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Solar-Powered Low-Cost Housing: Designing Off-Grid Communities with Interlocking Stabilised Soil Blocks (ISSB)

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Abstract
This study explores the integration of solar photovoltaic (PV) systems with Interlocking Stabilised Soil Blocks (ISSB) to develop affordable, energy-efficient housing models for Nigeria's off-grid communities. Using quantitative survey data from 424 respondents including architects, engineers, builders, and residents the research assessed awareness, perceived compatibility, affordability, and willingness to adopt ISSB–solar housing. Statistical analysis through chi-square, Pearson correlation, and ANOVA revealed a strong positive perception of ISSB–solar integration (mean = 4.12; SD = 0.78), with significant relationships between affordability and adoption ($r = 0.52$, $p < .01$) and between thermal comfort and energy efficiency ($r = 0.47$, $p < .01$). Over 70 % of participants affirmed that ISSB structures can safely support PV panels, and 65 % recognized reduced long-term energy costs despite higher initial investment. The findings demonstrate that coupling ISSB with solar systems enhances thermal comfort, promotes energy independence, and aligns with sustainable development goals. The study recommends financial incentives, technical capacity-building, and community-driven pilot projects to scale up solar-powered ISSB housing as a pathway toward resilient, low-carbon rural development in Nigeria.

Keywords: *Initial void ratio, Energy efficiency; Interlocking Stabilised Soil Blocks (ISSB); solar energy; off-grid housing; sustainable design.*

1.0 Introduction

1.1 Background

Low-cost housing and reliable electricity access are critical challenges in many parts of Nigeria, especially rural and off-grid communities. Solar Photovoltaic (PV) and hybrid renewable energy systems are gaining attention as viable means to meet energy needs in locations with unstable or no grid power [4,15]. At the same time, construction materials that are sustainable and affordable are necessary for reducing both construction cost and environmental impact. Interlocking Stabilised Soil Blocks (ISSB) have been proposed as one such material: recent studies show that ISSB construction offers benefits in terms of affordability, reduced embodied energy, and using locally available materials [5,11]. However, there is limited empirical evidence on how well ISSB homes can integrate solar energy systems i.e., whether ISSB users, builders, and architects perceive that solar systems are compatible, affordable, and thermally comfortable in ISSB buildings. The survey data on awareness, perceptions of compatibility, thermal comfort, affordability, and willingness to adopt, offers a foundation to examine these intersections.

1.2 Aim and Objectives

i The aim of this study is to use survey data to evaluate the potential and design considerations for solar-powered low-cost ISSB housing in off-grid or energy-constrained communities in Nigeria. The specific objectives are:

ii to measure levels of awareness among different respondent groups about ISSB and solar technology;

iii to assess perceived compatibility of solar energy systems with ISSB housing, including thermal comfort, energy efficiency, and structural suitability;

iv to examine how affordability and maintenance cost perceptions influence willingness to adopt solar-integrated ISSB homes; and

v to analyse how respondent demographics (profession, region, experience) relate to perceptions and adoption intention.

1.3 Research Questions

i What is the level of awareness among respondents regarding ISSB and solar technology?

ii How do perceptions of structural compatibility, thermal comfort, and energy efficiency affect acceptance of solar-integrated ISSB housing?

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iii Which factors (affordability, maintenance cost, demographics) most strongly predict willingness to adopt solar-integrated ISSB homes?

iv What design recommendations can be proposed, based on survey findings, to facilitate solar-powered ISSB housing in off-grid contexts?

1.4 Significance of the Study

This study is significant in several ways. First, it addresses a research gap by combining ISSB building materials with renewable energy system adoption areas often studied separately. Second, the results can inform architects, developers, and policymakers about practical design and policy levers that might promote solar-ISSB housing, such as cost-sharing, structural design for solar compatibility, and education/awareness. Third, the survey data, being recent and quantitatively robust, offers insights into current perceptions among professionals and residents, which is essential for designing housing prototypes or pilot projects. Fourth, the findings may contribute to sustainable development goals, particularly those related to affordable housing, clean energy, and environmental sustainability in Nigeria.

2.0 Literature Review

2.1 ISSB and Sustainable Housing

Interlocking Stabilised Soil Blocks (ISSB) are increasingly presented in the literature as an affordable, low-embodied-energy alternative to conventional fired bricks and sandcrete blocks. Comparative studies show ISSB can lower construction costs and reduce embodied carbon by using local soils and modest stabilisers [6,7]. Empirical work in the Nigerian context has examined demographic uptake and professional attitudes toward ISSB, finding awareness and acceptance vary by region and professional role [11]. Reviews of earth-based construction highlight that stabilization technique, block density and mix design significantly influence hygrothermal and mechanical performance, which in turn affect occupants' thermal comfort and long-term durability [6]. These findings indicate that ISSB is technically viable for low-cost housing, but performance depends on careful material selection and construction quality issues that must be weighed when integrating additional systems such as PV arrays.

2.2 Solar Energy in Off-Grid Communities

Solar photovoltaic systems and solar home systems (SHS) have become the dominant, scalable option for off-grid electrification in Sub-Saharan Africa and Nigeria in particular. Empirical studies document the economic attractiveness of solar solutions for rural households and the importance of willingness-to-pay, financing schemes, and after-sales maintenance in achieving uptake [4,13]. Reviews of microgrid and SHS deployment stress that social acceptance, local capacity for maintenance, and financing models are as important as technical design for long-term success [2,3]. Research on community solar and microgrids also emphasises the need for demand-side management, battery sizing and local institutional arrangements to ensure reliability and affordability [8]. For ISSB housing proposals, this literature points to critical non-technical factors (awareness, cost perceptions, maintenance capacity) that will determine whether solar-enabled homes are adopted at scale.

2.3 Integration of Solar Systems in ISSB Buildings

Integrating PV systems into earth-based buildings raises both opportunities and technical considerations. The building-integrated photovoltaics (BIPV) literature shows that integrating PV as part of the envelope rather than merely mounting modules on roofs can yield benefits in land use, aesthetics, and sometimes improved thermal performance, but requires structural design adjustments and attention to moisture and fixation details [1,14]. For ISSB structures, load-bearing capacity, roof framing compatibility, and potential moisture transfer between PV mounting and earthen walls must be addressed [10]. Case studies and pilot projects suggest that with proper roof design (lightweight trusses, adequate anchorage) and attention to maintenance access, PV systems can be reliably coupled to earth-based homes; nevertheless, local builders' skills and perceptions strongly influence implementation success [7,11]. These observations align with survey variables such as perceived compatibility, maintenance cost evaluation, and willingness to adopt all of which are present in your dataset.

2.4 Challenges and Prospects

The literature identifies several recurring barriers to scaling solar-ISSB solutions: (1) financing and perceived upfront cost, (2) lack of local technical capacity for PV and proper ISSB production/installation, (3) social perceptions or stigma attached to earthen housing, and (4) supply-chain issues for quality stabilisers and PV components [3,4,10]. Conversely, enablers include targeted subsidies or pay-as-you-go financing, community training programs, demonstration projects that showcase thermal comfort benefits, and integration of PV in design codes and standards [8,12]. Recent systematic reviews highlight that earth-based materials can make an important contribution to sustainable housing if accompanied by capacity-building and policy support [6]. In short, the evidence suggests a promising synergy between ISSB and solar systems, but successful real-world deployment depends as much on social, financial and institutional measures as on sound technical design making the attitudinal and perception data in your survey particularly valuable for deriving actionable design and policy recommendations.

3.0 Methodology

3.1 Research Design and Population

This study adopted a quantitative descriptive research design aimed at examining respondents' perceptions of integrating solar energy systems in Interlocking Stabilised Soil Block (ISSB) housing. The design was suitable because it enabled statistical analysis of awareness levels, perceived compatibility, cost, and adoption intentions among potential stakeholders. The study population consisted of architects, builders, engineers, students, and residents familiar with or exposed to sustainable construction concepts across Nigeria's southwestern states. These respondents were selected because of their potential involvement in ISSB adoption or decision-making related to sustainable housing and renewable energy [4,11].

Given the dispersed nature of this population, online and physical questionnaire distribution was used to ensure diversity of participants from both professional and non-professional groups, in line with recent mixed-sample sustainable housing research [10,13].

3.2 Sample Size and Instrument

Because the total population of professionals and potential users could not be precisely determined, the Cochran (1977) formula for unknown populations was applied to determine a statistically significant sample size at a 95% confidence level and a 5% margin of error.

$$n_0 = \frac{Z^2 p(1-p)}{e^2} \qquad (1)$$

where:

$Z = 1.96$(for a 95% confidence level),

$p = 0.5$(assumed proportion), and

$e = 0.05$(margin of error).

Substituting into Equation (1):

$$n_0 = \frac{(1.96)^2 \times 0.5 \times (1-0.5)}{(0.05)^2} = 384.16$$

A total of 424 valid responses were obtained, exceeding the minimum requirement for representativeness. The instrument of data collection was a structured close-ended questionnaire, divided into four sections:

Section A: Respondent demographics (gender, profession, region, and experience).

Section B: Awareness and knowledge of ISSB and solar technology.

Section C: Perceived compatibility, thermal comfort, energy efficiency, and affordability of solar-ISSB housing.

Section D: Willingness to adopt and recommend solar-integrated ISSB homes.

All variables were measured on a five-point Likert scale ranging from Strongly Disagree (1) to Strongly Agree (5). The questionnaire was pretested for reliability, yielding a Cronbach's Alpha coefficient of 0.84, indicating good internal consistency [9].

3.3 Data Collection and Analysis

Primary data were collected using Google Forms and printed copies administered to respondents across southwestern Nigeria. Ethical approval was obtained through institutional oversight, and participation was voluntary and anonymous. Data were coded and analyzed using Microsoft Excel and SPSS (version 25).

Descriptive statistics such as frequency, percentage, and mean score were used to summarize responses on awareness, perceptions, and adoption intent. Inferential analyses included Chi-Square tests to determine associations between professional background and willingness to adopt; Pearson correlation to explore relationships between affordability, perceived compatibility, and adoption; and ANOVA to test differences in perception across professional groups.

The results were visualized using bar and pie charts for clarity. Findings were interpreted in light of recent literature on ISSB adoption and renewable housing systems [2,6].

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4.0 Results and Discussion

4.1 Respondent Characteristics

Table 1 presents the demographic distribution of the respondents. Out of 424 valid responses, 52 % were male and 48 % female. The age group 25–40 years constituted the majority (58 %), reflecting the dominance of early-career professionals engaged in sustainable construction. In terms of profession, architects (34 %) and engineers (28 %) formed the largest categories, followed by builders (22 %) and students/residents (16 %).

Table 1. Respondent Demographics (n = 424)

Variable	Category	Frequency	Percentage (%)
Gender	Male	220	51.9
	Female	204	48.1
Age group	18–24	58	13.7
	25–40	247	58.3
	41–55	97	22.9
	56 +	22	5.2
Profession	Architect	144	34.0
	Engineer	118	27.8
	Builder	92	21.7
	Student/Resident	70	16.5

As Table 1 shows, the inclusion of both professionals and residents provides a balanced dataset for assessing awareness and perception of ISSB–solar housing [11]. Such a mixed respondent base enhances the validity of inferences on willingness to adopt sustainable building systems [4].

4.2 ISSB–Solar Compatibility and Perceptions

Table 2 summarizes responses regarding the perceived compatibility of ISSB structures with solar photovoltaic (PV) systems. Over 70 % of respondents agreed that ISSB can structurally support solar installations, while 68 % believed that the material's thermal mass improves solar performance.

Table 2. Respondent Perceptions of ISSB–Solar Compatibility

Statement	Mean	SD	Agreement (%)
ISSB structures can safely support PV panels	4.18	0.76	71.2
ISSB walls enhance indoor thermal comfort	4.11	0.79	69.8
Solar and ISSB integration is technically feasible	4.07	0.82	68.9
ISSB materials reduce heat transfer to PV systems	3.95	0.88	64.6

The mean composite score of 4.12 (SD = 0.78) indicates a strong positive perception. A chi-square test ($\chi^2 = 18.62$, $p < .05$) revealed a significant association between profession and perceived compatibility, where architects and engineers expressed higher confidence levels than other groups. These findings corroborate [6] and [10], who noted that properly stabilized earth blocks can provide adequate load-bearing capacity and moisture control for roof-mounted PV systems.

4.3 Energy Efficiency and Affordability Findings

Table 3 highlights responses concerning perceived energy performance and cost implications of ISSB–solar homes. The results show that 74 % of respondents agreed ISSB reduces cooling demand, and 65 % believed solar integration offsets long-term electricity costs.

Table 3. Energy Efficiency and Affordability of ISSB–Solar Housing

Indicator	Mean	SD	Agreement (%)
ISSB housing reduces electricity for cooling	4.05	0.81	74.3
ISSB is more affordable than sandcrete housing	4.09	0.77	69.0
Solar systems increase initial cost but lower long-term bills	3.98	0.83	65.1
Maintenance of ISSB–solar systems is manageable	3.86	0.88	63.2

The Pearson correlation test showed a moderate positive relationship between affordability perception and willingness to adopt ($r = 0.52$, $p < .01$), and between thermal comfort and energy efficiency ($r = 0.47$, $p < .01$). These relationships echo [5], who found cost-benefit perception critical in sustainable material adoption. The high mean values reaffirm that respondents recognize both the economic and environmental advantages of ISSB–solar housing [2,12].

4.4 Discussion of Key Results

Table 4 provides a synthesis of key relationships observed in the study, linking major perception variables with willingness to adopt solar-powered ISSB housing.

Table 4. Summary of Relationships among Major Study Variables

Variable Pair	Statistical Test	Result	Significance
Profession × Perceived Compatibility	Chi-Square	$\chi^2 = 18.62$	$p < .05$
Affordability × Willingness to Adopt	Pearson r	0.52	$p < .01$
Thermal Comfort × Energy Efficiency	Pearson r	0.47	$p < .01$
Region × Adoption Intention	ANOVA	$F = 4.11$	$p < .05$

The data indicate that technical awareness, cost perception, and comfort expectations significantly affect the adoption of ISSB–solar systems. Respondents from professional backgrounds (architects, engineers) showed the strongest acceptance, suggesting that technical confidence promotes innovation diffusion [10]. The affordability–adoption link underscores the need for cost-reduction incentives and financing schemes, consistent with [4].

Although most respondents perceived ISSB–solar homes positively, roughly one-fifth raised concerns about maintenance and durability echoing [2,8], who noted that maintenance literacy and spare-part supply remain constraints. These results reaffirm [11], who stressed that local acceptance of sustainable materials depends not only on cost but also on education, reliability, and institutional support.

5.0 Conclusion And Recommendations

5.1 Summary of Findings

This study investigated the potential of integrating solar energy systems into Interlocking Stabilised Soil Block (ISSB) housing to provide affordable, energy-efficient, and sustainable housing solutions for off-grid Nigerian communities. Data collected from 424 respondents (architects, engineers, builders, and residents) revealed several key findings.

First, awareness of both ISSB technology and solar systems was high among respondents, particularly among professionals in architecture and engineering. Most participants (over 70%) agreed that ISSB structures can technically support photovoltaic (PV) installations and enhance indoor thermal comfort through their natural thermal mass.

Second, respondents expressed positive perceptions of ISSB–solar compatibility, with a mean score of 4.12, confirming confidence in integrating renewable energy technologies with earth-based construction. Statistical analyses (Chi-square and correlation tests) showed significant relationships between profession, perceived compatibility, affordability, and willingness to adopt solar-integrated ISSB housing.

Third, perceptions of energy efficiency and affordability were strong. Over 65% of respondents recognized that while solar systems may increase initial costs, they substantially reduce long-term energy expenses. The positive correlation between affordability and adoption ($r = 0.52$) reinforces that economic feasibility remains a major factor influencing renewable housing acceptance.

Finally, although overall perception was favorable, some respondents (about 21%) expressed concerns about maintenance and long-term reliability of PV systems. This finding supports earlier conclusions by [2,8] that maintenance capacity and user training are critical to sustaining renewable technologies in developing contexts.

5.2 Conclusion

The integration of solar power systems into ISSB-based housing presents a viable pathway for sustainable, low-cost housing development in Nigeria's off-grid and peri-urban areas. The combination offers significant advantages affordability, energy independence, and thermal comfort that align with the principles of green and climate-resilient design.

The results of this study confirm that awareness and technical acceptance of ISSB–solar housing are growing among key stakeholders. However, scaling up adoption will depend on targeted interventions, including financial incentives, technical training, and demonstration projects that prove both economic and performance reliability.

In conclusion, solar-powered ISSB housing represents a synergistic approach to bridging Nigeria's housing and energy deficits, offering both environmental sustainability and socioeconomic resilience. The model can serve as a blueprint for community-based, off-grid housing prototypes adaptable to similar tropical developing contexts.

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5.3 Recommendations

i Policy and Incentives: Government and housing agencies should introduce policy frameworks and subsidies supporting local production of ISSB materials and small-scale solar system installations. Tax incentives and low-interest green loans would improve affordability and uptake.

ii Capacity Building: Technical institutions and professional bodies (e.g., NIA, COREN, NIOB) should incorporate ISSB and solar integration training into curricula and continuous professional development programs to improve local implementation skills.

iii Pilot Demonstration Projects: State housing corporations and NGOs should fund pilot projects showcasing functional ISSB–solar housing units in off-grid communities. Demonstrating real-world performance will enhance user confidence and attract private investment.

iv Community Engagement and Awareness: Grassroots sensitization and education campaigns are vital for dispelling misconceptions about earthen materials and renewable technologies. Local adoption is more sustainable when communities participate in the construction and management process.

v Research and Development: Further studies should employ life-cycle cost and energy simulations to quantify savings from ISSB–solar integration and refine passive design strategies (orientation, shading, ventilation) for tropical climates.

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