



## FIELD ASSESSMENT OF THERMAL CONDITIONS AND PASSIVE COOLING FEATURES IN SELECTED RESIDENTIAL HOUSING ESTATES IN YOLA, NIGERIA

Nachafiya Na'andeti \*, Daniel Labaran Abalaka and Ruth Rakiya Martins

Department of Architecture, Faculty of Architecture, Bingham University, Karu, Nasarawa State, Nigeria.

\*Corresponding author; Email: [naandeti007@gmail.com](mailto:naandeti007@gmail.com)

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### ABSTRACT

This paper reports a field assessment of indoor thermal conditions and passive-cooling features in selected residential housing estates in Yola, Adamawa State, Nigeria. Four housing estates were purposively selected and five dwellings were assessed in each estate. Fieldwork was conducted between March and May 2026 and comprised an architectural audit of 20 dwellings, spot indoor dry-bulb temperature observations at 60 room-level monitoring points, and an occupant survey involving 60 respondents. The assessment documented orientation, window-to-wall ratio (WWR), opening configuration, cross-ventilation, roof and ceiling characteristics, shading, building separation and vegetation. The overall observed indoor dry-bulb temperature was 27.42°C (SD = 1.38°C; range = 25.10–29.90°C). Estate-level means varied only from 27.31°C to 27.53°C. However, the observations cannot be interpreted as validated measurements of passive-envelope performance. Approximately 45% of respondents reported air-conditioning use and 60% reported reactive curtain or blind use. Monitoring consisted of spot observations rather than continuous seasonal logging, while relative humidity, mean radiant temperature and air velocity were not systematically measured. In addition, logger calibration offsets were substantial, with a mean offset of

0.42°C (SD = 2.15°C) and a range of –4.70°C to +4.70°C. Formal adaptive comfort compliance and causal inferential analyses were therefore not retained. The contribution of the study is instead a transparent descriptive baseline of existing housing characteristics and measured indoor temperatures, together with variables suitable for subsequent controlled monitoring and calibrated dynamic simulation.

**Keywords:** Passive Cooling; Thermal Conditions; Residential Housing; Yola; Natural Ventilation; Building Envelope.

### 1 INTRODUCTION

Thermal performance is an important dimension of housing quality in hot climates because the building envelope, openings, orientation, shading and ventilation influence the rate at which heat enters and leaves occupied spaces. Climate-responsive architecture therefore seeks to reduce unnecessary heat gain, encourage useful air movement and exploit thermal storage while limiting dependence on energy-intensive mechanical cooling. [1] linked orientation, site planning, air movement and material selection to climatic response, while [2] developed a building-oriented approach

to passive and low-energy cooling that considers ventilation, thermal mass, shading and evaporative processes. [3] similarly emphasised the physical basis of heat, air and building materials in climate responsive design.

In Nigeria, passive cooling is particularly relevant because residential buildings in savanna and hot-dry climatic zones can experience high solar gains and substantial daytime heat loads. Earlier work in Bauchi identified inadequate orientation, poor natural ventilation and weak climatic responsiveness as recurring residential design problems [4]. More recent Nigerian studies increasingly use simulation and field-informed modelling to investigate combinations of insulation, shading, orientation, ventilation and material choices. Tambaya [5] used building simulation and sensitivity analysis for residential buildings in Nigeria's hot-dry climate. Ibrahim et al. [6] combined field measurements, occupant surveys and simulation in a low-cost housing estate in Bauchi, while Xi et al. [7] investigated passive design and mechanical ventilation in a Nigerian tropical savanna context. Abdulkareem and Al-Maiyah [8] used validated simulation to examine passive design solutions for affordable housing in Abuja.

Yola presents a related but locally distinct design context. Although evidence from other Nigerian cities is useful, performance values obtained elsewhere should not automatically be treated as locally validated thresholds for Yola. This study therefore examines existing housing estates in Yola and identifies passive cooling features and observed indoor conditions. The study is deliberately descriptive because the observations are nested within only 20 dwellings, several explanatory variables were retained at estate level, monitoring was episodic, mechanical cooling and occupant shading affected indoor conditions, and key environmental variables were not measured. The purpose is therefore to provide a local field baseline and identify variables for controlled monitoring and calibrated simulation.

Bioclimatic design treats climate as a primary determinant of architectural form and environmental performance. Olgyay's climatic approach places orientation, solar exposure, wind and material behaviour within a single design process [1]. Givoni [2] explains passive cooling through natural ventilation, thermal storage, night cooling, evaporative cooling and solar control. Szokolay [3] reinforces the need to understand the physical basis of heat transfer and environmental control before selecting architectural interventions. For housing, these principles matter because envelope decisions are repeated across many units and can have cumulative consequences.

Passive cooling is rarely a single-device intervention. The effectiveness of an overhang depends on façade orientation, window geometry and glazing. Cross-ventilation depends on opening position, pressure differences, internal flow paths and outdoor wind conditions. Building separation can affect both solar shading and wind access, while vegetation depends on canopy size, density, distance from buildings and maintenance. Passive-cooling variables should therefore be treated as interacting components rather than isolated causes.

Thermal comfort is multidimensional. Air temperature is important, but perceived conditions are also affected by mean radiant temperature, humidity, air velocity, clothing, activity and adaptive behaviour. The present study did not systematically measure relative humidity, mean radiant temperature or air velocity, and a substantial proportion of occupants reported mechanical air-conditioning. It therefore does not support a formal adaptive-comfort compliance calculation. Accordingly, the occupant questionnaire is used only as contextual information about adaptive behaviour, rather than as a formal thermal-comfort outcome. Recent Nigerian research supports integrated rather than isolated interventions. Tambaya [5] used IES VE simulation and sensitivity analysis to examine envelope and passive-design variables. Ibrahim et al. [6] evaluated a larger housing-estate sample in Bauchi using field measurement, survey and simulation. Okonta [9] examined the relationship between building materials and indoor cooling across Nigerian climatic zones. Xi et al. [7] combined passive design and mechanical ventilation in a tropical savanna case, while Abdulkareem and AlMaiyah [8] evaluated affordable housing in Abuja using validated simulation. These studies show why design parameters should ultimately be tested under controlled or calibrated modelling conditions rather than inferred directly from small cross-sectional field samples. Relatively little published field work has documented the combined building-envelope characteristics, ventilation provisions, shading, spacing and vegetation of existing residential estates in Yola. The present study contributes a local descriptive baseline but does not claim to resolve causal performance of individual passive strategies.

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## 2 MATERIALS AND METHODS

### 2.1 Research design

The study adopted a descriptive field assessment design combining architectural observation, spot indoor dry-bulb temperature measurements and an occupant questionnaire. Fieldwork was conducted between March and May 2026. The study documented existing conditions rather than creating a controlled experimental comparison between passive and mechanically conditioned buildings.

## 2.2 Study area and case study estates

Four residential housing estates in Yola North and Yola South Local Government Areas were purposively selected: Federal Housing Estate (FHE), Police Housing Estate, Kwanan Waya (PHE), Resort Estate (RE), and Adasolid Estate, Nyako's Quarters (AE). The selection captured variation in typology, envelope construction, opening configuration, ventilation provisions, shading and estate morphology.

## 2.3 Sample and unit of analysis

Five dwellings were assessed in each estate, giving 20 dwellings. Three rooms were observed within each selected dwelling—the living room, master bedroom and secondary bedroom—producing 60 room-level monitoring points. The dwelling, rather than the individual room observation, is the principal physical unit because rooms within one dwelling are not statistically independent. The occupant survey involved 60 respondents, 15 per estate. The housing sample comprised eight semi-detached units (40%), seven detached units (35%) and five terraced units (25%).

## 2.4 Architectural audit

The audit documented orientation, WWR, opening configuration, cross ventilation, roof and ceiling characteristics, shading devices, building spacing and vegetation. Because some parameters were retained as estate level summaries rather than complete dwelling level measurements, they are not used here as independent predictors of room level temperature.

## 2.5 Indoor temperature observations

HOB0 MX1101 temperature loggers were used. A pre-deployment check was conducted against a reference thermometer, followed by individual offset correction. The calibration exercise reported a mean offset of +0.42°C (SD = 2.15°C), with individual offsets from −4.70°C to +4.70°C. Although correction was applied, this spread introduces uncertainty into fine-grained comparisons. Measurements were instantaneous spot observations during site visits rather than continuous time-series monitoring.

## 2.6 Occupant behaviour and confounding

Approximately 45% of respondents reported air-conditioning use and approximately 60% reported reactive curtain or blind use. These behaviours are major confounders for attribution of indoor temperature to passive-envelope design. The revised analysis therefore does not classify measured temperatures as pure passive performance and does not estimate causal effects of orientation, WWR or spacing.

## 2.7 Comfort assessment

A formal adaptive-comfort calculation is not retained in this article. ASHRAE Standard 55 requires environmental variables that were not systematically collected here, particularly air velocity and mean radiant temperature, together with appropriate humidity and outdoor reference conditions [10]. The questionnaire is therefore reported only as contextual information about occupant behaviour.

## 2.8 Statistical approach

The analysis is descriptive. Means, standard deviations, ranges and counts/proportions describe the observed sample. Inferential comparisons are not reported because observations are nested within 20 dwellings, several predictors were aggregated at estate level, and the design does not support independent estate level inference.

## 2.9 Ethical considerations

Formal institutional ethical approval was not obtained. Residents who participated were informed of the research purpose and participated voluntarily; consent was obtained before participation. No personally identifying information is reported. Access to selected estates was obtained through relevant management arrangements.

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## 3 RESULTS

### 3.1 Descriptive profile of selected estates

The 20 audited dwellings included eight semi detached, seven detached and five terraced units. This is a descriptive characteristic of the selected sample and is not presented as representative of all housing in Yola.

**Table 1: Descriptive characteristics of the selected housing estates.**

| Estate | Dwellings | Room observations | Mean WWR | Cross-ventilation | Vegetation  |
|--------|-----------|-------------------|----------|-------------------|-------------|
| FHE    | 5         | 15                | 20.1%    | 0/5 (0%)          | 4/5 (80%)   |
| PHE    | 5         | 15                | 18.6%    | 3/5 (60%)         | 4/5 (80%)   |
| RE     | 5         | 15                | 21.4%    | 3/5 (60%)         | 3/5 (60%)   |
| AE     | 5         | 15                | 19.8%    | 2/5 (40%)         | 3/5 (60%)   |
| Total  | 20        | 60                | —        | 8/20 (40%)        | 14/20 (70%) |

Note: WWR values are estate-level averages from the field records. Cross-ventilation and vegetation counts refer to audited dwellings. Unsupported building-separation values were not imputed.

### 3.2 Envelope and passive cooling features

Eaves were recorded in 12 of 20 units (60%), fixed fins or louvres in 4 units (20%), and verandas or balconies in 8 units (40%). Trees or other substantial vegetation were recorded in 14 units (70%). Five units (25%) had no ceiling. Glazing comprised single clear glass in seven units (35%), single tinted glass in eight units (40%) and double glazing in five units (25%). Wall thicknesses ranged approximately from 150–225 mm.

Cross-ventilation was recorded in 8 of 20 dwellings (40%). FHE recorded none in the five audited units; PHE and RE each recorded three of five, and AE recorded two of five. These observations show variation in ventilation provision but not ventilation effectiveness because air speed was not measured. Orientation was N–S in 40% of audited units, NE–SW in 35%, E–W in 15% and NW–SE in 10%. These proportions describe the sample and do not isolate orientation from shading, glazing, occupancy or mechanical cooling.

### 3.3 Indoor dry bulb temperature

Across 60 room-level observations, mean corrected indoor dry-bulb temperature was 27.42°C (SD = 1.38°C), with an observed range of 25.10–29.90°C. The difference between the lowest and highest estate-level means was 0.22°C. This narrow spread should not be interpreted as proof of equivalent passive performance because the observations were spot measurements, the sample was small, and occupant-controlled cooling and shading were present.

**Table 2: Descriptive indoor dry-bulb temperature by selected estate.**

| Estate  | n  | Mean °C | SD °C | Min °C | Max °C |
|---------|----|---------|-------|--------|--------|
| FHE     | 15 | 27.35   | 1.23  | 25.50  | 29.90  |
| PHE     | 15 | 27.31   | 1.57  | 25.10  | 29.50  |
| RE      | 15 | 27.47   | 1.39  | 25.10  | 29.90  |
| AE      | 15 | 27.53   | 1.42  | 25.10  | 29.70  |
| Overall | 60 | 27.42   | 1.38  | 25.10  | 29.90  |

Note: Values are descriptive summaries of the observed room level measurements. No inferential comparison is made because observations are nested within dwellings and the monitoring design does not support independent estate level inference.

### 3.4 Room level descriptive pattern

Living rooms had the highest room-category mean and secondary bedrooms the lowest. These differences are descriptive only; the study did not collect enough information to separate façade exposure, glazing, occupancy, internal gains, shading, air-conditioning or room position.

**Table 3: Descriptive indoor dry-bulb temperature by room category.**

| Room type         | N  | Mean °C | SD °C |
|-------------------|----|---------|-------|
| Living room       | 19 | 27.83   | 1.31  |
| Master bedroom    | 19 | 27.51   | 1.44  |
| Secondary bedroom | 22 | 26.98   | 1.30  |

Note: Room categories are descriptive; room level differences were not interpreted as causal effects.

### 3.5 Occupant adaptive behaviour

Approximately 45% of respondents reported air-conditioning use and approximately 60% reported reactive curtain or blind use. The measured indoor environment was therefore partly produced by occupant-controlled interventions, and the 27.42°C mean cannot be interpreted as the temperature maintained by passive design alone.

## 4 DISCUSSION

The principal empirical contribution is a local description of housing characteristics and observed indoor temperatures in four selected Yola estates. The study documents that 40% of audited dwellings had identifiable cross ventilation paths, eaves were present in 60%, fixed fins or louvres in 20%, verandas or balconies in 40%, and vegetation in 70%. Mean WWR values across the selected estates were close to 19–21%. These observations provide an inventory for subsequent design and modelling work.

The 27.42°C mean is a descriptive snapshot during the March–May 2026 campaign, not a year round benchmark and not evidence that a particular passive strategy caused a specific temperature reduction. Stronger conclusions require controlled comparison, precise instrumentation, repeated seasonal measurements and appropriate environmental covariates. The limited prevalence of identifiable cross ventilation paths suggests an opportunity for further investigation, but the audit did not measure airflow. Future work should pair opening geometry with calibrated air-speed measurements and, where appropriate, airflow network or CFD modelling. Shading and vegetation also require quantitative treatment: future studies should measure shading depth, façade orientation, glazing solar heat gain properties, canopy density and tree to façade distance.

The reported 45% prevalence of air conditioning use is central to interpretation. A mechanically cooled room cannot be treated as a naturally conditioned test cell for attribution to passive envelope design. The 60% prevalence of reactive curtain or blind use creates a related attribution problem. This is why the revised paper does not claim that measured temperature represents passive performance.

The reported calibration exercise also requires cautious interpretation. The mean offset was

+0.42°C, but SD was 2.15°C and the range was –4.70°C to +4.70°C. Although correction was applied, this spread is large relative to the 0.22°C difference between estate means. Corrected observations can support broad descriptive reporting, but fine-grained comparisons should not be treated as precise experimental effects.

Recent Nigerian research demonstrates the value of controlled modelling. [5] illustrates sensitivity analysis; [9] uses DesignBuilder to compare envelope and shading interventions; [7] tests passive design and ventilation in a tropical savanna context; [6] combines field observations with simulation in a housing estate; and [8] uses validated simulation in Abuja. The present study should therefore be viewed as a preliminary empirical inventory that precedes, rather than substitutes for, a calibrated Yola-specific simulation study.

### 4.1 Design implications and validation priorities for Yola housing

The field assessment identifies several parameters that warrant quantitative testing, including eaves depth, WWR, glazing properties, ceiling insulation, roof properties, ventilation openings and planting distance. Because these values were not experimentally tested and no DesignBuilder or EnergyPlus model was run, they are not reported here as empirically validated Yola optima. Instead, the findings define a simulation and validation matrix. The actionable next step is therefore not to assign a single optimal shading coefficient or WWR from this sample, but to construct a controlled parametric simulation. Candidate ranges can be based on the existing stock and established literature, then tested with Yola weather data and calibrated against independent field measurements.

**Table 4: Field-derived variables and questions for subsequent validation.**

| Variable         | Observed condition                     | Validation question                                                         |
|------------------|----------------------------------------|-----------------------------------------------------------------------------|
| Orientation      | 40% N-S; 35% NE-SW; 15% E-W; 10% NW-SE | How does orientation interact with shading and WWR using Yola weather data? |
| WWR              | Estate means 18.6–21.4%                | What WWR range balances solar gain, daylight and ventilation by façade?     |
| External shading | Eaves 60%; fins/louvres 20%            | What overhang depth and fin geometry provide effective solar control?       |

|                    |                       |                                                                                               |
|--------------------|-----------------------|-----------------------------------------------------------------------------------------------|
| Roof/ceiling       | 25% without ceilings  | What roof reflectance, insulation and ventilated-cavity combinations reduce heat gain?        |
| Cross-ventilation  | 8/20 dwellings (40%)  | What opening geometry and wind conditions produce useful indoor air speed?                    |
| Vegetation         | 14/20 dwellings (70%) | How do canopy density and tree to façade distance affect microclimate?                        |
| Mechanical cooling | 45% reported AC use   | How do free running and mechanically cooled scenarios <u>differ when modelled separately?</u> |

Note: The validation questions are research priorities, not empirically established optimum design values.

## 5 CONCLUSION

This study provides a descriptive field baseline of thermal conditions and passive-cooling features in four selected residential housing estates in Yola. Across 60 room-level observations, corrected indoor dry-bulb temperature averaged 27.42°C (SD = 1.38°C), while the audited housing stock showed inconsistent provision of cross-ventilation, shading, ceilings and vegetation. The evidence is useful for identifying variables that require further investigation, but it does not establish causal passive-cooling performance. Mechanical air-conditioning, reactive shading, episodic monitoring, incomplete environmental variables, nested observations and logger-offset variability constrain inference.

The revised article's contribution is therefore both empirical and methodological: it establishes a transparent local baseline while identifying the measurements and controls required for a stronger Yola-specific performance study. Calibrated multi-season field monitoring combined with independently validated dynamic simulation is the appropriate next stage for establishing quantitative parameters for orientation, WWR, shading, envelope construction, ventilation and landscape design.

## STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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### *Disclosure of conflict of interest*

The authors declare no conflict of interest.

### *Statement of ethical approval*

Formal institutional ethical approval was not obtained for this study.

### *Statement of informed consent*

Residents who participated were informed of the research purpose and participated voluntarily; informed consent was obtained before participation. No personally identifying information is reported.

### *Data availability*

- Nachafiya Na'andeti: study conception and design, field investigation, data organization, analysis and manuscript preparation.
- Daniel Labaran Abalaka: supervisory oversight, methodological review and critical revision.
- Ruth Rakiya Martins: supervisory oversight, methodological review and critical revision. All listed authors should review and approve the final version before submission.
- Nachafiya Na'andeti: study conception and design, field investigation, data organization, analysis and manuscript preparation.

*AI-assisted manuscript preparation*

Generative artificial intelligence was used during manuscript preparation for language editing, restructuring and presentation of the authors' existing research material. The authors reviewed the manuscript and remain responsible for the accuracy, interpretation, authorship and integrity of the submitted work.

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