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The Impact of Meteorological Changes on Human Comfort in Residential Buildings

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ABSTRACT

This research article investigates the effect of meteorological changes on the comfort of residents in Imo State, Nigeria, which is situated in a tropical monsoon climate. The study aims to assess the state of the indoor environment in residential buildings in Imo State, considering thermal changes caused by meteorological variations. A case study approach was adopted, focusing on a selected residential building in Umuasonye, Orji, Owerri North, Imo State. The study spanned a period of 10 years, from 2011 to 2021, and included physical observation, measurement, and qualitative analysis of the collected data. A case study approach was employed to overcome limitations in accessing a large sample size of individual residential buildings. The selected residential building in Umuasonye, Orji, Owerri North, Imo State served as a representative example for the study. Data collection involved physical observation, measurement, and qualitative analysis over a 10-year period, from 2011 to 2021. This approach allowed for a comprehensive understanding of the indoor environment and its relationship with meteorological changes. Findings reveal significant climate and weather changes in Imo State, leading to thermal variations in building spaces. The study assesses the impact on resident comfort and identifies adaptive strategies employed. During dry seasons, residents utilized cooling systems, ventilation, and reduced hot water usage. In wet seasons, measures such as closing windows, wearing thick clothing, and increased hot water usage were observed. This research provides valuable insights into the impact of meteorological changes on resident comfort in Imo State, Nigeria. It highlights the importance of climate-responsive building design and systems, showcasing adaptive strategies employed by residents. The case study approach contributes to knowledge for architects, building industry stakeholders, and users interested in promoting climate-responsive buildings and systems.

Keywords: Climate Change, Indoor Cooling, Thermal comfort, Residential Building.

1. INTRODUCTION

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) affirms that climate change is occurring globally [1]. Between 1906 and 2014 the world temperature rose from 0.56^{0}C to 0.92^{0}C degrees. Eleven of the twelve hottest years between 1850 and 2014 occurred in the last fifteen years [1]. The planet is expected to face an increase in temperature of an average of 0.2 degrees every ten years until the end of this century [2]. In return, these meteorological changes have impacted the indoor climate of residential buildings prompting residents to adopt adaptive strategies, active (cooling) systems and other measures to curtail the impact on them [3]. A rapidly warming planet poses an existential threat to all life on Earth. Just how bad it gets depends on how quickly we act [2]. Interestingly, one of the remarkable studies on the impact of Climate change on the indoor environment of building spaces is the study of [4]. This study focused on the effect of Climate change on indoor thermal comfort and energy use. A study by the World Bank (2017) revealed a rise in temperature and humidity levels constitutes a potential hazard to health and human comfort and accelerates many degradation processes and material damage. Subsequently, the amount of energy needed to maintain the condition of air in spaces at comfort levels keeps increasing [5]. Further study predicts that global warming will lead to adverse consequences for human health and well-being. The impact of several future periods, climate zones of southern Spain and orientations on thermal comfort was assessed. The results show that climate change triggers a more significant increase in outdoor temperatures in summer than in winter [6]. A critical review of the body of knowledge signals that much has not been done in specifically measuring the Impact of climate and weather changes on the comfort of building users located in the tropical monsoon climate with the motive of promoting climate-responsive buildings and systems. Against this backdrop, this research is tailored towards articulating the effect of climatic and weather changes on the comfort of residents in Imo state which lies in the tropical monsoon climate. To achieve this goal, this research studies the state of the indoor environment of residential buildings in Imo state laden with thermal changes, ascertains the effect of these thermal changes on the comfort of residents as well as recommends adaptive strategies to address these comfort disturbing issues by carrying out an integrated study on a residential building in Umuasonye, Orji, Owerri North in Imo state encapsulated in the evaluation of its thermal environment while taking cognizance of meteorological changes spanning from 1979 to 2021. The research results were further substantiated by a graphical representation of data on how human comfort is affected in residential buildings in Imo state. The audiences of this study are architects, users and other players in the building industry. One of the limitations faced in this study was the difficulty in accessing all the individual residential buildings in the study area tailored towards capturing and analyzing a sizeable sample size to better enhance the quality of the research results. As a result of this challenge, a typical case study research method was adopted using a residential development located at Orji, Owerri North L.G.A in Imo for sourcing data sets for the study (Noting that all the buildings in the study area fall under the Tropical Monsoon Climate). The study featured physical observation of the condition of the indoor spaces for a period of 10 years. Accessing the case study was so feasible, leading to the measurement of the living conditions of the occupants as well as the qualitative analysis of the collected data thereof.

2. LITERATURE REVIEW

2.1 The climate of Imo state

There are three distinct climate zones in Nigeria, a tropical monsoon climate in the south (which is where Imo state belongs), a tropical savannah climate predominantly in the central regions, and a Sahelian hot and semi-arid climate in the north of the country [7].

Imo State is located between latitude 4°45′N and 7°15′N and longitude 6°50′E and 7°25′E, with an area of about 5100 km^2 is also characterized by dry and wet seasons [4]. Interestingly, these seasons are marked by varying levels of thermal changes.

2.2 Climatic classification and meteorological data

Imo state is positioned at an elevation of 123.97 meters (406.73 feet) above sea level and is predominantly of Tropical monsoon climate (Classification: Am) [4].The state's mean annual temperature is 28.88ºC (83.98ºF). Imo is characterized by 234.25 millimetres of precipitation and has 268.89 rainy days (73.67% of the time) annually [5].

2.3. Meteorological changes

The Paris Agreement of 2015 presents a global framework to reduce global warming below 2°C, preferably to 1.5°C (degrees Celsius), compared to pre-industrial levels [8]. To realize this global temperature goal, countries aim to reduce the upsurge in greenhouse gas emissions quickly using the best instruments and methods at their disposal [5]. This target is known as "Net Zero" [9] and it entails achieving balance and equilibrium between greenhouse gas emissions released into the atmosphere and those expelled out of the atmosphere [10]

Meteorological changes are already evidenced by increasing air temperatures [11], melting glaciers and decreasing polar ice caps [12], rising sea levels, floods [13], increasing desertification, heat waves, droughts, and storms [14]. Evidently, meteorological change is not globally uniform and affects some regions more than others [15].

Table 2.1: Classification of the climatic zones on which the Imo state lies.

S/N	Classification	Count	Köppen-Geiger	Examples
1	Tropical monsoon climate	172	Am	Owerri, Umuoma, Imeabiam, Ekwurazu, Umuekwune
2	Tropical savanna climate	108	Aw	Umunakanu, Umueze, Elugu, Nkumato, Okwuohia, Umuopara

2.4. The effect of meteorological changes in Imo state for the past 40 years

Statistics show that there have been some significant changes in the climate and weather of Imo state from 1979 to 2021. The data source used is ERA5, the fifth-generation European Centre for Medium-range Weather Forecasts (ECMWF) atmospheric analysis

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of the global climate with a spatial resolution of 30 km [6]. For clearer communication, the meteorological data is hereby shown through graphical charts and interpretation below;

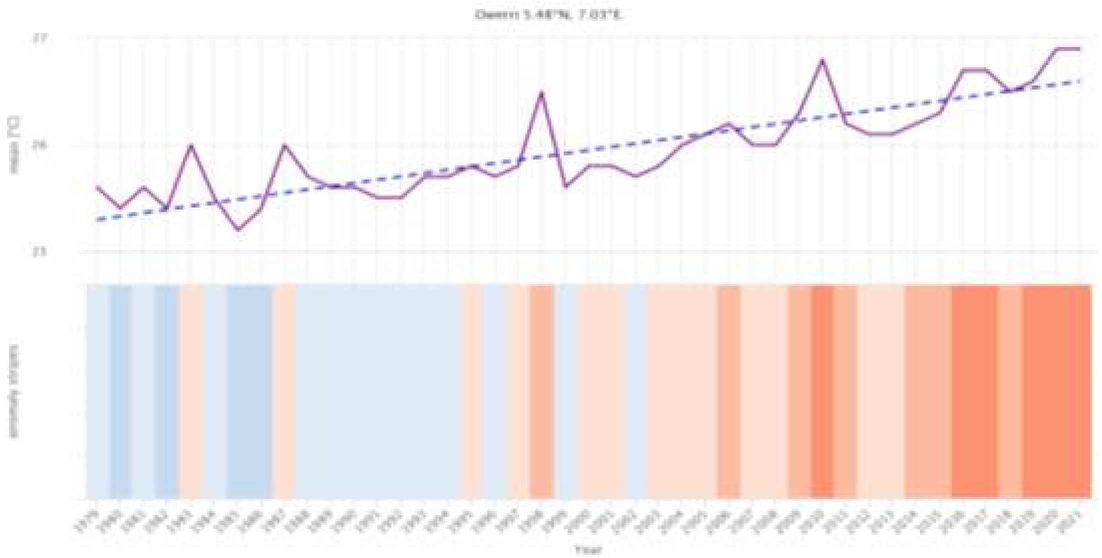

Figure 2.1: The mean annual temperature, and variations in Imo state from 1979 – 2022

The figure above shows an estimate of the mean annual temperature for a larger part of Imo state. The dashed blue line depicts the climate change variation, which from the above graph is going up from left to right, indicating that the temperature trend is positive, and Imo is getting warmer due to climate change. The lower part of the graph shows the warming stripes. Each coloured stripe represents the average temperature for a year - blue for colder and red for warmer years. From the graph, the yearly average temperature rises towards year 2021 [6].

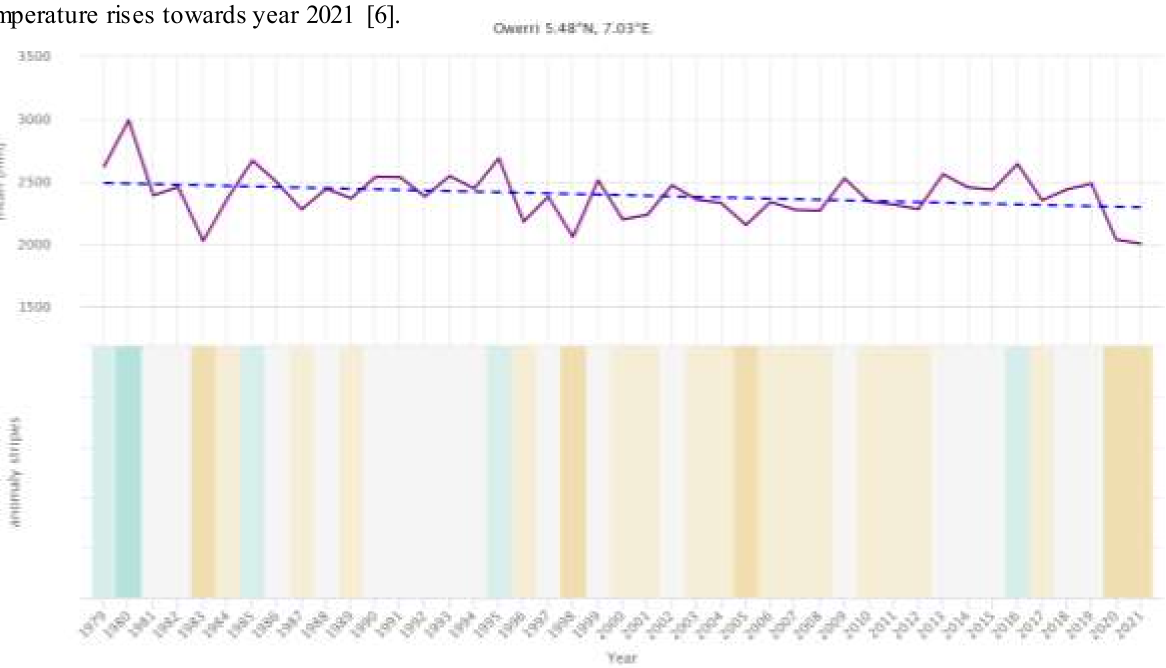

Figure 2.2: The mean annual rainfall, and variations in Imo state from 1979 – 2022

The figure above shows an estimate of mean total rainfall for the larger part of Imo state. The dashed blue line is the climate change trend or variation. From the graph, the trend line is going up from right to left, meaning that atmospheric and environmental conditions are becoming drier in Owerri over time. In the lower part, the graph denotes the rainfall stripes, and the brown coloured stripe represents the total rainfall of a year for drier years as evidenced in recent years (2020 – 2021). However, the brown coloured stripe represents the total rainfall of a year for drier years [6]. The climatic variability of this graph shows drastic fluctuations in climate especially rainfall with its associating challenge being gully erosion within the region of study [16].

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2.5 Thermal Changes and human comfort

Statistics show that meteorological changes in Imo state is gradually making the state warmer and drier on average as evidenced in the difference of 3.5^{0}C mean annual temperature leading to thermal changes in building spaces. These thermal changes in the indoor climate of buildings have the propensity of altering the wellbeing and living conditions of residents [7].

2.6 Primary objective of the study

This study is designed and embarked on to assess the propensity of climate and weather changes to improve or lower the living comfort of users in spaces encapsulated in determining the extent these changes can affect the characteristics of indoor spaces, the adaptive responses of occupants therein. This will further give way to the proposal of possible positions to adopt in mitigating the impact of meteorological changes on the comfort of users in indoor spaces.

3. RESEARCH METHODOLOGY

This research settled with the qualitative research methodology encapsulated with the use of Case study as a research method. In addition, the research instruments were physical observations, and discussions, thus, the research design framework is shown below;

Identification and Selection of Research method and instrument
(Mapping and selection of case study)

↓

Collection of Data using Qualitative analysis
(Responses were drawn out from observations)`

↓

Interpretation and Analysing of Data using thematic analysis
(The behaviour of the residents as well as the case study were analysed)

↓

Organisation and Presentation of Analysed Data using Charts
(The qualitative process presented the result in tables, figures, and charts)

Figure 3.1: Research design flow

To collect data for this study geared towards assessing the thermal levels as a result of meteorological changes in Imo state, physical observation and discussion with some residents were adopted. The data was collected and analysed qualitatively from a selected residential building (a 4-bedroom bungalow) located at Umuasonye in Orji, Owerri North, Imo state masked with a general observation of buildings located in Imo state.

3.1 A pictorial presentation of the selected case study

Plate 3.1: Pictorial view of the case study
Source: Snapshots of case study using Infinix Hot 12 Phone

Plate 3.2: View of a ceiling fan for ventilation
Source: Snapshots of case study using Infinix Hot 12 Phone

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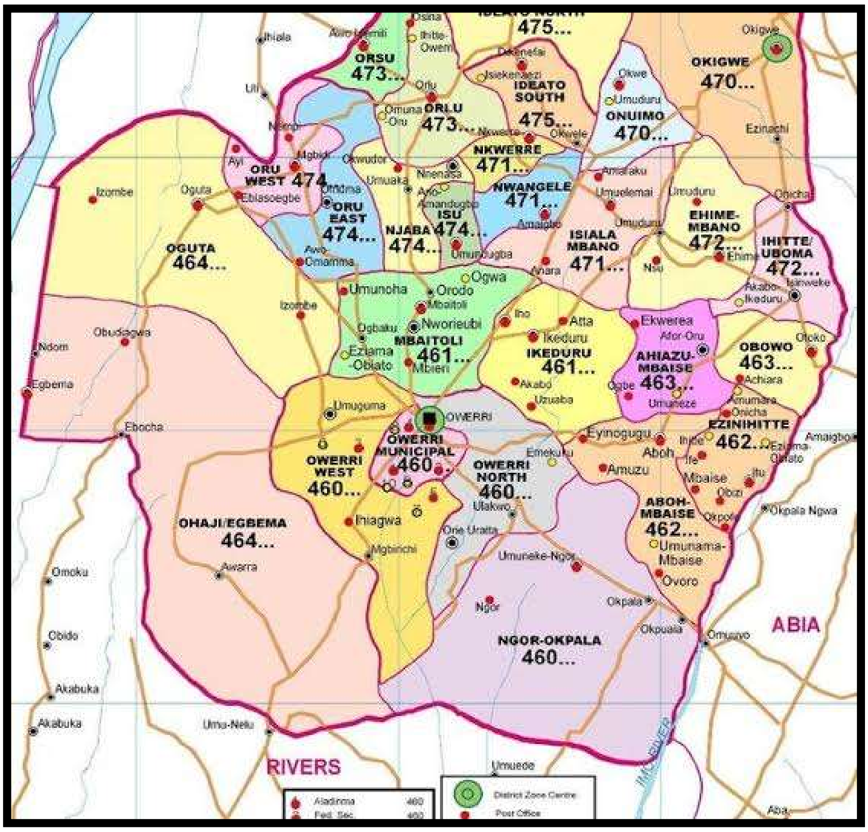

Figure 3.4: Map of the Imo state showing the location of the case study.

Source: Nanbol Listick Daniel et al (2017). Sokoto Journal of Medical Laboratory Science (SJMLS)

3.2 Case study

The selected residential building is sited on an undulating plain having about 50% of its landscaping area covered with concrete slab and earth respectively. The building is adjoined by an underground tank, soak-away pit, and septic tank on the west. The east has a concreted walkway of 1.5m bordered by a fence of 3.0m height. On the north, is an outdoor kitchen with concreted landscape floor while the south has some vegetation on natural soil with 3.6m distance away from the main building.

3.3 Study and analysis of its thermal environment

In this study, the effect of thermal changes in the selected residential building, and the way the residents respond to these thermal changes in their indoor spaces during the day and night for the wet and dry seasons were critically observed from 2011 - 2021. The table shows the average measurements of the thermal conductivity of the composite materials, elements and components that constitute the building.

To assess the thermal environment, measurements were taken of the thermal conductivity of the various materials and components that constituted the building. Table 2 provides a summary of these measurements, outlining the thermal conductivity (expressed in W/mK) of each material.

For the floor component, the concrete floor slab exhibited a thermal conductivity ranging from 2.0 to 3.2 (0.8), indicating its moderate heat conductivity. The floor screed had a slightly lower range of 1.1 to 2.2, suggesting a relatively lower heat conductivity. The wool carpet, on the other hand, showed excellent thermal insulation properties with a thermal conductivity of 0.18, indicating its ability to retain heat. In terms of the wall component, the 125mm thick solid sandcrete wall exhibited a thermal conductivity of 1.13, indicating moderate heat conductivity. The wall plaster, serving as the finish, had a lower thermal conductivity of 0.71.

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Table 3.1: Summary of the thermal conductivity of the selected materials that make up the case study

THERMAL PROPERTIES OF MATERIALS AND COMPONENTS		
S/N	**MATERIALS**	**Thermal Conductivity(W/mK)**
	Floor component	
1	Concrete floor slab	2.0 -3.2 (0.8)
2	Floor screed	1.1 – 2.2
3	Wool carpet	0.18
4	Unglazed Ceramic tiles	3.8
	Wall component	
5	125mm thick solid sandcrete wall	1.13
6	Wall plaster (as finish)	0.71
6	Emulsion paint	0.001
	Openings	
7	Glass louver window	0.8
8	Wooden casement window	0.1 – 0.2
	Roof / ceiling component	
9	Asbestos ceiling board	0.08
10	Corrugated iron roofing sheets	112.2

The emulsion paint, being a thin layer, had a minimal impact on thermal conductivity, with a value of 0.001. The openings in the building, such as the glass louver window, had a thermal conductivity of 0.8, indicating moderate heat conductivity. The wooden casement window exhibited a lower range of 0.1 to 0.2, suggesting better insulation properties. Lastly, for the roof/ceiling component, the asbestos ceiling board showed good insulation properties with a thermal conductivity of 0.08. However, the corrugated iron roofing sheets had a high thermal conductivity of 112.2, indicating significant heat transfer. By examining the thermal conductivity of these materials and components, the study aimed to understand how heat was transmitted through the building envelope and how it affected the indoor thermal environment.

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4. RESULTS AND DISCUSSIONS

4.1. Metrological impact on building materials, components, and systems

The results of this study confirm that changes in weather and climate have a direct impact on the parameters that make up the building envelope. Through careful observation, it was observed how variations in isolation, temperature, humidity, and other meteorological elements affect the external components of the building. The external components of the building, including walls, windows, and roofs, are particularly susceptible to thermal impacts caused by these changes. The alterations in isolation, temperature, humidity, and other meteorological factors lead to changes in heat transfer mechanisms such as conduction, convection, and radiation of heat waves. As a result, the thermal state of the living spaces within the building is inevitably altered. To provide visual evidence of these impacts, Figure 6 and Figure 7 were included in the study. These figures clearly demonstrate how external building features are influenced by meteorological elements. They provide a visual representation of the relationship between weather conditions and the thermal performance of the building envelope.
The findings highlight the need to consider weather and climate conditions when designing and constructing buildings. The impacts of meteorological changes on the external components of buildings emphasize the importance of implementing climate-responsive design strategies. By incorporating appropriate measures such as insulation improvements, shading devices, and ventilation systems, the adverse effects of weather and climate variations can be mitigated. Understanding how meteorological elements affect external building features enables architects, engineers, and building professionals to make informed decisions during the design and construction phases. By incorporating climate-responsive design principles, they can create buildings that are better equipped to withstand and adapt to changing weather and climate conditions. Ultimately, this leads to improved comfort, energy efficiency, and sustainability for the occupants.

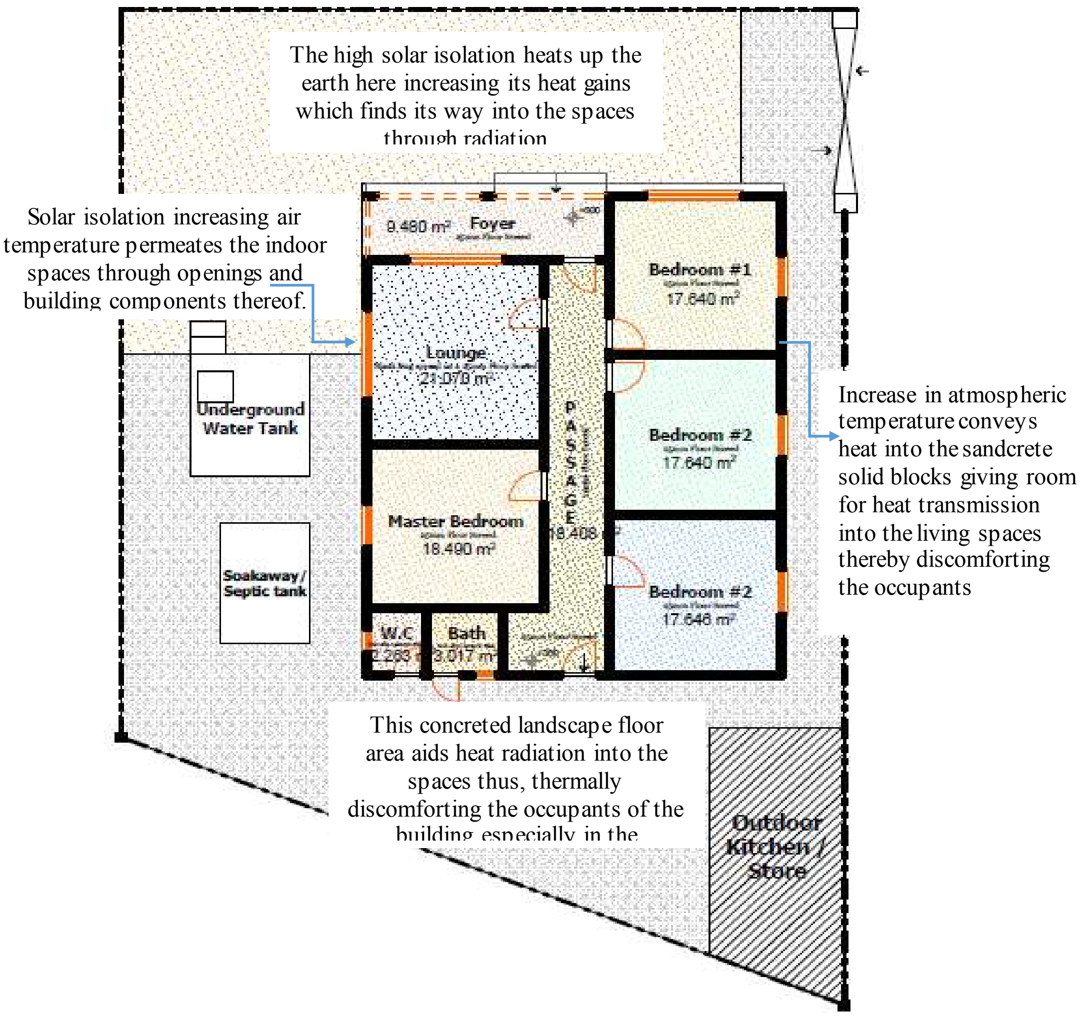

Figure 4.1: Plan layout of case study showing how it is affected by changes in temperature and other meteorological elements.

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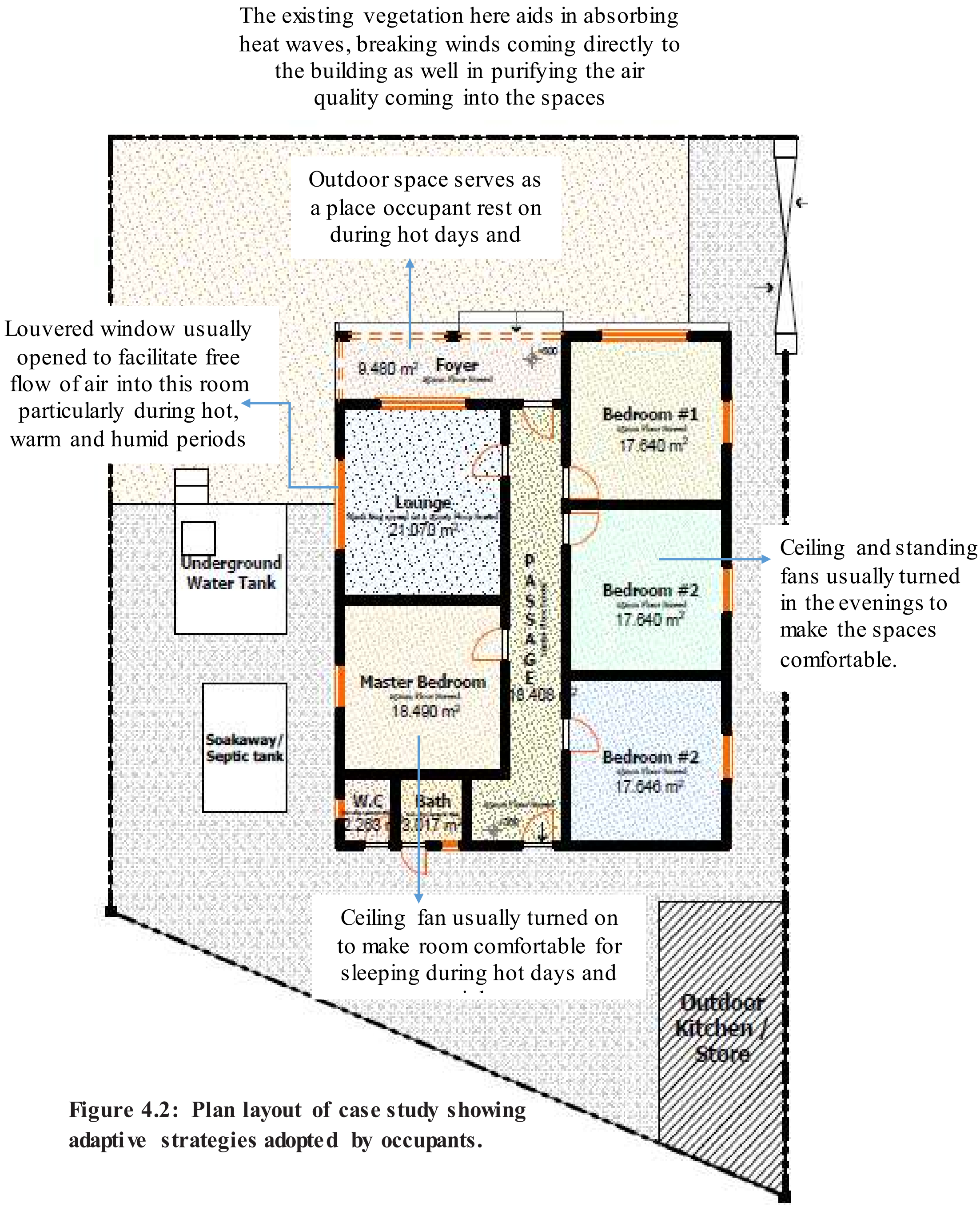

Figure 4.2: Plan layout of case study showing adaptive strategies adopted by occupants.

4.2 Adaptive Strategies and responses adopted by the Occupants

Having the living spaces impacted by thermal changes also comes with it periods that fail to meet the comfort requirement of the occupants. In order to cope with these unfavorable periods of the day and night, occupants of this studied residential development devised adaptive measures and responses.

Table 3 summarizes the observed thermal changes during the dry seasons in the case study. The characteristics, effects on human comfort, and adaptive strategies employed by the occupants are presented.

Increase in air and room temperature: During the dry seasons, particularly from 10:00 am to 12:00 pm, there is an increase in air and room temperature due to intense solar radiation and solar gains. This results in disturbed night sleep due to a warm and muggy indoor climate. Occupants used cooling and mechanical ventilating units to regulate the indoor climate. They also preferred opening their windows for natural ventilation. Additionally, there was a reduction in the use of hot water for bathing in the evenings.

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Increase in humidity: From 4:00 pm to 11:00 pm, there is an increase in humidity during the dry seasons. This leads to increased perspiration, causing itching and distress. To cope with the heat, occupants in the studied building preferred taking baths twice a day and opening windows during the day to promote natural ventilation.

Harmattan season: The dry season in this climatic zone, particularly in December, is characterized by Harmattan, which brings cool dry air and dust. While cooler conditions prevail during the day, it increases the risk of cold, catarrh, fever, and other respiratory diseases. Occupants wore sweaters and protective clothing to guard against the cold. They closed windows to prevent dust haze from entering indoor spaces. Some occupants used fireplaces in the outdoor kitchen to warm their bodies. Bathing every day became a challenge due to the inherent cold.

Cooler room temperature and cool breeze at night: From 1:00 pm to 6:00 am, the room temperature becomes cooler, and a cool breeze is present during the dry seasons. This makes night sleep more comfortable and cooler. As a result, there was a reduction in the usage of ventilating and other active systems. Windows were opened during this period to maintain comfort.

These findings highlight the thermal changes experienced during the dry seasons and the corresponding effects on human comfort. Occupants employ adaptive strategies such as using cooling systems, natural ventilation, adjusting bathing habits, and wearing appropriate clothing to manage these changes. Understanding these patterns can inform the design and implementation of strategies to enhance comfort during the dry seasons.

Table 4.1: Summary of the thermal changes observed during the dry seasons in the case study.

THERMAL CHANGES DURING THE DRY SEASONS			
S/N	**CHARACTERISTICS**	**EFFECTS ON HUMAN COMFORT**	**ADAPTIVE STRATEGY**
1	Increase in air and room temperature (usually from 10:00am to 12:00am) precipitated by intense solar radiation and solar gains	Night sleep is disturbed by a warm and muggy indoor climate.	Occupants relied on cooling and mechanical ventilating units to regulate the indoor climate. They preferred opening their windows during this period to stimulate natural ventilation. Evidently, there was a reduction in the use of hot water for bathing in the evenings
2	Increase in humidity usually from 4 pm to 11pm	Perspiration increases giving room to itching, distress,	Owing to the heat wave, most of the occupants of the studied building prefer taking their bath twice every day as well a opening their windows to promote natural ventilation of the spaces during the day.
3	The dry season in this climatic zone comes with Harmattan which is characterized by cool dry air as well as dust (usually in the month of December)	Cooler conditions increase among occupants during the day. This effect predisposes occupants to diseases such as cold, catarrh, fever and other related respiratory diseases.	The occupants of the building were seen wearing sweaters and other protective wear to guard against cold. Their windows were usually closed to prevent dust haze into the indoor spaces. Some of the occupants were seen heating up their bodies at fire place (in the outdoor kitchen). Bathing everyday became a challenge because of the inherent cold.
4	Cooler room temperature and cool breeze in the nights (from 1pm to 6am)	Night sleep became more comfortable and cooler from around 1:00am till morning.	There was a reduction in the usage of ventilating and other active systems. Windows were opened during this period to maintain the comfort.

Table 4 summarizes the observed thermal changes during the wet seasons in the case study. The characteristics, effects on human comfort, and adaptive strategies employed by the occupants are presented.

Increase in rainfall: During the wet seasons, the increased rainfall lowers the room temperature, resulting in cooler indoor air quality. While this can enhance human comfort, it can also lead to excessive cold exposure and potential health issues such as pneumonia, catarrh, and cough. To mitigate the cold air, occupants preferred to close their windows and wear thick clothes. Additionally, there was increased usage of hot and warm water for domestic purposes to protect their bodies. High humidity during hot days: The high humidity levels during hot days contribute to thermal discomfort in the indoor climate due to the

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accumulation of hot air in the building spaces. To alleviate this discomfort, occupants preferred to open their windows, allowing for better ventilation and air circulation.

Cooler indoor air in the nights: The indoor air during the nights is typically cooler, accompanied by a cool breeze. This period is generally comfortable for the occupants, except for some months between March and June. To optimize comfort during this time, the occupants increased the use of ventilating and cooling units in the evenings before sleep. Additionally, most windows were opened to facilitate the entry of the cool breeze.

These observations highlight the adaptive strategies employed by the occupants to maintain comfort during the wet seasons. They adjusted their behaviour by controlling window openings, using appropriate clothing, and utilizing cooling and ventilation systems. Understanding these thermal changes and adaptive strategies is crucial for designing buildings that can better respond to weather variations, ensuring occupants' comfort and well-being.

Table 4.2: Summary of the thermal changes observed during the wet seasons in the case study.

THERMAL CHANGES DURING THE WET SEASONS			
S/N	CHARACTERISTICS	EFFECTS ON HUMAN COMFORT	ADAPTIVE STRATEGY
1	Increase in rrainfall which lowers the room temperature	Cooler indoor air quality maximizing human comfort. Sometimes it could be colder exposing occupants to pneumonia, catarrh, cough and the likes.	They preferred closing their windows during this period to prevent the cold air from entering into the indoor spaces as well as wearing thick clothes. Evidently, there was an increased usage of hot and warm water for domestic purposes by the occupants to protect their body.
2	High humidity during hot days	This leads to thermal discomfort of the indoor climate owing to the increase in hot air in the building spaces during hot days.	The occupants prefer opening their windows.
3	The indoor air is usually cooler laden with cool breeze in the nights	Nights are usually comfortable except for some periods between March and June.	There was an increased use of ventilating and cooling units in the evenings prior to night sleep. Also, most windows were opened in this period.

4.3. Thermal transmission from the external to the internal environment of the case study

The research result proves that building materials pose thermal properties and responses to meteorological changes. During the day especially between 11:00 am to 4:00 pm the gable roof of the case study composed of corrugated iron roofing sheets characterized by high thermal conductivity of 112.2 W/Mk and pitched at a slope angle of 7^0(of low roof space) was observed radiating heat through the roof space to the ceiling board - made of asbestos which is characterized with thermal conductivity of 0.08 W/Mk dissipating the heat absorbed from the roof system into the indoor spaces of the building constituting in hot conditions in the indoor climate. More so, other external materials enveloping the building contribute to conveying different degrees of heat and cold into the indoor spaces and invariably affecting the living and sleeping conditions of the occupants in the building. During the period of observation, it was discovered that from 1:00 am to 8:00 am in the morning it's usually cooler and more comfortable in most times during the wet seasons owing to the fact that within this time frame the heat gained by the external building surfaces masked with some internal surfaces have lost their latent energy. This phenomenon of heat loss is further animated by a cool breeze at night to attain thermal comfort for the occupants.

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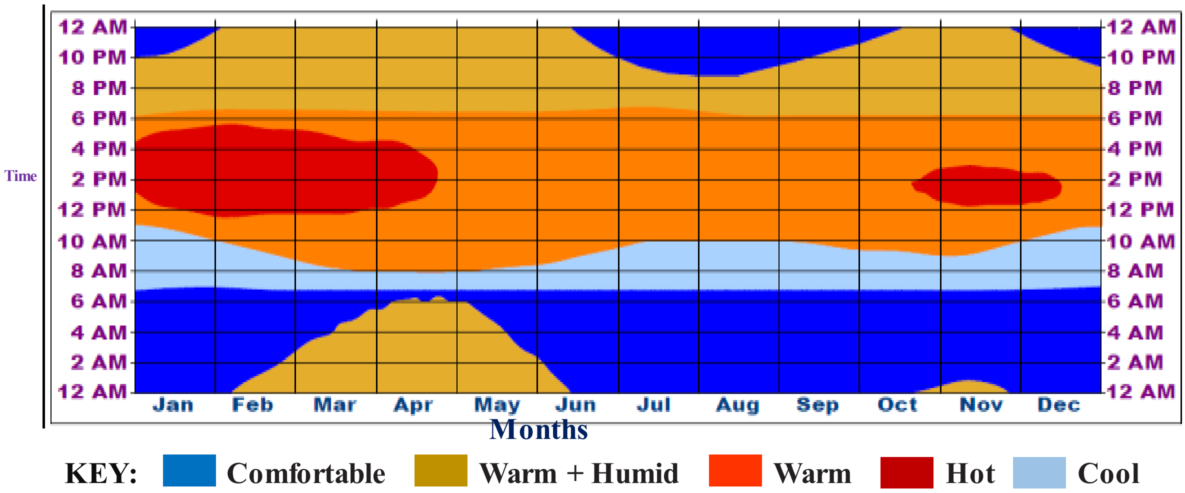

Figure 4.3: A representation of how thermal changes can affect human comfort in spaces

To present the research results obtained from the period of observation, a graph was used to roughly show the changes recorded in the indoor spaces across the years of study (during the dry and wet seasons). From 12:00am to 6:00am, the thermal condition of the indoor spaces was described as cool with some pockets of warm and humid conditions from February to May within the period of observation as captured by the graph. This condition was drawn to be precipitated by the loss in the latent energy of the heat gained by the surfaces that compose the space as well the indoor air. More so, from 10:00am to 6:00pm the indoor climate was described as Warm with pockets of hot periods (between 12:00pm and 4:00pm from the month of November to April These hot periods were also felt in wet seasons but were usually damped by the rains. From 6:00am to 10:00am in the morning, the indoor climate was described as comfortable and pleasing to the occupants while between 6:00pm to 11:00pm was classified as warm and humid due to the fact that the heat gained by the surfaces that compose the indoor spaces are at this point gradually increase the room air temperature and humidity thus, making the indoor spaces muggy and uncomfortable for the occupants.

In summation, the different conditions felt by the occupants of the studied residential building were characterised by a larger coverage for warm periods pushing up the high demand for energy by the occupants to regulate the indoor climate of their building spaces. In addition, this study has been able to roughly categorize the different conditions that constitute indoor spaces due to the corresponding impact of climate and weather variables in dry and wet seasons. To conclude the study, recommendations to address the issues of climate change on human comfort.

4.4. The relationship between thermal changes and human comfort

Changes in temperature affect human comfort as gathered from the case study. Occupants of the analysed residential building longed for cooling systems especially in the evening prior to night sleep due to an increase in room temperature during the day and on some nights.

5. CONCLUSION AND RECOMMENDATION

In conclusion, this research article focused on the impact of climatic and weather changes on the comfort of residents in Imo state, which lies in a tropical monsoon climate. The study aimed to assess the state of the indoor environment of residential buildings in Imo state, analyze the effect of thermal changes on the comfort of residents, and recommend adaptive strategies to address these comfort issues. The research findings revealed that meteorological changes, including increasing temperatures and decreasing rainfall, have significant implications for the indoor climate of buildings in Imo state.
The analysis of meteorological data from 1979 to 2021 showed a gradual increase in mean annual temperature and a decrease in mean total rainfall in Imo state. These changes indicate a warming and drying trend, which has led to thermal changes in building spaces. The thermal conductivity of materials and components in the selected case study building was examined, highlighting their impact on heat transfer and the indoor thermal environment.

The research also explored the adaptive strategies and responses adopted by the occupants of the studied residential building to cope with thermal changes. These strategies included the use of cooling and mechanical ventilating units, opening windows for natural ventilation, adjusting bathing habits, and wearing appropriate clothing. During the wet seasons, occupants tended to close windows to prevent cold air from entering and used hot water for domestic purposes to maintain comfort.

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The findings emphasize the importance of considering climate change and meteorological factors in the design and operation of residential buildings in Imo State. Architects, building industry professionals, and users need to be aware of the potential impacts of thermal changes on indoor comfort and implement appropriate design and adaptive strategies. Additionally, policymakers and stakeholders should prioritize climate-responsive building practices and systems to mitigate the adverse effects of climate change on human health and well-being.

While this research provides valuable insights into the specific context of Imo state, there are limitations to be acknowledged. The study faced challenges in accessing a large sample size of individual residential buildings, leading to the adoption of a case study approach. Further research should aim to expand the scope and scale of investigations to capture a more comprehensive understanding of the impact of climate and weather changes on building comfort in tropical monsoon climates.

Overall, this research contributes to the body of knowledge on the influence of climate change on the indoor environment and provides valuable insights for architects, building industry professionals, and policymakers in developing climate-responsive buildings and systems. By taking proactive measures and implementing adaptive strategies, it is possible to create comfortable and sustainable living spaces that mitigate the adverse effects of climatic and weather changes.

5.1. Recommendation

This study proposes the following recommendations

- *Keen attention to meteorological studies*
  In the design process of buildings, studies of the weather behaviour and climatic characteristics of the location of any proposed building project should be obtained and critically considered in the design of such buildings. Such studies are a prerequisite for designing climate-responsive buildings to promote human comfort in living spaces and lessen carbon footprints in buildings. For buildings located in the tropical monsoon climate, building elements like windows should be sizeable and strategically positioned to allow the free flow of air and cross ventilation in the building spaces. Green and water architecture should be promoted. Buildings should have ample roof space and headroom to lower heat transmission into spaces from the roof. To further promote the concept of designing buildings that respond to climate change, architects should lead their awareness in the building industry via conferences, workshops, seminars, television shows, radio programs, print media, social media and group discussions.

- *Comprehensive legislation and implementation of the climate protection act at the 3 tiers of government*
  The federal, state, and local governments should enact laws and regulations geared towards promoting climate-responsive designs, energy-efficient buildings, clean and renewable energy uses, and use of sustainable building materials and systems. They should be committed to implementing all national and international agreements on protecting the climate and ameliorating human living conditions in buildings.

- *Technology for Tropical monsoon climate*
  Advancements in technology for cooling systems should be adaptive to the climatic characteristics and potentials of the tropical monsoon climate. This study proposes futuristic technologies such as; solar-powered standing, and hand fans, hybrid air-conditioning units and humidifiers (which can solar powered and rechargeable), and solar roofs will be helpful in regulating the thermal changes in buildings. Such advancements should promote the use of clean and renewable energy sources.

- *Adoption of adaptive strategies and measures in the planning, design, construction, occupation, operation and maintenance of buildings*
  Design strategies should be considered and captured by architects in their building design and such recommendations communicated to the client in a clear format. Cooling strategies such as natural ventilation, evaporative cooling (direct and indirect), dehumidification, air conditioning, (active cooling) mechanical ventilation, high mass with night-time ventilation, high thermal mass and shading should be considered and incorporated into the building manual. However, cooling strategies for different thermal changes felt by users during the day and at night for the months of the year should be considered during the design, construction and post-construction stages of a building. The Heating, Ventilating, and Air-conditioning systems (HVAC) should be well designed and specified in the service drawings of a building taking cognizance of the climatic zone the building location falls in. Architects are encouraged to design building sites and landscapes taking cognizance of the orientation, zoning, thermal properties of landscaping elements, and ecosystem to stimulate adaptability within their climatic zones.

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- *Choice of building materials, components, methods, and systems*
  Stakeholders and players in the building industry should ensure the use of sustainable building materials and methods that regulate thermal exchange from the external environment to the internal environment of buildings. Architects should specify building materials that have minimal impact on climate change as well as prevent weather effects in building spaces. They should give special attention to shading devices, and open, green, and outdoor spaces in the building and urban environment.

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