Matthew Espeland

Evaluating Thermal Performance and Lifecycle Economics of Rural Housing in Northern Uganda

Evaluación del comportamiento térmico y la economía del ciclo de vida de las viviendas rurales en el norte de Uganda

Avaliação do desempenho térmico e da economia do ciclo de vida das habitações rurais no norte do Uganda

Keywords | Palabras clave | Palavras chave

Adaptive comfort, Cost of ownership, Vernacular architecture, Field study, Acholiland

Confort adaptativo, Coste de propiedad, Arquitectura vernácula, Estudio de campo, Acholiland

Conforto adaptativo, Custo de propriedade, Arquitetura vernácula, Estudo de campo, Acholiland

Abstract | Resumen | Resumo

Rural Uganda has a housing deficit of 2.4 million units amid rapid population growth, and prospective homeowners often have a choice between vernacular earth construction and imported industrial systems. Existing literature demonstrates the thermal superiority of earthen construction over industrial alternatives, yet few studies simultaneously quantify both physical performance and lifecycle economics using empirical data. This study addresses that gap with the construction of three prototype kiosks in Kalongo, Uganda, of enhanced wattle and daub, rammed earth, and interlocking stabilized soil blocks (ISSB). Indoor temperatures were monitored over 70 days and evaluated against the ASHRAE 55 Adaptive Comfort Model. Simultaneously, detailed capital expenditure and cost-of-ownership projections were drawn up. Wattle and daub showed the highest thermal compliance at 68.8%, followed by rammed earth (62.3%), and ISSB (59.7%). Rammed earth requires the lowest initial capital, whereas ISSB's lower maintenance cost offsets its higher capital requirement, reflecting a "predictability premium" embedded in industrial construction.

La Uganda rural presenta un déficit de 2,4 millones de viviendas en un contexto de rápido crecimiento demográfico, y quienes desean construir una vivienda suelen poder optar entre sistemas vernáculos de tierra y sistemas industriales importados. La literatura existente demuestra la superioridad térmica de la construcción con tierra frente a las alternativas industriales, pero pocos estudios cuantifican simultáneamente el comportamiento físico y los costes del ciclo de vida a partir de datos empíricos. Este estudio aborda esta cuestión mediante la construcción de tres prototipos en Kalongo, Uganda: uno

de entramado y barro, otro de tapial y un tercero de bloques de tierra estabilizada y encajables (ISSB). Las temperaturas interiores se registraron durante 70 días y se evaluaron de acuerdo con el Modelo Adaptativo de Confort de ASHRAE 55. Paralelamente, se realizaron estimaciones detalladas de la inversión inicial y del coste total de propiedad. El entramado y barro presentó el mayor grado de cumplimiento de los parámetros de confort térmico, con un 68,8 %, seguido del tapial (62,3 %) y los ISSB (59,7 %). El tapial requiere la menor inversión inicial, mientras que el menor coste de mantenimiento de los ISSB compensa su mayor inversión inicial, lo que refleja una "prima de previsibilidad" asociada a la construcción industrial.

As zonas rurais do Uganda enfrentam um défice habitacional de 2,4 milhões de unidades, num contexto de rápido crescimento populacional, e os futuros proprietários têm frequentemente de escolher entre a construção vernácula em terra e os sistemas industriais importados. A literatura existente demonstra a superioridade térmica da construção em terra face às alternativas industriais; no entanto, poucos estudos quantificam simultaneamente o desempenho físico e a economia do ciclo de vida utilizando dados empíricos. Este estudo aborda essa lacuna através da construção de três quiosques-protótipo em Kalongo, no Uganda, utilizando taipa reforçada, terra compactada e blocos de terra compactada com bordas entrelaçadas. As temperaturas interiores foram monitorizadas ao longo de 70 dias e avaliadas de acordo com o Modelo de Conforto Adaptativo ASHRAE 55. Simultaneamente, foram elaboradas projeções detalhadas relativas às despesas de capital e ao custo de propriedade. A taipa apresentou a maior conformidade térmica, com 68,8%, seguida da terra compactada (62,3%) e dos blocos interlaçados (59,7%). A terra compactada requer o menor investimento inicial, enquanto o menor custo de manutenção dos blocos compensa a sua maior necessidade de investimento, refletindo um "prémio de previsibilidade" inerente à construção industrial.

Introduction

The built environment of rural Uganda is shaped by the country's complex colonial history and the stark economic divide between urban centers and rural peripheries. In rural contexts, there is a limited spectrum of housing—the traditional *ot-lum* type or the more contemporary *duka* type (Fig. 1). The *ot-lum* can be characterized by its use of single-skin wattle and daub walls with a thatched roof over light framing elements, typically with a circular shape (Fig. 2). Family housing units consist of a series of these structures, each with a unique programmatic function, organized around a

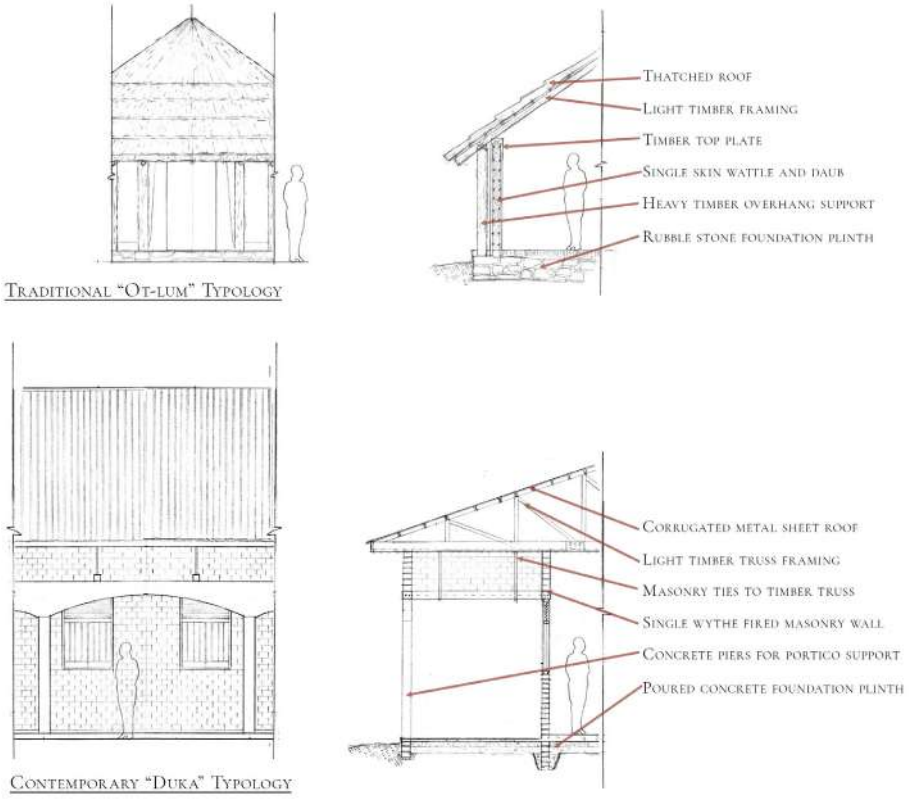


Figure 1. Comparison of *ot-lum* and *duka* types





Figure 2. Local examples of *ot-lum* types (Quinlan Gallagher)



Figure 3. Local examples of *dye-kal* arrangement



Figure 4. Local examples of *duka*

central courtyard or *dye-kal* (Fig. 3), the hub of the home (Girling 1960). Historically, materials for the *ot-lum* could be gathered in the vicinity, and many of the building materials are still local and able to be gathered. The construction and maintenance of an *ot-lum* is frequently a combined household self-building effort.

The *duka* shop-house has a rectilinear form, typically built of fired adobe blocks with timber-truss and sheet-metal roofing (Fig. 4). It is typically split between a shop at the front and a family apartment in the back. *Duka* building materials are normally purchased, particularly the fired bricks. These are hand-molded and stacked in large mounds for firing (Fig. 5), sometimes near the site, though they are normally seen on the periphery of communities. The vast quantities of firewood required for firing have a large carbon footprint. The complexities of *duka* construction often require the hiring of skilled labor, and the process tends to be phased according to the available capital, often leaving shells of homes awaiting further financing (Figs. 6 and 7).

The British colonial period, ending in 1962, marked a shift in tectonics from the semi-pastoral *ot-lum* to more permanent masonry homes. Colonial housing policy graded dwelling systems from more vernacular to more permanent (Byerley 2009). Contemporary intervention by foreign NGOs has further introduced imported building materials and construction methods that lack the inherent evolutionary adaptations of vernacular systems (Juma and Suhrke 2002). These imported systems have coincided with a demographic explosion. Uganda has roughly 46 million inhabitants and is one of the world's youngest countries, with a median age of 16.8 years (UBOS 2024). By 2040, the population is expected to double, exacerbating an existing housing deficit



Figure 5. Brick-firing mounds outside the village



Figure 6. Local masonry technique



Figure 7. Phased construction of a local *duka*

of 2.4 million units (Ministry of Finance, Planning and Economic Development 2024). Development occurs unevenly, with the southern urban centers enjoying most income and infrastructure improvements, as is evident in the allocation of permanent building systems. In the historically marginalized northern Acholiland region, wattle and daub walls are found in 16.1% of homes, with 85.3% of households opting for thatch roofs and 89.9% for earthen floors (UBOS 2021). This is in stark contrast with the capital Kampala, where just 1.3% of homes are of wattle and daub and 0.0% have thatched roofs. Broader Ugandan trends indicate a transition toward more permanent masonry, with 65.3% of homes now being built this way (UBOS 2021). Yet rural population growth means that the number of households relying on vernacular construction systems is also increasing. Existing literature shows a need for evaluation of a spectrum of building types responding to individual contexts and offering families a variety of housing solutions across demographic strata.

Academic studies in sub-Saharan contexts have analyzed lived experience and shown that earthen structures passively provide a more comfortable indoor space than industrial ones. Hailu et al. (2021) found that in Ethiopia 88% of traditional earthen home occupants were satisfied with their indoor environment, compared to 22% in modern homes. These findings are consistent with those of Widera (2021), showing 60-70% occupant satisfaction in selected vernacular dwellings across Togo, Benin, and Ghana, compared to 20% satisfaction in modern ones. Nematchoua et al. (2014) found that traditional structures outperform modern ones in both wet and dry seasons. In Uganda there are limited studies on thermal comfort, with Kajjoba et al. (2022) evaluating it in low-income housing in Kampala and finding that 67.8% of respondents reported comfort.

Recent research relies largely on computer simulations, subjective data, or predicted mean vote surveys. In-situ field studies that test these theories are scarce. Furthermore, the literature tends to be compartmentalized by specific thermodynamic envelopes (Carrobé, Rincón and Martorell 2021) or broad economic evaluations (Hashemi and Cruickshank 2015). Adegun and Adedeji (2017) reviewed 136 studies from 17 countries and confirmed that earthen materials are cheaper and more comfortable than contemporary alternatives in Africa. Few studies simultaneously quantify both physical performance and lifecycle economics across prototype models, though there have been calls for such analyses (Abdel Gelil Mohamed and Abo Eldardaa Mahmoud 2023). Furthermore, most studies focus on urban environments with stable supply chains and reliable material cost information. The present study's isolated rural setting involves the opportunity to leverage this research as a primary source for future economic studies.

Sanya's multi-criteria assessment effectively tabulates a variety of thermal, economic, and social factors, weighting them to appraise a spectrum of vernacular and modern building types (Sanya 2007). But the breadth of that study limited its ability to gather empirical evidence to verify its conclusions, and it relied instead on rigorous benchmarking. With the construction of full-scale architectural prototypes and a strict reliance on environmental data logged and measured against the ASHRAE 55 Adaptive Comfort Model, this study captures evidence that may be used to verify literary modeling. ASHRAE 55 has become the standard for validating naturally ventilated buildings in African contexts (Efeoma and Uduku 2014). Our study accordingly pursues three interrelated aims: to generate empirical thermal performance data across three construction types; to establish primary-source capital expenditure and cost-of-ownership data in a context where this is scarce; and to examine the relationship between thermal performance and lifecycle economics so as to inform future housing interventions in rural Uganda.

Methodology

Site Selection and Prototype Design

This research was conducted in Kalongo, Uganda (3°02'N, 33°22'E) from January to March, covering the end of the dry season and the onset of the wet one, with its active portion being in early January. Kalongo is located some 300 miles north of Kampala and 100 miles from Gulu, the nearest city (Fig. 8). Despite its nearly 10,000 inhabitants, Kalongo's traffic links are poorly maintained dirt roads that are often impassable after heavy rain. So the town has the desired supply-chain isolation albeit with logistics to support a field study. Previous engagement with the community afforded critical contacts and resources otherwise unavailable.

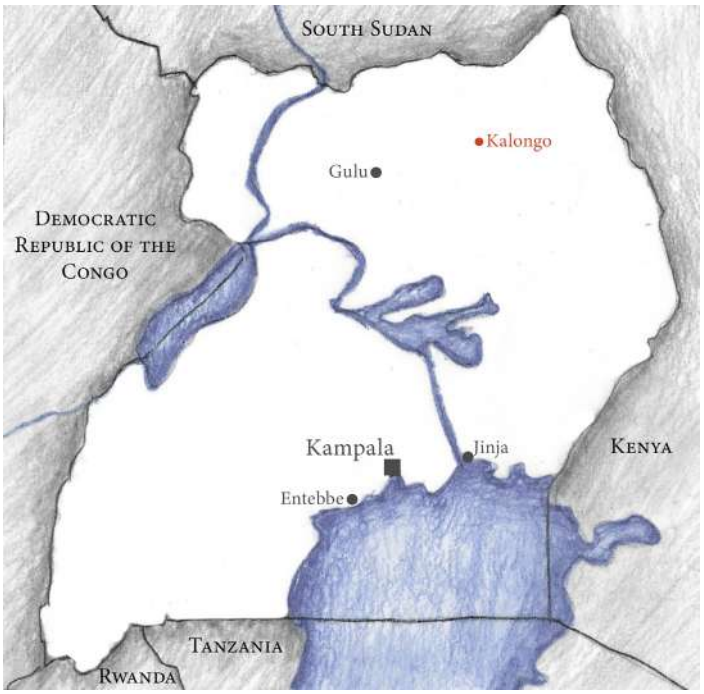


Figure 8. Map of Uganda



Figure 9. The three kiosks at the research site in Kalongo

After selection of the site, standard prototype kiosks were designed, each as a 9′ × 7.5′ rectilinear structure. Each one was oriented with its 7.5′ wall on the north-south axis. Each western wall included a 4.5′ × 4.5′ steel awning-style window with a small louvered opening above the operable portion, as is typical in the region. Each eastern wall included a 3′ × 6.75′ steel security door. Each kiosk's roof pitch was roughly 4:12. The kiosks shared a raised plinth foundation, consisting of rubble stones with cement and smaller stone infill. Wall thickness and roofing materials varied between kiosks so as to accurately reflect the reality of housing in Kalongo. Preliminary design drawings for each kiosk were given to a local contractor for verification and coordination, though some construction decisions were ultimately left to the builders, as they had greater knowledge of local systems and materials (Fig. 9).

Type Specifications

Kiosk 1: Triple-skin wattle and daub (Fig. 10). This type served as an enhanced proxy for the *ot-lum* hut. The walls consisted of an outer layer of daub applied to bamboo wattle, with an additional daub layer on the wattle interior, as is traditional. A 4″ air gap and a further wattle and daub layer were added as a departure from the traditional form, intended to test whether this type could be elevated to meet the demands of more sophisticated scaled development while remaining within a vernacular framework. The overall wall thickness was measured at 15″. As the connection between the top plate and rafters was not airtight, the builder included a small vented opening. The roof was constructed of large (4″ diameter) rafters. A 9″ layer of thatch was then laid on the rafters over plastic damp-proof membrane, which was also used for edge and penetration flashings. Insecticide was sprayed along the base during construction and timbers in direct contact with the foundation plinth were treated with spent motor oil, a common practice in Kalongo. The larger gum poles embedded in concrete at the corners were treated with spent motor oil and wrapped in plastic damp-proof membrane.



Figure 10. Kiosk 1 – Triple-skin wattle and daub

Kiosk 2: Rammed earth with buried formwork (Fig. 11). Designed as an idealized hybrid, this type was intended to provide high thermal performance without the capital intensity of cement masonry. The walls were constructed of monolithic rammed earth, using on-site soil (*murrum*) and local unskilled labor for manual compression using simple wooden rammers. To reduce the need for specialized labor, the builders employed a "lost formwork" technique whereby the bamboo used to form the earth was left embedded in the wall. The overall wall thickness was measured at 10″, a product of the corner support poles, similarly fashioned to those of Kiosk 1. A 9″ layer of thatch was also laid on this kiosk, applied over larger (4″ diameter) rafters and an additional perpendicular layer of bamboo purlins with 1″ diameter. As in Kiosk 1, a small vent gap was left between the top of the wall and the rafters. Damp and insect mitigation was applied as in Kiosk 1, albeit with damp-proof membrane only at the edges of the roof rather than all over it.

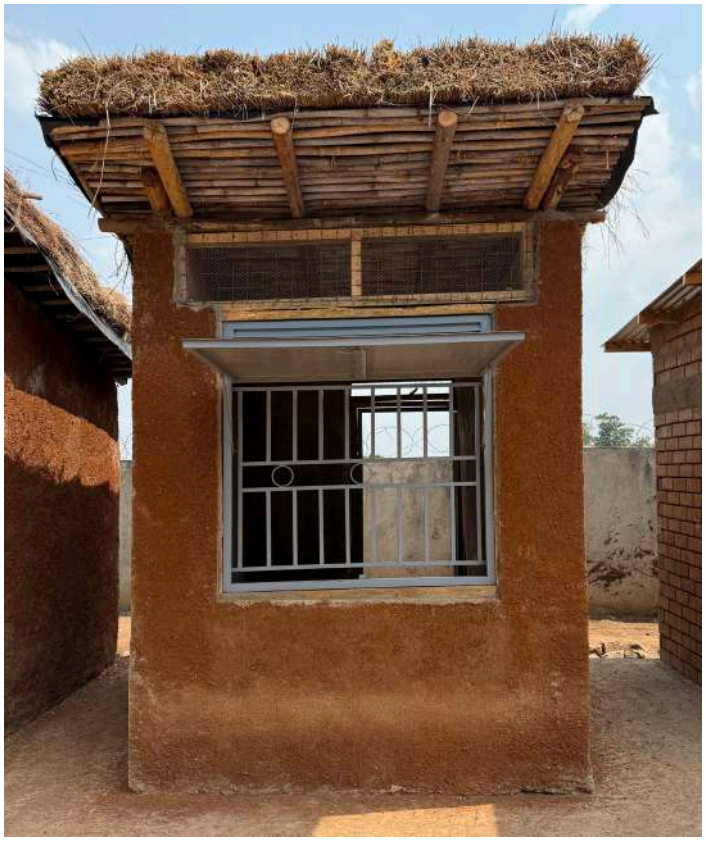


Figure 11. Kiosk 2 – Rammed earth with buried formwork

Kiosk 3: Interlocking stabilized soil blocks (Fig. 12). This type served as a proxy for the aspirational model of more permanent contemporary housing. The walls were constructed of interlocking stabilized soil blocks (ISSB) using a rented Makiga machine. ISSB were chosen for an idealized scenario limiting the use of fired bricks to minimize impact on forest reserves. ISSB generally also require less cement and therefore contain lower embodied energy than standard fired bricks (Hashemi and Cruickshank 2015). The machine was loaded with the mold for a standard block measuring 5″ (w) × 10″ (l) × 5″ (h). The soil mix was made on site using local *murrum* in a 1:1:5 mixture of sand, cement, and *murrum*. The blocks were then left to dry in the sun for two weeks. The walls were laid in a single wythe with no mortar. A 6″ concrete ring beam was poured on top of the ISSB, serving as a lintel for the window and door, with two embedded #4 reinforcing bars for tensile strength. A timber top plate was fitted over the ring beam with ISSB infill to allow for the slope of the roof, which was framed with timber rafters and finished with corrugated iron sheeting.

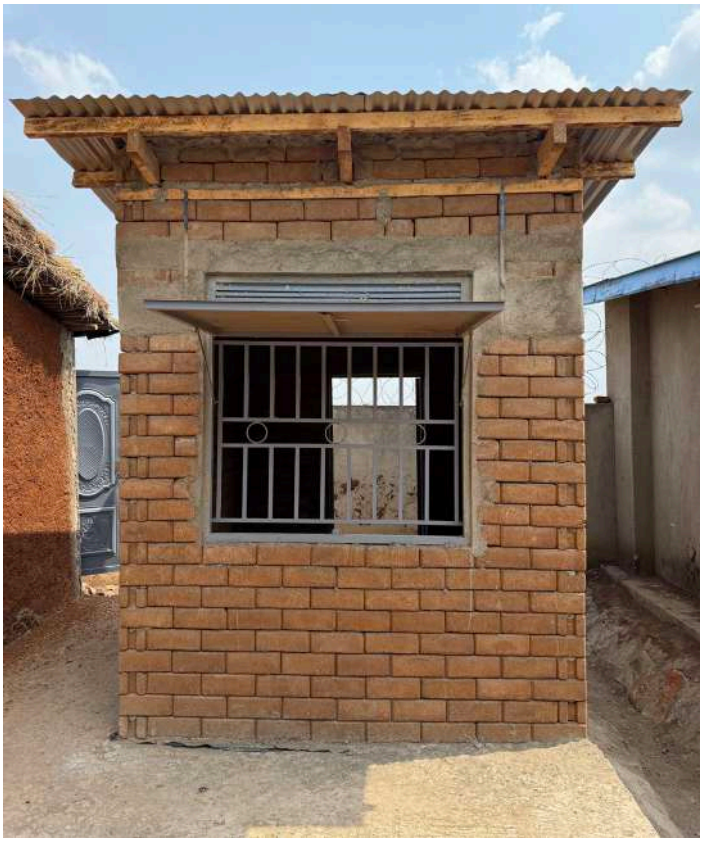


Figure 12. Kiosk 3 – Interlocking stabilized soil blocks

Data Collection and Evaluation Framework

Thermal Performance. One Elitech RC-51H temperature sensor was hung from the roof of each kiosk at a height of roughly 5.75′, out of direct sunlight at all times, to log the interior temperature and relative humidity every 15 minutes. Thermal data were collected in two phases. In an initial 4-day active monitoring period (Dec. 30 to Jan. 4), the windows in each kiosk were manipulated to isolate the effects of passive ventilation: open for the first 48 hours and closed for the remaining 48 hours. Subsequently, data continued to be logged at 15-minute intervals through March 10, with the windows closed and the kiosks unoccupied. This gave a total monitoring period of 70 days, from the peak dry season through the onset of the wet season. The extended dataset thus captures the purely inherent thermodynamic behavior of each envelope without occupant adaptation. The data

were evaluated using the ASHRAE 55 Adaptive Comfort Model. Failure times, in which the indoor temperatures transgressed preset acceptability limits, were then calculated for each kiosk.

Economic Evaluation. The builder used a live bill of quantities to track every cost related to construction. The costs of shared materials or tools (sand, water, etc.) were proportioned by relative use. The contractor's costs also include the transporting of materials to the remote site. Capital expenditure for each kiosk was broken down into major building components and cost categories (e.g., materials, tools, transport). Economic leakage, or the quantity of capital spent outside of Kalongo, was calculated for each kiosk. To evaluate long-term viability, a 20-year cost-of-ownership (CoO) projection was modeled, reckoning recurring maintenance costs for each kiosk and factoring in the unique relative rates of degradation. Local labor and material rates were generated by the builder. A sensitivity analysis collated different maintenance scenarios based on the builder's experience.

Results

Thermal Performance

Temperature data from each kiosk were benchmarked to acceptable standards using ASHRAE 55 Adaptive Analysis. While humidity data were also logged, the study scope was limited to dry-bulb temperature. The prevailing mean outdoor temperature (tpma) was 26.87°C (80.36°F), as reported by the Uganda National Meteorological Authority. While this outdoor temperature varies monthly, published climate data indicates variation that is statistically insignificant, with a range from 25°C to 27.5°C, and so including this calculation would shift the comfort limits only slightly (about 1°F) either way. A static comfort zone was therefore applied across the monitoring period for simplicity in comparison. Comfortable temperature was calculated to be:

$$T_{comf} = .31 \times t_{pma} + 17.8 = .31 \times (26.87°C) + 17.8 = 26.13°C$$

80% satisfaction is achieved with +/-3.5°C, giving an acceptable range of 22.63°C – 29.63°C (72.73°F – 85.33°F) (ASHRAE Standard 55-2020).

Over the initial 4-day field study, it was Kiosk 2 that showed greatest compliance with the prescribed temperature limits, at 63.8% of the time. Kiosk 3 was within the limits for 61.2% of the time, and Kiosk 1 performed least well, at 60.6%. These aggregate figures mask a sharp diurnal divergence. In the daytime cycle (07:00–19:00), Kiosk 1 did best by far, with a pass rate of 81.7% of the time. Kiosk 2 passed at 58.8%, and Kiosk 3 at 46.8%. In the nighttime cycle, however, Kiosk 3 outperformed the others with a pass rate of 76.5%. Kiosk 2 passed at 68.7% of the time, and Kiosk 1 only at 37.9%. All three kiosks responded to window management, with Kiosk 1 showing the greatest sensitivity, with its nighttime pass rate increasing to 52.4% with windows closed.

The failure profile for Kiosk 1 was cold-biased, as it stayed within the upper limit for 98.5% of the time, as opposed to 62.1% at the lower limit. Its magnitude of failure was significant: 9.1°F on the lower side. Conversely, Kiosk 3 was heat-biased, as its peak temperatures exceeded the upper limit by 10.6°F, with compliance of just 71.9%, but it remained above the lower limit for 89.3% of the time. Kiosk 2 had the most balanced profile, remaining within the upper and lower limits for 82.8% and 81.0% of the time, respectively.

After the 4-day active study, the sensors continued to log data for another 70 days. All the data for this period, plotted in Fig. 13, were in a closed, unoccupied state.

The initial pass rates varied over the monitoring period. Kiosk 1 achieved the highest overall compliance at 68.8%, followed by Kiosk 2 at 62.3%, and Kiosk 3 at 59.7%.

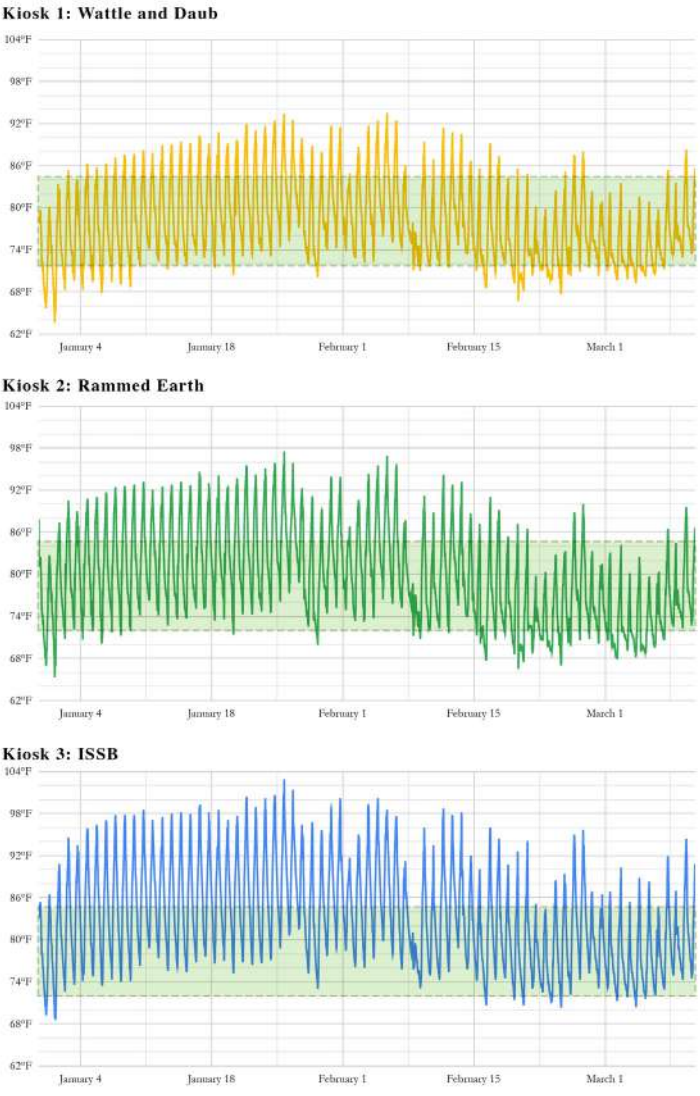


Figure 13. Thermal performance over 70 days

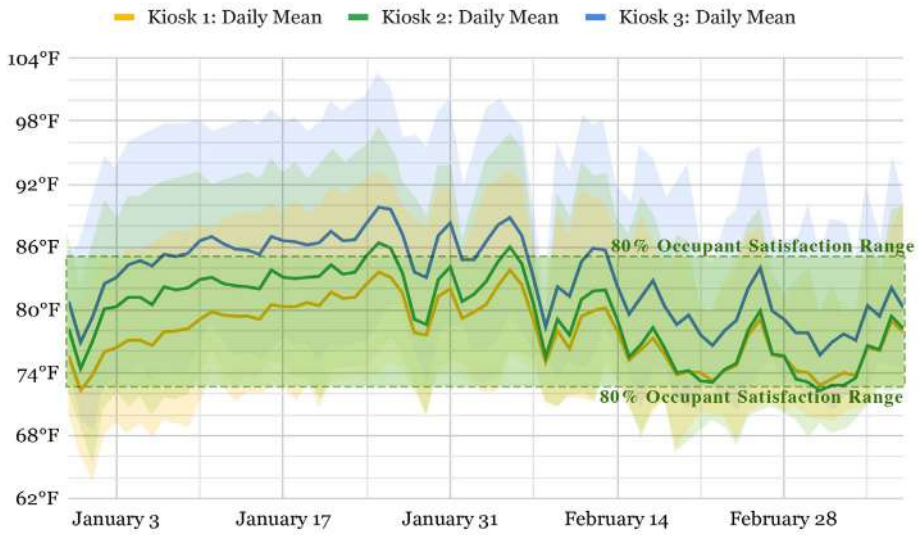


Figure 14. Daily mean over 70 days

Each kiosk's failure profile sharpened considerably with the larger dataset. Kiosk 1 remained cold-biased, failing the lower limit for 18.3% of the time. Its initial 98.5% upper-limit pass rate fell to 87.2% over the extended study. Kiosk 3 remained heat-biased, staying within the upper limit for only 63.4% of the time. A particularly warm day in January took all three kiosks to their peak temperature, with Kiosk 3 logging 102.9°F, a substantial 17.6°F above the upper limit. As the extended study allows analysis of kiosk performance across the dry and early wet seasons, the daily mean temperatures plotted through the study show the interiors cooling over the transition (Fig. 14). Kiosk 1 continued to fare better thermally, though the interior temperature difference between Kiosks 1 and 2 reduced as the season cooled.

Economic Evaluation

Rigorous price data collection allowed detailed analysis of capital expenditure (CapEx) for each kiosk. Kiosk 2 proved to be the most cost-efficient system, with a total cost of 6,992,175 Ugandan shillings (UGX) (~$1,998), followed by Kiosk 1 at UGX 7,799,676 (~$2,228). Kiosk 3 was the costliest at UGX 11,745,149 (~$3,356), roughly 68% more than Kiosk 2. These costs are charted in figure 15. To highlight each type's scalability, marginal costs (the outlay required to build a second kiosk) were calculated and compared, excluding any tools or materials able to be reused for another unit. Here again, Kiosk 2 remains the least costly at UGX 5.67 million. Kiosk 3 is still the costliest at UGX 8.25 million, though this represents only a 45% premium over Kiosk 2.

Capital expenditure for each kiosk was broken down by components as shown in figure 16. These costs concern mostly building materials, labor, and equipment, and chiefly materials, accounting for roughly 61% of CapEx in Kiosks 1 and 2 and 58% in Kiosk 3. The cost of the Makiga machine greatly increased the equipment cost for Kiosk 3, accounting for 22% of CapEx. Regarding economic leakage, non-local purchases are shown hatched in figure 16. Most of the capital spent for all three kiosks remained in Kalongo, though some industrial components, such as the steel windows and doors, were purchased in Kampala, along with the Makiga machine. Kiosk 3 involved most expenditure outside of Kalongo: roughly UGX 4.4 million, representing 37.6% of its CapEx. Kiosks 1 and 2 had about 29.6% and 33.1% of their CapEx spent outside Kalongo, roughly UGX 2.3 million each.

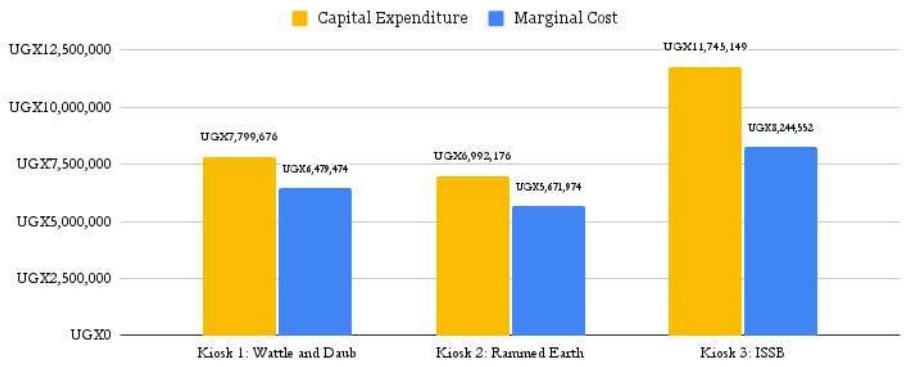


Figure 15. CapEx and marginal cost comparison

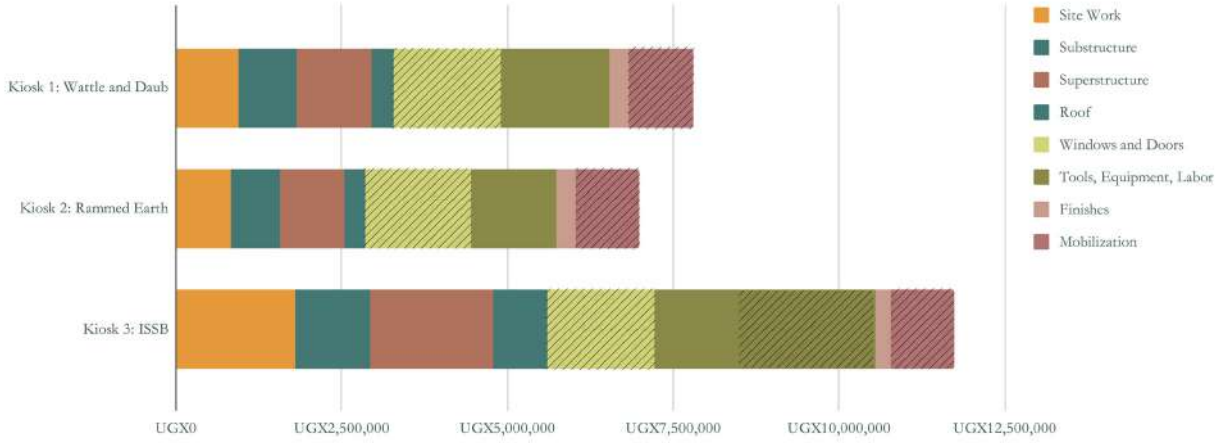


Figure 16. CapEx by building component with economic leakage

To accurately reflect the cost of ownership (CoO) for each building type, a rudimentary operational expenditure calculation was performed. The organic nature of the building systems coupled with the unpredictable climate of Kalongo made it necessary to run calculations based on varying maintenance requirements: low, standard, and high for each kiosk. In a region where standardized maintenance is not available, the scenarios were based on heuristic models provided by the contractor, checked with colleagues, as shown in table 1:

Kiosks 1 & 2	Low maintenance	Standard maintenance	High maintenance
Termite treatment	6 times yearly	18 times yearly	36 times yearly
Mud wall repair	3 years	2 years	1 year
Thatch roof repair	4 years	3 years	2 years
Thatch roof replacement	10 years	8 years	4 years

As Kiosk 3 is largely made of more industrial materials, its maintenance requirements were described as less involved, limited to termite treatment 3 times, 6 times, and 18 times yearly for the low, standard, and high maintenance scenarios, respectively.

Using rates gathered from local builders, CoO was charted for each kiosk with these maintenance schedules. The calculations were applied also to marginal cost as an exercise in scalability. CoO was reckoned over a hypothetical 20-year period. Under the standard maintenance scenario, Kiosks 1 and 2 generated roughly an additional UGX 2 million in maintenance requirements relative to Kiosk 3. Yet the high initial capital required for Kiosk 3 offsets its maintenance savings and it remains the most expensive type. In CoO analysis with marginal cost, the initial capital for Kiosk 3 is closer to that of Kiosks 1 and 2, making it the least expensive type after 20 years. Under high maintenance conditions, Kiosk 3 becomes the least expensive type after 20 years in both CapEx and marginal cost, incurring just UGX 1.5 million in maintenance, as opposed to some UGX 6.6 million for Kiosks 1 and 2. CoO for each scenario is plotted in figure 17, wherein the shaded area represents the range between high and low maintenance scenarios.

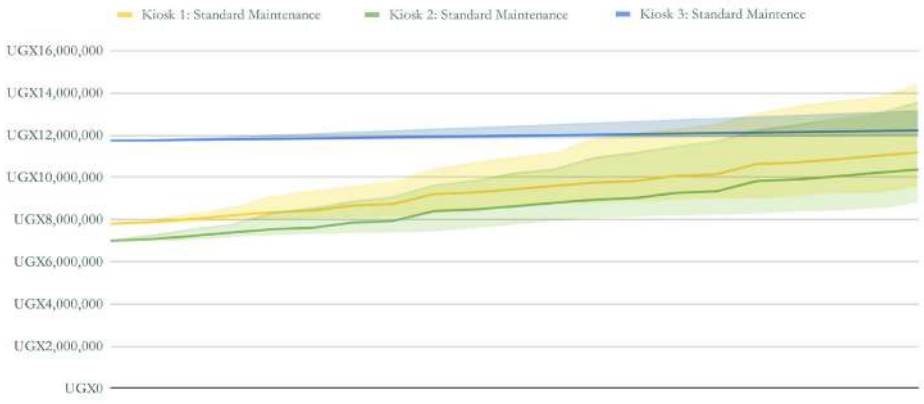


Figure 17. CoO over low, standard, and high maintenance scenarios

Discussion

Mechanics of Thermal Failure

While the aggregate thermal pass rates of the three types appear comparable (~60-69%), the figures mask divergent physical behaviors. Each system transgresses the comfort limits through distinct mechanisms embedded in its material properties, with implications for future adaptations.

Kiosk 1 (wattle and daub) showed the strongest passive cooling of the three, with the highest overall pass rate, while also complying with the upper comfort limit most frequently. The low thermal conductivity of its triple-skin mud walls effectively attenuated daytime solar heat gain. However, this same low thermal mass made it unable to store daytime heat for release during the cooler nights, resulting in the lowest pass rate at the lower limit. Kiosk 3 (ISSB) showed the opposing mechanism. The dense block walls stored and transmitted heat during the night, resulting in good nighttime compliance. But its highly conductive iron sheet roof chronically overheated the interior during the day. Kiosk 2 (rammed earth) performed intermediately. Its breathable thatch roof released accumulated heat during the day while its monolithic earth walls retained warmth at night. It showed the most evenly distributed failure profile and the closest approximation to a truly passive envelope.

The earth-walled prototypes (Kiosks 1 and 2) failed thermally in ways that can be partially addressed through behavioral adaptation, such as closing windows at night, occupying the space, or using blankets. The failures of the industrial system (Kiosk 3) require more architectural intervention, as the iron roof will continue to let the structure overheat regardless of occupant behavior. Addressing such failures involves material changes, such as insulation beneath the iron sheet or addition of radiant barriers, as opposed to behavioral changes. These findings underscore a fundamental asymmetry whereby the earth-walled prototypes provide superior passive cooling but cannot retain warmth overnight, while the industrial prototype provides nighttime stability at the cost of daytime heating. An alternate system, pairing the density of ISSB walls with a less conductive roof structure, would respond to some of these issues.

Economics of Permanence

The initial capital expenditure data highlights the added expense embedded in a transition to contemporary industrial housing materials, with Kiosk 3 being 68% more expensive than Kiosk 2. While this reflects a material upgrade, it is also the consequence of the region's isolation. The great distance from the nearest city coupled with poorly maintained roads inflates the baseline cost of industrial construction. Capital spent procuring industrial goods moreover does not recirculate in the local economy. Kiosk 3 left a large share of its construction budget outside of Kalongo, while the spending for Kiosks 1 and 2 was largely local. The steel windows and doors used in all three kiosks also reflect a consistent sourcing vacuum for industrial materials. Where local economic circulation is a priority, the distribution of expenditure warrants consideration by homeowners and builders.

Calculating the marginal cost of construction is crucial to evaluating the potential for mass adoption. The cost premium of Kiosk 3 over Kiosk 2 is reduced to just 45% in marginal cost, and just 28% over Kiosk 1. The largest saving in marginal cost concerns the Makiga machine, a one-time purchase that can be used for other projects. The region's high deforestation and termite risk also gives Kiosk 3 an advantage in terms of scalability, given its limited use of timber. But for subsistence-level households, securing the capital to access the machinery required for ISSB is often impossible, which limits them to the more vernacular options of Kiosks 1 and 2.

An economic insight emerges from the contrast of initial CapEx with 20-year CoO. The organic envelopes of Kiosks 1 and 2 can trap low-income families in a perpetual cycle of costly, labor-intensive operational expenditure (OpEx), though this risk is mitigated by abundant local generational craftsmanship. The CoO models confirm that in a "standard" maintenance scenario, Kiosk 2 remains the cheapest option at 15% less than Kiosk 3 after 20 years. Yet in an agrarian context such as Kalongo, household income is volatile, tied to uncontrollable environmental factors such as rainfall and crop yields. Organic buildings tend to degrade in parallel with these environmental pressures. This can force rural families to expend critical capital, both economic and human, on repairs and maintenance intrinsic to vernacular construction. Thus Kiosk 3's low OpEx increasingly offsets its initial CapEx, as shown empirically in the "high maintenance" CoO scenario. The steep initial cost of the ISSB structure can be justified as an investment for financial stability against environmental volatility, which homeowners may see as a "predictability premium."

Thermal and Economic Performance in the Social Context

The dissonance between the thermal performance of earth-walled systems and the durability of more industrial masonry results in a complex decision-making matrix for prospective homeowners. Architectural evolution in rural Uganda is moreover not driven only by thermal calculus. The sociocultural matrices conceptualized by Sanya show that material selection is also guided by questions of status and cultural relevance (Sanya 2012). Vernacular earth construction, while culturally relevant and thermally superior, is burdened with socioeconomic stigma linked to cyclical poverty. Organic architecture is visibly ephemeral, having evolved from pastoralism. The need to maintain and replace organic elements is thus a reminder of occupants' vulnerability. The psychological security derived from a more industrial, permanent structure can therefore outweigh thermal considerations, which occupants may mitigate through adaptive measures.

Improvements and Future Iterations

To contextualize the performances presented here, some limitations must be acknowledged. First, these prototypes were constructed as experiments rather than examples of established practice. As such, they lacked the craft input that would otherwise improve durability, performance, and aesthetic quality. Additionally, all temperature data were logged in unoccupied structures. Introducing a standard heat load would likely help mitigate Kiosk 1's nighttime cold while exacerbating Kiosk 3's daytime heat. The thermal performance of each kiosk would likely be improved if occupants adopted behaviors such as opening windows during the day and closing them at night. Most of the thermal data capture only a single operational state, though the brief ventilation phase confirmed that all three kiosks were responsive to climate management. And as the testing began some three weeks after completion, the earth walls may have still contained residual moisture, promoting evaporative cooling and so inflating daytime pass rates and nighttime fail rates. As the kiosks dried over the course of the study, their upper-limit performance tailed off, reaching equilibrium after a few weeks.

Some field observations must be included here for the sake of transparency and accuracy. First, Kiosks 1 and 2 showed significant termite damage some weeks after construction. Despite initial ground treatment, termites were able to infest the kiosks through the bamboo embedded in the walls, eventually making their way to the roof framing (Fig. 18). Once the damage was noticed, more aggressive treatment was applied, reflected in the "standard" maintenance scenario for conservative upkeep. Additionally, as the season transitioned from dry to wet, Kiosk 2 began to suffer water infiltration through its roof, as the lack of a damp-proof membrane let the heavy rain leak in after soaking through the thatch. Not only does this affect durability but it is also possible that the leakage cooled the kiosk during the wet season. Kiosks 1 and 2 were also beginning to show signs of degradation where the outside mud walls met the ground, likely as a result of insufficient plinth height. Lastly, it is worth noting that for Kiosks 1 and 2, bamboo was selected to replace wooden framing, given the lack of a local supply of quality lumber, and the aspirational idea of using a more resilient, abundant material for future construction.



Figure 18. Evidence of termite damage in Kiosks 1 and 2

Conclusions

Ultimately, this research does not seek to establish a single "best" construction system. Rather, it seeks to inform future architectural work in the region. The departure of these prototypes from more conventional local systems limits our ability to generalize the results to vernacular systems with generations of iterative design evolution. The overlapping complexities of thermal comfort, economic needs, and social stigmas also render a single design solution unlikely. Instead, these findings suggest that future architectural interventions should pragmatically retrofit industrial materials suited to this environmental context, without loss of durability and scalability. Concurrently, the large, growing demographic that still relies on vernacular earthen systems could benefit from design improvements to stabilize building integrity and improve maintenance predictability. The methodology employed in this study is transferable to other regions where tension between vernacular and industrial construction persists, as more of the world develops from rural contexts. The broader adoption of vernacular building methods faces many obstacles, including the dominance of industrial materials, the stigma attached to earth construction, and the erosion of craft knowledge. Addressing these barriers requires an understanding of the empirical evidence presented here and institutional support for craft training alongside development of hybrid vernacular-industrial systems. The future of rural construction in Uganda lies not in the replacement of one approach by another but in the simultaneous scaling and iterative improvement of both.

Acknowledgments

The author would like to express sincere thanks and admiration for the outstanding craftsmanship of Pasteur Rubaramira, who, with his skilled team at RUNHTec, was able to build the prototypes with meticulous detail and an understanding of the underlying design principles.

This research was supported by grant funding from the International Network for Traditional Building, Architecture & Urbanism (INTBAU) and the Institute of Classical Architecture & Art (ICAA) in conjunction with the Luminarts Foundation. The author has no conflicts of interest to disclose.

References | Referencias | Referências

Abdel Gelil Mohamed, Nermine; and Abo Eldardaa Mahmoud, Islam. 2023. Cost-effectiveness and affordability evaluation of a residential prototype built with compressed earth bricks, hybrid roofs and palm midribs. *Frontiers in Built Environment*, 9: 1058782. https://doi.org/10.3389/fbuil.2023.1058782

Adegun, Olumuyiwa B.; and Adedeji, Yomi M. D. 2017. Review of economic and environmental benefits of earthen materials for housing in Africa. *Frontiers of Architectural Research*, 6, 4: 519-528. https://doi.org/10.1016/j.foar.2017.08.003

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 2020. *ANSI/ASHRAE Standard 55-2020: Thermal Environmental Conditions for Human Occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Byerley, Andrew. 2009. Mind the gap! Seeking stability beyond the "tribal" threshold in late-colonial Uganda: The role of urban housing policy, 1945-1960. *African Studies*, 68, 3: 429-464. https://doi.org/10.1080/00020180903381214

Carrobé, Ariadna; Rincón, Lídia; and Martorell, Ingrid. 2021. Thermal monitoring and simulation of earthen buildings: A review. *Energies*, 14, 8: 2080. https://doi.org/10.3390/en14082080

Efeoma, Meshack O.; and Uduku, Ola. 2014. Assessing thermal comfort and energy efficiency in tropical African offices using the adaptive approach. *Structural Survey*, 32, 5: 396-412. https://doi.org/10.1108/SS-03-2014-0015

Espeland, Matthew. 2024. A proposed school for traditional building arts & crafts in Kalongo, Uganda. *Journal of Traditional Building, Architecture and Urbanism*, 5: 258-269. https://doi.org/10.51303/jtbau.vi5.759

Girling, Frank Knowles. 1960. *The Acholi of Uganda*. Colonial Research Studies 30. London: Her Majesty's Stationery Office.

Hailu, Haven; Gelan, Eshetu; and Girma, Yared. 2021. Indoor thermal comfort analysis: A case study of modern and traditional buildings in hot-arid climatic region of Ethiopia. *Urban Science*, 5, 3: 53. https://doi.org/10.3390/urbansci5030053

Hashemi, Arman; Cruickshank, Heather; and Cheshmehzangi, Ali. 2015. Improving thermal comfort in low-income tropical housing: The case of Uganda. In *Proceedings of the ZEMCH 2015 International Conference*, 613-622. Lecce: ZEMCH.

Juma, Monica Kathina; and Suhrke, Astri (eds.). 2002. *Eroding Local Capacity: International Humanitarian Action in Africa*. Uppsala: Nordiska Afrikainstitutet.

Kajjoba, Derrick; Kasedde, Hillary; Olupot, Peter W.; and Lwanyaga, Joseph D. 2022. Evaluation of thermal comfort and air quality of low-income housing in Kampala City, Uganda. *Energy and Built Environment*, 3, 4: 508-524. https://doi.org/10.1016/j.enbenv.2021.05.007

Ministry of Finance, Planning and Economic Development. 2024. *Background to the Budget Fiscal Year 2024/25*. Kampala: Ministry of Finance, Planning and Economic Development.

Kameni Nematchoua, Modeste; Tchinda, René; and Orosa, José A. 2014. Thermal comfort and energy consumption in modern versus traditional buildings in Cameroon: A questionnaire-based statistical study. *Applied Energy*, 114: 687-699. https://doi.org/10.1016/j.apenergy.2013.10.036

Sanya, Tom. 2007. *Living in Earth: The Sustainability of Earth Architecture in Uganda*. Doctoral dissertation, The Oslo School of Architecture and Design.

Sanya, Tom. 2012. Sustainable architecture evaluation method in an African context: Transgressing discipline boundaries with a systems approach. *Sustainability Science*, 7, 1: 55-65. https://doi.org/10.1007/s11625-011-0143-6

Uganda Bureau of Statistics. 2021. *Uganda National Household Survey 2019/2020*. Kampala: Uganda Bureau of Statistics.

Uganda Bureau of Statistics. 2024. *The National Population and Housing Census 2024 – Preliminary Report*. Kampala: Uganda Bureau of Statistics.

Uganda National Meteorological Authority. 2026. *Monthly Weather Bulletin: December 2025 Observed Climatological Performance*. Kampala: Ministry of Water and Environment. https://unma.go.ug/publications/monthly-bulletins/dec-2025 (consulted on 15/03/2026).

Widera, Barbara. 2021. Comparative analysis of user comfort and thermal performance of six types of vernacular dwellings as the first step towards climate resilient, sustainable and bioclimatic architecture in western sub-Saharan Africa. *Renewable and Sustainable Energy Reviews*, 140: 110736. https://doi.org/10.1016/j.rser.2021.110736

Biography | Biografía | Biografia

Matthew Espeland

Matthew is a graduate of the University of Notre Dame, where he earned a Bachelor of Architecture (B.Arch) with honors in 2024. He also completed minors in Italian Studies and Sustainability, reflecting broad academic interests and a commitment to integrating cultural and environmental considerations into practice. He currently works at a prominent Chicago-based residential architecture firm specializing in the application of traditional design and detailing to modern homes. His ongoing research focuses on vernacular building traditions, thermal performance, and housing economics in Uganda's Acholiland region, where he has conducted extensive fieldwork supported by grants from INTBAU and the Institute of Classical Architecture & Art in conjunction with the Luminarts Foundation.