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COLLEGE OF DEVELOPMENT STUDIES
CENTER FOR ENVIROMENT AND SUSTAINABLE DEVELOPMENT

INDOOR THERMAL COMFORT ANALYSIS OF CONDOMINIUM RESIDENTIAL HOUSES IN ADDIS ABABA, ETHIOPIA

A Thesis Submitted to the Centre for Environment and Sustainable Development, College of Development Studies, Addis Ababa University in Partial Fulfilment for the Requirement of MA Degree in Development Studies (Environment and Sustainable Development)

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This is to certify that the thesis titled "Indoor Thermal Comfort Analysis of Condominium Residential Houses in Addis Ababa, Ethiopia" prepared by Semira Akmel submitted in partial fulfillment of the requirements for the Degree of Master of Art in Development Studies (Environment and Sustainable Development) which complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Declaration

I, the undersigned, declare that the thesis titled “Indoor Thermal Comfort Analysis of Condominium Residential Houses in Hot and Cold Climatic Zones of Addis Ababa, Ethiopia” is my original work and done by me for the degree of Master of Art in Development Studies (Environment and Sustainable Development) under the guidance and supervision of Engdawork Assefa (PhD). This thesis has not been presented for a degree in any university and that all source of materials used for the thesis have been duly acknowledged.

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Abstract

Indoor thermal comfort is an important feature of sustainable building and is necessary for a safe indoor environment. In terms of thermal comfort, condominium building expectations, tolerance, and preferences vary across Addis Ababa's climate zones. As a result, the purpose of this study is to assess the internal thermal comforts of condominium residential houses in Addis Ababa, Ethiopia. Subjective and objective measurements were used in this investigation by collecting a cross sectional data from a sample of 130 condominium residents from September 4 to 12. The ASHRAE seven-point thermal feeling scale is used to determine the subjective measurement. To assess interior thermal comfort, an adaptive comfort model was used in accordance with the ASHRAE standard. In terms of thermal sensational votes between 1 and +1, 50.9 percent of respondents at Tsion condominium are content with the internal thermal environment, but 25.4 percent of respondents at Gelan condominium houses are. Similarly, 45.6 percent of Tsion condominium residents said they would want their properties to stay the same or only be slightly colder or warmer. Condominium houses in both hot and cold climates were, on average, not in conformity with the adaptive comfort standard's 80 percent acceptance zone. As a result, policymakers in the construction sector should address issues of thermal comfort in future planning.

Keywords: Thermal comfort; climate zone; condominium houses; Addis Ababa

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Contents

Abbreviation

ACS	Adaptive Comfort Standard
AC	Air Condition
AMV	Actual Mean Vote
ASHRAE	American Society of Heating, Refrigerating and Air condition Engineer
CE	Cooling Effect
EDGE	Excellence in Design for Greater Efficiencies
EMA	Ethiopian Metrological Agency
HVAC	Heating Ventilation and air Condition
IEQ	Indoor Environmental Quality
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
RH	Relative humidity
SET	Standard Effective Temperature
SAUPUC	School of Architecture art and Urban Planning, University of California
Ta	air Temperature
Tr	Radiant temperature
Va	Air velocity
AC	Air Condition

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CHAPTER ONE
INTRODUCTION

1.1. Background of the study

When it comes to evaluating the overall comfort of the environment, human health comes first. As a result, humans have tried to construct indoor situations in which they can feel at ease. Horr and his colleagues (2016). One of the most essential things that can affect human comfort is the climate (Rana et al, 2015). Because people spend roughly 80-90 percent of their time indoors, according to ASHRAE (2010) recommendations, several studies have shown that a wide range of comfort and health-related consequences are linked to architectural characteristics.

Thermal comfort, according to ASHRAE (2010), is a state of mind that reflects happiness with the thermal environment. It's tough to satisfy everyone in space because there are so many physiological and psychological differences between people. As a result, the ambient parameters required for comfort are not the same for everyone. Horr et al. claim that thermal comfort is the most significant and easily defined characteristic of indoor environmental quality (IEQ) (2016). As a result, it enables occupants to perform at their maximum capacity, and their work environment must be thermally comfortable. Thermal comfort, on the other hand, is determined by an individual's thermal adaptation, which is influenced by characteristics such as geographic location and climate, season, gender, race, and age. Quang and his colleagues (2014).

The temperature of the surrounding surfaces, air movement, relative humidity, and the rate of air exchange are all elements that can influence the indoor air temperature both inside and outside the home (ventilation). The dwelling's design and building materials are external elements that impact how well it protects its people. David & Ezratty, (2014); Fanger (1970).

Thermal comfort is influenced by a variety of elements, including environmental, personal, and other considerations. The individual's activity (metabolic rate) and the apparel he or she wears are personal factors. Other considerations include the individual's age, health state, and gender, as well as their adaptability to the local environment and the length of time they are exposed to temperatures outside their comfort zone. All of these factors will change throughout the day and over time for individuals and amongst members of the household, and will be influenced by household activities Hamzah et al (2018); Fanger (1970).

Thermal discomfort, according to David & Ezratty (2014), is a condition in which there is a potential harm to health, such as when the temperature goes below 18 0C or rises above 24 0C for an extended period of time, but it is not simply a lack of happiness with the ambient temperature. Thermal comfort is also the outcome of the interplay and adaption of environmental and human body characteristics, according to studies. According to Haruna et al (2018; Toy et al (2017) and ASHRAE (2010), a building's indoor thermal state is appropriate when 80 percent of its occupants are satisfied and comfortable.

The predicted mean vote (PMV) model consists of a seven-point thermal sensation scale ranging from (+3) hot, (+2) warm, (+1) slightly warm, (0) neutral, (-1) slightly cool, (-2) cool and (-3) cold and it is best suited to air-conditioned buildings in which the occupants have no control over their immediate surroundings (Jindal, 2018), however, the works by Dear & Brager (2002); Nicol & Humphreys (2002) suggested the importance of adaptive thermal comfort model over the PMV model, as the latter fails to predicts exactly actual thermal sensation in naturally ventilated buildings. The thermal comfort of persons who live in naturally ventilated buildings is influenced by both physiological and adaptive factors. As a result, Fanger's hypothesis fails to forecast thermal comfort in naturally ventilated structures. Nicol & Humphreys (2002; Dear & Brager (2002; Nicol & Humphreys (2002; Nicol & Humphreys (2002). The comfort zone reflects the comfortable upper and lower temperature parameters in the adaptive thermal comfort model. It is located around the neutrality or comfort line.

According to Nikolopoulos & Azar (2015), the primary premise of sustainable building performance is to offer people with a suitable working and living environment while avoiding high energy consumption. In buildings where people stay, the issue of thermal comfort is critical. Baharun and Ibrahim (2014). The office building is one of the most well-known in terms of people occupying it, particularly those who work there for a long time.

The design of enclosures and building orientation have a significant impact on the inside thermal environment of buildings, especially for those with natural ventilation. Albatayneh and colleagues (2018). The effect of direction on indoor temperature is also one of the most critical design variables. Lechner is a well-known figure in the (2015). However, because the external design has inadequate linkages to the inside environment, most traditional office concepts rely on a mechanical operation. Rodrigues & Le Hong (2013)

Now days there is incredible development of condominium building construction in Ethiopia, especially in the country’s capital, Addis Ababa. And the building construction industry is expected to continue with large scale as the needs of it are high in the city and other part of the country. The majority of condominium buildings currently being created in the city on a big scale use glass façade in the majority of their portions, particularly on the front side, without regard for the building orientation. However, as noted in the majority of study papers, glass curtain walls, huge windows on building facades, and building orientations have the potential to raise overheating concerns. Temperature rise is likely to cast doubt on the performance of present and future buildings in terms of occupant thermal comfort Bulti & Gabore (2020). As a result, in order to determine future growth, it is vital to assess the comfort level of those condominium structures.

Statement of the problem

Most buildings in developed countries use thermoactivated technology during construction which allows the building’s thermal mass to be activated with the aid of embedded piping, as well as providing an ideal indoor environment with reduced energy usage for heating and cooling Xu et al (2010).

Due to a lack of technology, developing countries rely on a range of traditional cooling solutions for their structures, including locally available construction materials such as mud block, grass roofs, building orientations, and plant utilization, among other things. Manzano and his colleagues (2015). Furthermore, developing countries have used a variety of strategies to regulate indoor thermal comfort, including the use of various shading, particularly upper shading Akadiri (2016), the installation of an external parapet wall as a divider between houses to prevent hot air from the neighbor's roof from moving into the house, the provision of slop to the roof in the direction of a courtyard to allow cold air to flow into the court Freewan (2019), and the use of extrinsic ventilation.

Ethiopia has a variety of climates, and buildings should be designed to provide good indoor thermal comfort while taking into account the microclimatic conditions of the area. However, almost all modern buildings in the country are designed and built without taking due account of these factors. The adaptation of building materials, type of built form, and orientation are decisions commonly made in most parts of Ethiopia without the consideration of climatic zone Yadeta et al (2019). For instance, as a strategy to provide shelter for low-income people of the country, modular condominiums are designed at the federal level and expanded to all cities and towns without taking into account the microclimates of the towns and cities, resulting in people suffering from indoor thermal discomfort Yadeta et al (2019). This is particularly notable in Addis Ababa city, where many condominium houses have been developed and transferred to people. Indoor thermal comfort issues were not taken into account during the design and construction phase of these residential condominium buildings. It is therefore a priority to determine whether or not these people are comfortable and to determine their degree of comfort and the range of acceptable conditions.

Yadeta et al (2019) did a study in Jimma city to examine inhabitants' views of thermal comfort and to determine the source of heat that permits the temperature of the indoor environment to be raised. However, the purpose of this study is to look into the residents' perceptions through subjective assessment. Furthermore, the research was limited to modern homes and was not backed up by objective evidence. Bulti & Gabore (2020) investigated the thermal comfort performance of the naturally ventilated buildings of five selected Addis Ababa sub-city administration offices in varied orientations in Addis Ababa city. The study also assessed and compared the thermal efficiency of office buildings in various orientations using the same thermal insulation materials. Despite the fact that this study used both subjective and objective approaches to assess thermal performance, it was limited to office building thermal analysis.

Hence, this study was proposed to contribute to filling these gaps by carrying out indoor thermal comfort analysis on condominium houses in in hot and cold climatic locations of Addis Ababa city, using objective and subjective evaluation methods. The research also aimed to identify the contributing factors that hamper or enable indoor thermal comfort in the city and provide passive solutions that would fit the city’s different climate conditions.

1.2. Objective of the study

1.2.1. General objective

To assess the indoor thermal comforts of condominium buildings in hot and cold climatic zones and identify the contributing factors that hamper or facilitate indoor thermal comfort in Addis Ababa, Ethiopia.

1.2.2. Specific objectives:

- To assess thermal comfort of occupants in condominium houses of different parts of the city
- To identify main factors that hinder or facilitate the indoor thermal comfort of residents in the selected study area.

- To assess the indoor temperatures and relative humidity levels of selected condominium buildings of the study area.

1.3. Scope of the study

This study focused only on government built residential condominium houses from a sample of only two condominium sites in Addis Ababa city. It was conducted by taking a sample of 130 condominium residents. This was done due to lack of sufficient time and budget. Had there was no budget and time constraint, a greater number of samples would be taken and in-depth analysis would be done by including more study sites to get comprehensive result. The data was analyzed by taking only a single day record of temperature and humidity only once.

1.4. Significance of the study

The finding of this study has number of significances. It helps the reader to understand the effect of thermal comfort and building energy while adjusting the indoor climate comfort in the sustainable development of the country. Moreover, it will be used by condominium developers and other concerned bodies such as, building designers and construction workers to take into consideration the issue of indoor thermal comforts in different building. Additionally, it is used as spring board for those who want to carry out further studies on of residents' thermal comfort in different city by using different methodology. Finally, it helps policy makers to take into account the issue of thermal comfort in the construction and housing development to be compatible in the changing thermal environment.

1.5. Organization of the study

The remaining part of the study is organized as follows. Chapter 2 deals with a review of related literature. Chapter 3 presents the methodology of the study. Chapter 4 is concerned with discussions and findings of the research. Finally, the last chapter presents summary, conclusions and recommendation.

CHAPTER TWO

RELATED LITERATURE REVIEW

2.1. Concepts of thermal comfort and energy

2.1.1. Thermal comfort

Thermal comfort is a feeling of being cold, hot, warm, slightly cooler and slightly warmer. Balanced exchange of heat between person's body and the environment or well felling in the weather condition refers a thermal comfort. It is important in a physical and psychological aspect of a person's Muhammed et al. (2013). Heating, ventilation, air condition and human activities are factors of thermal comfort. Uncomfortable indoor climate condition will reduce the productivities of occupants, poor performance and lead to a health problem. Keeping an indoor environment comfortable has an advantage in the sustainable development sector in the way of saving of energy, in addition to making occupants feel comfortable Muhammed et al. (2013).

Satisfactory thermal comfort in indoor environment occurs from natural ventilated are rather than artificial air condition. In many researches in school thermal comfort, students who seat near to window scores high grade because of the naturally ventilated air Muhammed et al. (2013). Places where more people occupied will have poor indoor air quality if it does not consider the thermal comfort of the space.

Generally, the measure effects of thermal condition in occupants are decrease productivity and poor performance and health. Studies states that a comfortable indoor environment will decrease 5%- 10% of the occupant performance in the well air-conditioned buildings and they categories the buildings successful and unsuccessful base on the air quality of interior spaces Muhammed et al. (2013).

According to Muhammed et al (2013) study, air temperature (Ta), air velocity (V), relative humidity (RH) and mean radiant temperature (Tr) categorize in the environmental factors of climate comfort and individual factors which have significant relation in affecting thermal comfort includes human activities and clothing. Additionally, diet, body built and health conditions are also factors which influencing thermal comfort.

Comfort zone defined as the range of temperature (climatic) conditions of air movement, humidity and exposure to direct sunlight, under which a moderately clothed most human comfortable feeling SAAUP (1991).

Based on mentioned researches, built environment is highly associated with the climate. Moreover, according to the climate characteristics, there are different classifications in architecture, such as cold, temperate, warm-humid and hot-dry climates. We can use this classification for achieving climate comfort level in building in different climates Rana et al (2015)

2.1.2. Influencing factors in thermal comfort

Since there are large variations from person to person in terms of physiological and psychological satisfaction, it is hard to find an optimal temperature for everyone in a given space. Laboratory and field data have been collected to define conditions that will be found comfortable for a specified percentage of occupants.

There are six primary factors that directly affect thermal comfort that can be grouped in two categories; personal factors and environmental factors. The former are metabolic rate and clothing level, the latter are air temperature, mean radiant temperature, air speed and humidity. Even if all these factors may vary with time, standards usually refer to a steady state to study thermal comfort, just allowing limited temperature variations.

Metabolic rate

People have different metabolic rates that can fluctuate due to activity level and environmental conditions Toftum et al., (2005). The ASHRAE 55-2010 Standard defines metabolic rate as the level of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface. Metabolic rate is expressed in met units.

ASHRAE Standard 55 provides a table of met rates for a variety of activities. Some common values are 0.7 met for sleeping, 1.0 met for a seated and quiet position, 1.2-1.4 met for light activities standing, 2.0 met or more for activities that involve movement, walking, lifting heavy loads or operating machinery. For intermittent activity, the Standard states that it is permissible to use a time-weighted average metabolic rate if individuals are performing activities that vary over a period of one hour or less. For longer periods, different metabolic rates must be considered ASHRAE (2017)

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

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

Food and drink habits may have an influence on metabolic rates, which indirectly influences thermal preferences. These effects may change depending on food and drink intake. Body shape is another factor that affects thermal comfort. Heat dissipation depends on body surface area. A tall and skinny person has a larger surface-to-volume ratio, can dissipate heat more easily, and can tolerate higher temperatures more than a person with a rounded body shape Szokolay and steven, (2010).

Clothing insulation

The amount of thermal insulation worn by a person has a substantial impact on thermal comfort, because it influences the heat loss and consequently the thermal balance. Layers of insulating clothing prevent heat loss and can either help keep a person warm or lead to overheating. Generally, the thicker the garment is the greater insulating ability it has. Depending on the type of material the clothing is made out of, air movement and relative humidity can decrease the insulating ability of the material Craig et al., (2009).

Air temperature

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

Mean radiant temperature

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

Air speed

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

Relative humidity

Relative humidity (RH) is the ratio of the amount of water vapor in the air to the amount of water vapor that the air could hold at the specific temperature and pressure. While the human body has thermo receptors in the skin that enable perception of temperature, relative humidity is detected indirectly. Sweating is an effective heat loss mechanism that relies on evaporation from the skin. However, at high RH, the air has close to the maximum water vapor that it can hold, so evaporation, and therefore heat loss, is decreased. On the other hand, very dry environments (RH < 20-30%) are also uncomfortable because of their effect on the mucous membranes. The recommended level of indoor humidity is in the range of 30-60% in air-conditioned buildings Balaras et al., (2007) but new standards such as the adaptive model allow lower and higher humidity’s, depending on the other factors involved in thermal comfort.

Skin wetness

Skin wetness is defined as "the proportion of the total skin surface area of the body covered with sweat" Frank, (2012). The wetness of skin in different areas also affects perceived thermal comfort. Humidity can increase wetness in different areas of the body, leading to a perception of discomfort. This is usually localized in different parts of the body, and local thermal comfort limits for skin wetness differ by locations of the body Fukazawa et al., (2009). The extremities are much more sensitive to thermal discomfort from wetness than the trunk of the body. Although local thermal discomfort can be caused by wetness, the thermal comfort of the whole body will not be affected by the wetness of certain parts.

2.1.3. Interplay of temperature and humidity

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

High humidity and low temperatures cause the air to feel chilly Randall et al., (2012). Cold air with high relative humidity "feels" colder than dry air of the same temperature because high humidity in cold weather increases the conduction of heat from the body. There has been controversy over why damp cold air feels colder than dry cold air. Some believe it is because when the humidity is high, our skin and clothing become moist and are better conductors of heat, so there is more cooling by conduction. The influence of humidity can be exacerbated with the combined use of fans (forced convection cooling) Morris et al., (2019).

Natural ventilation

Many buildings use HVAC unit to control their thermal environment. Other buildings are naturally ventilated and do not rely on mechanical systems to provide thermal comfort. Depending on the climate, this can drastically reduce energy consumption. It is sometimes seen as a risk, though, since indoor temperatures can be too extreme if the building is poorly designed. Properly designed, naturally ventilated buildings keep indoor conditions within the range were opening windows and using fans in the summer, and wearing extra clothing in the winter, can keep people thermally comfortable.

2.2. Models and indices to assess thermal comfort

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

2.2.1. Predicted mean vote (PMV)/Predicted percentage dissatisfied (PPD) method

The PMV/PPD model was developed by P.O. Fanger using heat-balance equations and empirical studies about skin temperature to define comfort. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale from cold (-3) to hot (+3). Fanger's equations are used to calculate the Predicted Mean Vote (PMV) of a group of subjects for a particular combination of air temperature, mean radiant temperature, relative humidity, air speed, metabolic rate, and clothing insulation Fanger, (1970). PMV equal to zero is representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits ($-0.5<PMV<+0.5$). Although predicting the thermal sensation of a population is an important step in determining what conditions are comfortable, it is more useful to consider whether or not people will be satisfied. Fanger developed another equation to relate the PMV to the Predicted Percentage of Dissatisfied (PPD). This relation was based on studies that surveyed subjects in a chamber where the indoor conditions could be precisely controlled Fanger (1970). PMV/PPD model is applied globally but does not directly take into account the adaptation mechanisms and outdoor thermal conditions Humphreys, (2007); Brager et al (1998).

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

The CBE Thermal Comfort Tool for ASHRAE 55 allows users to input the six comfort parameters to determine whether a certain combination complies with ASHRAE 55. The results are displayed on a psychometric or a temperature-relative humidity chart and indicate the ranges of temperature and relative humidity that will be comfortable with the given the values input for the remaining four parameters Cheung, et al (2019).

The PMV/PPD model has low prediction accuracy Veronika et al (2018). Using the world largest thermal comfort field survey database, the accuracy of PMV in predicting occupant's thermal sensation was only 34%, meaning that the thermal sensation is correctly predicted one out of three times. The PPD was overestimating subject's thermal unacceptability outside the thermal neutrality ranges ($-1\leq PMV\leq 1$). The PMV/PPD accuracy varies strongly between ventilation strategies, building types and climates.

2.2.2. Elevated air speed method

ASHRAE 55 (2013) accounts for air speeds above 0.2 meter per second (0.66 ft/s) separately than the baseline model. Because air movement can provide direct cooling to people, particularly if they are not wearing much clothing, higher temperatures can be more comfortable than the PMV model predicts. Air speeds up to 0.8 m/s (2.6 ft/s) are allowed without local control, and 1.2 m/s is possible with local control. This elevated air movement increases the maximum temperature for an office space in the summer to 30 °C from 27.5 °C (86.0–81.5 °F).

Virtual energy for thermal comfort

"Virtual Energy for Thermal Comfort" is the amount of energy that will be required to make a non-air-conditioned building relatively as comfortable as one with air-conditioning. This is based on the assumption that the home will eventually install air-conditioning or heating Gagge et al (1986). Passive design improves thermal comfort in a building, thus reducing demand for heating or cooling. In many developing countries, however, most occupants do not currently heat or cool, due to economic constraints, as well as climate conditions which border lines comfort conditions such as cold winter nights in Johannesburg (South Africa) or warm summer days in San Jose, Costa Rica. At the same time, as incomes rise, there is a strong tendency to introduce cooling and heating systems. If we recognize and reward passive design features that improve thermal comfort today, we diminish the risk of having to install HVAC systems in the future, or we at least ensure that such systems will be smaller and less frequently used. Or in case the heating or cooling system is not installed due to high cost, at least people should not suffer from discomfort indoors. To provide an example, in San Jose, Costa Rica, if a house were being designed with high level of glazing and small opening sizes, the internal temperature would easily rise above 30 °C (86 °F) and natural ventilation would not be enough to remove the internal heat gains and solar gains. This is why Virtual Energy for Comfort is important.

World Bank's assessment tool the EDGE software (Excellence in Design for Greater Efficiencies) illustrates the potential issues with discomfort in buildings and has created the concept of Virtual Energy for Comfort which provides for a way to present potential thermal discomfort. This approach is used to award for design solutions which improves thermal comfort even in a fully free running building. Despite the inclusion of requirements for overheating in CIBSE, overcooling has not been assessed. However, overcooling can be an issue, mainly in the developing world, for example in cities such as Lima (Peru), Bogota, and Delhi, where cooler indoor temperatures can occur frequently. This may be a new area for research and design guidance for reduction of discomfort.

Cooling effect

ASHRAE 55 (2017) defines the Cooling Effect (CE) at elevated air speed (above 0.2 meter per second (0.66 ft/s)) as the value that, when subtracted from both the air temperature and the mean radiant temperature, yields the same SET value under still air (0.1 m/s) as in the first SET calculation under elevated air speed.

The CE can be used to determine the PMV adjusted for an environment with elevated air speed using the adjusted temperature, the adjusted radiant temperature and still air (0.2 meter per second (0.66 ft/s)). Where the adjusted temperatures are equal to the original air and mean radiant temperatures minus the CE.

Local Thermal discomfort

Avoiding local thermal discomfort, whether caused by a vertical air temperature difference between the feet and the head, by an asymmetric radiant field, by local convective cooling (draft), or by contact with a hot or cold floor, is essential to providing acceptable thermal comfort. People are generally more sensitive to local discomfort when their thermal sensation is cooler than neutral, while they are less sensitive to it when their body is warmer than neutral ASHRAE (2020).

Radiant temperature asymmetry

Large differences in the thermal radiation of the surfaces surrounding a person may cause local discomfort or reduce acceptance of the thermal conditions. ASHRAE Standard 55 sets limits on the allowable temperature differences between various surfaces. Because people are more sensitive to some asymmetries than others, for example that of a warm ceiling versus that of hot and cold vertical surfaces, the limits depend on which surfaces are involved. The ceiling is not allowed to be more than +5 °C (9.0 °F) warmer, whereas a wall may be up to +23 °C (41 °F) warmer than the other surfaces.

Draft

While air movement can be pleasant and provide comfort in some circumstances, it is sometimes unwanted and causes discomfort. This unwanted air movement is called "draft" and is most prevalent when the thermal sensation of the whole body is cool. People are most likely to feel a draft on uncovered body parts such as their head, neck, shoulders, ankles, feet, and legs, but the sensation also depends on the air speed, air temperature, activity, and clothing.

Floor surface temperature

Floors that are too warm or too cool may cause discomfort, depending on footwear. ASHRAE 55 recommends that floor temperatures stay in the range of 19–29 °C (66–84 °F) in spaces where occupants will be wearing lightweight shoes.

Standard effective temperature

Standard effective temperature (SET) is a model of human response to the thermal environment. Developed by A.P. Gagge and accepted by ASHRAE in 1986, it is also referred to as the Pierce Two-Node model. Its calculation is similar to PMV because it is a comprehensive comfort index based on heat-balance equations that incorporates the personal factors of clothing and metabolic rate. Its fundamental difference is it takes a two-node method to represent human physiology in measuring skin temperature and skin wetness.

The SET index is defined as the equivalent dry bulb temperature of an isothermal environment at 50% relative humidity in which a subject, while wearing clothing standardized for activity concerned, would have the same heat stress (skin temperature) and thermoregulatory strain (skin wetness) as in the actual test environment.

Research has tested the model against experimental data and found it tends to overestimate skin temperature and underestimate skin wetness. Fountain and Huizenga (1997) developed a thermal sensation prediction tool that computes SET.

2.2.3. Adaptive comfort model

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

The ASHRAE-55 (2010) Standard introduced the prevailing mean outdoor temperature as the input variable for the adaptive model. It is based on the arithmetic average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question. It can also be calculated by weighting the temperatures with different coefficients, assigning increasing importance to the most recent temperatures. In case this weighting is used, there is no need to respect the upper limit for the subsequent days. In order to apply the adaptive model, there should be no mechanical cooling system for the space, occupants should be engaged in sedentary activities with metabolic rates of 1-1.3 met, and a prevailing mean temperature of 10–33.5 °C (50.0–92.3 °F).

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

Adaptive models of thermal comfort are implemented in other standards, such as European EN 15251 and ISO 7730 standard. While the exact derivation methods and results are slightly different from the ASHRAE 55 adaptive standard, they are substantially the same. A larger difference is in applicability. The ASHRAE adaptive standard only applies to buildings without mechanical cooling installed, while EN15251 can be applied to mixed-mode buildings, provided the system is not running.

There are basically three categories of thermal adaptation, namely: behavioral, physiological, and psychological.

Psychological adaptation

An individual's comfort level in a given environment may change and adapt over time due to psychological factors. Subjective perception of thermal comfort may be influenced by the memory of previous experiences. Habituation takes place when repeated exposure moderates future expectations, and responses to sensory input. This is an important factor in explaining the difference between field observations and PMV predictions (based on the static model) in naturally ventilated buildings. In these buildings, the relationship with the outdoor temperatures has been twice as strong as predicted de Dear et al., (1998).

Psychological adaptation is subtly different in the static and adaptive models. Laboratory tests of the static model can identify and quantify non-heat transfer (psychological) factors that affect reported comfort. The adaptive model is limited to reporting differences (called psychological) between modeled and reported comfort.

Thermal comfort as a "condition of mind" is defined in psychological terms. Among the factors that affect the condition of mind (in the laboratory) are a sense of control over the temperature, knowledge of the temperature and the appearance of the (test) environment. A thermal test chamber that appeared residential "felt" warmer than one which looked like the inside of a refrigerator Szokolay and steven (2010).

Physiological adaptation

The body has several thermal adjustment mechanisms to survive in drastic temperature environments. In a cold environment the body utilizes vasoconstriction; which reduces blood flow to the skin, skin temperature and heat dissipation. In a warm environment, vasodilation will increase blood flow to the skin, heat transport, and skin temperature and heat dissipation Nicol and Fergus (2001). If there is an imbalance despite the vasomotor adjustments listed above, in a warm environment sweat production will start and provide evaporative cooling. If this is insufficient, hyperthermia will set in, body temperature may reach 40 °C (104 °F), and heat stroke may occur. In a cold environment, shivering will start, involuntarily forcing the muscles to work and increasing the heat production by up to a factor of 10. If equilibrium is not restored, hypothermia can set in, which can be fatal Nicol and Fergus (2001). Long-term adjustments to extreme temperatures, of a few days to six months, may result in cardiovascular and endocrine adjustments. A hot climate may create increased blood volume, improving the effectiveness of vasodilation, enhanced performance of the sweat mechanism, and the readjustment of thermal preferences. In cold or under heated conditions, vasoconstriction can become permanent, resulting in decreased blood volume and increased body metabolic rate.

Behavioral adaptation

In naturally ventilated buildings, occupants take numerous actions to keep themselves comfortable when the indoor conditions drift towards discomfort. Operating windows and fans, adjusting blinds/shades, changing clothing, and consuming food and drinks are some of the common adaptive strategies. Among these, adjusting windows is the most common. Those occupants who take these sorts of actions tend to feel cooler at warmer temperatures than those who do not Lenzuni et al., (2009).

The behavioral actions significantly influence energy simulation inputs, and researchers are developing behavior models to improve the accuracy of simulation results. For example, there are many window-opening models that have been developed to date, but there is no consensus over the factors that trigger window opening Haldi et al., (2008).

People might adapt to seasonal heat by becoming more nocturnal, doing physical activity and even conducting business at night.

2.3. Energy

Energy is the important constituent in the economic development center. In the developing countries a billion of people don’t have access for electricity, and the countries have a great effort to attract investment in generating energy. The majority of growth comes from fossil fuels in the first and second industrial revolution in industrialization, transportation and electrification that have highly polluted the air. These local pollution and climate change increase the demand for power. Michael et al., (2019)

Energy policy of Ethiopia states that Ethiopia is the least in the development of energy in the world. There is different reason for low development of energy sector. Some of them are: the sector have limited human and technical capacity and lack of constant institutional arrangement; Low private sector Participation, low level of private sector participation of the development and supply of energy services; High dependence on imported petroleum fuels, leading high cost of importing petroleum products and it has an effect in foreign exchange service that where rising oil prices in the country; Big challenge to finance the energy sector program, to introduce modern energy service to minimize traditional solid biomass fuels that have a main role in deforestation and forest degradation of the country; Climate change is also a main reason that in Ethiopia there is harsh weather condition that results shortage of water and high level of silting and hear mostly use hydropower for electricity generation that vulnerable to climate change; A problem in an up-to-date energy data and due to insufficient technology transfer and lack of energy equipment manufacturing. To improve this development Policies strategy and procurements are important to make a change in the potential of energy supply and electricity generation capacity proportion to population growth and to change the traditional development path of petroleum and fuel wood consumption.

Also, for poor improvement of the development of renewable energy technologies, energy conservation and sustainable forest and wooden land management practice.

2.3.1. Thermal comfort and energy

Recent researchers on the field of thermal comfort have the same opinion in a change of standards of building construction and material will have an effect on reducing building energy on thermal comfort. Standards of thermal comfort are necessary to ensure good indoor climatic condition and to optimize the energy used in a building for heating or cooling purposes (Samar_et al., 2018). Also, it is important one analyzes the climate scenario and understand thermal condition of the building of selected area. Professionals also set up a standard for a better climate sensitive and energy saving building design. Also, it's important to focus on comfortable temperature on the room rather than focusing the temperature distribution of the room. Therefore, new standards have to be provided by considering knowledge of traditional methods of providing comfortable room temperature.

Energy consumption is increasing in the rapid growth of population and economy activities in the tropical countries which leads the reduction of energy resource. The building sector is one of the high amounts of energy user. In the building indoor air quality energy is consumed in the system of air conditioning system to adjust the thermal comforts of the occupants Qi et al., (2013). Building consumes 40% of the global energy and above 30% of CO_2 emission contributed. Building energy consumption for thermal comfort is associated with heating, ventilation, and air conditioning (HVAC) systems. Belen et al., (2020) They are installed with air conditioning and mechanical ventilation system to adjust thermal comfort of the indoor environment. This system consumes the most energy among all building services, which is 30–60% of the total energy consumption.

2.4. Theoretical frameworks

Recent studies have found international standards for indoor climate. ASHRAE's is one of the standards which is American Society of Heating, refrigerating and air condition engineer standard 55 thermal environmental conditions for human occupancy. Establish indoor environmental conditions to achieve ASHRAE accepted thermal comfort for occupants of building. Black Box theory is theoretical adaptive model of thermal comfort. Which detect thermal comfort with the help of factors like culture, climate, and social, psychological and behavioral adaptation impact. Which also called adaptive predicted mean vote (aPMV) Model. With have a concept of predicted mean vote (PMV) is greater than actual mean vote (AMV) in free running buildings Runming et al (2009).

For improving building sustainability, there are standard for thermal comfort. These standards determine the Energy consumption by a buildings environmental system. The standards developed based on laboratory experiments in the field studies Runming et al (2009).

In adaptive hypothesis has an opinion of building occupants has their own or different expectation according to the contextual factor and past thermal history modified buildings. That is people have their own preference which is people in warm climate zone prefer warmer indoor temperature and people living in cold Climate prefer cold indoor temperature Richard et al., (1998).

Extreme climate events of heat wave and cold wave affect the human health. This increases a mortality rate of elderly people, children and special health problem person Gholam (2018). Heat and cold waves describe parameter of events, frequency, length, amplitude and/or magnitude Gholam (2018). As Gholam (2018) mention the quantity may vary from paper to paper. According to the study, they will use daily maximum temperature to extract intensity, frequency and duration of heat wave for the scale of temperature change.

Emergence of climate comfort

Quick increase of population and development of industrial activities with unplanned consumption of fossil fuel have played a big role in the expansion of buildings in cities. City development with seriously increased pollutions will play a role as a factor in increasing climatic fluctuation and its environmental effects such as the change of desirable months in view of comfort climate in long period. Climate change and the emergence of urbanizing the built environment can bring a change in air temperature that affects the thermal comfort Richard et al., (2013). A change of daily temperature and relative humidity is affected by climate change. The important elements of climate view of human comforts are air temperature, humidity, wind and radiation. From, these four elements temperature and humidity have more effects on human health and comfort. Based from this problem numbers of human comfort measurement models have been developed. Shakoor et al (2008).

Climate change and thermal comfort in Ethiopia

Climate change is a change in climate which affects the human activity directly or indirectly in the type of temperature, rainfall and occurrence of extremes Belay (2016). It occurs in internal variability within the climate system and external factors by natural or human activities due to fossil fuel, removal of forest and quick urbanization and industrialization. Climate change causes the impact on several areas like public health, agriculture, food security, water resource, biodiversity, human settlement, energy, industry and financial service. Industrialized countries contributed a high amount of greenhouse gas emission as compared with the developing countries. Developing country like Ethiopia has less capable of mitigating or adapting to the changes. Additionally, highly dependence of the environment, the climate change affects the developing country more Belay (2016). As a rain-fed agriculture of Ethiopian economy which is sensitive to the climate change, the government makes policy and strategy to reduce climate variability and change. In Ethiopia the main impact of climate change is deforestation and loss of biodiversity, desertification and displacement of people are additional factors. In Ethiopia climate change has an impact in loss of agricultural productivity and health impacts. There for several actions has to be taken in policies, strategies and program Belay (2016).

Most of the countries in the world experiences the growth of Cities combined with an increasing of urban density leader to a considerable thermal stress and health risk. The thermal comfort varies with the climate zone of the countries. Mainly it depends on the major influencing thermal comfort factors of air temperature.

Architects and professionals often use international thermal comfort standards like ASHERAE in some countries. But in hot and humid Climate of tropical countries has to predict the comfort level, the standard is irrelevant. Therefore, the countries need more relevant index and standards which fit the comfortable temperature for the tropics Shafizal (2002). Hot and Humid area generally located close to the equator. Singapore is one of the countries found in tropical zone which experience naturally ventilated buildings. Moreover, Indonesia also located in the Southeast Asia region of tropical zone. When the air temperature rises, the related humidity will decrease. This is a common character of the hot-humid climate Shafizal (2002).

In mild climate countries like City of Australia, most of the houses are cold and the internal temperature in the sample houses were on average temperature is below 18℃. The occupants have thermal discomfort in their indoor thermal environment. The majority of the resident respond the climate and keep their thermal comfort mainly directed applying solutions in their body like by clothing, not their indoor space Lyriar (2019).

Effects of climate comfort on social, health and economy

Change of temperature has an effect in human health which is associated with increased illness and death. The coldness of the climate leads the feeling of stress and hot temperature increase stress. Therefore, the thermal environment has some health issues and health problems like heat stroke. Indoor air quality also affects mind and behavior of human physiology. Sleeping quality also affected by the thermal comfort. David et al., (2014). Range of thermal discomfort in room temperature is falls below 18℃ or rises above 24℃ David et al., (2014). Study state that in human health exposure from low and high temperature. In low temperature human bodies react in thickening of the blood and increase risk of cardiovascular events, also in high temperature responds a problem of health in respiratory organ, increase heat stroke and death David et al., (2014). Generally, effects of climate comfort in health and economy categorized in decrease productivity and poor performance and health Muhammed et al., (2013). Now a day people spent their time mostly in the building. When people spent more time in interior of the building, they will use air ventilation. When the displacement of air ventilation leads vertical temperature gradient. This results for thermal discomfort and decrease the productivity Muhammed et al., (2013). Thermal comfort considered buildings, which have a good indoor air quality increased productivity by 5-10%. The building categorized with unsustainable design while adjusting air quality through increasing energy consumption. When a number of people occur in same indoor space without regulating the temperature, the occupant performance will reduce gradually. Reasonable thermal comfort will come through natural ventilation. More over reasonable design, selected building material and building orientation also have an effect in interior air quality of a building. Muhammed et al., (2013) report Wind-catcher as an effective way of providing night cooling.

2.5. Empirical Reviews

This part of the paper discusses about the results of the study conducted by different scholars on the thermal comfort issues and their findings.

Yadeta et al., (2019) conducted a study on the human thermal comfort level and its analysis by computational fluid dynamics for naturally ventilated residential buildings of Jimma town, which is located in warm temperate oceanic climate of Ethiopia. He conducted his study by taking and measuring thermal variables such as air temperature, air speed and relative humidity of purposely selected brick wall and wooden wall residential buildings. He used computational dynamics to visualize the temperature distribution and air speed pattern in the residential buildings. As a result, the thermal comfort in the buildings was found outside the ASHRAE standard limits.

The result revealed that residential houses in Jimma town generate thermal discomfort due to improper designing and construction. The computational fluid dynamics simulation suggests that the use of adaptive mechanisms such as opening windows and changing cloths and internal window insulation to improve thermal comfort level of buildings in the town. By doing so, the study concluded that setting indoor thermal comfort by adaptive mechanism is a means to conserve final energy as it is environmentally friendly and generates no toxic.

David & Ezratty (2014) conducted a study on thermal discomfort and health in the view of protecting the susceptible from excess cold and excess heat in housing. He emphasized that the strategies used to reduce these levels should ensure that the health and wellbeing of residents is protected and improved. In addition, thermal discomfort in housing ranges from being uncomfortable to serious health impacts and avoiding this discomfort maintains wellbeing and protects the health of the most susceptible members of the populations. Human and building related factors that increase susceptibility to low and high temperatures were identified and analyzed. The result also shows that there are similarities between some of these factors and that tackling these together was provided protection for the most at risk from exposure to high and low temperature.

Yu et al., (2017) carried on a study of thermal comfort in residential buildings on the Tibetan plateau, the highest and largest plateau in the world which is located in the cold and severe cold zones according to the Chinese climatic division for building design and has unique climatic characteristics. A field examination of residential buildings was conducted in the Tibetan Alpine region with onsite environmental parameter measurements. In addition, a subjective survey questionnaire was used to collect data. Based on the results of the analysis of collected data, the value of adaptive thermal comfort was in the acceptable range for residential buildings in the study area.

A study conducted by Bulti & Gabore (2020) investigated thermal comfort performance of naturally ventilated buildings of five selected Addis Ababa sub-city administration buildings offices in different orientations to evaluate and compare the office building thermal performance in different orientations with the same thermal insulation materials. The study was based on building users survey, field measurements and secondary data review and analysis whereby the field survey was carried in the warmest month of the city for a selected room of the case study.

Results of the field study has shown that most of the occupants prefer a cooler environment and found their thermal environment uncomfortable. However, the indoor temperature fluctuation of the buildings and the humidity level are within the allowable limits. But sometimes the temperature level overpasses the acceptable range. In addition, the results showed that there are differences in thermal performances between buildings in different orientations.

Akande & Adebamowo (2011) conducted a study on indoor thermal comfort for residential buildings in hot dry and rainy season in Bauchi, in northern Nigeria by collecting data through field survey. The study evaluated and compared thermal comfort index with human responses. Consequently, the results showed that there is a need to review the fundamentals of the requirements for thermal comfort and adaptation by the occupants.

A study by Ibrahim et al., (2014) tried to explore the thermal comfort scenario of the residential buildings in Mubi metropolis with the view of offering measures to improve the comfort of people in their homes. The study was carried on by distributing 240 structured questionnaires to eight wards in the study area. The study revealed that the aggravation of thermal discomfort in Mubi were caused by some factors among which are: epileptic power supply, high cost of air conditioning systems, use of good heat conducting materials in buildings, poor building design and use of high heat emitting lighting devices. Thus, the result indicated that the majority of Mubi residents were thermally uncomfortable in their homes.

A study by Karayno (2000) on thermal comfort and building energy was carried out in Jakarta, the capital of Indonesia by participating 596 office workers working in seven multi-story office buildings. The study examined the neutral temperature of the whole sample. The study has also examined the neutral temperature by categorizing subjects into different sub group samples such as male and female, subjects under and over 40 years old, subjects who are considered to be thin, normal and fat, subjects with various ethnic backgrounds. As a result, the study revealed that comfort conditions could be achieved without unnecessary cooling in conditioned building.

Han et al., (2007) conducted a study on occupant's thermal comfort and residential thermal environment in a hot-humid climate of China by taking a field sampling from 110 respondents through survey questionnaire and measuring environmental comfort variables in three rooms in each of 26 residencies. The objective of the study was to measure and characterize occupant thermal perceptions in residences, compare observed and predicted percent of dissatisfied and distinguish differences between this study and similar studies performed in different climate zones.

In doing so, average clothing insulation for seated subjects was 0.54 clo with 0.15 clo. Only 48.2% of the measured variables are within the ASHRAE Standard 55-1992 summer comfort zone, but approximately 87.3% of the occupants perceived their thermal conditions acceptable, for subjects adapt to predominant conditions. The operative temperature denoting the thermal environment accepted by 90% of occupants was 22.0-25.91. In the ASHRAE seven-point sensation scale, thermal neutral temperature occurs at 28.61. Preferred temperature, mean temperature requested by respondents, was 22.81.

A study done by Haven et al (2012) on the indoor thermal comfort in the case of modern and traditional buildings in Semera city a hot-arid climatic region of Ethiopia. The study attempted to evaluate the indoor thermal comforts of modern and traditional buildings and identified the contributing factors that hindered or supported indoor thermal comfort in the study area. The was conducted by using the subjective measurement which is based on the ASHRAE thermal sensation scale by employing the adaptive comfort model to evaluate thermal comfort.

Accordingly, the results of the study that 88%and 22% of the respondents are satisfied with the indoor environment in traditional house and modern houses, respectively. Similarly, 83% of occupants in traditional houses expressed a preference for their homes to remain the same or be only slightly cooler or warmer.

2.6. Conceptual framework

Figure 1 below shows that the dependent variable, thermal comfort is influenced by indirect (personal, social and cultural) and direct (physical, physiological and psychological) factors. The adaptive comfort model was used to analyze this relationship by taking purposively a sample of residents from two condominium sites in Addis Ababa.

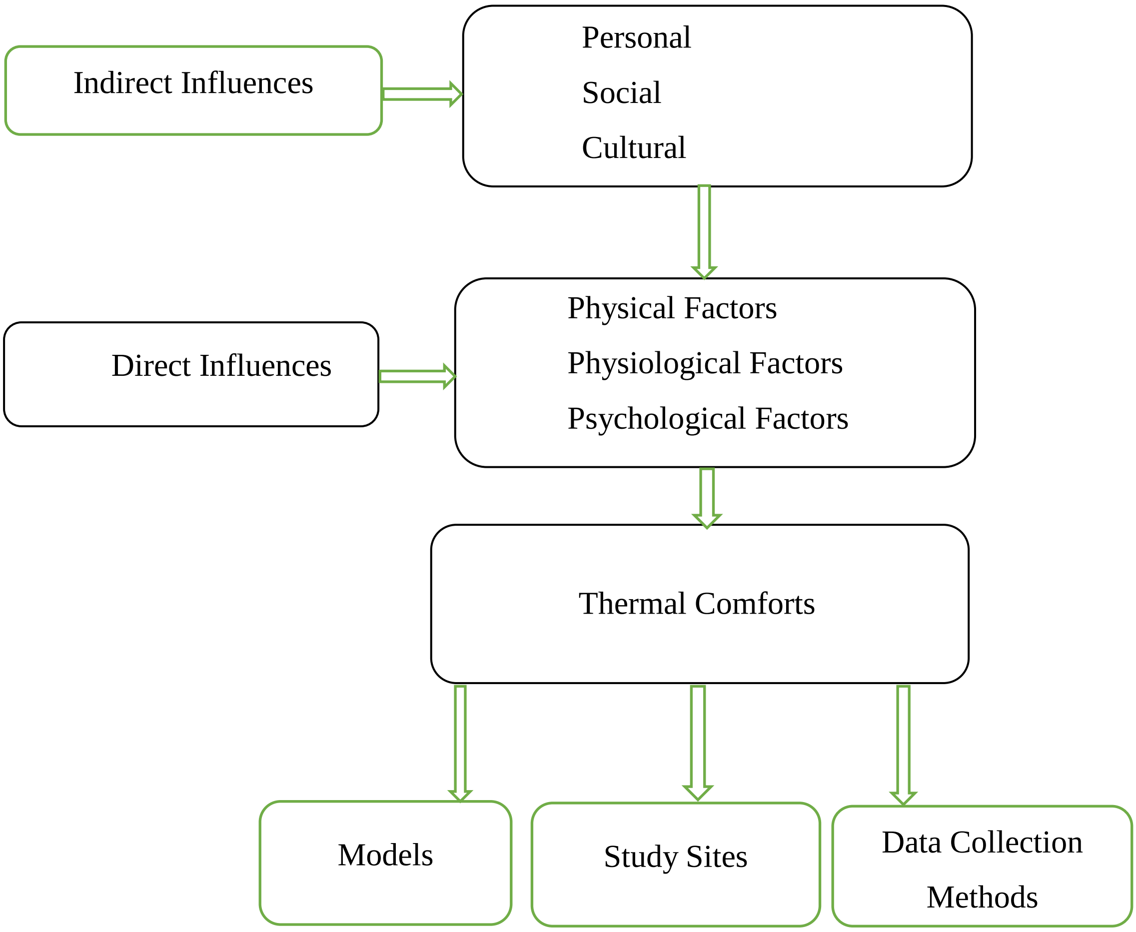


Figure 1: Conceptual framework

CHAPTER THREE

METHODOLOGY

3.1. Description of the study area

Addis Ababa has a warmest month from March through May. July is the most humid month, and August is the coldest month and cold from November to February at night. Zinabu et al (2020). Because of this seasonal weather conditions, the detailed data collection of the thermal comfort of the field study of the next months will not provide all seasonal data of the year. The study covered the area of different climatic zone of Addis Ababa. Based on the meteorology climate weather information and slope of Addis Ababa, Gulele Sub city and Akaki Kality sub-City were picked from cold and hot climate zone, respectively. Gulele sub city is located in northern parts of Addis Ababa near the mount Entoto with a population of 248,865. (Gulele sub-city administration).

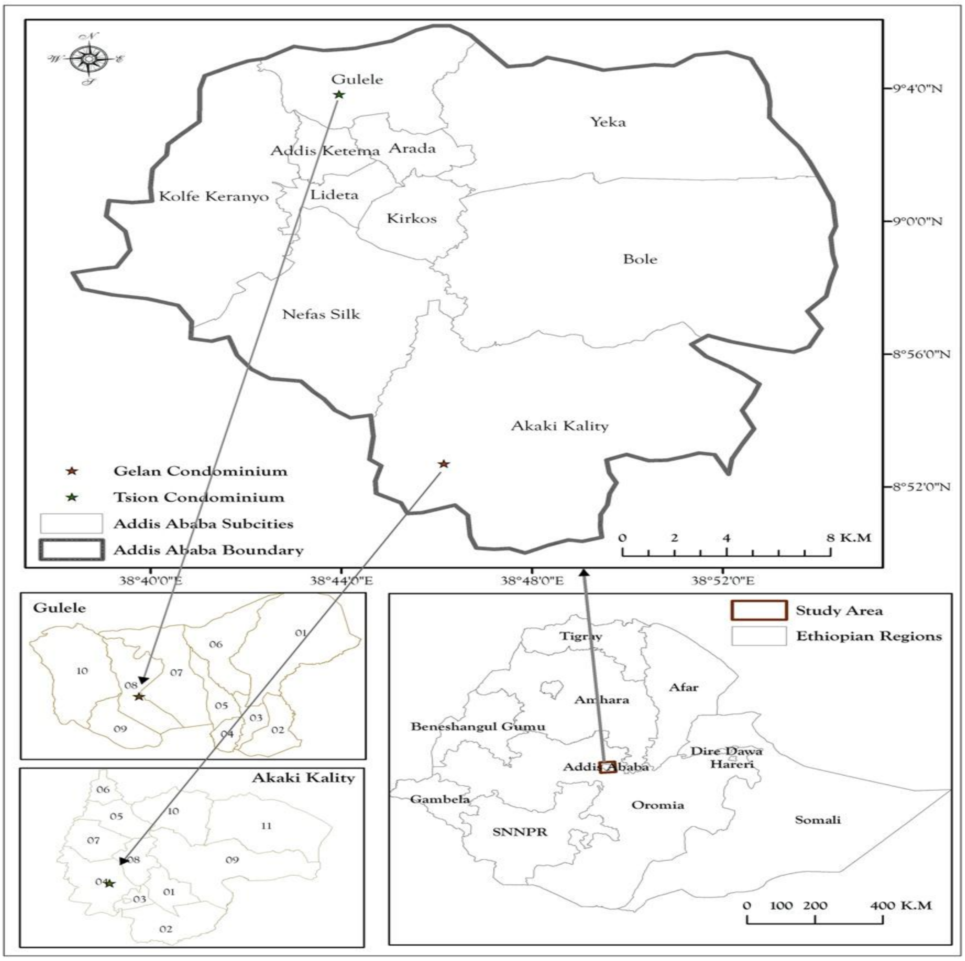


Figure 2: Map of the study area

Source: Geographic information system (GIS)

The Ethiopian Metrological Agency (EMA) presents the digital elevation model over a length of period for Addis Ababa. Accordingly, figure 3 below shows the elevation model for different sub-cities found in Addis Ababa. The dark blue and green colors represent higher elevation. Gulule sub-city is located in the higher elevation according to this model. Thus, Tsion condominium, one of the study areas in Gule sub-city which has an altitude of 2637 meters above sea level is located in highly elevated area. Whereas, the dark red color shows sub-cities that are found in low elevation. Akaki sub-city is found at the lower end of the map which represents the lower elevation. Gelan condominium which has an altitude that ranges between 2074m to 2130m with an average of 2100 meters above sea level is the other study area located in this area.

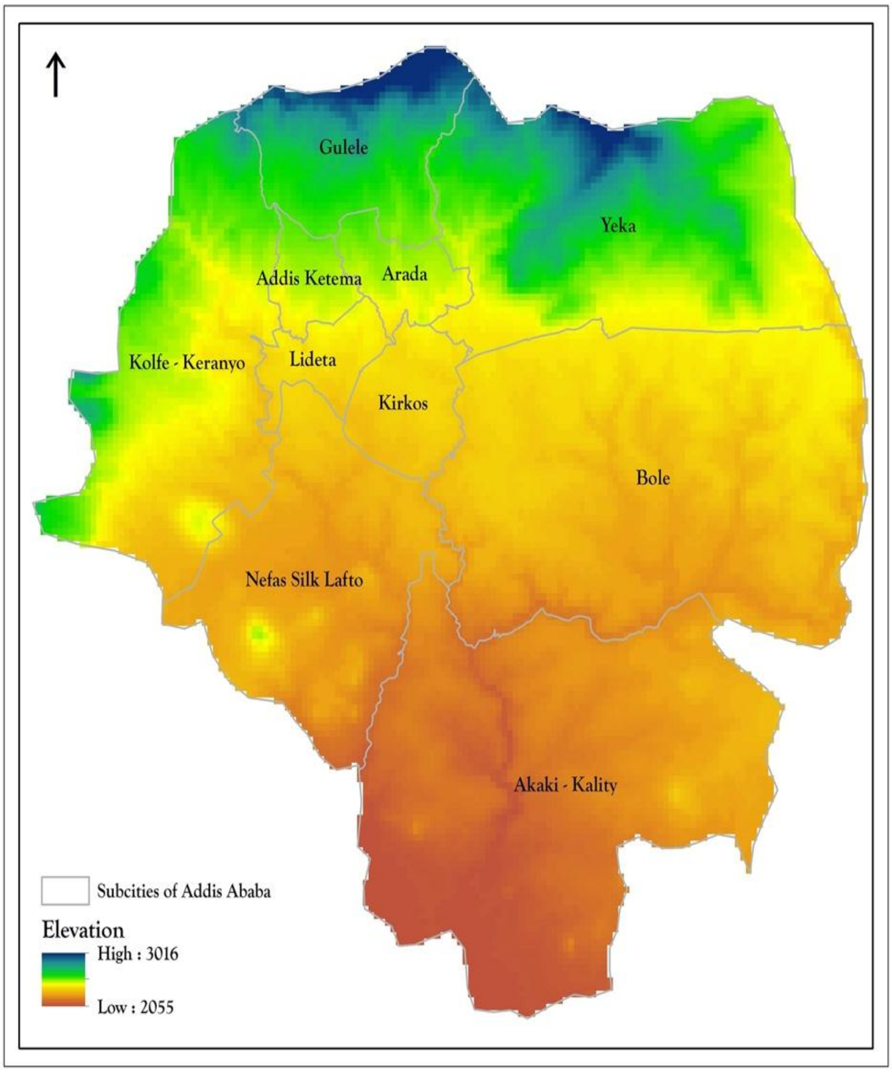


Figure 3: Digital elevation model of Addis Ababa

Source: Geographic information system (GIS)

Figure 4 below presents the temperature time series (1981-2016) reconstructed from station observations, remote sensing and other proxies by Ethiopian Metrological Agency. This interface allows users to view rainfall, maximum, minimum and mean temperature monthly climatology's and anomalies.

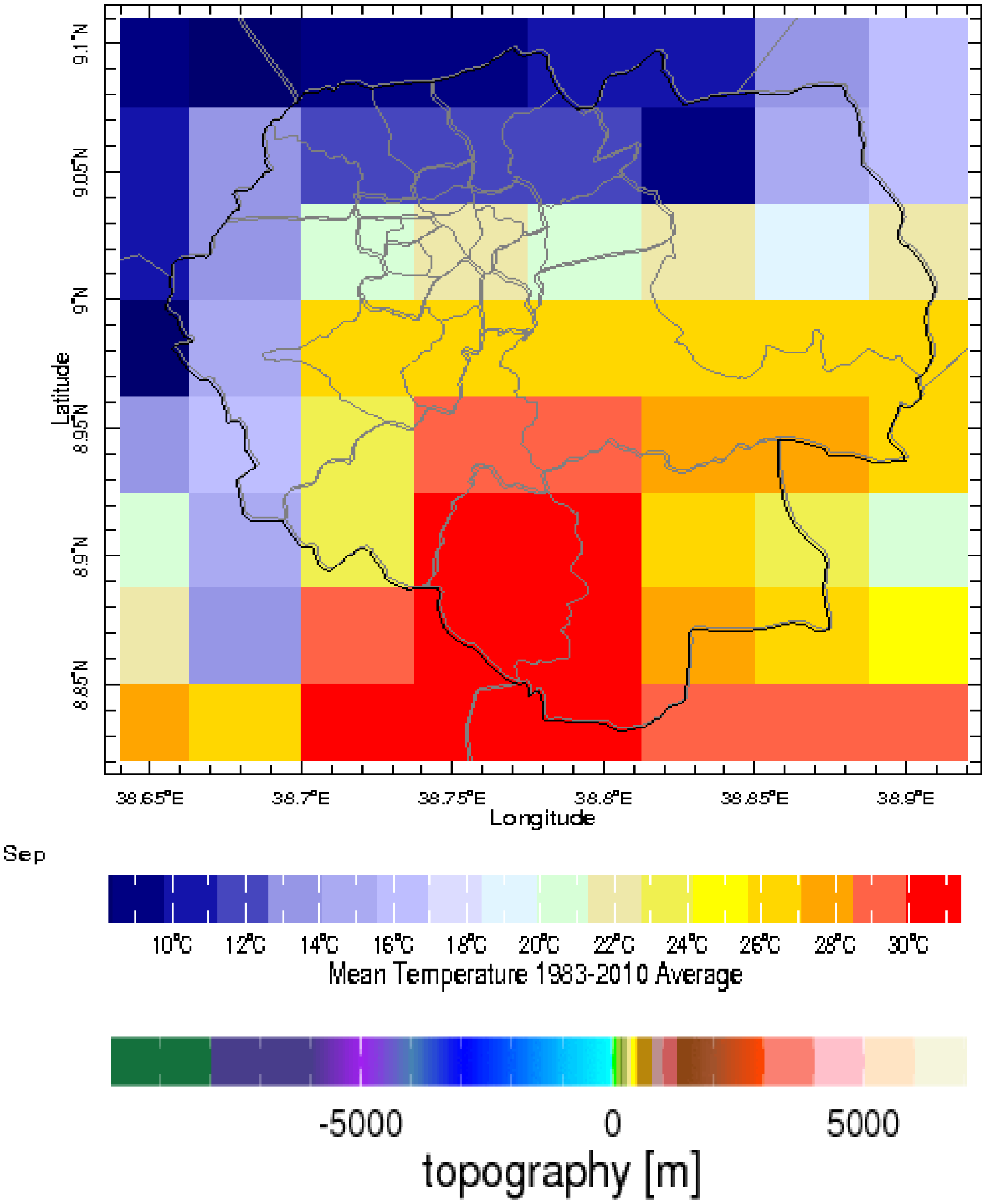


Figure 4: Mean temperature of Addis Ababa

Source: Ethiopian metrological agency

3.2. Research design

This study used qualitative and quantitative research approach. The study also used both primary and secondary data sources; both primary and secondary data sources are supplementary to each other. A primary source of data was collected by using quantitative and qualitative data collection techniques from occupants of condominium houses in both hot and cold climatic zones. Secondary data source was collected from journal articles, books, legal documents like proclamations, regulation and directives, statistical abstracts, study reports and thesis. Therefore, the research designs used here are the exploratory and descriptive design.

3.3. Sample and sampling technique

3.3.1. Sample size

Gulele and Akaki sub city was selected purposively based on its different climatic location based on EMA. Among two climatic zone in the study area, all the community households will be sampled. To obtain representative information from residents in the building, it is important to determine the sample size from the total households from hot and cold locations of the city. The number of the sample size is determined using a formula developed by (Kish, 1967).

$$n = \frac{n_1}{1 + \frac{n_1}{N}}$$

Where:

n = sample size

N = total population which is equal to 1850

$$n_1 = \frac{s^2}{v^2}$$

where:

S = maximum standard deviation among the population of elements (total error of 0.1 at a confidence interval of 95%) V = standard error of the distribution assumed to be 0.05 $s^2 = p$(1-p) where p represents the proportion of the population elements belonging to the class defined

$$s^2 = 0.3\ (1 - 0.7) = 0.21$$

$$n_1 = \frac{0.21}{(0.04)^2} = 131$$

$$n = \frac{131}{1 + \frac{131}{1850}} = 122$$

With 6% non-response rate the total sample size will be 130

3.3.2. Sampling technique

In the measurement of interior thermal comfort, there are two primary types of survey sampling. Transverse and longitudinal sample are the two types of sampling. In a transversal survey, the entire population or a significant section of it gives a single comfort rating. This method of sampling reduces sample bias while also minimizing interruption to the subjects' lives and activities. Humphreys et al. conducted a longitudinal survey in which each of a small number of individuals provided a large number of comfort assessments over a period of days or weeks (2012). Transverse survey sampling was used to collect information on the thermal sensation vote, the thermal satisfaction scale, and the thermal preference of inhabitants in residential structures in order to use a large sample size, decrease sampling bias, and ensure that the results are representative.

As a result, 130 sample informants were chosen from 1850 homes for subjective condominium house surveys. A proportional size allocation approach was utilized to achieve a representative sample size for each kebele. In this method of sampling, subjects are picked in proportion to their prevalence in the population. Grove and his colleagues (2013). This means that the sample size for each location was determined by the proportion of households that each location contributed to the total number of households (1850) in the two locations. The systematic sampling method was used to pick the sample households from every 14th and 15th unit of house for Tsion and Gelan condominium, respectively. The families were chosen based on their prior experience living in condominiums. Because the goal of the study is to assess the indoor thermal comfort of condominium buildings in Addis Ababa, two condominiums with almost identical orientations were chosen to collect data on relative humidity and air temperature. The main reason for selecting condominiums houses with the same characteristics in terms of the construction materials used and the availability of cooling and ventilation system. In a similar architectural design, condominium houses have five story which are connected by stairs. Their structure is made of stone and mortar, column, beams, and covered with corrugated iron sheet. All rooms have a rectangular design. Hence, due to the similar features, the floor plans and elevation plans of the two condominiums are represented as follows. (Figure 6 and 7)

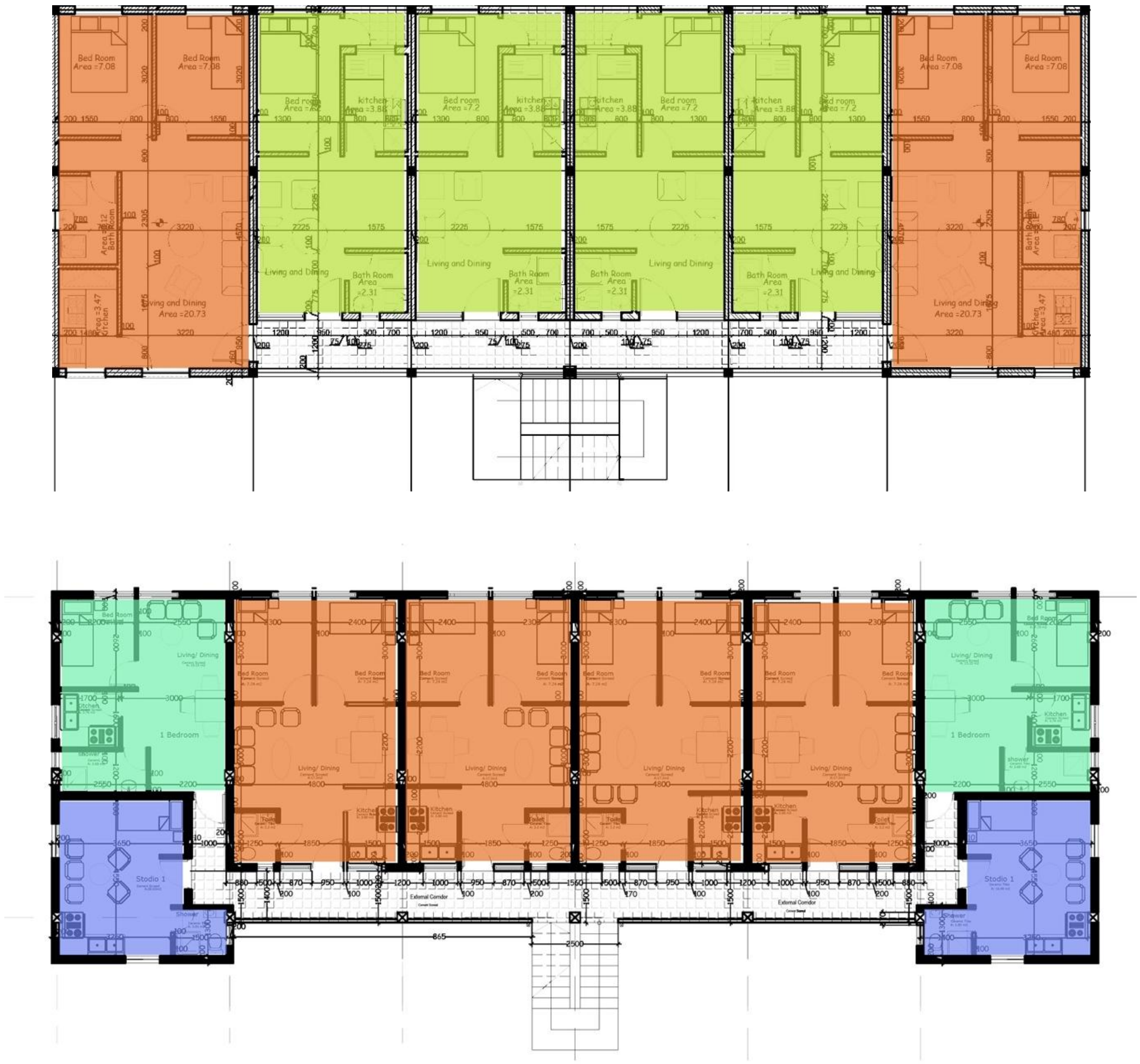


Figure 5: Floor plan of the condominiums

Figure 6: Elevation plan of the condominiums

3.4. Types of Data and Data Collection Instruments

3.4.1. Type and Source of Data

Data was collected from both primary and secondary sources. Primary data were collected from household surveys, focus group discussions, and key informant interviews with respondents who had experience of living in both types' climatic zones. Additionally, primary data were collected by personal measuring of the air temperature and relative humidity of condominium houses. The main sources for secondary data will be books, different articles, and government publications.

3.4.2. Methods for Evaluating Indoor Thermal Comfort

Subjective and/or objective measures can be used to assess indoor thermal comfort ASHRAE (2017). To analyze inhabitants' sensations, subjective ways include using the ASHRAE seven-point thermal sensory scale, thermal preference, standardized questioners, and interviews. This strategy will be influenced by the residents' adaption as well as their mood Laskari et al (2017). The objective measurement approach focuses on measuring interior thermal comfort factors such as air temperature, relative humidity, air velocity, and mean radiant temperature, and comparing these values to industry standards such as ASHRAE 55 and others Zaho (2020). Both methodologies were used in this study to compare the indoor thermal comfort of condominium houses in both climatic zones.

Figure 7: Digital Thermometer and Hygrometer

The device in figure 5 above was used to measure temperature and humidity at the study area. It can measure the maximum and minimum temperature and humidity records and can also be adjusted to measure temperature in °C and °F.

The device can measure an indoor temperature of 10 °C ~ + 60 °C or 14 °F ~ +140 °F and Outdoor temperature of -50 °C ~ + 70 °C or -58 °F ~ +158 °F; and 20% -90% relative humidity with the capacity of sensing up to 2m.

3.5. Data Analysis and Interpretation

The study employed mixed approach which incorporates both quantitative and qualitative method. The quantitative data is the primary data collected from sampled household was analyzed by using the Statistical Package for Social Scientists (SPSS v.21). Besides, the survey data was interpreted by using descriptive statistics such as mean, standard deviation, frequency distribution, percentage.

On the other hand, the qualitative data obtained through key informant interview and field observation was analysed by narrative analysis. This triangulates the data obtained by quantitative method.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents and discusses the results of the study. First, sample response rate then the demographic characteristics of respondents presented and discussed. The chapter also deals with the presentation and an analysis of data collected. The statistical methods used for analyzing the collected data includes frequency, percentage, descriptive statistics analysis (mean and standard deviation).

4.1. Sample response rate

A total of 130 questionnaires were distributed to the respondents and out of these questionnaires a total of 120 questionnaires were successfully completed and returned. Thus, the total response rate was 92%. This response rate can be seen as very good when compared to the guidelines in the literature. Babbie (1998) suggests that a 50% response rate is adequate, a 60% response is considered good while a 70% response rate is considered very Good. A low response rate is not acceptable and leads to concerns regarding external validity of the study.

4.2. Demographic characteristics of the respondents

The characteristics of the 120 respondents who participated in this study were presented in the form of tables and were described using frequency and percentage. The characteristics included gender, age, residence experience and climatic zones they were in. The researcher believed that these characteristics of respondents would help to have an overall picture about the respondents.

As shown in table 1 below the majority 45 (79%) and nearly one third 12 (21%) of the occupants in Tsion condominium from Gulele sub city are females and males, respectively. With respect to Gelan condominium (Akaki Kality sub city) 45 (71.4%) and 18 (28.6%) are females and males, respectively. When we compare the sex proportion of the two locations there were equal number of female respondents but with different proportions with respect to locations under consideration. The aggregate proportion of sex from both location sites are 90 (75%) and 30 (25%) are female and male, respectively. This is due to women are available at home during interview.

Table 1: Characteristics of respondents by sex

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Sex of respondent						
Male	12	21	18	28.6	30	25
Female	45	79	45	71.4	90	75
Total	57	100	63	100	120	100

Source: Own Survey

As shown from the summary statistics in table 2, the mean age of the occupants from Tsion condominium is 34.1 years with 18 and 75 years minimum and maximum age, respectively. The mean age of respondents from Gelan condominium is also 18 with a minimum and maximum age of 18 and 65, respectively. The mean age of respondents from both study areas are almost similar to the mean age of the total respondent.

Table 2: Summary of age of respondent

Location of respondent	Mean	Number	Std. Deviation	Minimum	Maximum
Tsion	34.1	57	13.9	18	75
Gelan	34.5	63	12.1	18	65
Total	34.3	120	13.0	18	75

Source: Own Survey

From table 3 below, we can observe that 31 (54.4%) and 26 (45.6%) of the residents from Tsion condominium (cold climatic zone) had previous experience of living outside and inside of Addis Ababa, respectively. From Gelan condominium, nearly the same number 31 and 32 of the respondents had previous experience of living outside and inside of the city, respectively. The overall number of residents from both locations also showed that nearly the same number of occupants have previous experience of living outside and inside of Addis Ababa. This experience of residence may help respondents to well recognize the climate change in the city.

Respondents were also asked about the climate zone they were in previously. Following this, 13 (22.8%), 20 (35.1) and 24 (42.1%) of the occupants were from cold, neutral and warm climate zones, respectively in the case of Tsion condominium. In the case Gelan condominium, the majority 33 (52.4%), 19 (30.1%) and 11 (17.5%) of them were in neutral, warm and cold climate zone, respectively.

Table 3: Previous residence and climate zones respondents were in

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Previous residence of respondent						
Addis Ababa	31	54.4	31	49.2	62	51.7
Out of Addis Ababa	26	45.6	32	50.8	58	48.3
Total	57	100	63	100	120	100
Climate zone respondents were in						
Cold	13	22.8	11	17.5	24	20
Neutral	20	35.1	33	52.4	53	44.2
Warm	24	42.1	19	30.1	43	35.8
Total	57	100	63	100	120	100

Source: Own Survey

It is revealed in table 4 that the majority 48 (84.2%) of respondents lived in Addis Ababa for more than five years in the case of Tsion condominium. Only 9 (15.8%) were lived for five years and less. Regarding to Gelan condominium, large number 50 (79.4%) and less number 13 (20.6%) of the occupants were lived for more than five years and less than five years, respectively. Thus, the increased length of residence may help occupants to understand the trend in which the climatic conditions of the city is changing over a year.

To well understand their characteristics, as depicted in table 4, occupants were also asked for how long they were occupied the building they live in. Based on this, the majority 49 (85.9%) and 42 (66.7%) of them occupied the building they live in for more than eighteen months in both sites, respectively. Very small numbers of occupants occupied in the building for eighteen months and less in both locations. However, there were no occupants for less than six months in the case of Gelan condominium. In general, the longer the period of occupancy in the building may help the residents to understand more about their indoor thermal sensation and preference (table 4). In relation to this, key informants from both locations said that the climatic condition of the city is changing over time and season.

Table 4: The length of years lived in Addis and period number of months occupied in the building

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Length of year lived in Addis Ababa						
1-5 years	9	15.8	13	20.6	22	18.3
> 5 years	48	84.2	50	79.4	98	81.7
Total	57	100	63	100	120	100
Number of months occupied in the building						
< 6 months	2	3.5	-	-	2	1.7
6-12 months	3	5.3	6	9.5	9	7.5
12-18 months	3	5.3	15	23.8	18	18.3
> 18 months	49	85.9	42	66.7	91	75.8
Total	57	100	63	100	120	100

Source: Own Survey

4.3. Floor location and direction of building

As specified in table 5, the same number 13 (22.8%) of the respondent’s house is located on ground and first floor of the building at the Tsion condominium houses. Additionally, 9 (15.8%), 12 (21.1%) and 10 (17.5%) of the occupant’s house are located on second, third and fourth floor of the building, respectively in case of Tsion condominium. In the case of Gelan condominium, almost similar number 13 (20.6%), 14 (22.2%) 15 (23.8%) and15 (23.8%) of occupants’ house are located on first, second, third and fourth floor, respectively.

Majority of the buildings in Tsion condominium sites are oriented to west, north and south. But a little more number 14 (24.6%) of buildings are faced to south. A small number 4 (7%) of them are faced to north west corner. In the case of Gelan condominium, large number 28 (44.4%) of the buildings are faced to north direction. Furthermore, equal number of the buildings are oriented to west and south direction (Table 5). Almost all 56 (98.2%) and 62 (98.4%) of the buildings are made of concrete in both Tsion and Gelan condominium, respectively. According to information gathered from key informants those occupants whom their houses were faced to south or north and their windows faced to afternoon sun light are complaining of the over hotness due to sun light. In similar way, those whom their front door faced to west also complain in the same way.

Table 5: Floor location, orientation and construction materials of the building

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
On which floor the respondents house located						
Ground Floor	13	22.8	6	9.5	19	15.8
First Floor	13	22.8	13	20.6	26	21.7
Second Floor	9	15.8	14	22.2	23	19.2
Third Floor	12	21.1	15	23.8	27	22.5
Fourth Floor	10	17.5	15	23.8	25	20.8
	57	100	63	100	120	100
In which direction the building face (orientation)						
East	8	14.0	1	1.6	9	7.5
West	11	19.3	17	27.0	28	23.3
North	11	19.3	28	44.4	39	32.5
South	14	24.6	17	27.0	31	25.8
NW corner	4	7.0	-	-	4	3.3
SW corner	9	15.8	-	-	9	7.5
Total	57	100	63	100	120	100
Construction material of the building						
Concrete	56	98.2	62	98.4	118	98.3
Other	1	1.8	1	1.6	2	1.7
Total	57	100	63	100	120	100

Source: Own Survey

On the other hand, occupants living on the ground in the case of Tsion condominium said that they felt coldness. whereas, occupants who live on the last floor in Gelan condominium complaining the over hotness due to absorbed heat from sunlight.

More number 30 (52.6%) of residents in Tsion condominium use light sometime during night. Whereas, 27 (47.4%) use light sometime day and night. In Gelan, nearly double of the respondents use light sometime during the night time. Compared to Tsion, large number of Gelan condominium residents use light sometime during night as specified in tale 6 above. In both locations occupants adjust their room temperature by opening their windows. Moreover, they use other methods such as opening and closing doors, using charcoal and wearing cloths to adjust to the room temperature (table 6).

Table 6: Lighting schedule and methods used to adjust the room temperature by the respondent

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Lighting schedule of the room						
Sometime on day & night	27	47.4	20	31.7	47	39.2
Sometime on night	30	52.6	43	68.3	73	60.8
Total	57	100	63	100	120	100
Methods used to adjust/control the room temperature						
Window shades	1	1.8	2	3.2	3	2.5
Portable heater	4	7.0	-	-	4	3.3
Portable fan	1	1.8	5	7.9	6	5
Adjustable air vents	1	1.8	-	-	1	0.08
Windows	21	36.8	37	58.7	58	48.3
Others	29	50.9	19	30.2	48	40
Total	57	100	63	100	120	100

Source: Own Survey

4.4. Comfort level and acceptability rate of temperature

The residents in both study area was asked to express their overall comfort level and acceptability rate of temperature at the moment of interview. Accordingly, more number 24 (42.1%) of the residents at Tsion condominium felt comfortable of the air temperature. Nearly the same number 16 (28.1%) and 17 (29.8%) of the respondents felt slightly comfortable and uncomfortable, respectively. However, in the case of Gelan, the majority 29 (46%) are slightly comfortable with temperature. Eighteen (28.6%) and 14 (22.2%) are thermally comfortable and uncomfortable, respectively (table 7).

In addition, the overall acceptability rate of temperature is 34 (59.6%) and 16 (28.1%) just acceptable and just unacceptable, respectively for residents in Tsion condominium. In Gelan the occupants' overall acceptability rate was 28 (44.4%) and 23 (36.5%) for just acceptable and just unacceptable, respectively (table 7).

Table 7: Overall comfort level and acceptability rate of temperature

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Description of overall comfort level						
Comfortable	24	42.1	18	28.6	42	35
Slightly uncomfortable	16	28.1	29	46.0	45	37.5
Uncomfortable	17	29.8	14	22.2	31	25.8
Very uncomfortable	-	-	2	3.2	2	1.7
Total	57	100	63	100	120	
Overall acceptability rate of temperature at the moment of interview						
Clearly acceptable	6	10.5	6	9.5	12	10
Just acceptable	34	59.6	28	44.4	62	51.7
Just unacceptable	16	28.1	23	36.5	39	32.5
Clearly unacceptable	1	1.8	6	9.5	7	5.8
Total	57	100	63	100	120	100

Source: Own Survey

As shown in table 8 below, similar number 26 (45.5%) of respondents at Tsion condominium houses responded that their sensation of air velocity in the class room is just right and slightly breezy. However, for breezy sensation, this number is larger 42 (66.7%) in the case of Gelan condominium. Therefore, the current condition of air speed is just right for occupants in the Gelan than in Tsion. A little number 5 and 4 of respondents felt that air velocity in the class room was too breezy and slightly still for Tsion and Gelan, respectively.

The majority 35 (61.4%) and 53 (84.1%) of residents preferred the current situation of air velocity to be neutral in the class room for Tsion and Gelan condominium, respectively.

However, 22 (38.6%) and very less 8 (12.7%) of occupants preferred the air velocity to decrease. More number of respondents in Gelan condominium preferred the air velocity in the class room as it is than in Tsion. (Table 8)

Table 8: Occupants' sensation and preference on air velocity in the class room

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Occupants' sensation of air velocity in the class room at the moment						
Slightly still	-	-	4	6.3	4	3.3
Just right	26	45.6	42	66.7	68	56.7
Slightly breezy	26	45.6	17	27.0	43	35.8
Too breezy	5	8.8	-	-	5	4.2
Total	57	100	63	100	120	100
Occupants' preference on air velocity in class room						
Increase	-	-	2	3.2	2	1.7
No change	35	61.4	53	84.1	88	73.3
Decrease	22	38.6	8	12.7	30	25
Total	57	100	63	100	120	100

Source: Own Survey

Occupants use different mechanisms to adjust their thermal comfort. As specified in table 9 below, majority of the respondents from the two study areas use natural ventilation such as wearing cloths and drink intake. Accordingly, 38 (66.7%) and 19 (33.3%) of occupants adjust their thermal comfort using natural ventilation and electrical and mechanical ventilation by Tsion condominium house residents, respectively. In the same manner, 53 (84.1%) and 10 (15.9%) of occupants of Gelan condominium also use natural ventilation and electrical and mechanical ventilation, respectively to adjust their thermal comfort.

Regarding consumption of energy to adjust thermal comfort level, 31 (54.4%) and 22 (38.6%) of occupants in Tsion condominium house consume very low and low energy, respectively. However, much more of the occupants 57 (90.5%) consume very low energy by Gelan condominium house residents. Thus, very low energy is consumed by Gelan condominium residents than by Tsion.

Table 9: Mechanisms used and energy consumption to adjust the thermal comfort

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Mechanism used to adjust the thermal comfort level						
Electrical and mechanical ventilation	19	33.3	10	15.9	29	24.2
Natural ventilation, fabrics, drink intake	38	66.7	53	84.1	91	75.8
Total	57	100	63	100	120	100
Energy consumption to adjust the thermal comfort						
Very low	31	54.4	57	90.5	88	73.3
Low	22	38.6	6	9.5	28	23.3
High	4	7.0	-	-	4	3.4
Total	57	100	63	100	120	100

Source: Own Survey

As it is observed in table 10 below, nearly same number 20 (35.1%) and 18 (31.6%) of respondents from Tsion condominium were seating and engaged in small activities during the interview, respectively. Additionally, 14 (24.6%) were engaged in hard activities. In case of Gelan condominium, the majority 30 (47.6%) were engaged in small activities. Furthermore, 19 (30.2%) and 13 (20.6%) of occupants were seating and engaged in hard activities, respectively. Nevertheless, very small number of people were sleeping 30 minutes before interview in both locations.

The finding also shows that 35 (61.4%) and 24 (38.1%) of respondents who wore in normal wear during interview were from Tsion and Gelan condominium, respectively. Majority of the respondents wore in light wear in Gelan condominium while only 8 (14%) was from Tsion. This may be due to hotness of temperature at Gelan. About 14 (24.6%) of occupants at Tsion condominium wore in heavy clothes while there were no one in the case of Gelan condominium.

Table 10: Activity engaged in and type of cloth worn by the respondent

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Activity engaged in 30 minutes before filling the questionnaire						
Sleeping	5	8.8	1	1.6	6	5
Seating	20	35.1	19	30.2	39	32.5
Small activities	18	31.6	30	47.6	48	40
Hard activities	14	24.6	13	20.6	27	22.5
Total	57	100	63	100	120	
Type of cloth worn at the moment of interview						
Light wear	8	14.0	39	61.9	47	39.2
Normal wear	35	61.4	24	38.1	59	49.1
Heavy wear	14	24.6	-	-	14	11.7
Total	57	100	63	100	120	100

Source: Own Survey

4.5. Main factors that affect thermal comfort

There are six primary factors that directly affect thermal comfort that can be grouped in two categories as personal factors and environmental factors. metabolic rate and clothing level are among the personal factors whereas, air temperature, mean radiant temperature, air speed and humidity are among environmental factors. Even if all these factors may vary with time, standards usually refer to a steady state to study thermal comfort, just allowing limited temperature variations.

Accordingly, the majority of respondents 45 (78.9%) and 40 (63.5%) who said that the main factor that affect their thermal comfort was temperature was from Tsion condominium house occupant and Gelan condominium occupant, respectively. This result is consistent with the conclusion reached by (Parsons, 2014) that one of the most important factors influencing indoor thermal comfort has been identified as air temperature. But, very small number of occupants from Tsion condominium said that other factors such as relative humidity, clothing insulation and personal activity are not the primary factors that affect their thermal comfort. Though they are less in number 18 (28.6%) respondents from Gelan condominium houses reported that personal activity is also one the factors that affect their thermal comfort next to temperature (table 11).

Ibrahim et al., (2014), conducted a study to explore the thermal comfort scenario of the residential buildings in Mubi metropolis with the view of offering measures to improve the comfort of people in their homes. He found that in addition to environmental and personal factors, the aggravation of thermal discomfort in Mubi were caused by some factors among which are: epileptic power supply, high cost of air conditioning systems, use of good heat conducting materials in buildings, poor building design and use of high heat emitting lighting devices.

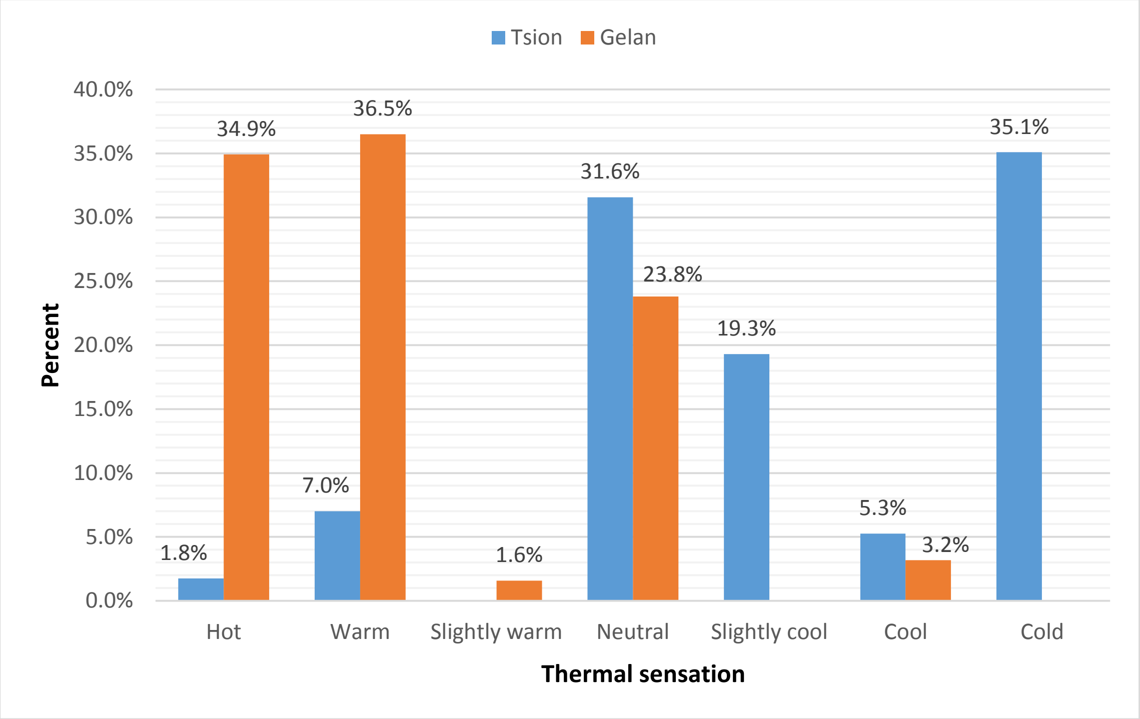
Table 11: Main factors that affect the thermal comfort

Variable	Location of occupant					
	Tsion		Gelan		Total	
	Number	Percent	Number	Percent	Number	Percent
Primary factors that affect the thermal comfort						
Temperature	45	78.9	40	63.5	85	70.8
Relative humidity	3	5.3	2	3.2	5	4.2
Clothing insulation	7	12.3	3	4.8	10	8.3
Personal activity	2	3.5	18	28.6	20	16.7
Total	57	100	63	100	120	100

Source: Own Survey

4.6. Thermal sensation, preferences, and satisfaction level

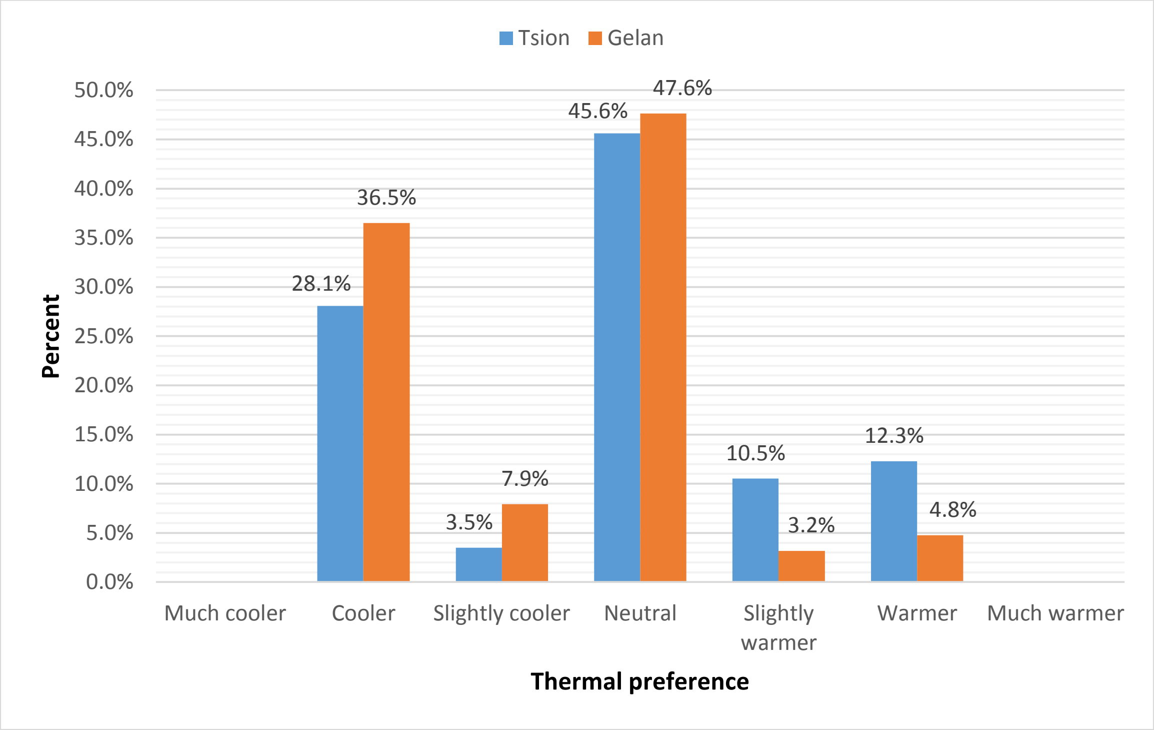
This part discusses the thermal sensation, thermal preference and thermal satisfaction of the occupants from the two study areas and compares the results of the study with the ASHRAE standard. The humidity sensation of residents is also discussed and compared with the standard.



Source: Own Survey

Figure 8: Thermal sensational scales for Tsion and Gelan Condominium

The tenants of condominium houses in Addis Ababa's cold and hot climatic zones were polled on their thermal experience. The percentage of people who voted for thermal sensation in both climatic zones is displayed above. Only 1.8 percent of respondents chose for the warm choice in condominium houses in the cold climatic zone (Tsion), as indicated in figure 3, and roughly 7% voted warm. Furthermore, 31.6 percent, 19.3 percent, 5.3 percent, and 35.1 percent of respondents, respectively, chose neutral, slightly cool, cool, and cold. Three central alternatives (-1 to +1) on the ASHRAE seven-point sensory scale represent the comfort zone ASHRAE (2017). According to this, 49.1 percent of respondents in Addis Ababa's cold climatic zone were in the comfort zone, while 50.9 percent were not. In the hot climatic zone, 1.6 percent of condominium house tenants chose the slightly warm choice, 36.5 percent chose the warm option, and 34.9 percent chose the hot option. Furthermore, 23.8 percent of voters were undecided, while 3.2 percent chose the cool option. According to the ASHRAE (2017) standard, 23.5 percent of occupants were in the comfort zone because they were in one of the three options (-1 to +1), while the rest (75 percent) were outside of it. A study by Haven et al (2012) on the indoor thermal comfort in the case of modern and traditional buildings in Semera city, in Afar region found that 88% percent of the occupants were in the 80% standard of ASHRAE. Therefore, the results from both locations are inconsistent with the results found by other studies in the literature.

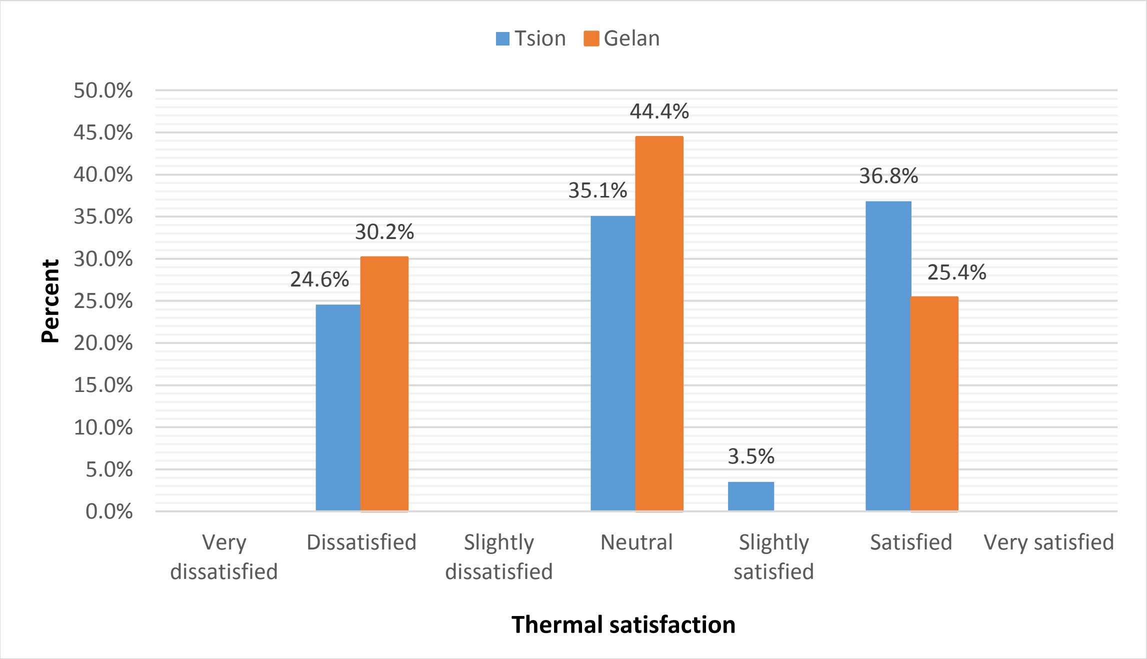


Source: Own Survey

Figure 9: Thermal preference scales for Tsion and Gelan Condominium

Figure 4 depicts the respondents' answers to the thermal environment in both the Gelan (hot climatic zone) and Tsion (cold climatic zone) condominium buildings in Addis Ababa, based on the predictor of thermal preference. As a result, 45.6 percent of Tsion condominium house occupants prefer that their home's thermal environment remain same, while 3.5 percent prefer it to be significantly cooler. In condominium houses, on the other hand, roughly 28.1 percent of residents said they would prefer a cooler climate. Furthermore, 10.5 percent and 12.3 percent of respondents chose somewhat warmer and slightly warmer temperatures, respectively. This finding indicates that the temperature conditions in Tsion condominium houses were lower than the respondents' preferred temperature. The results of the study also shows that 40.4% were out of the comfort zone of the preference scale and 59.6% were between the standard of the ASHRAE.

36.5 percent, 7.9 percent, and 47.6 percent of respondents said they would prefer cooler, somewhat cooler, and neutral temperatures in Gelan condominium houses, respectively. Furthermore, just 3.2 percent and 4.8 percent of respondents said that if they could modify their thermal environment, they would choose a little warmer and warmer climate, respectively. In other words, in the instance of Gelan condominium houses, 58.7% were in the comfort zone of the preference scale and 41.3 percent were outside of the ASHRAE standard. Consequently, people in both climatic zones indicated that they would prefer for their thermal environment to stay the same or change slightly. This result is inconsistent with other studies found in the literature Akande & Adebamowo (2011; Bulti & Gabore, (2020)



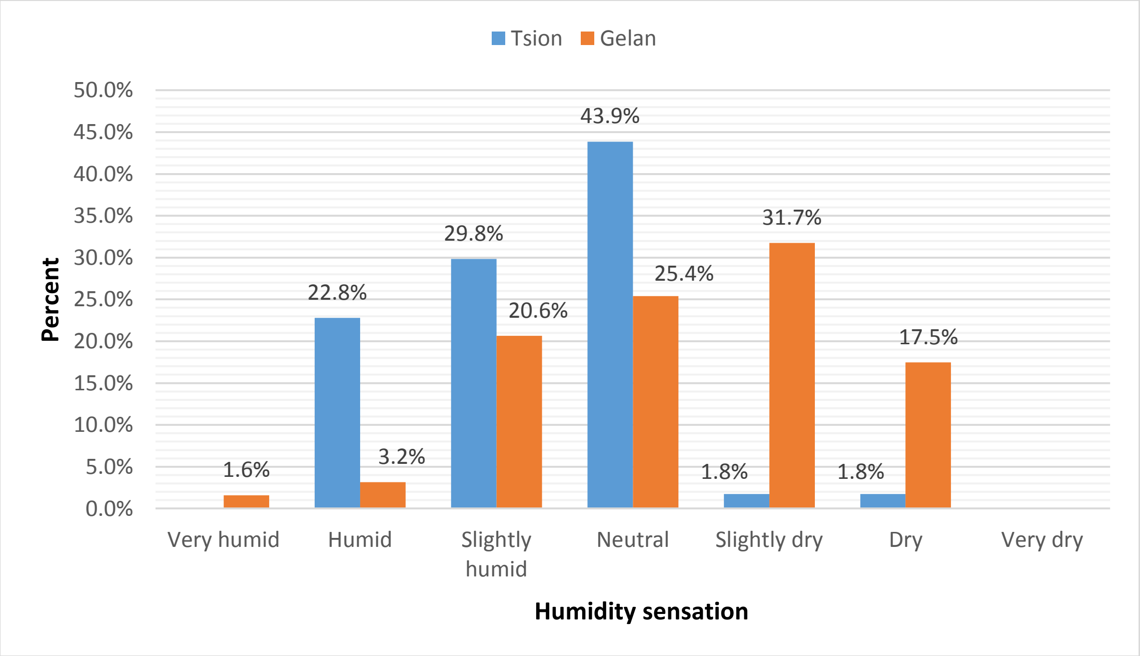
Source: Own Survey

Figure 10: Thermal satisfaction scales for Tsion and Gelan Condominium

Thermal satisfaction of interior parameters is influenced by a variety of psychological elements such as expectation levels, usage of controls, behaviors, and thermal background. Dili and his associates (2010). Figure 5 reveals that 24.6 percent of respondents were dissatisfied with the comfort at Tsion (cold climatic zone) condominium houses in the city, while 35.1 percent felt no change (neutral). On the other hand, approximately 3.5 percent and 36.8% of Tsion condominium house inhabitants, respectively, voted slightly happy and satisfied. (See Figure 5). As a result, tenants of Tsion condominium houses were dissatisfied, with a higher percentage of occupants in the discomfort zone (71.4%) than in the comfort zone (38.6 percent).

Figure 5 also shows that 30.2 percent of respondents were unsatisfied with the comfort of the Gelan condominium houses, while 44.4 percent of respondents were neutral. In contrast, 25.4 percent of respondents said they were satisfied. As a result, it is easy to conclude that the Gelan condominium satisfaction rating does not fulfill the ASHRAE thermal sensational scale criteria. The thermal satisfaction measure was discussed with the key informant interview participants in order to acquire a better understanding. The majority of the participants shared similar viewpoints, which can be stated as follows:

The majority of persons who reside in both condominium houses are happy with the existing thermal indoor climate, according to the key informant survey. The main reason for this is that the trend in climate change in Addis Ababa resulted in a comfortable thermal indoor climate over time and occupants are personally adapted to it.



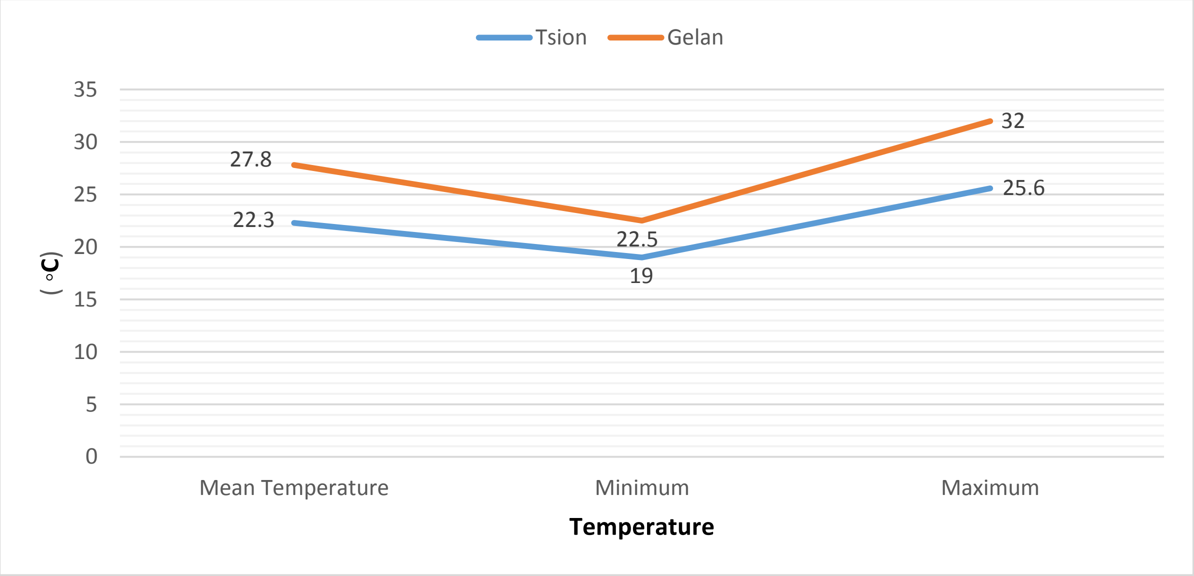
Source: Own Survey

Figure 11: Humidity sensational scales for Tsion and Gelan Condominium

Figure 6 above revealed that 22.8% and 29.8% of the occupants in the Tsion condominium houses described that their current humid sensation was humid and slightly humid, respectively. Moreover, the majority (43.9%) of them described that their current humid sensation was not changed (neutral). However, less of them described that their current humid sensation was slightly dry and dry. With regard to Gelan (hot climatic zone) of Addis Ababa, very few occupants described that their current humid sensation was very humid and humid where as 20.6% of them described slightly humid sensation. Furthermore 25.4% and 17.5% of the occupants described neutral (no change) and dry current humid sensation, respectively. But a little more (31.7%) of them described that their current humid sensation was slightly dry.

4.7. Indoor thermal environments

The thermal environment has the possibility to unfavorably affect human health Parsons (2014). One of the most important factors influencing indoor thermal comfort has been identified as air temperature. A change in air temperature can normally change a person's level of comfort, as evidenced by many studies Maarof et al (2009). In this study, the impact of environmental variables such as indoor air temperature and relative humidity on the thermal conditions of the Tsion condominium (cold climate zone) and Gelan condominium (hot climate zone) houses were investigated.



Source: Own Survey

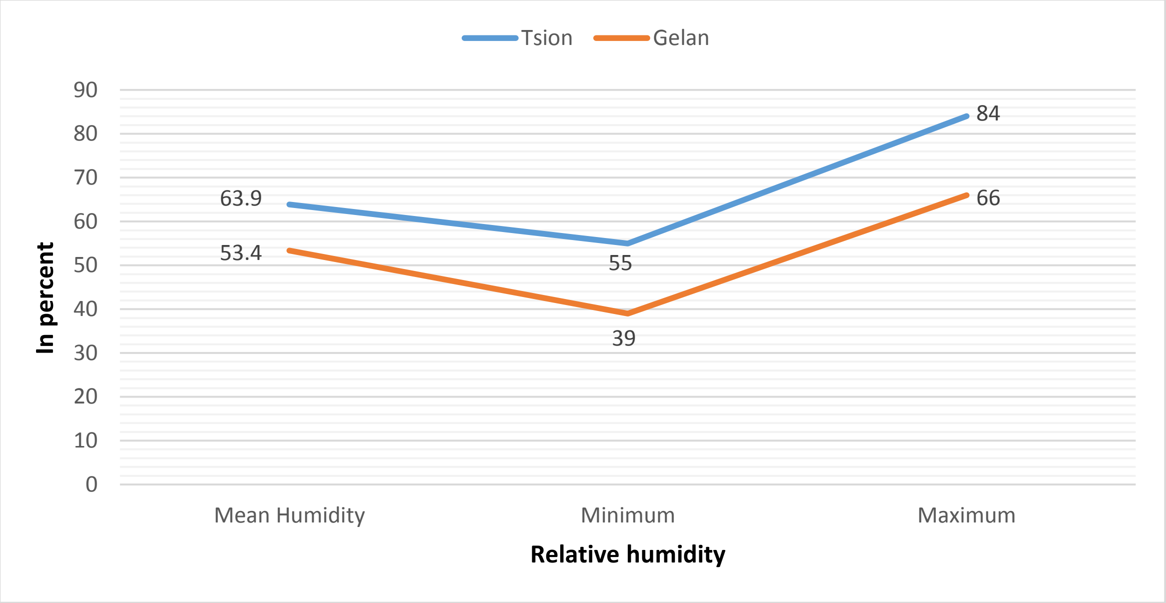
Figure 12: The mean temperature of Tsion and Gelan Condominium

The results of air temperature are presented for the month of September in figure 7 above.

According to the results, the mean temperature 22.3 °C and 27.8 °C for Tsion condominium and Gelan condominium houses, respectively. The minimum and maximum temperatures in the Tsion condominium house were 19 °C and 32 °C, respectively. On the other hand, the minimum and maximum temperature for Gelan condominium were 22.5 ˚C and 32 ˚C, respectively

According to the indoor thermal comfort temperature zones, the mean temperature of the condominium houses from both sites was in compliance with the 80% acceptability band of the adaptive comfort standard (ACS) model.

The comfortable states of temperatures in the condominium house are caused by the natural adaptation of occupants with the Addis Ababa city microclimate, according to information obtained from key informant interviews and field observations.



Source: Own Survey

Figure 13: The mean relative humidity of Tsion and Gelan Condominium

The ability of air particles to absorb heat and evaporate is determined by relative humidity, which is another important factor that affects indoor thermal comfort. The relative humidity must be low enough to enable the evaporative process to take place in order for this to occur (Maarof et al., 2009). The relative humidity (RH) data was also monitored, and the results showed that the mean relative humidity for Tsion condominium houses and Gelan Condominium houses were 53.4% and 63.9%, respectively. The result also showed that minimum and maximum relative humidity were 39% and 66%, respectively, for Tsion condominium houses. The mean relative humidity for Tsion condominium houses lied inside of the ASHRAE thermal comfort range (30 RH–60 RH). The minimum and maximum relative humidity for Gelan condominium houses were 55% and 84%, respectively. However, the mean relative humidity for Gelan lied outside the comfort range.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

This chapter conclude the study by summarizing the key research findings in relation to the research aims, as well as the value and contributions thereof. It also reviews the limitations of the study and propose opportunities for future research.

This study was aimed to evaluate the indoor thermal comfort of residents in condominium houses in different climatic zones of Addis Ababa city and to identify the contributing factors that hamper or facilitate indoor thermal comfort of residents.

The indoor thermal comfort of condominium houses built by the government in hot and cold climatic zones of the city were compared in this study. The research was carried out using both subjective and objective methods of assessment. According to the ASHRAE seven-point sensational scale, residents in both Tsion and Gelan condominium houses were not in compliance with the 80% acceptability band of the adaptive comfort standard.

The results indicated that the average indoor temperature in Tsion condominium houses (22.3°C) was lower than the indoor temperature of Gelan condominium houses (27.8°C) whereas, the mean relative humidity was 53.4% and 63.9% for Tsion and Gelan condominiums, respectively. However, the mean temperature and the mean relative humidity from both locations lie between the ASHRAE standard. Furthermore, among environmental factors which affect thermal comfort temperature is the main factor followed by clothing insulation in the case of Tsion condominium residents. In the case of Gelan condominium, personal activity is the main factor next to temperature.

Finally, the study has attempted to compare the indoor thermal comforts of condominium houses in the two climatic zones. However, although the research gives consideration to air temperature and relative humidity, attention was not given to other main factors that will affect the indoor thermal comfort such as air velocity, mean radiant temperature, clothing, and metabolism. Thus, future studies might concentrate on monitoring all the factors that affect indoor thermal comfort. This study has used the transverse method for subjective assessment and the survey was completed within one week. As a result, since the variation of temperature in a single day is limited and conditions vary between one day and the next, it could be difficult to distinguish between the effects of changed conditions and the way different sets of individuals respond to them.

5.2. Recommendations

From the discussion above we found that most of the condominium residence have experience indoor thermal discomfort and needs improved room air quality and temperature. Some household machineries, artificial lighting system in day time and using charcoal inside the room also add values in those thermal discomfort. Therefore, for the effort of more productivity scale and decrease energy consumption for adjustment of indoor thermal comfort every stakeholder and resident of condominium should practice the recommendation below.

In Addis Ababa a large-scale affordable program of condominium housing cover large portion of housing problems for the residences. These large number of populations play a great role in the development sector of the city. Hence, they have to get comfortable indoor space and they also have to minimize energy consumption from their living activity. The people who live in the condominium has to feel the responsibility of getting and using natural air conditioning system like using openings and planting trees for shade and good air quality. Thus, Government (Housing Development Corporation) have to practice the following recommendations.

- Governmental body who are involving in communal residential buildings project needs a deep study in indoor thermal comfort; problem source of the discomfort zone and solutions for those low-cost communal residential buildings.
- The residents which occupied the condominium and Addis Ababa housing development corporation ought to renovate the existing buildings to provide natural heating cooling system like providing shades by planting trees, providing accessible communal traditional cooking spaces, installing geothermal heat pump system.
- For the new under construction buildings Addis Ababa housing development corporation, revise the design, use climate compatible building material, and supervise the work very well. The design has to accommodate the orientation for quality air circulation, proportional openings for natural ventilation and lighting system, standard floor height for appropriate climatic zone and provide space for plants.

- Governmental body also installing eco-friendly AC system and give awareness for the resident and coworking with other organization like metrology agency.

Finally, plan and construction policy makers have to revise the rule, regulation and standards according to the climate zone.

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Appendix

Dear respondent

First, I would like to ask your willingness to answer the following questions; I am a student at Addis Ababa University, undertaking research as a requirement for the reward of my Master's degree in Environment and sustainable development. This survey is to assess indoor thermal comfort in selected climatic zones of Addis Ababa city condominium residential buildings. Kindly, note that, I will use the questioners for academic purposes only. Your answers will be kept confidential. Please use the encircle on your appropriate answers.

Thank you for your cooperation in advance!

Date ____/____/____ Time _________ Location _____________

Temperature(^{o}c) ______ Humidity (%) - __________

Section A – Personal profile

1. Age of respondent
2. Sex of respondent
3. Where u lived previously
    a. Addis Ababa b. Outside Addis Ababa
4. Before you occupied here, what kind of climate zone you were in
    a. Cold b. Neutral c. Warm

Section B – Climate and Building condition

1. How long have you lived in Addis Ababa?

A. Less than 1-year B. 1-5 year C. More than 5 years

2. How many months have you occupied this building?

A. Less than 6 months C. 12-18 months

B. 6-12 months D. More than 18 months

5. On which floor is your house located?

A. Ground floor B. First Floor C. Second Floor

D. Third Floor
E. Fourth Floor

4. In which direction does your building face?

A. East
B. West
C. North
D. South
E. Northwest Corner
F. Northeast Corner
G. Southwest Corner
H. Southeast Corner

5. Building construction material of the building

a. Concrete
b. Other

6. Lighting schedule of the rooms

a. Some time on day and night
b. Sometime on night
c. All day and night
d. All night

7. Which of the following do you use to adjust or control your classroom's environment? (Check any that apply)

A. Window blinds or shades
B. Thermostat
C. Portable heater
D. Room air-conditioning unit
E. Portable fan
F. Ceiling fan
G. Adjustable air vents
H. Windows
I. Other

8. What are you wearing right now?

A. Light wear
B. Normal
C. Heavy wear

9. Please describe your current thermal sensation

A. Hot
B. Warm
C. Slightly Warm
D. Neutral
E. Slightly cool
F. Cool
G. Cold

10. Please describe your current Humid sensation

A. Very humid
B. Humid
C. Slightly Humid
D. Neutral
E. Slightly dry
F. Dry
G. Very dry

11. Please describe your overall comfort level (Thermal comfort)

A. comfortable
B. Slightly uncomfortable
C. Uncomfortable
D. Very Uncomfortable

12. What do you like to be

A. Cooler
B. No change
C. Warmer

13. How do you rate the overall acceptability of temperature at this moment?

A. clearly acceptable
B. Just acceptable

C. Just unacceptable
D. Clearly unacceptable

14. How do you feel the air velocity in this class room at this moment?

A. Too still
B. Slightly still
C. Just right
D. Slightly breezy
E. Too breezy

15. How do you like to be about the air velocity?

A. Increase velocity
B. No change
C. Decrease velocity

Section C – Climate comfort related

1. How do you perceive the satisfaction scale of your comfort zone?
   a. Very dissatisfied
   b. dissatisfied
   c. Neutral
   d. Satisfied
   e. Very satisfied
2. What is your energy conception performance to adjust the thermal comfort?
   a. Very low
   b. Low
   c. High
   d. Very high
3. What mechanism did u use to adjust the thermal comfort level?
   a. Electrical and mechanical ventilation by energy consumption
   b. Natural ventilation, adjusting fabrics and drink intake
4. How does this thermal comfort affect your daily lives in this energy consumption to adjust it?
   a. high
   b. Normal
   c. Low
5. Do you use artificial ventilation system?
   a. Yes
   b. No
6. If yes, what is your criteria to use artificial ventilation system.
   a. Suitable for weather condition
   b. Availability of the market
   c. Energy concentration
   d. Indoor air quality
   e. Price (other)
7. For how long do you use air conditioning?
   a. Less than a year
   b. A year
   c. Above a year
8. If you are not using eco-friendly AC operation system, what is your reason?
   a. Lack of awareness
   b. Availability
   c. High price
9. What do you think the primary factors that affect the thermal comfort?

a. Temperate
b. Relative humidity
c. Clothing insulation
d. Personal activity (metabolic rate)

10. What activity are you engaged in 30 minutes before filling this questioner?
    a. Sleeping
    b. Seating
    c. Small activities
    d. Hard activities

Questions for Key Informants

1. Do you think Addis Ababa weather condition has a change in within 10 years
2. What do you think the main problem for indoor thermal discomfort
3. Do you think the condominium is good design to improve indoor thermal comfort
4. What do you think the preferable way to improve thermal comfort?
5. What role can government bodies have in making a building good indoor thermal comfort.