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# Integrated Performance Evaluation of Green and Conventional Buildings

**Sahil Kumar[1], Dhrruv Bhardwaj[2], Taniya Talaan[3], Shashank Poddar[4], Rushmita Nath[5], Kavita Verma[6]**
[1,2,3,4] students, Department Of Civil Engineering, B.Tech [5]Assistant Professor, [6]Associate Professor
Dr. Akhilesh Das Gupta Institute Of Professional Studies, New Delhi-110053

**Abstract – On a unit-free performance index, a GRIHA 3-star green building in Noida scores 72.62%, compared with 24.27% for a conventional residential building in East Delhi. This study compares the high-rise green project (G+14, 12,495 m²) and the low-rise conventional house (G+3, 784 m²) across energy, water, construction materials, and cost. Because a 15-storey tower and a 4-storey house cannot be judged fairly using raw totals, every figure is scaled to a per-floor and per-m² basis first. Per square metre, the Noida building cuts electricity by 79.31% and water by 89.60%, while also using fewer blocks, less timber formwork, curing water, diesel, grid power, and generating less construction waste. However, it demands more cement (+141.4%) and steel (+145.1%) per m² simply because a 15-storey frame needs heavier structural support. To weigh these mixed-unit trade-offs together, we propose the Green Building Performance Index (GBPI), a 0–1 score built via min–max normalisation across energy, water, cement, and construction waste (weighted 0.35, 0.25, 0.20, and 0.20). These weights and benchmarks are provisional, and the paper documents the dataset's limitations openly.**

**Keywords – green building, conventional building, normalisation, bill of quantities (BOQ), energy use, water use, GBPI, GRIHA, AAC blocks**

## I. INTRODUCTION

Constructing and operating buildings consumes massive quantities of materials, energy, and water [2], [3], [6]. While conventional projects follow standard local practices, green buildings try to bring those demands down through better planning, design, and material selection. Even so, green building benefits are often reported as raw project totals—such as overall kilowatt-hours saved—which can be misleading. Totals hide the effect of building size, making a tall structure look either wasteful or efficient just because of its floor count.

To avoid that distortion, this paper puts two very different buildings on a common footing. One is a high-rise, GRIHA 3-star green building (G+14) in Sector 22, Noida; the other is a standard-quality, low-rise residential building (G+3) in East Delhi. Since their heights and floor plates are nowhere near equal, we convert every resource figure to per-floor and per-m² values before comparing them.

### 1. Green Construction Materials

Green projects typically draw from a familiar set of low-impact materials, including fly ash bricks, autoclaved aerated concrete (AAC) blocks, bamboo, recycled or green steel, engineered wood and cross-laminated timber (CLT), cellulose insulation, stone or slate roofing, solar tiles, rammed earth or adobe, straw bale, and recycled plastics. Using prefabricated or modular components can also cut site waste and emissions noticeably [4], [5]. In our Noida case study, the main masonry shift replaces traditional red clay bricks in sand-cement mortar with lightweight AAC blocks fixed using thin polymer adhesive.

### 2. Need For The Study

This project grew out of four practical gaps in how building performance is usually discussed. Reporting savings as whole-building totals hides the role of building size and floor count. At the same time, project teams need to see whether resource reductions actually translate into cost savings through a Bill of Quantities (BOQ). On top of that, energy (kWh), water (kL), materials (tonnes), and cost (₹) all have different units, so comparing them side by side requires a unit-free scale. Having clear, data-backed numbers makes it much easier to weigh green against conventional options during planning.

### 3. Contribution And Structure

Our work adds three things: a normalised check on energy and water use, a per-m² comparison of BOQ materials, and a composite index (GBPI) that brings those mixed units into one score. Below, Section II covers related literature, Section III lays out the objectives and method, Section IV introduces the two case-study buildings, Sections V and VI present the results and GBPI scores, Section VII examines limitations, and Section VIII wraps up the findings.

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## II. LITERATURE REVIEW

For this project, we reviewed eight recent studies on building performance and optimisation alongside broader background literature. Grouping them into four themes (Table I) shows that while each explores simulation, retrofits, or multi-criteria ranking, none compares a green and a conventional building on a normalised, unit-free basis—the specific gap addressed here.

### 1. Energy Modelling And Optimisation

Sánchez-Zabala and Gómez-Acebo [8] developed building-energy metamodels for district energy-management platforms by pairing physics-based models with machine learning (including ensemble boosting). Using a genetic-algorithm optimiser, they matched the settings of a physics-based EnergyPlus-GENOPT predictive-control setup and cut computational cost while achieving 5–10% potential cost savings. In another study, Song [14] combined single- and double-layer hybrid optimisation across envelope, window, and heating parameters, reaching roughly 97% parameter-extraction accuracy. Both papers demonstrate strong numerical optimisation, though they rely on simulated parameters rather than measured, as-built resource data.

### 2. Retrofit And Operational Strategies

Looking at operational upgrades, Pinto and Amante [11] applied multiobjective optimisation to the TR5 building at UPC, finding that PV panels, cogeneration modules, and second-life Li-ion batteries were cost-effective, with solar PV supplying about 23% of electricity demand. Senthilkumar and Ayyathurai [12] paired Six Sigma with the NSGA-II genetic algorithm in DesignBuilder and EnergyPlus to tune air-conditioning setpoints for an Indian retail store, showing that zero-cost setpoint adjustments can manage energy well. Meanwhile, Luo and Oyedele [13] studied life-cycle retrofitting under climate change on two Bristol campus buildings and found that picking retrofits based only on current weather could over-estimate lifetime cost, energy, and carbon by up to 4.7%—or under-estimate them by as much as 54.7%—in future climates.

### 3. Decision-Making And Risk

Odoi-Yorke, Owusu, and Atepor [10] evaluated ten hybrid renewable energy systems for port operations in Ghana across technical, economic, environmental, socio-cultural, and policy criteria using fifteen decision-making algorithms, checking rank agreement via Spearman rank correlation. To bridge the gap between deterministic models and actual metered use, Ekström et al. [15] introduced stochastic parameters to estimate the probability that a design meets its energy targets, framing probabilistic risk analysis as practical decision support. Together, these studies shaped the weighted, multi-criteria structure we chose for the GBPI.

### 4. Sustainability Beyond Energy

Zhu and Feng [9] examined an individual house in Canada under BCESC energy updates to ask whether an energy-efficient home is automatically sustainable. Their conclusion—that energy efficiency by itself does not tell the whole sustainability story—is why our study also tracks water, construction materials, and site waste.

Table I: Summary of Reviewed Studies

| Theme | Studies | Relevance |
|---|---|---|
| Energy modelling | Sánchez-Zabala & Gómez-Acebo [8]; Song [14] | Energy can be optimised, but not on as-built data |
| Retrofit / operation | Pinto & Amante [11]; Senthilkumar & Ayyathurai [12]; Luo & Oyedele [13] | Cost and carbon trade-offs need a common basis |
| Decision-making | Odoi-Yorke et al. [10]; Ekström et al. [15] | Supports weighted multi-criteria scoring |
| Sustainability scope | Zhu & Feng [9] | Energy alone is not enough |

## III. OBJECTIVES AND METHODOLOGY

### 1. Objectives

We set out with three main goals: (1) to compare electricity and water use between the green and conventional buildings; (2) to prepare and compare Bill of Quantities (BOQ) resource and cost figures; and (3) to build a standardised, dimensionless evaluation score, the Green Building Performance Index (GBPI).

### 2. Research Phases

The project moved through five stages. In Phase 1 (literature review), we examined existing work on building energy, water, and material performance. In Phase 2 (framework development), we locked in a common basis using per-floor and per-m² normalisation plus percentage change against the conventional case. In Phase 3 (data collection), we compiled whole-building resource figures for the G+14 Noida site, used EDGE software for the base-case versus improved-case comparison and end-use graph generation, and calculated the BOQ cost and resource estimate for the G+3 East Delhi house on QuickBOQ.com, supplemented by past electricity and

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water bills [1]. In Phase 4 (analysis and validation), we compared all quantities on both bases and cross-checked our calculations against the raw data. Finally, Phase 5 (conclusions) brought together the operational, BOQ, and GBPI findings.

**3. Normalisation And Comparison**

Whole-building totals for the green project are split evenly across its 15 floors; we state this upfront because every green per-floor figure depends on it. For each resource, we compute:

*Per floor = Total ÷ Number of floors*(1)

*Per m² = Per-floor value ÷ Floor area per floor*(2)

*Reduction (%) = (Conv. − Green) ÷ Conv. × 100*(3)

In the BOQ resource comparison, percentage change is measured relative to the conventional building, so a negative value indicates lower consumption per m² in the green design.

**4. Composite Index**

Since energy (kWh/m²), water (kL/m²), and materials (t/m²) cannot simply be summed together, each metric is rescaled between a best-case target and a worst-case benchmark, as detailed in Section VI.

## IV. CASE STUDY BUILDINGS AND DATA

The two case-study structures differ across almost every physical parameter that drives resource demand—height, floor area, walling material, and jointing system (Table II).

Table II: Case Study Buildings

| Parameter | Green building | Conventional building |
|---|---|---|
| Configuration | G+14 (15 storeys) | G+3 (4 storeys) |
| Floor area | 833 m² per floor | 196 m² per floor |
| Total built-up area | 12,495 m² | 784 m² |
| Wall masonry | AAC blocks (600–700 kg/m³) | Red clay bricks (1,800–2,000 kg/m³) |
| Jointing / plaster | 2–3 mm polymer thin-bed adhesive | 12–15 mm sand-cement mortar (1:6) |
| Use / location | GRIHA 3-star multi-storey building, Sector 22, Noida | Residential, East Delhi, standard quality |

Walling in the Noida building weighs roughly a third as much as the conventional clay brickwork, and its 2–3 mm thin-bed adhesive joints require far less binder than 12–15 mm sand-cement mortar. Those two design choices directly explain why the green site sees fewer blocks, less construction waste, and lower curing-water demand per m².

For the G+14 green project, whole-building totals (electricity, water, cement, steel, blocks, sand and aggregate, timber, diesel, and construction waste) were divided by 15 floors. For the G+3 East Delhi house, we prepared resource quantities and a preliminary BOQ cost estimate for one 196 m² floor using QuickBOQ.com, taking operational electricity and water from past residential utility bills [1].

**1.. Results: Energy, Water, BOQ and Resources**

***A. Objective 1: Energy and Water***

On both per-floor and per-m² metrics, the Noida green building consumes less electricity and water than the East Delhi house. On a per-floor basis, 7,240 kWh compares against 8,234 kWh—a 12.07% drop. Once scaled per m², however, the gap widens dramatically because each green floor is over four times larger: 8.69 kWh/m² versus 42.01 kWh/m², or a 79.31% reduction. Water shows the same trend, dropping 55.79% per floor and 89.60% per m² (Table III).

Table III: Energy and Water, Per Floor and Per m²

| Parameter | Green | Conventional | Reduction |
|---|---|---|---|
| Electricity per floor | 7,240 kWh | 8,234 kWh | 12.07% |
| Electricity per m² | 8.69 kWh/m² | 42.01 kWh/m² | 79.31% |
| Water per floor | 176.93 kL | 400.2 kL | 55.79% |
| Water per m² | 0.2123 kL/m² | 2.041 kL/m² | 89.60% |

The green per-floor figures come from dividing whole-building totals of 108,600 kWh and 2,654 kL evenly by 15 floors. Looking at per-floor values is the conservative check—it gives no credit for the green building's much larger floor plate—whereas per-m² figures give a fairer picture of efficiency per unit of usable space.

**2. Base Case Versus Improved Case**

Figs. 1 and 2, generated using EDGE software, break down end-use water demand (m³/day) and energy use intensity (kWh/m²/year) between a base case and an improved case. Judging from the bar heights, total water demand drops from roughly 4.2 m³/day to about 1.4 m³/day (around 67% lower), while total energy use falls from about 72 to 31 kWh/m²/year

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(roughly 57% lower). Because these totals are read directly from the chart bars, they are approximate.

The segment labels pinpoint where those drops come from. On the water side, shower use falls from 1.12 to 0.65 m³/day (−42.0%), laundry from 0.44 to 0.20 m³/day (−54.5%), and kitchen demand from 0.24 to 0.19 m³/day (−20.8%), while the base case's heavy irrigation load (1.44 m³/day) shrinks to a sliver in the improved case. On the energy chart, cooling drops sharply from 28.74 to 8.33 kWh/m²/year (−71.0%), home appliances fall from 5.62 to 3.72 (−33.8%), common amenities ease from 4.02 to 3.54 (−11.9%), and hot water (14.02 in the base case) disappears as a labelled segment. Cooking remains unchanged at 7.54 kWh/m²/year, making up a larger slice of the smaller total. Overall, cooling drives the biggest energy gains, while irrigation and showers drive the water savings.

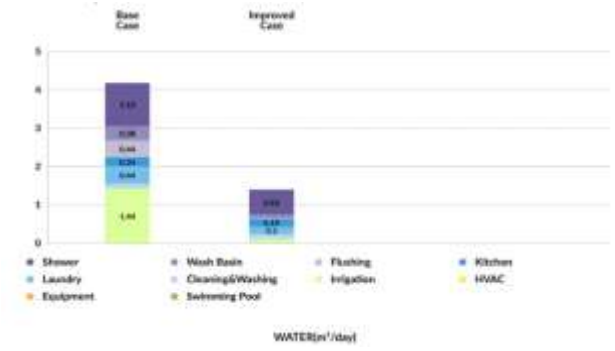



Fig.1. Water demand (m³/day) by end use: base case versus improved case.

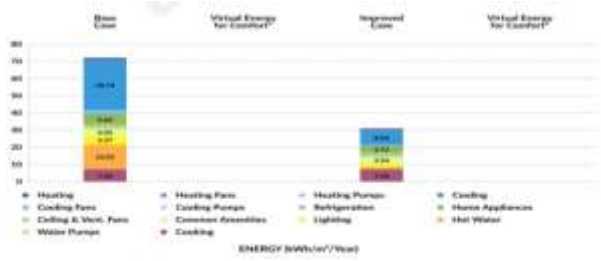


Fig.2. Energy use intensity (kWh/m²/year) by end use: base case versus improved case.

### 3. Objective 2: Boq Cost Of The Conventional Building

Our preliminary estimate from QuickBOQ.com puts the conventional building's core cost at ₹44.55 lakh. Grouping the 19 individual BOQ line items shows that finishes and structure account for most of the budget (Table IV).

Table IV: Conventional Building BOQ Cost, Grouped

| Group | Components | Cost (₹ lakh) | Share |
|---|---|---|---|
| Structure | Earthwork, PCC, RCC, reinforcement steel | 14.25 | 32% |
| Finishes | Brickwork, plastering, flooring, doors and windows, waterproofing, painting | 16.93 | 38% |
| Services | Electrical, plumbing, sanitary, kitchen | 7.58 | 17% |
| Other | External development, miscellaneous, labour, overheads, contingency | 5.80 | 13% |
| Total (core) | | 44.55 | 100% |

Individually, the biggest cost drivers are RCC and structure (15%), reinforcement steel (13%), and brickwork/blockwork and flooring (9% each). This estimate assumes 2,110 sq.ft in East Delhi at standard quality, priced between ₹1,906 and ₹2,318 per sq.ft, which gives a grand total range of ₹40.21 lakh to ₹48.90 lakh. The group totals in Table IV come from summing the underlying component costs.

### 4. Objective 2: Green Building Resource Boq

Table V lists the whole-building resource quantities for the Noida green project alongside the per-floor values obtained by dividing by 15.

Table V: Green Building Resource BOQ

| Resource | Total | Per floor (÷ 15) |
|---|---|---|
| Cement | 1,623 t | 108.20 t |
| Steel | 312 t | 20.80 t |
| Bricks / blocks | 1,087 thousand | 72.47 thousand |
| Sand / aggregate | 4,291 m³ | 286.07 m³ |
| Timber | 61 m³ | 4.07 m³ |
| Water | 2,654 kL | 176.93 kL |
| Diesel | 41,800 L | 2,786.67 L |
| Grid electricity | 108,600 kWh | 7,240 kWh |
| Construction waste | 192 t | 12.80 t |

### 5. Per-M² Resource Comparison

Table VI compares material and site-resource use per m². We calculate percentage change as (green unit − conventional unit) ÷ conventional unit × 100, so negative figures mean lower consumption in the green project. Fig. 3 illustrates these shifts visually.

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Table VI: Resource Use Per m²

| Resource | Conventional | Green | Change |
|---|---|---|---|
| Cement (t/m²) | 0.0538 | 0.1299 | +141.4% |
| Steel (t/m²) | 0.0102 | 0.0250 | +145.1% |
| Bricks / blocks (thousand/m²) | 0.1023 | 0.0870 | −14.9% |
| Sand / aggregate (m³/m²) | 0.2296 | 0.3434 | +49.6% |
| Timber formwork (m³/m²) | 0.0189 | 0.0049 | −74.1% |
| Curing water (kL/m²) | 1.5306 | 0.2124 | −86.1% |
| Diesel (L/m²) | 6.12 | 3.35 | −45.3% |
| Grid power (kWh/m²) | 22.96 | 8.69 | −62.2% |
| Construction waste (t/m²) | 0.0459 | 0.0154 | −66.4% |

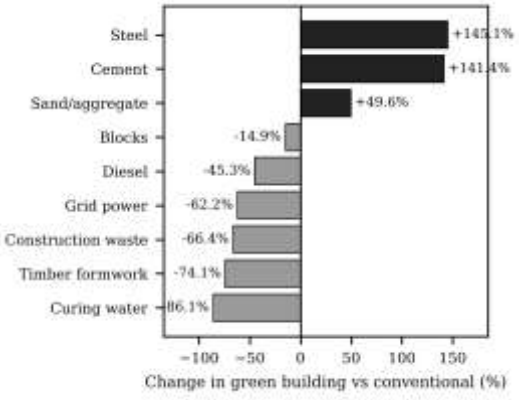



Fig.3. Change in per-m² resource use of the green building relative to the conventional building (dark bars: higher use; grey bars: lower use).

Looking at Fig. 3, a clear split emerges between structural materials and site-practice resources. Cement, steel, and sand/aggregate are higher in the Noida project because a G+14 tower requires a raft foundation, shear walls, and M35/M40 concrete—none of which a G+3 frame needs. Every other item is lower: AAC blocks reduce block count, reusable aluminium modular formwork cuts timber use, dimensionally accurate blocks generate less site waste, and self-curing compounds sharply reduce curing water.

## 6. Objective 3: The Green Building Performance Index (GBPI)

### *A. Formulation*

The GBPI combines energy, water, cement, and construction waste into a single 0–1 score. Each input is taken on a per-m² basis and scaled between a best-case target and a worst-case benchmark so that kWh, kL, and tonnes cancel out:

$$x_{norm} = (x_{max} - x) \div (x_{max} - x_{min}) \quad (4)$$

Since lower values are better for all four metrics, a normalised score near 1 sits close to the best benchmark, while a score near 0 sits near the worst. Taking a weighted sum gives the final index:

$$GBPI = \Sigma\,(w_i \times x_{norm,i}), \quad \Sigma\, w_i = 1 \quad (5)$$

Here $x_{min}$ is the best target value and $x_{max}$ the worst benchmark, drawn from ECBC (energy), GRIHA and NBC (water), IS codes (cement) and construction-and-demolition waste guidelines (waste). Energy carries the largest weight (0.35), followed by water (0.25). Table VII lists the parameters, benchmarks and weights.

Table VII: GBPI Parameters and Benchmarks

| Parameter | Unit | Best | Worst | Weight |
|---|---|---|---|---|
| 1. Energy (E) | kWh/m² | 5.0 | 25.0 | 0.35 |
| 2. Water (W) | kL/m² | 0.10 | 1.60 | 0.25 |
| 3. Cement (C), proxy for embodied carbon | t/m² | 0.04 | 0.15 | 0.20 |
| 4. Construction waste (CW) | t/m² | 0.01 | 0.05 | 0.20 |

Sources: ECBC benchmarks for multi-storey buildings (energy); GRIHA / NBC benchmarks for operational and curing water; IS code structural material benchmarks (cement); standard C&D waste management guidelines (waste).

These benchmarks and weights are provisional project assumptions; a sensitivity check is left for follow-up work.

## 7. Worked Result

Plugging the per-m² values from Table VI into Equations (4) and (5) produces the scores in Table VIII. For example, the conventional energy score works out to (25 − 22.96) ÷ 20 = 0.1020, and the green cement score is (0.15 − 0.1299) ÷ 0.11 = 0.1827.

Table VIII: GBPI Result (Value → Normalised Score)

| Parameter (weight) | Conventional | Green | Higher |
|---|---|---|---|
| Energy (0.35) | 22.96 → 0.1020 | 8.69 → 0.8155 | Green |
| Water (0.25) | 1.5306 → 0.0463 | 0.2124 → 0.9251 | Green |
| Cement (0.20) | 0.0538 → 0.8745 | 0.1299 → 0.1827 | Conv. |
| Waste (0.20) | 0.0459 → 0.1025 | 0.0154 → 0.8650 | Green |

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| Parameter (weight) | Conventional | Green | Higher |
|---|---|---|---|
| GBPI | 0.2427 (24.27%) | 0.7262 (72.62%) | Green |

Overall, the green building scores 72.62% versus 24.27% for the conventional house—a 48.35 percentage-point lead. It outperforms on energy, water, and waste, while lagging on cement because a 15-storey frame naturally needs more concrete per m². In that way, the index keeps the trade-off transparent: the green building's weakest component (0.1827 on cement) sits right next to its strongest (0.9251 on water), and the weights determine how they balance out.

## V. DISCUSSION AND LIMITATIONS

**1. What The Results Mean**

Taken together, our findings point to a more mixed picture than simply saying "green buildings use fewer resources." Operational electricity and water per m² are dramatically lower in the green project, as are six construction-stage items tied to material and site choices (blocks, timber, curing water, diesel, grid power, and waste). What climbs is structural material: cement and steel per m² more than double, and sand/aggregate rises by roughly 50%. That increase comes down to the structural engineering of a 15-storey frame rather than a flaw in green design, and a fairer follow-up would compare the Noida tower against a conventional high-rise of matching height.

The contrast between per-floor and per-m² electricity savings (12.07% vs. 79.31%) also underscores why normalisation matters. Per floor, the two buildings look fairly close; per m², the green building pulls far ahead because each of its floors covers more than four times the area. Presenting both views gives a more complete picture than picking just one.

On cost, we completed a full BOQ cost breakdown for the East Delhi house (₹44.55 lakh core) and a resource BOQ for the Noida building, but we did not have rupee unit rates for the green project. Because Objective 2 aims for a direct cost comparison, getting a rupee BOQ for the green building remains the main open gap.

**2. Limitations**

Several data and methodological caveats should be kept in mind when reading these numbers:

**3. Equal-Floor Assumption**

Green building totals are divided evenly by 15, which smooths over differences across podium, typical, or services floors.

- **Different data bases for energy:** Objective 1 uses 8,234 kWh per floor (42.01 kWh/m²) from residential utility bills, whereas the resource comparison and GBPI use 4,500 kWh per floor (22.96 kWh/m²). These represent different quantities (operational bills versus construction-stage grid power), and the conventional GBPI energy score shifts depending on which is plugged in—42.01 kWh/m² exceeds the 25 kWh/m² worst benchmark and would go negative unless capped.
- **Water definitions:** Conventional water is 400.2 kL per floor in Objective 1 but 300 kL of curing water in Table VI, while the green figure (176.93 kL) stays identical in both tables, meaning the two tables may not reflect the exact same water boundary for the green site.
- **Different building types:** Because we compare a single G+14 building against a single G+3 house with different locations and uses, the findings cannot be generalised broadly to all green or conventional projects.

**4. Cost Basis**

The conventional BOQ estimate is a preliminary figure for 2,110 sq.ft, while Table II lists 196 m² (roughly 2,110 sq.ft) per floor and 784 m² total, so the exact floor scope covered by the ₹44.55 lakh estimate needs confirmation.

**5. Provisional Gbpi Settings**

The benchmarks and weights are project-level choices. With energy and water together carrying 0.60 of the total weight, the score naturally rewards operational efficiency; a sensitivity check on these weights is needed before wider use.

**7) Embodied energy and life cycle:** Our scope excludes embodied energy, carbon emissions, and life-cycle cost, all of which prior studies (such as [7], [13]) highlight as critical.

**8) Base-case and improved-case charts:** Figs. 1 and 2 (generated in EDGE software) plot whole-building end-use totals (m³/day and kWh/m²/year) on a different basis from the per-floor and per-m² resource figures in Tables III and VI, so their absolute numbers should not be compared directly across tables. Segment values match the printed chart labels, while totals in the text are read off the bar heights.

**6. Future Work**

Going forward, this work can be extended by (i) collecting a rupee BOQ for the green building, (ii) aligning energy and water definitions across all tables, (iii) testing GBPI sensitivity to weights and benchmarks, (iv) adding a conventional high-rise as a closer comparator, and (v) bringing carbon emissions and life-cycle cost into the index.

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## VI. CONCLUSIONS

Comparing a G+14 green building in Noida with a G+3 conventional residential building in East Delhi on a normalised basis leads to four main takeaways:

- **Operational resources:** Per m², the green building uses 79.31% less electricity and 89.60% less water (12.07% and 55.79% less per floor).
- **Material resources:** On a per-m² basis, the green project cuts six construction-stage inputs—blocks (14.9%), timber (74.1%), curing water (86.1%), diesel (45.3%), grid power (62.2%), and construction waste (66.4%)—while requiring more cement (+141.4%), steel (+145.1%), and sand/aggregate (+49.6%) due to its 15-storey structural frame.

### 1. Cost

We built a ₹44.55 lakh core BOQ cost breakdown for the conventional house and a resource BOQ for the green project; adding rupee unit rates for the green building remains the next step.

### 2. Composite Index

Combining energy, water, cement, and waste into the unit-free GBPI yields 72.62% for the green building and 24.27% for the conventional building, a 48.35 percentage-point gap.

Overall, raw totals distort comparisons when buildings differ in scale, whereas pairing per-floor, per-m², and index-based views gives a much fairer assessment. The main caveats—equal-floor averaging, mixed energy and water boundaries across tables, and provisional GBPI weights—are documented in Section VII for future refinement.

### 3. Acknowledgment

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## REFERENCES

1. Electricity and water bills of past years of a residential building (project data).
2. D. Bansal and M. Mani (2014). An assessment of energy efficiency in Indian commercial buildings. Energy and Buildings, 73, 32–40.
3. L.F. Cabeza, L. Rincón, V. Vilariño, G. Pérez and A. Castell (2014). Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renewable and Sustainable Energy Reviews, 29, 394–416.
4. L. Jaillon, C.S. Poon and Y.H. Chiang (2009). Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. Waste Management, 29(1), 309–320.
5. C. Mao, Q. Shen, L. Shen and L. Tang (2013). Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects. Energy and Buildings, 66, 165–176.
6. P. Rajagopalan, V.M. Nair and C. Acharya (2010). Awareness and implementation of energy efficient technologies in Indian commercial buildings. Energy Policy, 38(11), 7284–7296.
7. C. Thormark (2002). A low energy building in a life cycle – its embodied energy, energy need for operation and recycling potential. Building and Environment, 37(4), 429–435.
8. I. Sánchez-Zabala and T. Gómez-Acebo (2024). “Building energy performance metamodels for district energy management optimisation platforms.” Energy Conversion and Management: X, 21, 100512.
9. Zhu and Feng (2023). “Is energy-efficient building sustainable? A case study on individual housing in Canada under BCESC energy updates.” Building and Environment, 239, 110452.
10. F. Odoi-Yorke, J.J. Owusu and L. Atepor (2022). “Composite decision-making algorithms for optimisation of hybrid renewable energy systems: Port of Takoradi as a case study.” Energy Reports, 8, 2131–2150.
11. E.S. Pinto and B. Amante (2022). “Polygeneration system optimization for building energy system retrofit: A case of study for TR5 building of UPC-Terrassa.” Energy and Buildings.
12. S. Senthilkumar and V. Ayyathurai (2022). “Energy efficiency management and setpoints optimisation strategy in retail store building, India.” Journal of Building Pathology and Rehabilitation, 7(1), Article 99.
13. X.J. Luo and L.O. Oyedele (2022). “Life cycle optimisation of building retrofitting considering climate change effects.” Energy and Buildings, 258.
14. Song (2022). Research on energy consumption parameter optimisation of green building. Inderscience.
15. Ekström et al. (2021). Probabilistic risk analysis and building performance simulations – Building design optimisation. SBUF.

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