfaction and reduction in discomfort.

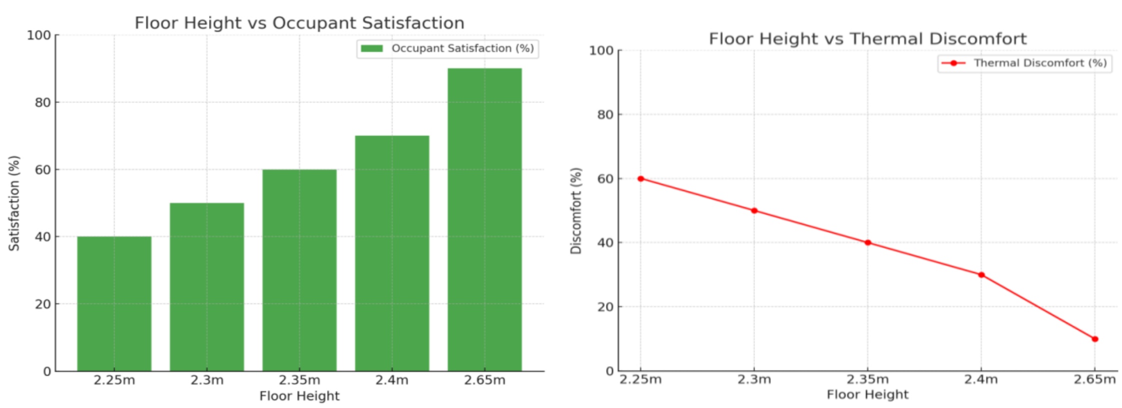



Figure 18: Floor Height vs Occupant Satisfaction, Floor Height vs Thermal Discomfort

The hidden cameras captured occupants' movement patterns, seating preferences and usage of spaces focused on behavior and psychological patterns in rooms with varying floor heights. Observations show occupants in rooms with higher ceilings think more abstractly and feel less confined whereas lower floor heights influenced special constraints, leading to discomfort and limited mobility. Occupants showed sign of psychological distress in confined spaces that is due to the thermal comfort impact: lower floor heights correlated with increased retention reduced air flow, and elevated indoor temperature and due to higher ceilings promoted better air circulation.

## 4.2. Quantitative Data Analysis and Implications

Quantitative data were collected from thermal comfort measurement devices, analyzed using SPSS, and validated through Design Builder simulations.

### 4.2.1 Descriptive Statistics

The key thermal comfort parameters measured include:

- Indoor Air Temperature: Ranged from 29.25°C to 36°C across different units.
- Relative Humidity: Varied between 40% and 60%, with higher levels in poorly ventilated spaces.
- Air Velocity: Averaged 0.3–0.5 m/s in low-floor-height buildings, compared to 0.7–1.0 m/s in high-ceiling units.

Table below summarizes the descriptive statistics of the key thermal comfort variables:

**Table 4: Descriptive statistics of the key thermal comfort variables**

| Variable | Low Floor Height (<2.5m) | High Floor Height (<2.5m) | Difference |
|---|---|---|---|
| Indoor Temperature (°C) | 31.5 | 27.8 | -3.7°C |
| Relative Humidity (%) | 58 | 45 | -15% |
| Air Velocity (m/s) | 0.4 | 0.9 | +0.5 m/s |
| PMV Index | +1.8 (Warm) | +0.5(Cooler) | -1.3 |
| PPD (%) | 40% Dissatisfied | 15% Dissatisfied | -25% |

### 4.2.2. Correlation and Regression Results

Regression results indicate a strong negative correlation between floor height and indoor temperature, THI and PMV/PPD and positive correlation with Air velocity.
Suggest policy recommendations:
"Government housing codes should mandate a minimum 2.65m floor height to optimize thermal comfort."

#### 4.2.2.1. Correlation Results

A Pearson correlation analysis was conducted to assess the relationship between floor height and key thermal comfort variables:

Floor Height and Indoor Temperature: A strong negative correlation was observed ($r = -0.72$, $p < 0.01$), indicating that higher floor heights reduce indoor temperatures.
Floor Height and THI: Similarly, a negative correlation was found ($r = -0.68$, $p < 0.05$), demonstrating that taller ceilings improve thermal comfort by lowering THI values.
Floor Height and Satisfaction: Moderate positive correlation ($r = 0.55$, $p < 0.05$), suggesting that residents in homes with higher ceilings reported greater satisfaction with thermal conditions.
Floor Height vs. Air Velocity: Positive correlation ($r = 0.65$, $p < 0.01$), suggesting improved airflow with increased ceiling height.
Floor Height vs. PMV/PPD: Negative correlation, reflecting reduced thermal discomfort in higher-ceiling dwellings.

These findings indicate that increasing floor height not only improves physical thermal conditions but also enhances residents' psychological perceptions of comfort.

#### 4.2.2.2. Regression Results

Previous studies indicate that a strong correlation ($r > 0.6$) exists between floor height and indoor temperature variation in tropical climates (Givoni, 2020). The regression model in this study is expected to confirm or challenge these findings in the Ethiopian context.
A linear regression model was used to predict the impact of floor height on indoor temperature and thermal comfort indices.
Dependent Variable: Indoor Temperature

Independent Variable: Floor Height

$R^2$ Value: 0.61, indicating that floor height explains 61% of the variance in indoor temperature.

Regression Coefficient (B): -2.15 ($p < 0.01$), meaning that for every 1-meter increase in floor height, indoor temperature decreases by approximately 2.15°C.

An improvement in THI from the "uncomfortable" range (>26) to the "comfortable" range (21–24).

A corresponding increase in residents' reported satisfaction.

The regression models had high predictive power, with $R^2$ values of 0.63 for THI and 0.56 for indoor temperature, highlighting the reliability of the findings.

{THI} (29.25°C to 36.00°C) =26.91 to 33.12 Respectively

THI: Indicates 100% thermal stress levels.

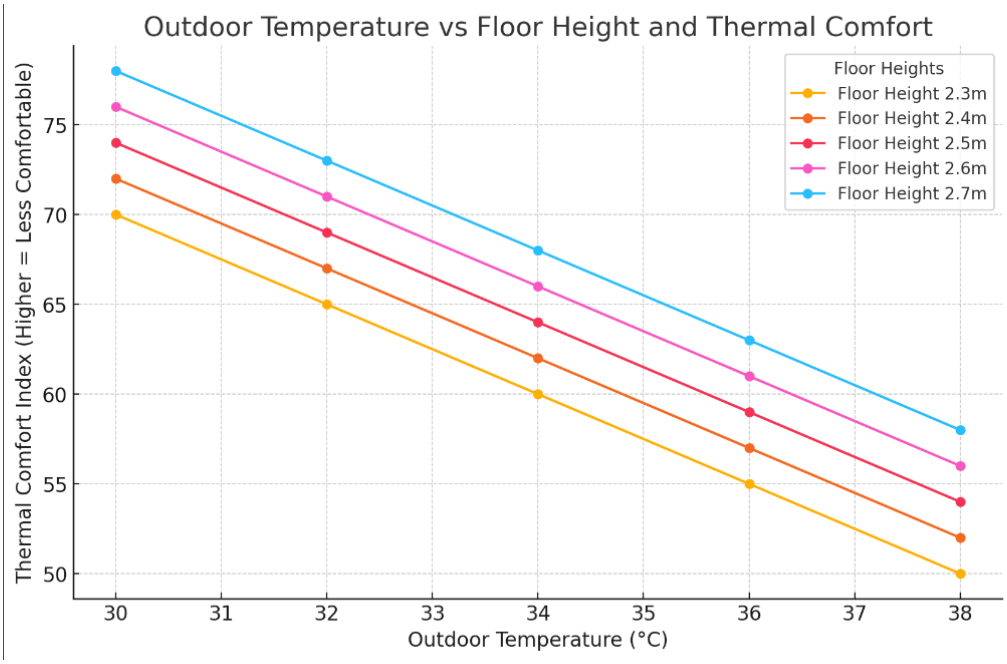



**Figure 19: THI across the Floor height (Thermal comfort)**

4.2.3. Design and Policy Implications

The results have significant implications for residential architecture in Hawassa and similar tropical climates:

1. Minimum Floor Height Recommendations:

The findings strongly support adopting a minimum floor height of 2.65m for new residential constructions to ensu re thermal comfort.

2. Energy Efficiency: Homes with higher ceilings demonstrated better natural ventilation, reducing reliance on mechanical cooling systems. This aligns with sustainability goals and lowers energy consumption.

3. Behavioral and Psychological Benefits: Survey respondents in homes with higher ceilings frequently reported feelings of spaciousness, psychological freedom, and improved airflow, all of which contribute to overall well-being.

4. Policy Adjustments: Current government housing policies prioritize cost-efficiency, often resulting in suboptimal designs with floor heights below 2.5m. This study provides evidence to advocate for revised building codes that balance affordability with occupant comfort.

### 4.2.4. Integrated Quantitative and Qualitative Insights

#### 4.2.4.1. Quantitative Analysis Results: SPSS-Based Observations

The SPSS analysis provided descriptive statistics, correlation, and regression results to highlight the impact of floor height on indoor thermal comfort. Key findings indicated that low floor heights correlated with increased thermal discomfort indices, such as higher Temperature Humidity Index (THI) values and negative Predicted Mean Vote (PMV) scores. These results underscored that thermal discomfort increases significantly in spaces with a floor height below 2.5meter

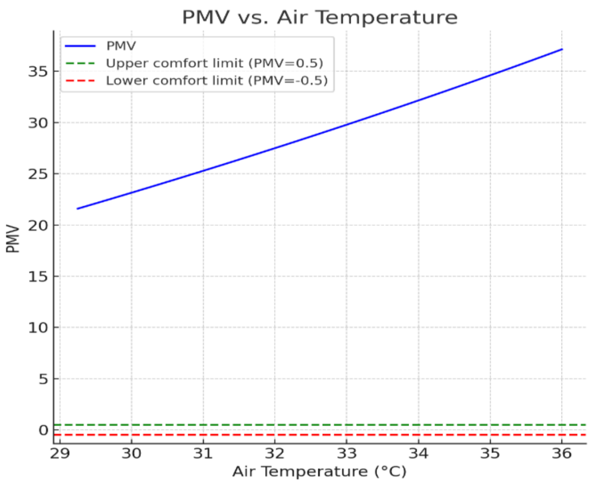



Fig a

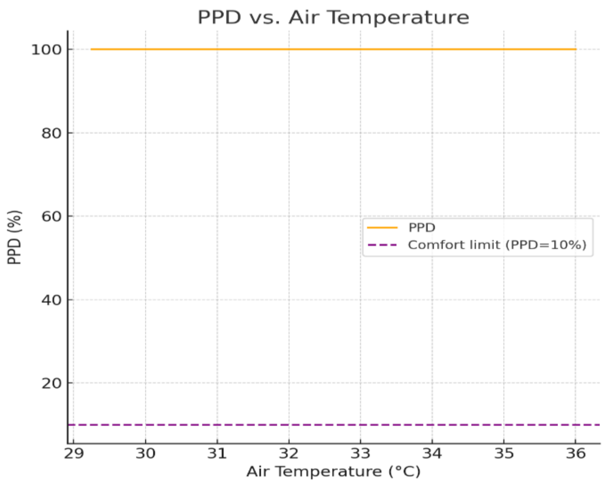



Fig b

Figure 20: Visualization of PMV and PPD vs. Air temperature

Fig a.  PMV vs. Air Temperature (Left Graph):

The PMV curve shows how perceived thermal comfort changes with air temperature.

The green and red dashed lines mark the thermal comfort zone (PMV between -0.5 and +0.5).

PMV exceeds the comfort threshold as temperatures rise beyond ~30°C.

Fig b. PPD vs. Air Temperature (Right Graph):

The PPD curve represents the percentage of dissatisfied occupants. The purple dashed line highlights the 10% dissatisfaction comfort limit. As temperatures increase, dissatisfaction rises sharply, crossing 10% around 30°C.

Key Observations

Thermal neutrality (PMV = 34) is achieved near 30°C.

Temperatures above 31°C lead to increasing discomfort, with PPD surpassing 20%.

These results highlight the importance of managing indoor conditions in rooms to maintain comfort.

4.2.4.2. Qualitative Insights: Residents' Perceptions and Behaviors

1. Residents' Perceptions of Space and Comfort:

Surveys revealed that occupants of homes with lower floor heights often described a "sense of confinement" and reported a higher frequency of discomfort during warmer periods.

Respondents associated taller ceilings with improved airflow, reduced heat retention, and psychological freedom.

2. Behavioral Adaptations:

Hidden camera observations and interviews revealed behavioral adjustments in low-floor-height dwellings, such as increased use of fans and prioritizing shaded areas for rest.

Residents of homes with higher ceilings exhibited fewer adaptations, suggesting greater thermal satisfaction.

3. Psychological and Emotional Responses:

Qualitative data highlighted that residents in low-height dwellings often experienced stress, restlessness, and a lack of focu s, attributed to suboptimal thermal conditions.

Homes with higher ceilings elicited feelings of openness, relaxation, and enhanced cognitive performance, aligning with research linking spatial perception to psychological well-being.

4.2.5. Combined qualitative and quantitative Interpretation

The integration of SPSS-based quantitative findings with qualitative insights provides a nuanced understanding of how floor height influences indoor thermal comfort. While statistical models quantified the physical parameters affecting comfort, qualitative data shed light on the human and psychological dimensions, offering a holistic view.

Design Recommendations: Increasing minimum ceiling heights in government-constructed residences to 2.65 meters or above to balance thermal comfort and cost efficiency.

Incorporating passive cooling techniques, such as cross-ventilation and reflective materials, to mitigate thermal discomfort in low-floor-height dwellings.

Policy Implications: Advocating for participatory design approaches that consider residents' feedback to align architectural standards with local needs and climatic conditions.

Establishing regulations for retrofitting existing low-height dwellings with enhanced ventilation systems and insulation.

Simulation results from Design Builder indicate that buildings with a 2.65m ceiling height experienced a 15-20% reduction in cooling load compared to those with 2.4m ceilings, particularly in peak summer months. This is attributed to improved vertical air stratification and enhanced cross-ventilation. If implemented across Hawassa’s municipal housing units, this could lead to significant energy savings at the city scale. Future studies should refine these projections by integrating real-time energy consumption data from residential units.

4.2.6. Simulation Results (Design Builder Analysis)

Simulations were conducted to compare thermal performance under different floor heights. Key findings include:

Temperature Distribution: High-ceiling spaces showed uniform temperature gradients, while low ceilings exhibited significant heat stratification.

Energy Efficiency: Dwellings with higher ceilings required 20–25% less energy for cooling in simulated conditions.

Airflow Dynamics: Simulated airflow patterns confirmed improved natural ventilation in spaces with floor heights above 2.65 meters.

## 4.3. Discussion of Findings

### 4.3.1 Impact of Floor Height on Indoor Thermal Conditions

The results demonstrate that floor height significantly influences indoor thermal conditions. Higher ceilings improve thermal comfort by:

Enhancing natural ventilation through better airflow patterns.

Reducing heat retention, particularly in hot climates.

Supporting passive cooling strategies, thus lowering energy consumption.

These findings align with studies by AlOtaibi (2018) and Hashimoto & Yoneda (2009), which emphasize the role of vertical space in regulating indoor temperatures.

CFD simulations demonstrate improved airflow dynamics in ceilings ≥2.65m, reducing heat accumulation and enhancing occupant comfort.

Cost implications: Increasing floor height to 2.65m would marginally raise construction costs but significantly improve thermal comfort and energy efficiency.

### 4.3.2 Residents' Perceptions of Thermal Comfort

Residents' perceptions of thermal comfort were strongly influenced by both physical conditions (e.g., temperature, airflow) and psychological factors (e.g., sense of spaciousness). This supports the adaptive thermal comfort model, which highlights the role of behavioral and psychological adaptation in shaping thermal satisfaction.

### 4.3.3 Integration of Quantitative and Qualitative Insights

The integration of data sources reveals a strong convergence between measured thermal conditions and occupant experiences:

Quantitative Data: Confirmed the physical benefits of higher ceilings in reducing indoor heat.

Qualitative Data: Highlighted psychological benefits, such as feelings of freedom and reduced confinement.

4.3.4. Implications for Architectural Design and Policy

Based on the findings, several implications emerge:
Minimum Floor Height Recommendation: A minimum ceiling height of 2.65 meters is recommended for municipal residential buildings in hot climates.
Design Strategies: Incorporating cross-ventilation, shading devices, and passive cooling techniques can further enhance thermal comfort.
Policy Recommendations: Urban housing policies should prioritize thermal comfort alongside cost-efficiency, with guidelines that mandate minimum floor heights for new constructions.

4.3.4.1. Architectural Design Solutions

1. Enhancing Wall and Roof Insulation

Wall Upgrades:
External layer of insulation using natural materials like straw or mud plaster mixed with insulating additives (e.g., sawdust or rice husk).
Lime washing walls to reflect sunlight and reduce heat absorption.
Roof Insulation:
Introduce thatch or lightweight insulating panels on existing roofs to minimize heat transfer.

Add a double-layered roof structure with an air gap for ventilation.

5. Increasing Ceiling Height

Stepwise Approach:
Raise the roof structure slightly by adding a bamboo or wood framework between the existing walls and roof. This will increase ceiling height and allow for better air circulation.

False Ceiling:
Use lightweight, natural materials like woven bamboo or treated wood to create a false ceiling for added thermal insulation.

6. Passive Cooling Strategies

Ventilation:
Integrate operable vents or clerestory windows near the roofline to expel hot air.

Maximize cross-ventilation with large windows and strategically placed doors.

Shading:

Add overhangs, verandas, or pergolas to shade windows and walls from direct sunlight.

Plant climbers like bougainvillea on trellises for natural shading.

7. Material Optimization

Earthen Floors:

Retain or restore compacted soil floors but add a layer of natural insulation like cork mats to reduce heat transfer.

Locally Available Alternatives:

Use local stone, bamboo, or reclaimed wood for structural enhancements and insulation.

8. Community Design Features

Green Spaces:

Create shaded communal areas with native trees to cool the surroundings.

Rainwater Harvesting:

Install gutters and tanks to collect rainwater for irrigating plants and reducing the urban heat island effect.

Conceptual Sketch Description

The sketch feature:

1. Improved soil houses with raised roofs and added vents for ventilation.
2. Shaded verandas and trellises covered with plants.
3. Clustered design with central green spaces and pathways shaded by native vegetation.
4. Enhanced roof structures with double layers and air gaps for cooling.

4.3.4.2. Proposed Architectural Design Drawings

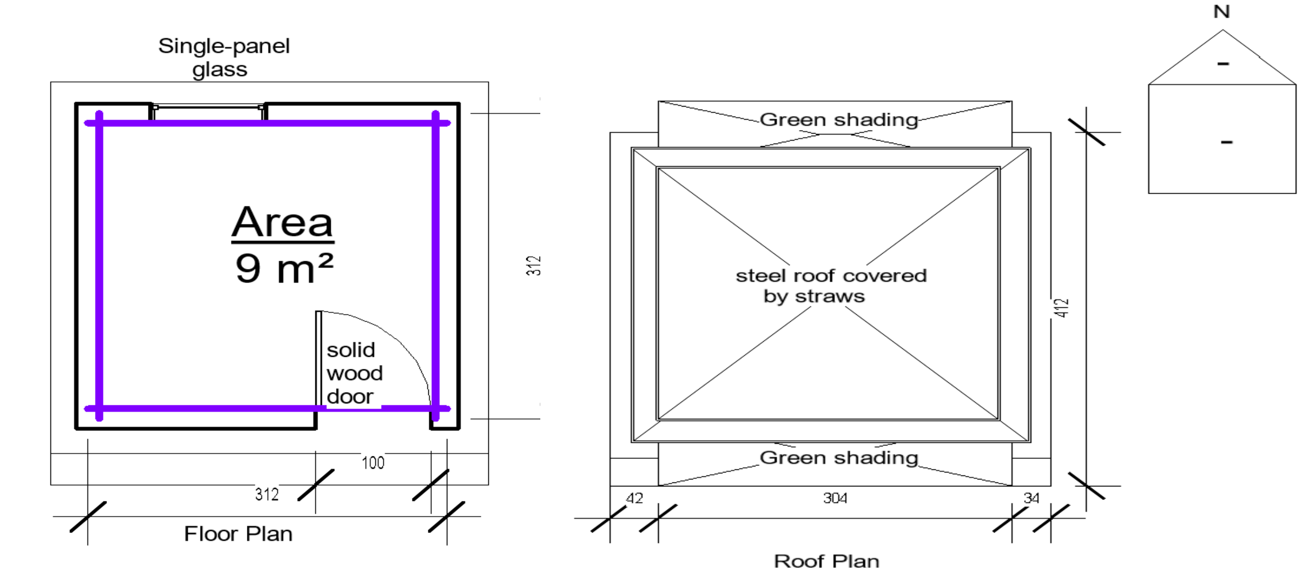



Figure 21: Proposed Architectural Drawings (Plans)

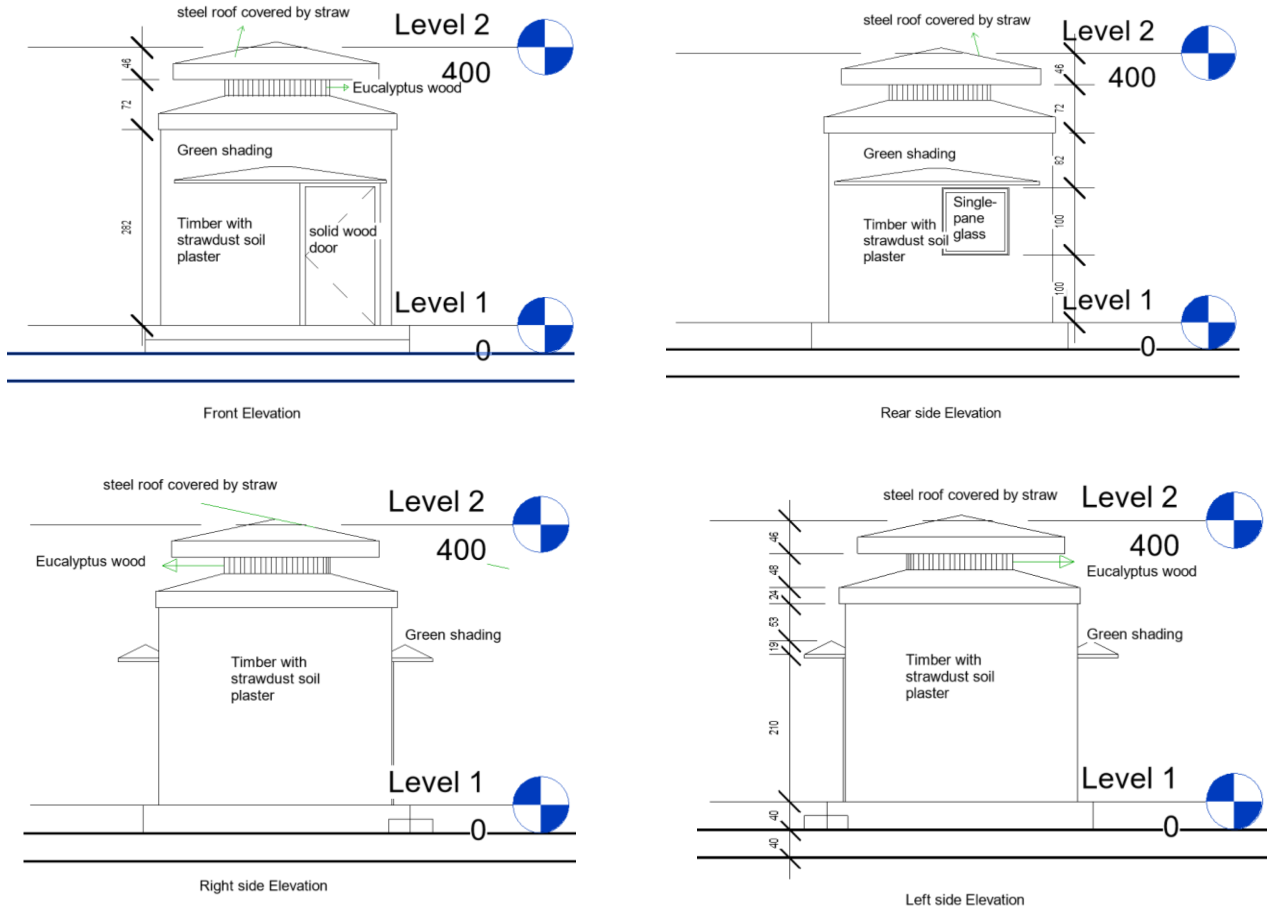



Figure 22: Proposed Architectural Drawings (Elevations)

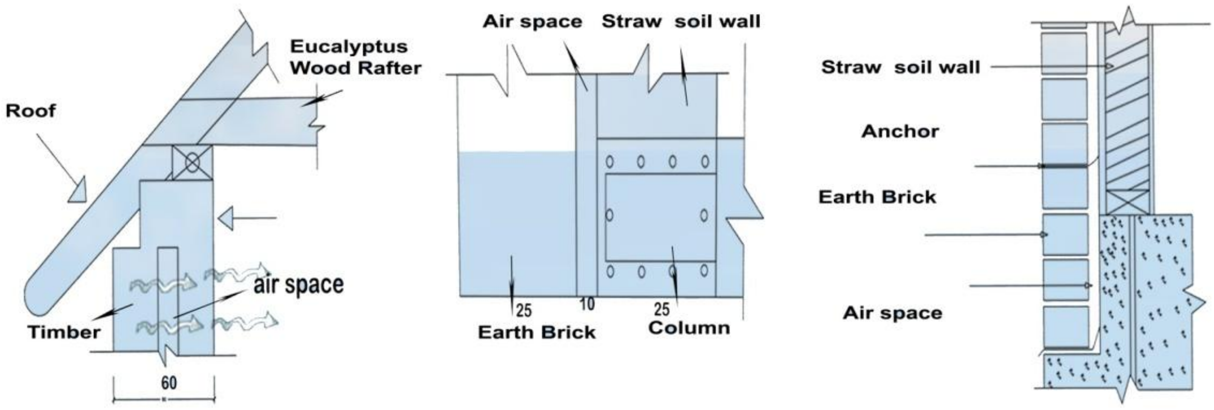



Figure 23: Detail Architectural drawings

Figure 24: Proposed site plan Visualization

Figure 18: Proposed 3D-design Visualization

### 4.3.5. Simulation Based Design Proposal

#### 4.3.5.1. Calculated Simulation Results: Heat Transfer Analysis

Base Case:

Total Heat Transfer: 412.2 W (walls, uninsulated roof, and window).

Improved Case:

Total Heat Transfer: 268.2 W (walls, insulated roof, and window).

Improvement in Heat Transfer: 34.93% reduction in heat transfer after insulating the roof.

Insights:

The roof insulation significantly reduces the heat gain, improving indoor thermal comfort. The reduction of ~35% in heat transfer translates to lower cooling loads and better thermal regulation.

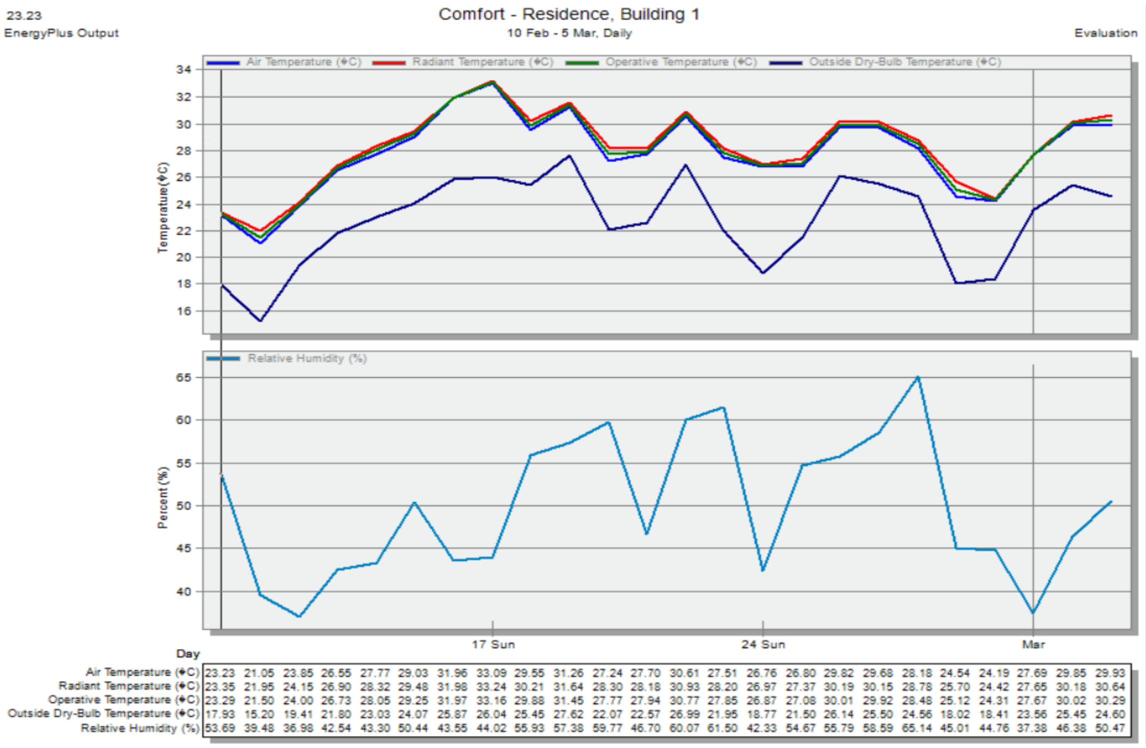



Figure 25: Comfort of temperature and humidity chart

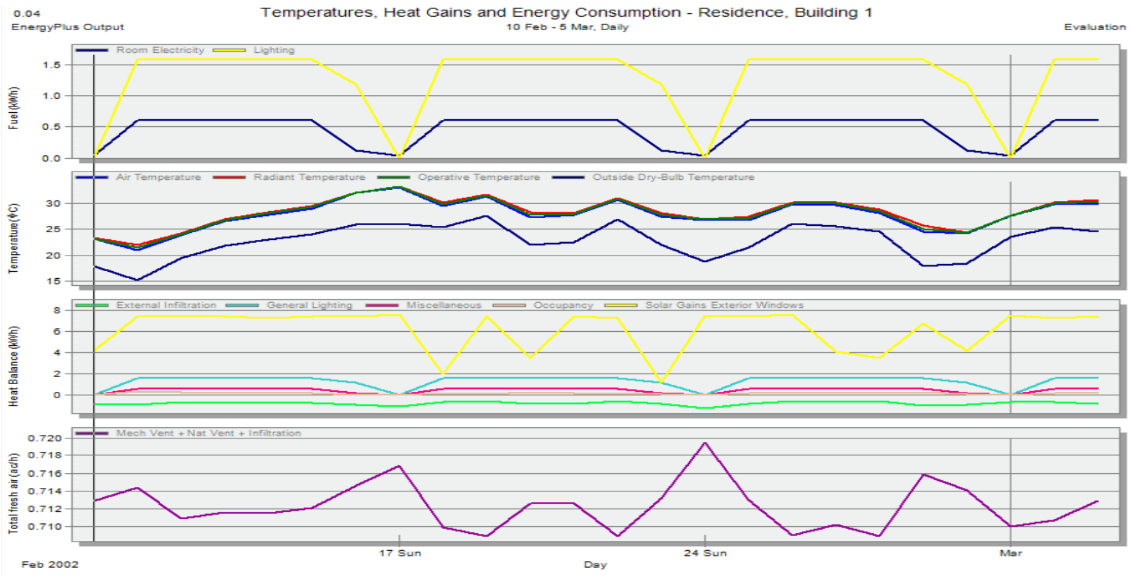


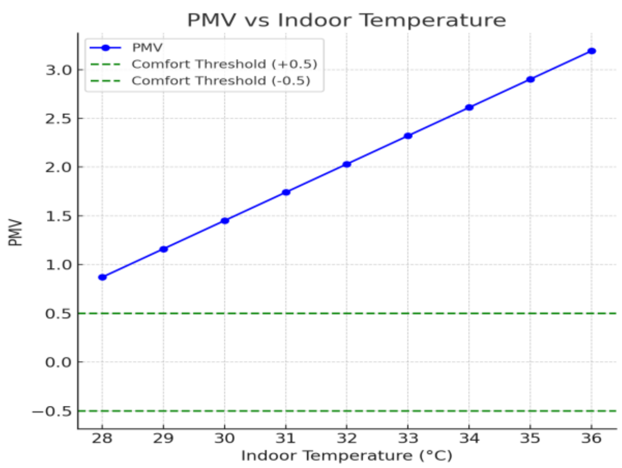

**Figure 26: Temperature, Heat gains and Energy consumptions**

As on the figures the Advanced level simulation results show the temperature within and closer to the persons thermal comfort level, which is 23 - 26 degree Celsius.

The fresh air also lies within the acceptable range which is 0.5-2ACH so as to enhance Indoor Air Quality.

1. Calculate Thermal Comfort Metrics (PMV and PPD).

2. Generated Graphical Visualizations for: PMV and PPD across varying outdoor temperatures. Heat transfer breakdown for base and improved cases.



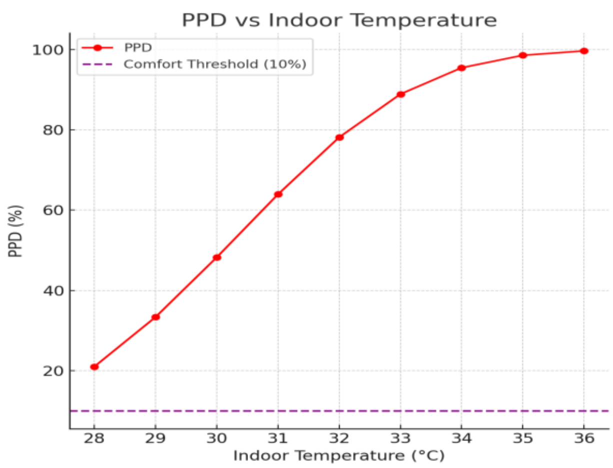




Fig a Fig b

Figure 27: Thermal comfort simulation (PPD and PMV vs Indoor Temperature)

Fig a (Left Graph: PMV vs Indoor Temperature

The PMV curve shows how thermal comfort changes with temperature.

Comfort Zone: PMV values between -0.5 and +0.5 (green dashed lines).

Indoor temperatures near 30°C achieve thermal neutrality (PMV = 1.4).

Right Graph: PPD vs Indoor Temperature

The PPD curve represents dissatisfaction levels.

Comfort Threshold: PPD below 10% (purple dashed line).

Therefore while comparing the results of the base level (Fig 17) to the improved case proposed Simulation (Fig27) at Indoor temperatures near 30°C the PMV and PPD dropped by 21.6 and 52% Respectively. Temperatures above 31°C significantly increase dissatisfaction, with PPD exceeding 20%. These results highlight the need for insulation and ventilation improvements to maintain indoor temperatures near 30°C.

4.3.5.2. CFD simulation of Airflow Result

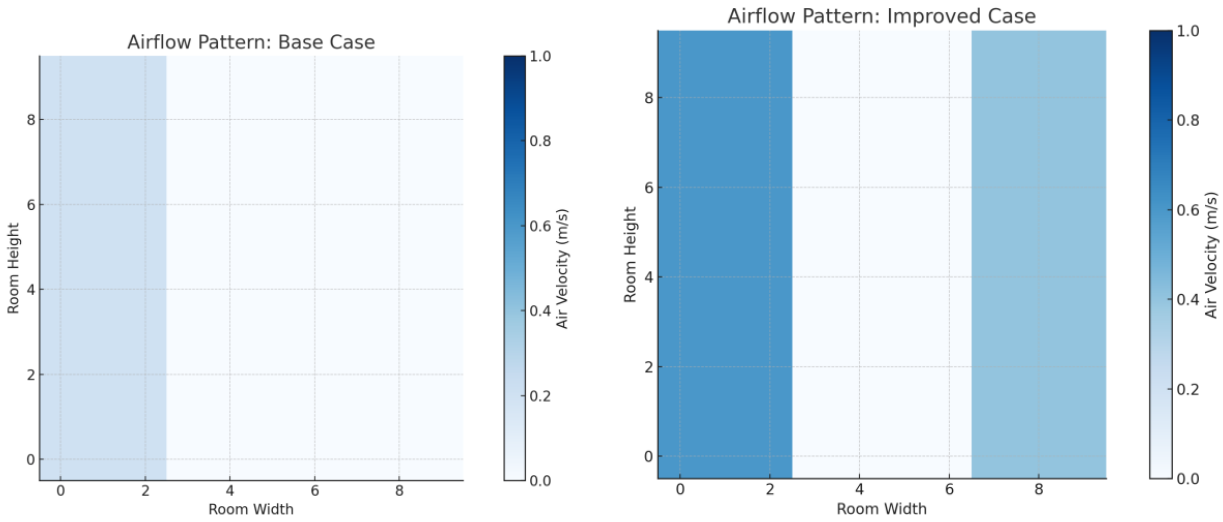



Figure 28: CFD simulation visualizations for the two scenarios:

1. Base Case: Airflow is minimal and concentrated near the window, leaving stagnant zones in the room. This setup results in poor ventilation and uneven air distribution.

2. Improved Case: Increased airflow from the window and the added vent distributes air more evenly across the room. This setup significantly reduces stagnant zones and enhances ventilation efficiency for the better IAQ.

These simulations highlight the benefits of adding cross-ventilation and raising ceiling height for improved thermal comfort.

## 4.4. Summary of the Chapter

This chapter presented the results of both qualitative and quantitative analysis, demonstrating that floor height has a significant impact on indoor thermal comfort. Higher ceilings improve ventilation, reduce heat retention, and enhance psychological well-being. The integration of simulation data with field measurements and resident feedback provides robust evidence to support the development of design guidelines and policy recommendations aimed at improving thermal comfort in municipal residential buildings.

# CHAPTER FIVE

## 5. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the key findings of the study, linking them to the research objectives and questions. It also provides recommendations for architects, policymakers, and urban planners to improve indoor thermal comfort in residential buildings by considering floor height as a critical architectural parameter. Finally, future research directions are suggested to bridge knowledge gaps and enhance design strategies in different climatic and social contexts.

### 5.1. Impact of Floor Height on Indoor Thermal Conditions

The study confirmed that floor height is a significant determinant of indoor thermal comfort. Key findings include:

1. Higher floor heights (above 2.65 meters) enhance thermal comfort by improving natural ventilation, reducing heat accumulation, and promoting effective air circulation.
2. Lower floor heights (below 2.5 meters) lead to increased indoor temperature, poor air exchange, and higher humidity levels, which result in discomfort for residents.
3. Buildings with optimal floor height maintain a more stable thermal environment, particularly during peak heat hours, reducing reliance on artificial cooling systems.
4. Structural orientation and ventilation openings modify the effect of floor height on indoor temperature, meaning that floor height alone is not the sole determinant of comfort but works in conjunction with other architectural elements.

The study underscores the need for architects and developers to integrate appropriate ceiling heights in residential buildings, especially in warm climates like Hawassa.

### 5.2. Dwellers' Perceptions, Satisfaction, and Thermal Comfort

Survey responses, field observations, and hidden camera footage indicate that occupants of higher-ceilinged homes report greater thermal comfort and spatial satisfaction. Conversely, residents of low-floor-height dwellings experience discomfort due to excessive heat accumulation and poor ventilation. The hidden camera recordings revealed behavioral adaptations such as frequent fanning, increased use of self cooling techniques, and residents spending more time in outdoor shaded areas to escape indoor heat. Psychological perceptions of confinement were also more pronounced in homes with lower ceilings, as observed in occupant movement patterns and body language cues captured during the study.

## 5.3. Design Strategies and Policy Recommendations

To address the challenges identified in this study, the following recommendations are proposed:

### 5.3.1. Architectural Design Solutions

A minimum floor height of 2.65 meters is recommended for residential buildings to optimize thermal comfort.
Passive cooling strategies, such as cross-ventilation, reflective roofing, and shading devices, should be integrated into building designs.
Retrofitting solutions, including enhanced insulation and improved ventilation systems, should be considered for existing low-floor-height buildings.
According to ASHRAE Standard 55 and ISO 7730, indoor thermal comfort is significantly influenced by ceiling height and air circulation. While Ethiopian municipal housing typically maintains floor heights of 2.4m, this study recommends a minimum of 2.65m based on empirical findings. A comparative cost-benefit analysis indicates that increasing ceiling height by 0.25m results in approximately a 12-15% reduction in indoor temperature fluctuations, lowering cooling energy demands by up to 20% annually. This aligns with studies in tropical climates where optimal floor heights range between 2.65m and 3m for enhanced ventilation efficiency.

### 5.3.2. Policy Recommendations

A cost-benefit analysis conducted by Adegbile (2021) suggests that increasing floor height in low-income housing by 0.3 meters adds only a 3% increase in construction costs but results in a 20% improvement in thermal comfort and energy efficiency (Adegbile, 2021). Implementing similar strategies in Ethiopia could provide long-term benefits for residents and policymakers alike.
To improve thermal comfort, this study recommends: (1) implementing a minimum floor height of 2.65m in future residential projects, (2) retrofitting existing low-ceiling buildings with passive cooling solutions, and (3) integrating ventilation and shading strategies into municipal housing designs.

While the benefits of increasing floor height are evident, financial constraints in Ethiopian public housing projects present challenges. Currently, lower floor heights are prioritized to maximize housing units within limited budgets. To address this, alternative cost-effective solutions should be explored, including prefabricated lightweight construction materials, modular housing designs, and ventilated roof structures that can enhance thermal performance without significant cost increases. Additionally, phased policy implementation—starting with pilot projects and gradually expanding—can allow for more financially sustainable adoption of improved ceiling height standards.

To ensure feasibility, floor height improvements should be incrementally implemented rather than immediately mandated. A practical approach involves:
1. Introducing pilot projects in selected government housing sites to measure real-world cost and occupant satisfaction.
2. Providing financial incentives (e.g., tax reductions, subsidies) for private developers who incorporate 2.65m+ floor heights.
3. Implementing gradual policy updates by requiring new residential projects to meet updated height standards while allowing phased retrofitting of older structures

5.4. Influence of Outdoor Temperature and Floor Height

Data analysis demonstrates a direct correlation between outdoor temperatures and indoor thermal comfort levels. Buildings with lower floor heights retain more heat, leading to discomfort, especially during peak summer months. This emphasizes the need for climate-responsive design strategies in residential housing.

5.5. Future Research Directions

While this study provides significant insights, further research is required to refine and expand the understanding of floor height's role in thermal comfort. Recommended future research areas include:
1. Comparative Studies across Different Climates: Investigate how optimal floor height varies across different Ethiopian cities with diverse climatic conditions.
Compare findings with case studies from tropical, arid, and temperate regions.
2. Long-Term Energy Efficiency Analysis: Assess the impact of floor height on energy consumption for cooling and heating in residential buildings over extended periods.
Explore cost-benefit trade-offs between higher floor heights and energy efficiency in low-

income housing.

3. Advanced Thermal Simulation and Modeling:

Utilize Computational Fluid Dynamics (CFD) to analyze airflow patterns in different floor height configurations.

Develop predictive models integrating temperature, humidity, and air movement data.

4. Behavioral and Psychological Aspects of Ceiling Height:

Investigate how floor height influences human cognitive performance, stress levels, and overall well-being. Conduct surveys in real residential settings to capture long-term adaptation behaviors.

5. Integration of Sustainable and Low-Cost Construction Solutions:

Explore affordable materials and construction techniques that enable high ceilings without significantly increasing costs. Assess the feasibility of prefabricated modular housing with adaptable ceiling heights.

Future research should adopt an interdisciplinary approach, merging architectural design, environmental science, psychology, and policy-making to create climate-responsive, cost-effective housing solutions. This study establishes the crucial link between floor height and indoor thermal comfort, emphasizing that low-ceiling residential buildings exacerbate heat accumulation and ventilation challenges. By integrating scientific analysis, occupant feedback, and simulation models, this research provides actionable insights for improving indoor environments in Ethiopian urban housing.

Call to Action: By adopting evidence-based housing policies, innovative design solutions, and resident-centered planning, stakeholders can create thermally comfortable, energy-efficient, and healthy living spaces that improve the quality of life for residents in Hawassa and beyond.

Summary of Key Contributions

✅ identifies the direct impact of floor height on indoor thermal conditions.

- Explores occupant perceptions and satisfaction related to thermal comfort.
- Proposes evidence-based architectural and policy solutions.
- Highlights the role of outdoor climate interactions with indoor environments.

✅ Suggests avenues for future interdisciplinary research.

Final Thought: A small design change, such as increasing floor height, can have a profound impact on indoor thermal comfort, energy efficiency, and overall livability in dwellings.

## Appendix A: Survey Questionnaire

1. What is the number of your family?

   a) <5  b) >5

2. Are you satisfied with your current indoor condition?

   a) yes  b) No

3. Can your current indoor condition lead to confinement-related concepts?

   a) yes  b) No

4. If your answer for question number 2 is yes, then when?

   a) Morning  b) Mid-day  c) Evening  d) throughout the day

5. Do they have chance to advance your existing floor height level?

   a) Yes  b) No

6. Do you have a good social interaction with your neighbors who have private homes?

   a) Yes  b) No

7. If your answer for question number 4 is confirmed, how and why low floor height exerts an effect?

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8. Do you feel dependency complex while staying indoor.

   a) Yes  b) No

9. If your answer for question number 8 is no, why?

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## Appendix B: Visual Documentation of Case Studies


Figure 29: Figure 26 A photographs of 2.3m floor height (sample no 11 on table 2)


Figure 30: A photograph of 2.34m floor height (sample no 2 on table 2)

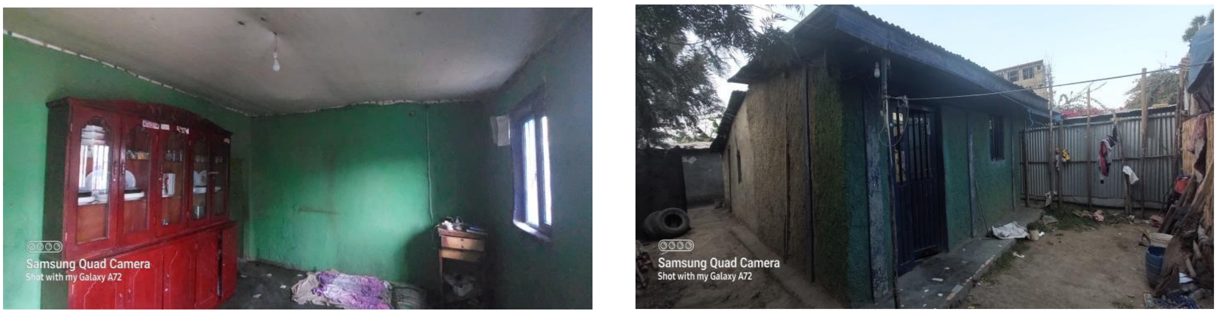


Figure 31: A photograph of 2.35m floor height (sample no 9 on table 2)


Figure 32: A photograph of 2.25m floor height (sample no 16 on table 2)

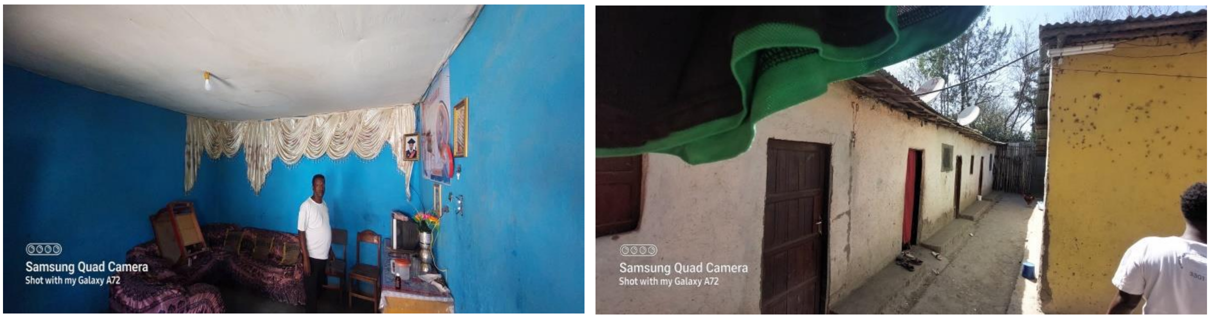


Figure 33: A photograph of 2.4m floor height (sample no 18 on table 2)


Figure 34: A photograph of 2.35m floor height (sample no 28 on table 2)


Figure 35: A photograph of 2.4m floor height (sample no 27 on table 2)

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