THE TRANSIENT HEAT FLOW IN THE SOUTH & WEST FACING HCB WALL OF CONDOMINIUM BUILDING IN ADAMA CITY,ETHIOPIA.

Ketsela Tolcha Desta

A Thesis submitted to

The department of Architecture

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of

Master of Science in Environmental Architecture

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

February, 2022

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APPROVAL OF BOARD OF EXAMINER

We, the undersigned, members of the Board of Examiners of the final open defense by **Ketsela Tolcha Desta** has read and evaluated his thesis entitled **"The transient heat flow in the south and west facing HCB wall of condominium building in Adama city, Ethiopia."** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Environmental Architecture.

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name: Ketsela Tolcha Desta

Signature: _______________

This MSc Thesis has been submitted for examination with my approval as a thesis advisor.

Name: Tibebu Assefa (PhD)

Signature: ______________

Date of submission February 03, 2022

ADVISOR'S APPROVAL SHEET

To: **Architecture department**

Subject: **Thesis Submission**

This is to certify that the thesis entitled **"The transient heat flow in the south and west facing HCB wall of condominium building in Adama city, Ethiopia"** submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Architecture, the Graduate Program of the Department of Architecture, and has been carried out by **Ketsela Tolcha Desta** ID. No PGR/19224/12, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

Tibebu Assefa (PhD)	___________________	_________________________
Name of major Advisor	Signature	Date

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ABSTRACT

In most of tropical regions of the world the major challenges in creating thermal friendly indoor space is heat. Heat is among one of the major determinant of thermal comfort that passes and leaves through the building facades; which the focal interface is between indoors and outdoors. This research aims to find the reaction of South and West facing façade of condominium building to the external environment as well as identify if the facades do fit for handling the warm climate of Adama city. Ambient temperature(indoor &outdoor) , surface temperature(exterior & interior) and humidity of the room within 2hrs interval (5 times a day) for four consecutive days in three months(March, April & May) were measured and used alongside the thermal conductivity values of the facade layers derived from literatures. MS Excel and formulas retrieved from literatures were used to analyze the data. Comparatively high thermal transmittance (1.2w/m^{2}k) ,low thermal insulance (0.83m^{2}k/w) & low absolute thermal resistance (10.406k/w , 9.756k/w is due to air gap) were among the results from the analysis , which indicate low performance of the facades. Relative humidity and room temperature results also do not completely fall inside the thermal comfort zone of Adama city: which depicts the existing facades are incapable of fulfilling thermal comfort throughout the daytime period. Heat transfer rate as low as -34.4J/sec (in April) & -45.29J/sec (in April) and as high as 73.3J/sec (in March) & 96.4J/sec (in March) were recorded for South and West facades respectively. Both facades do start gaining heat after midday, though the West facade receives quite more rapidly than South façade. Overall the existing facades do need optimization to enable them cope up with warm climate of Adama city. The research suggested optional facades by changing the existing air gap (16cm) of the facades to 20(+4cm) & 24(+8cm) in order to increase thermal performance of the facades with minor intervention. The results found were ,23.44% & 46.8% increase in absolute thermal resistance ,19.17% & 15.8% decrease in thermal transmittance for an extra 4 & 8cm air gap respectively.. This modification will enable the facades to have slower heat gain and faster heat loss, which is basic for maintaining thermal comfort in warm climates of Adama city.

Keywords: air gap, heat flow, south & west façade, surface temperature, thermal comfort

CHAPTER ONE

INTRODUCTION

The building facade is the focal interface between indoors and outdoors. and has an important role in controlling differences in the outdoor climate conditions, providing thermal comfort for residents and therefore determining the heating/cooling loads of the building (Albatayneh, 2018).Building facades or also referred as envelopes are the major components of the building that decide the thermal comfort level of the indoor space by interacting with the outdoor environment.

Heat is among one of the major determinant of thermal comfort that passes and leaves through the building facades. So selecting the proper thermal properties of a building envelope play a major role in determining the energy consumption pattern and comfort conditions in enclosed spaces. Therefore, understanding the heat transfer rate of the building facades helps to determine the ongoing thermal situation inside and outside the building. This, in turn, paves the way for selecting the appropriate building facades material and composition that get along with the climate of the specific area.

Due to the fact that building facades are the first responders of incoming heat to the building, studying what takes place inside the facades leads to a solution to tackle heat and thermal discomfort in warm and humid climates like Adama.

This study analyzes the heat transfer rate and related elements of the south and west building facades by measuring room and surface temperature as well as humidity of a common dwelling unit located in Adama city, to help builders, dwellers, municipalities, architects and other pertinent bodies make wise decisions in selecting the right building facade & façade material in future projects.

1.1 Background

Now a days terms like global warming, climate change, and other related with the case of handling natural and manmade environment are becoming top environmental issues. Such kind of environmental issues are expressed in many forms and their intensity is easily noticed in urban areas, where there is a dense existence of built structures.

Climate and buildings have a strong correlation in terms of creating a sustainable and thermal worthy indoor as well as outdoor living space for humans. These two elements shape each other in both positive and negative ways. These days' buildings are exerting pressure on the climate and it has lead humans to experience unconventional harsh climate. Large contribution to climate change comes from building sector. Energy consumption of buildings covers about 40% of the total energy (Albatayneh, 2018). Among the building sectors, the residential sector takes the lion share in energy consumption. In developing countries the residential building sector accounts for more than half of the electricity consumption (Amos Haruna et al , 2018) .Most of the energy consumption occurs during the so-called "operational phase" of the building for cooling, heating and lighting purposes (Daniel Marin, 2017). In Ethiopia ,even though there are not much available data related with the amount of energy consumed by residential sector , existing situation do resemble the above statement due to the fact that residence covers the largest percent coverage in land use. Building sector and climate characteristics by themselves are not solely responsible for exerting influence on energy use but building design and materials too.

In most of tropical regions of the world the major challenges in creating thermal friendly indoor space is heat. According to the State of the Tropics survey, about 50% of the world's inhabitants would live in the tropical regions before 2050 and consequently the demand for indoor thermal comfort in this region is increasing dramatically. Currently, most of the tropical developing countries are facing difficulties in achieving indoor thermal comfort in the absence of mechanical control because of inappropriate building design (Nusrat Jannat et al , 2020).

Skin acts as thermo regulator of human body, so is the building façade for buildings. Building facades now a days with the availability of advanced building materials has enabled buildings look aesthetically good. But this shouldn't be the primary goal of building facades. Especially in tropical areas where there is intense heat the building facades should have a capacity to moderate and limit the heat entering to and leaving from enclosed space of the building.

The building facades/external walls which form the major part of the building envelope thermally interact with the changing surrounding environment throughout the day influencing the indoor thermal comfort of the space (Nusrat Jannat et al , 2020). As part of the building envelope, walls account for a significant proportion of heat loss and gain. Almujahid et al,(2013) reported that about 1/3 of heat loss occurs through walls in case of un-insulated brick veneer dwelling (Ahmed , 2015).

The above statement justifies that building facades are the main gates of heat import and export to and from the building. It also amplifies the importance of facade orientations towards creating thermal comfort and indoor environment quality (IEQ). So Architects and other building industry professionals have to ensure that the design of the built form suits the intended use of the building and the specific needs of the client within the framework of the prevailing climatic conditions (Bano & Mohammad Kamal, 2016).

1.2 Statement of the problem

Above all the main purpose of buildings or dwelling units is to provide thermally comfortable indoor space for humans. Indeed buildings are also built for the sake of space maximization, aesthetics, cultural and historical essence, fantasy, economic motives and others. Nevertheless buildings should get along with the existing climate and surrounding.

In Adama and in most cities in Ethiopia, condominiums are perceived to be the problem solver of housing shortage by general public and government. These condominium buildings are built irrespective of the climate considerations. These dwelling units are found in the warmest and coldest regions of Ethiopia with same basic building material and space arrangement. Such lack of contextually inappropriateness has made condominium buildings less wanted and abandoned, which deviates from the intention of design and sustainability. Finding solution for thermal comfort problems in condominiums is simultaneously finding solutions to majority of buildings in Ethiopia which are basically made from HCB (Hollow Concrete block) as a main building material too.

Interviews made with condominium residents in Adama city indicate that, due to the hot and humid indoor space inside, they are forced to paint the window glass and use curtains almost all day to decrease the incoming solar heat. They also mentioned that they mostly use electric fans to get cooler air indoors in most time of the year. A research recently conducted by Haven Hailu (2020) , also indicates the contextual inappropriateness of the condominiums. According to the findings, the condominiums in Afar, Semera are not functioning well, they stand almost vacant and the thermal quality of the condominiums can be described as 'hot the whole day and the whole night'. This depicts that condominiums lack thermal comfort and heat is the main challenger of thermal comfort in tropical regions. Though the study conducted by Haven Hailu, (2020) is an eye opening towards understanding that there exists a problem of thermal comfort in condominiums located in hot areas, it lacks in deeply analyzing the material and arrangement of the condominium facades with respect to heat in a quantitative approach.

Adama city with the existing warm environment and increasing immigration, there will be a higher need in thermally comfortable condominiums and other residential buildings. However, the buildings with usual construction & use of the same wall material have detrimental effect in creating thermal comfort. With this in mind, this research looks into studying heat and its passageway to buildings ,which is primarily through building facades and determine whether the existing condominium façade(which is basically made from HCB ,Hollow Concrete Block), is capable of handling the warm climate of Adama city.

1.3 Objective of the study

General objective

The general objective of the study is to analysis the heat flow through the condominium facades located in Adama city, Ethiopia.

Specific objectives:

1, To evaluate the performance of the existing facade of the condominium with respect to

i, Comfort zone of Adama city

ii, South & West wall surface temperature

2, To compute

i, (a) Absolute thermal resistance (C^0/w) & (b) thermal conductance of the wall (w/ C^0)

ii, (a) Thermal transmittance of the wall (U-value: w/ m^2k) & (b) Thermal insulance of the wall (R-value: m^2k/w)

iii, Heat transfer rate of the wall (Q_{wall} : J/se &

iv, Heat flux of the wall (q_{wall} : w/m^2)

3, To suggest optimization of the existing façade/HCB wall

1.4 Research questions

Main question

How does heat flows through condominium facades located in Adama city, Ethiopia.

Specific Questions:

1, How is the existing facade of the condominium performs with respect to

i, Comfort zone of Adama city

ii, South & West wall surface temperature?

2, How much is

i, (a) Absolute thermal resistance (C^0/w) & (b) thermal conductance of the wall (w/ C^0)

ii, (a) Thermal transmittance of the wall (U-value: w/ m^2k) & (b) Thermal insulance of the wall (R-value: m^2k/w)

iii, Heat transfer rate of the wall (Q_{wall} : J/sec) &

iv, Heat flux of the wall (q_{wall} : w/m^2)

3, Is the optimized HCB wall will have more potential than Existing HCB wall in regulating heat?

1.5 Scope of the research

Spatial scope

The research has taken place in Adama city focusing on a condominium building located in Adama 01 kebele.The research was conducted in the warmest months of the year in Adama, which are March, April and May.

Thematic scope

West and south facades of a room located in a condominium building are where the research mainly focuses to point out how capable are the existing facades in moderating the hot climate of Adama.

1.6 The Significance of the research

Housing is and will be the basic need of human survival. The global climate with its current trend will also eventually worsen and make it very challenging for architects, construction professionals, government and other stakeholders to deliver a thermally suitable dwelling units and other buildings. So a better understanding of the heat in relation with the climate is fundamental. An optional building façade material is also another way of decreasing the problem.

The findings from this research will enable to understand the passage of heat from exterior to interior space of the dwelling units throughout the daytime. This in turn helps to adjust the selection, composition and arrangement of the exterior façade material of condominium buildings as well as other residences in Adama city and other cities in Ethiopia that have warm climate. It also helps to decide the optimal orientation of the building in site by taking a lesson from the thermal performance analysis of the south and west facades. Optional building facade materials will help to alleviate energy usage of residents for cooling which will save electricity bill for individuals and the government too. Production of optional facade material will also create a new door for job creation and economic up rise. Based on the initiation taken from this study, researchers could also work on other type of building facades and climates in Ethiopia for wider public, academic and country’s benefit.

1.7 Limitation

The measurements/data taken from the condominiums were using a single instrument for several times of a day in different period of months. This has made the research to be confined in a single condominium and HCB façade material in type. It was also limited to the warm seasons of Adama city, which didn’t consider its reaction to cold seasons. Except these, it has been done diligently to show the effect of consistent HCB wall usage in condominium buildings.

1.8 Description of the study area

Adama City is one of fast growing cities in the country with an estimated total population of 343,212 (CSA, 2009). Adama is also the second most populous city in Ethiopia.(cities alliance - cities without slums, 2019-2021).It is situated in Rift valley within Awash River Basin in Oromia Regional State of Ethiopia. It was established in 1916 on flat terrain characteristics and surrounded by plateaus, mountainous and ridged topography along Addis Ababa to Harar road at distance of about 96 km. It is located between8^{0}26’15”–8^{0}37’00”N,39^{0}12’15”-39^{0}19’45”E. Altitude of the area ranges from1489 -1976 m a.s.l. Average annual rainfall of Adama City is about 866.25 mm. Most of the rain occurs in rainy season (June to September). The minimum wind speed occurs during September (1.65m/s), while the wind with high velocity occurs during December, January and February (3.05-3.2m/s). The mean temperature in the city varies from 11.5 ^{o}C to 31 ^{o}C (Bulti et al , 2017).

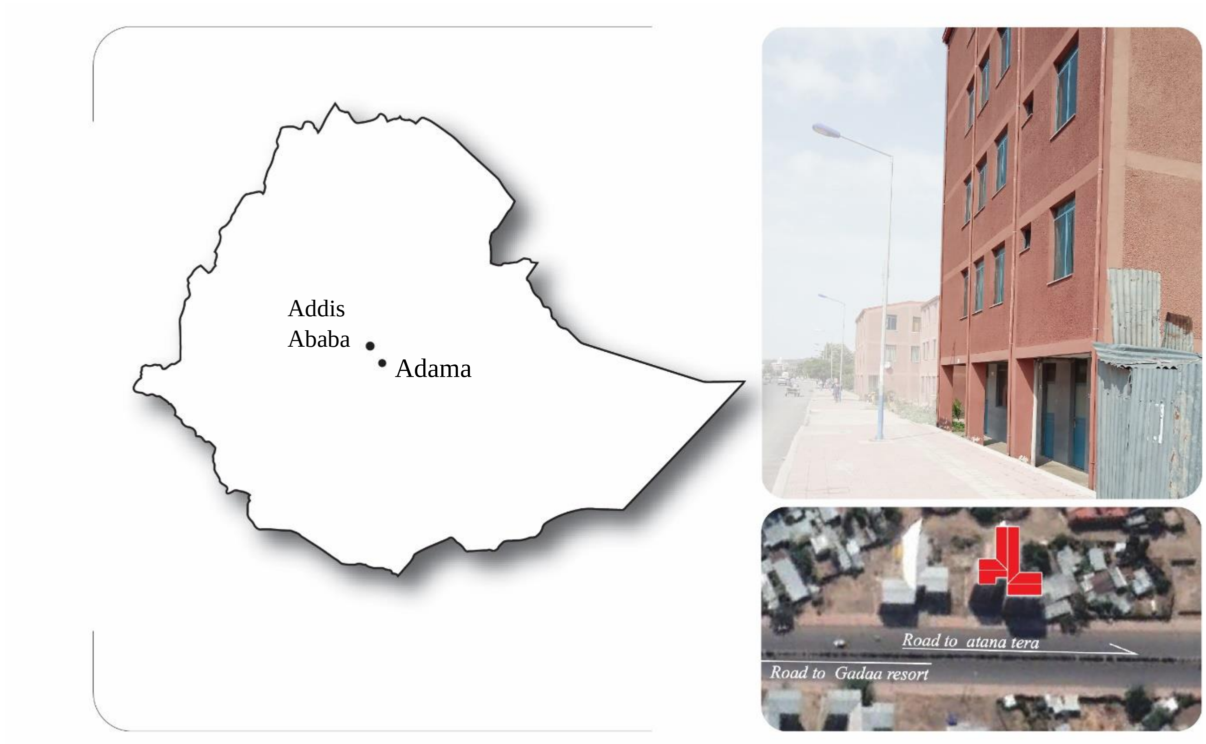

Figure 01: Study area

CHAPTER TWO

LITRATURE REVIW

2.1 Theoretical review

2.1.1 Thermal comfort and temperature

Wise architecture maximizes energy savings by placing spaces in the most advantageous position for day lighting, thermal comfort and solar integration (Los Alamos NLSD guide, 2017). Inorder to create such a space studying the temprature and thermal comfort is important.

Temperature is a very critical and widely measured variable (Cottrell, 2014).it is used in many aspects of proffesional fields to understand the thermal situation. The sensitivity of temperature can be seen in body temperature. For instance a temperature of more than 45 °C can cause irreversible brain damage and less than 18 °C can also lead to serious cardiac arrhythmia and death (Sayed & Fikry, 2019).Therefore the presence of optimal temperature indirectly implies the presence of thermal comfort.

Everyone agrees that light is a fundamental ingredient of good design, but agreement on the amount and quality of light, both natural and artificial, that makes good design is less easy to find (Napier, 2015). Rise in temperature is mostly related with the incoming source of heat/solar radiation and the transfer rate of it to the inner spaces of buildings

Reflectance of interior elements of a room do determine the level of heat created inside the space. Studies suggest the room surface reflectance for ceilings (greater than 90%) , floors (20-40%) , walls (50-70%) and furnishings (25-45%) (Los Alamos NLSD guide, 2017).The optimal temperature /temperature of the comfort is mainly dependent on the indoor ambient and surface temperature (Khadraoui M. et al, 2018).

Thermal comfort can be defined as the physiological interval where human can operate or tolerate the environment. It is the condition which human body expresses satisfaction with the thermal environment (ASHRAE Standard 55P, 2003). There are a number of standards used to evaluate comfort conditions, such as ISO7730 based on Fanger's predicted mean vote (PMV) equation and ASHRAE Std 55 (Nicol and Humphreys, 2002). Day lighting and passive design techniques are most recommended ways of improving thermal comfort as explained in most of the studies done previously.

Indoor environment quality is one of the major health concerns in the world as people spend about 80–90% of their time at home or other public indoor environments. Thermal comfort is a key variable of indoor environment quality which is influenced by the design techniques and materials used in building (Nusrat Jannat et al, 2020).Thermal comfort is determined by the room's temperature, humidity and air speed.

Day lighting generally improves occupant satisfaction and comfort. Recent studies show improvements in productivity and health in day lit schools and offices. Windows also provide visual relies, contact with nature, time orientation, the possibility of ventilation and emergency egress/exit (Los Alamos NLSD guide, 2017). Passive design techniques act in early stage of design on basic design parameters like shape factor, transparency ratio, orientation, thermal-physical properties of building materials and distance between buildings (Daniel Marin, 2017).

2.1.2 Room/indoor ambient temperature

Ambient temperature refers to the current air temperature; the overall temperature of the outdoor air that surrounds us. Indoor ambient temperature is sometimes called room temperature (Zhou and Gong, 2013). Room temperature is one of the fundamental characteristics of the indoor environment. It can be controlled with a degree of accuracy depending on the building and its HVAC system. The indoor temperature affects several human responses, including thermal comfort, perceived air quality, sick building syndrome symptoms and performance at work (O. Seppanen et al , 2006).

Increased evidence also shows that indoor environmental conditions substantially influence health and productivity. Room temperature could influence productivity indirectly through its impact on the prevalence of sick building syndrome (SBS) symptoms or satisfaction with air quality.
In a study made by (O. Seppanen et al., 2006) , it showed a decrease in performance by 2% per °C increase of the temperature in the range of 25-32 °C, and no effect on performance in temperature range of 21-25 °C..

The building envelope possesses the major responsibility in the determination of the indoor temperature of any type of building (M.Ponni, 2014). A building material with high thermal mass and adequate thickness delays the effect of temperature changes from the outside wall on the wall's interior. High thermal mass materials are considered very effective against rapid heat transfer, which is mainly due to their properties to absorb heat from solar radiation at a much slower rate than lightweight materials with a low thermal mass (M.Ponni, 2014).

2.1.3 Surface temperature

As the name tells surface temperature is the temperature of the outermost surface of any natural or manmade material. It is classified as interior and exterior surface temperature depending on the position and alignment of the material/organic body. For instance temperature of the surface of the wall that is facing towards the outdoor is exterior surface temperature.

The surface temperature of the wall/building facades is mainly dependent on the existing climate and the properties of the material, which the wall is made up of. The surface properties of building facades have implications for thermal performance of buildings (indoor temperatures, heating and cooling loads).The facade surface temperatures might also influence outdoor thermal comfort conditions for pedestrians too.

The color of the building facade even exerts influence on the surface temperature of the wall/building facades. According to Bansal et al. (1992), exposing a black light-weight construction building model to high solar radiation results in a higher day-time indoor temperature (up to 7K) than a white model (Azarnejad & Mahdavi, 2018).

2.1.4 Building facade and building orientation

Building orientation represents the relation between its elevations and the original geographical direction. In design process, it is important to consider the actual quantity of solar radiation on the facades of a building as a whole, as it affects the thermal load of the building and controls the thermal behavior and the amount of thermal comfort of the space . In addition, it affects the quantity of ventilation crossing inside the building, which in turn affects the quantity of energy consumed in it to achieve the thermal and life requirements (Rania Ashmawy et al , 2017).

Building orientation affects the air-conditioning or heating energy requirements by its regulation of then influence of two distinct climatic factors.

i. *Solar radiation* and its heating effects on walls and rooms facing different directions

ii. *Ventilation effects* associated with the relation between the direction of the prevailing winds and the orientation of the building. From the above two, solar influence on energy is the most significant in the tropics and is extensively covered by many others (Al Bakri Abdullah et al , 2016)

The orientation of a building should take in to consideration of the solar radiation difference throughout the day as well as throughout the year. Solar radiation intensity and sun ray are different for different time of a day as well as in seasons. The climate in which the building exists should also be take into account when designing for the best orientation of the building. There are two ways to ensure optimal orientation: Analyze various design parameters and certify optimal design and orientation for each building but this approach consume more designing time and cost. The second way is develop 'adaptable' designs which perform well across a range of orientations, which is used in the volume build industry (Morrissey, 2011), but this approach does not give the optimum building orientation (Albatayneh, 2018).

The best/optimal orientation of a building is objective to the program, geometry, form, climate, building material and other design parameters linked with the building design. The optimal orientation for a building in tropical climate zone differs from that of temperate. Rooms that face east have morning sun. South facing rooms have sun during the day and in the late afternoon and evening, rooms that face west will have direct sunlight. Best orientation, correct location on a site, and landscaping changes may decrease the energy consumption of a typical building by 20% and provide the building designers with the economical tools to reduce energy consumptions (Albatayneh, 2018).

Building facade is a face of a building in simple terms. It is sometimes referred to building envelope and building skin. The building envelope is the physical interface between the indoor and outdoor environments of a building, and it is responsible for much of the energy balance that occurs in the building. As a result, the type of construction used in the facade is a key factor in determining the energy performance of a building and therefore its level of sustainability. (Planas et al , 2018).Building façade has a closer meaning to building envelope but it is limited to specific face/side of a building. That is why it's common to say south facing façade not south facing envelope.

These days the evolution of facades towards creating comfortable indoor environment has reached to development of facades that are adaptable, dynamic, and responsive to the climate where the building is found. A substantial trend in both research and practice is the use of double skins in façade assemblies. A double skin provides a buffer zone for management of thermal extremes and an acoustic and wind protected zone which can support opening window panels (Napier, 2015).Apart from the type of facades, size and layout of openings/windows or commonly referred as WWR (window to wall ratio) also affect the management of thermal extremes indoors.

The location and orientation of a window or skylight, therefore, can be more important than its size in determining the quality of daylight room receives. Direct sunlight provides a high degree of illumination, especially during mid-day. Designers should take benefit on this situation in minimizing energy consumption for example by developing solar system for water heating and also electricity to generate the electrical instruments (Al Bakri Abdullah et al., 2016)

Overall ,the building envelope should be designed according to the climate to achieve the energy efficiency in the building (Bano & Kamal, 2016).Because building façade acts as a thermal barrier between the enclosed conditioned space and outside environment through which the thermal energy is transferred.

2.1.5 Measuring surface and room temperature

As expressed in earlier topics temperature is very critical and widely measured variable. This necessity of temperature has made temperature measurement to be advanced. Generally temperature measurement from earlier times till now could be categorized in three: Thermometers, Probes and Non-contact.

Thermometers are the oldest of the group. The need to measure and quantify the temperature of something started around 150 A.D. when Galen determined the ‘complexion’ of someone based on four observable quantities. The actual science of ‘thermometry’ did not evolve until the growth of the sciences in the 1500’s. The first actual thermometer was an air-thermo scope described in *Natural Magic (1558, 1589),* (Cottrell, 2014). Among the non contact category of temprature measurement ,infrared thermometr/thermography/IR is mainly used for measuring surface temprature in varies aspects of life and profession.

Infrared thermography is a powerful technique that allows to quantify the thermal field on a target surface. By this technique, a two-dimensional temperature field can be evaluated quantitatively, non-destructively and simultaneously at each pixel even when the observed objects have complex shapes as seen in the figure 02 below. Therefore, the increasingly recognized applicability has caused development of remote sensing diagnosis for various engineering applications (Datcu et al , 2005). One of the main factors that affect the infrared thermography temperature measurements accuracy is the surrounding radiation (Datcu et al., 2005).

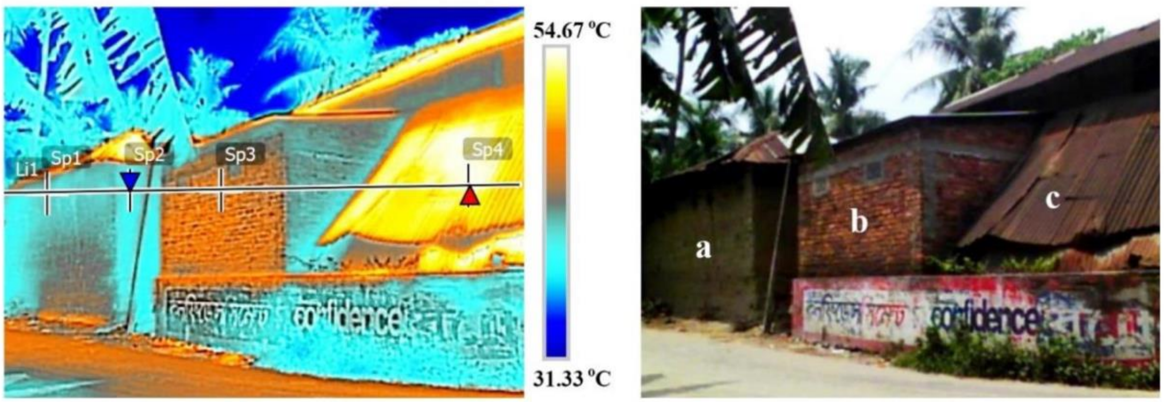

Figure 02 : Thermal images of (mud house (b) fired brick house (c) metal sheet house *,source: (Nusrat Jannat et al , 2020)*

Radiation is also used in temperature measuring tools to measure ambient air /room temperature. The measuring of surface temperatures at the building envelopes by means of well-practiced commercial temperature sensors are typically applied whose attributes can successfully be employed especially for the field of thermal building performance aspects (Slávik & Čekon, 2016)

2.1.6 Thermal performance of south and west facing facades

Metaphorically speaking thermal performance a facade could be taken as thermo-regulation of a body's skin. If the building facade does not follow the outside thermal variations means the building is a good thermal performer (M.Ponni, 2014).

Thermal performance /behavior of a building is complex and depends on the stresses to which it is subjected, notably the temperature of the outside air. The judicious choice of building materials contributes to the reduction of ambient air temperatures inside the building (Mokhtari, 2008). The architecture should thus aim to integrate the climatic data of the site, to reduce energy consumption due to heating and cooling (Benhouhou, 2012). The building envelope must be selected according to the loads and dynamic environmental conditions outside and inside (Khadraoui M A et al., 2018).

Building facade orientation plays a crucial role in maintaining energy performance and thermal comfort of a building. A study conducted on energy performance of a building states that the following building geometry factors have the highest to lowest influence: building orientation, plan shape, plan depth, and window-to-wall ratio (Babak Raji et al , 2017).

It is found that an air-conditioned building that has a southern facade consumes less energy. However, a western facade causes higher annual energy consumption by 26% over the southern facade (Rania E. et al , 2017).This statement indicates that even though south facades receives solar radiation throughout the day the intensity received by the west facade excels it. West-facing facades receive direct solar radiation for more hours during the day than a south and north facades and the radiation is at lower angle which makes it difficult to prevent from reaching the building envelope (Teklay W/abzgi, 2004).

2.1.7 Heat flow/transfer through walls

Heat, which is also referred as thermal energy passes through organic and manmade materials. This flow of heat from one place to another shapes the way humans perceive thermal conditions especially in enclosed spaces.

The basic requirement for heat transfer is the presence of a temperature difference. The temperature difference is the driving force for heat transfer, just as voltage difference for electrical current (Bahrami & Majid, 2013). Heat transfer is sometimes referred as heat gain or heat loss, depending upon whether heat transfer is to the building or from the building, respectively. In doing so the nature, orientation, thermal mass ,finishing material and other properties of the building facade play a major role in accepting/resisting the incoming heat.

Thermal mass is the ability of building materials to store heat (thermal storage capacity).The basic characteristic of materials with thermal mass is their ability to absorb heat, store it, and release it at a later time. Building materials that are heavyweight store a lot of heat so are said to have high thermal mass. Some of the wall finishing materials commonly used are; mortars, stuccos, and gypsum plastering and board (Teklay W/abzgi, 2004).In buildings the transfer of heat between the inside and outside environment is taking place through conduction, convection, and radiation (Teklay W/abzgi, 2004)

Conduction heat transfer in buildings occurs thorough building envelops such as walls, roofs, floors, doors and windows.

Convection heat transfers that utilize in buildings are of two types: natural and forced. In buildings natural convection is caused by the movement of air due to pressure difference. This pressure difference is caused by wind (speed and direction) and temperature difference across the building which drives the air to flow from higher to lower pressure in either side of the building. Forced convection is caused due to the movement of air with the help of mechanical systems like ventilation.

Radiation is a heat transfer mechanism where heat is transferred by electromagnetic waves. Heat transfers by radiation in buildings through transparent building envelops and from internal heat sources to the building envelope. The main source of radiant heat in a building is windows and glass doors which transmit solar radiation directly to the building.

The opposition of materials and air spaces to the flow of heat by conduction, convection, and radiation is called thermal resistance. The thermal resistance of building materials is largely a function of the number and size of air spaces that they contain (Norbert Lechner, 2015).The transfer of heat takes place differently for different facades depending on the walling arrangement and composition of the façade. For instance the heat transfer taking place in solid walls and composite walls is different.

Solid wall*:* Heat transfer through solid walls takes place only by conduction in the direction of temperature gradients. Such transfer is proportional to the temperature difference between the two surfaces of the wall and further depends on the materials composing the wall.

Hollow wall: Heat transfer through walls containing voids, such as hollow tile, frame, or the hollow types of brick walls, takes place by convection and radiation as well as conduction. Figure 03 below shows heat transfer through composite wall.

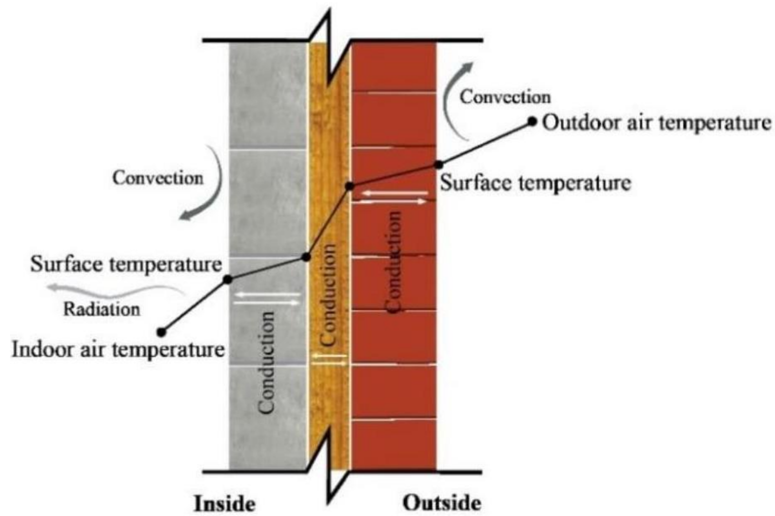

Figure 03 : Heat transfer through composite wall *,source: (Nusrat Jannat et al , 2020)*

There are many factors that determine the rate of heat transfer to and from the building through building facade. Most literatures state that the rate of heat transfer through building facade is proportional to the surface area of the facade & temperature difference and inversely proportional to the thickness of the building facade (Bahrami & Majid, 2013).The thickness of a facade is commonly linked with the thermal mass of a facade.

2.2 Contextual review

2.2.1 Condominium buildings in Ethiopia

Despite having one of the lowest proportions of urban population in the world at only 16.7 %, Ethiopia is rapidly urbanizing at a high annual growth rate of 3.49 %. Likewise Ethiopian cities suffer from a high degree of homelessness, environmental degradation, urban decay, a shortage of infrastructure and basic services, and high unemployment (UN-HABITAT, 2010).Such unfitting reality of urbanization and homelessness has forced the government to follow a new approach called condominium housing.

Condominium housing is a name given to the form of housing tenure where each resident household owns their individual unit, but equally shares ownership and responsibility for the communal areas and facilities of the building, such as hallways, heating systems, and elevators. There is no individual ownership over plots of land. All of the land on a condominium site is owned by all homeowners The government estimates that the current housing deficit is between 900,000 and 1,000,000 units in urban areas, and that only 30 per cent of the current housing stock is in a fair condition, with the remaining 70 per cent in need of total replacement (UN-HABITAT, 2010).

Contextually inappropriateness is the obvious problem of the condominium housing seen in Ethiopia ever since it started. These modular condominiums are designed at the federal level and then distributed to every cities and towns without the consideration of climatic factor (Haven Hailu , 2020). From the warmest areas of Ethiopia in Afar and Semera to the coldest highlands of Debrebirhan and Bale, condominium housing buildings were built with the very same building facade material and composition.

One prominent example for the lack of contextually appropriateness of condominium is a research conducted in Afar. According to the data collected from the relevant respondents confirmed that the reason for the comfort of a traditional house, 52% responded as a construction material is the basic reason for the comfort, 27.6% responded as the size of the openings and type is the basic factor for the comfort and 20.4% responded the construction techniques are the basic factor (Haven Hailu , 2020).This finding showed that more than half the respondents question the material of the facades as the main factor for not having a thermal comfort.

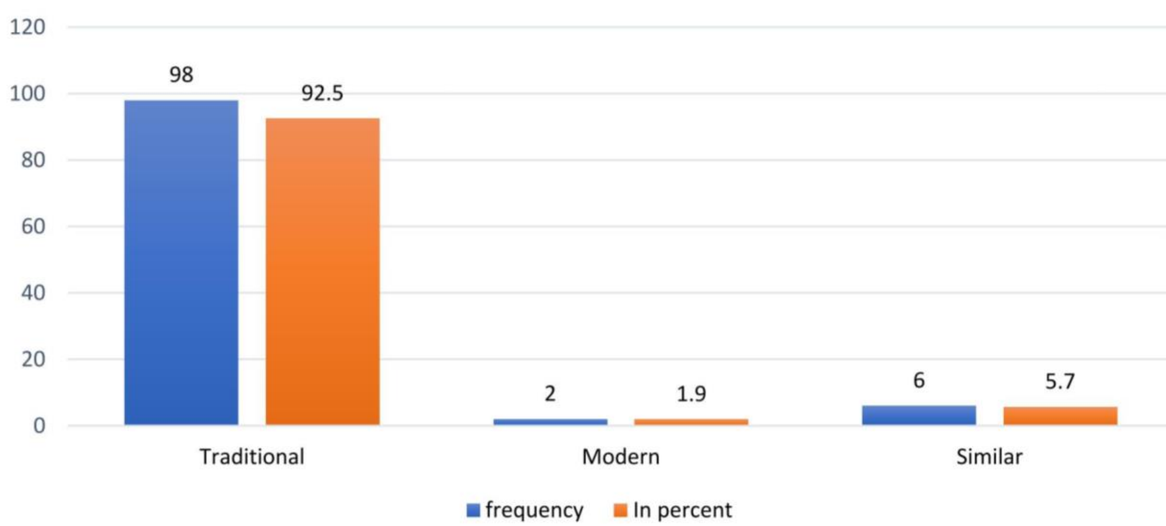

Figure 04 : Comparative climatic comfort of traditional house vs. modern building (Condominium) in Afar (field survey,2020) , (*Source : Haven Hailu , 2020)*

Another finding of the research as depicted in the figure 04 above indicates that more than 90% of the respondents prefer living in traditional houses. Nevertheless with all its contextual problems, condominiums are still being built all over Ethiopia with the same material regardless of the climatic condition at which they were built in.

2.2.2 Thermal environment of Adama city

Adama is known with its warm thermal environment. According to the data from the national metrology agency: eastern and central Oromia meteorology service center & data from Ethiopian Standard ES-EBCS 11: Code of practice for Mechanical Ventilation and Air- Conditioning in Buildings, there is a variation of thermal/heat intensity in seasons. Monthly average maximum temperature of Adama city for the past five years (2019-2015) shows that Autumn (Mar –May) is the warmest season of the year.

Table 01: Monthly average Max. Temperature of Adama city (2015-2019 G.C), *(Source: national metrology agency, eastern and central Oromia metrology service center, Adama.)*

	Station. Name :- Adama						Element :- Monthly Average Max.Temp.(oC)						
	spring /ጸደይ/ birraa			summer /በጋ/ bona			Autumn /በልግ/ arfaasaa			winter /ክረምት/ ganna			
Year	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Annual avg.**
2015	28.9	29.9	28.0	26.9	27.0	30.5	31.3	31.5	30.7	30.5	29.5	27.9	29.4
2016	28.3	29.4	27.9	26.6	28.0	29.4	32.8	30.3	29.7	29.6	27.0	27.1	28.8
2017	27.7	28.6	27.5	26.0	27.9	28.8	31.5	31.3	29.8	31.6	27.5	26.8	28.7
2018	28.8	29.3	28.1	27.3	26.8	29.6	30.0	29.8	29.9	28.8	27.2	27.2	28.6
2019	27.2	26.9	27.3	25.3	28.4	30.6	31.8	31.2	31.5	29.9	27.4	26.9	28.7
	28.2	28.8	27.8	26.4	27.6	29.8	31.5	30.8	30.3	30.1	27.7	27.2	**Monthly avg.**

highest monthly Ave.Max Temp. *2nd highest monthly Ave.Max Temp* *3rd highest monthly Ave.Max Temp*

Table 02: Monthly Max. , Min. & Average Temp. Of Adama city, *(DBT: Dry bulb Temp). (Source: Ethiopian Standard ES-EBCS 11: Code of practice for Mechanical Ventilation and Air- Conditioning in Buildings.)*

DBT(C^0)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max.	*30.1*	*32.09*	*32.71*	*32.5*	*33.38*	*32.68*	*29.54*	*28.47*	*29.46*	*29.87*	*29.22*	*28.7*	*33.38*
Min.	*7.61*	*10.11*	*10.92*	*12.42*	*13.67*	*12.99*	*13.81*	*13.61*	*12.29*	*9.83*	*9.31*	*8.02*	*13.67*
Mean	*22.45*	*21.98*	*21.79*	*20.08*	*19.71*	*19.69*	*15.73*	*14.86*	*17.17*	*19.87*	*19.91*	*20.68*	*19.71*

32.8 °C is recorded as the highest monthly average maximum temperature in March 2016.31.8 °C and is recorded as the second highest average maximum temperature. March is the warmest month of the year followed by April and May. Among the past five years (2019-2015) the highest annual average of max temperature was recorded in 2015.Following the autumn season winter, spring and summer accordingly follow, the warmest season rank.

Cities located in tropical regions like Adama face challenegs in creating heat friendly enviroenment. High temperatures, high humidity, and intense solar insolation are the typical features of the tropical weather. In the tropical zone, sun rays hit nearly overhead at midday and the cool day quickly gets warm until the early afternoon when temperatures reach the warmest. Afterward, space starts to cool off somewhat by the late afternoon when less heat energy hits the surface of the earth. However, it remains warm until the early evening after the sunset but begins to cool quickly before the sunrise of the next morning (Nusrat Jannat et al , 2020).

A study conducted by Solomon Abebe, (2020) on developing parametric solar envelope for Ethiopian cities, categorized the climate zones of Ethiopia in five categories. The research was conducted by analyzing calculated data tapped from 952 stations in Ethiopia. According to the findings form the research, Adam falls in to zone 3 of the climate zones, which is characterized by having less than 500 CDD (Cooling Degree Days) and less than 1000 HDD (Heating Degree Days) in reference to the ASHRAE standard, 1991.Warm areas have high CDD (takes time to cool down) and low HDD (it doesn't take much to get hot).

Another study conducted on categorizing climate zones of Ethiopia puts Adama in the temperate climate zone(among the six climate zones defined by the study).It also characterizes Adama of having mean minimum T range of 12-18 c , mean maximum temperature range of 25-30 c, relative humidity range of 55-75% ,wind speed range of 1.7-3.5 m/s ,solar radiation range of 24-26MJ(which is the highest of all categories) and rainfall range of 500-1000 mm (Daba Fufa ,2020).The study also defines the thermal comfort zone of Adama as depicted in figure 05 below.

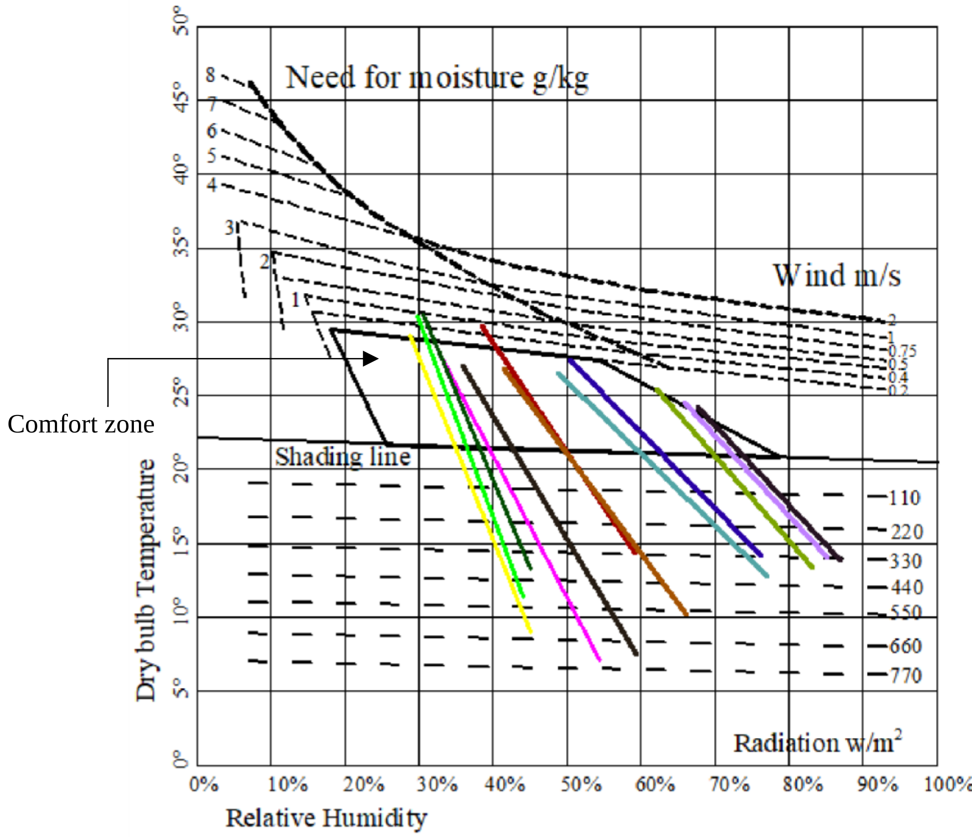

Figure 05: Comfort zone & Bioclimatic chart analysis of temperate zone (Adama city).

CHAPTER THREE

MATERIAL AND METHODS

3.1 Data

Relative humidity of the room, indoor and outdoor ambient temperature, exterior and interior surface temperature of south and west facades/wall were collected from the field as depicted in figure 06 below. These data were collected from a room found in the first floor of the newly built unoccupied condominium building located in kebele 01 in Adama city. The condominium building is selected due to its proximity and its advantage of gathering data that are not influenced by other factors that could have happened if it were occupied. In order to alleviate the radiation and heat on ground surface and the effect of shadow imposed by trees and nearby buildings, the measurements were taken from the first floor of the building. .Thermal conductivity (k) standard value of the materials that compose the facades/wall were used from literatures.

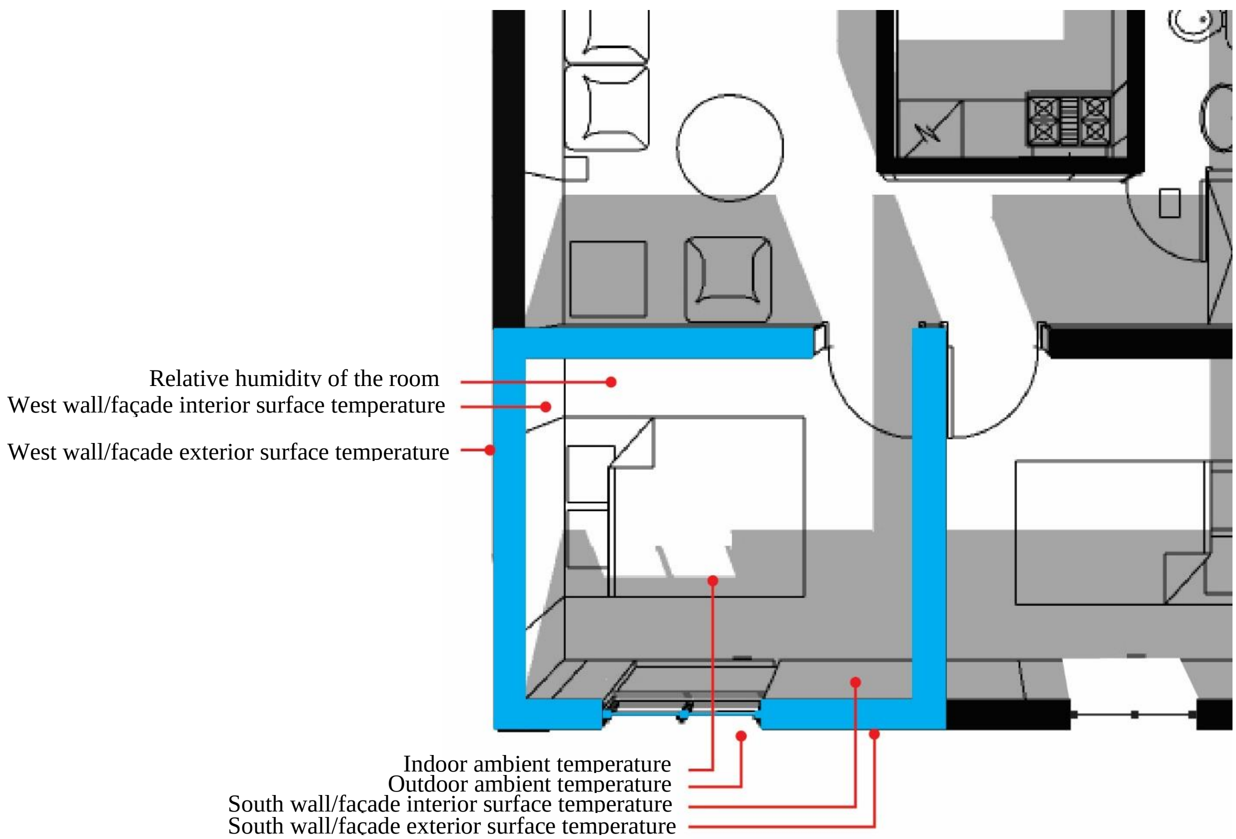

Figure 06: Spots where measurements were taken from

3.2 Data collection

The relative humidity of the room, indoor as well as outdoor ambient temperatures were measured using a digital hygrometer (temperature and humidity meter) as depicted in figure 07 b below. Exterior and interior surface temperature of the facades(both west and south) were measured using infrared thermometer (IR thermometer).As illustrated by F. Haghighat et al , (1985) about 55 percent of the overall heat transfer to the building is due to air infiltration, ventilation, windows, and doors and thus the effect is immediate. Another 30 percent of overall heat transfer is the result of conduction through ceiling and walls and the effect lags by a few hours. The remaining 15 percent is caused by the slabs and has a lag of days to months. The long-term performance of the building can be determined through the integration of short-term responses.

Taking these in to considerations the measurement were conducted for 5 times a day in 2 hrs. Interval for consecutive couple of days (4 days in this case) to understand the heat transfer effect in the building facades. These measurements were repeated for three months (from March 29,2021 to End of May (June 1,2021), which are the warmest seasons of the year in Adama city) in order to evaluate long term performance of the building facades.

Figure 07: Instruments used for data collection: *A, Infrared thermometer B, Digital Hygrometer*

The instruments were used to measure at a close distance from the walls to get accurate results. The tolerance level and other specification of the instruments used are found in appendix 4 & 5 of this paper.

3.3 Methods

Methods and data used in the research with respect to the specific objective are summarized and presented in Table 03 below.

Table 03: Summary of methods used in the research.

No	Specific objective	Data used	Method /Formula
1	***(i)*** Comparison with comfort zone of Adama city	- Relative Humidity (%) - Indoor ambient T.(^oC) *or K*	- Using MS excel software
	(ii) South & West façade/wall surface temperature	- South wall Interior surface T.(^oC) *or K* - South wall exterior surface T.(^oC) *or K* - West wall Interior surface T.(^oC) *or K* - West wall exterior surface T.(^oC) *or K*	
2	***(i,a)*** Absolute thermal resistance of the facade/wall(R_{wall}) in *k/w*	- Thermal conductivity (k) in *w/mk* - Thickness of (L)in *m* & - Surface area (A) in m^2 of each layer of facade material	$R_{wall} = \sum R_1+R_2+R_3+R_4+R_5$ $= \sum [L_1/(K_1A_1)]+\ldots\ldots[L_5/K_5A_5]$
	(i,b) Thermal conductance of the wall (C_{wall}) in *w/k*	- Absolute thermal resistance of the facade/wall(R_{wall}) in *k/w*	$C_{wall}=1/ R_{wall}$
	(ii,a) Thermal transmittance (U) in w/m^2k	- Surface area (A) in m^2 - Temperature difference (indoor & outdoor ambient T.) ΔT in *k* - Heat transfer /flow rate of the façade/	$U = Q_{wall} / [(T_2-T_1) *A]$

			wall (Q_{wall}) in *J/sec* or *watt*	
	(ii,b) Thermal insulance (R) in m^2k/w	-	Thermal transmittance (U) in w/m^2k	R=1/U
	(iii) Heat transfer /flow rate of the façade/ wall (Q_{wall}) in *J/sec* or *watt*	- -	Absolute thermal resistance of the façade (R_{wall}) in *k/w* Temperature difference (indoor & outdoor ambient T.) ΔT in *k*	$Q_{wall} = \Delta T/R_{wall}$ $= (T_2 - T_1)/ R_{wall}$
	(iv) Heat flux of the facade/wall (q_{wall}) in w/m^2	- -	Heat transfer /flow rate of the façade/ wall (Q_{wall}) in *J/sec* or *watt* Surface area (A) in m^2	$q_{wall} = Q_{wall}/A$
3	Suggestions for optimizations of the facade	-	Same data used in specific objectives 1 & 2 ,except the air gap inside the HCB wall is computed for 20 & 24 cm	***(i,a) , (ii,a) & (ii,b) ,(iii)***

Legend : R_1 & R_5 =Absolute thermal resistance of exterior & interior cement plastering respectively

R_2 & R_4 = Absolute thermal resistance of concrete

R_3 = Absolute Thermal resistance of air gap

$T_{in(max)}$ & $T_{in(min)}$ = Maximum & Minimum interior surface Temp. of the façade/wall respectively

$T_{out(max)}$ & $T_{out(min)}$ = Maximum & Minimum exterior surface Temp. of the façade/wall respectively

The condominiums in which the data were fetched from is dominantly built from hollow concrete block (HCB) and the one dimensional heat flow/transfer from exterior part of the wall/facade to the interior space of the room is depicted in figure 08 .Computation are done for a surface area equivalent to the size of a single HCB (0.08m^2) considering heat flow through it. The values found for the size of HCB (0.08m^2) were projected for a 1m^2 surface area of the facades as well as the entire surface area of facades (West F. : 9.29m^2 ,South F.:7.06m^2) depending on the computations.

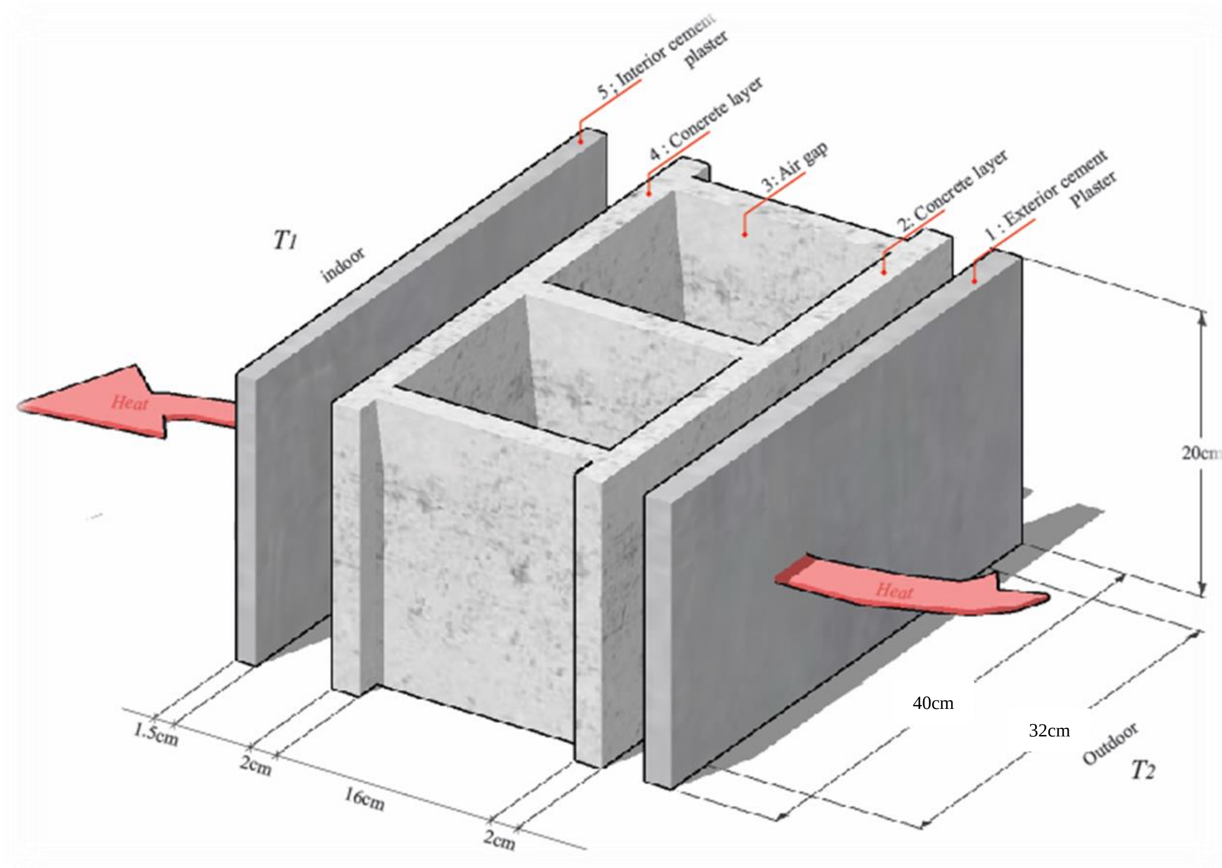

Figure 08: Material layer of the facades/External HCB wall where heat passes through.

Thermal conductivity, thickness and areas of each layer of the facade as well other data used are found in the Appendix 2 of this paper.

3.4 Data Analysis

3.4.1 Performance & response of the facade towards the climate of Adama

Measurements/field data were used to generate simplified graphical representation that tells how the facade was performing /responding to the climate during the days of measurement. Relative humidity of the room and indoor ambient temperature data were used to map and find out if it falls inside the thermal comfort zone of Adama, which is set by Daba Fufa ,(2020). Likewise ,south and west wall interior and exterior surface temperature were used to get the reaction of both façades(South and West).in all of these analysis, the data were fed to Microsoft Excel(Excel 2013) software to come up with simplified graphical presentation of the results.

3.4.2 Computation

I, (a) Absolute thermal resistance (R_{wall}) & (b) Thermal conductance of the wall (C_{wall})

Absolute thermal Resistance of the wall or commonly referred as resistance of the wall is calculated for each layers of the wall and summed up to get the Absolute thermal resistance of the facades.

Thermal conductance values are computed by inversing the values from Absolute thermal resistance of the wall.

II, (a) Thermal transmittance of the wall (U) & (b) Thermal insulance (R) of the wall

The formula for thermal transmittance in table 03 above is simplified as in Equation 1 below, so that the thermal transmittance value of the wall can be calculated using Thermal resistance of the wall (R_{wall}) and surface area of the wall (m^2).

$$U = \frac{Q_{wall}}{(T_2-T_1) * A} = \frac{(T_2-T_1) / R_{wall}}{(T_2-T_1) * A} = \frac{1}{R_{wall} * A} \quad \text{.................................Equation (1)}$$

Thermal insulance values are computed by inversing the values of thermal transmittance value.

III, Heat transfer /flow rate of the façade/ wall (Q_{wall})

Heat transfer rate mainly depends on the temperature difference and resistance of the wall. In this case both south and west façade are made from the same material and have the same arrangement of layers. Computed data from Absolute thermal resistance of the wall and field data of temperature difference (between indoor & outdoor ambient T.) were used to get the heat flow rate of the facade.

IV, Heat flux of the facade/wall (q_{wall})

Heat flux of the wall is computed by using data from heat transfer rate divided by the surface of the wall.

3.4.3 Optimization of the façade

Suggestions for optimization of the facade were made by computing for minor modifications of the existing HCB wall. These minor modifications were grasped from results in specific objective 2.Measurements from the field are taken as usual. Following that , *(i,a)* Absolute thermal resistance of the facade/wall(R_{wall}), *(i,b)* Absolute thermal conductance of the wall (C_{wall}) , *(ii,a)*

Thermal transmittance (U), *(iib)*Thermal insulance (R) and (iii) Heat transfer /flow rate of the façade/ wall (Q_{wall}) are computed again to see the difference between the newly suggested optimized HCB wall and the existing HCB wall.

CHAPTER FOUR

RESULT

4.1 Performance & Response of the facade towards the climate of Adama

4.1.1 Comfort zone of Adama city

By taking the thermal comfort zone of Adama city set by Daba Fufa, (2010) as a reference, the mapped relative humidity and indoor ambient temperature values show that, in most of the daytime there has been thermal comfort during the days of measurements in March. Though there are many factors other than heat, this indicates the facades have performed comparatively well in March as depicted in figure 09 (a) below.

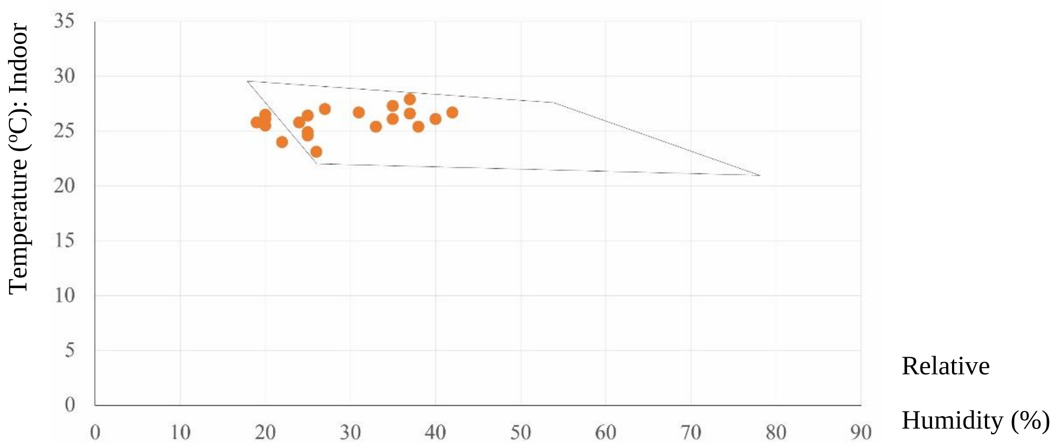

Figure 09 (a): Relative humidity and temperature chart of March (Mar. 29-Apr. 1, 2021)

The performance of the facades is mostly linked with the comfortable indoor space created inside. In the following month (April) the facades performance were not good. Almost more than half of the daytime period falls out of the thermal comfort zone, which indicates that there is uncomfortable thermal environment inside the room as seen in figure 09 (b) below.

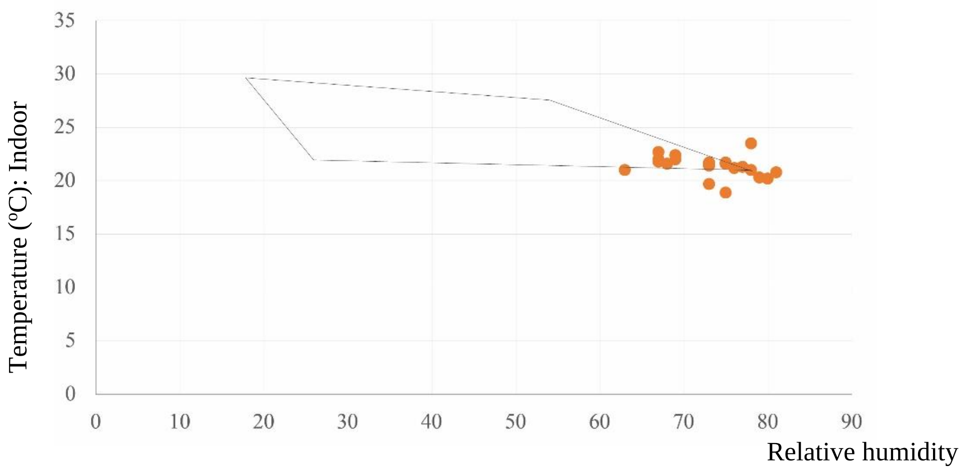

Figure 09 (b): Relative humidity and temperature chart of April (Apr. 28-May 01, 2021)

Like in previous months of measurement periods, in May too, there is inconsistent performance of facades. Not all of the day time period falls in the thermal comfort zone of Adama city (see figure 09, c).This fluctuation of comfort is a sign of not having satisfactory performance. A facade with good performance should stay in thermal comfort zone irrespective of the outside climate.

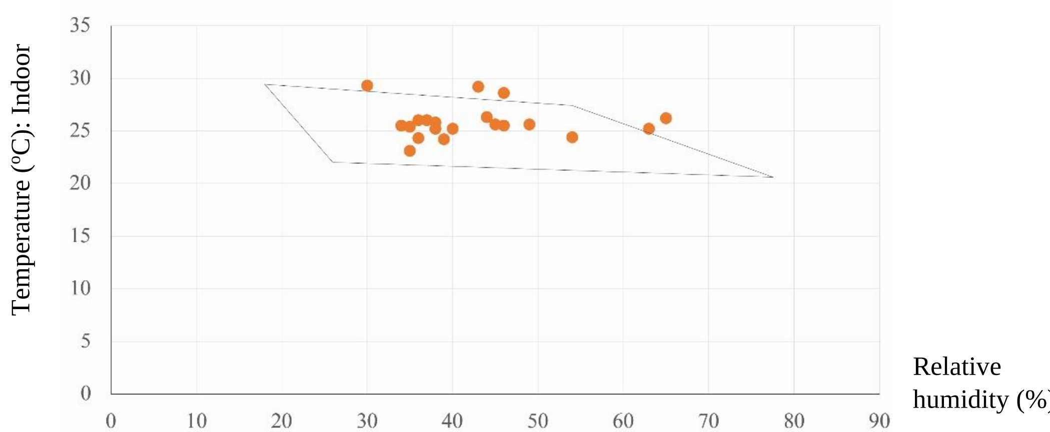

Figure 09 (c): Relative humidity and temperature chart of May (May 29-Jun 01, 2021)

4.1.2 South and West façade surface temperature

The response of the facades to external environment especially to solar radiation has a pattern as depicted in the figure 10 (a) below. In March, both facades have shown that they maintain to have similar interior surface temperature throughout the day.

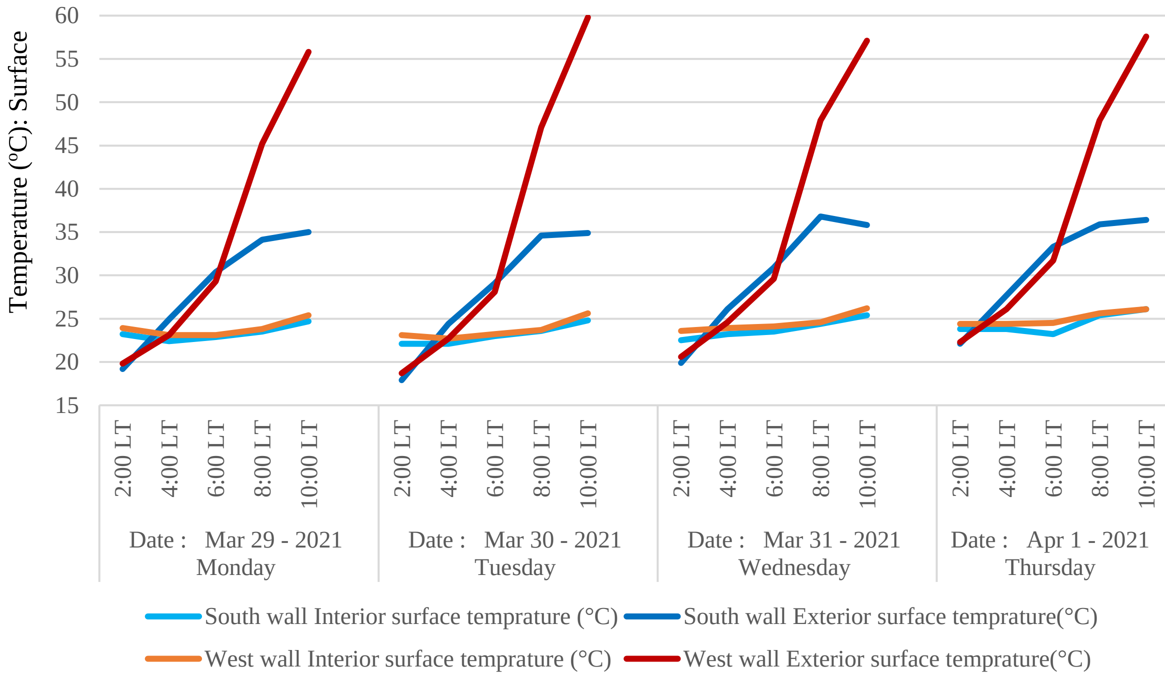

Figure 10 (a): South & west façade/wall surface temperatures in March
Note: LT = Local time

But the exterior surface temperature of the west facade excels in large amount. The difference is seen starting from mid-day (6 o'clock).this also means that after mid-day the west wall receives intense amount of solar radiation. A maximum of (South facade: 26.1 ºC & 36.4 ºC) and (West facade: 26.2ºC & 59.8 ºC) were recorded for interior and exterior surface temperature of the facades respectively.

Like in March, in April too, the interior surface temperature of both facades have similar thermal existence in the first two days of measurement. But the exterior surface temperature of both facades haven't gained much heat. In this month, a maximum of (South facade: 24.5 ºC & 27.2 ºC) and (West facade: 23.8ºC & 33.3 ºC) were recorded for interior and exterior surface temperature of the facades respectively.

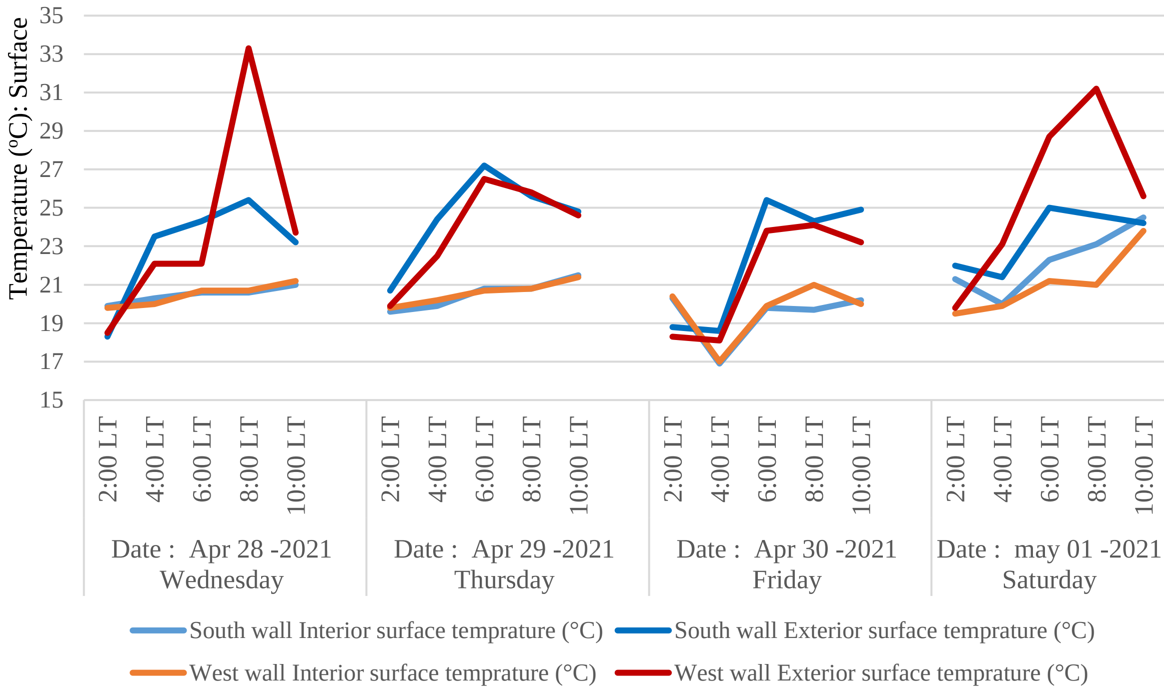

Figure 10 (b): South & west façade/wall surface temperatures in April

As shown in Figure 10 (c) chart below, there is an increase in temperature for interior and exterior surface of both facades during midday time. Like in the previous months, both facades have maintained similar interior surface temperature. More clearly, it is also seen that the exterior surface temperature of both facades starts to gain heat in greater amount after midday. In all of the three months, west facades have higher interior and exterior surface tempratures.in this month a maximum of (South facade: 26.8 ^{o}C & 32.6 ^{o}C) and (West facade: 27.2^{o}C & 46.2 ^{o}C) were recorded for interior and exterior surface temperature of the facades respectively.

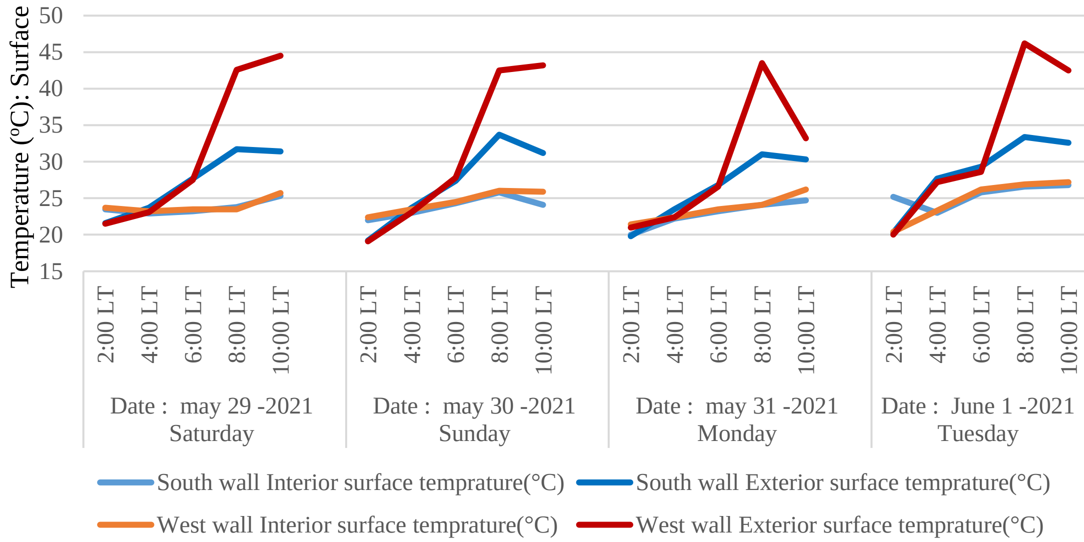

Figure 10 (c): South & west façade/wall surface temperatures in May

4.2 Computations

4.2.1 Absolute thermal resistance (R_{wall}) & Thermal conductance of the wall (C_{wall})

From the results in Table 04 below, the absolute thermal resistance of the air gap is higher than the rest of the layers composing the facades. Likewise, the concrete layer of the facade has higher thermal conductance than the rest of the layers composing the facade. Overall the thermal resistance of the wall for a single watt of heat to pass through a 0.08m^2 surface of the wall is 10.406k/w.

Table 04: Absolute thermal resistance & thermal conductance values of layers of the facade

NO.	Material layer of the facades *(from exterior to interior)*	Absolute thermal resistance *(R_{wall}) in k/w*	Thermal conductance (C_{wall}) in *w/k*
1	Exterior cement plastering	0.208	4.81
2	Concrete	0.143	6.7
3	Air gap	9.756	0.1
4	Concrete	0.143	6.7
5	Interior cement plastering	0.156	6.41
	Total(for 0.08m^2 surface area)	**10.406k/w**	**0.1w/k**

The values above indicate the absolute thermal resistance and thermal conductance for both facades, due to the fact that both facades have same façade layers and arrangement**.**

4.2.2 Thermal transmittance of the wall (U) & Thermal insulance (R) of the wall

In most of the world, thermal transmittance value is used as one of the parameters for setting building material regulations. Most countries set the thermal transmittance value of the wall, roof, and slabs depending on the climate of their own. It tells how much heat can a façade transmits from outside to inside or from inside to outside depending on the existing temperature variation. Accordingly, the thermal transmittance & thermal insulance value of the facade/wall is 1.2 w/m^2k and 0.83 m^2k/w respectively.

4.2.3 Heat transfer rate (Q_{wall})

In March, there is a heat loss to the outside environment in the morning and eventually after 4 O'clock there is an incremental rise in heat gain until it reaches its peak around 8 O'clock and falls (see figure 11 below). In those four days of measurement, a heat transfer rate as low as -0.4J/sec and as high as 0.83J/sec were seen. If one calculates these values for an entire surface of the walls, one gets the lowest and highest heat transfer rate of -46.45J/sec & 96.4J/sec for west facade and -35.3J/sec & 73.3J/sec for south façade.

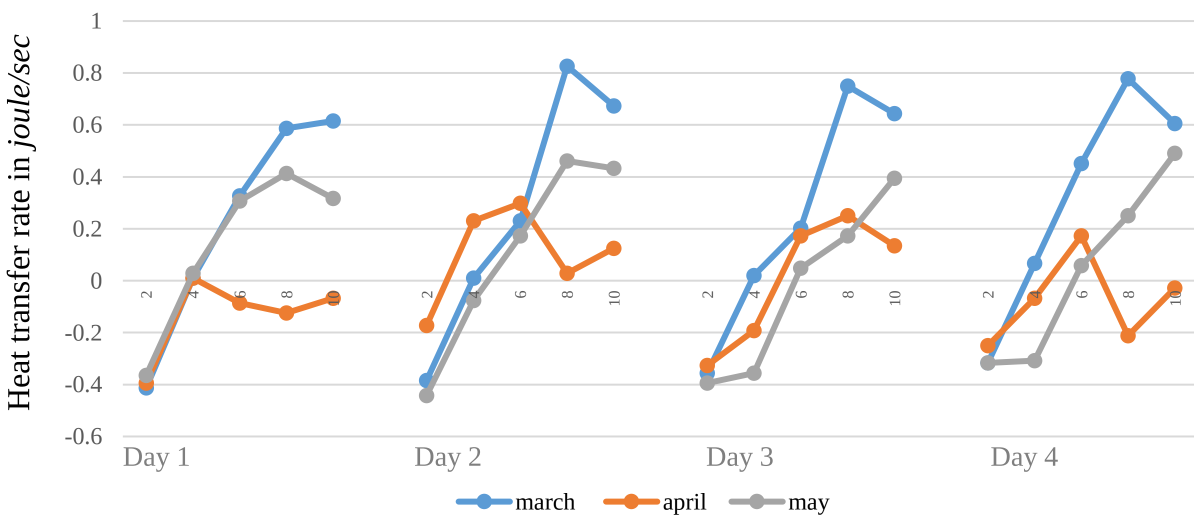

Figure 11: Heat transfer rate in *joule/sec* of the facades in March, April & May

Note: As illustrated in Table 03 above, heat transfer rate is the ratio of indoor and outdoor ambient temp. Over absolute thermal resistance of the wall (which is the same for both facades).so the above result in figure 11 represents the cumulative effect of both facades.-ve values indicate heat loss. (2, 4…10 =2 o'clock local time, 4 o'clock local time…)

Unsteady and non-uniform heat flow rate has been seen in April. In all of the days there is a heat loss at the beginning of the day. Then unpredicted pattern of heat flow follows throughout the day. A heat transfer rate as low as -0.39J/sec and as high as 0.29J/sec were recorded. The lowest and highest heat transfer rate of -45.29J/sec & 33.68J/sec for west facade and -34.4J/sec & 25.6J/sec for south façade were recorded respectively.

In the following month (May), during the early period of the daytime there is a heat loss to the outside environment. In the first two consecutive days there is a decline in heat gain after midday .But in the following two days there hasn't been a decline in heat gain from midday on. A heat transfer rate as low as -0.44J/sec and as high as 0.49J/sec were recorded. The lowest and highest heat transfer rate of -51.1J/sec & 56.9J/sec for west facade and -38.83J/sec & 43.24J/sec for south façade were recorded respectively.

4.2.4 Heat flux (q_{wall}).

Higher amount of heat gain and heat loss takes place in west façade than the south as the heat flux results presented in Table 05 below indicates., The higher the heat flux means higher heat flow in small amount of surface area of the facade. In contrast, lower heat flux indicates higher heat loss in small amount of surface area of the façade. Due to the fact that both facades are made from the same material, the change in heat flux is generated by the orientation and amount of solar radiation intake.

Table 05: Highest and lowest heat flux values of the facades in each month

Surface		**March**	**April**	**May**
	Unit	*w/m²*	*w/m²*	*w/m²*
HCB sized surface of the wall	*highest*	10.38	3.63	6.12
	Lowest	-5	-0.49	-5.5
South facade	*Highest*	916	320.35	540.1
	Lowest	-441.3	-43.2	-485.38
West facade	*Highest*	1205.4	421.3	710.7
	Lowest	-580.6	-56.9	-638.7

4.3 Optimization of the façade

Results presented in table 04 above indicated that, the air gap in the layers of the existing facades has higher thermal resistance value than other layers composing the facade. According to literatures, higher thermal resistance contribute to thermal comfort in tropical regions. Taking these into considerations, earlier computations(Absolute thermal resistance of the facade/wall(R_{wall}),Thermal conductance of the wall(C_{wall}) , Thermal transmittance (U), Thermal insulance (R) and Heat transfer /flow rate of the façade/ wall (Q_{wall})) are computed again for an extra 4cm air gap(20cm in total) and 8cm air gap (24cm in total) to see the difference. Figure 13 below shows the existing and optimized HCB block of the facades.

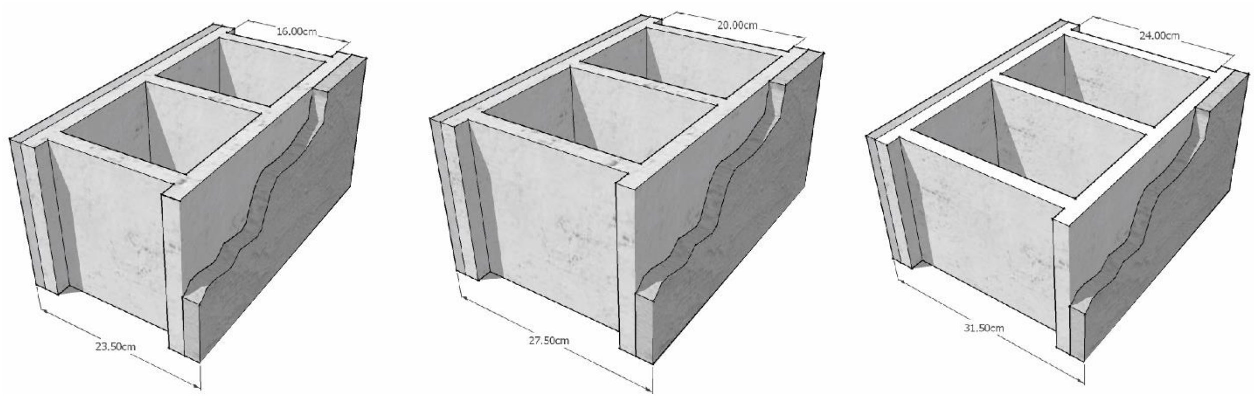

Fig 12: Visual illustration of existing and optimized HCB block of the facades

The computed results for newly suggested/optimized facades are presented in Table 06 below. Accordingly, an extra 4cm air gap added to the existing facade will enable it to have 23.44% increase in absolute thermal resistance, 20% decrease in thermal conductance and 19.17% decrease in thermal transmittance. Similarly ,an extra 8cm air gap to the existing facade will enable it to have an increase in absolute thermal resistance by half (46.8%),35% decrease in thermal conductance and 15.8% decrease in thermal transmittance. These values indicate that the optimized facades will have more potential in resisting incoming solar radiation than existing facade.

Table 06: R_{wall} ,C_{wall} ,U and R values of optimized and existing facade

Façade type	**Absolute thermal resistance ,R_{wall}** *(k/w)*	**Thermal conductance,C_{wall}** (*w/k)*	**Thermal Transmittance**,U *(w/m²k)*	**Thermal insulance**,R (*m²k/w)*
Existing /16cm air gap	10.406	0.1	1.2	0.83
20cm air gap	12.845	0.08	0.97	1.03
24cm air gap	15.28	0.065	0.82	1.22

The results of the optimized facades heat flow as presented in Table 07 below also indicates that, an increase in air gap of facades has led to an increase in thermal resistance of the wall ,which in turn has decreased rate of heat gain and increased rate of heat loss. So from the results, these optimized facades will have a potential of slow heat gain from outside and faster heat loss to the outside environment during day time.

Table 07: Heat transfer rate (Q_{wall}) of optimized and existing facade

			March	**April**	**May**
Existing 16cm	South facade	*highest*	73.3J/sec	25.6J/sec	43.24J/sec
		lowest	-35.3J/sec	-34.4J/sec	-38.83J/sec
	West façade	*highest*	96.4J/sec	33.68J/sec	56.9J/sec
		lowest	-46.45J/sec	-45.29J/sec	-51.1J/sec
20cm air gap	South facade	*highest*	59.12J/sec	21.28J/sec	32.7J/sec
		lowest	-30J/sec	-28.2J/sec	-35.3J/sec
	West façade	*highest*	77.8 J/sec	27.9J/sec	42.9J/sec
		lowest	-39.48J/sec	-37.2J/sec	-46.5J/sec
24cm air gap	South facade	*highest*	49.42J/sec	17.65J/sec	29.1J/sec
		lowest	-24.71J/sec	-26.48J/sec	-26.5J/sec
	West façade	*highest*	65.03J/sec	23.2J/sec	38.3J/sec
		lowest	-32.5J/sec	-34.8J/sec	-34.8J/sec

CHAPTER FIVE

DISCUSSION

4.3 Response of the facade towards the climate of Adama

The performance of the facades is detrimental factor in maintaining indoor thermal comfort. Such performance of facades is indeed essential in warm climate places like Adama. The existing facades of the condominiums has shown that their performance fluctuates and are incapable of fulfilling daytime thermal comfort.

Even though the performance of the facades is not solely responsible for the fluctuation of thermal comfort, the performance of the facades takes the lion share due to the fact that most of heat gain and heat loss in a building takes place through ceiling and walls. The facades unable to cooperate for the thermal comfort of the room will result in an unhealthy and unfitting indoor environment leading to SBS (sick building syndrome). In Ethiopia, for instance in Gonder town due to SBS, skin symptoms account 10 %, rhinitis 8 %, Mucosal symptoms account for 64 % (Belachew et al, 2018) of disease.

In order to improve the existing facades, passive design strategies are very effective and not costly. In his study of Developing a thermal comfort zone chart for different climatic zones of Ethiopia ,(Daba Fufa ,2020) revealed that most of the climate zones (Warm-dry, Warm-humid, Temperate , Cool, and Cold) except the hot dry zone don't need mechanical cooling if the passive strategy in the bioclimatic chart applied properly. Passive design strategy also means optimizing the building materials of the building to better respond to the external environment.

In almost all of surface temperatures analysis, the results indicate that the solar heat gained by the exterior surface of the wall is not rapidly transferred to the indoor environment and that is why the exterior surface temperature rises so quickly while the interior surface temperature rise slowly during the day time. This also means in other terms the wall delays/resists the solar heat coming from exterior surface of the façade during day time. But the degree to which the wall resists and regulates the outdoor environment is not adequate. Inadequacy of the thermal resistance of the wall s is clearly seen by the thermal comfort zone results too.

The intensity of solar heat gain is the major factor for the cooling or heating load in a particular building apart from other factors like building materials, building envelopes, orientation & geographical location of the building, (Jemal Worku, 2014).The influential effect of orientation in shaping the heat flow and indoor environment is clearly seen from the surface temperature results of west and south facades having the same material composition and arrangement. So increasing the thermal resistance (sometimes referred as thermal mass) of the wall will help to regulate the harsh outdoor environment and result in thermal comfort for residents in condominium buildings located in Adama city. This adjustments will also work for all buildings with HCB wall/facades located in Adama city too.

4.4 Computations

Methods to reduce the amount of consumed energy depend on understanding factors that affect the thermal design of buildings, such as thermal performance of building materials and thermal insulation (Firas Sharaf, 2020).The use of insulating materials to maintain indoor thermal comfort is a common practice in western countries. Methods to reduce the amount of consumed energy depend on understanding factors that affect the thermal design of buildings, such as thermal performance of building materials and thermal insulation (Firas Sharaf, 2020). Insulating materials give the walls the ability to delay passage of the incoming heat.

Such practice is hardly seen in Ethiopia due to the higher cost and very limited options of insulating materials. As the heat transfer between the inside and the outside of the room is through the building facades, the properties of these components will have a critical role on heat transfer, (Jemal Worku, 2014).The findings on the thermal resistance of the existing facades indicate that, the air gap inside the walls is responsible for 93.8% of the walls resistance towards incoming heat. This is very high value compared to other material layers composing the facade. So focusing on the air gap for optimizing/improving the insulating property of the wall will reduce the need for insulating materials.

Heat transfer results of the existing HCB wall dictate that there is uneven flow of heat during the day time. During the start of the day (before midday), there is a heat loss towards the outside environment. But after midday there is much heat gain by the facades. This indicates that the wall is in state of continued heat gain and heat loss process depending on the solar radiation intensity and climate. There is also heat flow difference between months and facades as seen from the findings. Due to the fact that both facades (South and West) are entirely made from the same materials composition and arrangement, the difference in heat flow rate is generated by the temperature difference (indoor and outdoor) and orientation of the facades.

Among the months in which the study is carried out, there is consistency in heat transfer rate in March and May. But in April there is inconsistency in heat transfer/flow rate.in one of the days in April, there has been no heat gain by the facades. This indicates that the wall is losing heat to the outside environment all day. That is also to mean that, the outside environment is colder than the inside all day long. Such incapable of holding the heat for longer time of a day is a sign of inadequate thermal resistance/mass. One of the disadvantage of light weight buildings having low thermal mass is, they tend to have high temperature fluctuations which result in high heating loads , high cooling loads and thermal discomfort (Feremnet Amha, 2017).

In most of the results from computations ,south facade have low heat transfer rate, low interior and exterior surface temperatures and low heat flux compared to west facade. Such results lead to the conclusion that south facades receive low solar radiation input than west. This is another indication of the crucial importance of considering orientation of rooms, facades and building for better thermal comfort.

4.5 Optimization of the façade

The existing facade/HCB wall has been found to be incapable of maintaining the thermal comfort zone of Adama city during day time period in March, April and May months of the year. Unable to perform well of the existing facades in the hottest season of the year in Adama is revealed in fluctuation of indoor surface temperatures, inconsistent heat transfer rate and other indicative results. So optimizing the facade is needed to maintain indoor thermal comfort throughout the daytime period.

In most of the above discussions, having increased thermal resistance will enable the facades to have slow heat gain and faster heat loss is set as a basic optimization way. In order to have increased thermal resistance, increasing air gap (main contributor to thermal resistance of the existing façade) is also set as major contributor to the intended improvements. Increased air gap is indirectly referring to having increased thickness of wall too.

Some of the researches made in Ethiopia also recommend for Optimization of the existing HCB wall/façade. One of the study titled "Optimization of Building Wall to Control Indoor Temperature using MATLAB Software and Finite Difference Method ", (D.Zeleke & M.Kasay , 2015) states that 25cm optimum wall thickness is required for a favorable indoor temperature of 298ok/25°C,though it doesn’t clearly states in which climate zone do such type of wall thickness is required. Two years after, another study stated that, average thickness of 25cm is recommended for concrete wall to create a thermal comfort. However, as the temperature increases other thermal storage mechanisms should be considered (Feremnet Amha, 2017).

Studies mentioned above and results found from the analysis dictate that, having optimized wall with additional air gap thickness will help to achieve better thermal comfort for residents residing in warm climate of Adama. The computed results for the optimized HCB wall also indicate a boosted performance of the existing HCB wall.

These optimized facades will have 23.44 %(for extra 4cm air gap) -46.8 %(for extra 8cm air gap) thermal resistance. The optimized facade will have a wider thickness of 27.5cm (for extra 4cm air gap) and 31.5cm (for extra 8cm air gap) which is higher thermal mass. But there should careful consideration of structural compactness of this optimized facades on usage and production .a prototype should be made and experimental tests should also be carried out for further realization of this newly optimized HCB walls.

Improved thermal transmittance (U value) is also one of the advantages of the optimized facades compared to the existing one. Figure 14 below shows some of the standard values of thermal transmittance set by different countries to bring indoor thermal comfort for their citizens. In Ethiopia there isn’t available data on the standard U value set in regulations. But U vales from studies made by individual scholars are included to get the overview.

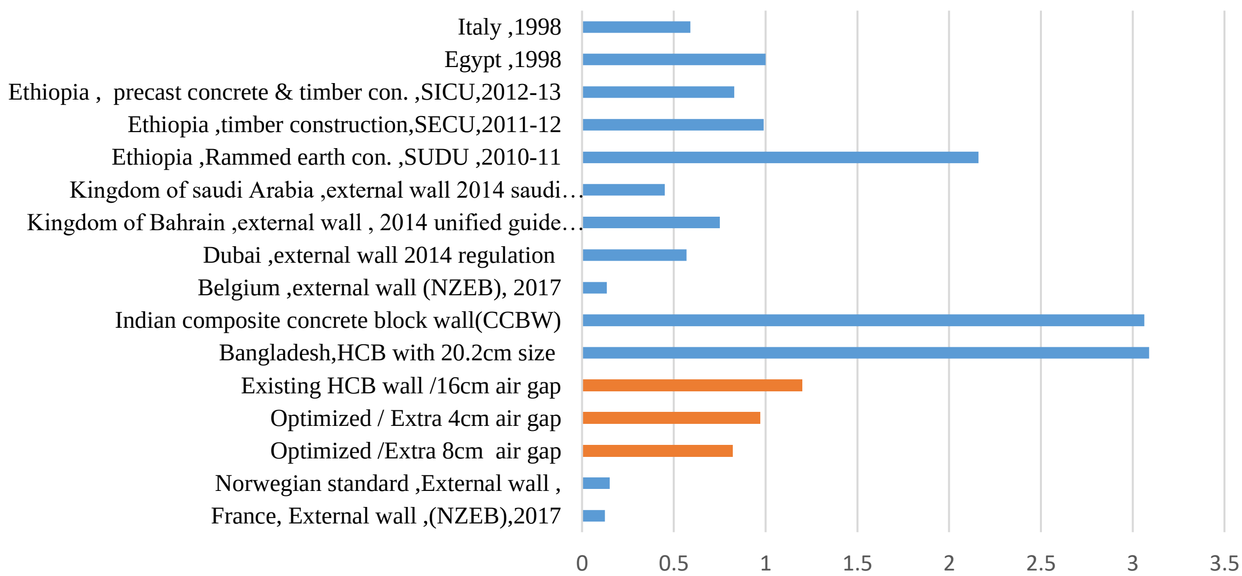

Figure 13 : U values comparison with different countries standards ,*Note :SECU(sustainable emerging city unit), SICU(sustainable incremental city unit), SUDU(sustainable urban dwelling unit),NZEB(net zero energy building),*

As illustrated in the above diagram the U values of countries with warmer climate like Egypt, Dubai, Kingdom of Bahrain, Kingdom of Saudi Arabia have U value below 1.This indicates that lower U value is needed in warm climates in order to slow down the heat flow rate. The optimized facades have lower U value than existing HCB wall, which will enable them to decrease fluctuations.

If properly executed, this optimized facades will enable residents to live in a comfortable indoor space without having expenses for insulation and other unnecessary air conditioning costs.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Most of the finding in previous chapters conclude that the existing HCB wall facade are not fully capable of maintaining indoor thermal comfort of Adama city. Fluctuating heat flow rate and other results also implicate that the existing facades do not keep the momentum of thermal comfort throughout the daytime period. West facade has been found to have higher interior and exterior surface temperatures as well higher heat transfer rate compared to south facade of the condominium building. The difference were generated due to the orientation and solar radiation intake of the facades. Though the study is carried out in only the hottest months of the year, where the need for thermal comfort is higher in Adama city, the facades are not entirely in worse position of performance. By increasing the air gap layer of the facade, a remarkable improvement could be achieved as the computed results of the suggested/optimized facades indicate.

By having an extra air gap to the existing facades, 23.44 - 46.8% extra thermal resistance can be attainable. This increase in thermal resistance will equip the existing wall a capacity to slow heat gain and faster heat loss during the daytime. This in turn will create cooler indoor space during the sunny and warm daytime environment of Adama city.

Because the study is made on HCB wall, which is the most available and widely used wall material in Ethiopia, the optimized HCB wall can be used to bring thermally comfortable indoor space in a warm climate of Ethiopia. Apart from optimization of the existing wall, a spatial orientation and arrangement of south and west facade should be implemented on the design of the condominiums and other residential buildings as well in order to provide comfortable indoor space.

5.2 Recommendation

- Buildings, irrespective of their programs, should carefully be integrated with the existing climate and context.
- Institutions responsible for realization of mass building construction projects (for instance condominiums) should always consider the indoor thermal comfort, orientation and other design amenities apart from the cost.

- It will make remarkable benefit for academic and larger community if further researches continued to work on different climates and building material settings.
- Further researches that involve producing prototype and conducting experiments on the suggested optimized facades should proceed in order realize the usage of such advantageous building materials and benefit the general public.
- Incorporating standards that set the thermal comfort of building materials in reference to building programs and different climates into EBCS (Ethiopian Building Code Standards).

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Annex - 1

Field Data

Month	Date	Time	Indoor *ambient Temperature (°C)*	Outdoor *ambient Temperature* (°C)	Humidity *of the room* (%)	Interior *surface temperature (°C)*		Exterior *surface temperature(°C)*	
						SOUTH F.	*WEST F.*	*SOUTH F.*	*WEST F.*
March	Mar 29 - 2021 Monday	2:00 LT	24	19.7	33	23.2	23.9	19.2	19.8
		4:00 LT	24.6	24.7	31	22.4	23.1	24.9	23.1
		6:00 LT	25.5	28.9	30	22.9	23.1	30.4	29.3
		8:00 LT	26.1	32.2	31	23.5	23.8	34.1	45.2
		10:00 LT	26.4	32.8	25	24.7	25.4	35	55.8
	Mar 30 - 2021 Tuesday	2:00 LT	23.1	19.1	26	22.1	23.1	17.9	18.7
		4:00 LT	24.9	25	25	22.1	22.7	24.4	22.7
		6:00 LT	25.8	28.2	27	23	23.2	29.1	28.1
		8:00 LT	25.8	34.4	24	23.6	23.7	34.6	47.1
		10:00 LT	26.5	33.5	20	24.8	25.6	34.9	59.8
	Mar 31 - 2021 Wednesday	2:00 LT	25.4	21.7	33	22.5	23.6	19.9	20.6
		4:00 LT	25.4	25.6	38	23.2	23.9	26.1	24.6
		6:00 LT	26.1	28.2	35	23.5	24.1	30.9	29.6
		8:00 LT	26.7	34.5	31	24.4	24.6	36.8	47.9
		10:00 LT	27	33.7	27	25.4	26.2	35.8	57.1
	Apr 1 - 2021 Thursday	2:00 LT	26.7	23.4	42	23.8	24.4	22.1	22.3
		4:00 LT	26.1	26.8	40	23.8	24.4	27.7	26.1
		6:00 LT	26.6	31.3	37	23.2	24.5	33.3	31.7
		8:00 LT	27.3	35.4	35	25.4	25.6	35.9	47.9
		10:00 LT	27.9	34.2	37	26.1	26.1	36.4	57.6
April	Apr 28 -2021 Wednesday	2:00 LT	22	17.9	67	19.9	19.8	18.3	18.5
		4:00 LT	21.6	21.7	75	20.3	20	23.5	22.1
		6:00 LT	21.3	20.4	77	20.6	20.7	24.3	22.1
		8:00 LT	21.6	20.3	75	20.6	20.7	25.4	33.3
		10:00 LT	21.4	20.7	73	21	21.2	23.2	23.7
	Apr 29 -2021 Thursday	2:00 LT	22.7	20.9	67	19.6	19.8	20.7	19.9
		4:00 LT	21.6	24	68	19.9	20.2	24.4	22.5
		6:00 LT	21.8	24.9	67	20.8	20.7	27.2	26.5
		8:00 LT	21.7	22	73	20.8	20.8	25.6	25.8
		10:00 LT	22	23.3	69	21.5	21.4	24.8	24.6
	Apr 30 -2021 Friday	2:00 LT	20.3	16.9	79	20.3	20.4	18.8	18.3
		4:00 LT	20.8	18.8	81	16.9	17	18.6	18.1
		6:00 LT	21.2	23	76	19.8	19.9	25.4	23.8
		8:00 LT	20.2	22.8	80	19.7	21	24.3	24.1

		10:00 LT	21.7	23.1	75	20.2	20	24.9	23.2
	May 01 -2021 Saturday	2:00 LT	19.7	17.1	73	21.3	19.5	22	19.8
		4:00 LT	18.9	18.2	75	20	19.9	21.4	23.1
		6:00 LT	22.4	24.2	69	22.3	21.2	25	28.7
		8:00 LT	23.5	21.3	78	23.1	21	24.6	31.2
		10:00 LT	21	20.7	63	24.5	23.8	24.2	25.6
May	May 29 -2021 Saturday	2:00 LT	25.2	21.4	38	23.5	23.7	21.6	21.5
		4:00 LT	24.2	24.5	39	22.9	23.2	23.7	23.1
		6:00 LT	26	29.2	36	23.2	23.5	27.7	27.5
		8:00 LT	25.5	29.8	34	23.8	23.5	31.7	42.6
		10:00 LT	26.3	29.6	30	25.3	25.7	31.4	44.5
	May 30 -2021 Sunday	2:00 LT	26.3	21.7	44	22	22.4	19.2	19.1
		4:00 LT	24.4	23.6	54	23	23.5	23.7	23.1
		6:00 LT	25.6	27.4	49	24.3	24.5	27.4	27.8
		8:00 LT	26	30.8	37	25.8	26	33.7	42.5
		10:00 LT	24.3	28.8	36	24.1	25.9	31.2	43.2
	May 31 -2021 Monday	2:00 LT	25.8	21.7	38	20	21.4	19.8	21
		4:00 LT	27.9	24.2	46	22.2	22.4	23.5	22.4
		6:00 LT	25.2	25.7	49	23.2	23.5	26.8	26.6
		8:00 LT	25.6	27.4	45	24.1	24.1	31	43.5
		10:00 LT	25.4	29.5	35	24.7	26.2	30.3	33.2
	June 1 -2021 Tuesday	2:00 LT	23.1	19.8	35	25.2	20.4	20.3	20
		4:00 LT	28.2	25	43	23	23.3	27.7	27.2
		6:00 LT	26.2	26.8	55	25.8	26.2	29.3	28.6
		8:00 LT	25.5	28.1	46	26.6	26.9	33.4	46.2
		10:00 LT	25.2	30.3	40	26.8	27.2	32.6	42.5

Annex - 2

Spatial dimensions and thermal conductivity values of façade layers

Building Façade layers	**Thickness** (L) in m	**Area** (A) in m^2	**Thermal conductivity** (k) inW/mk
Exterior cement plastering	0.02	0.08	1.2
Concrete	0.02	0.08	1.75
Air gap	0.16	0.064	0.256
Concrete	0.02	0.08	1.75
Interior Cement plastering	0.015	0.08	1.2

Note: L & A values above indicate for HCB sized surface area of the façade.

Annex – 3
Calculated data

Month	Date	Time	Mean T of south F. (˚C)	Mean T of west F. (˚C)	(T_2-T_1) (˚C)	Q_{wall} (Joule/sec) - base case	Q_{wall} (Joule/sec) - 20cm air gap	Q_{wall} (Joule/sec) - 24cm air gap	q_{wall} (W/m2) - base case
March	Mar 29 - 2021 Monday	2:00 LT	21.2	21.85	-4.3	-0.41322	-0.33476	-0.28141	-5.16529
		4:00 LT	23.65	23.1	0.1	0.008601	0.007785	0.006545	0.120123
		6:00 LT	26.65	26.2	3.4	0.292423	0.264694	0.222513	4.084182
		8:00 LT	28.8	34.5	6.1	0.524641	0.474893	0.399215	7.327503
		10:00 LT	29.85	40.6	6.4	0.550443	0.498248	0.418848	7.687872
	Date : Mar 30 - 2021 Tuesday	2:00 LT	20	20.9	-4	-0.34403	-0.31141	-0.26178	-4.80492
		4:00 LT	23.25	22.7	0.1	0.008601	0.007785	0.006545	0.120123
		6:00 LT	26.05	25.65	2.4	0.206416	0.186843	0.157068	2.882952
		8:00 LT	29.1	35.4	8.6	0.739658	0.669521	0.562827	10.33058
		10:00 LT	29.85	42.7	7	0.602047	0.544959	0.458115	8.40861
	Mar 31 - 2021 Wednesday	2:00 LT	21.2	22.1	-3.7	-0.31822	-0.28805	-0.24215	-4.44455
		4:00 LT	24.65	24.25	0.2	0.017201	0.01557	0.013089	0.240246
		6:00 LT	27.2	26.85	2.1	0.180614	0.163488	0.137435	2.522583
		8:00 LT	30.6	36.25	7.8	0.670852	0.60724	0.510471	9.369594
		10:00 LT	30.6	41.65	6.7	0.576245	0.521604	0.438482	8.048241
	Apr 1 - 2021 Thursday	2:00 LT	22.95	23.35	-3.3	-0.28382	-0.25691	-0.21597	-3.96406
		4:00 LT	25.75	25.25	0.7	0.060205	0.054496	0.045812	0.840861
		6:00 LT	28.25	28.1	4.7	0.404232	0.365901	0.307592	5.645781
		8:00 LT	30.65	36.75	8.1	0.696654	0.630596	0.530105	9.729963
		10:00 LT	31.25	41.85	6.3	0.541842	0.490463	0.412304	7.567749
April	Apr 28 -2021 Wednesday	2:00 LT	19.1	19.15	-4.1	-0.394	-0.31919	-0.26832	-4.92504
		4:00 LT	21.9	21.05	0.1	0.00961	0.007785	0.006545	0.120123
		6:00 LT	22.45	21.4	-0.9	-0.08649	-0.07007	-0.0589	-1.08111
		8:00 LT	23	27	-1.3	-0.12493	-0.10121	-0.08508	-1.5616
		10:00 LT	22.1	22.45	-0.7	-0.06727	-0.0545	-0.04581	-0.84086
	Apr 29 - 2021	2:00 LT	20.15	19.85	-1.8	-0.17298	-0.14013	-0.1178	-2.16221
		4:00 LT	22.15	21.35	2.4	0.230636	0.186843	0.157068	2.882952

		6:00 LT	24	23.6	3.1	0.297905	0.241339	0.20288	3.723813
		8:00 LT	23.2	23.3	0.3	0.02883	0.023355	0.019634	0.360369
		10:00 LT	23.15	23	1.3	0.124928	0.101207	0.085079	1.561599
	Apr 30 -2021 Friday	2:00 LT	19.55	19.35	-3.4	-0.32673	-0.26469	-0.22251	-4.08418
		4:00 LT	17.75	17.55	-2	-0.1922	-0.1557	-0.13089	-2.40246
		6:00 LT	22.6	21.85	1.8	0.172977	0.140132	0.117801	2.162214
		8:00 LT	22	22.55	2.6	0.249856	0.202413	0.170157	3.123198
		10:00 LT	22.55	21.6	1.4	0.134538	0.108992	0.091623	1.681722
	May 01 -2021 Saturday	2:00 LT	21.65	19.65	-2.6	-0.24986	-0.20241	-0.17016	-3.1232
		4:00 LT	20.7	21.5	-0.7	-0.06727	-0.0545	-0.04581	-0.84086
		6:00 LT	23.65	24.95	1.8	0.172977	0.140132	0.117801	2.162214
		8:00 LT	23.85	26.1	-2.2	-0.21142	-0.17127	-0.14398	-2.64271
		10:00 LT	24.35	24.7	-0.3	-0.02883	-0.02336	-0.01963	-0.36037
May	May 29 -2021 Saturday	2:00 LT	22.55	22.6	-3.8	-0.36517	-0.29583	-0.24869	-4.56467
		4:00 LT	23.3	23.15	0.3	0.02883	0.023355	0.019634	0.360369
		6:00 LT	25.45	25.5	3.2	0.307515	0.249124	0.209424	3.843936
		8:00 LT	27.75	33.05	4.3	0.413223	0.334761	0.281414	5.165289
		10:00 LT	28.35	35.1	3.3	0.317125	0.256909	0.215969	3.964059
	May 30 -2021 Sunday	2:00 LT	20.6	20.75	-4.6	-0.44205	-0.35812	-0.30105	-5.52566
		4:00 LT	23.35	23.3	-0.8	-0.07688	-0.06228	-0.05236	-0.96098
		6:00 LT	25.85	26.15	1.8	0.172977	0.140132	0.117801	2.162214
		8:00 LT	29.75	34.25	4.8	0.461272	0.373686	0.314136	5.765904
		10:00 LT	27.65	34.55	4.5	0.432443	0.350331	0.294503	5.405535
	May 31 -2021 Monday	2:00 LT	19.9	21.2	-4.1	-0.394	-0.31919	-0.26832	-4.92504
		4:00 LT	22.85	22.4	-3.7	-0.35556	-0.28805	-0.24215	-4.44455
		6:00 LT	25	25.05	0.5	0.048049	0.038926	0.032723	0.600615
		8:00 LT	27.55	33.8	1.8	0.172977	0.140132	0.117801	2.162214
		10:00 LT	27.5	29.7	4.1	0.394003	0.31919	0.268325	4.925043
	June 1 -2021 Tuesday	2:00 LT	22.75	20.2	-3.3	-0.31712	-0.25691	-0.21597	-3.96406
		4:00 LT	25.35	25.25	-3.2	-0.30751	-0.24912	-0.20942	-3.84394
		6:00 LT	27.55	27.4	0.6	0.057659	0.046711	0.039267	0.720738
		8:00 LT	30	36.55	2.6	0.249856	0.202413	0.170157	3.123198
		10:00 LT	29.7	34.85	5.1	0.490102	0.397042	0.33377	6.126273

Note: The heat transfer rate and heat flux values above are calculated for 0.08m2 (HCB sized surface area) of the wall.

Annex - 4

Specification of instruments used in the research

A, Infrared Thermometer

Temperature range	-50^{o}C - 600^{o}C (-58^{o}F - 1112^{o}F)
Accuracy	0^{o}C - 380^{o}C (32^{o}F - 716^{o}F) : ±1.5 ^{o}C(±2.7^{o}F) or ±1.5% -50^{o}C - 0^{o}C (-58^{o}F - 32^{o}F): ±3 ^{o}C(±5^{o}F) Whichever is greater
Resolution	0.1^{o}C or 0.1^{o}F
Repeatability	1% of reading or 1 ^{o}C
Response time	500msec ,95% response
Spectral response	8-14μm
Emissivity	0.95 preset
Distance to spot ratio	12:1
Operating Temperature	0 - 40 ^{o}C (32 - 104 ^{o}F)
Operating Humidity	10-90%RH non-condensing, up to 3.0 ^{o}C (86 ^{o}F)
Storage Temperature	-20 - 60 ^{o}C (-4 - 140 ^{o}F)
Power	1.5 AAA*2 battery
Typical battery life	Laser off: 12hrs.

Annex - 5

B, Digital Hygrometer (Humidity & Temperature meter)

Specifications			Remark
Temprature range	Indoor	-10^oC - 50^oC (14^oF - 122^oF)	
	Outdoor	-50^oC - 70^oC (-58^oF - 158^oF)	
Temperature resolution		0.1 ^oC/ ^oF	
Humidity range		20%RH – 99%RH	Less than 40% :*dry*, more than 70% :*wet* and 40%-70% & 20 ^oC-25 ^oC : *comfort* signal appear on the screen of the instrument
Humidity accuracy		±5%RH	
Humidity resolution		±1%RH	
Calendar		1999/1/1 – 2048/12/31	
Battery		AAA 1.5V	