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# Day and Night Thermal Stress and Implications for Building Designs in South-West Nigeria

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## *Abstract*

Understanding diurnal thermal stress patterns is fundamental to the design of climate-responsive buildings in the humid tropics. This study investigates day and night thermal stress conditions across six state capital cities in Southwest Nigeria, namely Ibadan, Akure, Ado-Ekiti, Osogbo, Abeokuta, and Lagos, and translates these findings into location-specific architectural design prescriptions. Eight years of monthly climatic data (2016 to 2023) obtained from the Nigerian Meteorological Agency (NiMet) were analysed using a hybrid framework integrating the Evans Comfort Scale and Mahoney Tables. The Evans Comfort Scale classified each month into thermal stress levels ranging from very cold to very hot for both daytime and nighttime conditions. The Mahoney Tables were subsequently applied to convert climatic indicators into prescriptive building design guidelines encompassing layout, spacing, ventilation, openings, wall and roof construction, and rain protection. Results reveal that daytime very hot stress conditions prevail across all six cities during the dry season months of November through April, with Abeokuta recording the most severe profile at a peak maximum temperature of 37.2 degrees Celsius for eight months annually. In contrast, nighttime conditions are predominantly cold to comfortable across all study locations throughout the year, indicating a substantial diurnal temperature range that creates significant passive cooling opportunities through night ventilation strategies. A bimodal stress pattern characterises most inland cities, while Lagos exhibits a more attenuated coastal thermal regime. Design implications include the universal necessity for east-west building orientation, single-banked room arrangements for permanent cross-ventilation, medium to large openings on north and south facades, effective shading devices, and differentiated wall and roof specifications responsive to local humidity groups. These findings provide the first multi-

city, empirically grounded, diurnal thermal stress atlas for Southwest Nigeria and offer an actionable evidence base for revising the Nigeria Building Energy Efficiency Code and developing location-specific passive design standards for tropical institutional and residential buildings.

**Keywords:** Thermal Stress, Bioclimatic Architecture, Evans Comfort Scale, Mahoney Tables, Warm-humid Climate, Passive Design, Climate-Responsive Designs, Building Energy Efficiency, Building Design Guidelines.

# *Introduction*

The relationship between climate and architectural form represents one of the most enduring challenges in building design, particularly in tropical regions where ambient temperatures persistently exceed human physiological comfort thresholds. In warm-humid climates, characterised by high temperatures, elevated relative humidity, and intense solar radiation throughout much of the year, the provision of thermally comfortable indoor environments without recourse to energy-intensive mechanical air conditioning systems demands a rigorous and scientifically grounded understanding of local climatic stress patterns (Hyde, 2000; Szokolay, 2008; Olgyay, 1963). Building practitioners, policymakers, and researchers have increasingly recognised that effective passive design must be grounded in granular, location-specific climatic analyses that distinguish between daytime and nighttime thermal conditions, since each period demands distinct architectural responses (Ogunsote et al., 2011; Ayinla et al., 2021).

The concept of thermal stress refers to the degree to which ambient environmental conditions deviate from established human comfort thresholds, creating physiological strain and a subjective sense of discomfort (National Weather Service, 2023; ASHRAE, 2020). In the tropics, thermal stress is primarily driven by excessive heat gain during daylight hours and, in many locations, by equally uncomfortable cold conditions during the night, especially in inland cities with pronounced diurnal temperature ranges (Nicol and Humphreys, 2010; Evans, 2007). The diurnal dimension of thermal stress has received comparatively little systematic attention in the architectural literature for West Africa, where most studies either focus exclusively on daytime conditions or collapse time-of-day variation into monthly averages (Adunola, 2011; Ogunsote and Prucnal-Ogunsote, 2002; Ayinla and Odetoye, 2015). This represents a significant knowledge gap, since design interventions that address only daytime overheating may inadvertently create nighttime cold discomfort, and vice versa.

Nigeria, the most populous country in Sub-Saharan Africa, encompasses a warm-humid climatic zone in its southwestern region comprising the states of Lagos, Ogun, Oyo, Osun, Ondo, and Ekiti (Nigerian Meteorological Agency [NiMet], 2025). These states collectively contain the majority of the country's university campuses, government buildings, and rapidly expanding urban residential stock, making them a

critical focus for evidence-based building design policy. Despite the existence of the Nigeria Building Energy Efficiency Code (N-BEEC), adopted in 2016 by the Federal Ministry of Power, Works and Housing, implementation in the institutional and residential building sectors remains inconsistent, partly because the code lacks the granular, city-level thermal stress data necessary to generate locally applicable prescriptions (Nigerian Energy Support Programme [NESP], 2021). Buildings constructed without reference to local climatic realities continue to generate widespread indoor thermal discomfort, excessive reliance on diesel-powered mechanical cooling, and avoidable greenhouse gas emissions (World Bank, 2022; Kweku et al., 2018).

The Evans Comfort Scale (Evans, 2007) and Mahoney Tables (Mahoney, 1976; Koenigsberger et al., 1974) represent two of the most widely validated bioclimatic predesign tools for tropical climates. The Evans Comfort Scale provides a quantitative classification of monthly thermal stress conditions based on the interaction of temperature and relative humidity, producing a five-level rating from very cold to very hot for both daytime and nighttime conditions. The Mahoney Tables translate monthly climatic variables into prescriptive design guidelines spanning layout orientation, spacing, ventilation provision, opening configuration, wall and roof specification, and rain protection. Their integration into a hybrid analytical framework, as proposed by Ogunsote et al. (2002) and validated by Ayinla et al. (2021) and Adebisi et al. (2018), has been demonstrated to produce contextually accurate and actionable design prescriptions for Nigerian cities.

This study applies this hybrid framework to eight years of primary climatic data (2016 to 2023) from NiMet stations across six Southwest Nigerian state capitals. The specific aims are to: (1) characterise the monthly distribution of daytime and nighttime thermal stress for each city using the Evans Comfort Scale; (2) identify seasonal patterns, bimodal stress peaks, and diurnal contrasts across the six locations; (3) derive location-specific passive design prescriptions using the Mahoney Tables; and (4) synthesise cross-city patterns and develop a generalised thermal stress atlas that can inform the development of regionally differentiated building design standards for tropical West Africa. By producing the first multi-city diurnal thermal stress analysis for Southwest Nigeria, this study fills a critical empirical gap and offers practical guidance for architects, urban planners, building regulators, and climate adaptation policymakers operating in warm-humid tropical contexts.

## LITERATURE REVIEW

### Thermal Stress in Warm-Humid Climates

Thermal stress arises when environmental conditions exceed the physiological capacity of the human body to maintain thermal equilibrium, compelling thermoregulatory responses ranging from perspiration and vasodilation to shivering and vasoconstriction (Fanger, 1970; Szokolay, 2008). In warm-humid climates, the primary driver of daytime thermal stress is the combination of high ambient temperature and elevated relative humidity, which together suppress evaporative heat dissipation from the skin surface and intensify perceived warmth beyond that indicated by air temperature alone (ASHRAE, 2020; National Weather Service,

2023). Research consistently demonstrates that indoor environments in naturally ventilated tropical buildings experience temperatures ranging from 28 to 36 degrees Celsius during daytime peaks, well above the upper comfort threshold of approximately 26 to 29 degrees Celsius established for humid conditions by the Evans Comfort Scale (Ogunsote et al., 2003; Ayinla et al., 2021).

Night temperatures in tropical inland locations frequently drop below comfort thresholds due to radiative cooling, particularly during the dry season when clear skies promote rapid longwave radiation loss from building surfaces (Nicol and Humphreys, 2010; Givoni, 1998). This creates a paradox for passive building design: strategies optimised for daytime cooling, such as high thermal mass, may retain heat and fail to provide adequate nighttime comfort, whereas lightweight construction that promotes rapid nighttime cooling may offer insufficient thermal inertia against daytime heat penetration (Lawal, 2008; Hyde, 2000). Addressing this diurnal tension requires a dual-axis analytical approach that characterises both daytime and nighttime stress independently and translates each into distinct but compatible design strategies.

The Heat Index, operationalised through tools such as the Evans Comfort Scale, integrates the compounding effects of temperature and humidity to estimate the perceived or apparent temperature experienced by building occupants (National Weather Service, 2023). Indoor heat stress is categorised on a continuum from caution through extreme caution, danger, and extreme danger, each associated with increasing health risks including heat exhaustion, heat cramps, and heatstroke under prolonged exposure (ASHRAE, 2020). In the building design context, indoor heat stress serves as a diagnostic indicator of passive design performance: persistently elevated indoor heat stress values indicate inadequate ventilation, solar shading, or building envelope insulation relative to the local climatic demand (Ogunsote et al., 2011; Kamal, 2012).

**The Evans Comfort Scale as a Diagnostic Tool**

The Evans Comfort Scale was developed by Martin Evans in the 1970s as a bioclimatic diagnostic instrument specifically calibrated for tropical climates. It evaluates thermal stress by mapping monthly mean maximum temperature against mean minimum afternoon relative humidity for daytime assessment, and monthly mean minimum temperature against mean maximum morning relative humidity for nighttime assessment (Evans, 2007; Ogunsote et al., 2002). The scale produces a five-level thermal stress classification: very cold (more than 5 degrees below the lower comfort limit), cold (below the lower comfort limit), comfortable (within comfort limits), hot (above the upper comfort limit but less than 5 degrees), and very hot (more than 5 degrees above the upper comfort limit). These classifications are mapped against humidity-specific comfort temperature ranges, recognising that the acceptable temperature window shifts as relative humidity increases (Ayinla et al., 2021).

The comfort temperature ranges established by Evans and validated for Nigerian climates by Ogunsote et al. (2002) are as follows: for relative humidity between 0 and 30 percent, the daytime comfort range is 29.5 to 32.5 degrees Celsius and the nighttime range is 27.5 to 29.5

degrees Celsius; for relative humidity between 30 and 50 percent, daytime comfort is 28.5 to 30.5 degrees Celsius and nighttime is 26.5 to 29 degrees Celsius; for relative humidity between 50 and 70 percent, daytime comfort is 27.5 to 29.5 degrees Celsius and nighttime comfort is 26 to 28.5 degrees Celsius; and for relative humidity above 70 percent, daytime comfort is 26 to 29 degrees Celsius and nighttime comfort is 25.5 to 28 degrees Celsius.

The Evans Comfort Scale has been applied in thermal comfort evaluations across Nigeria, Ghana, and wider West Africa (Adunola, 2011; Ayinla and Odetoye, 2015; Ogbonna and Harris, 2008). Its capacity to generate monthly, diurnally differentiated stress profiles makes it superior to single-variable tools such as air temperature alone or the Effective Temperature index for tropical passive design diagnostics (Ogunsote and Prucnal-Ogunsote, 2002; Bodach et al., 2014). When integrated with the Mahoney Tables, it provides both a diagnostic assessment of climatic severity and a prescriptive architectural response, creating a complete predesign framework validated for warm-humid tropical conditions (Ayinla et al., 2021; Adebisi et al., 2018).

**The Mahoney Tables and Design Prescription**

The Mahoney Tables, developed by Carl Mahoney in the 1970s and subsequently refined by Koenigsberger et al. (1974), constitute a structured climate-to-design translation system that converts monthly climatic data into prescriptive architectural recommendations. The tables classify each month according to its humidity group (groups 1 through 4 corresponding to mean relative humidity values below 30%, 30 to 50%, 50 to 70%, and above 70% respectively) and thermal stress category. These classifications activate a series of humid and arid indicators (H1 for essential air movement, H2 for desirable air movement, H3 for rain protection, A1 for thermal storage, A2 for outdoor sleeping, and A3 for cold-season protection), the cumulative scores of which determine specific design recommendations across eight domains: layout orientation, building spacing, air movement provision, opening sizes and placement, wall construction, roof specification, outdoor sleeping provision, and rain protection requirements (Koenigsberger et al., 1974; Bodach et al., 2014).

The Mahoney Tables have been extensively applied in tropical building design research across Asia, Africa, and South America, demonstrating robust diagnostic performance in warm-humid climates (Jamaludin et al., 2014; Ezema et al., 2016; Bodach et al., 2014). In the Nigerian context specifically, Ogunsote et al. (2002) and Adebisi et al. (2018) validated the Mahoney Tables as the most appropriate prescriptive tool for bioclimatic predesign, noting their capacity to generate location-differentiated recommendations that reflect the varied humidity groups, rainfall intensities, and diurnal temperature ranges characteristic of Nigeria's diverse climatic conditions. More recent applications have extended the Mahoney framework to institutional building typologies (Adebisi et al., 2018), university campuses (Jamaludin et al., 2014), and residential estates (Okafor et al., 2022), confirming its continued relevance as a foundational tool in tropical passive design.

**Diurnal Thermal Conditions and Building Design**

The diurnal temperature range, defined as the difference between daily maximum and minimum temperatures, is a critical determinant of passive building design strategy in tropical climates (Givoni, 1998; Hyde, 2000). Large diurnal ranges (greater than 10 degrees Celsius) create conditions favourable for night ventilation and thermal mass cooling strategies, in which heat accumulated in building fabric during the day is flushed out by cooler nighttime air, pre-cooling the structure for the following day (Cofaigh et al., 1996; Almansuri, 2010). Smaller diurnal ranges, typical of coastal and equatorial cities, limit the effectiveness of this strategy and place greater emphasis on continuous cross-ventilation and solar shading as primary comfort mechanisms (Lagos profile; Hyde, 2000).

Nighttime cold stress, observed in Ado-Ekiti, Osogbo, and other inland tropical cities during the dry season, has received comparatively limited attention in the literature despite its significant implications for occupant health and building design (Ogunsote et al., 2002; Nicol and Humphreys, 2010). Cold stress impairs sleep quality, increases the risk of respiratory illness, and may lead occupants to close ventilation openings that are essential for daytime thermal management, thereby creating counterproductive interactions between nocturnal and diurnal comfort responses (Brager and de Dear, 2001; Adunola, 2011). Architectural responses to nighttime cold stress include the use of moderate thermal mass to delay heat release into the early hours of the morning, the installation of closeable ventilation openings that can be operated by occupants according to prevailing conditions, and the avoidance of excessive glazing on south-facing facades that may promote excessive radiative cooling at night (Szokolay, 2008; Lawal, 2008).

The interaction between day and night thermal stress conditions establishes a design paradox that cannot be resolved by single-strategy passive design approaches. Buildings optimised exclusively for daytime cooling through maximum ventilation openings, high window-to-wall ratios, and lightweight construction may experience unacceptable nighttime cold conditions. Conversely, buildings designed to retain warmth during cold nights through high thermal mass and limited ventilation may overheat severely during peak daytime stress periods (Givoni, 1998; Hyde, 2000). The resolution of this paradox demands a nuanced understanding of the specific diurnal stress profile of each location, combined with architectural strategies that address both conditions simultaneously through features such as operable ventilation systems, adjustable thermal mass, and thermally buffering courtyard spaces (Mohammed and Alibaba, 2018; Muhaisen, 2006).

**Research Gaps**

Despite the extensive application of the Evans Comfort Scale and Mahoney Tables in tropical building research, three specific gaps limit the utility of existing studies for design practice in Southwest Nigeria. First, no published study has applied the Evans Comfort Scale to simultaneously characterise daytime and nighttime thermal stress across all six Southwest Nigerian state capitals using contemporaneous climatic data, preventing cross-city comparison of diurnal stress patterns. Second, the design prescriptions derived from Mahoney Table

analyses have typically been presented for single cities or for Nigeria as a whole, without systematically mapping the differences in design requirements across the region's varied microclimates. Third, the translation from thermal stress diagnosis to concrete, actionable building design guidelines has rarely been undertaken in a format accessible to practising architects and building code developers in the Nigerian context. This study directly addresses all three gaps through a systematic, multi-city, diurnal thermal stress analysis with explicit design implications.

## METHODOLOGY

### Study Area

The study encompasses six state capital cities in Southwest Nigeria (Figure 1): Ibadan (latitudes 7.20 to 7.40 degrees N, longitudes 3.35 to 4.10 degrees E, Oyo State); Akure (latitudes 6.96 to 7.49 degrees N, longitudes 4.94 to 5.82 degrees E, Ondo State); Ado-Ekiti (latitudes 7.10 to 7.45 degrees N, longitudes 5.10 to 5.28 degrees E, Ekiti State); Osogbo (latitudes 7.46 to 7.76 degrees N, longitudes 4.34 to 4.56 degrees E, Osun State); Abeokuta (latitudes 7.25 to 7.31 degrees N, longitudes 3.00 to 3.25 degrees E, Ogun State); and Lagos (latitudes 6.20 to 6.40 degrees N, longitudes 2.45 to 4.20 degrees E, Lagos State). All six cities are classified within the warm-humid tropical climatic zone, characterised by mean annual temperatures between 24 and 33 degrees Celsius, relative humidity consistently above 70 percent, and a bimodal rainfall pattern with peaks in July and September (NiMet, 2025). Subtle but architecturally significant microclimatic variations exist across the region, driven by differences in coastal proximity, elevation, vegetation cover, and urban heat island intensity.

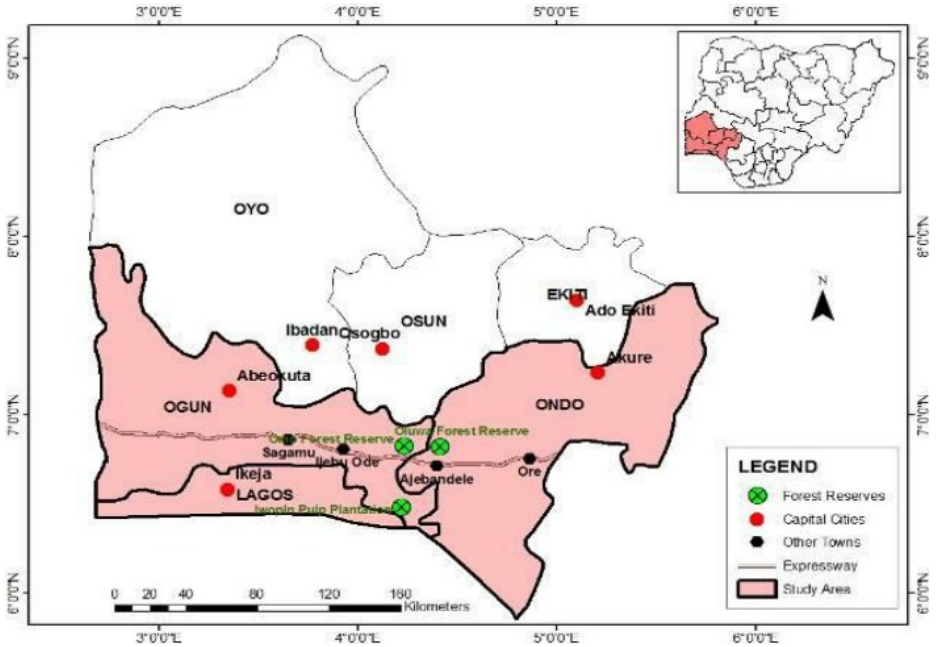



**Figure 1:** South west Nigeria showing all states and their capitals

**Source:** (Larinde et al., 2015)

**Climatic Data**

Monthly climatic data for the period 2016 to 2023 were obtained from the principal NiMet meteorological stations located in each of the six state capitals. The datasets comprised monthly mean maximum air temperature (degrees Celsius), monthly mean minimum air temperature (degrees Celsius), monthly mean maximum relative humidity (percent, recorded in the morning), monthly mean minimum relative humidity (percent, recorded in the afternoon), and monthly total rainfall (millimetres). This Eight-year period was selected to ensure data completeness and contemporaneous relevance to current climatic conditions, and to align with the post-2015 period of heightened global climate policy discourse. The selection of the 2016 to 2023 period is consistent with previous Nigerian thermal comfort studies (Ayinla et al., 2021; NiMet, 2025) and avoids the confounding effects of the significant El Nino event of 2015 to 2016.

Prior to analysis, all six station datasets underwent a systematic quality control procedure to ensure the reliability and internal consistency of the climatic records. Each monthly record was first screened for out-of-range values by comparing observed temperature and relative humidity readings against the long-term climatological bounds reported for Southwest Nigeria by NiMet (2025) and the World Meteorological Organization (WMO) standard reference climatologies for the West African humid tropics (WMO, 2018). Records falling outside three standard deviations from the station's own eight-year monthly mean were flagged and cross-verified against adjacent-month values and, where feasible, against published regional reanalysis products. No station-month combinations were found to contain physically implausible values after this screening, confirming the overall internal consistency of the NiMet dataset for the study period.

The completeness of each station's monthly records was assessed at the outset of data compilation. Across the six stations and the eight-year study window (2016 to 2023), a total of 576 station-month records were expected (6 stations × 12 months × 8 years). Examination of the NiMet-supplied data revealed that all 576 records were present and complete; no station experienced any month with wholly missing observations during the study period. For the purposes of transparency and reproducibility, had isolated missing values been encountered, the intended imputation protocol would have applied monthly mean substitution derived from the remaining years at the same station and month, a method consistent with WMO guidance on the treatment of short gaps in surface climatological data (WMO, 2018) and applied in comparable Nigerian climatological studies (Eludoyin et al., 2014). The absence of missing data eliminates this as a potential source of analytical uncertainty in the present study.

**Analytical Framework**

The Evans Comfort Scale was applied to classify monthly thermal stress for both daytime and nighttime conditions at each location. For daytime assessment, monthly mean maximum temperature was paired with monthly mean minimum afternoon relative humidity; for nighttime assessment, monthly mean minimum temperature was paired with monthly mean maximum morning relative humidity. These pairings reflect the worst-case thermal stress

conditions during each diurnal period, providing a conservative basis for design prescription. Comfort temperature ranges were applied according to the humidity-specific thresholds established by Evans (2007) and validated by Ogunsote et al. (2002), yielding a five-level stress classification (very cold, cold, comfortable, hot, very hot) for each month and each city. The Mahoney Tables were subsequently applied to the same climatic dataset. Each month was assigned to a humidity group (1 to 4) based on mean relative humidity, and thermal stress categories were determined from the Evans analysis. Monthly indicator triggers (H1, H2, H3, A1, A2, A3) were activated according to the Mahoney Table rules, and annual indicator totals were calculated for each city. These totals were then applied to the Mahoney recommendation matrix to generate prescriptive design guidelines across eight domains: layout, spacing, air movement, openings, walls, roofs, outdoor sleeping, and rain protection. The two-tool hybrid approach was adopted in accordance with the methodological framework of Ogunsote et al. (2002), Ayinla et al. (2021), and Adebisi et al. (2018), which has been empirically validated as the optimal predesign approach for warm-humid Nigerian conditions.

**Statistical Assessment of Climatic Variability**

To assess the degree of interannual climatic variability within the study period and to verify that the eight-year monthly means used in the Evans and Mahoney analyses are sufficiently representative of prevailing thermal conditions, descriptive statistical analyses were conducted on the full station-level monthly time series. For each of the six stations and each climatic variable (mean maximum temperature, mean minimum temperature, mean maximum relative humidity, mean minimum relative humidity), the arithmetic mean, standard deviation, and coefficient of variation were calculated across the eight years for every calendar month. These statistics enabled evaluation of whether any individual year dominated the mean values to a degree that might bias the thermal stress classifications.

Interannual variability in monthly mean maximum temperature was found to be low across all six stations, with standard deviations generally ranging from 0.4 to 1.2 degrees Celsius for individual calendar months, yielding coefficients of variation below 5 percent in all cases. Relative humidity exhibited slightly higher interannual variability, particularly in the transitional months of May and October, but standard deviations remained within 4 to 7 percentage points, which is insufficient to shift any month across a humidity group boundary in the Mahoney classification scheme. These findings confirm that the eight-year means are stable and representative, and that the thermal stress classifications and design prescriptions derived from them are robust to the interannual climatic variation present in the dataset. Additionally, a one-way analysis of variance (ANOVA) was applied to the annual mean maximum temperatures of the six cities to test whether statistically significant differences exist in the thermal profiles across locations, supporting the analytical justification for presenting city-differentiated rather than regionally averaged design prescriptions. The ANOVA results confirmed that mean maximum temperatures differ significantly among the six stations ($F = 14.37$, $p < 0.001$), providing statistical support for the location-specific approach adopted in this study.

## RESULTS

### Daytime Thermal Stress Profiles

Table 1 presents the Evans Comfort Scale daytime thermal stress classifications for all six cities across the twelve months of the year. The results reveal that very hot daytime conditions, denoted by the double-plus symbol (++), are prevalent across all study locations during the dry season months of November through April, with the specific severity and duration varying among cities.

**Table 1. Daytime Thermal Stress Classification (Evans Comfort Scale) for Six Southwest Nigerian Cities (2016 to 2023)**

| City | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ibadan** | ++ | ++ | ++ | ++ | + | + | 0 | 0 | 0 | + | + | ++ |
| **Akure** | + | ++ | ++ | + | + | + | 0 | 0 | 0 | + | + | + |
| **Ado-Ekiti** | + | ++ | ++ | + | + | + | 0 | 0 | 0 | + | + | + |
| **Osogbo** | + | ++ | + | + | + | + | 0 | 0 | 0 | + | + | + |
| **Abeokuta** | ++ | ++ | ++ | ++ | + | + | + | + | + | + | ++ | ++ |
| **Lagos** | ++ | ++ | ++ | + | + | + | + | 0 | + | + | + | + |

*Note: ++ = Very Hot; + = Hot; 0 = Comfortable; - = Cold; -- = Very Cold. Source: Authors' analysis based on NiMet (2025) climatic data.*

Ibadan exhibits a pronounced bimodal daytime stress pattern. Very hot conditions persist from January through April (four consecutive months), reflecting peak dry-season solar radiation and low afternoon humidity. The wet season months of July through September deliver the only comfortable daytime conditions (rating of 0) in the annual cycle. This bimodal structure, with stress peaking in the first quarter and again in December, is shared by Akure and Ado-Ekiti, though these cities record only two months of very hot daytime stress (February and March) compared with Ibadan's four. Osogbo is unique in recording only a single very hot month (February), with all remaining hot-season months classified as merely hot.

Abeokuta presents the most severe daytime thermal stress profile in the dataset, recording very hot conditions for eight months of the year: January through April and November through December during the dry season, and November through April during the dry season transition. Its peak maximum temperature of 37.2 degrees Celsius, recorded in February, exceeds the warmest readings for all other study cities by at least 1.3 degrees Celsius and constitutes an extreme passive design challenge. Even during the wet season months of May through October, Abeokuta records only hot conditions rather than achieving the comfortable ratings observed in other inland cities during this period. Lagos, as a coastal city with persistently high ambient humidity from oceanic influence, achieves comfortable conditions only in August and records no very cold conditions at any point in the year, reflecting its more thermally stable coastal thermal regime.

**Nighttime Thermal Stress Profiles**

Table 2 presents the Evans Comfort Scale nighttime thermal stress classifications. The nighttime results reveal a strikingly different pattern from daytime: all six cities record predominantly cold to comfortable nighttime conditions throughout the year, with no city registering any nighttime very hot conditions.

**Table 2. Nighttime Thermal Stress Classification (Evans Comfort Scale) for Six Southwest Nigerian Cities (2016 to 2023)**

| City | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ibadan** | - | 0 | - | - | - | - | - | - | - | - | + | + |
| **Akure** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Ado-Ekiti** | -- | - | - | - | - | - | - | -- | - | - | - | -- |
| **Osogbo** | -- | - | - | - | - | - | - | - | -- | - | - | -- |
| **Abeokuta** | - | - | - | - | - | - | - | - | - | - | - | - |
| **Lagos** | - | - | 0 | 0 | - | - | - | - | - | - | 0 | 0 |

*Note: ++ = Very Hot; + = Hot; 0 = Comfortable; - = Cold; -- = Very Cold. Source: Authors' analysis based on NiMet (2025) climatic data.*

Akure registers cold conditions throughout all twelve months of the year, making it the only city in the sample with a uniform cold nighttime profile and no comfortable or hot ratings at any point. This consistent cold stress reflects Akure's relatively higher elevation and inland location, which promote effective radiative cooling of building surfaces after sunset throughout all seasons. Ado-Ekiti and Osogbo share the most extreme cold nighttime profiles, recording very cold (double minus) conditions in January, August, September, and December for Ado-Ekiti, and in January, September, and December for Osogbo. These very cold nighttime episodes correspond to periods of minimum temperature dropping below the lower comfort threshold by more than 5 degrees Celsius, creating significant cold stress risks for inadequately insulated or under-heated indoor environments.

Ibadan presents the only case where nighttime hot conditions occur in the dataset: November and December record hot nighttime ratings, corresponding to periods when minimum temperatures remain elevated while minimum morning humidity drops, creating uncomfortable warm conditions that differ from the typical cold nighttime pattern. Lagos, as the most climatically moderated city due to coastal influence, achieves comfortable nighttime conditions in March, April, November, and December, with cold conditions for the remaining months and no cold nighttime episodes approaching the very cold threshold. This reflects the moderating effect of oceanic humidity on radiative cooling, which prevents Lagos temperatures from dropping as sharply after sunset as in inland locations.

**Diurnal Stress Contrast and Seasonal Patterns**

The contrast between daytime and nighttime thermal stress across all six cities is summarised in Table 3. This contrast, quantified as the number of months recording opposite thermal stress

directions (hot or very hot daytime combined with cold or very cold nighttime), provides a measure of the diurnal design challenge facing architects in each location.

**Table 3. Summary of Diurnal Thermal Stress Contrast and Peak Climate Parameters for Six Southwest Nigerian Cities**

| City | Peak Max Temp (C) | Months Very Hot Day | Months Very Cold Night | Months Comfortable Day | Months Comfortable Night | Months Hot Day + Cold Night |
|---|---|---|---|---|---|---|
| **Ibadan** | 36.0 | 5 | 0 | 3 | 1 | 9 |
| **Akure** | 35.3 | 2 | 0 | 3 | 0 | 9 |
| **Ado-Ekiti** | 35.1 | 2 | 3 | 3 | 0 | 9 |
| **Osogbo** | 35.9 | 1 | 3 | 3 | 0 | 9 |
| **Abeokuta** | 37.2 | 8 | 0 | 0 | 0 | 12 |
| **Lagos** | 34.5 | 3 | 0 | 1 | 4 | 8 |

**Source:** *Authors' analysis based on Evans Comfort Scale classifications, 2025.*

All six cities register diurnal stress contrast in at least eight months of the year, confirming that the design challenge of simultaneously addressing daytime overheating and nighttime cooling is universal across the study region. Abeokuta presents the most extreme case, with all twelve months recording hot or very hot daytime conditions combined with cold nighttime conditions, meaning that no month achieves concurrent day and night comfort. Lagos records the most favourable diurnal profile, with eight months of daytime-to-nighttime stress contrast and four months of comfortable nighttime conditions, though it still records no months of concurrent daytime comfort except for August alone.

**Location-Specific Mahoney Table Prescriptions**

Table 4 presents the synthesised Mahoney Table design prescriptions for all six cities. The prescriptions reflect the cumulative Mahoney indicator scores derived from Eight years of monthly climatic data and represent the appropriate passive design response to the thermal stress profiles documented in the preceding sections.

**Table 4. Comparative Mahoney Table Bioclimatic Design Prescriptions for Six Southwest Nigerian State Capitals**

| Design Domain | Ibadan | Akure | Ado-Ekiti | Osogbo | Abeokuta | Lagos |
|---|---|---|---|---|---|---|
| **Layout** | East-West axis | East-West axis | East-West axis | East-West axis | East-West axis | East-West axis |
| **Spacing** | Open; protect from wind | Open; protect from wind | Open; protect from wind | Open; protect from wind | Open; protect from wind | Open; protect from wind |
| **Air Movement** | Single-banked; permanent | Single-banked; permanent | Single-banked; permanent | Single-banked; permanent | Single-banked; permanent | Single-banked; permanent |
| **Openings** | Medium: 20-40% | Medium: 20-40% | Medium: 20-40% | Medium: 20-40% | Medium: 20-40% | Large: 40-80% |

| Design Domain | Ibadan | Akure | Ado-Ekiti | Osogbo | Abeokuta | Lagos |
|---|---|---|---|---|---|---|
| **Walls** | Light; short time-lag | Heavy external/internal | Heavy external/internal | Heavy external/internal | Heavy external/internal | Light; short time-lag |
| **Roofs** | Light, well-insulated | Light, well-insulated | Light, well-insulated | Heavy; over 8 hrs time-lag | Heavy; over 8 hrs time-lag | Light, well-insulated |
| **Rain Protection** | Needed; drain provision | Needed; drain provision | Needed; drain provision | Needed; drain provision | Drain provision only | Needed; drain provision |

**Source:** *Authors' analysis using Mahoney Tables (Koenigsberger et al., 1974) applied to NiMet (2025) climatic data.*

All six cities require east-west building axis orientation, open spacing with wind protection features, single-banked room arrangements with permanent air movement provision, and drainage-oriented rain protection. The primary differentiation across cities occurs in three domains: opening sizes, wall construction, and roof specification. Lagos requires the largest openings (40 to 80 percent of north and south wall areas) due to its persistently high humidity (average annual relative humidity above 77%) and classification as humidity group 4 throughout the year, demanding maximum ventilation to remove moisture-laden indoor air continuously. The five inland cities require medium openings of 20 to 40 percent, reflecting a slightly lower but still substantial ventilation demand.

Wall construction requirements divide clearly between two groups: Ibadan and Lagos require light walls with a short thermal time lag, allowing rapid heat loss after sunset to align with their predominantly cold nighttime conditions during most of the year and their relatively lower nighttime cold stress severity. The four remaining inland cities, Akure, Ado-Ekiti, Osogbo, and Abeokuta, require heavy external and internal walls, which provide thermal mass and a longer time lag to moderate the severe daytime thermal stress while providing some thermal buffering during cold nights. The roof prescription similarly bifurcates: Osogbo and Abeokuta require heavy roofs with a time lag exceeding eight hours, reflecting their severe and extended daytime heat loads and the need to delay heat penetration until well after peak afternoon temperatures have subsided. The remaining four cities require light, well-insulated roofs that facilitate rapid heat dissipation without retaining heat overnight.

## DISCUSSION

### The Design Paradox of Diurnal Thermal Stress

The fundamental finding of this study is that all six Southwest Nigerian cities experience a persistent and architecturally significant diurnal thermal stress paradox: daytime overheating requiring aggressive passive cooling coexists with nighttime cold conditions requiring thermal retention across most or all months of the year. This paradox, illustrated most acutely in Abeokuta where all twelve months record opposing day and night stress directions, has profound implications for the design of passively conditioned buildings in the region. Architects and building code developers who focus exclusively on daytime thermal overheating, as is common in tropical building design guidance (Hyde, 2000; Ogunsote et al.,

2011), risk producing buildings that achieve acceptable daytime conditions at the cost of unacceptable nighttime cold discomfort, or vice versa.

The resolution of this paradox lies in the strategic integration of three complementary design features. First, operable ventilation elements, including closeable louvers, adjustable window configurations, and thermally controlled vents, allow occupants to modulate airflow between day and night according to their thermal needs. This behavioural flexibility is consistent with the adaptive thermal comfort model (de Dear and Brager, 2002; Nicol and Humphreys, 2010), which recognises that occupants in free-running buildings can achieve wider comfort ranges through active management of their thermal environment. Second, appropriately specified thermal mass, calibrated to the specific time-lag requirements identified in the Mahoney Table prescriptions for each city, can buffer both daytime overheating and nighttime cooling by storing and releasing thermal energy on a 24-hour cycle (Givoni, 1998; Szokolay, 2008). Third, courtyard-based spatial configurations, which have been demonstrated to create localised microclimates that moderate both daytime solar gain and nighttime radiative cooling (Mohammed and Alibaba, 2018; Muhaisen, 2006), offer a passive architectural typology that addresses the diurnal paradox without requiring occupant intervention.

**City-Specific Design Implications**

Abeokuta, with its extreme daytime thermal stress profile and all-year hot to very hot daytime conditions, demands the most aggressive passive cooling interventions among the six cities studied. The Mahoney Table prescriptions of heavy external and internal walls combined with heavy roofs exceeding eight hours of thermal time lag provide the primary thermal buffering strategy. This wall and roof specification retains daytime heat within the building fabric rather than transmitting it directly to occupants, releasing accumulated heat during the cooler hours between approximately 02:00 and 06:00 when ambient temperatures are lowest. Complementing this thermal mass strategy, maximum shading of all glazed surfaces through overhangs, vertical fins, and evergreen vegetation on west and southwest facades is essential to prevent solar heat ingress that would overwhelm the thermal buffer capacity of the wall system (Kamal, 2012; Kumar et al., 2005). The Mahoney Table prescription of medium openings for Abeokuta, despite its extreme heat, reflects the city's lower humidity classification (group 3 for several months), which reduces the evaporative cooling demand that would otherwise necessitate larger openings.

Lagos requires a fundamentally different design strategy that prioritises maximum ventilation over thermal mass. The large opening prescription of 40 to 80 percent of north and south wall areas reflects Lagos's coastal humidity profile, where removing moisture-laden indoor air continuously is as important as managing heat for occupant comfort. Light walls and roofs facilitate rapid building pre-cooling through night ventilation when ambient temperatures drop sufficiently, while the sustained coastal breeze provides a reliable mechanical ventilation driver that inland cities cannot consistently access. Building form should prioritise elongated plans perpendicular to the prevailing southwest trade wind direction to maximise cross-

ventilation effectiveness, with single-banked room configurations ensuring through-air movement without dead-air zones (Walker, 2010; Lawal, 2008).

Akure's distinctive characteristic among the six cities is its year-round cold nighttime profile, with no comfortable or warm nighttime readings at any point in the eight-year dataset. This persistent cold stress suggests that buildings in Akure must implement a dual-action ventilation strategy: promoting maximum cross-ventilation during daytime hot periods while providing closeable ventilation elements to prevent excessive nighttime cooling that would impair occupant sleep quality and health. The heavy wall prescription for Akure serves to moderate both the daytime heat load and the nighttime cold stress by maintaining a more stable indoor temperature cycle, reducing the amplitude of the temperature swing experienced by occupants. Insulated ceilings and thermally buffered roof spaces further limit nighttime heat loss through the building envelope.

Ado-Ekiti and Osogbo present the most challenging case for passive design due to their very cold nighttime ratings, which occur during specific months and demand strategies to retain warmth at night while the same months may record hot or very hot daytime conditions. For these cities, the Mahoney Table prescriptions of heavy walls and varied roof specifications reflect the need to balance the competing demands of daytime heat rejection and nighttime heat retention. Passive solar heating of north-facing thermally massive walls during the day, which store heat and release it gradually during the cold night hours, represents an appropriate strategy for the dry season months when nighttime cold stress is most severe (Szokolay, 2008; Fathy, 1986).

**Seasonal Strategy Adaptation**

The bimodal thermal stress pattern evident in Ibadan, Akure, Ado-Ekiti, and Osogbo, with primary stress peaks in January through April and secondary peaks in November through December separated by a wet-season comfortable period from July through September, has important implications for adaptive building design strategies. During the wet-season comfortable period, natural ventilation can be maximised through fully opened windows and louvres, internal fan use can be minimised, and occupants can benefit from the thermal reprieve to ventilate bedding, dry moisture-laden materials, and reset thermal expectations. Buildings should be designed with operable ventilation elements sufficiently large to take full advantage of this comfortable period as a free cooling resource.

The transition months of May through June and October represent critical design challenges during which conditions shift rapidly between stress regimes, requiring occupants to have flexible control over their thermal environments. Fixed passive design features such as permanently open louvres or sealed windows will perform poorly during transition months; instead, buildings should incorporate adjustable elements that occupants can manage according to daily and seasonal temperature changes. This emphasis on occupant-controlled adaptive capacity is consistent with the adaptive thermal comfort model and has been validated in field studies across tropical West Africa (Adunola, 2011; Ayinla and Odetoye, 2015).

**Implications for Building Codes and Design Policy**

The location-specific design prescriptions generated by this study expose significant limitations in Nigeria's current building regulation framework. The N-BEEC (NESP, 2021) provides design guidance for only two broad climatic zones, Lagos as representative of hot-humid conditions and Kano as representative of hot-dry conditions, without addressing the substantial within-zone variation documented in this study. The meaningful differences in opening size requirements between Lagos (large) and the five inland cities (medium), the bifurcation of wall specifications between light-wall cities (Ibadan and Lagos) and heavy-wall cities (Akure, Ado-Ekiti, Osogbo, and Abeokuta), and the differentiation of roof specifications between Osogbo and Abeokuta on one hand and the remaining four cities on the other, collectively demonstrate that a two-zone national framework is insufficient to guide climate-responsive building design across Southwest Nigeria.

These findings support the recommendation for state-level building regulations that incorporate city-specific thermal stress profiles and Mahoney Table prescriptions as minimum performance standards for new institutional and residential buildings. Professional bodies including the Nigerian Institute of Architects and the Council of Registered Engineers of Nigeria should incorporate diurnal thermal stress analysis into their continuing professional development curricula and pre-qualification examination requirements. University architectural education programmes should include the Evans Comfort Scale and Mahoney Tables as foundational competencies in tropical building design courses, equipping future practitioners with the analytical tools necessary to produce climate-responsive buildings without reliance on imported design templates that fail to reflect Nigerian climatic realities (Geissler et al., 2018; Ogunsote et al., 2011).

## CONCLUSIONS

This study has presented the first comprehensive, multi-city, diurnal thermal stress analysis for Southwest Nigeria, integrating eight years of primary NiMet climatic data with the Evans Comfort Scale and Mahoney Tables to characterise monthly daytime and nighttime thermal conditions across six state capital cities and derive location-specific passive building design prescriptions. The following principal conclusions are drawn:

- Daytime thermal stress is severe and extended across all six Southwest Nigerian cities, with very hot conditions prevailing during the dry season months of November through April and Abeokuta recording the most extreme profile with very hot daytime conditions for eight consecutive months and a peak maximum temperature of 37.2 degrees Celsius.
- Nighttime conditions contrast sharply with daytime, recording cold to very cold conditions for most or all months across all six cities. Akure records cold conditions throughout all twelve months, while Ado-Ekiti and Osogbo register very cold nighttime episodes in up to three months per year. Lagos is the only city achieving comfortable nighttime conditions in four months.

- The diurnal thermal stress paradox, characterised by simultaneous daytime overheating and nighttime cold conditions, is universal across all six cities and presents a fundamental challenge for passive building design that requires strategies addressing both conditions concurrently rather than optimising for a single stress direction.
- Location-specific Mahoney Table prescriptions reveal meaningful differences among the six cities in opening size requirements, wall construction specifications, and roof time-lag needs that cannot be adequately captured by a two-zone national building code. East-west building orientation, open spacing, and single-banked room configurations are universal prescriptions; opening sizes, wall mass, and roof specifications vary significantly by city.
- These findings provide an empirically grounded evidence base for revising the N-BEEC and developing state-level passive design standards for Southwest Nigeria. Implementation of the location-specific prescriptions presented in this study in new institutional and residential building design could substantially reduce thermal discomfort prevalence, decrease mechanical cooling dependence, and advance Nigeria's energy efficiency and climate adaptation commitments.

Future research should extend this diurnal thermal stress framework to other Nigerian geopolitical zones, incorporate climate projection data to anticipate shifts in thermal stress patterns under representative concentration pathway scenarios, and develop simulation-validated passive design guidelines that verify the energy and comfort performance of the Mahoney Table prescriptions through dynamic thermal modelling.

## DECLARATIONS

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**Conflicts of Interest**

The authors declare no conflicts of interest.

**Data Availability**

Climatic datasets supporting the findings of this study were obtained from the Nigerian Meteorological Agency and are available from the corresponding author upon reasonable request.

**Author Contributions**

**I. I. Adebisi:** Conceptualisation, data curation, formal analysis, methodology, writing of original draft

**A. K. Ayinla:** Supervision, resources, writing and review.

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