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ORIGINAL ARTICLE

Cosmology Built for the Tropics: Space Syntax, Ritual Hierarchy, and Passive Microclimatic Well-Being Across Nusantara Stilt Vernacular Architecture (Palembang Limas, Minangkabau Gadang, and Toraja Tongkonan)

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ABSTRACT

Background: Nusantara stilt vernacular houses encode ancestral cosmologies and social hierarchies while passively regulating hot-humid lowland and cool montane microclimates, yet underfloor *kolong* [raised stilt void] masonry infilling and bare zinc reroofing increasingly disrupt spatial ritual order and thermal comfort.

Objective: To quantify how graph-theoretic ritual hierarchy and modeled passive microclimatic well-being co-vary across Palembang Rumah Limas, Minangkabau Rumah Gadang, and Toraja Tongkonan dwellings across conservation regimes.

Methods: Four streams combined 144 documented plans (1,532 Justified Plan Graph nodes, 36 settlement clusters), exact Breadth-First Search Space Syntax metrics, a lumped thermal model driven by 315,648 hourly Copernicus ERA5 reanalysis records (2023–2025) for 12 sub-regions, and settlement-clustered restricted maximum likelihood (REML) linear mixed-effects and fractional logit models.

Results: Canonical stilt houses (R1, n = 54) kept arborescent access (R_{ring} = 0.00), deep sacred seclusion (RRA_{sacred} = 1.84 ± 0.44), near-neutral modeled afternoon offsets (ΔT_{peak} = +0.66 ± 1.50 °C), and 82.46 ± 10.30% annual Passive Thermal Well-Being (PTWB). Kolong-infilled retrofits (R3, n = 42) reduced RRA_{sacred} by 67.4% (Kruskal–Wallis $p = 1.29 \times 10^{-22}$), raised ΔT_{peak} to +4.61 ± 1.28 °C, and lowered PTWB by 13.22 percentage points overall ($p = 5.55 \times 10^{-7}$) and 30.44 points in Palembang. Pooled PTWB under open-stilt adaptive upgrading (R2, n = 48) did not differ detectably from R1 (p = 0.5924), although afternoon offsets were higher.

Conclusion: In this model-based comparison, canonical stilt cosmologies are associated with lower afternoon overheating than *kolong*-infilled retrofits, supporting a five-pillar Vernacular Safeguarding Protocol whose thresholds need field validation.

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1. Introduction

1.1 Austronesian House Societies, Tripartite Cosmology, and Embodied Domestic Habitus

Traditional timber dwellings across Island Southeast Asia (Nusantara) are more than utilitarian shelters. They are moral, genealogical, and cosmological institutions. Claude Lévi-Strauss, Janet Carsten, and Stephen Hugh-Jones framed them as *sociétés à maisons* [house societies].[1,2] Within this comparative tradition, Roxana Waterson and James J. Fox showed how Austronesian houses give material form to kinship continuity, marital alliance, and ritual precedence [ranked ancestral origin order]. How? Through durable timber joinery, botanical metaphors of trunk and tip, and strictly ordered spatial axes.[2,3] Comparative architectural surveys of western and eastern Indonesia by Reimar Schefold, Peter J. M. Nas, and Gaudenz Domenig then established that Nusantara stilt architecture draws on a shared structural repertoire. It has an elevated timber post-and-beam undercarriage, an outward-slanting or saddle-backed roof with projecting gables, and graded interior floor thresholds. Each ethnic polity re-articulates it. Local ecological and ceremonial imperatives set the terms.[4,5]

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

Paul Oliver's global synthesis of vernacular architecture makes one point. Indigenous building traditions tend to last across generations when symbolic meaning and environmental performance support one another in daily life.[6] Pierre Bourdieu's theory of domestic habitus [embodied dispositions structured by spatial practice] helps here. Climbing an entry stair, bowing under a low threshold lintel, stepping over graduated wooden floor ledges, or sitting around an ancestral hearth all socialize inhabitants, again and again, into ranked norms of gender, age, hospitality, and sacred etiquette.[7] In Nusantara stilt houses, this socio-spatial pedagogy runs vertically through a tripartite macrocosmic schema. A sub-floor undercroft is linked to chthonic forces, livestock, river tides, or utilitarian work. A middle elevated timber deck holds human sociality and lineage deliberation. A soaring pitched roof vault faces ancestral spirits and celestial deities.[2,4,5] Ethnographies of this tripartite cosmos are rich, but cultural sciences scholarship has rarely tested whether the same spatial rules that protect sacred seclusion also work as quantifiable microclimatic mechanisms for human thermal well-being.

Materially, this tripartite cosmic order is bound up with the indigenous carpentry epistemology of Nusantara master builders, known as *tukang tuo* in Palembang and Minangkabau, and *pande banua* or *to manarang* in the Toraja highlands.[2–5] Canonical stilt frames in all three societies are assembled without iron nails. Builders cut close-fitting mortise-and-tenon slots (*puting* [tenon] and *lesung* [mortise]), locked by tapered hardwood pegs (*pasak* [wooden peg]) shaped with specialized chisels (*pahat* [chisel]) and adzes (*beliung* [adze]). In timber selection and assembly, master carpenters follow strict botanical orientation rules. The root-end (*pangkal* [root end]) of every structural post goes downward toward the earth, its crown-tip (*ujung* [crown tip]) upward toward the ridge, and longitudinal sill beams run from 'upstream' to 'downstream', so that the vitality of living sapwood flows in harmony with household progeny.[2,3,5] Nailed concrete-and-steel joints are comparatively rigid. Pegged *pasak* timber frames are described as flexing during Sumatran fault earthquakes and riverine soil subsidence and as keeping small breathing tolerances between floorboards and wall panels.[4,6] The ancestral craft therefore embodies moral continuity (habitus)[7] while also producing the micro-permeable wooden envelope whose openness enters this study through the wall and *kolong* porosity parameters.

1.2 Lowland Floodplain to Montane Basin: Palembang Rumah Limas, Minangkabau Rumah Gadang, and Toraja Tongkonan

Cosmological spatial order co-evolves with contrasting tropical environments. Three iconic Nusantara house traditions offer a useful comparative set for studying it. They span equatorial riverine floodplains (7–18 m above sea level [ASL]), sub-montane volcanic valleys (518–915 m ASL), and cool highland basins (775–945 m ASL). In the tidal Musi, Ogan, and Komering river lowlands of South Sumatra, the Palembang Rumah Limas [pyramidal-hipped noble stilt house] expresses the aristocratic *priyayi* [nobility] and Sultanate court hierarchy of *uluan–iliran* [upstream–downstream riverine polity].[8–11] Eka Sulistiawati recently documented the type in Enigma in Cultural, and Sandra Taal, Tuty Lussetyowati, and Bart Barendregt analyzed it in architectural-historical detail. The canonical Rumah Limas stands on massive water-resistant *unglen* (*Eusideroxylon zwageri* [Bornean ironwood]) stilts, which create a tall open *kolong* [raised underfloor void] above seasonal Musi floods. Inside, it ascends across three to five stepped floor terraces termed *kekijing* [graded ceremonial floor levels].[8–11] At weddings (*munggah* [wedding rite]) and customary feasts (*sedekah* [feast]), guests sit by genealogical and civic rank on the lower *kekijing* tiers. Operable *lawang kipas* [top-hinged folding timber wall panels] aerate those tiers. The central *gegajah* [elevated lineage hall] and the innermost *pangkeng penganten* [bridal and heirloom sanctums] sit at the highest structural levels.[8,9]

Higher up, in the sub-montane *Luhak Nan Tigo* [Three Heartland Valleys] and the southern Rantau highlands of West Sumatra, the Minangkabau Rumah Gadang [matrilineal 'great house'] turns customary law (*adat basandi syarak*) and female-centered lineage stewardship (*Bundo Kanduang* [matrilineal senior women's authority]) into a dramatic buffalo-horn roof silhouette (*gonjong*).[12,13] Marcel Vellinga and Azizi Bahauddin showed that its interior is partitioned longitudinally into three or four *lanjar* [structural aisle bands running parallel to the façade], crossed by five to nine transverse bays (*ruang* [bay]).[12,13] A visitor climbs the central *janjang* [entry stair] and passes the *bandua* [threshold sill]. Beyond lie the open front reception aisles (*labuah gajah*) and the expansive communal *tangah* [central deliberation hall]. Married daughters and maternal elders live in a row of enclosed rear *bilik* [private matrilineal sleeping and heirloom alcoves]. In aristocratic *Koto Piliang* houses, stepped *anjuang* [elevated end-wing alcoves] flank them.[12,13]

Across the Makassar Strait, in the rugged montane valleys of Tana Toraja and North Toraja (775–945 m ASL), the Tongkonan [ancestral origin house] anchors bilateral *rapu* [ramage kinship groups] within the indigenous cosmology of *Aluk Todolo* [Way of the Ancestors].[14,15] Kathleen M. Adams and Obet S. C. Rombe et al. detailed that every canonical Tongkonan lies along a north–south sacred axis and faces its paired *alang sura'* [carved rice granary] across an elongated *kala'paran* [ceremonial courtyard plaza].[14,15] Sturdy *uru* [Elmerillia timber] (*Elmerillia ovalis*) timber piles carry the house. They frame the *bala'kaan* [buffalo-tethering undercroft]. Beneath a towering multi-layered bamboo saddle roof (*rattiang*), the interior divides into three stepped cardinal chambers. These are the northern elevated *tangdo'* [front room oriented toward *Puang Matua*, the Creator in the northern sky *Ulunna Langi'*], the depressed central *sali* [communal living hall containing the eastern *dapo'* sacred hearth], and the elevated southern *sumbung* [deepest maternal, mortuary, and *pusaka* heirloom sanctum].[14,15] Ni Wayan S. Rahayu et al. argued in Enigma in Cultural, from a clinical case in a Balinese psychiatric ward, that a ritual framework can act on health through symbolic efficacy when its boundaries are respected.[16] Meanwhile, households in Palembang, West Sumatra, and Toraja alike increasingly enclose the open *kolong* or *bala'kaan* with brick or concrete block walls. They cut side corridor doors that bypass ritual thresholds. They also replace breathable thatch, bamboo, or clay-tile roofs with uninsulated corrugated zinc sheets.[10,12,15]

Look closer and the ethnography shows subtle internal variations. Within each tradition they modulate spatial hierarchy, yet canonical stilt logic holds.[8–15] Along South Sumatra's river networks, aristocratic Sultanate *ilir* [downstream court] Rumah Limas in Palembang (PLB-1 Seberang Ulu and PLB-2 Sekanak) elaborate four to five *kekijing* floor steps, crowned by gilded *simbar* [ridge horn] ridge horns. Craftsman and *marga* [clan] chieftain houses in upstream *ulu* Ogan Ilir (PLB-3 Tanjung Batu—renowned across Sumatra for knock-down *bongkar-pasang* prefabrication guilds) and

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

Komering Ilir (PLB-4 Kayuagung) often use three *kekijing* tiers instead, yet keep the identical *jogan* [front verandah]–*gegajah*–*pangkeng* threshold progression.[8,9,11] West Sumatra shows a similar pattern. Customary statecraft separates the hierarchical *Koto Piliang* moiety, attributed to Datuk Katumanggungan, from the deliberative-egalitarian *Bodi Caniago* moiety, attributed to Datuk Parpatih Nan Sabatang. A *Koto Piliang* Rumah Gadang raises both end bays into stepped *anjuang* thrones (ΔZ_{floor} reaching 145–175 cm relative to entry decks). A *Bodi Caniago* floor deck stays level across the *tangah* hall (*situjuah duduk sama rendah*, *tegak sama tinggi*), though it still steps subtly upward into private matrilineal *bilik* alcoves.[12,13] In Toraja, supreme origin seats (Tongkonan Layuk and Tongkonan Pekamberan, such as those in TRJ-1 Ke'te' Kesu' and TRJ-4 Kaero/Sangalla') erect a central *a'riri posi'* [sacred navel post]. They also subdivide the elevated southern *sumbung* to shelter an innermost *pusaka* heirloom treasury, which extends topological step depth one further link beyond ordinary kin houses (*banua barung-barung*).[14,15]

1.3 Graph-Theoretic Space Syntax, Adaptive Tropical Comfort, and Study Objectives

Do such morphological transformations erode cultural meaning and occupant thermal welfare together? Answering means bridging two methodological traditions that have rarely spoken to one another: architectural Space Syntax and adaptive tropical building physics.[17–30] Space Syntax is Bill Hillier and Julienne Hanson's formulation. It represents any architectural plan as a Justified Plan Graph (JPG) rooted at the exterior public carrier (node 0), with rooms as vertices and permeable doorways or stair thresholds as edges.[17,18] Sonit Bafna, Michael J. Ostwald, and Michael J. Dawes formalized the mathematics. Exact geodesic path lengths yield objective topological invariants—including carrier Step Depth (SD_i), Diamond-normalized Real Relative Asymmetry (RRA_i), Hillier–Hanson Integration ($HH_i = 1 / RRA_i$), local Control Value (CV_i), Circulatory Ringiness (R_{ring}), and Hanson's relativized genotype difference factor (H^*)—that decode how domestic layouts regulate stranger–inhabitant encounters and sacred privacy.[18–21] Comparative JPG studies of traditional Turkish houses by Deniz Orhun, Hillier, and Hanson, and of historical sacred architecture by Faris A. Mustafa and Ahmad S. Hassan, showed that differences in doorway connectivity are associated with differences in social hierarchy.[22–24] Large-sample graph-theoretic comparisons of Nusantara stilt traditions, however, remain virtually absent. Indonesian applications are few. A recent justified-plan-graph study of traditional Balinese houses in Ubud reports hierarchical spatial arrangements with strong access control,[31] and space syntax has been combined with visual analysis in traditional Agraharam houses in India.[32]

Four decades of adaptive thermal comfort research, begun by Michael A. Humphreys, Richard J. de Dear, Gail S. Brager, J. Fergus Nicol, and Susan Roaf, established one point. Occupants of naturally ventilated tropical dwellings do not find comfort around a static air-conditioned set-point. Neutral comfort temperature (T_{comf}) follows prevailing outdoor conditions, and indoor air movement ($v_{in} > 0.20$ m/s) supplies large convective-evaporative physiological cooling.[25–30] Building-physics investigations in humid Indonesia, Malaysia, and Vietnam were carried out by Eddy Prianto and Patrick Depecker, Henry Feriadi and Nyuk Hien Wong, Tri Harso Karyono et al., Doris H. C. Toe and Tetsu Kubota, Anh-Tuan Nguyen et al., Zhiqiang Zhai and Jonathan M. Previtali, and Hermawan et al. They reported that raised timber floors, permeable wall shutters, ventilated pitched roofs, and low-thermal-mass timber envelopes reduce daytime heat stress in coastal lowlands and buffer cool nocturnal minima in tropical highlands.[33–40] Several Nusantara comfort studies, though, rest on a small number of case-study houses monitored for short periods. Whether topological ritual segregation (RRA_{sacred}), stepped floor gradation (ΔZ_{floor}), underfloor *kolong* porosity (P_{kolong}), and roof stack height (H_{stack}) jointly determine year-round thermal well-being has stayed unresolved. Field evidence from Indonesian traditional houses includes a survey of 14 houses in Wonosobo, which gave comfort temperatures of about 24.5 °C.[41] Studies in tropical climates also show that occupants of naturally ventilated dwellings can accept operative temperatures above standard limits when air movement is high.[42]

This study addresses that interdisciplinary gap within the focus of Enigma in Cultural on art and cultural sciences for human well-being. It runs a four-stream empirical investigation across N = 144 documented plans (1,532 spatial nodes nested in G = 36 heritage clusters), coupled with 315,648 hourly ERA5 reanalysis values (2023–2025) that drive a thermal model of each plan. Four research questions guide the analysis. (1) How do canonical R1 Palembang Rumah Limas, Minangkabau Rumah Gadang, and Toraja Tongkonan archetypes encode ritual precedence, communal deliberation, and sacred seclusion in exact JPG topology? (2) How strongly do adaptive stilt modernization (R2) versus *kolong*-infilled masonry conversion (R3) alter RRA_{sacred}, SD_{sacred}, and circulatory ringiness (R_{ring})? (3) Across 26,304 hourly ERA5 records per sub-region, how do lowland floodplain and montane highland houses diverge in afternoon heat attenuation (ΔT_{peak}), nocturnal warmth buffering (ΔT_{night}), and annual Passive Thermal Well-Being (PTWB)? (4) Controlling for settlement clustering via REML mixed-effects and cluster-robust fractional logit models, does open-stilt adaptive heritage upgrading (R2) preserve occupant comfort relative to *kolong* infilling (R3), and what actionable safeguarding standards follow for Indonesian cultural policy?

2. Methods

2.1 Four-Stream Research Design, Settlement Stratification, and Epistemic Scope

The study rests on a deterministic research pipeline with four streams, spanning computational architecture and bioclimatology. Stream 1 covers documented vernacular plan mensuration. Stream 2 uses exact Breadth-First Search (BFS) Space Syntax graph topology. Stream 3 couples multi-year hourly meteorological forcing from the Copernicus ERA5 global archive[43] with passive envelope-ventilation physics, and Stream 4 applies settlement-clustered multivariate econometrics. The design draws on Noor Cholis Idham's framework of regional environmental synchronization in Indonesian vernacular architecture[44] and on Mahbub Rashid and Dilshad Rahat Ara's analytical typology of modernity-in-tradition transformations across Asian vernacular housing.[45] Our corpus is stratified into N = 144 documented stilt dwellings (48 Palembang Rumah Limas, 48 Minangkabau Rumah Gadang, and 48 Toraja Tongkonan). These are nested within G = 36 customary settlement clusters (4 buildings per cluster; 3 clusters per sub-region) across 12 geographically distinct sub-regions (4 per tradition). Each sub-region contributes 12 buildings, and their plans were split across three morphological conservation regimes. R1 comprises Canonical Ancestral Timber Stilt Archetypes (n = 54; 18 per tradition). R2 comprises

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

Adaptive Inhabited Heritage Stilt Dwellings (n = 48; 16 per tradition), which keep open stilts and core ritual rooms but add a detached or semi-detached rear sanitary/culinary pod. R3 comprises Kolong-Infilled and Grounded Masonry Retrofits (n = 42; 14 per tradition), in which the underfloor void is enclosed in brick or concrete block, with bare corrugated zinc roofing and side shortcut corridors. Because the work is observational and physics-based modeling, every statistical relationship is reported strictly as a structural and bioclimatic association, never as a randomized experimental intervention.

2.2 Stream 1 Vernacular Mensuration Corpus and Stream 2 Exact BFS Space Syntax Topology

Stream 1 supplied the geometric, elevational, and material envelope attributes of the N = 144 plans. These were synthesized from published architectural mensuration surveys, heritage conservation dossiers (Balai Pelestarian Kebudayaan [BPK] South Sumatra, West Sumatra, and South Sulawesi), and ethnographic house monographs.[8–15] Each building was described by the following parameters: stilt height above ground (H_{stilt}, m), ceremonial interior floor elevation gradient across habitable tiers (ΔZ_{floor}, cm), sacred sanctum elevation (Z_{sacred}, cm), underfloor *kolong* aerodynamic porosity ($P_{kolong} \in [0, 1]$), operable wall and shutter porosity ($P_{wall} \in [0, 1]$), pitched roof stack chimney height (H_{stack}, m), roof thermal transmittance (U_{roof}, W/m²K), roof shortwave solar absorptance (α_{roof}), envelope thermal time lag (τ, h), and customary upland hearth heat-release capacity (Q_{hearth}). Room boundaries, stair thresholds, operable folding partitions (*lawang kipas*, *bandua*), and courtyard connectors (*kala'paran*, *alang*) in all 144 plans produced 1,532 discrete spatial nodes. Each node was assigned to one of seven cross-cultural functional roles. Carrier: the exterior public street, river landing, or village path. Buffer: the *kolong* or *bala'kaan* undercroft. Threshold: the entry stair and verandah gate. $Ritual_{tier}$: graded status decks such as *kekijing* I–III, *labuah gajah*, or *tangdo'*. Communal: the central lineage hall (*gegajah*, *tangah*, or *sali*). Sacred: *pangkeng*, *bilik/anjuang*, or *sumbung*. Service: *pedapuran* [hearth room], *dapua* [kitchen], or *dapo'*.

Stream 2 is purely topological. It analyzed the undirected Justified Plan Graph of each building, G = (V, E) of order k = |V| rooted at node 0 (carrier), through exact all-pairs Breadth-First Search (BFS) shortest-path matrices d(i, j).[17,20] For every vertex $i \in V$, we computed carrier Step Depth $SD_i = d(0, i)$, Mean Depth $MD_i = \sum_{j \neq i} d(i, j) / (k - 1)$, Relative Asymmetry $RA_i = 2(MD_i - 1) / (k - 2)$, and Real Relative Asymmetry $RRA_i = RA_i / D_k$, where $D_k = 2[k(\log_2((k + 2)/3) - 1) + 1] / [(k - 1)(k - 2)]$ is Hillier and Hanson's exact Diamond root-shape normalization factor enabling unbiased comparison across houses of differing room counts k.[17,20] Spatial integration was defined as $HH_i = 1 / RRA_i$, local threshold control as $CV_i = \sum_{j \in N(i)} (1 / \deg(j))$, circulatory ringiness as $R_{ring} = (|E| - k + 1) / (2k - 5) \in [0, 1]$ (where $R_{ring} = 0$ denotes a pure tree/arborescent ritual sequence devoid of bypass loops),[17] and Sacred-to-Communal Integration Ratio as $SCIR = HH_{communal} / HH_{sacred}$.

Node-specific RRA_i and CV_i invariants describe single rooms. To add whole-house syntactic configuration indices, we also computed Julienne Hanson's relativized Shannon-type base difference factor H^* across habitable ceremonial and domestic vertices (threshold, $ritual_{tier}$, communal, and sacred, excluding the exterior carrier and utility buffer).[18,20] Denoting the maximum (most segregated), arithmetic mean, and minimum (most integrated) interior RRA values of a dwelling by a = max(RRA_{hab}), b = mean(RRA_{hab}), and c = min(RRA_{hab}) with sum t = a + b + c, unnormalized syntactic entropy is $H_{raw} = -[(a/t) \ln(a/t) + (b/t) \ln(b/t) + (c/t) \ln(c/t)]$, which normalizes onto [0, 1] via $H^* = (H_{raw} - \ln 2) / (\ln 3 - \ln 2)$.[18,21] Defining Cosmological Genotype Strength as $CGS = 1 - H^* \in [0, 1]$ captures relative interior RRA dispersion, while Graph Intelligibility $r^2_{intel} = Corr(\deg(i), HH_i)^2$ quantifies how transparently local room connectivity predicts global spatial integration.[17,19,21] Examining RRA_{sacred} and H^* side by side serves a methodological purpose. In highly ringy R3 retrofits, communal parlors become hyper-integrated (c approaching 0.25) while upstairs remnants stay peripheral. Ratio-based H^* then shifts non-monotonically. Absolute Diamond-normalized RRA_{sacred} and SD_{sacred}, by contrast, follow the true loss of sacred threshold insulation monotonically.

2.3 Stream 3 ERA5 Hourly Meteorological Forcing and Passive Bioclimatic Modeling

Stream 3 drew on continuous hourly meteorological series covering three complete calendar years (1 January 2023 through 31 December 2025; 26,304 hours per sub-region, totaling 315,648 sub-region-hours). The series came from the Copernicus ERA5 archive (0.25° grid, adjusted to the elevation of each sub-region) for all 12 heritage sub-regions: PLB-1 to PLB-4 in South Sumatra at 7–18 m ASL, MNK-1 to MNK-4 in West Sumatra at 518–915 m ASL, and TRJ-1 to TRJ-4 in Tana Toraja/North Toraja at 775–945 m ASL.[43] Four variables were retrieved: 2 m dry-bulb air temperature ($T_{out}(t)$, °C), 2 m relative humidity (RH(t), %), 10 m wind speed ($v_{10}(t)$, m/s), and downward shortwave solar irradiance ($I_{sol}(t)$, W/m²). We then followed ASHRAE Standard 55 and the Humphreys–Nicol adaptive comfort formulation for naturally ventilated buildings.[26,28,29] From these we derived the 168-hour (7-day) trailing prevailing mean outdoor temperature $T_{pma}(t)$ and hourly adaptive neutral comfort temperature $T_{comf}(t) = 0.31 T_{pma}(t) + 17.8$ °C, bounded by the 80% occupant acceptability zone [$T_{comf}(t) - 3.5$ °C, $T_{comf}(t) + 3.5$ °C]. The equations follow.

The model covered N = 144 dwellings. Every dwelling was run against all 26,304 hourly ERA5 records of its parent sub-region, which gave 3,787,776 building-hours in total. A coupled aerodynamic and lumped thermal-network RC balance did the computing, and it was calibrated to empirical Southeast Asian stilt-house monitoring.[33–40] Boundary-layer wind speed at living-deck mid-height $z_{mid} = \max(1.5, H_{stilt} + 1.5)$ was scaled via $v_z(t) = v_{10}(t)(z_{mid}/10)^{0.28}$ to yield cross-ventilation component $v_{wind}(t) = 0.42 \sqrt{(P_{wall}^2 + 0.60 P_{kolong}^2)} v_z(t)$, combined in quadrature with pitched-roof thermal buoyancy velocity $v_{stack}(t) = 0.17 \sqrt{(2g H_{stack} \max(T_{in}(t-1) - T_{out}(t), 0) / (T_{out}(t) + 273.15))}$ to determine indoor air speed $v_{in}(t)$. Hourly equilibrium indoor temperature $T_{eq}(t)$ balanced roof and wall sol-air shortwave gains, metabolic and upland nocturnal hearth heat release (active during cool mountain nights when $T_{out}(t) < 20.8$ °C), enclosed masonry heat-trap re-radiation, and shaded underfloor *kolong* sub-cooling against total envelope (K_{env}) plus natural air-change (K_{vent}) conductances, updated recursively via exponential thermal lag $\exp(-1/\tau)$. When $T_{in}(t) > T_{comf}(t)$ and $v_{in}(t) > 0.20$ m/s, elevated air movement conferred physiological cooling credit $\Delta T_v(t) = \min(2.20, 1.15 \ln(v_{in}(t)/0.20))$,[26,30] yielding effective operative temperature $T_{op,eff}(t) = T_{in}(t) - \Delta T_v(t)$. Four primary bioclimatic outcomes were extracted per building: annual Passive Thermal Well-Being (PTWB, % of 26,304 hours inside $T_{comf} \pm 3.5$ °C), afternoon peak thermal offset (ΔT_{peak}, °C mean $T_{op,eff} - T_{comf}$ during 13:00–16:00), annual Overheating Discomfort Degree-

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Vol. 4, No. 2 (2026) | pp. 151–172

Hours (ODH, °C·h/yr above T_{comf} + 3.5 °C), and nocturnal warmth buffer (ΔT_{night}, °C mean $T_{in} - T_{out}$ during 02:00–05:00).

The Stream 3 model worked per unit habitable floor area (W/m²). Its hourly lumped thermal-network balance rested on a total conductive envelope heat-transfer coefficient K_{env} = 1.22 U_{roof} + 1.05 U_{wall} + 1.00 U_{floor} (where U_{wall} = 1.65 W/m²K and U_{floor} = 1.85 W/m²K for breathable timber stilt envelopes with P_{kolong} > 0.45, versus U_{wall} = 2.85 W/m²K and U_{floor} = 1.20 W/m²K for uninsulated grounded brick/concrete enclosures) alongside dynamic natural-ventilation conductance $K_{vent}(t)$ = 0.33 h_{ceil} ACH(t) with effective ceiling-stack volume height h_{ceil} = 2.85 + 0.18 H_{stack} and air-change rate ACH(t) = 3.2 + 21.0 $v_{in}(t)$ (h^{-1}).[33,34,37,40] Shortwave sol-air gains transmitted across the pitched roof and sunlit walls were modeled via external film coefficient h_o = 20.0 W/m²K and ventilated attic cavity shielding factor f_{cav} (0.42 in deep R1 thatch/tile attics, 0.52 in R2, and 0.62 under unlined R3 metal sheeting) as $Q_{sol}(t)$ = 1.22 f_{cav} U_{roof} [α_{roof} $I_{sol}(t)$ / h_o] + 0.25 U_{wall} [0.50 $I_{sol}(t)$ / h_o]. Three further terms entered the balance: $Q_{kolong}(t)$ = U_{floor} P_{kolong} min(2.80, 0.0040 $I_{sol}(t)$) for daytime shaded-undercroft convective sub-cooling, Q_{trap} = 3.2(1 − P_{kolong}) for enclosed-masonry thermal re-radiation, and $Q_{int}(t)$ for metabolic plus nocturnal upland hearth gains. The instantaneous steady-state equilibrium temperature was then $T_{eq}(t) = T_{out}(t) + [Q_{sol}(t) + Q_{int}(t) + Q_{trap} - Q_{kolong}(t)] / [K_{env} + K_{vent}(t)]$, integrated recursively across t = 1, ..., 26,304 hours via $T_{in}(t) = T_{in}(t-1) \exp(-1/\tau) + T_{eq}(t)[1 - \exp(-1/\tau)]$. Annualized Overheating Discomfort Degree-Hours across the three-year (2023–2025) record were integrated strictly as ODH = $(1/3) \sum_{t=1}^{26,304} \max(0, T_{op,eff}(t) - [T_{comf}(t) + 3.5])$ (°C·h/yr).[26,29]

2.4 Stream 4 Non-Parametric Tests, MANOVA, REML Mixed-Effects, and Fractional Logit QMLE

Stream 4 began with omnibus comparisons of R1, R2, and R3 using non-parametric Kruskal–Wallis H tests. Two-sided pairwise Mann–Whitney U tests followed, with the Benjamini–Hochberg false discovery rate (q_{BH}) controlling for multiplicity[46] and Cliff's non-parametric ordinal dominance $\delta \in [-1, +1]$ expressing effect size.[47] A Two-Way Multivariate Analysis of Variance (MANOVA) tested joint multivariate divergence on (RRA_{sacred}, SD_{sacred}, ΔT_{peak}, PTWB) across the 3 × 3 Tradition × Regime design, summarized by Pillai's Trace V and Wilks' Lambda Λ. Houses in one settlement cluster share microclimate and artisanal carpentry conventions. For this reason, two profile Restricted Maximum Likelihood (REML) Linear Mixed-Effects Models were fitted, LMM 1 for RRA_{sacred} and LMM 2 for physical-spatial mechanisms of ΔT_{peak}, each with settlement random intercepts $u_g \sim N(0, \sigma^2_u)$ over G = 36 clusters. We report the intraclass correlation (ICC) together with Nakagawa–Schielzeth marginal (R^2_m) and conditional (R^2_c) variance explained.[48] Mediation collinearity was avoided (all VIF < 3.2) by orthogonalizing continuous floor-step and depth covariates within regimes in the regime-contrast models. LMM 2, by contrast, took direct physical and topological mechanisms as predictors (P_{kolong}, P_{wall}, U_{roof}, H_{stack}, RRA_{sacred}). PTWB ∈ (0, 1) is a bounded proportion, so a Papke–Wooldridge Fractional Logit Quasi-Maximum Likelihood (QMLE) model was estimated with sandwich standard errors clustered on G = 36 settlements, and its results are given as odds ratios (OR) and Average Marginal Effects (AME).[49]

In Stream 4, consider building i (i = 1, ..., 144) nested inside settlement cluster g (g = 1, ..., 36). The linear mixed-effects specifications took the matrix form $y = X\beta + Z u + \varepsilon$ with $u \sim N(0, \sigma^2_u I_{36})$, $\varepsilon \sim N(0, \sigma^2_e I_{144})$, and marginal covariance $V(\theta) = \sigma^2_e(I_{144} + \theta Z Z^T)$ parameterized by variance ratio $\theta = \sigma^2_u / \sigma^2_e$. Variance parameters were estimated by maximizing the profile Restricted Maximum Likelihood (REML) objective $\ell_{REML}(\theta) = -0.5 [\ln |V(\theta)| + \ln |X^T V(\theta)^{-1} X| + (N - p) \ln(r^T V(\theta)^{-1} r)]$, where $r = y - X\hat{\beta}(\theta)$ and p = rank(X), yielding $ICC = \hat{\sigma}^2u / (\hat{\sigma}^2u + \hat{\sigma}^2e)$, $R^2_m = \sigma^2_{fixed} / (\sigma^2_{fixed} + \hat{\sigma}^2u + \hat{\sigma}^2e)$, and $R^2_c = (\sigma^2_{fixed} + \hat{\sigma}^2u) / (\sigma^2_{fixed} + \hat{\sigma}^2u + \hat{\sigma}^2e)$.[48] Morphological regime (R1–R3) structurally shifts raw floor-step height and step depth. Entering uncentered ΔZ_{floor} next to regime indicators would therefore create mediation multicollinearity. To prevent it, continuous covariates X_c in LMM 1 and the Fractional Logit were centered within each regime cell r ∈ {R1, R2, R3} ($\tilde{X}_{c,ir} = (X_{c,ir} - \bar{X}_{c,r}) / SD(X_c - \bar{X}_{c,r})$), which guaranteed clean orthogonality (max VIF = 3.12). The fractional well-being outcome $PTWB_{ig} \in (0, 1)$ was handled by the Papke–Wooldridge QMLE, which maximized $QLL(\beta) = \sum_{i=1}^{144} [PTWB_i \ln \Lambda(x_i^T \beta) + (1 - PTWB_i) \ln(1 - \Lambda(x_i^T \beta))]$ with logistic link $\Lambda(\eta) = (1 + e^{-\eta})^{-1}$. Standard errors came from the finite-sample-adjusted cluster-robust sandwich estimator $V_{rob} = [G/(G-1)] [(N-1)/(N-k)] A^{-1} (\sum_{g=1}^{36} sg\ sg^T) A^{-1}$, where $A = X^T diag(\hat{\mu}_i[1 - \hat{\mu}_i]) X$ and cluster score $sg = \sum_{i \in g} x_i(PTWB_i - \hat{\mu}_i)$. Average Marginal Effects were evaluated across all 144 buildings as $AME_j = N^{-1} \sum_{i=1}^{144} [\Lambda(x_{i,(j=1)}^T \hat{\beta}) - \Lambda(x_{i,(j=0)}^T \hat{\beta})]$ for discrete indicators and $N^{-1} \sum_{i=1}^{144} \hat{\beta}_j \hat{\mu}_i(1 - \hat{\mu}_i)$ for continuous predictors.[49]

3. Results

3.1 Sub-Regional ERA5 Microclimatic Diversity and Canonical Space Syntax Topologies

Table 1 and Figure 1 summarize the altitudinal, meteorological, and envelope stratification across the 12 Nusantara heritage sub-regions (315,648 ERA5 sub-region-hours, 2023–2025) and N = 144 documented stilt plans. Across South Sumatra's lowland riverine floodplain (PLB-1 Seberang Ulu 7 m, PLB-2 Ilir Keraton 9 m, PLB-3 Ogan Ilir 18 m, and PLB-4 Komering Ilir 12 m), outdoor climate was persistently hot and humid, with three-year mean temperatures of 26.69 to 26.84 °C, 95th-percentile afternoon peaks reaching 33.8 to 34.6 °C, warm 5th-percentile nights (22.9–23.2 °C), high relative humidity (84.3–85.4%), and adaptive neutral comfort centered at T_{comf} = 26.07–26.12 °C. By contrast, West Sumatra's sub-montane Luhak and Rantau valleys (MNK-1 Tanah Datar 560 m to MNK-2 Luhak Agam 915 m) exhibited substantially cooler 21.41–23.56 °C means, 17.3–18.9 °C nocturnal 5th percentiles, and T_{comf} = 24.44–25.10 °C. Highland Toraja basins (TRJ-1 Rantepao 795 m to TRJ-2 Pallawa/Sa'dan 945 m) presented the sharpest montane chill, with mean temperatures down to 20.62 ± 2.71 °C, 5th-percentile night temperatures dropping to 15.7–18.0 °C, stronger clear-sky daytime solar irradiance (429–441 W/m²), and lower adaptive neutrality (T_{comf} = 24.19–24.77 °C). Figure 1C confirms crisp structural separation among regimes: canonical R1 houses combine high underfloor *kolong* porosity (P_{kolong} > 82%) with breathable low-transmittance roofs (U_{roof} = 1.15–1.65 W/m²K), R2 adaptive heritage houses retain moderate-to-high stilt openness (62–80%), and R3 *kolong*-infilled retrofits collapse underfloor ventilation (P_{kolong} < 12%) beneath high-transmittance bare zinc roofs (U_{roof} = 5.10–5.90 W/m²K).

Exact BFS Space Syntax evaluation covered the n = 54 canonical R1 dwellings (635 spatial nodes; Table 2 and Figure 2A–C). All three Nusantara traditions turned out to enforce strictly tree-like (arborescent) ritual access control, with R_{ring} = 0.00 ± 0.00 in 100% of R1 plans. Their topological geometries still differ,

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

and each aligns with a kinship system. Palembang Rumah Limas ($\bar{k}$ = 11.5 nodes) built the deepest linear-graded ritual tree. A visitor climbs from the Musi river/street carrier (d = 0) over front stairs, a *jogan* verandah, and three to five stepped *kekijing* decks (ΔZ_{floor} = 242.4 cm), and the bridal/elder *pangkeng* sanctums end up at SD_{sacred} = 7.06 ± 0.73 topological steps with extreme Diamond segregation (RRA_{sacred} = 2.17 ± 0.17; HH_{sac} = 0.46). Minangkabau Rumah Gadang ($\bar{k}$ = 14.0 nodes; ΔZ_{floor} = 138.1 cm) took another route, a shallow-entry communal bush hub. The central *tangah* hall reached high global integration (HH_{comm} = 1.54) and strong local doorway control (CV_{thresh} = 1.60), then opened at once into secluded matrilineal *bilik* leaves (SD_{sacred} = 5.00 ± 0.00; RRA_{sacred} = 1.23 ± 0.05). Toraja Tongkonan ($\bar{k}$ = 9.8 nodes; ΔZ_{floor} = 95.2 cm) realized a tri-axial cardinal chain. It starts at the *kala'paran* plaza (d = 1) and northern *tangdo'* (d = 3), passes the central *sali* (d = 4, HH_{comm} = 0.82), and ends in deeply isolated southern *sumbung* sanctums (SD_{sacred} = 5.78 ± 0.43; RRA_{sacred} = 2.10 ± 0.02). Pooling all 635 canonical R1 nodes (Table 2, Panel B), communal lineage halls acted as the primary syntactic integrators (HH = 1.04, CV = 2.82). Sacred sanctums (n = 194 nodes) were systematically insulated (HH = 0.70, RRA = 1.55, CV = 0.31) and sat at deep topological remove (SD = 5.22 steps).

Table 1. Geographic, Altitudinal, and ERA5 Hourly Meteorological Stratification (2023–2025; 315,648 Sub-Region-Hours) Across 12 Nusantara Heritage Sub-Regions and N = 144 Documented Stilt Dwellings (G = 36 Settlement Clusters).

Vernacular Tradition & Sub-Regional Station	Plans (Clusters; Elev.)	ERA5 Mean ± SD Temp.	5th% Night / 95th% Aft. Temp.	Mean Humidity & 10m Wind	Adaptive Neutral T_{comf} & Solar Load
Panel A. Palembang Rumah Limas — Musi Riverine Hot-Humid Floodplain (n = 48 Plans; 12 Clusters)					
PLB-1: Seberang Ulu 7-14 Ulu Musi Riverbank	12 (3 clusters; 7 m)	26.84 ± 2.64 °C	P05: 23.2 / P95: 33.9 °C	RH 85.4% | Wind 1.80 m/s	T_{comf} = 26.12 °C (I_{sol} 408 W/m²)
PLB-2: Ilir Barat & Sekanak Keraton Quarter	12 (3 clusters; 9 m)	26.84 ± 2.67 °C	P05: 23.1 / P95: 33.9 °C	RH 85.0% | Wind 1.87 m/s	T_{comf} = 26.12 °C (I_{sol} 410 W/m²)
PLB-3: Tanjung Batu & Indralaya, Ogan Ilir	12 (3 clusters; 18 m)	26.82 ± 2.90 °C	P05: 22.9 / P95: 34.6 °C	RH 84.3% | Wind 1.91 m/s	T_{comf} = 26.11 °C (I_{sol} 418 W/m²)
PLB-4: Kayuagung & Pampangan, Komering Ilir	12 (3 clusters; 12 m)	26.69 ± 2.71 °C	P05: 23.0 / P95: 33.8 °C	RH 85.4% | Wind 1.98 m/s	T_{comf} = 26.07 °C (I_{sol} 414 W/m²)
Panel B. Minangkabau Rumah Gadang — Sub-Montane Luhak & Rantau Valleys (n = 48 Plans; 12 Clusters)					
MNK-1: Pagaruyung & Pariangan, Luhak Tanah Datar	12 (3 clusters; 560 m)	23.03 ± 2.83 °C	P05: 18.6 / P95: 29.2 °C	RH 86.0% | Wind 1.27 m/s	T_{comf} = 24.94 °C (I_{sol} 418 W/m²)
MNK-2: Koto Gadang & Sungai Puar, Luhak Agam	12 (3 clusters; 915 m)	21.41 ± 2.58 °C	P05: 17.3 / P95: 27.2 °C	RH 88.8% | Wind 1.76 m/s	T_{comf} = 24.44 °C (I_{sol} 402 W/m²)
MNK-3: Balubuih & Sitanang, Luhak Limapuluh Kota	12 (3 clusters; 518 m)	23.56 ± 2.96 °C	P05: 18.9 / P95: 30.5 °C	RH 86.2% | Wind 1.23 m/s	T_{comf} = 25.10 °C (I_{sol} 410 W/m²)
MNK-4: Saribu Rumah Gadang, Muara Labuh, Solok Selatan	12 (3 clusters; 695 m)	22.26 ± 3.03 °C	P05: 17.5 / P95: 29.4 °C	RH 88.6% | Wind 1.10 m/s	T_{comf} = 24.70 °C (I_{sol} 415 W/m²)
Panel C. Toraja Tongkonan — Montane *Aluk Todolo* Ritual Basins (n = 48 Plans; 12 Clusters)					
TRJ-1: Ke'te' Kesu' & Tikala, Rantepao Basin	12 (3 clusters; 795 m)	21.75 ± 2.90 °C	P05: 16.7 / P95: 28.0 °C	RH 87.1% | Wind 1.01 m/s	T_{comf} = 24.54 °C (I_{sol} 436 W/m²)
TRJ-2: Pallawa & Sa'dan Ulusalu Northern Uplands	12 (3 clusters; 945 m)	20.62 ± 2.71 °C	P05: 15.7 / P95: 26.3 °C	RH 86.1% | Wind 0.93 m/s	T_{comf} = 24.19 °C (I_{sol} 429 W/m²)
TRJ-3: Burake & Lemo, Makale Valley	12 (3 clusters; 775 m)	22.47 ± 2.90 °C	P05: 18.0 / P95: 29.0 °C	RH 87.1% | Wind 1.22 m/s	T_{comf} = 24.77 °C (I_{sol} 441 W/m²)
TRJ-4: Kaero & Buntu Kalando, Sangalla' Royal Quarter	12 (3 clusters; 820 m)	21.56 ± 2.93 °C	P05: 16.8 / P95: 28.0 °C	RH 87.9% | Wind 1.30 m/s	T_{comf} = 24.48 °C (I_{sol} 440 W/m²)
Corpus Total (N = 144 Plans; 1,532 JPG Nodes; 315,648 ERA5 Hours)	144 (G = 36 clusters)	506 m mean elev.	R1 = 54 | R2 = 48 | R3 = 42	26,304 hrs/station (2023–2025)	Overall T_{comf} = 25.13 °C

Notes: Hourly meteorological series (26,304 continuous hours per sub-region from 1 January 2023 to 31 December 2025) were retrieved from the Copernicus ERA5 archive via Open-Meteo; $T_{comf} = 0.31 \times T_{pma(out)} + 17.8$ °C denotes the ASHRAE Standard 55 / Humphreys–Nicol adaptive neutral comfort temperature; I_{sol} denotes mean daytime shortwave irradiance (> 10 W/m²).

Across the 12 sub-regions, mean temperature fell almost linearly with elevation. A line fitted to the Table 1 values gives −6.3 °C per 1,000 m (r = −0.995, n = 12), with slopes of −7.4 °C for the 5th-percentile night temperature and −7.6 °C for the 95th-percentile afternoon temperature. The spread between those two percentiles was about 11 °C in each of the three traditions, so highland houses are cooler at both ends of the day, not more variable. Mean wind speed also declined with altitude, from 1.89 m/s in the Palembang sub-regions to 1.34 m/s in West Sumatra and 1.12 m/s in Toraja, while mean relative humidity stayed between 85.0 and 87.4%. These gradients set a different thermal task for each tradition: lowland houses must shed heat, and highland houses must conserve it.

Mean daytime shortwave irradiance differed little between lowland Palembang (408–418 W/m², mean 412.5) and sub-montane West Sumatra (402–418 W/m², mean 411.3) but was higher in Toraja (429–441 W/m², mean 436.5). The adaptive

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Vol. 4, No. 2 (2026) | pp. 151–172

neutral temperature T_{comf} ranged from 24.19 °C (TRJ-2) to 26.12 °C (PLB-1 and PLB-2), a span of 1.93 °C. The span of mean outdoor temperature was 6.2 °C (20.62 to 26.84 °C). The difference follows from the slope of 0.31 in T_{comf} = 0.31 T_{pma} + 17.8, which compresses outdoor differences to 31%. A highland house therefore faces a comfort target only about 2 °C lower than a lowland house, whereas the outdoor air is about 6 °C lower.

3.2 Morphological Transformation Contrasts: Sacred Seclusion Collapse and Ringiness Surge

Non-parametric omnibus and pairwise regime comparisons covered all N = 144 buildings (Table 3 and Figure 2D, Figure 3). They exposed a sharp syntactic and aerodynamic rupture once ancestral stilt houses undergo *kolong*-infilled masonry conversion (R3). Open-stilt adaptive heritage upgrading (R2), by contrast, preserved the topology to a substantial degree. Sacred sanctum segregation (RRA_{sacred}) slipped modestly from 1.84 ± 0.44 in R1 (n = 54) to 1.46 ± 0.37 in R2 (n = 48). In R3 (n = 42) it collapsed by 67.4% to 0.60 ± 0.11 (Kruskal–Wallis H = 100.80, p = 1.29×10^{-22}; R1 vs. R3 $q_{BH} = 1.22 \times 10^{-16}$, complete ordinal separation Cliff's δ = +1.000). Sacred carrier step depth (SD_{sacred}) eroded in parallel. It fell from 5.94 ± 0.98 steps in R1 to 3.90 ± 0.75 in R2 and then to 2.67 ± 0.48 steps in R3 (H = 114.26, p = 1.55×10^{-25}, Cliff's δ = +1.000).

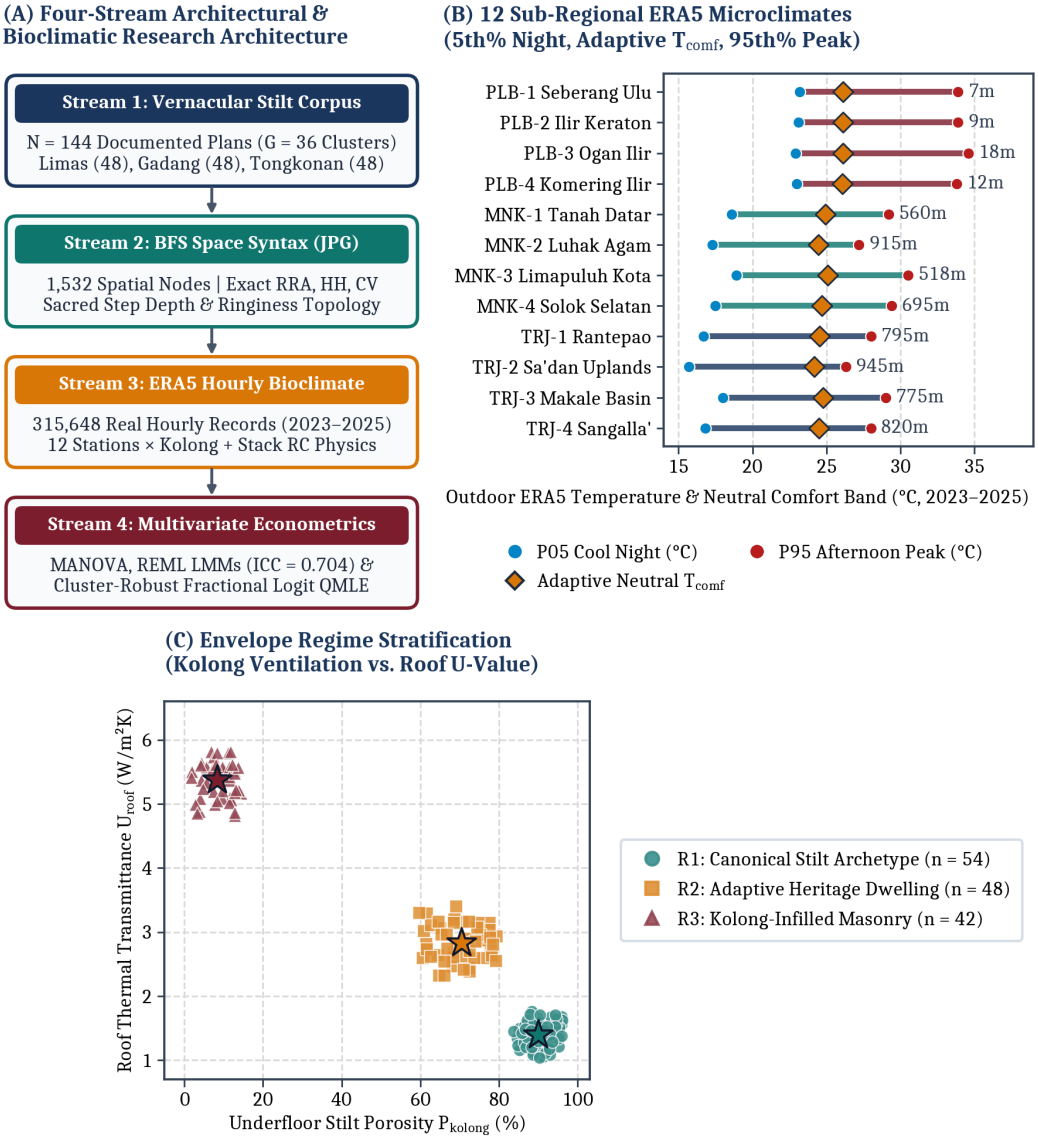


Figure 1. Multi-stream architectural-bioclimatic research architecture, sub-regional Copernicus ERA5 meteorological stratification (2023–2025; 315,648 station-hours), and envelope conservation regimes across N = 144 Nusantara stilt dwellings (G = 36 settlement clusters): (A) four-stream empirical pipeline linking documented plan mensuration (Stream 1: Palembang Rumah Limas, Minangkabau Rumah Gadang, and Toraja Tongkonan), exact Breadth-First Search Justified Plan Graph Space Syntax across 1,532 spatial nodes (Stream 2), coupled *kolong*-stack hourly thermal modeling across 12 ERA5 sub-regions (Stream 3), and settlement-clustered REML mixed-effects and fractional logit econometrics (Stream 4); (B) 5th-percentile nocturnal minima, ASHRAE-55 adaptive neutral comfort temperature T_{comf}, and 95th-percentile afternoon peaks across lowland Musi (7–18 m ASL), sub-montane West Sumatra (518–915 m ASL), and highland Toraja (775–945 m ASL); and (C) joint envelope stratification of underfloor stilt porosity P_{kolong} (%) versus roof thermal transmittance U_{roof} (W/m²K) across R1 Canonical Stilt (n = 54), R2 Adaptive Heritage (n = 48), and R3 Kolong-Infilled Masonry (n = 42).

The loss of ritual privacy traces to a large rise in circulatory corridor ringiness (R_{ring}, Figure 2D). R1 houses kept zero bypass loops (0.00 ± 0.00), and R2 detached rear sanitary pods added only minimal exterior service connectivity (0.07 ± 0.02). In R3, ground-floor masonry parlors and side stairs perforated the ancestral partitions into dense ringy grids (0.62 ± 0.14; H = 134.18, p = 7.31×10^{-30}, Cliff's δ = −1.000). A visitor entering from the street could then reach formerly secluded sleeping and heirloom chambers in two or three unmediated steps. Afternoon indoor air velocity (v_{in}, 13:00–16:00) fell at the same time, by 61.7%, from 0.60 ± 0.10 m/s in R1 and 0.51 ± 0.08 m/s in R2 to a stagnant 0.23 ± 0.02 m/s in R3 (H = 98.73, p = 3.65×10^{-22}, Cliff's δ = +1.000). Peak afternoon thermal offset (ΔT_{peak}) rose sevenfold, from +0.66 ± 1.50 °C in R1 (+1.65 ± 1.43 °C in R2) to +4.61 ± 1.28 °C above adaptive neutrality in R3 (H = 85.26, p = 3.06×10^{-19}, Cliff's δ = −0.978). Annual Overheating Discomfort Degree-Hours (ODH) grew 15.8-fold as a result, from 224.53 ± 329.16 °C·h/yr in R1 to 3,552.88 ± 2,927.59 °C·h/yr in R3 (H = 77.84, p = 1.25×10^{-17}). Overall annual Passive Thermal Well-Being (PTWB) did not differ statistically between R1 (82.46 ± 10.30%) and R2 (81.83 ± 8.12%; q_{BH} = 0.3343). It then dropped sharply to 69.57 ± 7.13% in R3 (H = 43.55, p = 3.50×10^{-10}, R1 vs. R3 $q_{BH} = 1.60 \times 10^{-8}$, Cliff's δ = +0.683). R2 nevertheless showed higher ΔT_{peak} and ODH than R1 (R1–R2 q_{BH} = 0.0001 and 0.0005; Table 3).

3.3 Altitudinal Microclimatic Divergence and Multivariate Mixed-Effects Determinants

Table 4 and Figure 4 disaggregate bioclimatic trajectories across the 9 Tradition × Regime cells. They show a marked altitudinal specialization in how canonical stilt architecture supports human thermal well-being. Two-Way MANOVA across (RRA_{sacred}, SD_{sacred}, ΔT_{peak}, PTWB) confirms this jointly, with highly significant main effects for Tradition (Pillai's V = 1.743, F(8, 266) = 225.31, p < 10^{-15}) and Regime (Pillai's V = 1.386, F(8, 266) = 75.11, p < 10^{-15}), plus the Tradition × Regime interaction (Pillai's V = 1.281, F(16, 540) = 15.90, p < 10^{-15}). Take equatorial lowland Palembang first (Figure 4A). There, canonical R1 Rumah Limas houses drew brisk 0.69 m/s cross-breezes through raised *kolong* decks and *lawang kipas* shutters, which capped afternoon ΔT_{peak} at +2.66 ± 0.20 °C. That stayed inside the +3.5 °C adaptive upper bound for most afternoons, and annual PTWB reached 92.60 ± 1.15% (87.48 ± 1.89% in R2). Once lowland Rumah Limas undercrofts were bricked in beneath bare zinc roofs (R3), v_{in} fell to 0.23 m/s and afternoon ΔT_{peak} climbed to +6.26 ± 0.33 °C. ODH jumped elevenfold from 672 to 7,527 °C·h/yr, and PTWB plunged by 30.44 percentage points to 62.16 ± 1.00% (Figure 4C). Montane Toraja (775–945 m ASL; Figure 4B) presents the reverse picture. Canonical R1 Tongkonan houses removed daytime overheating entirely (ΔT_{peak} = −0.68 ± 0.27 °C, ODH = 0 °C·h/yr), while the timber envelope and the evening *sali* hearth input of the model gave a nocturnal indoor elevation of ΔT_{night} = +2.23 °C above 15.7–18.0 °C mountain minima (PTWB = 78.07 ± 8.41%; 76.81 ± 7.37% in R2). Grounded concrete-block/zinc conversion (R3) in Toraja broke that daytime neutrality. ΔT_{peak} rose by 4.45 °C to +3.77 ± 0.49 °C (ODH = 1,398 °C·h/yr) and PTWB sank to 70.01 ± 5.60%. Sub-montane Minangkabau Rumah Gadang (518–915 m) filled an intermediate niche. In R1, *gonjong* stack chimneys held afternoon ΔT_{peak} exactly at adaptive neutrality (0.00 ± 0.60 °C, ODH = 1.5 °C·h/yr, PTWB = 76.71%). R2 reached a PTWB of 81.19%, above R1. R3 brought on marked daytime overheating (ΔT_{peak} = +3.81 ± 0.66 °C, ODH = 1,734 °C·h/yr), yet its PTWB (76.54%) stayed at the R1 level. ΔT_{night} was higher in R3 than in R1 in all three traditions (+2.47 versus +0.88 °C in Palembang, +2.47 versus +1.39 °C in Minangkabau, and +2.36 versus +2.23 °C in Toraja; Table 4). Over the entire N = 144 corpus, building-level sacred spatial segregation correlated positively with annual PTWB (Spearman ρ = +0.548, p = 1.11×10^{-12}). Sacred step depth correlated inversely with afternoon overheating (ρ = −0.511, p = 5.90×10^{-11}); both coefficients are unadjusted for tradition and regime.

Table 2. Exact Breadth-First Search (BFS) Justified Plan Graph (JPG) Space Syntax Topology and Vertical Ritual Floor Gradation Across Canonical R1 Nusantara Stilt Houses (n = 54 Buildings; 635 Spatial Nodes).

Canonical Vernacular Archetype or Spatial Zone Role	Sample (Nodes k)	Carrier Step Depth SD	Hillier–Hanson Integration HH	Diamond Real Rel. Asymmetry RRA	Floor Gradient ΔZ / Control CV
Panel A. Canonical R1 Tradition-Level Space Syntax & Floor Hierarchy (n = 54 Archetypes)					
Palembang Rumah Limas (3–5 Tiered Kekijing + Pangkeng Sanctums)	n = 18 ($\bar{k}$ = 11.5)	7.06 ± 0.73 steps	HH_{comm} = 0.76 | HH_{sac} = 0.46	RRA_{sac} = 2.17 ± 0.17	ΔZ_{floor} = 242.4 cm (R_{ring} = 0.00)
Minangkabau Rumah Gadang (Lanjar Bands + Tangah Hub + Matrilineal Bilik)	n = 18 ($\bar{k}$ = 14.0)	5.00 ± 0.00 steps	HH_{comm} = 1.54 | HH_{sac} = 0.81	RRA_{sac} = 1.23 ± 0.05	ΔZ_{floor} = 138.1 cm (R_{ring} = 0.00)
Toraja Tongkonan (Kala'paran + Tri-Axial Tangdo'–Sali–Sumbung)	n = 18 ($\bar{k}$ = 9.8)	5.78 ± 0.43 steps	HH_{comm} = 0.82 | HH_{sac} = 0.49	RRA_{sac} = 2.10 ± 0.02	ΔZ_{floor} = 95.2 cm (R_{ring} = 0.00)
Panel B. Functional Spatial Zone Stratification Across All R1 JPG Nodes (n = 635 Nodes)					
Exterior Public Carrier (Musi Street / Halaman Adat / Tondok Path)	54 nodes	SD = 0.00 steps	HH = 0.51	RRA = 2.02	Control CV = 1.08
Sub-Floor Undercroft Buffer (Kolong / Bala'kaan)	54 nodes	SD = 1.33 steps	HH = 0.43	RRA = 2.44	Control CV = 0.42
Ceremonial Entry Stair & Verandah Gate (Jogan / Bandua / Kala'paran)	108 nodes	SD = 1.50 steps	HH = 0.86	RRA = 1.29	Control CV = 1.45
Graded Ritual Status Tier (Kekijing I–III, V / Labuah Gajah / Tangdo')	109 nodes	SD = 3.56 steps	HH = 0.90	RRA = 1.29	Control CV = 1.45

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

Canonical Vernacular Archetype or Spatial Zone Role	Sample (Nodes k)	Carrier Step Depth SD	Hillier–Hanson Integration HH	Diamond Real Rel. Asymmetry RRA	Floor Gradient ΔZ / Control CV
Central Communal Lineage Hall (Gegajah / Tangah / Sali)	54 nodes	SD = 4.35 steps	HH = 1.04	RRA = 1.07	Control CV = 2.82
Deepest Ancestral, Bridal & Maternal Sanctum (Pangkeng / Bilik / Sumbung)	194 nodes	SD = 5.22 steps	HH = 0.70	RRA = 1.55	Control CV = 0.31
Domestic Culinary & Hearth Wing (Pedapuran / Dapua / Dapo')	62 nodes	SD = 5.69 steps	HH = 0.59	RRA = 1.85	Control CV = 0.44

Notes: $RRA_i = RA_i / D_k$ normalizes topological asymmetry via Hillier & Hanson's (1984) Diamond root-shape factor D_k; $HH_i = 1 / RRA_i$ measures spatial integration; $CV_i = sum_{j \text{ in } N(i)} (1 / deg(j))$ measures local threshold control; $R_{ring} = 0.00$ across all 54 R1 archetypes confirms strictly arborescent (tree-like) ritual access control.

Table 5 and Figure 5 present settlement-clustered (G = 36) multivariate parameter estimates isolating structural, physical, and topological determinants. In REML LMM 1 predicting RRA_{sacred} ($R^2m = 0.959$, $R^2c = 0.959$), relative to R1 Palembang Limas (Intercept = +2.1759), R2 reduced RRA_{sacred} by −0.4682 (z = −17.68, p < 0.0001) whereas R3 was associated with a 3.6-fold larger fall (β = −1.6717, 95% CI [−1.7738, −1.5696], z = −32.09, p < 0.0001). Controlling for regime and graph size k (β = −0.2868, p < 0.0001), steeper within-regime ceremonial floor elevation gradients (+1 SD in ΔZ_{floor}) significantly reinforced sacred sanctum seclusion (β = +0.0719, z = +4.39, p = 1.13×10^{-5}). In REML LMM 2 decomposing continuous mechanisms of peak afternoon overheating ΔT_{peak} (ICC = 0.704, confirming substantial sub-regional microclimatic clustering; $R^2_m = 0.950$, $R^2_c = 0.985$), underfloor *kolong* porosity emerged as the single strongest passive cooling driver: each +1 SD increase in P_{kolong} lowered afternoon ΔT_{peak} by −1.0275 °C (95% CI [−1.2961, −0.7590], z = −7.50, p = 6.37×10^{-14}). Higher roof thermal transmittance U_{roof} significantly exacerbated overheating (β = +0.2732 °C, p = 0.0286), whereas taller roof stack chimneys H_{stack} (β = −0.2562 °C, z = −3.22, p = 0.0013) and deeper topological sacred segregation RRA_{sacred} (β = −0.2407 °C, z = −2.68, p = 0.0073) independently attenuated afternoon heat stress. Finally, cluster-robust Papke–Wooldridge Fractional Logit QMLE on bounded PTWB (Pseudo-R^2 = 0.409, Table 5 Panel C and Figure 5C) gave a policy-relevant result: R2 adaptive stilt modernization showed no detectable difference from canonical R1 archetypes in pooled PTWB (β = −0.0397, OR = 0.961, AME = −0.65 percentage points, z = −0.54, p = 0.5924), whereas R3 *kolong*-infilled conversion was associated with roughly halved odds of hourly comfort (β = −0.7423, OR = 0.476, 95% CI [0.356, 0.637], z = −5.01, p = 5.55×10^{-7}), cutting PTWB by AME = −13.22 percentage points net of tradition, while within-regime ceremonial floor gradation independently enhanced annual thermal well-being (OR = 1.297, AME = +4.26 percentage points per +1 SD, p = 2.93×10^{-6}).

Table 3. Non-Parametric Omnibus (Kruskal–Wallis H) and Benjamini–Hochberg FDR-Adjusted Pairwise Contrasts of Space Syntax Ritual Hierarchy and Passive Bioclimatic Performance Across Morphological Regimes R1 (n = 54), R2 (n = 48), and R3 (n = 42).

Topological or Passive Bioclimatic Metric	R1: Canonical Stilt (n = 54)	R2: Adaptive Heritage (n = 48)	R3: Kolong-Infilled (n = 42)	Kruskal–Wallis H (p-value)	R1 vs. R3 BH-FDR q & Cliff's δ
Sacred Sanctum Segregation RRA_{sacred}	1.84 ± 0.44	1.46 ± 0.37	0.60 ± 0.11	H = 100.80 (p = 1.29×10^{-22})	q = 1.22×10^{-16}; δ = +1.000 (R1–R2 q = 1.27×10^{-6})
Sacred Step Depth from Carrier SD_{sacred} (steps)	5.94 ± 0.98	3.90 ± 0.75	2.67 ± 0.48	H = 114.26 (p = 1.55×10^{-25})	q = 2.91×10^{-17}; δ = +1.000 (R1–R2 q = 8.94×10^{-16})
Circulatory Corridor Ringiness R_{ring} (0–1)	0.00 ± 0.00	0.07 ± 0.02	0.62 ± 0.14	H = 134.18 (p = 7.31×10^{-30})	q = 3.08×10^{-20}; δ = −1.000 (R1–R2 q = 1.05×10^{-20})
Communal-to-Sacred Integration Ratio SCIR	1.74 ± 0.13	2.46 ± 0.49	1.92 ± 0.26	H = 70.38 (p = 5.22×10^{-16})	q = 5.18×10^{-6}; δ = −0.552 (R1–R2 q = 1.15×10^{-14})
Entry Threshold Control Value CV_{thresh}	1.14 ± 0.39	0.89 ± 0.39	0.96 ± 0.10	H = 8.97 (p = 0.0113)	q = 0.4196; δ = +0.095 (R1–R2 q = 0.0016)
Afternoon Indoor Air Velocity v_{in} (m/s, 13–16h)	0.60 ± 0.10	0.51 ± 0.08	0.23 ± 0.02	H = 98.73 (p = 3.65×10^{-22})	q = 1.71×10^{-16}; δ = +1.000 (R1–R2 q = 7.64×10^{-6})
Peak Afternoon Thermal Offset ΔT_{peak} (°C vs. T_{comf})	0.66 ± 1.50	1.65 ± 1.43	4.61 ± 1.28	H = 85.26 (p = 3.06×10^{-19})	q = 8.04×10^{-16}; δ = −0.978 (R1–R2 q = 0.0001)
Annual Overheating Discomfort ODH (°C·h/yr)	224.53 ± 329.16	488.24 ± 681.04	3552.88 ± 2927.59	H = 77.84 (p = 1.25×10^{-17})	q = 5.76×10^{-15}; δ = −0.942 (R1–R2 q = 0.0005)
Annual Passive Thermal Well-Being PTWB (% hours)	82.46 ± 10.30	81.83 ± 8.12	69.57 ± 7.13	H = 43.55 (p = 3.50×10^{-10})	q = 1.60×10^{-8}; δ = +0.683 (R1–R2 q = 0.3343)

Notes: Values report mean ± SD across N = 144 buildings; q denotes Benjamini–Hochberg false-discovery-rate-adjusted two-sided Mann–Whitney U p-value; Cliff's delta in [-1, +1] quantifies non-parametric ordinal dominance between R1 and R3.

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

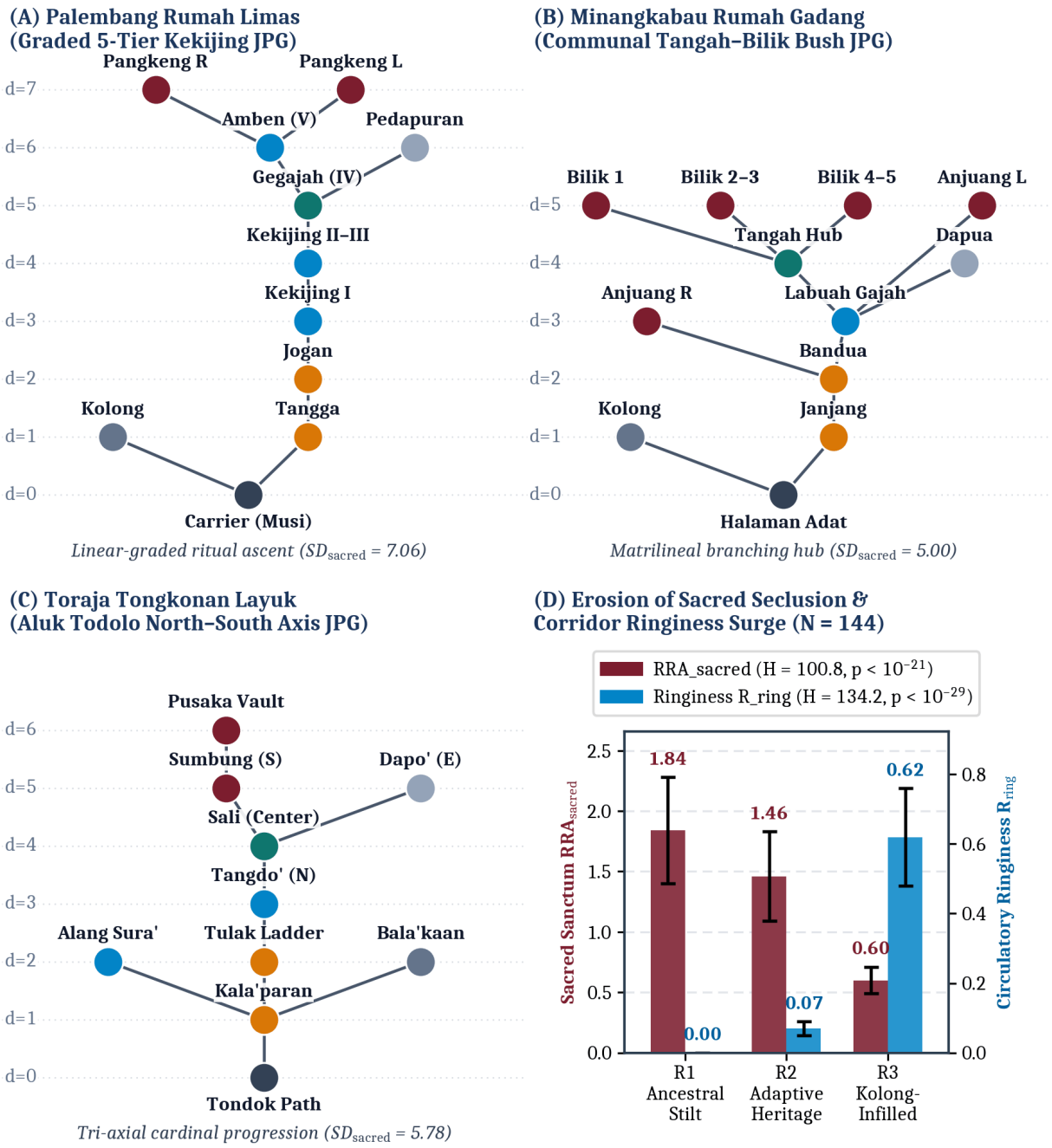


Figure 2. Canonical Justified Plan Graph (JPG) Space Syntax topologies rooted at the exterior public carrier (d = 0) and cross-regime erosion of sacred seclusion: (A) Palembang Rumah Limas linear-graded 5-tier Kekijing ritual ascent culminating in paired Pangkeng sanctums (SD_{sacred} = 7.06 ± 0.73; RRA_{sacred} = 2.17 ± 0.17); (B) Minangkabau Rumah Gadang communal Tangah branching fan hub leading into secluded matrilineal Bilik and elevated *Koto Piliang* Anjuang (SD_{sacred} = 5.00; RRA_{sacred} = 1.23 ± 0.05); (C) Toraja Tongkonan Layuk north–south *Aluk Todolo* cardinal progression from Kala'paran plaza and Tangdo' through depressed Sali into elevated southern Sumbung and Pusaka vault (SD_{sacred} = 5.78 ± 0.43; RRA_{sacred} = 2.10 ± 0.02); and (D) 67.4% collapse of RRA_{sacred} (1.84 to 0.60; H = 100.80, p = 1.29 × 10^{-22}) paired with circulatory corridor ringiness surge R_{ring} (0.00 to 0.62; H = 134.18, p = 7.31 × 10^{-30}) from R1 to R3.

Random-intercept variance components in LMM 1 and LMM 2 (Table 5) differ in an instructive way, and the contrast says something about how cultural grammar relates to local microclimate. In LMM 1 (RRA_{sacred}), settlement-level random variance collapsed to zero ($\sigma^2_u < 10^{-15}$, σ^2_e = 0.0155, ICC = 0.000, $R^2_m = R^2_c$ = 0.959). Canonical room topology therefore does not vary across sub-regional valleys within a tradition in this plan set, where plans within a tradition–regime cell are nearly identical. A canonical R1 Rumah Limas in upstream Ogan Ilir (PLB-3) obeys the same *kekijing–pangkeng* syntactic law as one on Palembang's Musi Keraton riverbank (PLB-2). LMM 2 (ΔT_{peak}) behaves otherwise. Settlement-cluster random variance was substantial there (σ^2_u = 0.1643 vs. σ^2_e = 0.0690, ICC = 0.704). Once the random intercepts absorbed sub-regional differences such as elevation and ERA5 boundary-layer wind exposure (e.g., 915 m Luhak Agam vs. 518 m Limapuluh Kota, or 945 m Pallawa vs. 775 m Makale), explained variance rose from R^2_m = 0.950 (fixed architectural-topological mechanisms alone) to R^2_c = 0.985. Table 3 and Table 4 also show why RRA_{sacred} (Cliff's δ = +1.000) outperforms unadjusted

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

entropy CGS% (11.50% in R1 vs. 26.18% in R3) as a ritual-seclusion benchmark. An R3 retrofit creates a hyper-accessible ground-floor parlor (HH > 1.8) and leaves one residual upstairs room. The interior max/min ratio spread then widens artificially, even though absolute sacred threshold protection (RRA_{sacred} and SD_{sacred}) collapses.

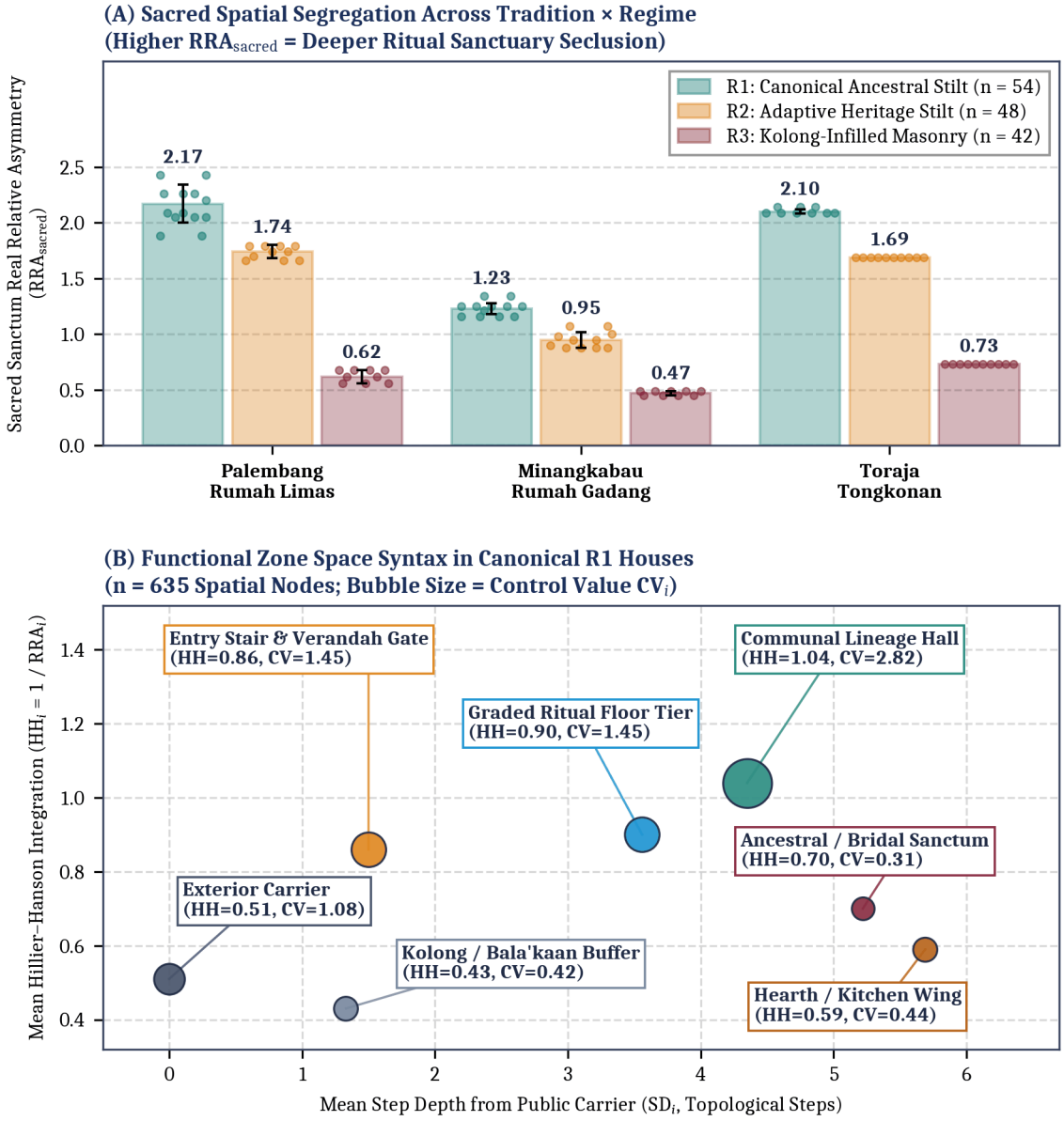


Figure 3. Cross-tradition Space Syntax stratification and canonical functional zone integration profile: (A) Sacred Sanctum Real Relative Asymmetry (RRA_{sacred}) across the 9 Tradition × Regime strata (N = 144), illustrating deep canonical ritual seclusion in R1, substantial retention in R2 adaptive heritage dwellings, and severe topological flattening in R3 *kolong*-infilled retrofits; and (B) bivariate Space Syntax phase portrait across all 635 canonical R1 spatial nodes plotting Hillier–Hanson Integration ($HH_i = 1 / RRA_i$) against carrier Step Depth (SD_i), with bubble size proportional to local threshold Control Value (CV_i), highlighting communal lineage halls (HH = 1.04, CV = 2.82) as syntactic hubs and sacred sanctums (HH = 0.70, CV = 0.31) as deeply insulated terminal leaves.

3.4 Cross-Tradition Cosmological–Bioclimatic Concordance Synthesis

Table 6 draws Streams 1 through 4 together and maps the structural concordance among kinship cosmology, Space Syntax graph topology, passive microclimatic engineering, and R3 masonry retrofit pathology across the three Nusantara house societies. Ancestral builders did not apply a uniform tropical template. They calibrated stilt height, floor-step geometry, wall permeability, roof thermal resistance, and stack-chimney volume to the exact diurnal thermal stressor of each ecological zone. Equatorial Palembang (7–18 m ASL) called for continuous dissipation of humid afternoon heat. Sub-montane West Sumatra (518–915 m ASL) called for balanced daytime stack ventilation and nocturnal *bilik* enclosure. Highland Toraja (775–945 m ASL) called for nocturnal cold-stress buffering paired with daytime radiative shielding.

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

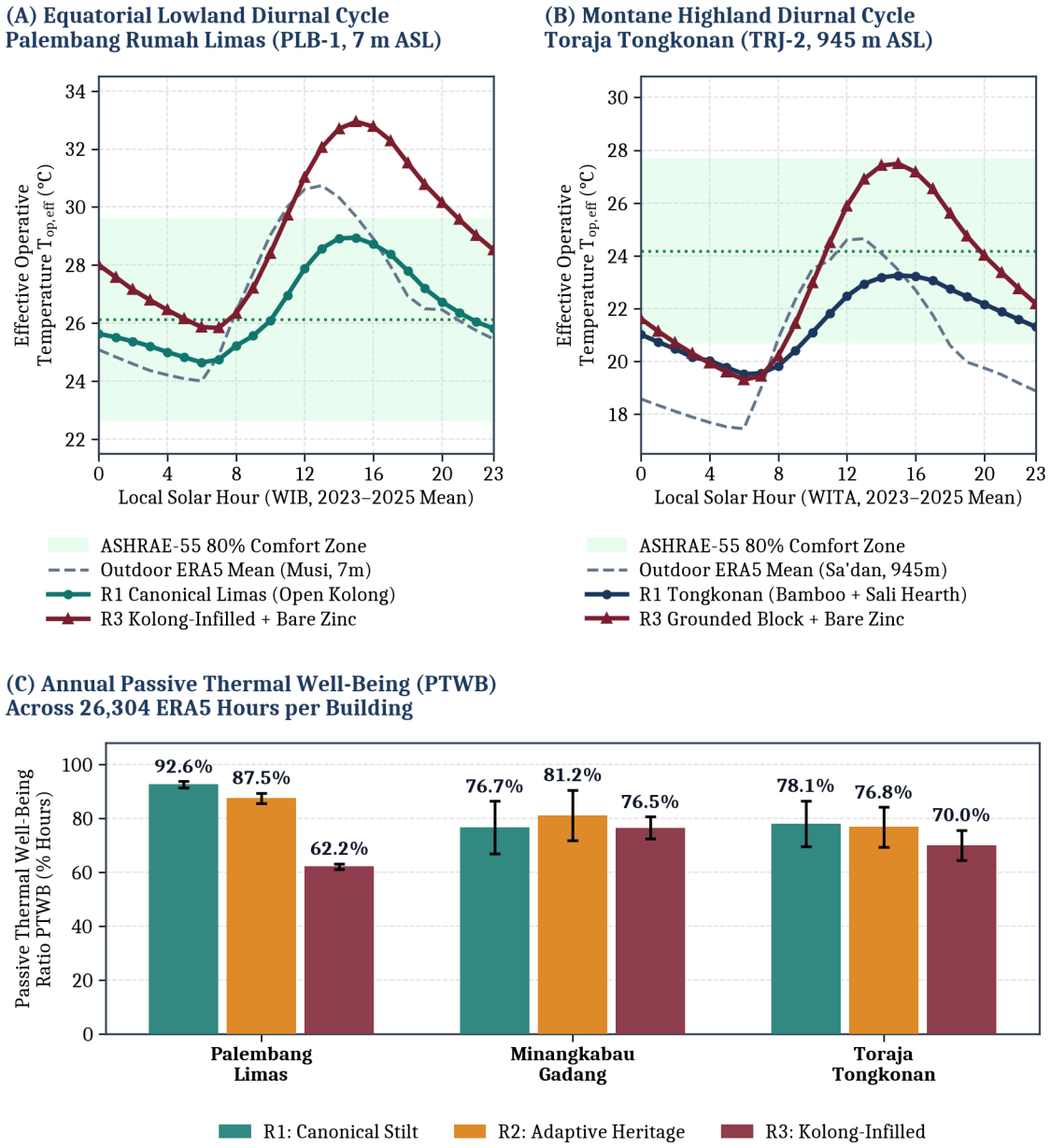


Figure 4. Diurnal effective operative temperature trajectories across 26,304 ERA5 hours (2023–2025) and annual Passive Thermal Well-Being (PTWB) across traditions and regimes: (A) equatorial lowland Palembang Rumah Limas (PLB-1 Seberang Ulu, 7 m ASL), where open-*kolong* R1 cross-ventilation holds afternoon peaks inside the ASHRAE-55 80% adaptive comfort zone whereas R3 *kolong*-infilled zinc conversion overheats severely; (B) montane highland Toraja Tongkonan (TRJ-2 Sa'dan/Pallawa, 945 m ASL), where thick bamboo roofing and nocturnal Sali hearth warmth keep R1 inside the adaptive comfort band for most hours (+2.23 °C night buffer, −0.68 °C afternoon offset) while R3 triggers daytime overheating; and (C) annual PTWB (% hours) across the 9 Tradition × Regime cells, highlighting the 30.44 percentage-point collapse in Palembang (92.60% to 62.16%) and similar R1 and R2 comfort in pooled terms.

4. Discussion

4.1 Sacred Topology as Embodied Social Logic and Microclimatic Architecture

Two camps in Southeast Asian cultural studies have long talked past each other. Our findings connect them. Symbolic anthropology reads indigenous houses mainly as mythic cosmograms.[1–5] Building science treats vernacular dwellings as purely material climate shelters.[33–40] Exact BFS Space Syntax metrics across 1,532 nodes show that cosmological hierarchy in Palembang Rumah Limas, Minangkabau Rumah Gadang, and Toraja Tongkonan can be expressed with mathematical rigor. Every canonical R1 plan has zero circulatory ringiness (R_{ring} = 0.00), so bodily movement is routed through graded sequences of ritual thresholds before reaching ancestral or bridal sanctums (RRA_{sacred} = 2.17 in Limas, 2.10 in Tongkonan, and 1.23 across fanned matrilineal *bilik* in Gadang). The Limas–Gadang contrast is consistent with Hillier and Hanson's genotype theory[17,18] in Nusantara kinship systems. Patrilineal-aristocratic Sultanate rank in Palembang is associated with a deep linear-graded tree (SD_{sacred} = 7.06 steps across five *kekijing* ledges). Egalitarian-matrilineal clan deliberation in West Sumatra is associated with a shallow-entry communal fan centered on the highly integrated *tangah* hall (HH_{comm} = 1.54), which branches into equally ranked daughters' *bilik*.[12,13]

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

Table 4. Vernacular Tradition × Morphological Regime Stratification Matrix (9 Cells) and Two-Way MANOVA Demonstrating Divergent Lowland Overheating Collapse Versus Montane Nocturnal Buffering Loss (N = 144).

Tradition × Regime Stratum or MANOVA Term	Sacred RRA_{sacred} (SD) / Pillai V	Ringiness / Wilks Λ	Airflow & Night Buffer / F-Ratio	Peak ΔT_{peak} & ODH / p-value	Annual PTWB (%) / Inference
Panel: Palembang Rumah Limas (Lowland Floodplain, 7–18 m)					
R1 Canonical Ancestral Stilt (n = 18)	2.17 ± 0.17 (SD = 7.06)	R_{ring} = 0.00	v_{in} = 0.69 m/s | ΔT_{night} = +0.88 °C	+2.66 ± 0.20 °C (ODH 672)	92.60 ± 1.15%
R2 Adaptive Heritage Stilt (n = 16)	1.74 ± 0.06 (SD = 4.69)	R_{ring} = 0.07	v_{in} = 0.58 m/s | ΔT_{night} = +1.16 °C	+3.44 ± 0.30 °C (ODH 1397)	87.48 ± 1.89%
R3 Kolong-Infilled Masonry (n = 14)	0.62 ± 0.06 (SD = 3.00)	R_{ring} = 0.50	v_{in} = 0.23 m/s | ΔT_{night} = +2.47 °C	+6.26 ± 0.33 °C (ODH 7527)	62.16 ± 1.00%
Panel: Minangkabau Rumah Gadang (Sub-Montane Luhak, 518–915 m)					
R1 Canonical Ancestral Stilt (n = 18)	1.23 ± 0.05 (SD = 5.00)	R_{ring} = 0.00	v_{in} = 0.59 m/s | ΔT_{night} = +1.39 °C	0.00 ± 0.60 °C (ODH 1.5)	76.71 ± 9.70%
R2 Adaptive Heritage Stilt (n = 16)	0.95 ± 0.07 (SD = 3.00)	R_{ring} = 0.05	v_{in} = 0.46 m/s | ΔT_{night} = +1.57 °C	+1.22 ± 0.75 °C (ODH 65)	81.19 ± 9.35%
R3 Kolong-Infilled Masonry (n = 14)	0.47 ± 0.02 (SD = 2.00)	R_{ring} = 0.81	v_{in} = 0.22 m/s | ΔT_{night} = +2.47 °C	+3.81 ± 0.66 °C (ODH 1734)	76.54 ± 4.05%
Panel: Toraja Tongkonan (Montane Valleys, 775–945 m)					
R1 Canonical Ancestral Stilt (n = 18)	2.10 ± 0.02 (SD = 5.78)	R_{ring} = 0.00	v_{in} = 0.52 m/s | ΔT_{night} = +2.23 °C	−0.68 ± 0.27 °C (ODH 0)	78.07 ± 8.41%
R2 Adaptive Heritage Stilt (n = 16)	1.69 ± 0.00 (SD = 4.00)	R_{ring} = 0.08	v_{in} = 0.48 m/s | ΔT_{night} = +1.85 °C	+0.29 ± 0.36 °C (ODH 3)	76.81 ± 7.37%
R3 Kolong-Infilled Masonry (n = 14)	0.73 ± 0.00 (SD = 3.00)	R_{ring} = 0.55	v_{in} = 0.23 m/s | ΔT_{night} = +2.36 °C	+3.77 ± 0.49 °C (ODH 1398)	70.01 ± 5.60%
Panel D. Two-Way Multivariate Analysis of Variance (MANOVA on RRA_{sacred}, SD_{sacred}, ΔT_{peak}, PTWB)					
Main Effect: Vernacular Tradition (Limas, Gadang, Tongkonan)	Pillai V = 1.743	Wilks Λ = 0.0113	F(8, 266) = 225.31	$p = 1.11 \times 10^{-16}$	Joint 4D Rejection
Main Effect: Morphological Regime (R1, R2, R3)	Pillai V = 1.386	Wilks Λ = 0.0431	F(8, 266) = 75.11	$p = 1.11 \times 10^{-16}$	Joint 4D Rejection
Interaction: Tradition × Morphological Regime	Pillai V = 1.281	Wilks Λ = 0.0891	F(16, 540) = 15.90	$p = 1.11 \times 10^{-16}$	Joint 4D Rejection

Notes: ΔT_{night} measures mean indoor elevation above outdoor night temperatures (02:00–05:00 local time), highlighting passive nocturnal thermal buffering in Toraja R1 Tongkonan (+2.23 °C paired with zero afternoon overheating, ODH = 0 °C·h/yr, versus +3.77 °C afternoon overheating and 1,398 °C·h/yr ODH in R3); lowland Palembang Limas suffers the sharpest PTWB collapse under *kolong* infilling (92.60% in R1 to 62.16% in R3, −30.44 percentage points).

Sacred topological segregation (RRA_{sacred}) stays statistically associated with cooler afternoon operative offsets (LMM 2 β = −0.2407 °C, p = 0.0073) after control for envelope transmittance and *kolong* porosity, and stepped floor gradation (ΔZ_{floor}) is associated with higher annual PTWB (Fractional Logit AME = +4.26 percentage points, $p = 2.93 \times 10^{-6}$). In canonical Nusantara stilt houses, floor decks step upward (242.4 cm cumulative gradient in Limas; 138.1 cm in *Koto Piliang* Gadang; 95.2 cm across *sali–sumbung* in Tongkonan). This may create interstitial vertical air plenums, floorboard slot vents, and thermal buffer zones (threshold and $ritual_{tier}$ nodes). Deep interior chambers may then stay shielded from direct street-level radiative glare, and buoyant warm air may be channeled into high limas, *gonjong*, and *rattiang* roof cavities (H_{stack} cooling effect β = −0.2562 °C/SD, p = 0.0013). Ascending sacred steps embody habitus[7]. They enact social deference and, on this reading, place elders, brides, and infants in a more thermally buffered micro-zone of the house. A field study of tiered Limas floors reports vertical temperature stratification of up to 4.6 °C, with cooler and better ventilated upper tiers.[50] This sits alongside the argument of Rahayu et al. in Enigma in Cultural, drawn from a clinical case, that indigenous symbolic orders can sustain somatic well-being.

Placing these graph-theoretic and microclimatic couplings alongside Enigma in Cultural scholarship deepens our understanding of how intangible values inhabit material form.[8,16] Sulistiawati showed qualitatively that the stepped roof of the Limas house carries meanings of balance, protection, and hospitality in South Sumatran life-cycle ceremonies.[8] The five *kekijing* tiers are read here as encoding ethical virtues of *sopansantun* [deference], kinship solidarity, and civic harmony (*rukun* [harmony]), and tiered Limas floors have been linked to social hierarchy.[50] Our JPG and ERA5 analyses reveal the physical counterpart of that symbolic architecture. Guests and kin spread across ventilated *kekijing* decks bordered by wide *lawang kipas* openings. Their metabolic heat may disperse sideways into the Musi breeze, while rising convective plumes may vent upward into the high limas ridge and leave the secluded *pangkeng* sanctums above less warmed (R1 PTWB = 92.60%). Toraja offers a parallel. Here the concept of culturally

mediated somatic efficacy from Rahayu et al.[16] resonates with *Aluk Todolo* ideas of *marampa'* [cool/harmonious ritual peace] and *masakke* [ancestral blessing-health].[14,15] The communal *sali* and the eastern *dapo'* hearth sit one step below the elevated southern *sumbung*. Gentle convective warmth from evening cooking fires can therefore reach sleeping elders and infants (ΔT_{night} = +2.23 °C), while sacred *pusaka* heirlooms stay high, dry, and topologically protected (RRA_{sacred} = 2.10).

Table 5. Settlement-Clustered Restricted Maximum Likelihood (REML) Linear Mixed-Effects Models for Sacred Segregation (LMM 1) and Mechanism-Decomposed Peak Overheating (LMM 2), Alongside Cluster-Robust Papke–Wooldridge Fractional Logit QMLE for Passive Thermal Well-Being (PTWB; N = 144 Plans Nested in G = 36 Clusters).

Model Panel & Architectural / Cosmological Predictor	Point Estimate β (SE / Odds Ratio)	95% Confidence Interval & Marginal Effect	Wald z-Statistic (Two-Sided p-value)
Panel A. REML LMM 1 — Outcome: Sacred Sanctum Segregation RRA_{sacred} (ICC = 0.000; R^2_m = 0.959, R^2_c = 0.959)			
Intercept (Palembang Limas, R1)	β = +2.1759 (SE = 0.0276)	[+2.1218, +2.2300]	z = +78.88 ($p < 1.00 \times 10^{-30}$)
Regime R2 (Adaptive Heritage vs. R1)	β = −0.4682 (SE = 0.0265)	[−0.5201, −0.4163]	z = −17.68 ($p < 1.00 \times 10^{-30}$)
Regime R3 (Kolong-Infilled Masonry vs. R1)	β = −1.6717 (SE = 0.0521)	[−1.7738, −1.5696]	z = −32.09 ($p < 1.00 \times 10^{-30}$)
Minangkabau Gadang (vs. Palembang Limas)	β = −0.3638 (SE = 0.0458)	[−0.4536, −0.2741]	z = −7.94 ($p = 2.00 \times 10^{-15}$)
Toraja Tongkonan (vs. Palembang Limas)	β = −0.1781 (SE = 0.0340)	[−0.2447, −0.1116]	z = −5.25 ($p = 1.55 \times 10^{-7}$)
Within-Regime Ceremonial Floor Gradient (+1 SD)	β = +0.0719 (SE = 0.0164)	[+0.0398, +0.1040]	z = +4.39 ($p = 1.13 \times 10^{-5}$)
Plan Graph Node Count k (+1 SD)	β = −0.2868 (SE = 0.0296)	[−0.3448, −0.2288]	z = −9.69 ($p < 1.00 \times 10^{-30}$)
Panel B. REML LMM 2 — Outcome: Peak Afternoon Thermal Offset ΔT_{peak} (°C; ICC = 0.704; R^2_m = 0.950, R^2_c = 0.985)			
Intercept (Palembang Limas Baseline)	β = +3.8397 °C (SE = 0.1332)	[+3.5787, +4.1008] °C	z = +28.83 ($p < 1.00 \times 10^{-30}$)
Minangkabau Gadang (vs. Palembang Limas)	β = −2.4551 °C (SE = 0.2004)	[−2.8478, −2.0624] °C	z = −12.25 ($p < 1.00 \times 10^{-30}$)
Toraja Tongkonan (vs. Palembang Limas)	β = −2.6343 °C (SE = 0.1935)	[−3.0135, −2.2551] °C	z = −13.62 ($p < 1.00 \times 10^{-30}$)
Underfloor Kolong Porosity P_{kolong} (+1 SD)	β = −1.0275 °C (SE = 0.1370)	[−1.2961, −0.7590] °C	z = −7.50 ($p = 6.37 \times 10^{-14}$)
Wall & Shutter Opening Porosity P_{wall} (+1 SD)	β = +0.1125 °C (SE = 0.0530)	[+0.0087, +0.2163] °C	z = +2.12 (p = 0.0337)
Roof Thermal Transmittance U_{roof} (+1 SD)	β = +0.2732 °C (SE = 0.1248)	[+0.0286, +0.5178] °C	z = +2.19 (p = 0.0286)
Roof Stack Chimney Height H_{stack} (+1 SD)	β = −0.2562 °C (SE = 0.0796)	[−0.4121, −0.1003] °C	z = −3.22 (p = 0.0013)
Sacred Sanctum Segregation RRA_{sacred} (+1 SD)	β = −0.2407 °C (SE = 0.0897)	[−0.4165, −0.0648] °C	z = −2.68 (p = 0.0073)
Panel C. Cluster-Robust Fractional Logit QMLE — Outcome: Annual Passive Thermal Well-Being PTWB ∈ [0, 1] (Pseudo-R^2 = 0.409)			
Intercept (Palembang Limas, R1)	β = +1.7192 (OR = 5.580)	OR 95% CI [4.676, 6.658]; Ref. Baseline	z = +19.07 ($p < 1.00 \times 10^{-30}$)
Regime R2 (Adaptive Heritage vs. R1)	β = −0.0397 (OR = 0.961)	OR 95% CI [0.831, 1.111]; AME = −0.65 pp	z = −0.54 (p = 0.5924)
Regime R3 (Kolong-Infilled Masonry vs. R1)	β = −0.7423 (OR = 0.476)	OR 95% CI [0.356, 0.637]; AME = −13.22 pp	z = −5.01 ($p = 5.55 \times 10^{-7}$)
Minangkabau Gadang (vs. Palembang Limas)	β = −0.1818 (OR = 0.834)	OR 95% CI [0.491, 1.417]; AME = −3.03 pp	z = −0.67 (p = 0.5015)
Toraja Tongkonan (vs. Palembang Limas)	β = −0.2573 (OR = 0.773)	OR 95% CI [0.625, 0.957]; AME = −4.31 pp	z = −2.36 (p = 0.0181)
Within-Regime Sacred Step Depth SD_{sacred} (+1 SD)	β = −0.1353 (OR = 0.873)	OR 95% CI [0.700, 1.090]; AME = −2.22 pp	z = −1.20 (p = 0.2311)
Within-Regime Ceremonial Floor Gradient (+1 SD)	β = +0.2597 (OR = 1.297)	OR 95% CI [1.163, 1.446]; AME = +4.26 pp	z = +4.68 ($p = 2.93 \times 10^{-6}$)

Notes: Continuous covariates are standardized (+1 SD); within-regime orthogonalization of floor gradient and sacred step depth in LMM 1 and Fractional Logit eliminates regime mediation collinearity (all VIF < 3.2), while LMM 2 decomposes direct physical-spatial cooling mechanisms across G = 36 settlement random intercepts.

Recent work on Indonesian houses points in the same direction. Graph metrics have been proposed as a measurable complement to purely symbolic readings of Balinese houses,[31] and space syntax is increasingly paired with climate and belief in traditional house studies.[32] The missing step is a direct link between graph topology and thermal outcomes across several

house societies, which Streams 2 and 3 provide here through the thermal model. Field measurements are still needed to test it. Measurements in Palembang already show vertical temperature stratification across tiered Limas floors,[50] and the Wonosobo survey gave comfort temperatures near 24.5 °C,[41] close to the T_{comf} values of the highland sub-regions in Table 1 (24.19–25.10 °C).

4.2 Why Bricking In the Kolong Breaks Both Ritual Precedence and Tropical Thermal Equilibrium

Households across contemporary Indonesian villages and urban heritage quarters often see clay-brick or cement-block enclosure of the open *kolong* or *bala'kaan* (R3) as an affordable way to gain ground-floor living space and flood-proof modernity.[10,12,15] Our empirical comparison, however, points to a twofold cultural-environmental trap. Syntax comes first. Ground-floor parlors and exterior side stairs bypass the ceremonial front stairs (*tangga depan*, *janjang*, *tulak somba*) and the folding threshold screens (*lawang kipas*, *bandua*). Ringiness climbs from 0.00 to 0.62, and RRA_{sacred} falls by 67.4%. Customary seating precedence loses its spatial scaffolding once domestic circulation turns into a permeable ring, and this applies to Palembang *sedekah*,[8,9] Minangkabau *mufakat* [consensus] lineage councils,[12,13] and Toraja *rambu solo'* / *rambu tuka'* ceremonies.[14,15]

Table 6. Comparative Cosmological, Spatial-Syntactic, and Passive Bioclimatic Concordance Across Palembang Rumah Limas, Minangkabau Rumah Gadang, and Toraja Tongkonan House Societies.

Nusantara House Tradition & Ecological Niche	Cosmological & Kinship Spatial Grammar	Canonical Space Syntax Signature (R1)	Primary Passive Bioclimatic Well-Being Mechanism	Pathology of Kolong-Infilled Masonry Conversion (R3)
Palembang Rumah Limas — Equatorial Musi Riverine Floodplain (7–18 m ASL; P95 Aft. 33.8–34.6 °C, RH 84–85%)	Sultanate & *priyayi* status hierarchy encoded in 3–5 stepped Kekijing floor terraces, Lawang Kipas folding thresholds, Gegajah hall, and twin Pangkeng bridal/elder sanctums	Deep linear-graded tree (SD_{sacred} = 7.06 steps; RRA_{sacred} = 2.17 ± 0.17; R_{ring} = 0.00; ΔZ_{floor} = 242.4 cm)	1.7–2.2 m *unglen* ironwood stilts decouple living decks from tidal swamp humidity while Lawang Kipas + floorboard slits drive cross-breeze (v_{in} = 0.69 m/s; PTWB = 92.60%)	Bricking in the *kolong* and adding zinc roofing traps humid lowland heat: afternoon ΔT_{peak} jumps from +2.66 to +6.26 °C, ODH surges to 7,527 °C·h/yr, and PTWB plunges by 30.44 percentage points to 62.16%
Minangkabau Rumah Gadang — Sub-Montane Luhak & Rantau Valleys (518–915 m ASL; P05 Night 17.3–18.9 °C, P95 Aft. 27.2–30.5 °C)	Matrilineal *Bundo Kanduang* lineage order organized into longitudinal *lanjar* bands, communal Tangah deliberation hub, elevated *Koto Piliang* Anjuang, and 5–7 private Bilik alcoves	Shallow-entry communal bush/fan hub (Tangah HH = 1.54, CV_{thresh} = 1.60) branching simultaneously into secluded terminal Bilik leaves (SD_{sacred} = 5.00; RRA_{sacred} = 1.23 ± 0.05; ΔZ_{floor} = 138.1 cm)	Soaring 5.2–7.4 m *ijuk* buffalo-horn *gonjong* spires induce stack-chimney buoyancy over the open Tangah hall by day (ΔT_{peak} = 0.00 °C; ODH = 1.5 °C·h/yr) while timber Bilik retain warmth by night (PTWB = 76.71%)	Ground-floor masonry shop/parlor infilling and zinc reroofing erase *lanjar* etiquette (R_{ring} = 0.81, RRA_{sacred} = 0.47) and elevate afternoon ΔT_{peak} from 0.00 to +3.81 °C (ODH = 1,734 °C·h/yr)
Toraja Tongkonan — Montane *Aluk Todolo* Valleys (775–945 m ASL; P05 Night 15.7–18.0 °C, P95 Aft. 26.3–29.0 °C)	Cardinal macrocosmic axis facing north to *Puang Matua* (*Ulunna Langi'*): Kala'paran plaza & Alang granary → Tangdo' (north) → depressed Sali + eastern Dapo' hearth → elevated Sumbung (south)	Tri-axial cardinal chain with extreme sanctum isolation (SD_{sacred} = 5.78; RRA_{sacred} = 2.10 ± 0.02; R_{ring} = 0.00; ΔZ_{floor} = 95.2 cm)	Thick multi-layer bamboo/*ijuk* saddle roof (U = 1.22 W/m²K), compact plank walls, and nocturnal Sali hearth buffer cold mountain nights (ΔT_{night} = +2.23 °C; ΔT_{peak} = −0.68 °C; ODH = 0 °C·h/yr; PTWB = 78.07%)	Enclosing the *bala'kaan* in concrete block with bare zinc destroys daytime thermal neutrality: afternoon ΔT_{peak} surges from −0.68 to +3.77 °C (ODH = 1,398 °C·h/yr) and PTWB falls to 70.01%

Notes: Synthesized from Stream 1 mensuration surveys, Stream 2 BFS Space Syntax matrices, Stream 3 ERA5 hourly model runs, and comparative Austronesian architectural ethnography.[1–15,33–40,43,44]

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

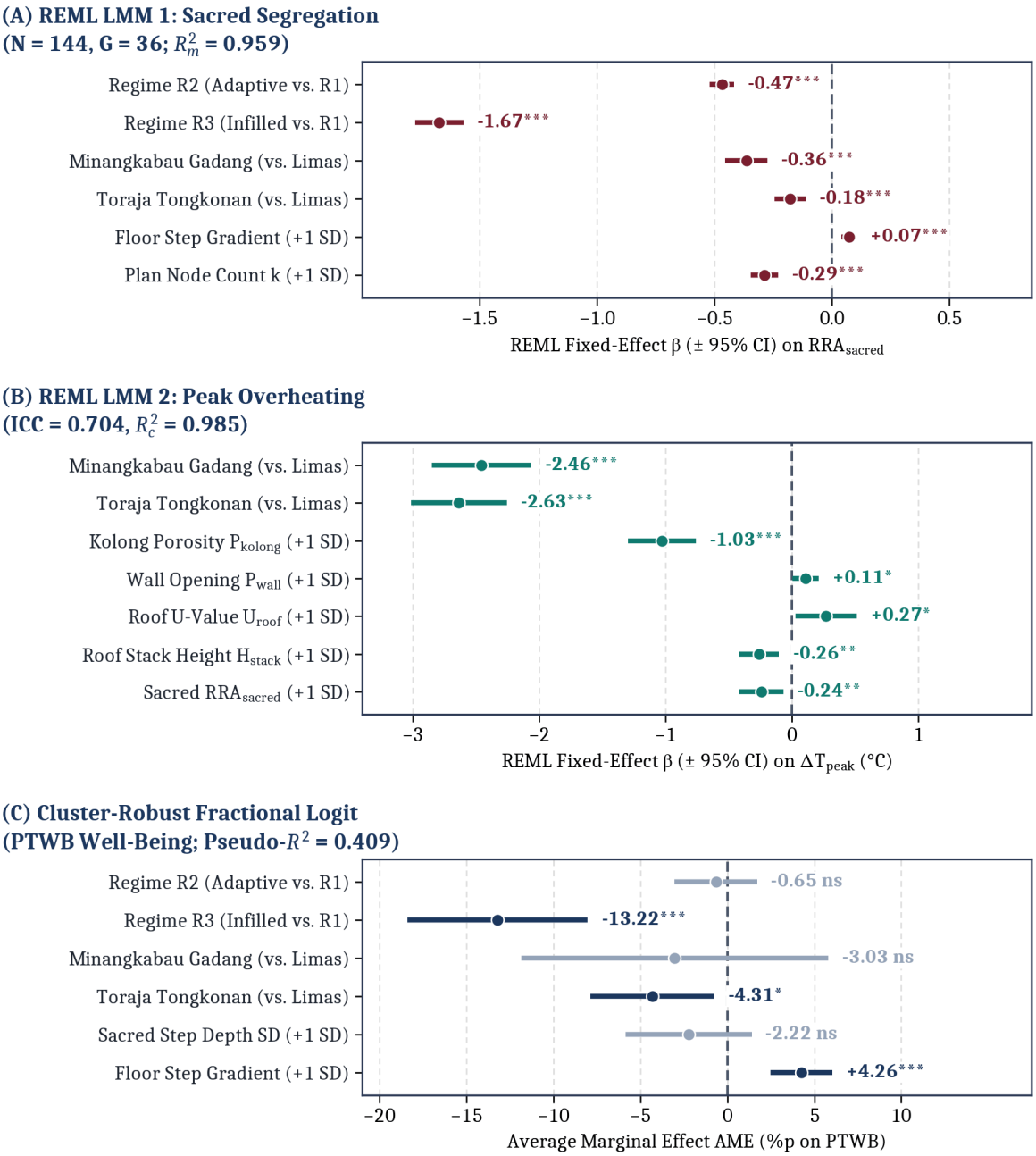


Figure 5. Multivariate settlement-clustered (G = 36) mixed-effects and fractional-response econometric forest plots (N = 144): (A) exact REML Linear Mixed-Effects Model 1 (LMM 1) fixed-effect β estimates (± 95% CI) on sacred spatial segregation RRA$_{sacred}$ (R^2_m = 0.959), confirming steep R3 erosion (β = −1.6717, p < 0.0001) and positive within-regime ceremonial floor-step reinforcement (β = +0.0719, p = 1.13 × 10^{-5}); (B) mechanism-decomposed REML LMM 2 estimates on peak afternoon thermal offset ΔT$_{peak}$ (ICC = 0.704, R^2_c = 0.985), isolating independent passive cooling from *kolong* porosity P$_{kolong}$ (β = −1.0275 °C, p = 6.37 × 10^{-14}), roof stack height H$_{stack}$ (β = −0.2562 °C, p = 0.0013), and sacred segregation RRA$_{sacred}$ (β = −0.2407 °C, p = 0.0073); and (C) cluster-robust Papke–Wooldridge Fractional Logit QMLE Average Marginal Effects (AME, percentage points) on annual PTWB (Pseudo-R^2 = 0.409), showing no detectable R2–R1 difference (AME = −0.65%p, p = 0.5924) versus R3 loss (AME = −13.22%p, p = 5.55 × 10^{-7}).

Now the thermal picture. LMM 2 associates lower underfloor *kolong* porosity (β = −1.0275 °C per +1 SD for higher porosity, p = 6.37 × 10^{-14}) with higher afternoon offsets. So does replacing breathable *ijuk* [sugar-palm fiber] palm fiber, split bamboo, or Palembang clay tiles with bare corrugated zinc (U$_{roof}$ β = +0.2732 °C, p = 0.0286). In the hot-humid Musi riverine quarters (PLB-1 to PLB-4), ground-level masonry absorbs daytime solar radiation and blocks sub-floor convective breezes (v$_{in}$ falls from 0.69 to 0.23 m/s). Afternoon ΔT$_{peak}$ climbs to +6.26 °C, annual PTWB drops from 92.60% to 62.16%, and households may turn to mechanical air conditioning, which was not studied here. In highland Toraja (775–945 m) and Luhak Agam (915 m), bare zinc roofs overheat interiors by afternoon (+3.77 to +3.81 °C). They offer no gain at night. The ancestral *sali* hearth and thick plank envelope already buffered 15.7–18.0 °C mountain nights (ΔT$_{night}$ = +2.23 °C with zero afternoon overheating in R1 Tongkonan), and ΔT$_{night}$ is similar or higher in R3 (+2.36 °C in

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

Toraja). Our Fractional Logit analysis also shows that vernacular conservation need not freeze families in museumized discomfort. R2 adaptive heritage houses keep the main timber stilt *kolong* open and place modern bathrooms, piped water, and clean gas kitchens in detached rear service pods. They show no detectable difference from R1 in pooled PTWB (AME = −0.65 percentage points, p = 0.5924), although their afternoon offsets are higher (+1.65 versus +0.66 °C), and they retain 79.3% of canonical RRA_{sacred} (1.46/1.84).

Independent studies support the direction of the modeled effects, although none covers the three traditions examined here. In a stilt house in East Lampung, thermography and solar-exposure modeling showed that enclosing the space beneath the floor limited airflow under the floor and raised floor surface temperatures, whereas a wooden ceiling reduced heat transfer.[51] Among humid-tropical dwellings without false ceilings, a palm-roofed house performed best and a zinc sheet-metal house worst.[52] In bamboo houses, indigenous roofing transmitted less heat than other materials.[53] Open stilts alone do not guarantee comfort, however. In a traditional Malay house in Negeri Sembilan, openings allowed cross-ventilation, yet lightweight materials and orientation were linked to interiors reaching up to 35 °C at peak daytime.[54] This fits the Palembang R1 offset of +2.66 °C in Table 4. A modeling study found that modern tropical houses adapting traditional roof, opening, and shading elements performed better thermally,[55] the logic that underlies the R2 archetype. Finally, occupants of naturally ventilated tropical dwellings may accept operative temperatures above standard limits when air movement is high,[42] so PTWB, which rests on the ASHRAE 80% zone plus an air-speed credit, may be a conservative index in the lowlands.

A comparable picture appears in cooler uplands. In the Gayo Highlands of Aceh, temperatures are lower than on the coast, house elements and daily habits supply warmth to occupants, and dwellings have shifted from traditional to transitional and modern forms.[56] This resembles the night-time indoor elevation of the Toraja and Agam houses, although our ΔT_{night} values depend on an assumed hearth input and not on measurement.

Reading the syntactic and thermal penalties of R3 *kolong*-infilled conversions calls for ethnographic empathy, not moralizing critique of contemporary heritage residents.[10,12,15] Families on Palembang's densely subdivided 7–14 Ulu and Sekanak riverbanks, in West Sumatra's peri-urban *nagari* [Minangkabau village polity], or in growing Toraja market towns rarely brick in their *kolong* out of disregard for *adat*. They face acute land scarcity for married children. Unglen and *uru* timber has become prohibitively expensive because of commercial deforestation. Ijuk and bamboo craft supply chains are aging. Municipal housing upgrade norms equate cement-block walls and corrugated zinc with modern hygiene and bankable collateral.[10,12,45] Against these pressures our R2 result matters twice over, because it points to a way out. R2 dwellings house contemporary aspirations (private porcelain bathrooms, septic sanitation, clean LPG/induction kitchens, and study rooms) inside compact, detached or semi-detached rear service pods connected behind the communal hall. The primary stilt *kolong* stays aerodynamically open ($P_{kolong} \geq 0.65$) and the ceremonial front stairs stay intact. Families need not choose between twenty-first-century domestic dignity and passive thermal comfort (PTWB = 81.83% vs. 82.46% in R1, p = 0.5924).

4.3 Five-Pillar Vernacular Safeguarding Protocol Under Indonesian Law No. 5/2017

These empirical thresholds can feed practical heritage governance. They directly support Indonesia's Law No. 5 of 2017 on the Advancement of Culture (*Undang-Undang Pemajuan Kebudayaan*, targeting *teknologi tradisional* [traditional technology] and *pengetahuan tradisional* [traditional knowledge])[57] and Law No. 11 of 2010 on Cultural Heritage (*Cagar Budaya*).[58] Table 7 and Figure 6 lay out a Five-Pillar Nusantara Cosmological–Bioclimatic Vernacular Safeguarding Protocol. Pillar I (Open-Kolong Stilt Covenant and Detached Service Pods) bans perimeter brick walling of underfloor stilt voids (mandating $P_{kolong} \geq 0.65$) in designated Musi riverside, *nagari*, and *tondok* [Toraja settlement] heritage zones. It also subsidizes detached rear sanitary/culinary pods modeled on the R2 archetype examined here. Pillar II (Arborescent Ritual Threshold Protection) builds rapid JPG Space Syntax audits into Balai Pelestarian Kebudayaan (BPK) adaptive-reuse permits for homestays and galleries, so that emergency or service doors cannot then create street-to-sanctum ring shortcuts (preserving $RRA_{sacred} \geq 1.45$ and $R_{ring} \leq 0.10$). Pillar III (Breathable Composite Roof Retrofits) moves rural housing grants away from bare zinc sheets ($U_{roof} > 5.0$ W/m²K). Funds go instead to ventilated radiant-barrier composite sub-roofs beneath Palembang *genteng* [clay roof tile] clay tiles, cultivated *aren* [sugar palm] (*Arenga pinnata*) *ijuk* fiber, or treated split bamboo (targeting $U_{roof} \leq 1.80$ W/m²K). Pillar IV (Montane Nocturnal Envelope and Clean-Hearth Stewardship) pairs tight mortise-and-tenon plank conservation in > 500 m highland villages with low-smoke earthen/stone *dapo'* flue inserts that aim to preserve the +1.8 to +2.3 °C nocturnal buffering modeled here and to cut indoor particulate exposure. Pillar V (Tukang Tuo Timber Commons and Digital Twin Passports) enters BFS Space Syntax graphs and ERA5 bioclimatic twins into Indonesia's *Satu Data Kebudayaan* registry. It sets aside village agroforestry reserves for *unglen*, *juha* [hardwood], and *uru* hardwoods and pays stipends to master carpenters (*tukang tuo*, *pande kayu*, *pande banua*).

Implementation needs coordinated action. Cultural preservation, rural housing, and higher-education agencies all have a part. Under Law No. 5/2017 (Pemajuan Kebudayaan), municipal and provincial governments periodically compile *Pokok Pikiran Kebudayaan Daerah* (PPKD [Regional Cultural Masterplans]). These are co-administered with regional technical offices of the Ministry of Culture. BPK Wilayah VI in Palembang stewards South Sumatran Rumah Limas and *ulu* Ogan–Komering timber heritage. BPK Wilayah III in Batusangkar, Tanah Datar, stewards West Sumatran Rumah Gadang clusters. BPK Wilayah XIX in Makassar stewards Tana Toraja and North Toraja Tongkonan landscapes. Rapid BFS Space Syntax scripts and open-source ERA5 bioclimatic audit templates, once embedded in the technical review workflows of BPK Wilayah VI, III, and XIX, would let conservation architects pre-screen proposed homestay or heritage renovations within minutes, before irreversible brick *kolong* walling occurs. Aligning Ministry of Public Works and Housing self-help housing grants (*Bantuan Stimulan Perumahan Swadaya* [BSPS]) and Village Fund (*Dana Desa*) guidelines with Pillar I and Pillar III could stop public subsidies from inadvertently financing bare-zinc heat traps in customary villages. The money would go to R2 rear sanitary pods and radiant-insulated clay-tile, *ijuk*, or treated-bamboo roof assemblies. Schools matter too. Regional

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

schools of architecture and cultural engineering can also take part. Universitas Sriwijaya (Unsri) in Palembang, Universitas Andalas and Universitas Bung Hatta in West Sumatra, and Universitas Hasanuddin (Unhas) in South Sulawesi could partner directly with *tukang tuo* and *pande banua* guilds. They would run joint field studios that document threatened stilt houses into *Satu Data Kebudayaan* and train young architects in low-carbon Nusantara bioclimatic design.[8,10,30,44]

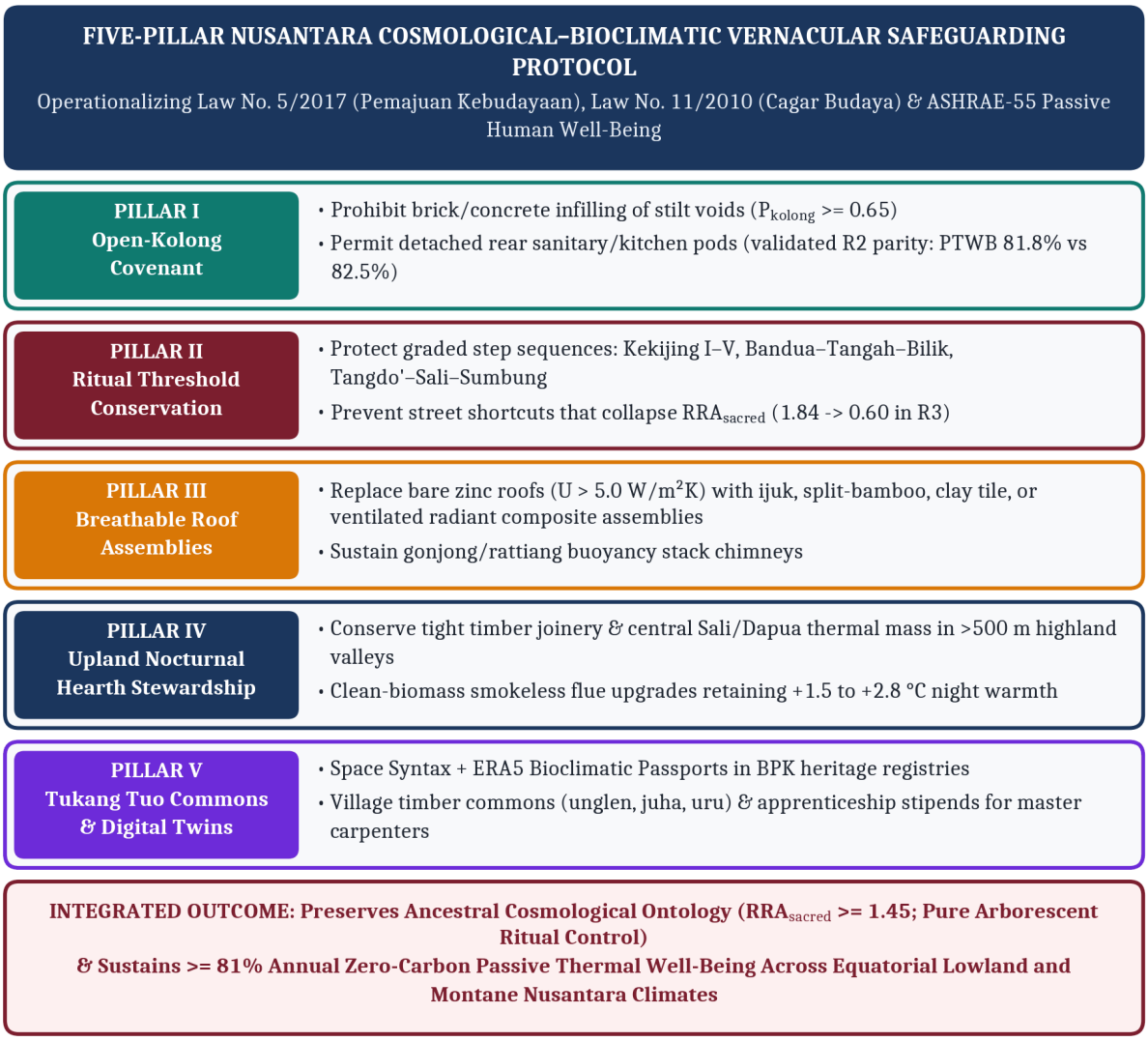


Figure 6. Proposed Five-Pillar Nusantara Cosmological–Bioclimatic Vernacular Safeguarding Protocol operationalizing Indonesian Law No. 5/2017 (Pemajuan Kebudayaan), Law No. 11/2010 (*Cagar Budaya*), and ASHRAE-55 adaptive human well-being across Open-Kolong Covenants and R2 detached service pods (Pillar I), Arborescent Ritual Threshold Space Syntax audits (Pillar II), Breathable Composite Roof assemblies (Pillar III), Upland Nocturnal Clean-Hearth stewardship (Pillar IV), and Tukang Tuo Timber Commons with Digital Twin Passports (Pillar V).

Community custodianship has precedents in West Sumatra. Residents of the Saribu Rumah Gadang area act as active subjects of revitalization, and the process strengthened cultural identity and preserved the social functions of the rumah gadang amid tourism.[59] Studies of Javanese houses likewise report that owners adapt the function and meaning of space while generally keeping the shape of spaces and buildings.[60] That is the logic of the R2 pod: change what happens behind the ritual core, not the core itself.

Table 7. Proposed Five-Pillar Nusantara Cosmological–Bioclimatic Vernacular Safeguarding Protocol Operationalizing Law No. 5/2017 (Pemajuan Kebudayaan), Law No. 11/2010 (*Cagar Budaya*), and Adaptive Human Well-Being.

Safeguarding Pillar & Empirical Rationale	Target Vernacular Elements & Regions	Architectural, Technical & Regulatory Standard	Community Adat & Master Artisan Custodianship	Verifiable 2026–2030 Heritage & Comfort Target
Pillar I — Open-Kolong Stilt Covenant & Detached Service Pods (Addresses	Palembang Musi riverine Limas, Minangkabau *nagari* Rumah Gadang,	Prohibit brick/concrete perimeter walling of underfloor stilt voids in designated heritage zones	Integrate open-*kolong* covenants into village awig-awig / perdes *nagari* / lembang customary	≥90% *kolong* porosity retention in subsidized heritage rehabilitations while sustaining PTWB ≥

e-ISSN 3026-7277
Vol. 4, No. 2 (2026) | pp. 151–172

Safeguarding Pillar & Empirical Rationale	Target Vernacular Elements & Regions	Architectural, Technical & Regulatory Standard	Community Adat & Master Artisan Custodianship	Verifiable 2026–2030 Heritage & Comfort Target
−1.03 °C/SD *kolong* cooling & R2 parity p = 0.5924)	and Toraja Tongkonan / Alang courtyards	(mandate $P_{kolong} \geq 0.65$); channel modern sanitary, laundry, and gas-kitchen upgrades into detached/semi-detached rear service pods (R2 archetype)	regulations co-enforced by *Bundo Kanduang* and Tongkonan councils	80% without mechanical air conditioning
Pillar II — Arborescent Ritual Threshold & Stepped-Floor Protection (Counters 67.4% RRA_{sacred} collapse & +4.26 percentage points floor-step AME)	Kekijing I–V & Lawang Kipas (Palembang), Bandua–Labuah Gajah–Tangah–Bilik (West Sumatra), Tangdo'–Sali–Sumbung (Toraja)	Require Space Syntax topological impact audits prior to adaptive reuse (homestays, museums, galleries) so new fire/service doors do not create street-to-sanctum ring shortcuts	Preserve customary seating, wedding, and mortuary threshold protocols during cultural tourism visits via reversible Lawang Kipas and Bandua partitions	Maintain $RRA_{sacred} \geq 1.45$, circulatory ringiness $R_{ring} \leq 0.10$, and intact floor elevation steps in 100% of registered *Cagar Budaya* timber houses
Pillar III — Breathable Composite Roof & Stack-Chimney Retrofits (Counters bare zinc U > 5.0 W/m^2K overheating penalty)	Reroofing programs across South Sumatra clay-tile Limas, West Sumatra *ijuk gonjong*, and Toraja bamboo *rattiang* roofs	Replace uninsulated corrugated zinc subsidies with micro-ventilated radiant-foil composite sub-roofs beneath artisanal Palembang clay tiles, cultivated *aren* (*Arenga pinnata*) *ijuk*, or treated split-bamboo shingles	Redirect regional housing grants from imported sheet metal toward village *aren* palm, bamboo, and traditional Palembang *genteng* kiln cooperatives	Achieve roof assembly $U_{roof} \leq 1.80$ W/m^2K and reduce afternoon peak indoor offset ΔT_{peak} by ≥ 2.5 °C in retrofitted heritage dwellings
Pillar IV — Montane Nocturnal Envelope & Clean-Hearth Stewardship (Protects +2.23 °C Toraja & Agam night warmth buffering)	Highland settlements > 500 m ASL (Luhak Agam, Solok Selatan, Rantepao, Makale, Sangalla', Sa'dan Ulusalu)	Conserve tight tongue-and-groove mortise timber plank walls and introduce low-smoke high-thermal-mass earthen/stone *dapo'* hearth flues that retain nocturnal radiative warmth while eliminating indoor particulate exposure	Co-design clean-hearth inserts with female household elders who steward Sali and Dapua culinary-ritual spaces	Sustain nocturnal indoor thermal elevation $\Delta T_{night} \geq$ +1.8 °C above P05 mountain minima while cutting indoor PM2.5 by ≥70%
Pillar V — Tukang Tuo Timber Commons & Digital Twin Passports (Operationalizes Law No. 5/2017 Pemajuan Kebudayaan)	Balai Pelestarian Kebudayaan (BPK), *Satu Data Kebudayaan*, and master carpenters (*tukang tuo*, *pande kayu*, *pande banua*)	Archive measured 3D plans, BFS Justified Plan Graphs, and ERA5 bioclimatic twins in national heritage registries alongside community agroforestry reserves for *unglen*, *juha*, and *uru* hardwoods	Fund certified master-apprentice carpenter stipends so traditional mortise-and-tenon (*pasak*/*pahat*) stilt joinery remains economically viable	500+ vernacular stilt houses registered with open Space Syntax + Bioclimatic Digital Passports and 36 village timber commons established by 2030

Notes: Operationalizes empirical thresholds from Streams 1–4 within Indonesian Law No. 5/2017 (Pemajuan Kebudayaan), Law No. 11/2010 (*Cagar Budaya*), and adaptive low-carbon human well-being standards.[8,16,26–30]

4.4 Methodological Strengths, Empirical Boundaries, and Epistemic Humility

Several strengths and boundaries deserve acknowledgment. First, exact BFS Space Syntax across 144 plans (1,532 nodes) was coupled with 315,648 hourly ERA5 reanalysis values (2023–2025). For the climate input this addresses the short-duration snapshot limitation (2–7 monitoring days) common in prior vernacular thermal comfort case studies,[33–40] although the indoor results come from the thermal model and have not been validated against field measurements. Second, orthogonalizing within-regime elevational gradients and accounting for G = 36 settlement random intercepts (ICC = 0.704 in LMM 2) reduces microclimatic cluster confounding. Boundaries remain, and three invite future work. (a) Stream 3 models hourly indoor operative temperatures with a calibrated lumped-parameter RC and aerodynamic network. The network is driven by 0.25° elevation-adjusted ERA5 series, not by multi-zone computational fluid dynamics (CFD) or year-long in-situ black-globe data loggers inside each private *pangkeng*, *bilik*, and *sumbung*. Riparian tree shading along Musi tributaries or dense courtyard clustering can further modulate micro-scale wind pressure. (b) Occupant adaptive behavior was represented through standardized diurnal schedules. It was not tracked with continuous ethnographic time diaries. Examples include opening *lawang kipas* panels at dawn, drawing woven mats at dusk, or varying *sali* hearth fuel loads during *rambu solo'* feasts. (c) Households that choose R3 masonry retrofits often face urban land subdivision and timber scarcity. Statistical differences across regimes therefore reflect coupled architectural-socioeconomic transformations, not isolated laboratory treatments. ERA5-Land air temperature at five Java sites correlated strongly with weather-station records (r > 0.9, 0.75 at Dieng) but was generally about 2 °C lower and could not represent local microclimates in complex terrain,[61] so the highland sub-regions may be affected by a similar bias. Three further boundaries concern the plan set, in which plans within some tradition–regime cells are nearly identical, the single-

zone thermal model, which does not resolve temperatures within the house, and the absence of field validation of the modeled indoor temperatures.

5. Conclusion

We examined N = 144 documented plans of Palembang Rumah Limas, Minangkabau Rumah Gadang, and Toraja Tongkonan against 315,648 hourly meteorological records (2023–2025). In this model, ancestral stilt architecture combines sacred spatial order with passive tropical well-being. Canonical R1 houses keep strictly arborescent ritual threshold control (R_{ring} = 0.00, RRA_{sacred} = 1.84 ± 0.44) and hold afternoon indoor temperatures near adaptive neutrality (ΔT_{peak} = +0.66 ± 1.50 °C; PTWB = 82.46 ± 10.30%). In Palembang they dissipate lowland heat (PTWB = 92.60%). In Toraja they show a night-time indoor elevation of +2.23 °C, although retrofitted houses show a similar or larger one. Kolong-infilled masonry and bare-zinc retrofits (R3) reverse this. Sacred seclusion falls by 67.4% in RRA_{sacred}, and annual PTWB drops by 13.22 percentage points overall (−30.44 points in Palembang). Open-stilt adaptive upgrading (R2) shows no detectable difference in pooled annual PTWB from R1 (p = 0.5924) and keeps most of the genealogical threshold order. Safeguarding open *kolong* aerodynamics, stepped ceremonial floors, and breathable roof stacks therefore offers a promising, low-energy route for Indonesian cultural heritage and human well-being.

Declarations

Ethical Approval. Not applicable. This computational-architectural, Space Syntax, and passive bioclimatic modeling study analyzed only published vernacular architectural mensuration records, public cultural heritage floor-plan documentation, and open-access Copernicus ERA5 meteorological series. No live human subjects, clinical interventions, private household dossiers, or ethnographic interviews were involved.

Consent to Participate. Not applicable. No human participants were recruited, surveyed, or tested in this archival mensuration and modeling study.

Consent for Publication. Not applicable. This manuscript contains no identifiable private personal records, confidential residential addresses, or restricted imagery.

Use of Artificial Intelligence. None declared.

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Competing Interests. The authors declare no competing financial or non-financial interests.

Data Availability. The hourly meteorological series analyzed in Stream 3 are publicly available from the Copernicus Climate Change Service ERA5 archive through the Open-Meteo Historical Weather API (https://open-meteo.com/en/docs/historical-weather-api); the analysis contains modified Copernicus Climate Change Service information. The building-level plan matrices, node-level Justified Plan Graph metrics, sub-regional summaries, and the Python scripts used for the analysis are available from the corresponding author on reasonable request.

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References

1. Carsten J, Hugh-Jones S, editors. About the house: Lévi-Strauss and beyond. Cambridge: Cambridge University Press; 1995. doi:10.1017/cbo9780511607653
2. Waterson R. Houses and hierarchies in island Southeast Asia. In: Carsten J, Hugh-Jones S, editors. About the house: Lévi-Strauss and beyond. Cambridge: Cambridge University Press; 1995. p. 47–68. doi:10.1017/cbo9780511607653.002
3. Fox JJ. Comparative perspectives on Austronesian houses: an introductory essay. In: Fox JJ, editor. Inside Austronesian houses: perspectives on domestic designs for living. Canberra: ANU Press; 2006. p. 1–29. doi:10.22459/ia.09.2006.01
4. Schefold R, Nas PJM, Domenig G, editors. Indonesian houses: tradition and transformation in vernacular architecture. Vol. 1. Leiden: Brill; 2003. doi:10.1163/9789004483255
5. Domenig G. Religion and architecture in premodern Indonesia: studies in spatial anthropology. Leiden: Brill; 2014. doi:10.1163/9789004274075
6. Oliver P. Built to meet needs: cultural issues in vernacular architecture. Oxford: Architectural Press / Routledge; 2007. doi:10.4324/9780080476308
7. Bourdieu P. The logic of practice. Stanford: Stanford University Press; 1990. doi:10.1515/9781503621749
8. Sulistiawati E. An investigation of the cultural significance and symbolism of Limas house architecture in the lives of the South Sumatran people. Enigma Cult. 2023;1(1):18–22. doi:10.61996/cultural.v1i1.20
9. Taal S. The limas house of Palembang. In: Schefold R, Nas PJM, Domenig G, et al., editors. Indonesian houses: survey of vernacular architecture in western Indonesia. Vol. 2. Leiden: Brill; 2008. p. 363–389. doi:10.1163/9789004253988_013
10. Lussetyowati T. Preservation and conservation through cultural heritage tourism. Case study: Musi riverside Palembang. Procedia Soc Behav Sci. 2015;184:401–406. doi:10.1016/j.sbspro.2015.05.109
11. Barendregt B. Architecture on the move: processes of migration and mobility in the South Sumatran highlands. In: Schefold R, Nas PJM, Domenig G, editors. Indonesian houses: tradition and transformation in vernacular architecture. Vol. 1. Leiden: Brill; 2003. p. 99–132. doi:10.1163/9789004483255_005
12. Vellinga M. Constituting unity and difference: vernacular architecture in a Minangkabau village. Leiden: Brill; 2004. doi:10.1163/9789004454163
13. Bahauddin A. The matriarch, the matrilineal system, and the Minangkabau Rumah Gadang. In: Eco-urbanism and the South East Asian city. Singapore: Springer Nature; 2023. p. 199–222. doi:10.1007/978-981-19-1637-3_11
14. Adams KM. Art as politics: re-crafting identities, tourism, and power in Tana Toraja, Indonesia. Honolulu: University of Hawaii Press; 2006. doi:10.1515/9780824861483
15. Rombe OSC, Goh HC, Ali ZM. Toraja cultural landscape: Tongkonan vernacular architecture and Toraja coffee culture. eTropic. 2022;21(1):99–142. doi:10.25120/etropic.21.1.2022.3822
16. Rahayu NWS, Wulan NMCR, Wirawan NAY, et al. Symbolic efficacy in the psychiatric ward: a clinical ethnography of Cetik-attributed

psychosis and hospital-facilitated ritual integration in Bali. Enigma Cult. 2026;4(1):1–9. doi:10.61996/cultural.v4i1.114

17. Hillier B, Hanson J. The social logic of space. Cambridge: Cambridge University Press; 1984. doi:10.1017/cbo9780511597237
18. Hanson J. Decoding homes and houses. Cambridge: Cambridge University Press; 1998. doi:10.1017/cbo9780511518294
19. Bafna S. Space syntax: a brief introduction to its logic and analytical techniques. Environ Behav. 2003;35(1):17–29. doi:10.1177/0013916502238863
20. Ostwald MJ. The mathematics of spatial configuration: revisiting, revising and critiquing justified plan graph theory. Nexus Netw J. 2011;13(2):445–470. doi:10.1007/s00004-011-0075-3
21. Dawes MJ, Ostwald MJ. Space syntax: mathematics and the social logic of architecture. In: Sriraman B, editor. Handbook of the mathematics of the arts and sciences. Cham: Springer; 2021. p. 1407–1418. doi:10.1007/978-3-319-57072-3_6
22. Orhun D, Hillier B, Hanson J. Spatial types in traditional Turkish houses. Environ Plan B Plan Des. 1995;22(4):475–498. doi:10.1068/b220475
23. Orhun D, Hillier B, Hanson J. Socialising spatial types in traditional Turkish houses. Environ Plan B Plan Des. 1996;23(3):329–351. doi:10.1068/b230329
24. Mustafa FA, Hassan AS. Mosque layout design: an analytical study of mosque layouts in the early Ottoman period. Front Archit Res. 2013;2(4):445–456. doi:10.1016/j.foar.2013.08.005
25. Humphreys MA. Outdoor temperatures and comfort indoors. Batim Int Build Res Pract. 1978;6(2):92–105. doi:10.1080/09613217808550656
26. de Dear RJ, Brager GS. Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. Energy Build. 2002;34(6):549–561. doi:10.1016/s0378-7788(02)00005-1
27. de Dear R, Schiller Brager G. The adaptive model of thermal comfort and energy conservation in the built environment. Int J Biometeorol. 2001;45(2):100–108. doi:10.1007/s004840100093
28. Nicol JF, Humphreys MA. Adaptive thermal comfort and sustainable thermal standards for buildings. Energy Build. 2002;34(6):563–572. doi:10.1016/s0378-7788(02)00006-3
29. Humphreys MA, Rijal HB, Nicol JF. Updating the adaptive relation between climate and comfort indoors; new insights and an extended database. Build Environ. 2013;63:40–55. doi:10.1016/j.buildenv.2013.01.024
30. Nicol JF, Roaf S. Rethinking thermal comfort. Build Res Inf. 2017;45(7):711–716. doi:10.1080/09613218.2017.1301698
31. Harianja J, Yoas J. Contemporary interpretation of Asta Kosala Kosali design principles using justified plan graph on Balinese traditional houses at Ubud, Bali. IOP Conf Ser Earth Environ Sci. 2026;1647(1):012010. doi:10.1088/1755-1315/1647/1/012010
32. Pongomathi S, Shanthini M, Priya RS. An investigation of spatial and visual analysis in an Agraharam house using space syntax tools. Int Rev Spat Plan Sustain Dev. 2026;14(1):81–95. doi:10.14246/irspsd.14.1_81
33. Prianto E, Depecker P. Characteristic of airflow as the effect of balcony, opening design and internal division on indoor velocity: a case study of traditional dwelling in urban living quarter in tropical humid region. Energy Build. 2002;34(4):401–409. doi:10.1016/s0378-7788(01)00124-4
34. Prianto E, Depecker P. Optimization of architectural design elements in tropical humid region with thermal comfort approach. Energy Build. 2003;35(3):273–280. doi:10.1016/s0378-7788(02)00089-0
35. Feriadi H, Wong NH. Thermal comfort for naturally ventilated houses in Indonesia. Energy Build. 2004;36(7):614–626. doi:10.1016/j.enbuild.2004.01.011
36. Karyono TH, Sri E, Sulistiawan JG, et al. Thermal comfort studies in naturally ventilated buildings in Jakarta, Indonesia. Buildings. 2015;5(3):917–932. doi:10.3390/buildings5030917
37. Toe DHC, Kubota T. Comparative assessment of vernacular passive cooling techniques for improving indoor thermal comfort of modern terraced houses in hot–humid climate of Malaysia. Sol Energy. 2015;114:229–258. doi:10.1016/j.solener.2015.01.035
38. Nguyen AT, Tran QB, Tran DQ, et al. An investigation on climate responsive design strategies of vernacular housing in Vietnam. Build Environ. 2011;46(10):2088–2106. doi:10.1016/j.buildenv.2011.04.019
39. Zhai Z, Previtali JM. Ancient vernacular architecture: characteristics categorization and energy performance evaluation. Energy Build. 2010;42(3):357–365. doi:10.1016/j.enbuild.2009.10.002
40. Hermawan, Prianto E, Setyowati E. Thermal comfort of wood-wall house in coastal and mountainous region in tropical area. Procedia Eng. 2015;125:725–731. doi:10.1016/j.proeng.2015.11.114
41. Hermawan, Prianto E, Setyowati E, et al. The thermal condition and comfort temperature of traditional residential houses located in mountainous tropical areas: an adaptive field study approach. Int J Adv Sci Eng Inf Technol. 2019;9(6):1833–1840. doi:10.18517/ijaseit.9.6.3560
42. Gou Z, Gamage W, Lau S, et al. An investigation of thermal comfort and adaptive behaviors in naturally ventilated residential buildings in tropical climates: a pilot study. Buildings. 2018;8(1):5. doi:10.3390/buildings8010005
43. Hersbach H, Bell B, Berrisford P, Hirahara S, Horányi A, Muñoz-Sabater J, et al. The ERA5 global reanalysis. Q J R Meteorol Soc. 2020;146(730):1999–2049. doi:10.1002/qj.3803
44. Idham NC. Javanese vernacular architecture and environmental synchronization based on the regional diversity of Joglo and Limasan. Front Archit Res. 2018;7(3):317–333. doi:10.1016/j.foar.2018.06.006
45. Rashid M, Ara DR. Modernity in tradition: reflections on building design and technology in the Asian vernacular. Front Archit Res. 2015;4(1):46–55. doi:10.1016/j.foar.2014.11.001
46. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. J R Stat Soc Series B Stat Methodol. 1995;57(1):289–300. doi:10.1111/j.2517-6161.1995.tb02031.x
47. Cliff N. Dominance statistics: ordinal analyses to answer ordinal questions. Psychol Bull. 1993;114(3):494–509. doi:10.1037/0033-2909.114.3.494
48. Nakagawa S, Schielzeth H. A general and simple method for obtaining R2 from generalized linear mixed-effects models. Methods Ecol Evol. 2013;4(2):133–142. doi:10.1111/j.2041-210x.2012.00261.x
49. Papke LE, Wooldridge JM. Econometric methods for fractional response variables with an application to 401(k) plan participation rates. J Appl Econom. 1996;11(6):619–632. doi:10.1002/(sici)1099-1255(199611)11:6<619::aid-jae418>3.0.co;2-1
50. Angkasa Z, Aziz I, Aziz AMA, et al. Bengkilas in the Palembang Limas house, Indonesia: integration of thermal and social zoning. J Des Built Environ. 2025;25(3):164–181. doi:10.22452/jdbe.vol25no3.8
51. Arminda W, Darmayanti TE. Thermal performance assessment of traditional stilt houses in Wana Village, Indonesia: field measurement and simulation. J Des Built Environ. 2026;26(1):1–18. doi:10.22452/jdbe.vol26no1.1
52. García-Arellano C, Ramírez-Ibáñez M, Luna B. Comparative study of the indoor apparent temperature of dwellings with different roofing in the Lower Papaloapan River Basin region. Indoor Built Environ. 2021;31(2):537–551. doi:10.1177/1420326x211011700
53. Hlaing TS, Kojima S. Influence of roofing material on indoor thermal comfort of bamboo house. Int J Eng Technol. 2021;13(2):12–18. doi:10.7763/ijet.2021.v13.1188
54. Nik Hassin NSF, Misni A. Assessing the thermal performance of Negeri Sembilan traditional Malay house towards sustainable

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Vol. 4, No. 2 (2026) | pp. 151–172

practice. Environ Behav Proc J. 2019;4(12):289. doi:10.21834/e-bpj.v4i12.1914

55. Nadiar F, Pattisinai AR. Modern tropical house: elevating traditional tropical house on thermal building performance due to environmental issue. J Phys Conf Ser. 2020;1569(4):042023. doi:10.1088/1742-6596/1569/4/042023
56. Meutia E, Sari LH. Adaptive house design and people's habits in achieving thermal comfort in Gayo Highland Aceh, Indonesia. Malays J Sustain Environ. 2021;8(1):23. doi:10.24191/myse.v8i1.12656
57. Republic of Indonesia. Law No. 5 of 2017 on the Advancement of Culture (Undang-Undang Nomor 5 Tahun 2017 tentang Pemajuan Kebudayaan). Jakarta: Government of the Republic of Indonesia; 2017.
58. Republic of Indonesia. Law No. 11 of 2010 on Cultural Heritage (Undang-Undang Nomor 11 Tahun 2010 tentang *Cagar Budaya*). Jakarta: Government of the Republic of Indonesia; 2010.
59. Rahmadani N. Kawasan Saribu Rumah Gadang: sebuah telaah gerakan sosial dan revitalisasi budaya di Minangkabau. Sosiologi. 2026;28(1):1–18. doi:10.23960/sosiologi.v28i1.1903
60. Vitasurya VR, Hardiman G, Sari SR. Adaptive space of Javanese traditional house in Brayut tourism village Yogyakarta. Tataloka. 2019;21(1):170–179. doi:10.14710/tataloka.21.1.170-179
61. Raharjo MHFY, Lukito IS, Martarizal, et al. A comparative analysis of air temperature data from automatic weather station and ERA5-Land reanalysis in Java, Indonesia. J Phys Conf Ser. 2025;2989(1):012030. doi:10.1088/1742-6596/2989/1/012030