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Article

Indoor Thermal Comfort Analysis: A Case Study of Modern and Traditional Buildings in Hot-Arid Climatic Region of Ethiopia

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Abstract: Indoor thermal comfort is an essential aspect of sustainable architecture and it is critical in maintaining a safe indoor environment. Expectations, acceptability, and preferences of traditional and modern buildings are different in terms of thermal comfort. This study, therefore, attempts to evaluate the indoor thermal comforts of modern and traditional buildings and identify the contributing factors that impede or facilitate indoor thermal comfort in Semera city, Ethiopia. This study employed subjective and objective measurements. The subjective measurement is based on the ASHRAE seven-point thermal sensation scale. An adaptive comfort model was employed according to the ASHRAE standard to evaluate indoor thermal comfort. The results revealed that with regards to thermal sensational votes between −1 and +1, 88% of the respondents are satisfied with the indoor environment in traditional houses, while in modern houses this figure is 22%. Likewise, 83% of occupants in traditional houses expressed a preference for their homes to remain the same or be only slightly cooler or warmer. Traditional houses were, on average, in compliance with the 80% acceptability band of the adaptive comfort standard. The study investigated that traditional building techniques and materials, in combination with consideration of microclimate, were found to play a significant role in regulating the indoor environment.

Keywords: bioclimatic; thermal comfort; vernacular house; condominium houses; Semera

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1. Introduction

People spend up to 90% of their time inside buildings, so the quality of their indoor environments has a significant impact on their quality of life [1]. Buildings should thus consider the bioclimatic condition of the location where they are constructed in order to improve the living standards of their occupants [2,3]. According to a study conducted by Akande & Adebamowo [4], the term bioclimatic refers to the designing of buildings based on the context of the local climate in order to provide the optimum thermal comfort of the place.

Thermal comfort is defined by the American Society of Heat, Refrigeration, and Air-conditioning Engineers (ASHRAE) as a condition of mind which expresses satisfaction with the thermal environment [5]. Studies have also stated that thermal comfort is the result of the interaction and adaptation of environmental and human body parameters [6,7] and according to ASHRAE [5], the indoor thermal condition in a building is acceptable when 80% of the building occupants are satisfied and comfortable within it.

The study undertaken by Fanger [8] reveled that thermal comfort is determined by thermal environments, personal factors, and other contributing factors. Environmental factors include air temperature, air velocity, humidity, and radiation [9], while clothing and activity (metabolic rate) are categorized as personal factors [10]. Contributing factors includes food and drink, acclimatization, body shape, subcutaneous fat, age and sex, and health status [11].

Fanger's static model (PMV-PPD model) [8] of thermal comfort was a pioneering intervention in human comfort research, defining comfort limits particularly in tightly controlled chambers/air-conditioned buildings. The predicted mean vote (PMV) model consists of a seven-point thermal sensation scale ranging from (+3) hot to (−3) cold [12] and it is best suited to air-conditioned buildings in which the occupants have no control over their immediate surroundings [13]. However, the works by Dear and Brager [14], Nicol [15], Nicol and Humphreys [16], and Fanger and Toftum [17] 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 conditions of people living in naturally ventilated buildings depend not only on physiological aspects but also on adaptive nature. Because of this, Fanger's theory fails in predicting thermal comfort conditions in naturally ventilated buildings [14,16]. In the adaptive thermal comfort model the comfort zone is around the neutrality/comfort line and represents the comfortable upper and lower temperature parameters. Acceptability levels of 90% and 80% limit the comfort zone, with the ideal comfort temperature falling between 2–3 °C on either side of the comfort line, which is considered an acceptable limit [18]. The temperature range identified corresponds to 90% and 80% acceptability limits and could reach approximately 30 °C according to the ASHRAE 55-2017 standard [5] (Figure 1).

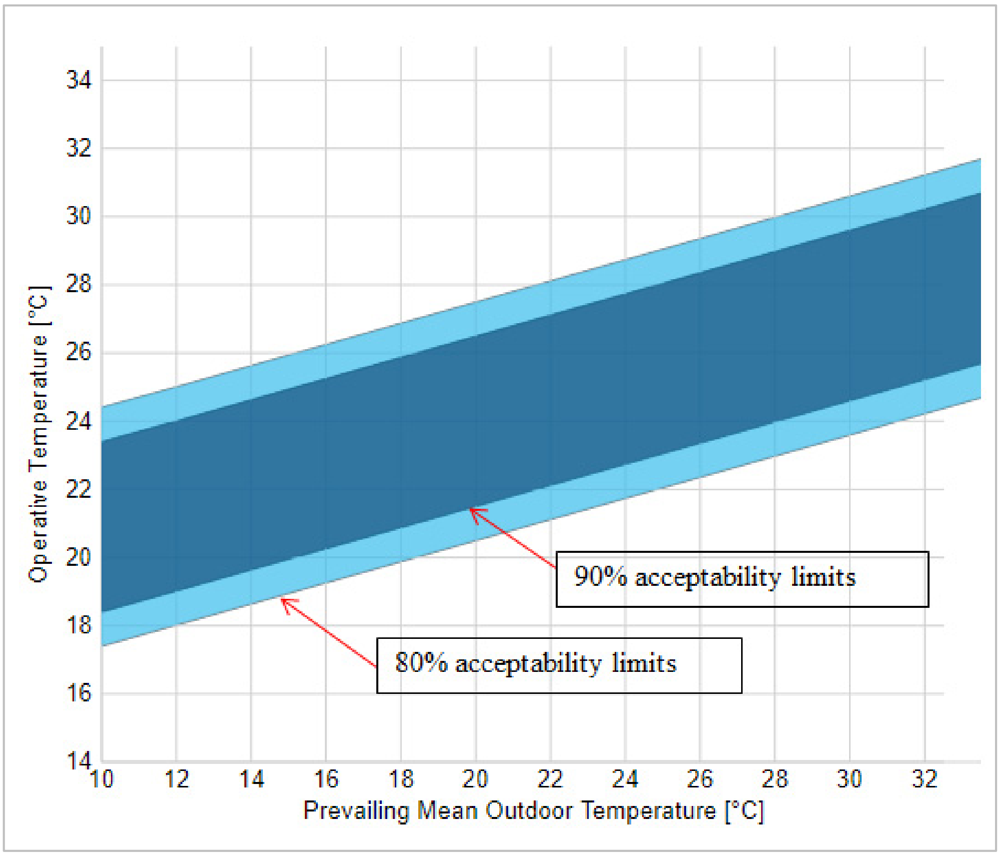

Figure 1. Adaptive comfort models represented in ANSI/130 ASHRAE 55:2017.

Studies have shown that good indoor thermal comfort has a significant role in affecting occupant wellbeing, health, and productivity [19,20]. According to Dovjak et al. [21] the failure of humans to respond to the indoor environment through the thermo regulatory mechanism causes thermal discomfort. Thermal discomfort in buildings induces psychological stress, depression, and anxiety, as well as poor physical health, expressed as heart disease, insomnia, headache, and low arousal levels [8,22]. Therefore, avoiding thermal discomfort within dwellings is not just about residents' satisfaction and comfort; it is also about protecting the health of the occupants [9].

Green buildings are those defined as buildings that increase the efficiency with which they use resources, energy, water, and materials while reducing their impacts on human health and the environment [23]. They are currently viewed as a good example of buildings that enhance the indoor thermal comfort of occupants [24,25] and green building materials that are locally available, renewable, recyclable, and have a low embodied energy [26,27] are thought to be the ideal materials for enhancing the indoor thermal comfort of buildings in different parts of the globe [3]. Besides, orientation and forms of buildings also have an important role in providing better indoor thermal comfort [28]. Additionally, research carried out previously has shown that passive design strategies can provide the benefit of achieving indoor thermal comfort while consuming low operating energy [29,30]. According to Simons et al. [31], these methods are definitely more cost-effective than considering technology-assisted solutions.

Scholars argue that indoor thermal comfort is crucial for all occupants to be productive and healthy [32]. Taking this into account, Western countries give considerable attention to indoor thermal comfort, and they attempt to adjust the thermal comfort of their buildings using various techniques rather than relying solely on the behavioral adjustments that our bodies are provided with by nature to regulate temperature governing the thermal balance [33]. According to Nielsen [34], most buildings in developed countries use thermo-active technology during construction. This 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 [35].

In contrast, developing countries use a variety of traditional cooling techniques for their buildings owing to a lack of technology, such as locally available construction materials including mud block, grass roofs, building orientations, and use of plants, among other things [36]. Furthermore, developing countries have adopted a variety of strategies to regulate indoor thermal comfort, including the use of various shading, particularly upper shading [23], 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 enable cold air to flow in to the court [37], and the use of external structures such as wooden pergola embodied with vegetation and water to enhance the moisture of the air [22].

Studies have shown that traditional buildings that use passive design techniques for heating and cooling purposes can provide better indoor thermal comfort in comparison to modern buildings [38,39]. For instance, a study carried out by Karyono [40] on the traditional architecture of Java, Indonesia, revealed that the roof of a traditional building plays an important role in providing shade protection from direct solar radiation. It was argued that in modern buildings, the height from the roof ceiling permits the transfer of heat through radiation. On the contrary, in traditional buildings natural roof materials such as bamboo, wood, and straw, among others, absorb solar radiation slowly. According to Karyono [40] the roofs of the traditional buildings are commonly equipped with porous materials which permit hot air to move from the inside to outside. The study concludes that microclimate consideration plays an important role in the creation of thermal comfort in buildings. Similarly, research conducted by Fernandes et al. [41] on older architecture in northern and the southern parts of Portugal showed that older houses could provide good thermal performance by passive strategies and occupants felt comfortable conditions most of the time.

Traditional houses are often well adapted to local climate and environmental conditions, including sociocultural circumstances [42]. Despite all these benefits, however, most of the features of traditional houses have disappeared in contemporary housing developments in sub-Saharan African countries such as Ethiopia.

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 [20,43]. For instance, as a strategy to provide shelter for low-income people of the country, modular condominiums are designed at the federal level and distributed to all cities and towns without taking into account the microclimates of the towns and cities, resulting in people suffering from indoor thermal discomfort. The is particularly notable in Semera city, where many condominium houses have been developed and transferred to people, however owing to the high temperature of the indoor space, people are not interested in living in the houses. Indoor thermal comfort issues were not taken into account during the design and construction phase of these residential 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.

In contrast, traditional houses in Semera city have been built using traditional building materials and passive design strategies, taking into account the hot-arid climatic condition of the area. These typical dwellings offer people pleasant inside temperatures, despite the severe hot desert climate. In this regard, the current research compares the thermal comfort of traditional houses and condominium houses, as well as the factors that contribute to or impede better indoor thermal comfort from an architectural point of view.

Despite the fact that numerous studies on thermal comfort have been conducted around the world, research on indoor thermal comfort in hot-arid climates is still limited [44]. Nicol [45] conducted a limited study on sedentary subjects in hot-arid area of Iraq and concluded that people who habitually live in hot-arid climates were adapted to and mostly comfortable at a temperature of 32 °C. The results of study conducted by Nicol [45] contrast with the study conducted by Hamphreys and Nicol [46] on English office workers who were comfortable at a temperature of 20–25 °C [45]. More recently, Cena and de Dear [44] carried out a large field study in Kalgoorlie-Boulder, located in a hot-arid region of Western Australia. The main result of their study was that thermal neutrality in accordance with the ASHRAE sensation scale occurred at 20.3 °C in winter and at 23.3 °C in summer. Ariffin et al. [18] have also conducted thermal comfort studies on traditional and modern houses in hot-arid climatic regions of Algeria. The results showed that traditional houses performed best in retaining the temperature nearest to the comfort range as indicated in the ASHRAE 55 [5] standards. Based on the results of the study undertaken by Ariffin et al. [18], traditional houses have a better ability to provide indoor thermal comfort for more extended periods than the modern houses in the same condition. Low thermal conductivity due to thinner walls and the use of non-local building materials such concrete in the modern houses create higher temperature variations compared to traditional houses [18].

Studies on indoor thermal comfort in developing countries are not far from the awareness creation stage [39,40]. This situation is also true in Ethiopia, where expectations, acceptability, and preferences of indoor thermal comfort of traditional and modern buildings, as well as the factors that contribute to or impede better indoor thermal comfort in buildings, is severely lacking. A study was conducted by Yadeta et al. in Jimma city to analyze perceptions of residents with regard to thermal comfort and to investigate the source of heat that allows the temperature of the indoor environment to be increased [20]. However, this study focuses only on investigating the perception of the residents through subjective assessment. Moreover, the study was limited to modern homes and was not supported by objective assessment.

Hence, this study is intended to contribute to filling these gaps by carrying out a more comprehensive indoor thermal comfort analysis on traditional and condominium houses in Semera city, which is found in a hot-arid climatic region of the country, through objective and subjective evaluation methods. The research also aims to identify the contributing factors that impede or facilitate indoor thermal comfort in the city and provide passive solutions and strategies that would fit the city's climate conditions, be culturally acceptable, provide affordable residencies particularly for low-income households, and reduce energy use.

2. Materials and Methods

2.1. Description of the Study Area

Semera is a new city on the Awash-Asseb highway in the northeast of Ethiopia, and is planned to replace Asaita as the capital city of the Afar region located in the administrative zone 1. Semera has a latitude of 11°47′32″ N and longitude of 41°0′31″ E [47] and is situated at a distance of 595 km from Addis Ababa (Figure 2). The altitude of the city is 433.5 m above sea level.

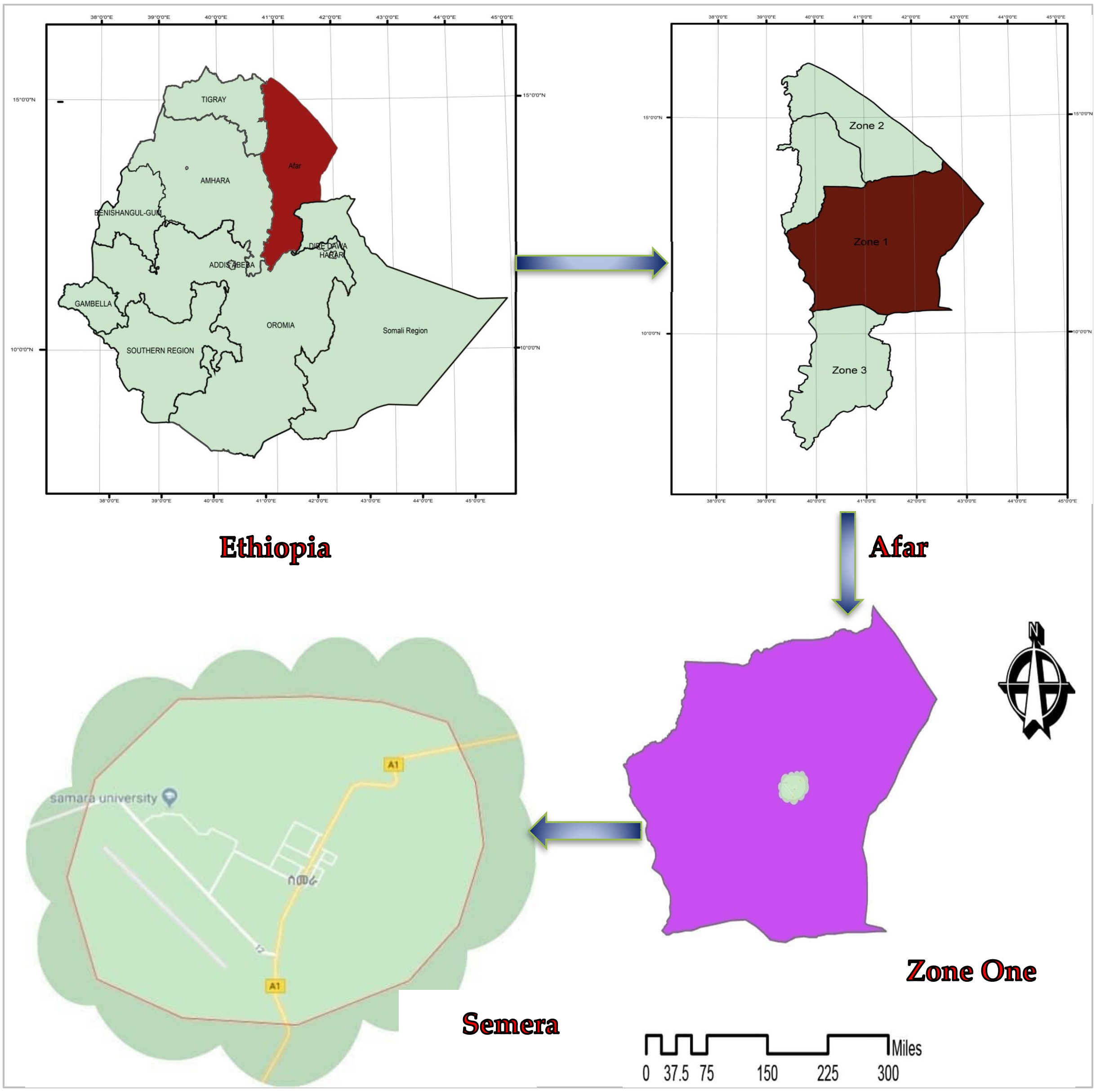

Figure 2. Map of the study area.

Today, the modified Köppen climate classification is the most generally used system for classifying different climates in the world. It recognizes six main climatic types including tropical moist climates, dry climates, moist mid-latitude climates with mild winters, moist mid-latitude climates with cold winters, and polar climates [48]. According to the Köppen climatic classification subtype, Semera city is under "Bsh" hot semi-arid climate category (Figure 3). The temperature in the city ranges from an average daily maximum of 36.7 °C to a daily minimum of 18.3 °C. In the months of June, July, and August the temperatures reach up to 40 °C. The mean humidity is highest in November (74%) and lowest in July (28%). Semera receives an average of 210.8 mm of precipitation per year. With 55.9 mm of precipitation on average, August is the month with the most precipitation and December is the month with the least precipitation with an average of 2.5 mm.

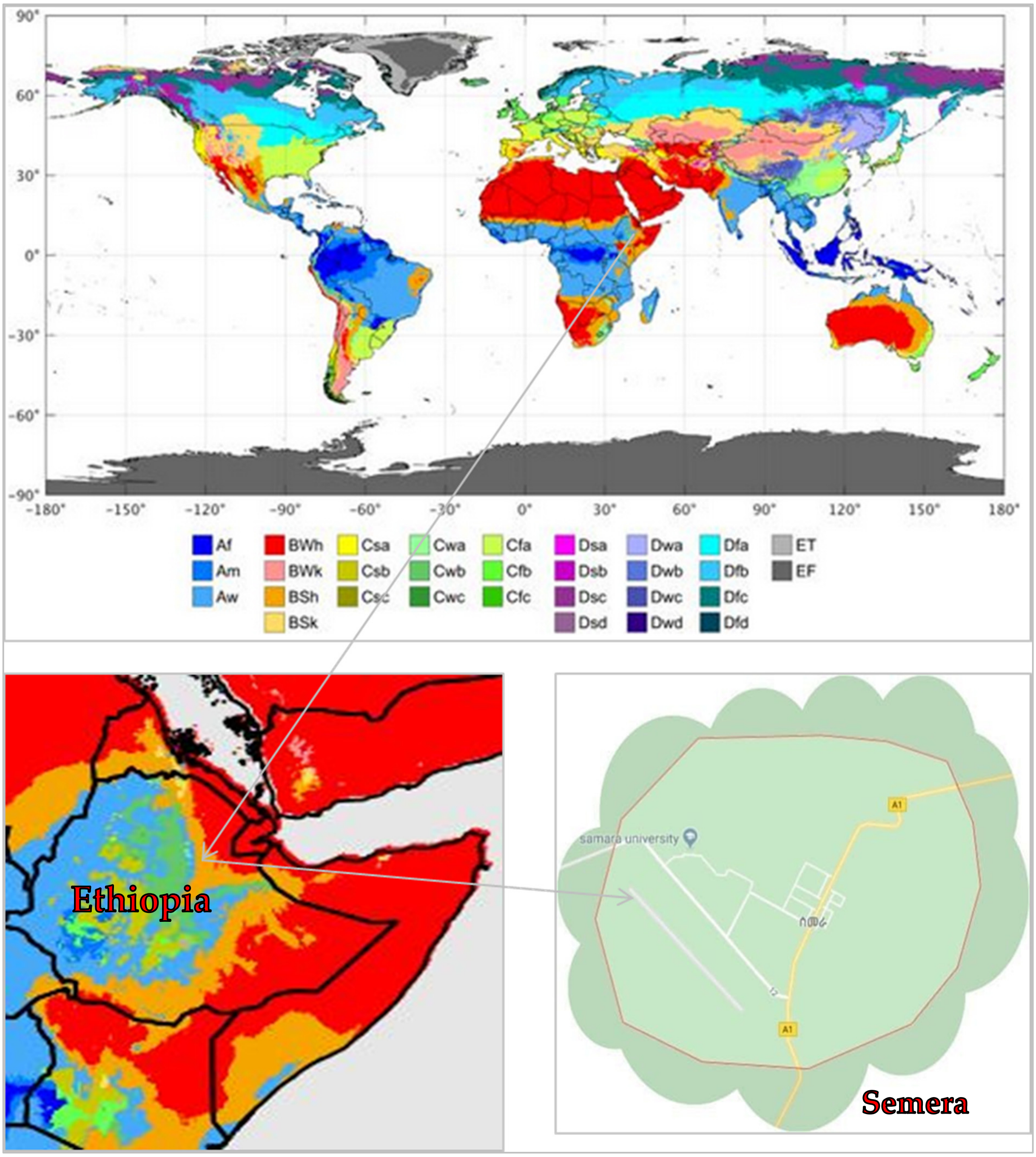

Figure 3. Climate map of the study area based on the Köppen climate classification.

2.2. Methods for Evaluating Indoor Thermal Comfort

Indoor thermal comfort can be measured using subjective and/or objective methods [5]. Subjective methods include using the ASHRAE seven-point thermal sensational scale, thermal preference, standardized questioners, and interviews to assess residents' feelings. The residents' adaptation as well as their mood will influence this method [49]. The objective measurement approach is focused on measuring the indoor thermal comfort variables of the indoor environment such as air temperature, relative humidity, air velocity, and mean radiant temperature, and comparing these values to standards such as the ASHRAE 55 and others [50]. In this study, to compare the indoor thermal comfort of traditional houses with condominium houses, both methods were employed.

2.2.1. 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 of houses. Additionally, primary data were collected by personal measuring of the air temperature and relative humidity of traditional houses and condominium houses. The main sources for secondary data were books, different articles, and government publications.

2.2.2. Sampling Technique and Sample Size

Semera city has five kebeles (the lowest level of town or city administration). Out of the total kebeles, kebele 01 and 02 were selected purposively in consultation with experts of the city administration. These kebeles were selected as all condominiums houses are found in kebeles 01 and 02 of the city. There are two basic forms of survey sampling in indoor thermal comfort assessment. These are transverse and longitudinal sampling. In the transverse survey the whole or a substantial proportion of a population each give a single comfort assessment. This type of sampling helps to reduce sampling bias and also minimizes disruption to the lives and work of the subjects. In the longitudinal survey each of a small number of subjects gives a large number of comfort assessments over an extended period of perhaps several days or weeks [51]. In this study, in order to use a large sample size, to reduce sampling bias, and to make sure that the results will be representative, transverse survey sampling was used to collect information on the thermal sensation vote, the thermal satisfaction scale, and the thermal preference of the occupants in the traditional residential buildings and modern residential buildings. Therefore, to obtain representative information from both the traditional and modern buildings it is important to determine the sample size from the total households of kebeles 01 and 02.

The number of the sample size was determined using a formula developed by Kish [52].

$$n = \frac{n^1}{1 + n^1/N}$$

where:

n = sample size

N = Total population size

N = 1750 (total population size)

$$n^1 = \frac{S^2}{V^2}$$

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

$S^2 = 0.5\ (1-0.5)$
$S^2 = 0.25$

$$n^1 = \frac{0.25}{(0.05)^2}$$

$$n^1 = 100$$

$$N = \frac{100}{1 + \frac{100}{1750}}$$

$$N = 94.59 \approx 95$$

$$\frac{12}{100} \times 95 = 11.4 \approx 11(\text{contingency})$$

$$N = 11 + 95 = 106\ (\text{population sample size})$$

Accordingly, out of 1750 households, 106 sample informants were selected for subjective surveys for condominium houses. To achieve a representative sample size for each kebele, a proportional size allocation approach was used. Subjects are chosen in proportion to their prevalence in the population in this type of sampling [53]. This means that the sample size for each kebele was determined by the proportion of households contributed by each kebele to the total number of households (1750) in the two kebeles. The sample households were selected using the purposive sampling method. The households were selected based on their experience of living in both traditional houses and condominium houses. Similar to condominium houses, for traditional houses 106 sample informants were selected for the subjective survey following the same procedure.

Since the study aim is to compare the indoor thermal comfort of traditional houses (vernacular) and standard condominium houses in Semera city, two houses, one traditional and one condominium, with nearly the same orientation were selected for measuring relative humidity and air temperature data. The main reason for selecting one traditional house was that traditional houses have the same characteristics in terms of the construction materials used and the availability of traditional cooling and ventilation system. In a similar architectural design, condominium houses have four floors and floors are connected by stairs. Their structure is made of stone and mortar, plaster, beams, and flat rooftops. All rooms have a rectangular design. Hence, due to the similar features, one house was also selected from condominium houses randomly.

2.2.3. Temperature and Humidity Data Collection

Air temperature and relative humidity are important factors in determining comfort levels in hot-arid climatic regions [54]. Hence, since Semera city is categorized as a hot-arid climate region, the objective measurement was restricted only to air temperature and relative humidity to evaluate the indoor thermal comfort. In this study, the data of indoor and outdoor temperature and humidity were collected using two digital thermometers. The temperature and humidity data were recorded in both the traditional house as well as in the standard condominium house in the absence of any kind of mechanical cooling and ventilation system. The data were recorded for three consecutive months with gaps of three days, resulting in eight measurements per month. The data were manually recorded five times in a day with intervals of three hours starting from 7:00 a.m. to 6:00 p.m. Among all the seasons in the study area, Bega (winter) and Belg (autumn) are those that causes major discomfort due to the presence of high relative humidity at elevated temperatures. Hence, it is important to assess the indoor thermal comfort in these two seasons. The months of February, March, and April were considered in this study. The month of February will represent Bega (winter) and the months of March and April will represent Belg (autumn) seasons in the study area. The air temperature and relative humidity measurements were carried out on the third floor at a northwest orientation. Since the recorded data for both houses was required over three consecutive months the selection of the room was dependent on the willingness of the homeowners for both types of houses. However, data loggers were placed in the room at a position in which sunlight and heating and cooling devices did not affect them. Figure 4 shows the sensors and data loggers used for the purpose of this study.

Figure 4. Sensors and data loggers used for the purpose of data collection.

Detailed descriptions and specifications of the sensors and data loggers are provided Table 1 below.

Table 1. Specifications of the sensors and data loggers.

Digital infrared thermometer	Digital hygrometer
Infrared thermometer color screen display	Humidity range: 10~99% RH
Range: −50∼400 °C (−58 °F~752 °F)	Resolution humidity 1% RH
Accuracy: ±1.5 °C/±1.5%	Accuracy humidity ±5% RH (40–80%)
Resolution: 0.1 °C/0.1 °F	Storage condition 20–80% RH
Distance spot ratio: 12	Auto power off and data hold
Emissivity: 0.95 (fixed)	Humidity range: 10–99% RH
°C/°F unit selectable	Laser ON/OFF selectable

2.2.4. Questionnaire Survey

The questionnaires were used to evaluate the thermal comfort vote of the occupants. The questionnaire obtained data related to the age of building, number of occupants in a building, factors that contribute to or impede better thermal comfort in buildings, and the methods used regulate the thermal comfort of buildings including energy consumption, construction material, cooling and heating methods, and opening size.

One of the disadvantages of the thermal comfort vote is that there is often a difference in the use of the scales by people with different languages or cultures [55]. Thus a person living in a cold climate might see “warm” as having a positive connotation (“nice and warm”), while the inhabitant of a hot climate would say the same of “cool” (“nice and cool”). This tends to skew the use of the scale by creating confusion between comfort and hotness. To overcome these challenges it is advisable to add a preference vote [56]. Hence, in this study, the thermal sensational, preferences, and satisfaction scale of the respondents were assessed by the ASHRAE seven-point thermal sensational scale [57] as shown in Table 2 below. Participants were asked to rate their thermal sensation, preference, and satisfaction on the ASHRAE seven-point scale. These helped to gather information on how the occupants feel within their home indoor environment. The measurement of metabolic rate for each respondent was not undertaken since the aim of study is not to compare observed comfort vote and predicted PMV [51] and the respondent activities were restricted to sitting or standing or reading, or writing doing light work during the period of assessment. The metabolic rate of these activates ranges between 1.0 met and 1.3 met. During the subjective measurement, the majority of women wear the guntiino, a long stretch of cloth tied over the shoulder and draped around the waist and some of them wear a baati. A baati is a long dress made out of comfortable polyester. Men wear the macawis (ma'awiis), a sarong-like garment worn around the waist and a large cloth wrapped around the upper part of their body. There were also respondents wearing short sleeve shirts, sandals, and trousers. Hence, in general the clothing insulation of the cloth worn by participants was between 0.5 clo and 1.0 clo. Both in the traditional and modern houses, occupant behavior was classified into three lifestyles: low consumer, standard consumer, and high consumer, and during the subjective measurement the respondents came from all the three occupant behavior groups. For each sampled household, respondents with a sensible mind and keen observation skills regarding indoor thermal comfort levels were selected for the survey. They were briefed about the scope of the survey and were given sufficient information regarding how to respond to the questionnaire before conducting the survey. The questionnaire was administered on the first week of February for the respondents in both the traditional and condominium houses.

Table 2. Thermal sensation scale.

Thermal sensation scale						
Cold	Cool	Slightly cool	Neutral	Slightly Warm	Warm	Hot
−3.0	−2.0	−1.0	0.0	1.0	2.0	3.0
Thermal preference scale						
Much cooler	Cooler	Slightly cool	No change	Slightly Warmer	Warmer	Much warmer
−3.0	−2.0	−1.0	0.0	1.0	2.0	3.0
Satisfaction scale						
Very dissatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
−3.0	−2.0	−1.0	0.0	1.0	2.0	3.0

A key informant interview was also conducted with purposively selected owners of the traditional houses, with the people who had earlier experience of living in both types of houses, and with construction workers and experts in the Semera city municipality. The main instrument used to interview the key informant was a semi-structured interview, which contained open-ended questions whereby the respondents were given the chance to discuss all issues of concern. The semi-structured interview deals with particular features of the houses, especially regarding the comfort level and the adaptive solutions used to provide optimum thermal comfort in the house. In addition, the key informants were asked about user preferences concerning residential architecture in the city.

2.2.5. Indoor Thermal Comfort Evaluation Model

There are two main thermal comfort models used by ASHRAE; the predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD) model and adaptive thermal comfort models [58]. The adaptive thermal comfort method only works in free-run buildings and not in air-conditioned buildings, whereas PMV/PPV only works well in air-conditioned buildings and not in free-running buildings [59]. Based on the ANSI/ASHRAE 55 [5] standard, the adaptive comfort model may only be applied to occupant-controlled, naturally conditioned spaces, where (i) no mechanical cooling system is installed (regard-less of its operational status), (ii) no heating system is in operation, (iii) occupants' metabolic rates range between 1.0 met and 1.3 met, (iv) the occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions with a clothing resistance that ranges, at least, between 0.5 clo and 1.0 clo, and (v) the prevailing mean outdoor temperature falls between 10 °C and 33.5 °C. Therefore, in this study the adaptive comfort model was used to evaluate whether the existing indoor thermal conditions of traditional and modern buildings were in compliance with the 80% acceptability band of the adaptive comfort standard model or not at the given clothing and activity level.

The fundamental justification for using the adaptive comfort model in this study is that both the selected building (i.e., the traditional and modern buildings) are naturally ventilated buildings, in which building occupants have access to operable windows, they have some form of heating installed which is controlled by the building occupants, and building occupants have developed some adaptive approaches to adapt to their natural environment, such as opening or closing doors and windows, changing their clothes, activity level, or their intake of hot or cold drinks. Additionally, since the prevailing mean outdoor temperatures for the months of March, April, and May are 28.37 °C, 30.37 °C, and 33.53 °C, respectively, the adaptive comfort model was used to evaluate whether the existing indoor thermal conditions of traditional and modern buildings were within the acceptability of 90% and 80% comfort limits or not in this study. Moreover, the reason for using the adaptive thermal comfort model over other thermal comfort modules (i.e., the predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD)) was that it uses a wider range of operative temperature to sustain occupants' thermal comfort. Similarly, studies have also used the adaptive thermal comfort model to evaluate indoor thermal comfort with the acceptability of 90% and 80% limits of the comfort zone [60–63].

The acceptable operative temperature limits from the adaptive comfort model were determined based on the measured outdoor air temperature. This standard introduces the prevailing mean outdoor temperature (Tmo) 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 for the period under study.

The adaptive thermal comfort temperature for free-running buildings (the comfort temperature, Tc) can be calculated through ASHRAE 55 [5].

$$\mathrm{Tc} = 17.8 + 0.31 \times \mathrm{Tmo}$$

where,

Tmo: prevailing mean outdoor temperature (°C).

Tc: operative temperature (°C).

To find the adaptive thermal comfort 80% acceptability limit inside the building, where at least 80% of the occupants are satisfied with the temperatures ranges [58], we used the following equation:

80% acceptability limits impels to Tc $\pm$ 3.5 °C

Then,

Upper 80% acceptability limit (°C) = Tc + 3.5 °C

Lower 80% acceptability limit (°C) = Tc $-$ 3.5 °C

Different researches have been undertaken on indoor thermal comfort using ASHRAE, the adaptive comfort standard for objective evaluation, and the ASHRAE seven-point thermal sensation scale for subjective measurement in areas that have the same climatic condition with Semera town, i.e., a hot-arid climate [4,18,64], and the research results have revealed that the methods and standards used acceptable for hot-arid climate regions. Therefore, the adaptive comfort standard method is applicable in the local context of the study area.

The analysis and discussion of quantitative and qualitative data were performed by triangulating results to either supplement or verify qualitative responses and/or quantitative results. For instance, the data obtained from the household survey on the thermal comfort vote were verified and supported by the data obtained from the air temperature and relative humidity measurements.

3. Description of the Case Study

3.1. Characteristics of Traditional Houses

Old thatch roof houses constitute some of the first permanent living houses in Semera city, according to information obtained from key informant interviews (Figure 5). The walls of the houses are made of wood and plastered with thick mud. The roof is built in wood and covered in thick thatch. The floor is usually made of sand, but it may also be made of soil. Sand and soil floors promote the use of evaporative cooling. When water is sprayed on sand floors, hot and dry air comes in contact with water and it begins to evaporate with the help of latent energy taken from the air. There are no ceilings in these houses, and the internal space elevation is up to 4 m.

Figure 5. Thatch village.

The roofs of thatch houses have a small link to the wall, which reduces heat transfer from the roof to the wall during the day. The roofs of these houses can also provide shade to the walls from the harshest sun (Figure 6). When the door is closed, small and opposite windows are the only sources of natural light (Figure 7). These windows on opposite sides facilitate cross ventilation.

Figure 6. Roof shading.

Figure 7. Narrow windows.

The thatch roof houses also have a special approach towards the climate of the area. The houses in the compound are distinguished by their separation from one another. They are arranged far apart and arbitrarily without a pattern, not only because of their detachment, but also because of their orientation. As a result, they may provide a large compound for air circulation. The majority of these houses have a basket shelter attached to the front, providing cool air to the surrounding area (Figure 8).

Figure 8. Basket shelter attachments.

Similar to thatch roof houses, old thick brick houses are also other permanent living houses in Semera city. These buildings were built 40 to 50 years ago according to inhabitants of the area (Figure 9).

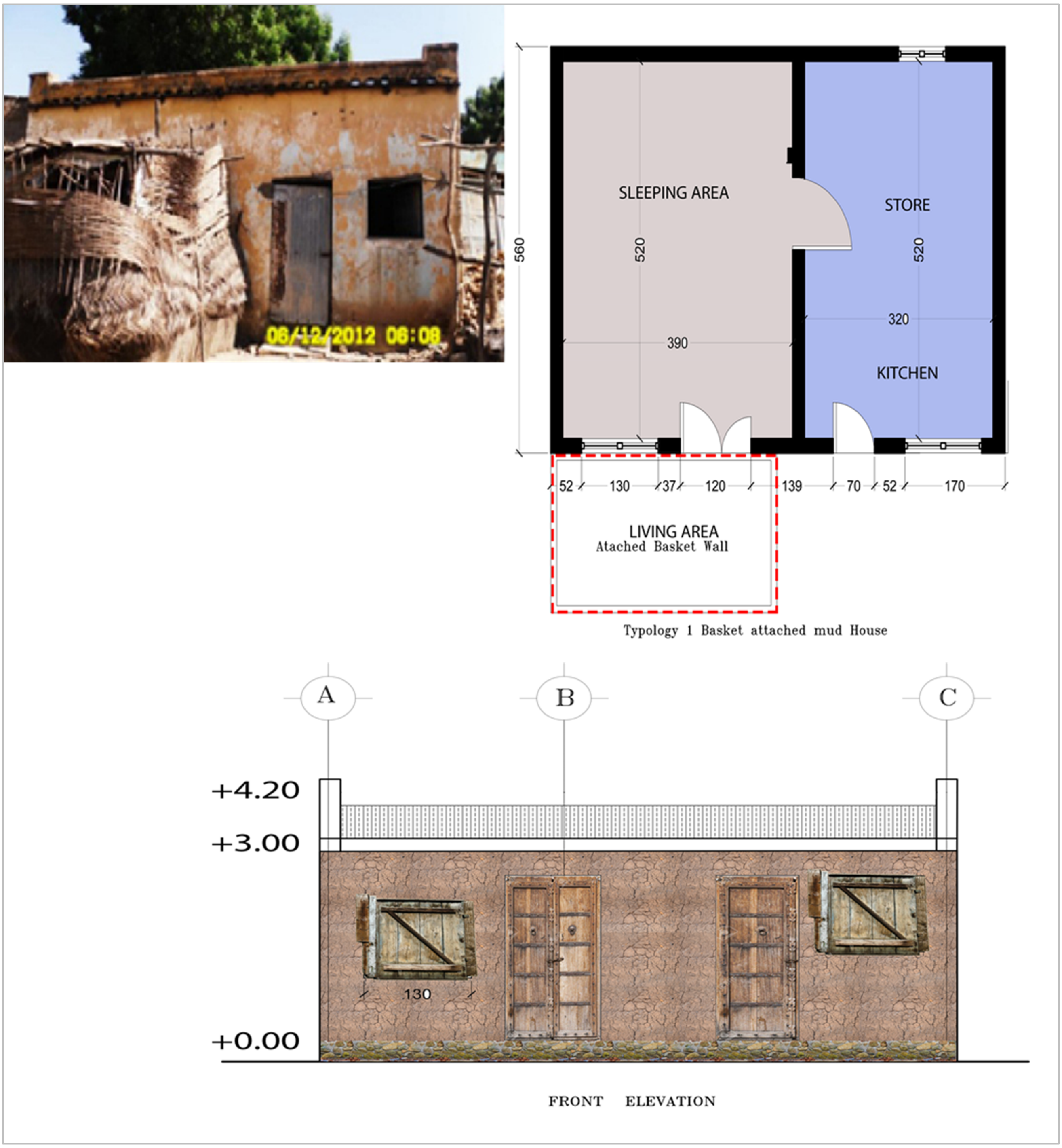

Figure 9. Old thick brick house with a basket shelter extension.

The thick brick walls have a high thermal mass, which is one of the key ecological characteristics of these houses. The majority of old thick brick houses have small unglazed window openings on the top or just one regular unglazed window per room (Figure 10).

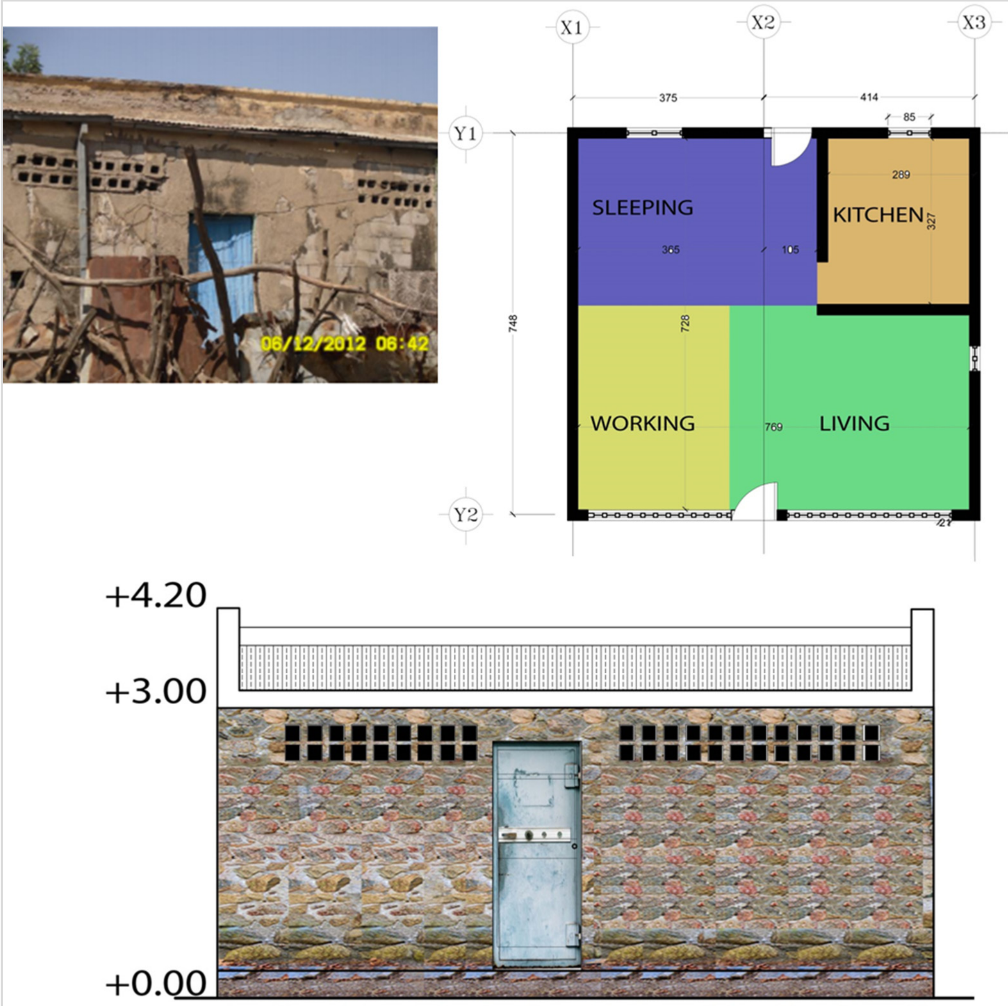

Figure 10. Old thick brick houses with small windows.

Based on data obtained from field observations, all thick brick houses have two doors that are opposite to one other (Figure 11). When the internal space becomes hot, cross ventilation enables hot air from the rooms to be exhaled through one door and cold air from the basket shelter to be inhaled through the other door. Every block can contain two, three, or more units that are oriented in a row. A large backyard with trees and a straw shelter is located behind these row houses. Cooking, eating, and gathering are done in these straw houses, which have progressed to basket houses. To enter this courtyard, the second door has a value (Figure 12). Researches revealed that straw has an important role in thermal efficiency and the formation of health buildings [65].

Old thick brick houses often have an internal space elevation above 4 m without a ceiling. As the hot air floats to the higher roof, the occupants will be able to enjoy cooler air on the ground (Figure 13). A sand or soil floor is also among the features of these houses. Painting the external wall white is also among the characteristics observed on old thick brick houses (Figure 14).

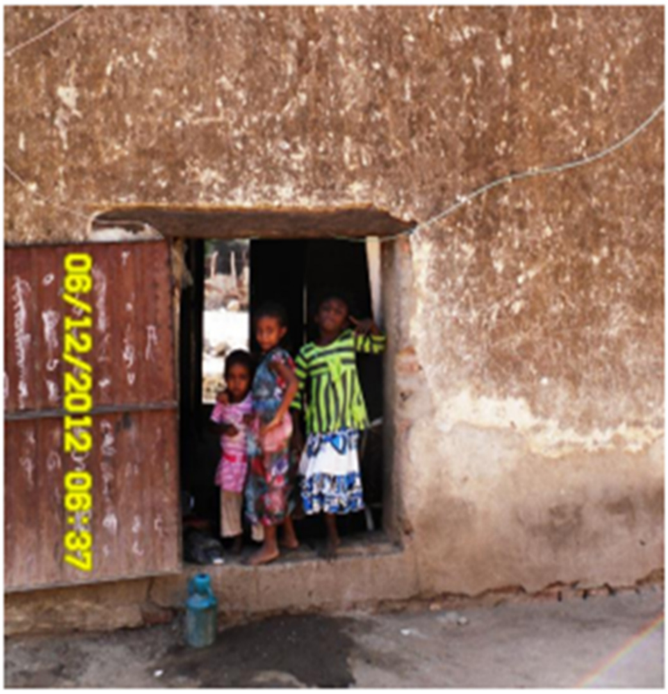

Figure 11. Old thick brick houses with doors opposite one another.

Figure 12. Backyard basket shelters.

In general, according to information obtained from the field survey and key informant interviews, it is possible to infer that traditional houses in Semera city have certain physical characteristics in common. Mud is used as a flooring medium in all traditional buildings, and mud combined with wood is used for the walls. They have no ceiling at all, and the roofs are made of grass, plastic, soil, and sometimes by iron sheet. The majority of these houses have a basket shelter attached to the front. These types of materials and construction methods have been used in the city in order to regulate the thermal comfort of the indoor environment. Similar to traditional houses in Semera city, studies reference the fact that traditional houses in hot-arid climatic regions of the tropics use these types of material and construction techniques to regulate the indoor environment [66–68].

Figure 13. High internal spaces.

Figure 14. White painted external wall.

3.2. Characteristics of Condominium Houses

The condominium houses in Semera city are made of plastered concrete hollow block (CHB) walls with wide glass windows, reinforced concrete (RC) slabs, and a ceiling, and in most cases, a small balcony linked to the units, which is rather narrow. The condominium blocks are located on the ground floor plus four stories (G + 4) in height. There are three unit typologies incorporated into each condominium block: a studio, one-bedroom, and one-bedroom unit types (Figure 15). Each unit has a bathroom, which includes a shower, flushing toilet, and basin, and a separate kitchen. Each unit has water, sewage, and electricity connections. The ground floor is allocated for commercial purposes and the commercial units are small shops, restaurants, pharmacies, salons, and music shops.

Figure 15. Typical floor plan of a condominium block.

The orientation of the doors and windows in condominium houses are primarily for entry and openings, with no consideration for environmental implications. Most of the windows in the condominium houses are wide, however, the wider portion is the non-operable part of the window and the operable part is narrower, thus the harshest sun penetrates the wide fixed glass but very low wind or air circulation is allowed (Figure 16).

Figure 16. Kitchen with small operable window in a condominium house.

According to the data gathered through field observations, almost all bedrooms in the condominium houses lack operable windows (Figure 17). Residents use the bedrooms for storage, instead using the corridor and balcony as bedrooms for this and other reasons (Figure 18).

Figure 17. Bedroom used for storage in a condominium house.

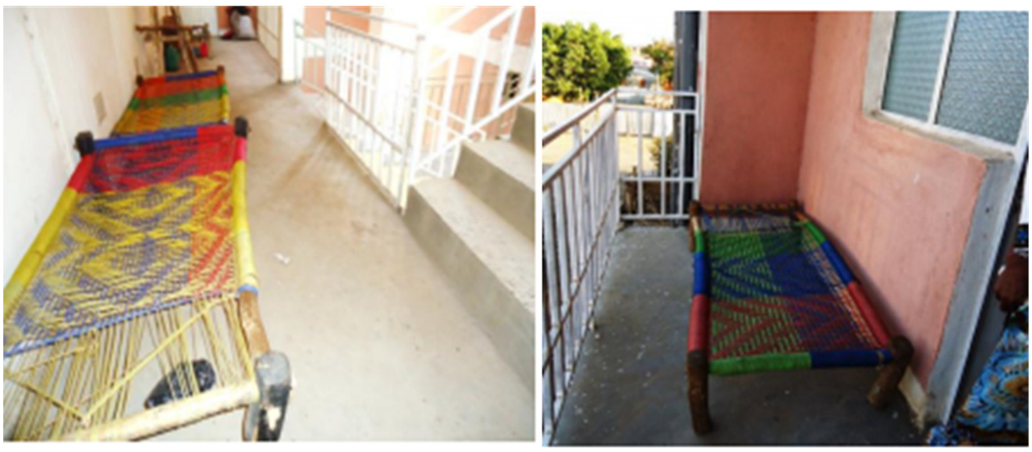

Figure 18. Bed positioned at corridor and balcony.

Unlike traditional homes, condominium houses are generally hot both during the day and at the night. The fixed glass window and bounded concrete hollow block wall are responsible for the daytime and nighttime heat, respectively.

4. Results and Discussion

4.1. Analysis of Thermal Sensation, Preferences, and Satisfaction Level

The thermal sensation vote of the occupants in both condominiums and traditional houses were registered. The percentage of thermal sensation vote in the study area is shown in Figure 19. As shown in the figure, with regards to condominium houses about 63.2% of respondents voted for the warm option, while about 14.2% voted slightly warm, and 14.15% voted hot. Approximately 5.65% of respondents voted for the neutral (0) option and 2.8% voted for slightly cool. According to the ASHRAE seven-point sensation scale, three central options (−1 to +1) indicate the comfort zone [5]. Based on this, 77.35% of respondents were not in the comfort zone and 22.65% were in the condominium houses.

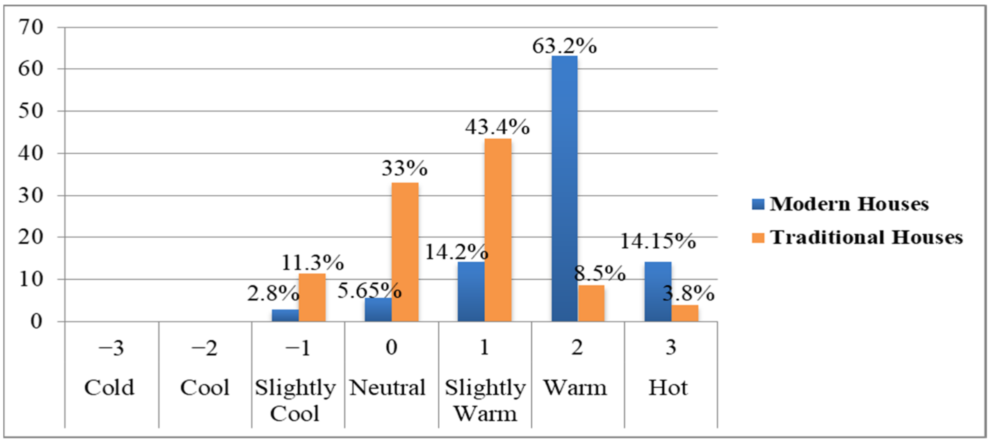

Figure 19. Thermal sensational scales for condominium and traditional houses.

Regarding the traditional houses, 43.4% of the respondents voted for the slightly warm option, about 33% of respondents voted for the neutral option, almost 11.3% voted for slightly cool, 8.5% voted warm, and about 3.8% voted for the hot option (Figure 19). According to the ASHRAE [5] standard, 87.7% were within the comfort zone since they were positioned in one of three center alternatives (−1 to +1), whereas 12.3% were outside of the comfort zone.

Centered on the predictor of thermal preference, Figure 20 depicts the respondents' responses to the thermal environment in both the traditional and condominium houses. Based on Figure 20, 19.8% of the occupants in condominium houses would prefer for the thermal environment of their home to remain the same (no change), while 21.7% would prefer it to be a bit cooler. On the other hand, in the condominium houses, about 32% of occupants indicated that they would prefer a cooler environment and 26.5% a much cooler environment. This finding indicates that the temperature conditions in condominium houses were higher than the respondents' preferred temperature. Based on the finding, 58.5% were out of the comfort zone of the preference scale and 41.5% were between the standard of the ASHRAE.

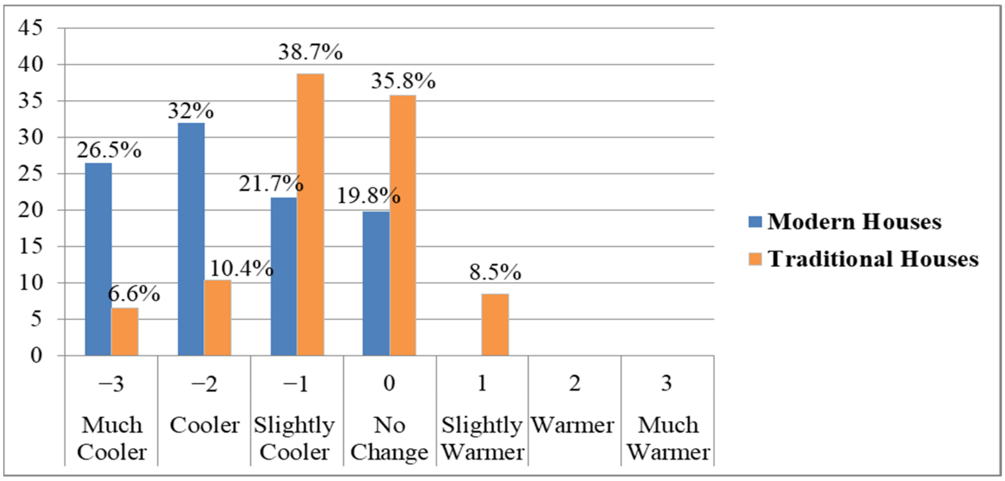

Figure 20. Thermal preference scale for condominium and traditional houses.

Concerning traditional houses, 38.7% of the respondents stated that they would prefer a slightly cooler temperature, while 35.8% preferred no change in the conditions. Additionally, 10.4% and 6.6% of respondents indicated that they would prefer to have a cooler and much cooler condition, respectively, if they had an opportunity to change their thermal environment. Finally, 8.5% of respondent voted for the slightly warmer option (Figure 20). In other words, people in general indicated that they would prefer for their thermal environment to stay the same or change slightly. This coincides with the survey, where 83% of occupants stated that they wished for their home to remain the same or to be only slightly cooler or slightly warmer. Similar to this study, the study investigated by Fernandes et al. [68] on the thermal efficiency of older buildings in Egypt and Portugal revealed that there is a connection between the thermal output of older buildings and human comfort perception. Because of their differences in location, the study found that typical passive techniques in both case studies were different. However, traditional passive strategies were used in both countries to achieve acceptable thermal conditions and reduce mechanical system loads.

Several psychological variables, such as expectation levels, use of controls, behaviors, and thermal background, influence thermal satisfaction of indoor parameters [38]. In the present work, about 17.92% of respondents voted that they were very dissatisfied, while 33.92% felt dissatisfied with the comfort of the condominium houses. On the other hand, about 20.75%, 10.38%, and 8.49% of the condominium house occupants voted slightly dissatisfied, neutral, and slightly satisfied, respectively (Figure 21). Accordingly, the residents of the condominium houses were not satisfied and the number of occupants in the discomfort zone is greater than the comfort zone.

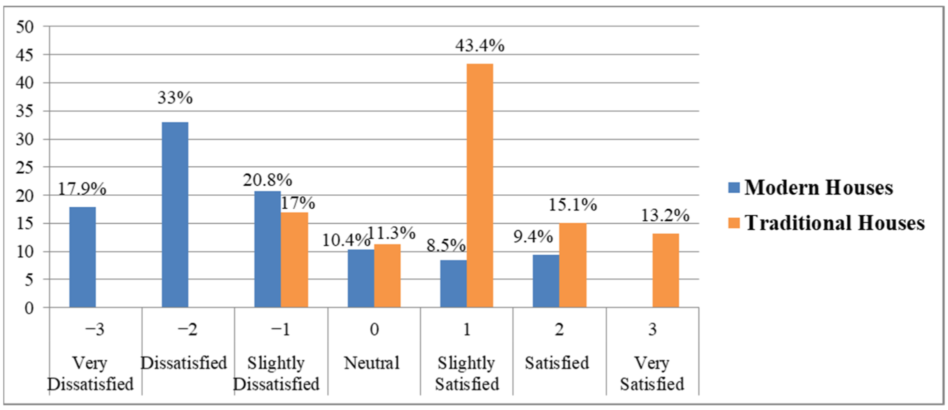

Figure 21. Thermal satisfaction scales for condominium and traditional houses.

Based on Figure 21, about 20.8% of respondent voted that they were slightly dissatisfied, while 11.3% and 43.4% of the respondents voted neutral and slightly satisfied with the comfort of the traditional houses, respectively. On the other hand, 15.1% and 13.2% of the respondents voted satisfied and very satisfied, respectively. With this knowledge, it is simple to conclude that the satisfaction scale in a traditional home meets the ASHRAE thermal sensational scale standard. To gain a better understanding, the participants of the key informant interview were asked about the thermal satisfaction scale. The views reflected by most of the participants were more or less similar and can be summarized as follows:

> *" . . . the majority of people who live in old traditional houses are happier with the thermal indoor climate than those who live in new buildings such as condominiums. The main reason for this is that traditional houses have a high internal space elevation without a ceiling and a sand-based floor, resulting in a comfortable thermal indoor climate."* (Key informant interview, 2020).

4.2. Analyses of Indoor Thermal Environments

The thermal environment has the potential to adversely affect human health [69]. One of the most important factors influencing indoor thermal comfort has been identified as air temperature. A change in air temperature can normally alter a person's level of comfort, as evidenced by numerous studies [54]. In this study, the impact of environmental variables such as indoor air temperature and relative humidity on the thermal conditions of traditional and condominium houses were investigated.

The results of air temperature are presented for the month of February in Figure 22 below. Indoor temperatures in traditional houses ranged from 18 °C to 31 °C, according to the results. The lowest and highest temperatures in the condominium house were 16 °C and 34 °C, respectively, on the 13 and 29 February.

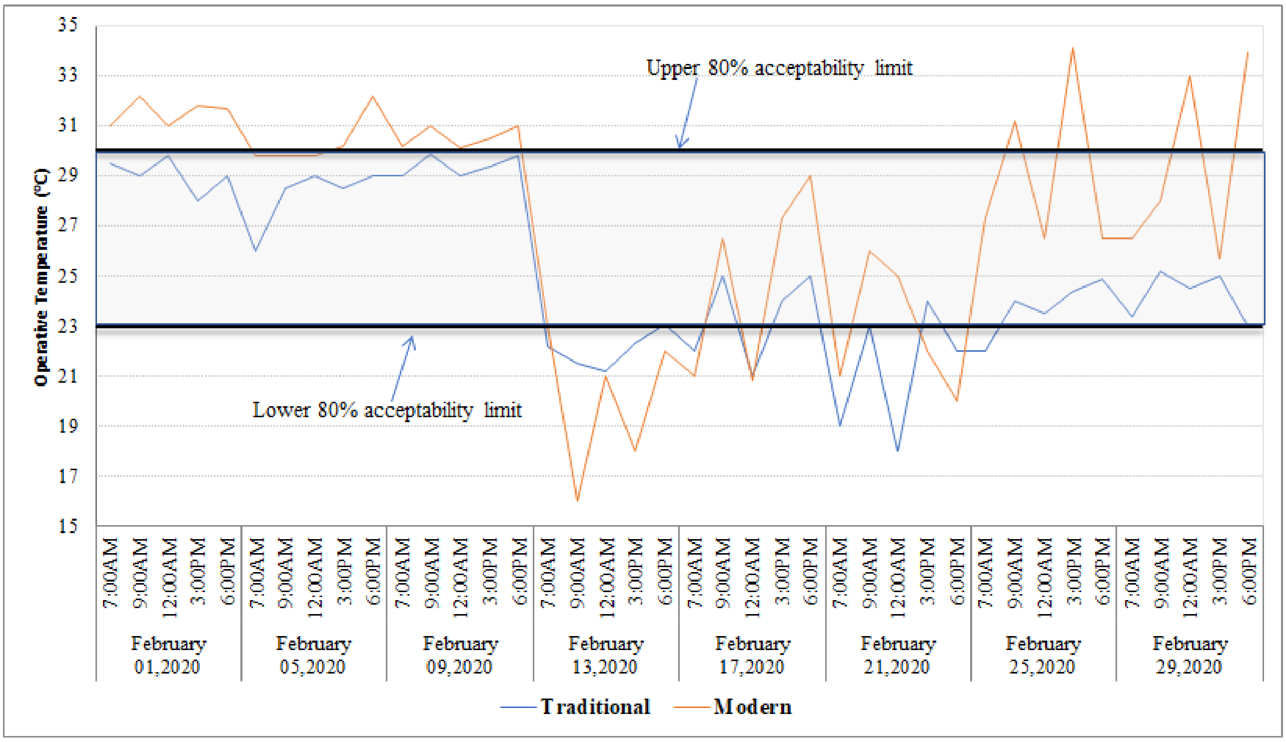

Figure 22. Indoor thermal comfort evaluation from February 2020.

The adaptive thermal comfort ranges of the 80% acceptability limit were calculated for both the traditional and modern houses. The black lines in Figure 22 shows the higher and lower 80% acceptability limits for both the traditional and modern houses. Based on the adaptive thermal comfort standard, for the month of February, the indoor thermal comfort temperature zones were expanded to 23 °C and 30 °C (Figure 22).

According to the indoor thermal comfort temperature zones, the condominium house was only in compliance with the 80% acceptability band of the adaptive comfort standard (ACS) model on 17, 21, 25, and 29 February. However, hourly, 7 a.m. and 12 a.m. from 17 February, 7 a.m. and 6 p.m. from 21 February, 9 a.m. and 3 p.m. from 25 February, and 12 a.m. and 6 p.m. from 29 February were out of 80% acceptability limit. Out of the reported results, two days, 13 and 21 February were not in compliance with the 80% acceptability band of the adaptive comfort standard model for the traditional home (Figure 22).

The uncomfortable states of the condominium house are caused by the adaptation of modern design styles that are incompatible with the Semera city microclimate, according to information obtained from key informant interviews and field observations. Traditional buildings, on the other hand, have good thermal comfort because they were constructed with high thermal mass materials including stone, mud, and thatch. They also use a light paint on the exterior of the houses, which helps to keep the temperature down. Buildings made with low thermal conductivity materials, such as wood in the ceiling and light paint on the exterior parts of the structure, have strong thermal comfort, according to studies [70].

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 [54]. For the month of February, relative humidity (RH) data was also monitored, and the results showed that condominium houses were outside of the ASHRAE thermal comfort range (30 RH–60 RH), except in 05 February, while the readings of the traditional houses indicated that all of the reported data were within the range of thermal comfort zone, except at 6 p.m. on 21 and 25 February and 3 p.m. on 29 February (Figure 23).

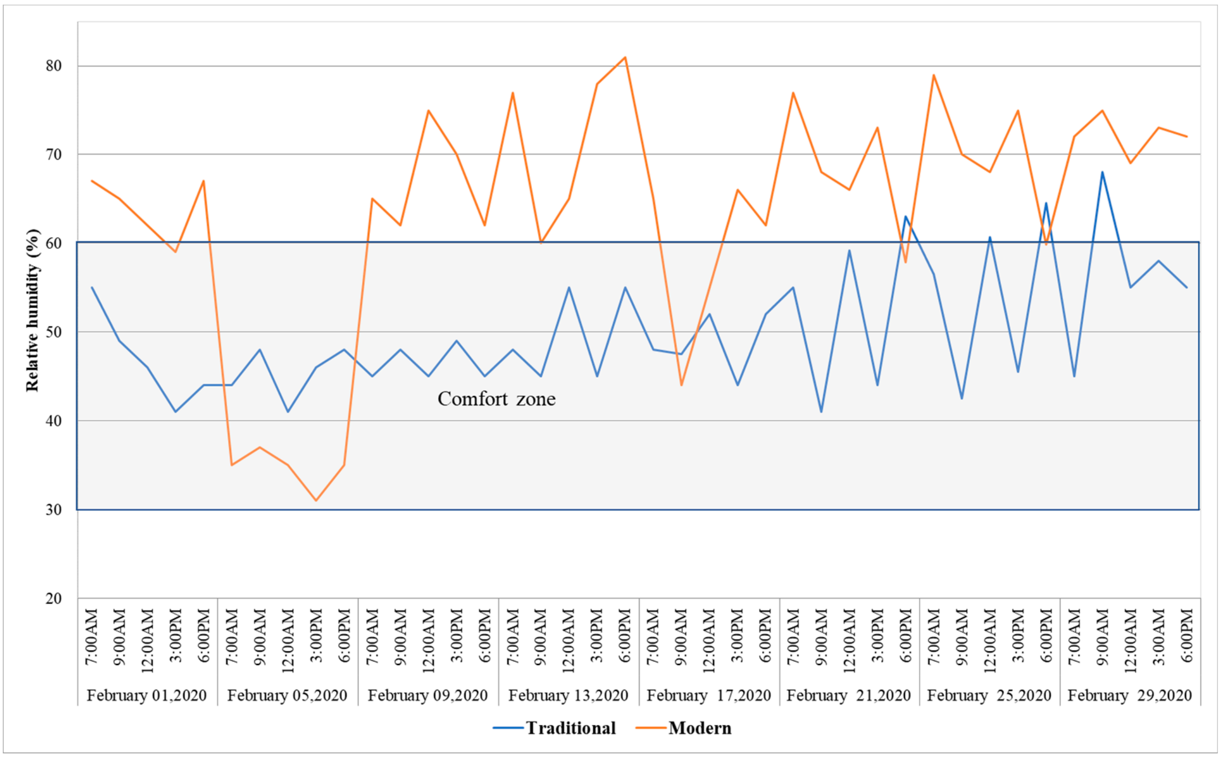

Figure 23. Humidity data from February 2020.

The month of March has a high temperature when compared to February. Based on the adaptive thermal comfort standard, for the month of March, the indoor thermal comfort temperature zones were expanded to 23.7 °C and 30.7 °C (Figure 24). In the case of condominium houses, as shown in Figure 24, 2, 6, 10, and 14 March were not in compliance with the 80% acceptability band of the adaptive comfort standard model. Similarly, in the traditional house, 2, 6, and 10 March were not in compliance with the 80% acceptability band of the adaptive comfort standard model. In comparison to condominium houses, however, the traditional house is preferable because the temperature reported in the traditional house was close to 80% acceptability band of the adaptive comfort standard model and the reading consistency is better than the condominium houses. The uncomfortable states of both types of residencies were due to high temperatures of the environment in the month. However, in addition to the high temperatures during the month, according to information obtained from key informant interviews, discomfort is induced in condominium buildings because the houses were built without taking into account the climatic conditions of the area. This finding is in consistent with that of Akadiri [23], who found that poor design that did not recognize the microclimatic conditions of Nigeria's hot-dry climatic zone was one of the factors that affected the occupants' physiological comfort, mental and physical work ability, health, and leisure.

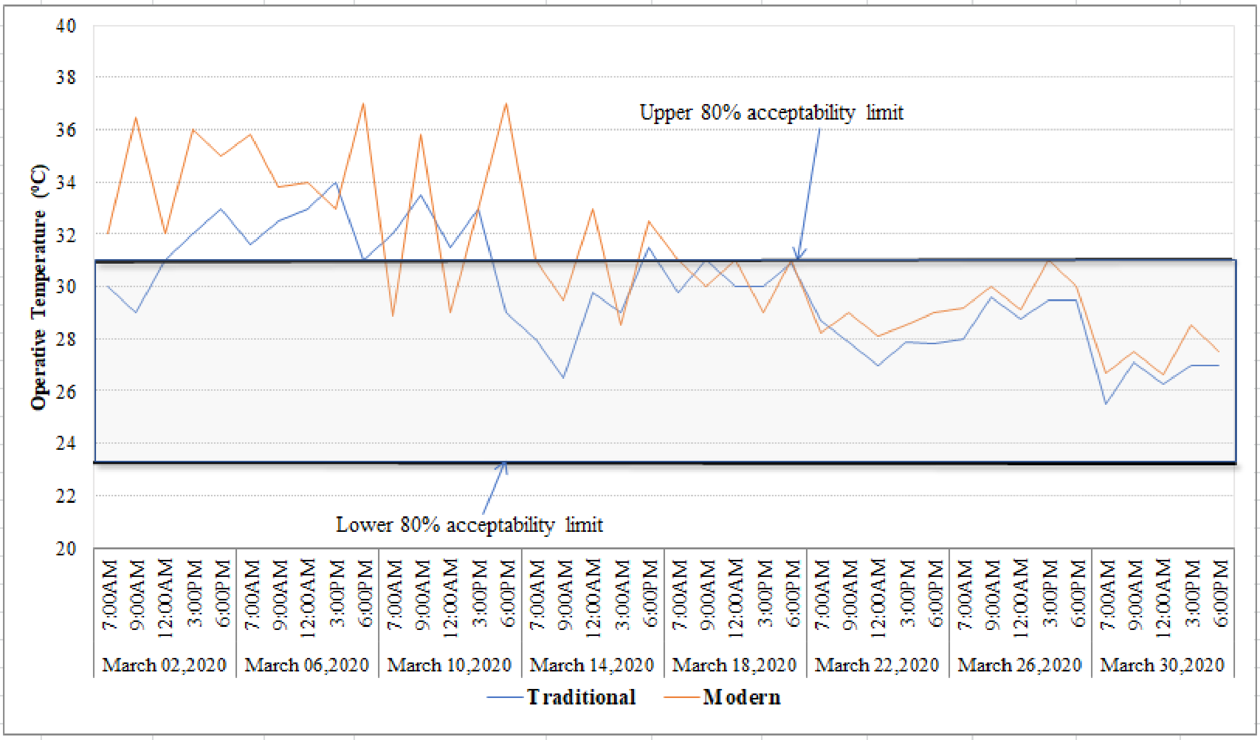

Figure 24. Indoor thermal comfort evaluation from March 2020.

For the month of March, Figure 25 below depicts the relative humidity of a traditional home and a condominium house. The reported humidity indicates that almost all traditional and condominium houses are out of the comfort zone. The range was extremely high in the condominium house with no daily consistency. Excessive indoor humidity in the modern houses results in very little fresh air exchange occurring naturally as most of the windows are non-operable. This causes air in interior rooms to stagnate as humidity from natural living activities including cooking, bathing, and simply breathing accumulate to high levels. Kitchen and bathrooms contribute to the humidity levels inside the modern houses. These rooms do not have exhaust fans sized to remove excess water vapor. Uncomfortable conditions in the houses were exacerbated by bad design solutions, according to information gathered from key informants. According to studies, many residential buildings in developing countries, especially those in tropical regions, are unsuitable for their occupants because a large proportion of them are poorly built for the climate [23,42].

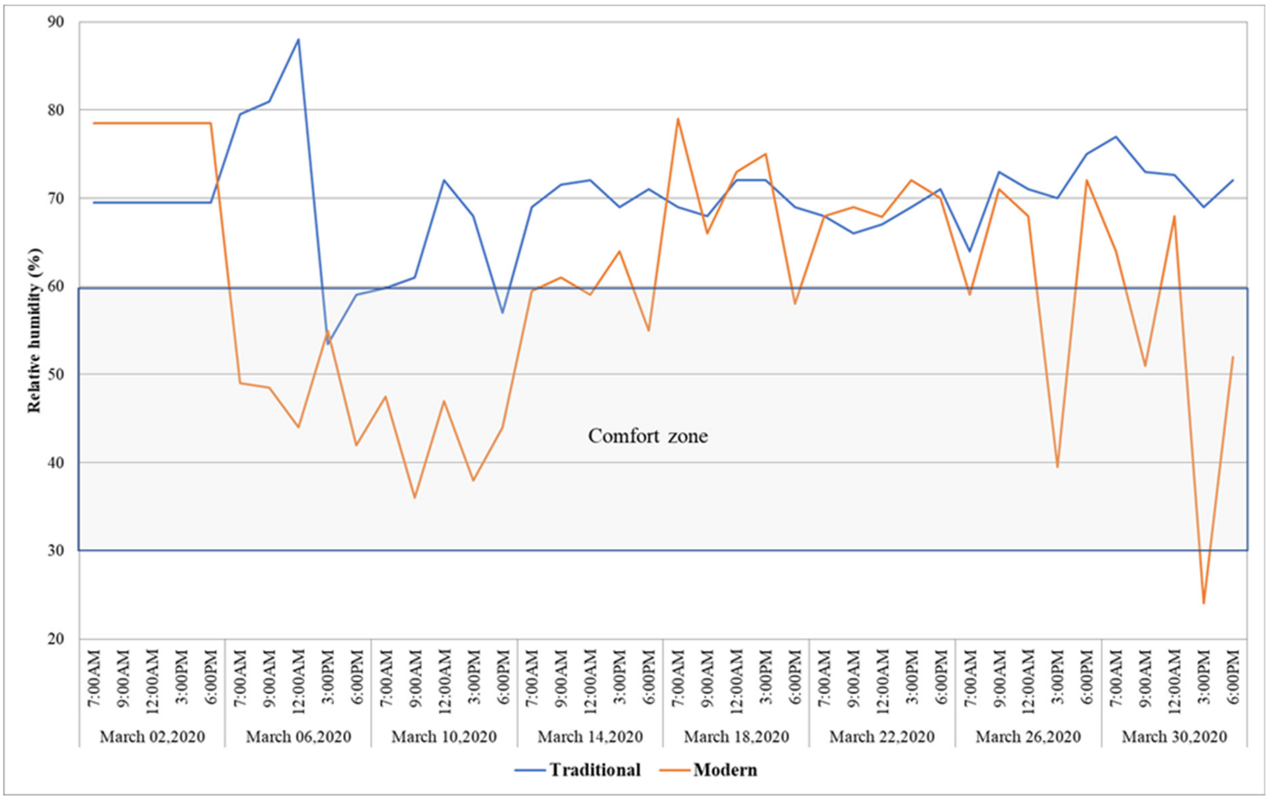

Figure 25. Humidity data from March 2020.

The temperature and relative humidity of the traditional and condominium buildings were also measured for the month of April. Figure 26 illustrates the temperature variations of the traditional house and a condominium house. The adaptive thermal comfort ranges of the 80% acceptability limit were also calculated for both the traditional and modern houses for the month of April. Based on the adaptive thermal comfort standard, for the month of April, the indoor thermal comfort temperature zones were expanded to 31.7 °C and 24.7 °C (Figure 26). Condominium house were compliance with the 80% acceptability band of the adaptive comfort standard model in all the measured days, except at 9 a.m. and 3 p.m. on 8 and 12 April, and at 12 a.m. in 16 April.

The data collected from the traditional house shows that it was in compliance with the 80% acceptability band of the adaptive comfort standard model. The shading, light paint for the exterior walls, high internal space elevation without a ceiling, and local materials (brick, mud, and thatch) contributed to the consistent indoor air temperature. According to studies, applying materials with low thermal conductivity, such as mud, bricks, straw, and sand, significantly reduces heat transfer [71] and promotes a sustainable living environment by reducing thermal stress [65]. According to a study conducted by Sghiouri et al. [72], using clay and straw in a building lowers the indoor temperature by 5 °C on the hottest summer days, lowering overall energy demand by 65% and decreasing the number of uncomfortable hours due to overheating by 25%.

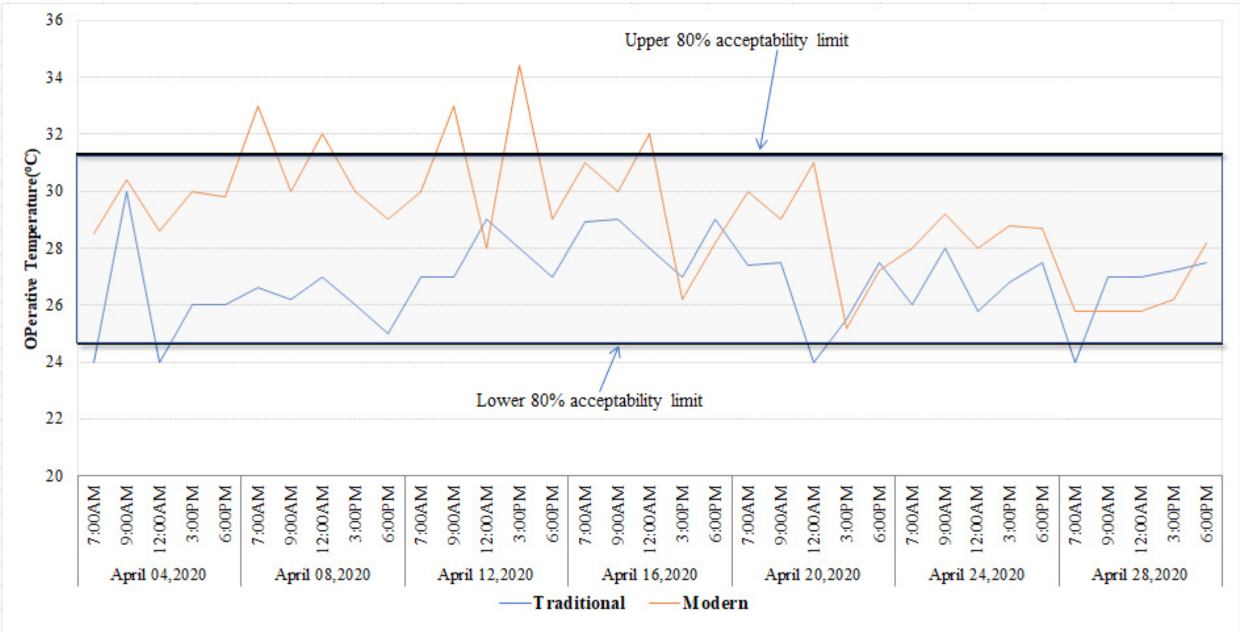

Figure 26. Indoor thermal comfort evaluation from April 2020.

For the month of April, relative humidity (RH) data was also monitored, and the results showed that condominium houses were outside of the ASHRAE thermal comfort range (30 RH–60 RH) except on 08 and 16 April, while traditional houses' readings indicated that all of the reported data are within the range of thermal comfort zone, except on 04 and 24 April (Figure 27).

In general, according to the recorded data from three consecutive months there was a difference in air temperature and relative humidity readings. In the month of February, the traditional house was in compliance with the 80% acceptability band of the adaptive comfort standard model. The condominium house, on the other hand, was partly in compliance with the 80% acceptability band of the adaptive comfort standard model, but in comparison to March and April, the month of February was preferable. A maximum temperature of 32 °C was recorded for the condominium house in the month of March, and a minimum temperature of 22 °C was recorded for the traditional house. In all three months, the traditional house performed better than the condominium house in terms of recorded humidity results. Overall, the traditional house was more in compliance with the 80% acceptability band of the adaptive comfort standard (ACS) model than condominium house.

This finding was also supported by the information obtained from the household survey. According to the findings of the household survey, almost all respondents (92.5%) agreed that the traditional house is more comfortable than the condominium house, 5.6% responded that the comfort levels of both houses are similar, and 1.9% claim that the modern house is more comfortable than the traditional house (Figure 28).

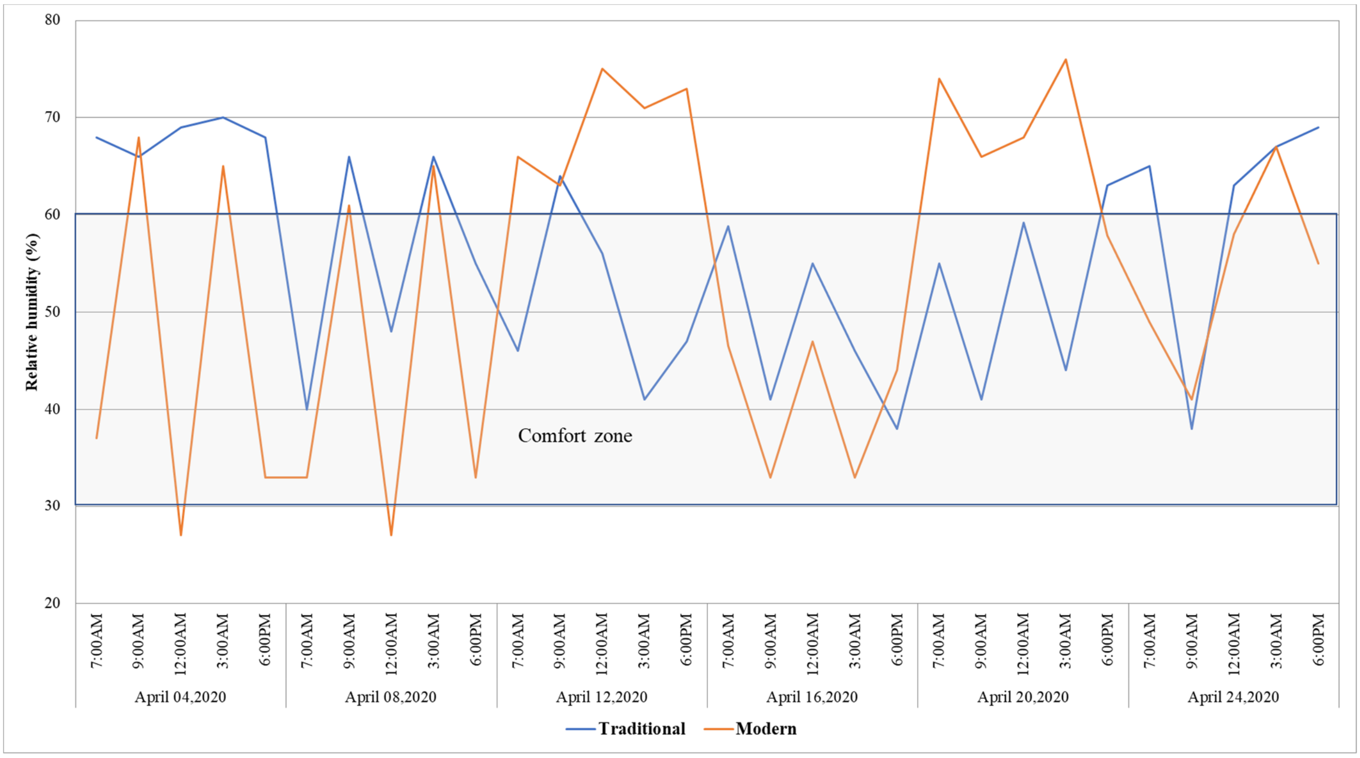

Figure 27. Humidity data from April 2020.

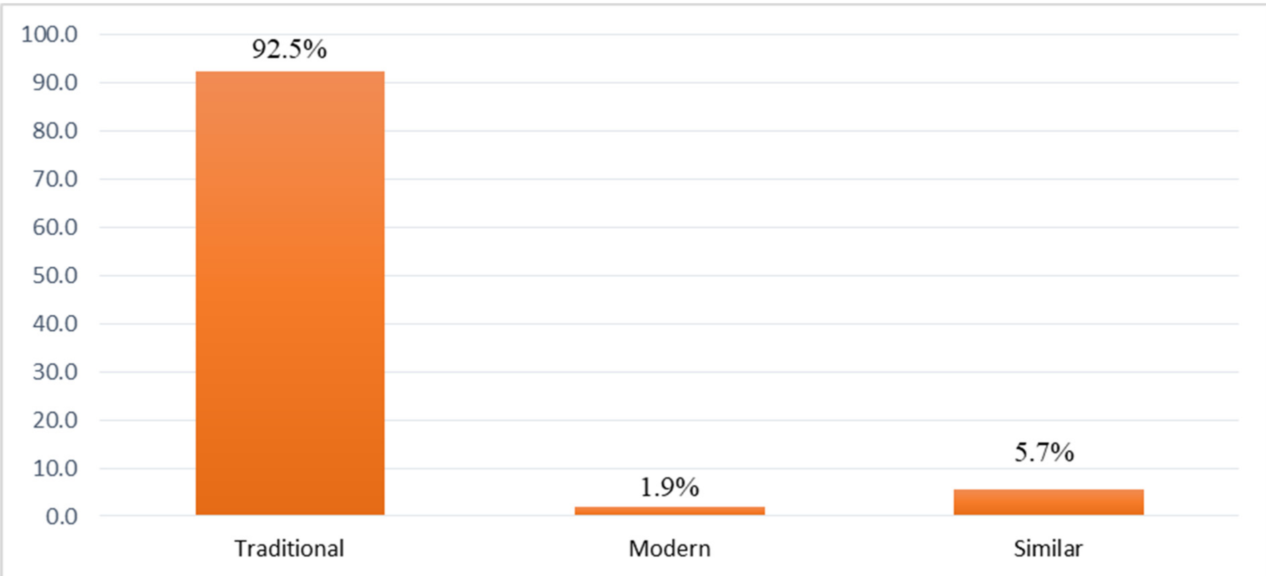

Figure 28. Comparing thermal comfort between traditional and condominium houses.

To gain a better understanding, the participants of the key informant interview were also asked about the indoor thermal comfort of the traditional and condominium houses. The views reflected by most of the participants were more or less similar and can be summarized as follows:

"—condominium houses are completely unsuitable for Semera city, as they are multistory buildings that make it difficult to construct basket shelters. It's also too hot, both during the day and at night. Because of the discomfort, the majority of traditional house dwellers do not want to live in condominiums. Some of them want to sell their unit and develop conventional G + 0 housing instead. The condominium denies the behavior of the people.

> *The majority of condominium dwellers spend most of their time at the basket shelters on the ground, at balconies and corridors and others prefer to spend their time at cafeterias away from their homes".* (Key informant interview, 2020)
>
> *" . . . ..residents of condominium houses used rooms mainly for storing different materials, while cooking, sleeping, and other tasks are performed in the corridor and balconies outside the room due to the discomfort of the room (Figure 29)".* (Key informant interview, 2020)

Figure 29. Beds furnished outdoor for sleep.

4.3. Rationales behind Better Indoor Thermal Comfort in Traditional Houses

Mixtures of internal and external factors affect a building's thermal comfort [73–75]. According to information obtained from key informant interviews, household surveys, and field observations, numerous factors in the study area have led to better indoor thermal comfort in traditional houses. The key factors have been linked to the three potential points mentioned below.

First, construction materials have been identified as the main reason for better indoor thermal comfort. In the city of Semera, traditional houses such as those made with thick brick walls and thatched-roofs are made of materials with a high thermal mass, such as brick, wood, mud, and thatch. Thermal mass plays a crucial role in absorbing heat during the day and returning it at night thus maintaining the environmental conditions in the comfort range [67]. The study conducted by Dincyurek et al. [75] on the vernacular architecture of the hot climatic region of Cyprus revealed that there were 9–11 °C yearly diurnal temperature variations due to the use of special materials with low thermal conductivity, such as mud and limestone in traditional houses, demonstrating the importance of indoor temperature stability for creating a comfort zone. Sand flooring is also common in traditional houses in Semera city, enhancing the use of evaporative cooling. During the hot hours, people spray water on the sand floor. The hot air inside is cooled as the sprayed water evaporates. These types of building materials have been used in various parts of the world. For instance, Folaranmi et al. [76] discovered that using natural earth with a mixture of sand, stone, and water with clay provided traditional houses with a more comfortable indoor temperature during the day while keeping the house warm at night. Singh et al. [70] found that light colors on outside surfaces and local materials with low thermal conductivity, such as wood, bamboo, or palm tree, and stone, mud, and lime, were used in buildings to minimize heat transfer from the outside to the inside. According to a study of the literature in the field of older architecture, such ingenuity, when used in modern buildings, can dramatically increase thermal comfort and energy savings [71].

Secondly, according to the information obtained from the key informant interviews, household surveys, and field observations, openings and the type of windows represent another important factor that contributes to the good indoor thermal comfort of traditional houses. Studies also show that openings play an important role in hot-arid climatic regions [77]. Small, uplifted windows are popular in Semera cities' traditional houses. These small, elevated windows serve as a source of light as well as a means of removing hot air from the ground. For both thick brick houses and thatched roof houses, having two opposite openings per room is a popular technique. It is common for brick houses to have two opposite doors, with the second door drawing cool air from the basket shelter or trees and with the first door removing hot air from the building, a process known as cross ventilation. According to studies, cross ventilation offered indoor thermal comfort 70% of the time [78,79]. For the thatched roof houses there are two opposite and small windows fixed around the top of the wall. Even though these windows are not enough for cross ventilation, they are suitable for removing raised hot air from the room.

Finally, construction techniques have also been identified as a key factor that has resulted in improved indoor thermal comfort in the traditional houses of Semera city. The attachment of a big tree or a straw shelter which is modified to a bamboo basket shelter is a very common and significant strategy used by traditional houses in Semera city to regulate the indoor environment. This shelter feeds cooler air to the houses. The thick brick houses are attached to shelters by their second door and to trees at the main door. The thatched roof houses are attached to shelters or trees to their front. These basket shelters are followed trees wide enough to treat the hot air. According to studies, tree and shrub plantation plays an important role in defining wind flow and achieving mutual shading on buildings and hard paving [80,81].

Traditional houses also have a high internal space elevation up to 4m without a ceiling, which is an important construction technique. This high internal elevation allows hot air to rise from the bottom of the room to the upper sphere, allowing those on the ground to enjoy the cooler air. Reduced ceiling heights produce a small increase in indoor temperature for the majority of the year in areas with hot weather, such as in tropical countries [82,83]. In the traditional houses of Semera city there is small link between the roof and the wall, which reduces heat transfer from the roof to the wall during the day. These roofs provide not only protection for the interior space, but also shade for the walls from the harshest heat. According to study, a building's roof plays an important role in providing shade and protection from direct solar radiation [40].

4.4. Implications for Designing Thermally Comfortable Residential Buildings in Hot-Arid Climatic Regions of Ethiopia

Based on insights gained from the literature review, stakeholders' interviews, and field observations, the following recommendations are made to improve indoor environmental conditions of buildings by adapting some important benefits from traditional houses, such as important skills, constriction techniques, and materials. Hence, the following design strategies should be considered for designing thermally comfortable residential buildings in hot-arid climatic regions of Ethiopia:

Proper Building Orientation: The results of key informant interviews and field observations revealed that in the majority of houses in Ethiopia's hot-arid climatic zone, such as Semera city, proper orientation is not given due consideration. However, buildings that are properly oriented have a significant advantage in promoting better indoor thermal comfort [58]. Due to the relationship of building orientation to natural ventilation, orientation should be considered with respect to the sun to reduce facades facing east and west and to accept local prevailing winds [67]. Hence, building orientation in Ethiopia's hot-arid climate region should emphasize solar gain reduction and natural ventilation promotion. This can be achieved using elongated forms along the east-west direction with the main openings facing north and south. According to a study conducted by Wong and Li [84], a residential cooling load can be decreased by 8 to 11% through adopting an east-west orientation.

Proper Openings: According to the finding of the study, the size and location of openings have an impact on the houses' indoor thermal comfort. It is estimated that 40% of the unwanted heat that builds up in a building is gained through openings [85]. Openings play a significant role in the interaction between outdoor and indoor air, which impacts on energy use, indoor air quality, and thermal performance [86]. Mochida et al. [87] claim that a comfortable indoor thermal environment can be achieved by controlling window openings. Therefore, since Ethiopia's hot-arid climatic area experiences high temperatures, large openings on the north and south facing facades should be placed away from direct sunlight and shaded by roof overhangs, verandas, or horizontal shading devices, and openings on the east and particularly west facing walls should be avoided or restricted to a minimum to reduce heat gain as much as possible. Furthermore, high- and low-level openings should be created in walls bordering courtyards to facilitate air movement, and small openings in perimeter walls are needed for cross ventilation to provide better thermal comfort in houses built in the hot-arid climatic regions of Ethiopia, as practiced in the traditional houses of Semera city. The size of windows in the old thatch roof houses and old thick brick houses of Semera city is small (1.7 m) creating an impact on providing acceptable daylight conditions in the rooms. Therefore, to improve the daylight in the rooms, windows should be at least 10% of a room's floor area, with at least 5% that can be opened for ventilation. The space depth should ideally not exceed 2.5 times the window head height (when there are no shading devices) and 2 times the window head height (when shading devices are used).

Encourage Natural Ventilation: According to the findings of the study, residents of hot-arid climatic regions of the country, such as Semera city, were uncomfortable due to the intense heat. As a result, effective ventilation and an internal temperature below the outside level are critical for buildings. Natural ventilation keeps the air moving within the indoor environment and, therefore, keeps the inhabitants cooler even without the use of energy [88]. Wong and Huang [89] conducted a comparison study on the indoor air quality of naturally ventilated and air-conditioned bedrooms in Singapore residential buildings. They discovered that air-conditioned bedrooms are often overcooled, resulting in a high level of dissatisfaction among users. In naturally ventilated bedrooms, however, the use of fans was enough to achieve the desired thermal comfort. Hence, in order to create a more comfortable indoor atmosphere in Ethiopia's hot-arid climatic zone, buildings should have operable windows to allow natural ventilation, and buildings should have natural ventilation provisions that are either horizontal (cross ventilation) or vertical (ventilation) (stack effect). According to the research, single side window openings can ventilate a space up to a depth of 6 to 7 m [90], whereas cross ventilation can ventilate a space up to a depth of 15 m [49].

Building Materials: Building materials play an important role in sustainable design, both in terms of thermal performance and environmental impact [91]. According to the findings of the study, traditional construction materials are still used in houses found in hot-arid climatic regions of Ethiopia such as Semera city, to regulate the indoor environment. According to Gezer [92], buildings constructed with vernacular materials perform better in terms of providing the desired thermal comfort while lowering energy costs. However, certain traditional building materials are no longer compatible with modern construction technologies; however, their advantages can be considered by combining modern and traditional materials in the construction of various building elements [93]. Hence, in order to provide sustainable residential buildings in Ethiopia's hot-arid climatic region, it is critical to use locally available materials and technologies, particularly renewable organic materials such as timber, trees, and bamboo, as well as materials with a high thermal mass such as brick, wood, mud, and thatch, which are also practiced in the traditional houses in Semera city.

Encourage greenery practices: Vegetation has the potential to alter the microclimate of a place and therefore it should be incorporated in design. According to Akande [48], when buildings in hot climates are surrounded by vegetated windows, they gain a natural freshness that protects them from the sun's ray. The benefits of trees and plants are acknowledged by Raeissi and Taheri [94]. According to them, tree planting can lead to changes in temperature and relative humidity, as well as psychological benefits for humans. As per their findings, adequate tree planting will reduce cooling loads of a house by 10% to 40%. Greenery practices are very poor in Ethiopia's hot-arid climatic regions, such as in Semera city. To establish pleasant indoor and outdoor environments in the country's hot-arid climatic regions, the planting of indigenous/native plants that are adaptable to the local climate as well as to other conditions such as native soils, pest problems, and seasonal droughts is crucial. It is also critical to plant trees on the east and west orientations to provide shade.

5. Conclusions

The indoor thermal comfort of condominium houses built by the government and traditional (vernacular) houses built by the indigenous Semera peoples 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, traditional house occupants have a strong sensational scale level, a good preference for their dwellings, and a high level of satisfaction with the indoor thermal comfort. However, residents of condominium houses faced major challenges in terms of thermal sensation, preference, and comfort, and some residents wished to return to a traditional home.

The average indoor temperature in condominium houses was higher than the indoor temperature of traditional houses with the same outdoor temperature, according to the study's findings.

Based on the results of the study, the traditional houses were more compliant with the 80% acceptability band of the adaptive comfort standard (ACS) model in comparison to the condominium houses. Poor design in relation to the microclimate, poor natural ventilation, and the use of non-local building materials such as concrete in the condominium houses has resulted in high indoor temperatures. However, traditional houses regulate the indoor air environment using locally available material and through proper openings and orientation. In order to encourage sustainable residential buildings with respect to indoor thermal comfort in the hot-arid climatic regions of the country, proper building orientation, appropriate openings, appropriate selection of building materials by taking the microclimate condition of the region into account, the promotion of greenery practices, adequate natural ventilation, and the application of certain design elements that can provide natural cooling are urgently needed.

The findings are hoped to contribute to a better understanding of the present situation of indoor thermal comfort in traditional and condominium houses in hot-arid climatic region of the country. Due to scant literature, the findings from this research have wider applicability to hot-arid climatic regions in sub-Saharan Africa. Moreover, the findings will inform building professionals and architects about how to consider different strategies to provide sustainable buildings within different climatic zones.

Finally, the study has attempted to compare the indoor thermal comforts of traditional houses with respect to condominium houses. 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 should 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. Therefore, this study will recommend that futures studies use the longitudinal survey method to conduct a large number of comfort assessments. It should be noted that the results of this study are based on the data captured in condominium houses built by the Government. The results and conclusions drawn from this study, therefore, may not be applicable to modern buildings constructed by private developers. Therefore, it is also suggested that there is a need for more comparative case studies on modern and traditional buildings. Such studies would significantly advance our understanding of how to promote sustainable residential building with respect to thermal comfort in the hot-arid climatic regions of Ethiopia in particular and more widely in sub-Saharan Africa.

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References

1. Arif, M.; Katafygiotou, M.; Mazroei, A.; Kaushik, A.; Elsarrag, E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *Int. J. Sustain. Built Environ.* **2016**, *5*, 1–11. [CrossRef]
2. Ragheb, A.A.; El-Darwish, I.I.; Ahmed, S. Microclimate and human comfort considerations in planning a historic urban quarter. *Int. J. Sustain. Built Environ.* **2016**, *5*, 156–167. [CrossRef]
3. Samuel, D.L.; Dharmasastha, K.; Nagendra, S.S.; Maiya, M.P. Thermal comfort in traditional buildings composed of local and modern construction materials. *Int. J. Sustain. Built Environ.* **2017**, *6*, 463–475. [CrossRef]
4. Akande, O.K.; Adebamowo, M.A. Indoor thermal comfort for residential buildings in hot-dry climate of Nigeria. In Proceedings of the Conference: Adapting to Change: New Thinking on Comfort, Cumberland Lodge, Windsor, UK, 9–11 April 2010; Volume 911, pp. 133–144.
5. Ashrae, A. Thermal environmental conditions for human occupancy. In *ANSI/ASHRAE Standard 55*; American Society of Heating, Refrigerating and Air Conditioning Engineers: Atlanta, GA, USA, 2017.
6. Toy, S.; Kántor, N. Evaluation of human thermal comfort ranges in urban climate of winter cities on the example of Erzurum city. *Environ. Sci. Pollut. Res.* **2017**, *24*, 1811–1820. [CrossRef]
7. Haruna, A.C.; Muhammad, U.D.; Oraegbune, O.M. Analysis of indoor thermal comfort perception of building occupants in Jimeta, Nigeria. *Civ. Environ. Res.* **2018**, *10*, 11–20.
8. Fanger, P.O. *Thermal Comfort—Analysis and Application in Environmental Engineering*; Danish Technical Press: Copenhagen, Denmark, 1970.
9. Ormandy, D.; Ezratty, V. Thermal discomfort and health: Protecting the susceptible from excess cold and excess heat in housing. *Adv. Build. Energy Res.* **2016**, *10*, 84–98. [CrossRef]
10. Havenith, G.; Holmér, I.; Parsons, K. Personal factors in thermal comfort assessment: Clothing properties and metabolic heat production. *Energy Build.* **2002**, *34*, 581–591. [CrossRef]
11. Hamzah, B.; Gou, Z.; Mulyadi, R.; Amin, S. Thermal comfort analyses of secondary school students in the tropics. *Buildings* **2018**, *8*, 56. [CrossRef]
12. Mahar, W.A.; Amer, M.; Attia, S. Indoor thermal comfort assessment of residential building stock in Quetta, Pakistan. In *European Network for Housing Research (ENHR) Annual Conference 2018*; Uppsala University: Uppsala, Sweden, 2018.
13. Jindal, A. Thermal comfort study in naturally ventilated school classrooms in composite climate of India. *Build. Environ.* **2018**, *142*, 34–46. [CrossRef]
14. Dear, R.J.D.; Brager, G.S. Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. *Energy Build.* **2002**, *34*, 549–561. [CrossRef]
15. Nicol, F. Adaptive thermal comfort standards in the hot–humid tropics. *Energy Build.* **2004**, *36*, 628–637. [CrossRef]
16. Nicol, J.F.; Humphreys, M.A. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy Build.* **2002**, *34*, 563–572. [CrossRef]
17. Fanger, P.O.; Toftum, J. Extension of PMV model to non-air-conditioned buildings in warm climates. *Energy Build.* **2002**, *36*, 533–536. [CrossRef]
18. Ariffin, N.A.M.; Behaz, A.; Denan, Z. Thermal Comfort Studies on Houses in Hot Arid Climates. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2018; Volume 401, p. 012028.
19. Abbaszadeh, S.; Zagreus, L.; Lehrer, D.; Huizenga, C. Occupant Satisfaction with Indoor Environmental Quality in Green Buildings. Ph.D. Thesis, UC Berkeley, Berkeley, CA, USA, 2006.

20. Yadeta, C.; Tucho, G.T.; Tadesse, E.; Alemayehu, E. Human Thermal Comfort and Its Analysis by Computational Fluid Dynamics for Naturally Ventilated Residential Buildings of Jimma Town, South West Ethiopia. *Ethiop. J. Educ. Sci.* **2019**, *15*, 102–115.
21. Dovjak, M.; Shukuya, M.; Krainer, A. Exergetic issues of thermoregulation physiology in different climates. *Int. J. Exergy* **2015**, *17*, 412–432.
22. Djongyang, N.; Tchinda, R.; Njomo, D. Thermal comfort: A review paper. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2626–2640. [CrossRef]
23. Akadiri, P.O. Evaluating the Performance of Bioclimatic Design Building in Nigeria. *Civ. Environ. Res.* **2016**, *8*, 60–66.
24. Khoshbakht, M.; Gou, Z.; Lu, Y.; Xie, X.; Zhang, J. Are green buildings more satisfactory? A review of global evidence. *Habitat Int.* **2018**, *74*, 57–65. [CrossRef]
25. Aigbavboa, C.; Thwala, W.D. Performance of a green building's indoor environmental quality on building occupants in South Africa. *J. Green Build.* **2019**, *14*, 131–148. [CrossRef]
26. Latha, P.K.; Darshana, Y.; Venugopal, V. Role of building material in thermal comfort in tropical climates—A review. *J. Build. Eng.* **2015**, *3*, 104–113. [CrossRef]
27. Radivojević, A.; Đukanović, L. Material Aspect of Energy Performance and Thermal Comfort in Buildings. *Energy Resour. Build. Perform.* **2018**, 61–86. Available online: https://raf.arh.bg.ac.rs/handle/123456789/824 (accessed on 17 November 2020).
28. Pathirana, S.; Rodrigo, A.; Halwatura, R. Effect of building shape, orientation, window to wall ratios and zones on energy efficiency and thermal comfort of naturally ventilated houses in tropical climate. *Int. J. Energy Environ. Eng.* **2019**, *10*, 107–120. [CrossRef]
29. Heerwagen, D. *Passive and Active Environmental Controls: Informing the Schematic Designing of Buildings*, 1st ed.; McGraw Hill: New York, NY, USA, 2004.
30. Lauber, W. *Tropical Architecture*, 1st ed.; Prestel: Munich, Germany, 2005; pp. 42–65.
31. Simons, B.; Koranteng, C.; Woanyah-Deladem, S. Thermal comfort evaluation of high-rise buildings in Accra, Ghana. *Adv. Appl. Sci. Res.* **2012**, *3*, 5002–5507.
32. Guedes, M.C.; Matias, L.; Santos, C.P. Thermal comfort criteria and building design: Field work in Portugal. *Renew. Energy* **2009**, *34*, 2357–2361. [CrossRef]
33. de Dear, R.J.; Brager, G.S. Developing an adaptive model of thermal comfort and preference. *ASHRAE Trans.* **1998**, *104 Pt 1A*, 145–167.
34. Nielsen, L.S. Building Integrated System Design for Sustainable Heating and Cooling. *Rehva J.* **2012**, 24–27. Available online: https://www.rehva.eu/fileadmin/hvac-dictio/01-2012/02-2012/building-integrated-system-design-for-sustainable-heating-and-cooling.pdf (accessed on 18 February 2021).
35. Xu, X.; Wang, S.; Wang, J.; Xiao, F. Active pipe-embedded structures in buildings for utilizing low-grade energy sources: A review. *Energy Build.* **2010**, *42*, 1567–1581. [CrossRef]
36. Manzano-Agugliaro, F.; Montoya, F.G.; Sabio-Ortega, A.; García-Cruz, A. Review of bioclimatic architecture strategies for achieving thermal comfort. *Renew. Sustain. Energy Rev.* **2015**, *49*, 736–755. [CrossRef]
37. Freewan, A.A. Advances in Passive Cooling Design: An Integrated Design Approach. In *Zero and Net Zero Energy*; Intech Open: London, UK, 2019.
38. Dili, A.S.; Naseer, M.A.; Varghese, T.Z. Thermal comfort study of Kerala traditional residential buildings based on questionnaire survey among occupants of traditional and modern buildings. *Energy Build.* **2010**, *42*, 2139–2150. [CrossRef]
39. Nematchoua, M.K.; Tchinda, R.; Orosa, J.A. Thermal comfort and energy consumption in modern versus traditional buildings in Cameroon: A questionnaire-based statistical study. *Appl. Energy* **2014**, *114*, 687–699. [CrossRef]
40. Karyono, T.H. Report on thermal comfort and building energy studies in Jarkata, Indonesia. *Build. Energy J.* **2000**, *35*, 77–90. [CrossRef]
41. Fernandes, J.; Pimenta, C.; Mateus, R.; Silva, S.M.; Bragança, L. Contribution of portuguese older building strategies to indoor thermal comfort and occupants' perception. *Buildings* **2015**, *5*, 1242–1264. [CrossRef]
42. Ali, N.; Taki, A.; Painter, B. Comparative study of traditional and contemporary Islamic dwelling design: The case of Benghazi, Libya. *Glob. Dwell. Approach. Sustain. Des. Particip.* **2020**, *193*, 39.
43. Gutierrez, E.S.; Murtagh, V.; Crété, E. Detailed shelter response profile Ethiopia: Local building cultures for sustainable and resilient habitats. *Villefontaine* **2018**, *60*, 2018.
44. Cena, K.; De Dear, R. Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate. *J. Therm. Biol.* **2001**, *26*, 409–414. [CrossRef]
45. Nicol, J.F. An analysis of some observations of thermal comfort in Roorkee, India and Baghdad, Iraq. *Ann. Hum. Biol.* **1974**, *1*, 411–426. [CrossRef]
46. Humphreys, M.A.; Nicol, J.F. An investigation into thermal comfort of office workers £. *lnst. Heat. Vent. Eng.* **1970**, *38*, 181–189.
47. Mamo, G.; Abebe, F.; Worku, Y.; Hussein, N. Bovine tuberculosis and its associated risk factors in pastoral and agro-pastoral cattle herds of Afar Region, Northeast Ethiopia. *J. Vet. Med. Anim. Health* **2013**, *5*, 171–179. [CrossRef]
48. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World Map of the Ko¨ ppen-Geiger climate classification. *Meteorol. Z.* **2006**, *15*, 259–263. [CrossRef]
49. Laskari, M.; Carducci, F.; Isidori, D.; Senzacqua, M.; Standardi, L.; Cristalli, C. Objective and subjective evaluation of thermal comfort in the Loccioni Leaf Lab. *Energy Procedia* **2017**, *134*, 645–653. [CrossRef]

50. Zhao, Q.; Lian, Z.; Lai, D. Thermal Comfort models and their developments: A review. *Energy Built Environ.* **2020**, *2*, 21–33. [CrossRef]
51. Nicol, F.; Humphreys, M.; Roaf, S. *Adaptive Thermal Comfort: Principles and Practice*; Routledge: London, UK, 2012.
52. Kish, L. *Survey Sampling (No. 04; HN29, K5.)*; John Wiley & Sons, Inc.: New York, NY, USA, 1965.
53. Grove, S.K.; Burns, N.; Gray, J.R. *The Practice of Nursing Research: Appraisal, Synthesis and Generation of Evidence*, 7th ed.; Elsevier Saunders: Amsterdam, The Netherlands, 2013.
54. Maarof, S.; Jones, P. Thermal Comfort Factors in Hot and Humid Region: Malaysia. 2009. Available online: https://www.irbnet.de/daten/iconda/CIB14241.pdf (accessed on 18 February 2021).
55. Humphreys, M.A. Why did the piggy bark? In some effects of language and context on the interpretation of words used in scales of warmth and thermal preference. In Proceedings of the Conference: Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, UK, 27–29 July 2008; pp. 27–29.
56. Andamon, M.M.; Williamson, T.J.; Soebarto, V.I. Perceptions and expectations of thermal comfort in the Philippines. In Proceedings of the Conference on Comfort and Energy Use in Buildings: Getting Them Right, Windsor, UK, 27–30 April 2006.
57. Version, D. Challenging the assumptions for thermal sensation scales. *Build. Res. Inf.* **2016**, *45*, 572–589. [CrossRef]
58. Albatayneh, A.; Alterman, D.; Page, A.; Moghtaderi, B. The significance of the orientation on the overall buildings thermal performance-case study in Australia. *Energy Procedia* **2018**, *152*, 372–377. [CrossRef]
59. Alfano, F.R.D.A.; Olesen, B.W.; Palella, B.I. Povl Ole Fanger's impact ten years later. *Energy Build.* **2017**, *152*, 243–249. [CrossRef]
60. De Vecchi, R.; Sorgato, M.J.; Pacheco, M.; Cândido, C.; Lamberts, R. ASHRAE 55 adaptive model application in hot and humid climates: The Brazilian case. *Archit. Sci. Rev.* **2015**, *58*, 93–101. [CrossRef]
61. Mousli, K.; Semprini, G. Thermal performances of traditional houses in dry hot arid climate and the effect of natural ventilation on thermal comfort: A case study in Damascus. *Energy Procedia* **2015**, *78*, 2893–2898. [CrossRef]
62. Yao, R.; Costanzo, V.; Li, X.; Zhang, Q.; Li, B. The effect of passive measures on thermal comfort and energy conservation. A case study of the hot summer and cold winter climate in the Yangtze River region. *J. Build. Eng.* **2008**, *15*, 298–310. [CrossRef]
63. Ali, H.H.; Al-Hashlamun, R. Assessment of indoor thermal environment in different prototypical school buildings in Jordan. *Alex. Eng. J.* **2019**, *58*, 699–711. [CrossRef]
64. Hashemi, R.L.; Heidari, S. Evaluating adaptive thermal comfort in residential buildings in hot-arid climates Case study: Kerman province. *J. Arch. Hot Dry Clim.* **2018**, *6*, 43–65. [CrossRef]
65. Almusaed, A.; Almssad, A.; Homod, R.Z.; Yitmen, I. Environmental profile on building material passports for hot climates. *Sustainability* **2020**, *12*, 3720. [CrossRef]
66. Akande, O.K. Passive design strategies for residential buildings in a hot dry climate in Nigeria. *WIT Trans. Ecol. Environ.* **2010**, *128*, 61–71.
67. UN-Habitat. *Sustainable Building Design for Tropical Climates: Principles and Applications for Eastern Africa [Online]*; UN-Habitat: Nairobi, Kenya, 2015.
68. Fernandes, J.E.P.; Debaieh, M.; Mateus, R.; Silva, S.M.; Bragança, L.; Gervásio, H. *Thermal Performance and Comfort of Older Earthen Buildings in Egypt and Portugal*; 3rd Restapia, 3rd Versus; CRC Press: Sostierra, Portugal, 2017; pp. 95–100.
69. Parsons, K. *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance*; CRC Press: Boca Raton, FL, USA, 2014.
70. Singh, M.K.; Mahapatra, S.; Atreya, S.K. Thermal performance study and evaluation of comfort temperatures in older buildings of North-East India. *Build. Environ.* **2010**, *45*, 320–329. [CrossRef]
71. Shaeri, J.; Yaghoubi, M.; Aflaki, A.; Habibi, A. Evaluation of thermal comfort in traditional houses in a tropical climate. *Buildings* **2018**, *8*, 126. [CrossRef]
72. Sghiouri, H.; Charai, M.; Mezrhab, A.; Karkri, M. Comparison of passive cooling techniques in reducing overheating of the clay-straw building in semi-arid climate. *Build. Simul.* **2020**, *13*, 65–88. [CrossRef]
73. Prakash, D.; Ravikumar, P. Analysis of Thermal Comfort and Indoor Air Flow Characteristics for a Residential Building Room under Generalized Window Opening Position at the Adjacent Walls. *Int. J. Sustain. Built Environ.* **2015**, *4*, 42–57. [CrossRef]
74. Deng, X.; Paul, C.; Zhenjun, M.; Georgios, K. Numerical Analysis of Indoor Thermal Comfort in a Cross-Ventilated Space with Top-Hung Windows. *Energy Procedia* **2017**, *121*, 222–229. [CrossRef]
75. Tan, Z.; Xiang, D. Assessment of Natural Ventilation Potential for Residential Buildings across Different Climate Zones in Australia. *Atmosphere* **2017**, *8*, 177. [CrossRef]
76. Dincyurek, O.; Mallick, F.H.; Numan, I. Cultural and environmental values in the arcaded Mesaorian houses of Cyprus. *Build. Environ.* **2003**, *38*, 1463–1473. [CrossRef]
77. Folaranmi, A.O.; Philip, A.; Stephen, O.; Amina, B. Bioclimatic Design Principle a Solution to Thermal Discomfort in Minna Residences, Niger State Nigeria. *J. Environ. Earth Sci.* **2013**, *3*, 45–51.
78. Boukhris, Y.; Gharbi, L.; Ghrab-Morcos, N. Influence of night natural ventilation on Tunisian summer thermal comfort. In Proceedings of the 2014 5th International Renewable Energy Congress (IREC), Hammamet, Tunisia, 25–27 March 2014; pp. 1–5.
79. Omrani, S.; Garcia-Hansen, V.; Capra, B.R.; Drogemuller, R. Effect of natural ventilation mode on thermal comfort and ventilation performance: Full-scale measurement. *Energy Build.* **2017**, *156*, 1–16. [CrossRef]
80. Coutts, A.M.; White, E.C.; Tapper, N.J.; Beringer, J.; Livesley, S.J. Temperature and human thermal comfort effects of street trees across three contrasting street canyon environments. *Theor. Appl. Climatol.* **2016**, *124*, 55–68. [CrossRef]

81. Nasir, R.A.; Ahmad, S.S.; Zain-Ahmed, A.; Ibrahim, N. The Role of Tree Shades for Adaptive Thermal Comfort. *Asian J. Behav. Stud.* **2018**, *3*, 179–189. [CrossRef]
82. Huang, C.; Zou, Z.; Li, M.; Wang, X.; Li, W.; Huang, W.; Xiao, X. Measurements of indoor thermal environment and energy analysis in a large space building in typical seasons. *Build. Environ.* **2007**, *42*, 1869–1877. [CrossRef]
83. Guimaraes, R.P.; Carvalho, M.C.R.; Santos, F.A. The influence of ceiling height in thermal comfort of buildings: A case study in belo horizonte, Brazil. *Int. J. Hous. Sci.* **2013**, *37*, 75–86.
84. Wong, N.H.; Li, S. A Study of the Effectiveness of Passive Climate Control in Naturally Ventilated Residential Buildings in Singapore. *Build. Environ.* **2007**, *42*, 1395–1405. [CrossRef]
85. Taleb, H.M. Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in UAE buildings. *Front. Archit. Res.* **2014**, *3*, 154–165. [CrossRef]
86. Yao, M.; Zhao, B. Window opening behaviour of occupants in residential buildings in Beijing. *Build. Environ.* **2017**, *124*, 441–449. [CrossRef]
87. Mochida, A.; Yoshino, H.; Takeda, T.; Kakegawa, T.; Miyauchi, S. Methods for controlling airflow in and around a building under cross-ventilation to improve indoor thermal comfort. *J. Wind Eng. Ind. Aerodyn.* **2005**, *93*, 437–449. [CrossRef]
88. Hernández, S. *Eco-Architecture III: Harmonisation Between Architecture and Nature*; WIT Press: Southampton, UK, 2010; Volume 128.
89. Wong, N.K.; Huang, B. Comparative Study of the Indoor Air Quality of Naturally Ventilated and Air-Conditioned Bedrooms of Residential Buildings in Singapore. *Build. Environ.* **2004**, *39*, 1115–1123. [CrossRef]
90. Hamdani, M.; Bekkouche, S.M.A.; Benouaz, T.; Cherier, M.K. Study of Natural Ventilation through Openings on Buildings under Saharan Climatic Conditions. *Int. J. Appl. Environ. Sci.* **2018**, *13*, 39–57.
91. Utama, A.; Gheewala, S. Influence of material selection on energy demand in residential houses. *Mater. Des.* **2009**, *30*, 2173–2180. [CrossRef]
92. Gezer, N.A. The effects of construction materials on thermal comfort in residential buildings: An analysis using Ecotect 5.0. Ph.D. Thesis, METU, Ankara, Çankaya, 2003.
93. Soflaei, F.; Shokouhian, M.; Mofidi Shemirani, S. Traditional Iranian courtyards as microclimate modifiers by considering orientation, dimensions, and proportions. *Front. Archit. Res.* **2016**, *5*, 225–238. [CrossRef]
94. Raeissi, S.; Taheri, M. Energy Saving by Proper Tree Plantation. *Build. Environ.* **1999**, *34*, 565–570. [CrossRef]