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Research Article

Mitigating Climate Change Impacts in Buildings using Passive Design Strategies: Putting Costs to Contexts

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Abstract: Across the global construction industry, climate change mitigation is achieved using design and construction practices that optimise energy efficiency. The scope of these practices varies with regional contexts. In Nigeria and other regions, their adoption is slow due to the absence of cost benchmarks to drive their implementation decisions. In this study, we appraised the first cost premium (FCP) and the payback periods of selected passive designs strategies (PDS) in retrofitted residential buildings. Using cost data from two categories of 150 retrofitted residential building designs, analytical estimating processes showed that integrating five PDS would attract FCP totaling ₦ 3,612.17/m^2 and ₦ 9,250.00/m^2 for bungalow and maisonette buildings. Procuring these FCPs also has varying levels of reduction in energy consumption that are necessary to mitigate the impacts of climate change. The financial benefits in energy savings from two PDS (roof insulation and overhang) could only pay-off the FCP for bungalows with cost-savings of 81%, while reducing the FCP for maisonettes by 70% in one year. The discounted FCP after one year becomes zero for the bungalow and ₦ 2,650.00/m^2 for the maisonette. The short-term payback periods provide a significant incentive for developers to adopt energy-efficient designs in building development.

***Keywords*:** adoption, cost premium, energy efficiency, hot and humid climate, sustainable buildings

1. Introduction

One of the pertinent contributions of buildings to climate change is the increase in embodied and operational carbon [1]. The projected growth in building electricity expenditures [2] suggests that climate-responsive designs and buildings are desirable. Climate change mitigation essentially focuses on energy efficiency, and the resultant expenditures are also contingent on the savings in buildings' energy consumption [2]. The scope of energy saving represents the effectiveness of climate change mitigation response [3]. The term "climate change mitigation" refers to the practices that abate greenhouse gas emissions and enhance the sequestration of terrestrial carbon [4]. This paper reports on the research which determined the first cost premium (FCP) of passive designs strategies (PDS) for the Nigerian hot and humid contexts. Sustainable buildings (SB) encourage the efficient use of resources such as energy, water and materials [5]. However, the practices enabling SB are subject to regional standards, patterned on the bioclimatic conditions of a place. Based on inherent variation in regional climates, sustainable building design (SBD) therefore encompasses passive and

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active energy-efficient design strategies.

In Nigeria, two design guidelines are evolving to direct energy-efficient building development, namely: Building Energy Efficiency Guidelines [6] and Building Energy Efficiency Code of Nigeria (BEECN) [7]. These guidelines set out criteria for achieving energy efficiency during the design and use phase of buildings. Limited research, however, championed their financial implications and FCP. Due to the dearth of knowledge about the financial implications of SBD practices, their adoption is low [8]. Therefore, the stakeholders in developing countries are laggard in implementing SBD due to the absence of cost benchmarks to navigate project decisions at the design stages [9,10]. The dearth of the relevant cost benchmarks in SB triggers low adoption and cost uncertainties [11,12]. Research in SB in Nigeria examined conceptual, institutional, and regulatory issues. This paper advances the cost of SBD using a quantitative approach developed using analytical estimating.

The paper connects SB to the realization that building energy efficiency can reduce greenhouse gas emissions associated with climate change [13]. The focus of the paper lies in passive energy-efficient designs capable of reducing the operational carbon footprint of buildings [14]. This paper is based on the financial assessment approach that integrates annual energy-savings outputs with construction cost inputs. The research evaluated the construction costs and financial benefits of passive energy-efficient designs in Nigeria. The objectives were to establish the potential FCP and financial benefits of implementing passive energy-efficient design requirements in residential project development. Since construction stakeholders often prioritise budgeting for SBs on established rational economic criteria [15], this study will improve the adoption of SBs [16]. In addition, the research outputs would promote SB awareness [17] as well as improving SB implementation decision-making processes [12].

2. Theoretical development

2.1 *Climate change and building energy efficiency*

The term "climate change" refers to changes in the earth's climatic conditions caused by variations in atmospheric conditions caused by human activities [4]. Buildings are responsible for the consumption of numerous of the earth's resources: energy, water, materials, agricultural lands, timber, coral leaves, and rainforest destruction [18]. The uptake of these resources in the development and operation of buildings contributes to climate change, ozone depletion, pollution, and landfill waste, among other environmental degradations. The impacts of resource depletion stretch into generations, thereby distorting the flow between the sustainability of today's environment and the future [18]. Buildings, therefore, affect the natural environment through energy use, global warming, climate change, resource depletion, waste generation, and pollution [18,19].

In Nigeria, evidence abounds to show that the climatic conditions are changing, e.g., rise in temperature, variation in mean sea level, frequent harsh weather conditions and flooding [20]. These impacts have produced commonly spread implications across the country, even though the states in the northern hemisphere are more vulnerable than those in the south [4]. The implications for energy generation and its availability, however, continue to be the most acute effect of climate change on buildings [20]. Enabling climate change strategies therefore advocate passive and active energy-efficient design strategies to optimise energy consumption in buildings [21]. However, their costs remain an unsettled concern [4,21]. Designing new buildings and retrofitting existing buildings to be energy-efficient is the way to reduce climate change. The financial analysis of climate change adaptations also relies on energy cost savings in buildings [2]. As a result, Nigeria's construction industry should focus on building more efficient housing infrastructure as a way to fight climate change [4].

2.2 *Passive design strategies for climate change mitigation in building development*

The term "PDS" is used to depict ways of achieving internal comfort in a building using non-active practices. However, the use of the natural movement of heat, air, balanced solar gain and cooling are prevalent considerations in passive design practices [22]. Strategies associated with PDS include building orientation, thermal massing, efficient lighting, daylighting, and transparency ratio optimisation [6,22,23]. Building orientation represents the most strategic approach to achieving passive cooling and is responsible for 80% of the energy efficiency achievable through PDS [8].

This is achieved by orienting solar glazing to the north-south for optimal heating, shading, and daylighting. Thermal mass refers to the heat absorption and emission rate of a material [24]. Thermally efficient materials regulate space temperature by absorbing and emitting heat when the ambient temperature drops [6]. Lighting is clearly one of the building's major energy-consumption elements. [8]. However, both artificial lighting and daylighting system solutions are often considered in PDS. The use of low-energy lights and re-lamping by reducing lighting intensity during design are examples of contemporary PDS for artificial lighting. "Controlled entry of natural light into space through windows, clerestories, or skylights" [24] is what daylighting implies. The use of daylighting effectively in PDS has been associated to a 25% reduction in the use of artificial lighting during the day [24]. Although a variety of factors influence the efficiency of daylighting, the visual transmittance index dominates the critical literature. The window-to-wall ratio (WWR) is a measurement of a building's natural ventilation and daylighting. The amount of heat gained by the building is reduced through shading. It is considered one of the most effective PDS for tropical climates [25]. Internal shading devices, such as fin walls, vertical or horizontal shading overhang devices, and extended roof overhangs, are integrated into the building structure, whilst external shading devices include eaves, awnings, screens and shutters, louvres, verandahs, pergolas, trees, and shrubs [25]. Based on the foregoing, the literature on PDS is extensive. The specifications for each strategy also vary with the bioclimatic condition in which it is applied. Table 1 shows the energy savings associated with incorporating selected PDS in the study area. Gyoh et al. [26] demonstrated that a variety of PDS yield varied energy savings through design simulation experiments utilizing bioclimatic data in Nigeria's hot and humid environment.

Table 1. The classification of green facades [6]

	Strategies/cost variables	Savings	Energy saved (kWh/m^{2}a)
1	Conventional concrete building	-	
2	Centralized air handling system	+ 6%	205
3	Secondary ventilated roof	+ 8%	195
4	Large overhangs to shade walls	+ 5%	35
5	Roof insulation	+ 6%	75
6	Wall insulation	+ 6%	20
7	Floor insulation	+ 4%	5
8	Airtightness	+ 2%	100
9	Double glazing	+ 4%	15
10	Light colour walls	+ 0%	15
11	Landscaping to create shade	+ 5%	15

2.3 *Putting contexts to costs*

The most prevalent approach to evaluating the costs of SB is to compare the costs of SBD with the costs of similar conventional designs [27]. The second strategy to price the financial implications of SB adopted analytical estimating. This strategy was used to price the costs of SBD schemes by putting costs on local green design policies [28,29]. A plethora of cost benchmarks in the SBs are also developed from historical cost data of completed projects [30]. Due to the limitations posed by low adoption of SBD in developing countries and the resultant dearth of cost data from completed projects [31], this study progressed using analytical estimating. Analytical estimating refers to the breakdown and pricing of the aggregated activities of the project systems using current market values [32]. The process also compares the outputs with the cost of conventional designs to establish the cost differential resulting from energy-efficient retrofits. The use of this approach is global [27,28] and also represents the most sophisticated approach based on a theoretical standpoint, robust processes and data requirements [33]. The use of historical data is criticised for the inability to enhance the lifecycle socio-economic analysis associated with the SB [1]. This theoretical gap further supports the advocacy on the use of analytical estimating. Socio-economic analysis is important to the emerging markets in producing evidence of how insignificant extra investment can produce future benefits in the short-medium term [8]. Analytical estimating, on the other hand, is based on current market values and a combination of different data needs that are flexible to enhance lifecycle costing [34].

3. Material and methods

3.1 *Research design and population*

The study was descriptive research aimed at attributing the financial implications of varying energy-efficient design practices in buildings. The research design combined secondary data synthesis with archival studies. The building's 150 samples consist of two categories of residential buildings (bungalow and maisonette). A bungalow traditionally refers to buildings on a single floor, having living rooms and bedrooms, a kitchen, toilets, and other functional spaces. A maisonette, on the other hand, refers to a single-household dwelling on two floors with only a guest room on the ground floor. The study optimised different building sizes in order to characterise different energy consumption levels. The sizes of the bungalow buildings varied from 45 to 350 m^2, while the sizes of maisonettes ranged from 163 to 802 m^2. The interest in studying residential property is directed towards solving the housing problems faced by households in Nigeria.

3.2 *Data collection and sampling*

Two categories of data were collected in the study, namely: secondary and primary. The secondary data comprised published data on the performance of sustainable retrofits in the research environment [6,26]. The study also collected primary data through auditing and analytical estimating processes of conventional building designs (CBD) obtained from architectural firms in the South-South Region of Nigeria. The primary data collection was set out with the screening of 450 approved CBD (bungalow and maisonette) for energy efficiency using three parameters: orientation, building form factor, and compactness ratio. The screening produced 150 designs that met the sampling requirements. 30 research clusters comprising five groups in the six states of the South-South Region of Nigeria were set up; each group comprised an electrical engineer, a quantity surveyor, and an architect. The responsibilities of the research clusters included retrofitting selected designs using the requirements of the BEECN, performing cost estimating, and producing relevant data needed in the study. The data collection for the study, therefore, involved the six stages shown in Figure 1.

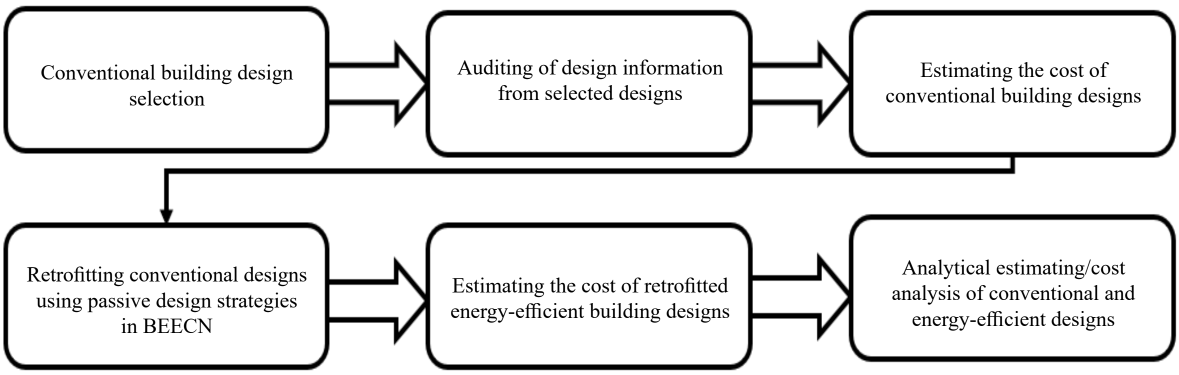

Figure 1. Data collection flow chart

3.3 *Data analysis*

The study engaged in descriptive and inferential data analysis using percentages, mean, analytical estimating, and a one-sample *t*-test. In the inferential statistics category, the study adopted paired sample *t*-test to evaluate the hypothesis, which examined whether the cost premium for bungalow and maisonette buildings is related or different. The test was directed at developing a logical underpinning for aggregating the FCP in both categories for cost management purposes. The validity of the *t*-test involved the *p*-value (± 0.05).

In the descriptive analysis, mean, percentages, and analytical estimating were applied. The data was initially normalised to a common unit, that is, cost per square area, since each conventional and retrofitted energy-efficient building design is similar in terms of its sizes. The study thereafter performed a trade-off between the costs of both designs to obtain the cost premium for achieving improved energy efficiency in building designs. The study further priced the energy savings of SBD (secondary data) using current electricity tariffs obtained from Port Harcourt Electricity Distribution in Nigeria to obtain their financial benefits. The trade-off between the average cost premium and their financial benefits per annum produced the payback duration for investment in SBD. Equation 1 shows the payback duration (*PD*), while Equation 2 shows the derivative of the percentage cost premium (*PCP*). In Equation 1, *CP* represents the cost premium, while *C* is the financial equivalent of energy savings achieved. Similarly, in Equation 2, *CCBD* represents the cost of conventional building designs.

$$PD = \frac{CP}{C} \tag{1}$$

$$PCP = \frac{CP}{CCBD} \times 100\% \tag{2}$$

3.4 *Research variables*

Table 2 shows the design interventions for achieving energy efficiency in buildings in Nigeria. The requirements in Table 2 largely follow the recommendations in BEECN. The basis flows from the understanding that the most important strategy for mitigating climate change in the construction sector is to optimise energy consumption [21]. This research synergised this knowledge and past studies to extract only the PDS imperative to energy efficiency. Two scoping studies [6,7] provide in-depth discussions of the scientific experiments underpinning the development of BEECN. The scope of this study is limited to the five PDS listed in Table 2.

Table 2. Measurement of PDS in the study

	Variable	Passive sustainable design strategies	Unit	Costing unit
1	WWR	20% of external walls	Percentage	Naira/m^2
2	Shading (Extended Roof Overhang)	1.2 m projected distance from the wall	Metre	Naira/m^2
3	Lighting	Lighting at 6 W/m^2 low energy lamps	W/m^2	Naira/m^2
4	Thermal massing	Aluminum long-span roof covering, 0.55 mm thick, 50 mm mineral wool	*U*-value	Naira/m^2
5	Daylighting	Solar e-Clear glazing with 60% visual transmittance index (VTI)	VTI	Naira/m^2
6	Energy-savings	Financial savings in energy consumption using passive design retrofits only - $ 2.84 or ₦ 1,364/m^2	kWH	Naira/m^2

4. Results

The results of the study are presented in two sections, namely: the cost of PDS, tests of hypothesis, and energy savings from energy-efficient designs.

4.1 *The costs of passive energy-efficient designs*

The results in Table 3 show that seeking to improve the building's energy performance in this region would add to the construction cost. This implies that implementation of the design interventions in Table 2 would attract an incremental cost. However, the *CP* results from only four design interventions, namely: extended roof overhang, energy-efficient daylighting, WWR, and insulated roof covering. The fifth design intervention, on the other hand, has no added cost effect but cost-savings. In specific terms, efficient lighting (at 6 W/m^2) would result in a reduction in construction costs. The five PDS were grouped to reflect the elements of the building in which each occurs. Roof-related interventions, that is, extended roof overhang and insulated roof covering, made the most significant contributions to the total additional cost of energy-efficient designs. Table 3 shows the average cost premium for three elements (window, roof, and lighting). The *CP* for roof-related interventions is ₦ 5,400.00/m^2 and ₦ 5,040.00/m^2 for bungalow and maisonette buildings, respectively. The amounts are equivalent to 6.00% and 5.09% extra expenditure on the cost of similar conventional buildings. Window-related interventions (low-energy solar e-glass - Pilkington with safety shield clear glass and a WWR of 20%) have the second most significant *CP*. The *CP* for window-related interventions is ₦ 3,985.00/m^2 and ₦ 4,670.81/m^2. This is equivalent to 4.43% and 5.09% extra expenditure on the cost of alternate designs. On the other hand, lighting intervention has no extra cost but produces significant cost-savings; the net extra cost is - ₦ 262.50/m^2 and - ₦ 341.00/m^2 respectively for both categories of buildings. The implication indicates that efficient lighting (6 W/m^2) reduces the total cost of construction. Table 3 also shows the minimum and maximum extra costs of improving each intervention. These benchmarks are objective to guide decision-makers about the upper and lower cost thresholds for budgeting decisions. The variance suggests the average cost benchmarks are not fixed but vary with the uncharacterised properties of the building.

Table 3. Cost premium in SBD using PDS

Element	Building type	Net additional cost	Net percentage addition	Maximum additional costs	Maximum additional costs (%)	Minimum additional costs	Minimum percentage addition (%)
Window	Bungalow	₦ 3,985.39/m^2	4.43%/m^2	₦ 5,670.94/m^2	6.30%/m^2	₦ 1,035.05/m^2	1.15%/m^2
	Maisonette	₦ 4,670.81/m^2	5.09%/m^2	₦ 9,337.14/m^2	10.37%/m^2	₦ 1,646.35/m^2	1.83%/m^2
Roofing	Bungalow	₦ 5,400/m^2	6.0%/m^2	₦ 5,750.00/m^2	7.50%/m^2	₦ 4,050.00/m^2	4.50%/m^2
	Maisonette	₦ 5,040.00/m^2	5.09%/m^2	₦ 6,300.00/m^2	7.00%/m^2	₦ 3,780.00/m^2	4.20%/m^2
Lighting	Bungalow	- ₦ 262.5/m^2	0.47%/m^2	- ₦ 420.00/m^2	0.47%/m^2	- ₦ 105.00/m^2	0.12%/m^2
	Maisonette	- ₦ 341.00/m^2	0.38%/m^2	₦ 525.00/m^2	157.00/m^2	₦ 0.58%/m^2	0.18%/m^2

$ 1 = ₦ 410.352

The combined *CP* for the five PDS in Table 3 is presented in Figure 2. The total mean *CP* for bungalows is ₦ 3,612.17/m^2 with upper and lower limits of ₦ 8,262.14/m^2 and ₦ 571.35/m^2. For the maisonette building category, the mean *CP* is ₦ 9,250.00, while the upper and lower limits are ₦ 11,841.32 and ₦ 6,275.32, respectively. In terms of percentage addition, the mean *CP* is 3.90% and 10.56% for bungalow and maisonette buildings, respectively.

The difference between the upper and lower limits of the *CPs* and between the mean *CP* for bungalow and maisonette is numerically significant (Figure 2). This premise was further examined to ascertain the statistical significance of the perceived variations with a view to guide appropriate cost management decisions. The analysis is imperative as the discrepancies may pose prejudice to the future estimation of *CP* relying on these benchmarks. A paired sample t-test was conducted to determine whether the aggregated average *CP* of both categories of buildings differed significantly. The paired sample t-test, otherwise referred to as the dependent sample test, was valid based on the critical p-values.

The result in Table 4 shows a negative correlation coefficient r (150), - 0.023, $p > 0.05$ (0.868). The null hypothesis, H_0, was accepted. The correlation is weak, insignificant, unrelated and cannot be aggregated for cost management purposes. As a result, it is not possible to have a unified *CP* benchmark for bungalow and maisonette buildings. Moreover, since r is the degree of association, - 0.023 indicates an inverse order relationship and an increase in the *CP* of the bungalow is expected to cause a decrease in the *CP* of the maisonette. Similarly, the t-statistic also indicates a negative value, and since the p-value is less than 0.05, t (55) = - 9.336, $p < 0.000$, the null hypothesis is rejected. The inference agrees with the result of the correlation, buttressing that both samples are different.

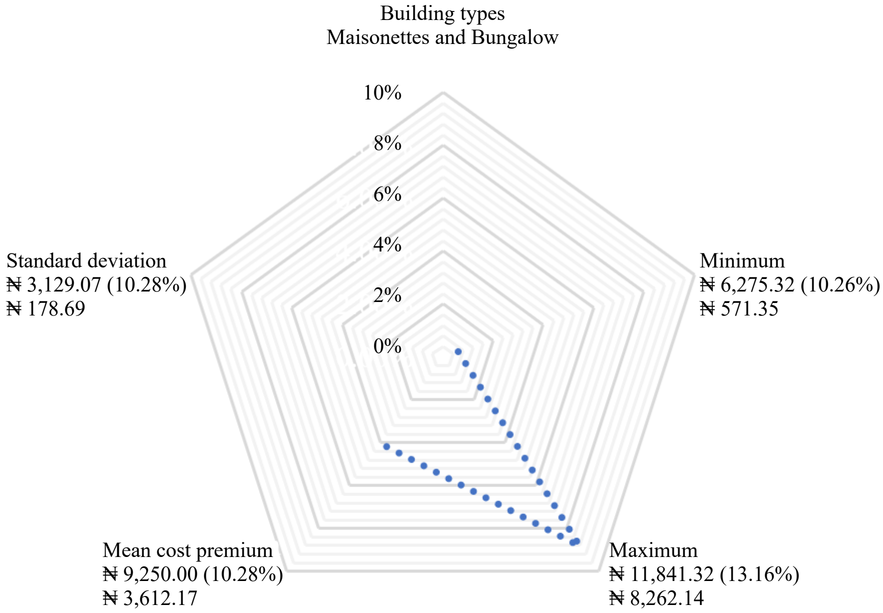

Figure 2. Combined cost premium for bungalows and maisonettes

Table 4. Paired samples *t*-tests of aggregated costs premium of bungalow and maisonettes

Category	*N*	Correlation	Sig.	Decision
Pair 1 C1 and C2	56	- 0.023	0.868	Accept H_0
Pair 1 C1 and C2	*t*-test	*Df*	Sig. (2-tailed)	
	- 9.336	55	0.000	Reject H_0

C1 refers to maisonette buildings; C2 refers to bungalow buildings

4.2 *The financial benefits of PDS*

Nydahl et al. [2] stated that energy efficiency represents climate change mitigation across sectors. Accounting for the cost of climate change mitigation depends on the savings in energy consumption. The benefits of passive designs reported in this study are established energy-savings from secondary data. Energy-savings from each intervention in the literature [26] are used to calculate the financial benefits in this section, which are based on the current electricity rate of ₦ 60.00/kWh. Table 5 shows the total financial benefits accruable to roof-related PDS is only ₦ 6,600.00/m^2 per annum. When the financial benefits are discounted from the *CP* in Table 3 (₦ 9,250.00/m^2 and ₦ 3,612.17/m^2), the net *CP* in the research environment becomes - ₦ 2,987.83/m^2 and ₦ 2,6500.00/m^2 at the end of the first year. The payback duration and financial savings could be greater when the energy-savings accruing from other interventions are incorporated into the trade-off calculation. The total *CP* could be paid off in less than a year and two years, respectively, for the bungalow and maisonette. Therefore, the payback duration of an energy-efficient bungalow is less than a year and two years for a maisonette SBD.

Table 5. Financial benefits of selected PDS

	Strategies/cost variables	Savings	Energy saved (kWh/m²a)	Cost/m² (₦)
1	Large overhangs to shade walls	+ 5%	35	2,100.00/m²a
2	Roof insulation	+ 6%	75	4,500.00/m²a
3	Inclusive PV			
	Total			6,600.00/m²a

Adapted from Table 1

5. Discussions

Based on the increasing difficulty of implementing full-scale SB in developing countries due to the dearth of relevant standards, PDS are often adopted to define the scope of SB by optimising building energy consumption. The delimitation follows the empirical evidence in which various researchers in Nigeria interpreted SB using energy-efficient strategies [35,36]. The enabling guidelines for SB in Nigeria (BEECN) also support energy efficiency; the *CP* reported in this study therefore develops from the financial implications of energy-efficient SB praxis. The results of the study showed that energy-efficient SB requires extra funding averaging ₦ 3,612.17/m^2 and ₦ 9,250.00/m^2 respectively for bungalow and maisonette buildings. The discounted *CP* from the financial pricing of potential energy savings due to roof-related PDS intervention was - ₦ 2,987.83/m^2 and ₦ 2,6500.00/m^2, one year into the use phase of the buildings. This implies that the *CP* of the bungalow has a payback duration of less than one year and less than two years for maisonette buildings.

The standard deviation of the individual *CP* estimated from their means is significant, thereby making the *CP* unduly disconnected from the mean. As a result, the dispersion of the mean *CP* from the total sample in each category is diverse. Moreover, the average *CP* for the two buildings, in addition to the significant deviation within each sample, also shows a significant dispersion (Table 3). This result poses a significant reliability bias to the *CP*'s characterisation using a common benchmark. A vista of research windows is conceptualised for the need to explore the appropriate yardstick for attributing the cost of SB in practice and research. This study, therefore, posits that the cost of SB is contingent on other critical parameters different from the size of the building adopted in this study as well as in other global studies. Alternative normalisation of *CP* could offer newer dimensions for explaining the unchartered territories in *CP* characterisation since cost/m^2 is laden with significant variance.

The results of the study validate three converging views from the literature on the cost of SB. The first viewpoint posits that energy-efficient SB has varying *CP*, which varies according to regional standards [23]. This study affirmed this position through the varying *CP*s reported for the different PDS interventions. The second view affirms that the cost of SB could be similar to the cost of conventional buildings. The short-term payback periods of less than one to two years in this study back up this assumption. The third view asserts that SB may be less expensive than conventional buildings; this study shows that the *CP*s are extinguished in less than one to two years. Therefore, against the popular perception that has increasingly linked SBs with only long-term financial benefits [37], this research provides new evidence to buttress that those benefits could be short-term. The implications suggest that SB (using PDS) would be financially freestanding in less than one to two years. Two years into the use-life of the project, energy-efficient SBs are more economical than conventional buildings. The study also shows that certain SB features are available at little or no extra cost. Examples include efficient lighting. The cost of efficient lighting in this study has a negative cost effect; overall, this strategy reduces construction costs by ₦ 302.00/m^2. Sun et al. [22] showed that efficient lighting represents a more cost-effective PDS, while Onyenokporo and Ochedi [38] asserted that low-cost PDS are effective in achieving energy efficiency in buildings in Nigeria.

From these results, the adopters of SB are likely to implement PDS with low or zero extra cost due to the accruing *CP*, e.g., efficient lighting. The adopter's inclination for low-cost PDS is consistent with Morris et al. [39] findings' in the United States. Morris et al. [39] showed that green adopters in the United States implemented low-cost design strategies. From this position, stakeholders are not likely to implement roof shading due to its higher *CP*. The effect of *CP* in this context agrees with the theoretical implication of rational decision consumption theory. Rational economic decision theory links consumption decisions to certain factors in which cost is overarching. The implication is that, with the established *CP* information, adopters of SB would imperatively not respond to cost-laden PDS. But in order to upscale the adoption of SB among stakeholders, it is important to decouple cost-laden decision-making to allow the tangible and non-tangible benefits of related practises to interplay at the adoption decision interface. Stakeholders must likewise engage consciously in research and practises that can reduce the *CP* as a departure point for driving education for sustainable development in the construction industry. Future and existing professionals, as well as clients and the general public, must be exposed to the understanding that SB is achievable at a low-cost or a zero-cost investment through modification of existing conventional building practices. This is very significant for promoting the implementation of energy-efficient passive design practises in order to mitigate the impacts of climate change. It is also important to stress that the benefits and payback period of SB could be short-term compared to the long-term orientation popularly propagated in the literature.

Amidst its grandstanding outputs, the study is limited by the prospective structure of its data as well as excessive reliance on hard costs alone. To improve this limitation, future studies may seek out post-project data as well as data incorporating soft costs in order to model a robust scientific path to resolve the regional cost issues inhibiting the implementation of SB. Again, even though the FCP did not strictly address lifecycle cost concerns, issues of inflation would not influence the performance of the established cost benchmarks. As shown in a previous study [39], cost inflation of over 25% did not dissuade adopters, even though other contexts could have accounted for this resilient consumption behaviour. Moreover, the study arrived at this benchmark through a trade-off between SB and conventional building costs, with inflation expected to have a uniform impact on both construction approaches.

6. Conclusion

SBD complying with passive energy-efficient design requirements are operative to mitigate climate change. The mitigation of climate change through SBD practise in the construction industry also draws extra expenditure above the cost of the conventional construction approach. Even though SBD is in operation to minimise energy consumption at a cost premium, it also provides financial benefits by reducing energy use. This study affirmed that the scope of the added expenditures attributed to SBD varies along with regional contexts, bioclimatic design specifications, and policy. In Nigeria, the adoption of five PDS (efficient shading, WWR, daylighting, lighting, and thermal massing) to improve the energy performance of conventional building designs requires extra expenditures. The estimated cost premium associated with these PDS varies with the type of building. For residential buildings, the established cost premium for bungalows is ₦ 3,612.17/m^2 and ₦ 9,250.00/m^2 for maisonette buildings. The annual financial benefit in energy savings attributed to roof insulation and extended overhang (shading) alone is ₦ 6,600/m^2 per annum. The discounted cost premium after one year into the operational life of the buildings shows over 82% cost savings for the bungalow and a 71% reduction in the cost premium for the maisonette. Bungalow and maisonette residential buildings adopting PDS have less than one to two years' payback periods, respectively. The short-term payback periods established provide ample incentive for the viable promotion of investments in SBDs as a significant departure from the traditional long-term orientation known across the globe. The cost benchmarks are likewise adequate to drive SBD implementation in developing markets with similar bioclimatic conditions towards climate change impact mitigation. The research provides insight on the expenses of SBD and establishes cost benchmarks for advising the decision to implement passive energy-efficient building design during the planning stages of project development.

Conflict of interest

The authors declare no conflict of interest.

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