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Transformation of Vernacular Housing and its Effects on Indoor Thermal Comfort:
A Case Study in a Tropical Coastal Village in Kenya

***Richard Njoroge Kariuki, Stephen Diang'a, Francis Gachari and Victoria Okumu**

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Abstract

A study at the tropical coast of Kenya was undertaken in March, May and July 2024 to assess the effect of transformation of building envelop design of vernacular dwelling houses on the indoor thermal comfort. In three case study houses in Kilifi County, indoor air temperature, relative humidity, mean radiant temperature and air speed measures were taken using data loggers. The rectangular house type with mud walls and palm leaf thatch roof was found to have the lowest thermal discomfort with a daily mean of 3.0°CHrs. The preceding traditional rounded oblong shaped house of grass thatch covering and the subsequent contemporary brick wall and metal sheet roof had higher mean thermal discomfort levels of 8.2°CHrs and 7.5°CHrs, respectively. Using linear correlation between indoor operative temperature and outside air temperature, thermal discomfort levels were predicted for the whole year and in the future considering climate change. Indoor thermal discomfort was predicted to increase by up to 90 % when surface air temperatures increase by 1°C. It is recommended that as vernacular houses undergo building envelop design transformation, vaulted insulated ceilings and high-level permanent vents be used to reduce indoor thermal discomfort.

Keywords: Building envelop, Mijikenda, thermal comfort, tropical humid climate, vernacular buildings

INTRODUCTION

Vernacular building has been described as the fundamental expression of the culture of a community (ICOMOS, 2002) as well as a result of interaction with the natural physical factors such as availability of natural materials and climate (Asadpour, 2020). Control of indoor thermal conditions by passive means is recommended for energy conservation, reduction in carbon emission, human comfort, health and wellbeing (Šujanová et al., 2019). The building features that have been shown to have significant impact on indoor thermal comfort are the thermo physical properties of envelop materials such as thermal transmittance, thermal mass and solar reflectance as well as the building geometry, spatial dimensions and presence of air openings (Chandel et al., 2016; Fitriaty et al., 2023; Kisilewicz, 2019).

Previous studies have shown that buildings constructed using vernacular materials and technologies generally provide a better indoor thermal environment compared to their contemporary counterparts (Nguyen et al., 2019). Despite this, there has been transformation of housing in sub-Saharan Africa away from vernacular building materials. Tusting et al. (2019) found that prevalence of houses built with industrial processed finished materials increased from 32% to 51% between 2000 and 2015 in this region. In Kenya the influence of modernity and technical progression supports the growing movement away from vernacular and traditional building materials. Between 1989 and 2019 the use of thatch as a roofing material reduced from 40% to 6.7% while the use of corrugated iron roofing sheets increased from 52% to 80.3%. Walling by wattle and daub reduced from 57% to 27.5% while use of masonry blocks and bricks increased from 12% to 43%. (Central Bureau of Statistics, 2001; Kenya National Bureau of Statistics, 2019). This

**Corresponding author:*
***Richard Njoroge Kariuki** Lecturer at the Department of Architecture and Built Environment of the Technical University of Mombasa. PhD student in Construction Engineering and Management at the Jomo Kenyatta University of Agriculture and Technology.*
Email: rnkariuki@gmail.com

shows a significant change of building envelop construction that is expected to have altered the indoor thermal environment.

Studies of thermal performance of dwelling houses have been done in other parts of the tropics: in South East Asia (Dahlan & Ghaffarianhoseini, 2016; Fitriaty et al., 2020; 2021; Zune et al., 2020) and in West Africa (Okafor et al., 2022; Widera, 2021). However, literature review and bibliographical studies of vernacular buildings show that Africa in general is underexplored and that the eastern African region is, essentially, unexplored in studies of vernacular architecture. In a review of 127 studies on sustainable features of vernacular architecture, Nguyen et al., (2019) found that only eight such studies were from Africa: six from North Africa and two from West Africa. In a bibliometric study of research trends in vernacular architecture, 715 published articles covering a period from 1971 to 2019, only 7 were from African countries: 3 from North Africa, 2 West Africa and 2 South Africa (Benkari et al., 2020).

Vernacular buildings are product of the physical and socio-cultural context. There is therefore a need for research on the thermal performance of vernacular built environment in eastern Africa region. The objective of this study is to determine the effect of transformation in building envelop configuration and materials on indoor thermal conditions in vernacular dwelling houses of the Mijikenda community of the Kenyan coast.

THEORY

The framework for the evolution of vernacular architecture is primarily socio-cultural with materiality as a secondary factor (Rapoport, 1969). Asadpour (2020) refers to the two approaches as a cultural-sociological reality and as a material-physical substance, respectively. The cultural-sociological approach is based on behavioural or cultural influences and the adaptation to the social conditions of dwellers. Vernacular buildings are also said to be a result of interaction with nature. This is the view of vernacular architecture as a material-physical substance, a result of physical factors such as availability of materials and climate conditions.

Transformation from vernacular architecture is a manifestation of the socio-cultural changes that occur as an evolutionary process in society due to innovation and contacts with other cultures. This socio cultural change has accelerated globally fuelled by rapid migration, urbanisation, education, technological progress and economic growth. (Greenfield, 2016).

In architecture this transformation has resulted in changing trends and practices that have affected the form, materiality and spatial organisation of dwelling houses (Nur et al., 2021; Ralwala, 2022). The effect of globalisation and urbanisation is such that those exposed to new ideas and with improved economic status tend to abandon traditional housing that they consider impermanent and associate them with low social and economic status (Bosman & Pittaway, 2019; Hadjri et al., 2007; Monzur & Jany, 2022).

The changes due to availability of materials and technology plays a part in this transformation. This is attributed to limited sources of some natural materials such as grass and palm leaves for thatch coupled with availability of new industrially produced products such as corrugated galvanised roofing sheets, and concrete blocks that are easier to work with and have low maintenance requirements (Bosman & Pittaway, 2019; Monzur & Jany, 2022).

The effect of government policy has also been said to contribute to this transformation. This includes colonial rule in Africa and other regions in the global south which resulted in changes in family structure, new typologies, architectural styles and building techniques (Kamenju, 2013, pp. 120–136). Governments may also place restrictions on use of local materials on the basis of building stability, health and fire safety. Public housing schemes are sometimes launched without incorporation of vernacular forms, spatial organisation or materials (Monzur & Jany, 2022).

The transformations of vernacular houses has the potential to alter the indoor thermal environment of the dwelling houses. In tropical humid areas, studies show higher thermal discomfort as a result of changes in the roof materials from thatch and fired clay tiles to metal sheets and concrete slabs (Fitriaty et al., 2020; Widera, 2021; Zune et al., 2020). In wall construction, the changes have been from bamboo, timber boards and mud walls to concrete bricks (Dahlan & Ghaffarianhoseini, 2016; Okafor et al., 2022; Oleiwi & Mohamed, 2022). Thermal comfort is also negatively affected by changes to elements in vernacular houses that enhanced natural ventilation such as raised floors, internal courtyards, steep roof pitches that provided extra ceiling height, eave and gable openings (Dili et al., 2010; Zune et al., 2020).

Iwuagwu (2016) proposed remedies to manage change so as to benefit from the positive attributes of vernacular architecture. The suggestions include reengineering traditional materials, as is the case with compressed stabilised earth blocks, to suit the present requirements in building and overcome some of the challenges of low strength and durability. The author further recommends that governments use local building materials in public housing projects as a way to improving environmental sustainability and preserving traditional heritage.

RESEARCH METHODS

A quantitative method approach that applies a case study research strategy (Bryman, 2012; Robson, 2024, p. 150) and on site data collection by measurements of thermal parameters was used . According to Kothari & Garg (2019), using a case study strategy, a researcher can take one single social unit or more of such units for intensive study over a period of time so as to obtain enough information for drawing correct inferences. It is a method of study in depth rather than breadth that places emphasis on a full analysis of a limited number of conditions and their interrelations.

Three case study dwelling houses were purposefully selected as typical cases that represent the transitional dwelling house types of the Mijikenda people, an ethnic community of nine related Bantu sub groups inhabiting the East African coastal hinterland of Kenya. This area has a hot humid tropical climate characterized by high humidity (annual average of 78.4%) and high air temperatures (annual average of 26.4 °C) (United Nations Human Settlements Programme (UN-Habitat), 2016).

The Mijikenda live in dwelling houses characterized by a variety of building envelop solutions that evolved over time. In the period between the sixteenth and the nineteenth century, they lived in fortified villages *(kayas)* in the forest clearings at the ridges of the coastal belt. (Spear, 1978). The individual houses were rectangular with rounded ends constructed with a network of slender branches tied to form a mesh and covered with grass thatch from ground to roof peak. They had a door right in the centre and no other openings (Anyamba & Adebayo, 1994; Spear, 1978). In the nineteenth century, the *kaya* settlements were abandoned with the dispersal of the Mijikenda to individual homesteads in the vacant land on the coastal plains and the adoption of the rectangular Swahili/Arab type house consisting of wattle framed walls of mud and coral aggregate infill with gable end palm thatch roofs (Orchardson, 1986). Today, the dwelling houses at the Kenyan Coast are mostly constructed using soil bricks and coral blocks masonry walls bonded with cement mortar ((56% in 2019) and roofing using corrugated iron sheets (74% in 2019). (Kenya National Bureau of Statistics, 2019).

The location of study was Fimboni village, Kitsoeni sub location, Chasimba location in Kilifi County inhabited by members of the Chonyi sub tribe of the Mijikenda (**Figure 1**). This rural village, approximately 40kms north north east of Mombasa City contained all three types of transitional vernacular building types identified for this study (**Figure 2**).

All the three cases were available for thermal data collection in the months of March, May and July 2024, were occupied throughout the study period and are approximately equal in floor area and space organization. The three months were selected as they represent the range of annual temperatures from the warmest in March and the coolest in July as well as May whose temperature reflects the annual mean. Data collection was limited to three months to maintain cooperation by the occupants of the houses in allowing placement of data collection loggers indoors. The three case study houses had similar floor materials, rectangular shape and north south orientation relative to the solar direction. The relevant differences between them is summarised in **Table 1**.

The following data related to indoor thermal conditions of the buildings was collected:

a) House geometry, structure and building elements characteristics. This was carried out using on site sketches, photography and

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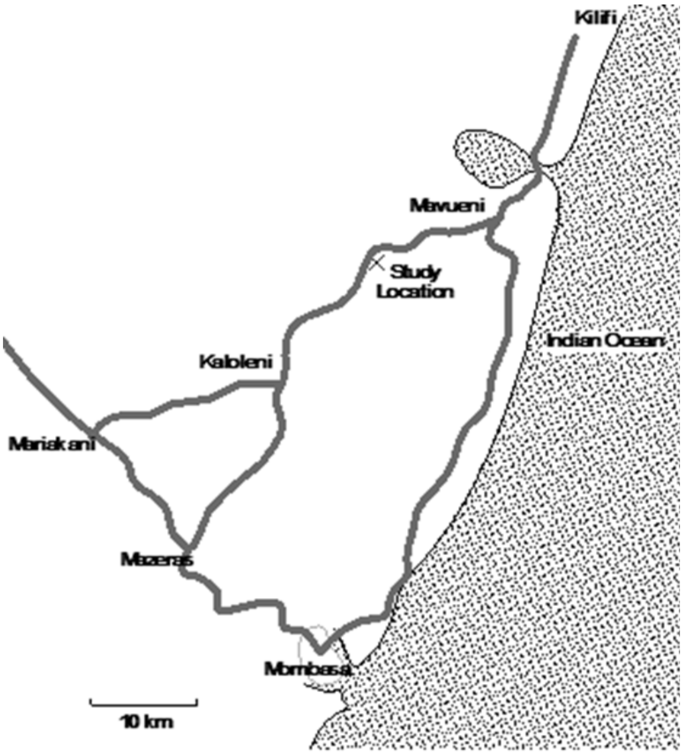

FIGURE 1
Case study site location approx 38 km NNE of Mombasa City and 16 km west of the Indian Ocean Coast.Coordinates: -3.7164, 39.7124
Source: Field survey, 2025

Type A (Kaya)
Rectangular with rounded ends constructed with a network of slender branches covered with grass thatch from ground to roof peak.

One door at the centre and no other openings.

Compressed earth floor.

Floor dimensions: 6.80m x 2.95m
Overall height: 2.95m

Type B (Swahili/Arab)
Rectangular two roomed house consisting of wattle and daub walls with gable end palm thatch roofs

One door into the first room and a door opening to the second room. No other openings.

Compressed earth floor

Floor dimensions: 6.30m x 3.40m
Overall height: 4.19m

Type C (Contemporary)
Rectangular three roomed house built with soil bricks bonded with cement mortar. Corrugated iron sheets roofing on sawn timber from palm tree trunks.

One door centered in the middle room. A door opening into the other rooms from the middle room.

One window opening with wire mesh for two rooms.

Compressed earth floor.

Floor dimensions: 8.15m x 3.65m
Overall height: 3.75m

FIGURE 2
Dwelling types for case study data collection
Source: Field survey, 2025

TABLE 1
Case study building characteristics that affect indoor thermal conditions

		HOUSE A	HOUSE B	HOUSE C
1.	Floor to Roof Height	2.95metres	4.19metres	3.65 metres
2.	Openings	One door only	Door and roof air gaps	Door and two single sided windows
3	Roof Material Thermal Properties	Low thermal transmittance and low thermal mass	Low thermal transmittance and low thermal mass	Very high thermal transmittance and low thermal mass
4	Wall Material Thermal Properties	Low thermal transmittance and low thermal mass	High thermal transmittance and high thermal mass	High thermal transmittance and high thermal mass

Source: Field survey, 2025

overall spatial measurements using steel measuring tapes.

b) Internal spatial measurements of individual spaces using steel measuring tapes.

c) Material specifications and dimensions of the building elements and components: walls, roofs, floors, windows, and doors. This was be carried out by visual inspection and measurements using steel measuring tapes and steel vernier calipers.

d) Internal air temperature, radiant temperature, humidity and air velocity measured using data loggers with respective sensors that conform to ISO 7726: 1998 (**Table 2** and **Figure 3**). Measurements were taken continuously in March (highest mean monthly air temperature), May (average) and July (coolest).

e) The external air temperature data was sources from records of the Mombasa Weather Station.

The data loggers were placed on plastic stools 600mm above the floor level in the bedrooms such as to ensure minimum interruption in the daily activities of the occupants.

RESULTS AND DISCUSSION

Measured Thermal Parameters

The mean external air temperature as recorded at the Mombasa Weather Station in March, May and

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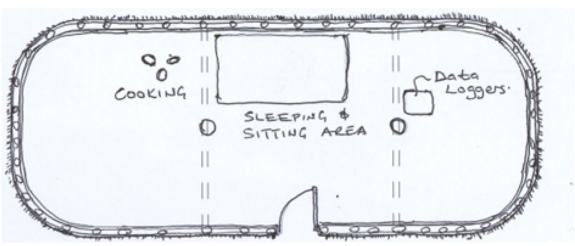
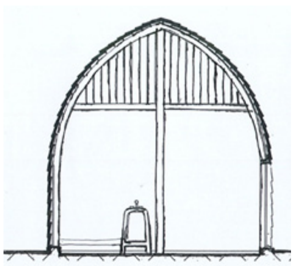
TABLE 2
Instruments for indoor measurement of thermal environment

	Instrument Description		Parameter	Range	Accuracy
a.	HOBO U12 Temperature/ Humidity/External Data Logger		Air Temperature	-20°C to +70°C	±0.35°C
			Relative Humidity	5% to 95%	2.5%
b.	40mm diameter black globe with the HOBO U12 external data logger probe.		Globe Temperature	-20°C to +70°C	±0.35°C
c.	BTMETER BT-846A Pro HVAC Anemometer		Air speed	0 to 45m/s	±0.3% + 0.1 reading
		 Logger setup on stools	The data loggers were placed on plastic stools 600mm above the floor level in the bedrooms such as to ensure minimum interruption in the daily activities of the occupants.		

Source: Field survey, 2025

House Type	Floor Plan	Section
"Kaya" Type "A"		

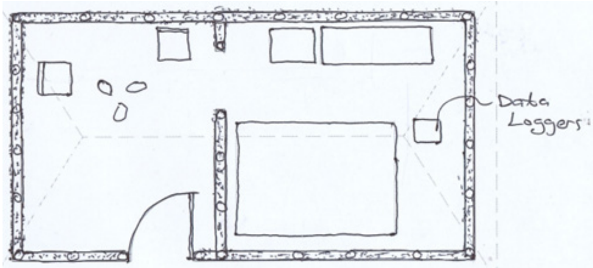
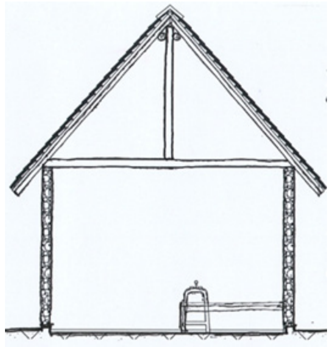
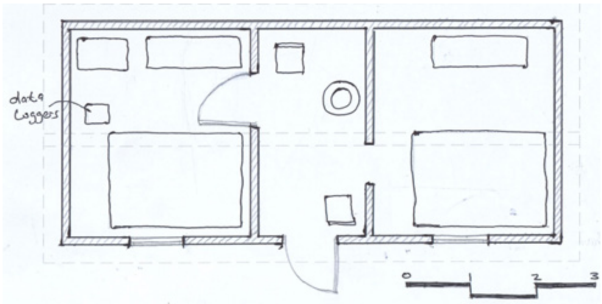
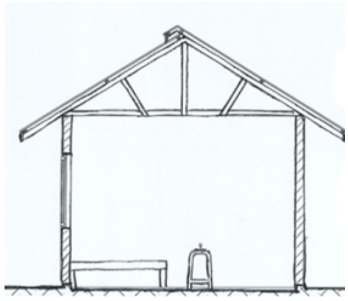
House Type	Floor Plan	Section
“Swahili/ Arab” Type “B”		
“Modern” Type “C”		

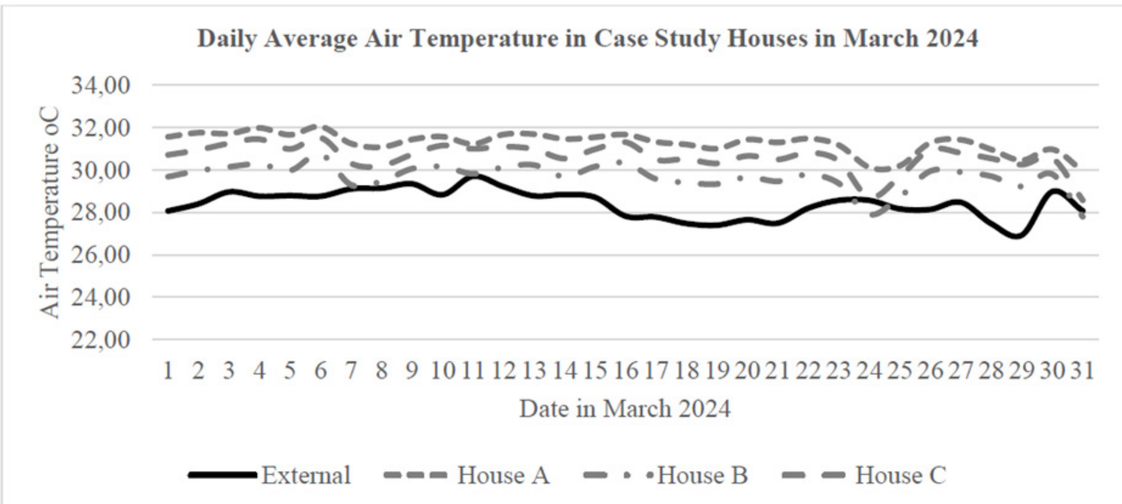
FIGURE 3
Location of data loggers in the case dwelling houses
Source: Field survey, 2025

July 2024 was 28.4, 27.0 and 25.4°C, respectively. In all cases, the indoor air temperature exceeded the outdoor air temperature. The mean indoor air temperature was highest in House Type A and lowest in House Type B in all three months. The graphs in **Figure 4** summarise the average indoor air temperature for the three houses in March, May and July.

The measured indoor globe temperature was lower than the air temperature in all cases. From these measured values, the mean radiant temperature was calculated using the ISO 7726 (2023) formula:

where

t_r is the mean radiant temperature in °C



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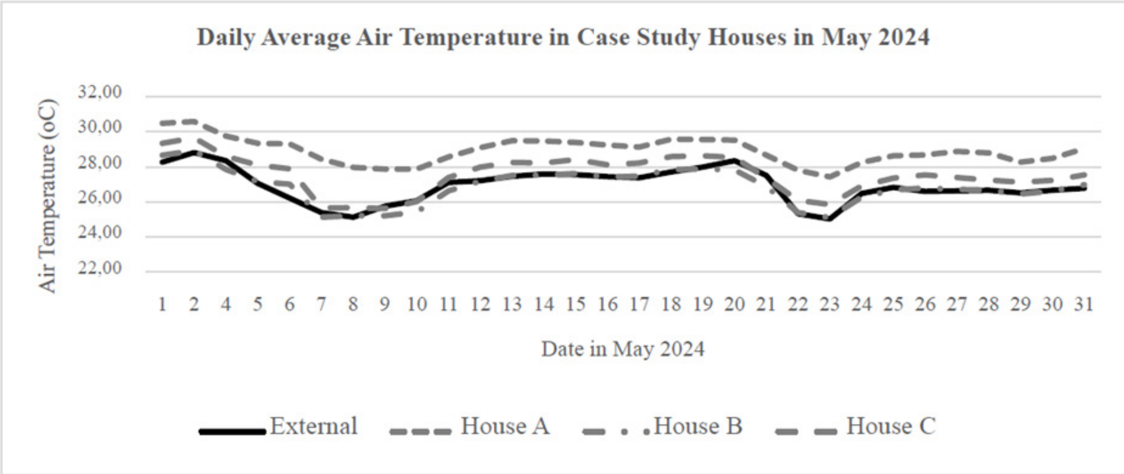


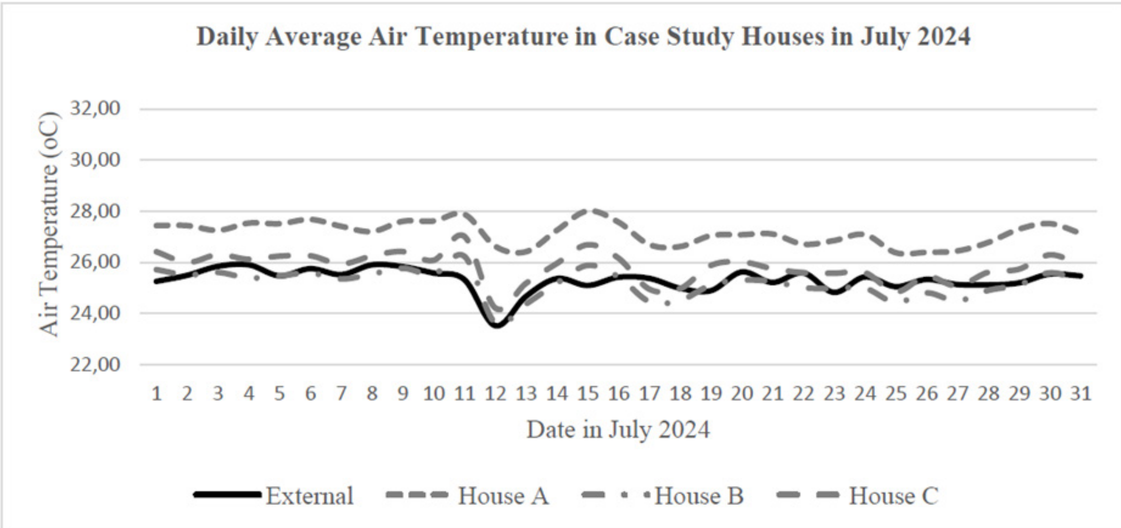


FIGURE 4
Daily average indoor air temperature in March, May and July
Source: Field survey, 2025

t_g is the globe temperature in ºC

t_a is the air temperature in ºC

ε_g is the emissivity of the globe (0.95)

D is the diameter of the globe (0.04m) (ISO 7726, 2023)

The indoor air speeds were all below 0.2m/s required to activate the anemometer. **Table 3** is a summary of the mean measured values (air temperature, relative humidity, globe temperature) and calculated values of mean radiant temperature.

In all the houses the mean relative humidity was between 72% and 80% without significant differences between the three houses. The ASHRAE 55 standard (ASHRAE, 2017) sets an upper limit of the upper limit for humidity ratio of 0.012 which translates to approximately 75% relative humidity at the recorded indoor temperatures. Studies on the effect of relative humidity in the tropics show high tolerance. Djamila et al., (2014)

$$\bar{t}_r = \left[\left(t_g + 273\right)^4 + \frac{0.25 \times 10^8}{\varepsilon_g} \left(\frac{\left|t_g - t_a\right|}{D} \right)^{1/4} \times \left(t_g - t_a\right) \right]^{1/4} - 273$$

TABLE 3
Mean values of measured thermal parameters

Month Year	House	Indoor Air Temperature °C	Relative Humidity %	Globe Temperature °C	Mean Radiant Temperature °C	Air Speed m/s
	House A	31.3	72.3	31.0	30.8	<0.2
March 2024	House B	29.7	76.3	29.4	29.4	<0.2
	House C	30.6	72.0	30.3	30.2	<0.2
	House A	29.0	75.3	28.7	28.6	<0.2
May 2024	House B	26.9	79.5	26.7	26.6	<0.2
	House C	27.6	75.8	27.4	27.3	<0.2
	House A	27.1	78.5	26.9	26.7	<0.2
July 2024	House B	25.2	79.5	24.9	24.8	<0.2
	House C	25.8	75.8	25.5	25.4	<0.2

Source: Field survey, 2025

in studies carried out in Malaysia argued that in humid climates the effect of relative humidity variation is limited since the subjects are exposed to high humidity all year round. In addition, the parameter of air temperature is highly correlated to relative humidity.

Thermal Discomfort

The measure of indoor thermal condition used in this study is the degree hour discomfort (DhC), time during which the indoor temperature exceeds the specified comfort range is weighted by the number of degrees the range has been exceeded. The indoor temperature is the operative temperature which incorporates air temperature, radiant temperature and air speed and is calculated as:

$T_o = AT_e + (1 - A)T_r$

where

T_o is the operative temperature
T_a is the average air temperature
T_r is the mean radiant temperature

A = 0.5 when air velocity < 0.2m/s (ASHRAE, 2017)

In this study, the indoor air speeds were all lower than 0.2m/s. In that case the indoor operative temperature is calculated as:

$T_o = (T_e + T_r)/2$

The comfort zone is determined by the ASHRAE 55 adaptive formula:

$T_c = 17.8 + 0.31T_m \pm 3.5°C$

where

T_c is the comfortable operative temperature range for 80% acceptability

T_m is the mean monthly external air temperature

DhC calculates the time during which actual operative temperature exceeds the comfort range weighted by the number of degrees the range has been exceeded (**Table 4**).

$$DhC = \sum_{i=1}^{24}(wfi.hi)$$

where:
DhC is the mean daily degree hours of discomfort (°C.hr)
wf is a weighting factor of degrees outside comfort zone (°C)

h is time in steps of one hour (hr).

Figure 5 show the distribution of mean hourly discomfort levels over a 24 hour period. The shaded part is the discomfort level where operative temperature in °C exceeds the upper comfort limit

TABLE 4
Calculation of daily average thermal discomfort levels in the case houses

		Operative Temperature °C		Mean Monthly External Air Temperature °C	ASHRAE 55 Adaptive Comfort Zone °C	Thermal Discomfort (DhC) °C Hrs
		Mean	Range			
March	House A	31.1	29.8 - 32.5	28.4	23.1 - 30.1	23.5
	House B	29.5	27.5 - 32.1	28.4	23.1 - 30.1	10.2
	House C	30.4	27.8 – 33.6	28.4	23.1 - 30.1	23.3
May	House A	28.8	27.6 - 29.8	27.0	22.7 - 29.7	0.3
	House B	26.7	25.0 - 28.9	27.0	22.7 - 29.7	0.0
	House C	27.4	25.3 – 30.3	27.0	22.7 - 29.7	1.7
July	House A	26.9	25.9 - 27.8	25.3	22.1 - 39.1	0.0
	House B	25.0	23.2 - 27.1	25.3	22.1 - 39.1	0.0
	House C	25.6	23.3 – 28.5	25.3	22.1 - 39.1	0.0

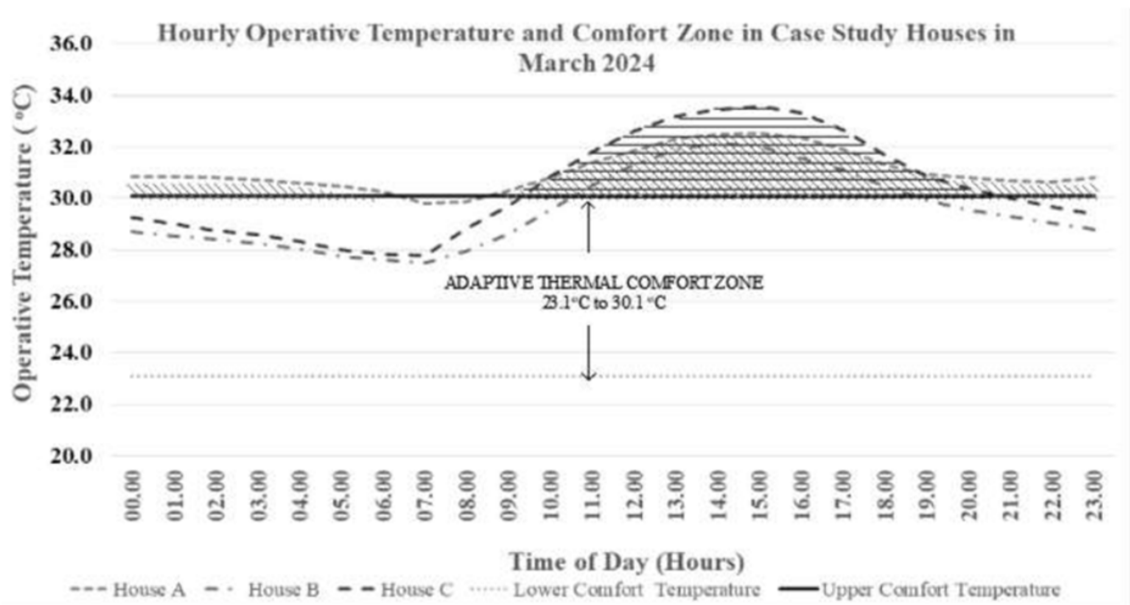
Source: Field survey, 2025

and time in hours. In all three houses, operative temperature exceeded the comfort zone between 11 am and 9 pm in the month of March. In July, indoor temperatures were all within comfortable range.

House Type B was significantly more comfortable than the other two houses.

In addition to the differences in the daily mean thermal discomfort levels, the results show significant differences in the diurnal range of operative temperature between the three houses (**Table 5**). House C had high range of between 5.0°C (May) to 5.8°C (March)with high discomfort levels between 11am and 5pm. On the other hand House A had a significantly lower range of between 1.9°C (July) to 2.7°C (March). Indoor temperatures were higher in house type C than in house type A during the day. At night, house C was cooler.

Strong linear regression correlations were found between outdoor air temperatures and indoor operative temperatures (**Figure 6**). The linear regression equation for each of the three houses



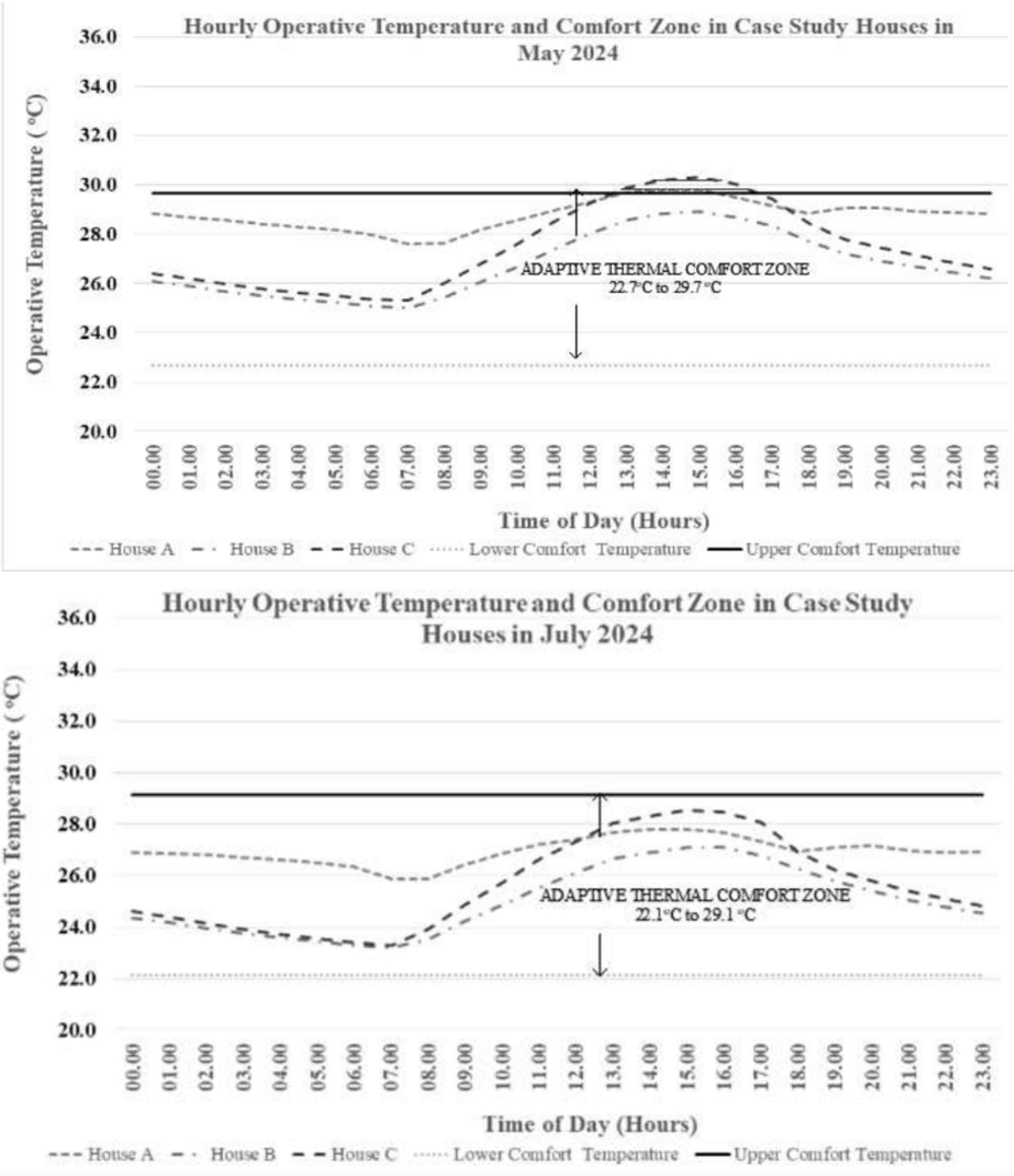


FIGURE 5
Hourly operative temperature and comfort zone in March, May and July
Source: Field survey, 2025

was established and used to estimate expected thermal discomfort levels in all twelve months of the year.

Outdoor Air Temperature as recorded at the Mombasa Meteorological Station March, May and July 2024 ranged from 22.4 to 32.0°C

Using the linear equations, the year long monthly and daily discomfort levels were calculated as shown in **Table 6** and **Figure 7**.

House Type B shows a significantly lower thermal discomfort level (daily average of 3.0°C.Hrs) compared to House Type A and C (8.2 and 7.5 °C.Hrs, respectively). In January, February and March, high thermal discomfort, averaging over 0.5oC every hour are projected in the two house types.

TABLE 5

Calculation of daily average thermal discomfort levels in the case houses

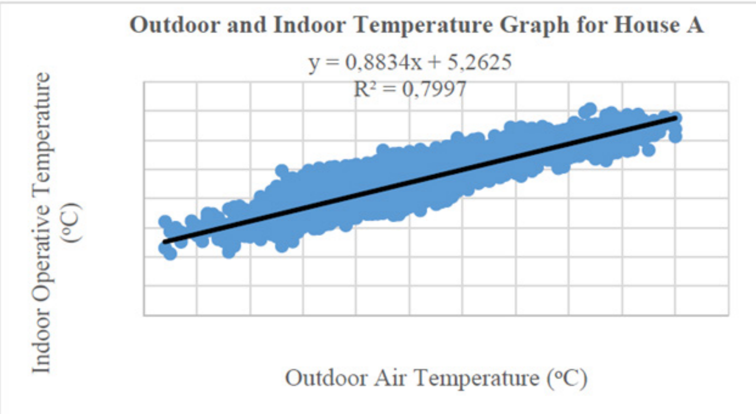
		Highest Operative Temperature °C	Lowest Operative Temperature °C	Diurnal Operative Temperature Range °C
	House A	32.5	29.8	2.7
March 2024	House B	32.1	27.5	4.6
	House C	33.6	27.8	5.8
	House A	29.8	27.6	2.2
May 2024	House B	28.9	25.0	3.9
	House C	30.3	25.3	5.0
	House A	27.8	25.9	1.9
July 2024	House B	27.1	23.2	3.9
	House C	28.5	23.3	5.2

Source: Field survey, 2025

HOUSE A

Indoor Operative Temperature (average of indoor air temperature and mean radiant temperature) ranged from **24.2 to 34.2 °C**

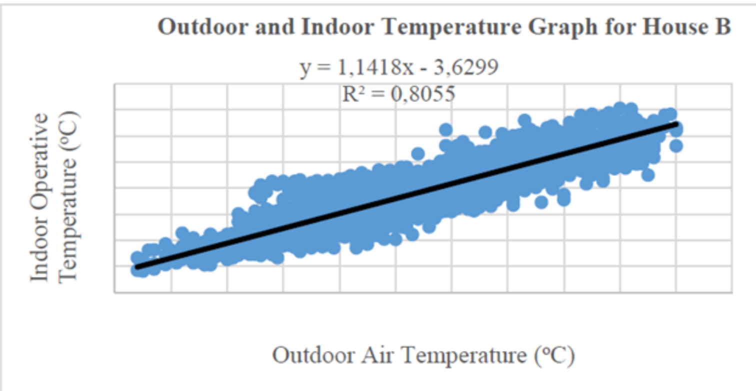
Linear Correlation: $T_{indoor} = 0.88T_{outdoor} + 5.26$ ($R^2 = 0.800$)



HOUSE B

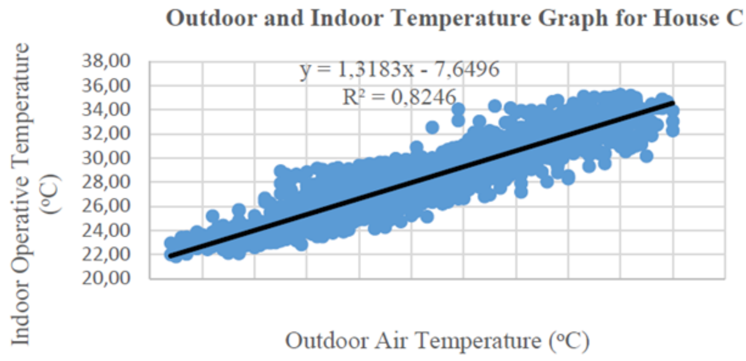
Indoor Operative Temperature (average of indoor air temperature and mean radiant temperature) ranged from **21.6 to 34.1 °C**

Linear Correlation: $T_{indoor} = 1.14T_{outdoor} - 3.63$ (R^2 0.806)



HOUSE C

Indoor Operative Temperature (average of indoor air temperature and mean radiant temperature) ranged from **21.8 to 35.2 °C**



Linear Correlation: $T_{indoor} = 1.32T_{outdoor} - 7.65$ (R^2 0.825)

FIGURE 6
Correlation between indoor operative temperature and outdoor air temperature
Source: Field survey, 2025

TABLE 6
Projected year long thermal discomfort levels

MONTH	Monthly Thermal Discomfort (°C. Hrs)			Daily Thermal Discomfort (°C. Hrs)		
	HOUSE A	HOUSE B	HOUSE C	HOUSE A	HOUSE B	HOUSE C
January	541.8	236.2	536.2	17.5	7.6	17.3
February	693.8	295.4	691.9	22.4	9.5	22.3
March	724.8	314.3	697.3	23.4	10.1	22.5
April	202.5	52.3	163.3	6.5	1.7	5.3
May	96.1	21.7	133.3	3.1	0.7	4.3
June	84.3	0.6	36.3	2.7	0.0	1.2
July	1.5	0.0	0.0	0.0	0.0	0.0
August	0.1	0.0	0.0	0.0	0.0	0.0
September	16.6	0.0	0.1	0.5	0.0	0.0
October	112.7	0.6	55.6	3.6	0.0	1.8
November	174.0	69.0	108.0	5.6	2.2	3.5
December	406.9	135.3	367.0	13.1	4.4	11.8
AVERAGE	254.6	93.8	232.4	8.2	3.0	7.5

Source: Field survey, 2025

Contributing Factors to Thermal Discomfort Differences

It has been found that in hot areas, indoor temperature and thermal discomfort increases with reduction in ceiling height (Guimarães et al., 2013). Openings provide natural ventilation which is the main indoor cooling strategy for low thermal discomfort in hot humid areas (Guedes & Cantuaria, 2019, p. 69; Manzano-Agugliaro et al., 2015). Omrani et al. (2017) determined that cross ventilation was significantly more effective than single sided ventilation. For building envelop materials in hot humid areas, high insulation materials with low thermal transmittance reduce heat gain and therefore are expected to reduce thermal discomfort (Fitriaty et al., 2020; Widera,

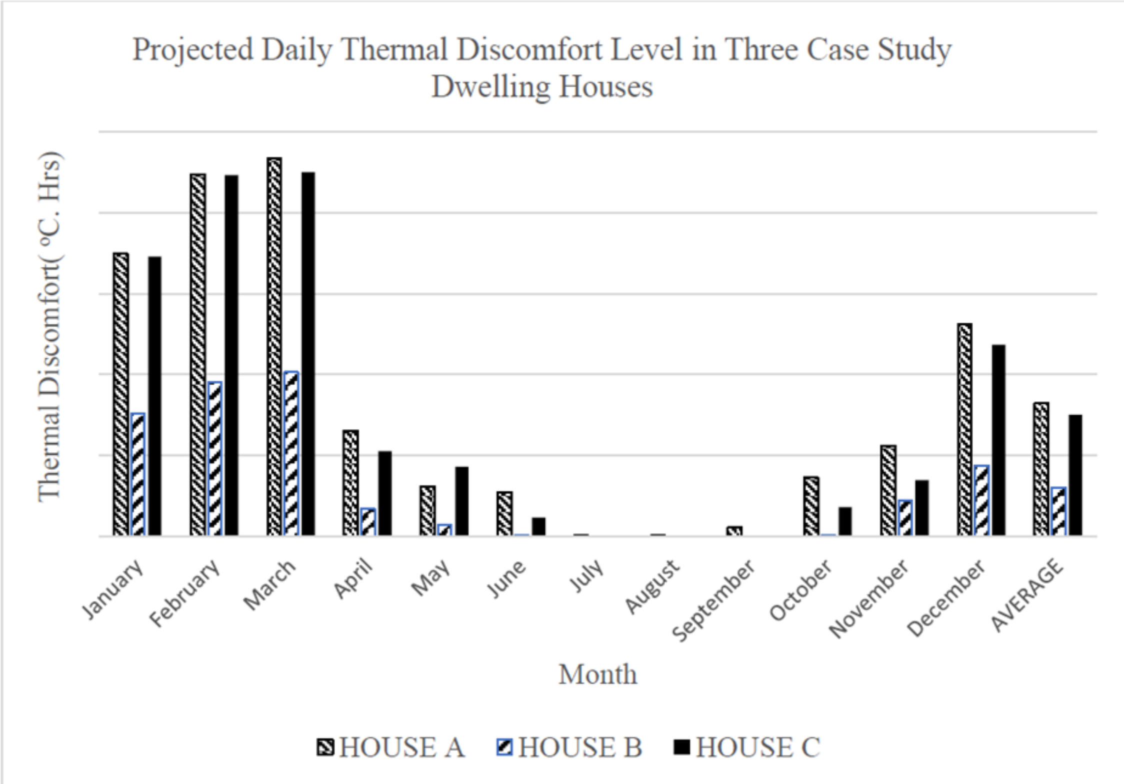


FIGURE 7
Projected yearlong monthly thermal discomfort levels
Source: Field survey, 2025

2021). On thermal mass, lightweight building materials with low thermal capacity materials to allow rapid cooling at night in hot humid areas are recommended (Fitriaty et al., 2020; United Nations Human Settlements Programme (UN-Habitat), 2016, p. 92)

Table 7 shows the comparison of Type A and Type B houses to determine the cause of the significant difference between the two in thermal discomfort. The difference in the thermal discomfort level is likely a result of the space height difference and presence of roof ventilation gaps in Type B rather than the building envelop material thermo-physical properties.

Table 8 shows the comparison of Type B and Type C houses to determine the cause of the significant difference between the two in thermal discomfort. House B had the advantage of floor to ceiling height, cross ventilation and low thermal transmittance roof compared to C.

Predicted Effects of Climate Change

Climate change, the long-term shifts in temperatures and weather patterns, has been described as one of the major challenges of our time (United Nations, 2025). The African continent has been warming at a slightly faster rate than the global average, at about +0.3 °C per decade between 1991 and 2023 (World Meteorological Organisation, 2024). At that rate, at least a 1oC rise in temperature is expected within the next 30 to 40 years. Using the linear equations in **Figure 6**, and increasing outdoor temperature by 1°C, thermal discomfort levels are expected to increase as shown in **Table 9**.

With the projected 1 °C, the period of excessive thermal discomfort will extend to November to April in Houses A and C with averages of over 2 °C above comfort level every hour in January, February and March (**Figure 8**).

Thermal discomfort is expected to, on average, increase by 61%, 90% and 74% in house types A, B and C, respectively.

CONCLUSION

The study of three rural dwelling house types at the coast of Kenya show significant thermal

TABLE 7
Differences between Type A and Type B house that affect thermal comfort

	HOUSE A	HOUSE B	Differences and Effects on Thermal Comfort
Space Height	2.95metres	4.19metres	The space height of House B is an advantage for thermal comfort.
Openings	The only opening is the door.	Has a door opening as well as air gaps at the eaves and at the roof hips	Air gaps in House B provide roof ventilation which allow air movement and cooling.
Roof material	Grass is of low thermal transmittance and low thermal mass	Makuti is of low thermal transmittance and low thermal mass	The roof materials for the two houses have similar thermo-physical properties.
Wall Material	Grass is of low thermal transmittance and low thermal mass	Mud is of higher thermal transmittance and higher thermal mass	Thermal transmittance and thermal mass favours House A

Source: Field survey, 2025

TABLE 8
Differences between House B and House C house that affect thermal comfort

	HOUSE B	HOUSE C	Differences and Effects on Thermal Comfort
Space Height	4.19metres	3.65 metres	The space height of Type B is an advantage for thermal comfort.
Openings	Has a door opening as well as air gaps at the eaves and at the roof hips	Has a door opening and two windows, one for each bedroom.	Roof cross ventilation in House B compared to House C singles sided window openings.
Roof Material	Makuti is of low thermal transmittance and low thermal mass	Galvanized iron sheets with high thermal transmittance and low thermal mass	Low transmittance roof in House B better than High transmittance in House C
Wall Material	Mud is of high thermal transmittance and thermal mass	Soil bricks are of high thermal transmittance and thermal mass	The wall materials for the two houses have similar thermo physical properties.

Source: Field survey, 2025

discomfort in the months of December, January February and March. The house constructed with palm leaf thatch roof, mud and wattle walls, having ventilation air gaps at the roof and high roof floor to roof height had on average, significantly lower thermal discomfort throughout the year. Higher thermal discomfort was found in the houses with lower floor to roof heights, without cross ventilation and with high thermal transmittance galvanised iron roofing sheets.

The relative humidity levels were found to be at the upper limit of comfort. High diurnal range of indoor temperature was recorded in the house containing a galvanised corrugated iron roofing sheet with significant differences between the daytime and nightime thermal conditions compared to the house made of grass thatch walls and roof. With the current trend of rising temperature due to climate change, thermal discomfort in the study area is expected to significantly increase during the hot months

TABLE 9
Projected year long thermal discomfort levels with 1oC rise in temperature

MONTH	Monthly Thermal Discomfort (ºC. Hrs)			Daily Thermal Discomfort (ºC. Hrs)		
	HOUSE A	HOUSE B	HOUSE C	HOUSE A	HOUSE B	HOUSE C
January	805.5	427.5	861.5	26.0	13.8	27.8
February	1034.8	512.4	1063.9	33.4	16.5	34.3
March	1042.1	553.6	1150.8	33.6	17.9	37.1
April	341.3	124.8	329.8	11.0	4.0	10.6
May	282.1	83.7	195.3	9.1	2.7	6.3
June	169.2	22.3	142.8	5.5	0.7	4.6
July	29.2	0.0	4.7	0.9	0.0	0.2
August	11.1	0.0	0.8	0.4	0.0	0.0
September	75.6	0.0	34.1	2.4	0.0	1.1
October	161.2	24.8	99.2	5.2	0.8	3.2
November	328.6	96.1	331.7	10.6	3.1	10.7
December	629.7	286.4	652.8	20.3	9.2	21.1
AVERAGE	409.2	177.6	405.6	13.2	5.7	13.1

Source: Field survey, 2025

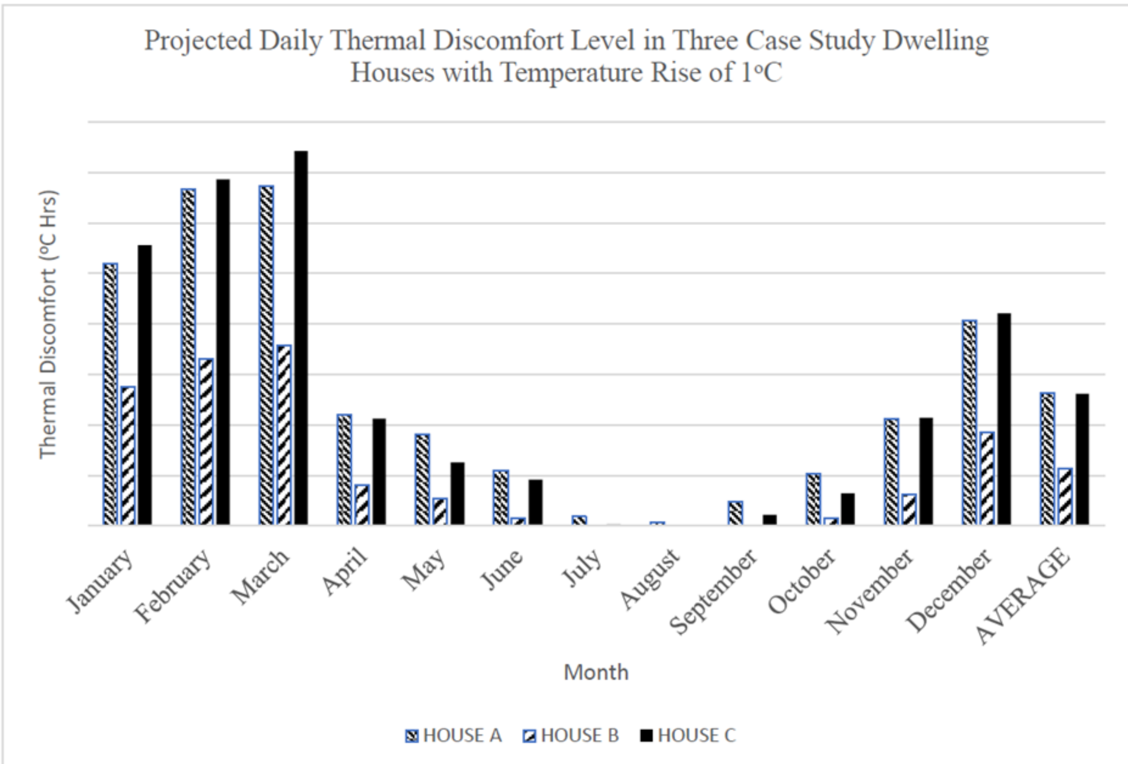


FIGURE 8
Projected yearlong monthly thermal discomfort levels with 1oC rise in outdoor temperature
Source: Field survey, 2025

between November and April.

In the transformation of the Mijikenda housing from the traditional grass thatched type to the adopted Swahili/Arab type the indoor thermal conditions improved. From the Swahili/ Arab type to the contemporary brick and metal sheet type the thermal conditions deteriorated. Two vernacular building envelop designs provided two different indoor thermal conditions. Whereas previous studies in other tropical humid areas show generally better performance of vernacular dwelling houses compared to modern ones, the traditional "*kaya type*" house of the Mijikenda people was not more comfortable than the contemporary house.

RECOMMENDATIONS

The study shows that indoor thermal comfort improved when the traditional "*Kaya*" type house was replaced with a house type with better ventilation. Thermal comfort subsequently reduced when the "Swahili/Arab" type house was replaced with a house with a high transmitting envelop material.

It is recommended that to improve thermal comfort, dwelling houses to be designed so as to:

i. Provide for cross ventilation through windows and roof openings;
ii. Use low thermal transmitting envelop materials such as agricultural fibre based cement sheets to replace palm leave thatch that is no longer easily available;
iii. Provide vaulted ceilings using insulation materials such as fibre boards to reduce thermal transmittance and maintain high ceiling height.

Further studies are recommended to determine the quantitative contribution of the different envelop design characteristics (thermo-physical properties of the building materials, ventilation type and spatial dimensions) to the indoor thermal conditions of dwelling houses in tropical hot humid areas.

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