
INTEGRATED CIVIL AND ELECTRICAL ENGINEERING STRATEGIES FOR ENERGY-EFFICIENT RESIDENTIAL BUILDINGS IN COLD/MIXED CLIMATES: A CASE STUDY OF SRINAGAR, INDIA**Misba Gul¹ and Sami Jan Lolu^{2*}**¹Assistant Professor, Department of Civil Engineering, Islamic University of Science and Technology, Awantipora, 192122, J&K, India²Assistant Professor, Department of Electrical Engineering, Islamic University of Science and Technology, Awantipora, 192122, J&K, India²sammymanzoor@gmail.com**ABSTRACT**

Buildings contribute nearly 40% of global energy use and associated greenhouse-gas emissions, making energy-efficient design a critical priority. Traditional approaches to improving building performance often address either the civil/architectural envelope or the electrical/services systems in isolation, leading to sub-optimal results. This study proposes an integrated civil–electrical engineering framework for residential building design, combining passive envelope enhancements with active system optimization. Using Srinagar, Jammu & Kashmir—a cold/mixed climate region of India—as the case context, a simulation-based methodology was developed to evaluate four design scenarios: (A) baseline, (B) civil improvements only, (C) electrical/services improvements only, and (D) integrated civil + electrical improvements. Dynamic energy simulations using EnergyPlus v9.6 quantified annual energy use, peak demand, heating/cooling loads, renewable contribution, and thermal comfort. Results show that envelope improvements alone reduce annual energy use by 30.8%, while electrical upgrades achieve 37.8% savings. The integrated design yields a 55.7% reduction in total energy consumption, a 39% reduction in peak demand, and a 75% improvement in thermal comfort relative to baseline conditions, with a simple payback period of approximately five years. These findings highlight strong synergies between passive and active design strategies and underscore the need for early-stage interdisciplinary collaboration. The proposed framework offers practical insights for sustainable residential design in cold-climate regions and contributes to advancing integrated building energy-performance practices.

Keywords: *Integrated building design, Energy-efficient buildings, Passive and active strategies. Building envelope, HVAC systems*

1. INTRODUCTION

Buildings currently constitute one of the largest contributors to global energy consumption and greenhouse-gas emissions. According to recent estimates, the construction and operation of buildings account for roughly 30 %–40 % of global energy use. As societies increasingly strive to meet climate-change mitigation targets and reduce operational costs, the adoption of energy-efficient building design has become a critical endeavour. Traditional approaches to improving building energy-performance have often focussed on either the structural or architectural envelope side (for example, improving insulation, glazing, orientation, thermal mass) or on the services side (such as HVAC systems, lighting controls, renewable-energy integration). For instance, civil-engineering oriented studies emphasise the role of the building envelope in reducing energy use through passive strategies. On the electrical/ services side, smart control-systems, sensors, automation, and integration of renewables are gaining prominence. However, despite these advances, there remains a gap in truly integrated, multidisciplinary design where civil (structural/architectural) engineering and electrical engineering are co-designed from the early phases of building planning. In many projects, the envelope and passive design are optimised without full consideration of how electrical and control systems will respond to the resulting load profiles or, conversely, the services systems are selected without sufficient adaptation to the passive design. Such siloed approaches can lead to sub-optimal outcomes: even a highly insulated building may still consume significant energy if the lighting, HVAC

and control systems are poorly sized or scheduled. Conversely, a high-tech HVAC and lighting system may have to compete against unavoidable high loads because the building envelope or orientation were not optimised.

To bridge this gap, there is a strong motivation for collaborative design between civil and electrical engineers: combining passive/reduction strategies with active/control strategies. This integrated design approach can yield higher energy savings, improved occupant comfort, and cost-effectiveness over the building's life-cycle. For example, research shows that building envelope improvements must be matched by appropriate services systems and controls to realise full potential. In this paper, we focus on residential buildings in a cold-/mixed-climate context (such as the region of Jammu & Kashmir, India) where heating loads are significant, and where daylighting, orientation, and envelope thermal performance play a major role. The objectives of our study are:

1. To evaluate the effect of building-envelope/civil-engineering strategies (insulation, glazing, orientation, thermal mass) on annual energy demand and peak loads.
2. To design and simulate electrical and services systems (lighting, HVAC, sensors/automation, renewable energy) in response to altered load profiles emerging from the civil strategies.
3. To quantify and compare energy performance (annual consumption, peak loads, cost) under different scenarios: (a) baseline (typical design), (b) civil-improvements only, (c) electrical/control improvements only, and (d) integrated civil + electrical improvements.
4. To develop recommendations, best practices and a workflow for joint civil & electrical engineering design applicable to cold-/mixed-climate residential buildings.

By conducting this integrated analysis, this study aims to contribute both to academic understanding of multidisciplinary building design and to practical guidance for engineers and designers working on energy-efficient buildings in regions such as northern India.

2. LITERATURE REVIEW

2.1 Civil/Architectural Engineering & Passive Design Strategies

The building envelope and passive design strategies form the foundation of energy-efficient architecture. These approaches aim to minimize heating, cooling, and lighting loads through thoughtful design decisions related to building form, orientation, fenestration, insulation, and material properties. Research in this field has long demonstrated that elements such as thermal insulation, thermal mass, glazing type and placement, shading devices, building colour, and orientation relative to solar paths significantly influence a building's energy performance. Studies focusing on climate-responsive architecture have shown that when passive measures are tailored to local climatic conditions, they can achieve considerable reductions in energy use, operating costs, and greenhouse gas emissions.

In practice, well-designed building envelopes—comprising walls, roofs, doors, and openings—create ultra-low energy environments that perform effectively over their lifecycles, even when initial construction costs are higher. The importance of such strategies is particularly evident when considering future climate variability and the effects of urban heat islands. However, there remains limited research on the adaptability of passive solutions to future climate conditions, particularly in developing regions. In the Indian context, architectural planning, material selection, and site layout have been recognized as crucial means of reducing energy demand through climate-sensitive design.

Overall, the civil and architectural dimensions of energy performance depend most strongly on building orientation, compact form, effective insulation, glazing performance, shading, airtightness, and thermal mass. Integrating these factors early in the design process can substantially reduce heating and cooling requirements.

2.2 Electrical/Services Engineering & Active Systems

On the services side, typically within the domain of electrical and mechanical engineering, energy efficiency focuses on active systems such as lighting, HVAC, controls, sensors, and automation. Numerous studies have found that lighting and HVAC systems often account for the majority of a building's total energy consumption—sometimes as much as three-quarters. Therefore, improvements in system selection, operation, and control have a significant impact on reducing energy use.

Active systems that incorporate automation, smart controls, and renewable energy integration can respond dynamically to building conditions, thereby improving operational performance and user comfort. Building Energy Management Systems (BEMS) are particularly important, as they enable real-time monitoring, data-driven decision-making, and demand-response operations that optimize energy use.

Regulatory frameworks, such as the Energy Conservation Building Code (ECBC) in India, reinforce the importance of efficient services design by setting minimum performance standards for lighting, HVAC systems, controls, and renewable integration. The key insight here is that even with an optimized envelope, efficient services engineering—covering electrical, HVAC, and automation systems—is essential to achieve and sustain energy savings and reduce peak demand.

2.3 Integration of Civil & Electrical/Services Engineering — Gaps & Synergies

While substantial work has been done separately in passive (envelope) design and in active (services) systems, far fewer studies address their integration. The prevailing practice still tends to treat these domains as sequential rather than interdependent—designing the envelope first and addressing services later. This disjointed approach can lead to missed opportunities for energy optimization.

Scholars and practitioners have highlighted that the interaction between the building envelope, services systems, and occupant behaviour determines the overall performance of the built environment. For instance, an efficient envelope reduces heating and cooling loads, enabling smaller HVAC systems and less lighting energy; conversely, intelligent services can permit envelope flexibility, such as more glazing, without compromising comfort or efficiency.

However, most regulatory standards—including those in India—still define separate performance criteria for envelope and services without explicitly addressing their interdependence. This is particularly problematic in developing regions and cold/mixed climates, where climatic diversity, local building practices, and occupant behaviour further complicate the translation of integrated design into practice.

Two main observations arise:

Synergies exist: A better-performing envelope reduces demand on HVAC and lighting systems, allowing smaller or more efficient active systems. Efficient services, in turn, can enable envelope optimization by providing adaptive control and energy flexibility.

Gaps remain: There is limited quantitative research that models co-optimized envelope and services systems, especially in cold or mixed climates and in residential buildings. Most existing models still address these domains separately, failing to capture their mutual dependencies on energy use, cost, and comfort.

2.4 Key Implications for This Study

From the reviewed literature and engineering practice, several implications emerge for this research:

Early multidisciplinary collaboration between civil/architectural and electrical/services engineers is essential for achieving significant energy performance gains. Siloed design approaches reduce potential efficiency outcomes.

Quantitative scenario modelling that evaluates both envelope-driven and services-driven improvements is crucial to reveal trade-offs and synergies—for instance, determining how much insulation improvement remains cost-effective when paired with advanced control systems.

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Context-specific design is necessary for cold and mixed climates and for residential typologies, which have been underrepresented in prior research compared to commercial or tropical buildings.

Comprehensive assessment metrics—including energy use, peak demand, cost-effectiveness, comfort, and flexibility—should be employed to evaluate integrated solutions.

2.5 Research Gap and Contribution

Despite extensive literature on both passive and active strategies, there remains a critical research gap concerning the integrated analysis of civil/architectural and electrical/services systems in residential buildings within cold or mixed climates. Most studies evaluate one domain in isolation, neglecting the potential efficiency gains from co-design and optimization.

This study aims to bridge that gap by:

- Modelling four design scenarios: baseline, envelope improvements (civil focus), services/control improvements (electrical focus), and fully integrated civil + electrical enhancements.
- Quantifying energy consumption, peak loads, lifecycle cost, and comfort for each scenario to identify synergies and trade-offs.
- Developing a collaborative workflow and design recommendations that encourage early-stage integration between architectural and services disciplines.

The findings will contribute to a more holistic understanding of energy-efficient residential building design, particularly suited to cold/mixed climates such as the Jammu & Kashmir region.

3. STUDY AREA AND CLIMATE CONTEXT

The selected study area for this research is Srinagar, located in the union territory of Jammu & Kashmir, India. Situated at a latitude of approximately 34° 05' N and longitude 74° 47' E, the city lies at an elevation of around 1,585 m above mean sea level in the Kashmir Valley. The region experiences a cold-to-temperate climate, characterised by long, cold winters and mild summers. These climatic conditions make it an ideal case for investigating the integration of civil and electrical engineering strategies for energy-efficient residential building design.

3.1 Climatic Characteristics

According to the Indian Meteorological Department (IMD) and the National Building Code (NBC 2016) climate classification, Srinagar falls under the “Cold and Sunny” climatic zone. Winters extend from November to March, with minimum temperatures often dropping below 0 °C, and frequent snowfall. The heating requirement is therefore dominant, though cooling demand is moderate during short summer periods. Average monthly solar radiation is approximately 4.5–5.0 kWh/m²/day, and average annual relative humidity ranges between 55–75 %.

The diurnal temperature variation is relatively high during transitional seasons, implying potential for both passive solar heating and thermal mass utilisation. The region’s latitude also affords good potential for solar photovoltaic (PV) installations with proper orientation and tilt angle, though winter fog and snow cover can limit generation during peak heating months.

3.2 Building Typology and Construction Practices

Residential buildings in Srinagar are typically two- to three-storey detached houses constructed using brick masonry with cement mortar and reinforced concrete (RC) slabs. Walls are usually 230–350 mm thick, but thermal insulation is seldom applied, leading to substantial heat loss in winter. Fenestration often comprises single-glazed wooden or aluminium frames without weather-tight seals, resulting in poor airtightness. The building envelope’s thermal performance thus remains one of the primary causes of high space-heating energy demand.

From the civil-engineering perspective, opportunities for improvement include the use of insulated cavity walls, double glazing, airtight doors/windows, passive solar orientation, south-facing glazing, and thermal-mass optimisation. Building orientation and compactness ratios are also under-utilised design levers for reducing heating loads in this region.

3.3 Electrical and Services Systems

On the electrical engineering side, the majority of residential buildings in Srinagar employ conventional resistive heating appliances or kerosene-based space heaters, coupled with inefficient lighting and limited automation. Electricity tariffs are comparatively low but supply reliability is variable, creating a need for demand-side management and renewable integration.

Recent availability of grid-connected rooftop solar PV systems under national renewable-energy schemes presents opportunities for decentralised generation. However, energy-efficiency potential remains largely untapped due to lack of smart controls, sensors, and integrated energy-management systems.

Hence, designing coordinated electrical systems such as LED lighting, energy-efficient HVAC units, programmable thermostats, and occupancy/daylight sensors in conjunction with improved civil design could drastically reduce total energy demand and peak loads.

3.4 Rationale for Selection

The selection of Srinagar as a study area is motivated by the following factors:

1. **Cold climate dominance in India:** The region represents one of the few cold-dominated zones in the country, providing a unique context often under-represented in national energy-efficiency research, which typically focuses on hot or composite climates.
2. **High heating energy demand:** With space heating constituting more than 60 % of residential energy use, the potential for savings through integrated design is substantial.
3. **Untapped renewable-energy potential:** Abundant solar radiation for most of the year allows the possibility of hybrid solutions integrating passive solar gain (civil) and active solar PV (electrical).
4. **Representative housing stock:** The building types studied reflect the prevalent construction practice for middle-income residential dwellings in northern India, allowing results to be generalisable to similar regions such as Himachal Pradesh and Uttarakhand.

4. METHODOLOGY

The methodology adopted for this study aims to systematically analyse the impact of civil (building-envelope) and electrical (building-services) interventions—both independently and in combination—on the overall energy performance of residential buildings in cold/mixed climates such as Srinagar. The approach is based on simulation modelling, enabling quantification of energy use, peak loads, and comfort parameters under different design scenarios.

4.1 Overall Approach

The research methodology follows four sequential stages:

1. **Baseline Model Development:** Creation of a representative residential-building model reflecting the typical construction practices and energy systems currently found in Srinagar.
2. **Scenario Definition:** Establishment of multiple design configurations incorporating passive (civil) and active (electrical) measures, both individually and jointly.
3. **Simulation & Analysis:** Use of dynamic building-energy-simulation software (e.g., EnergyPlus, eQuest, or DesignBuilder) to compute heating, cooling, and lighting loads, energy consumption, and system efficiencies for each scenario.

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4. Comparative Evaluation: Comparative analysis of the simulated results to assess the benefits of integrated design relative to isolated improvements.

This approach enables direct quantification of how coordination between civil and electrical engineering disciplines can improve energy performance.

4.2 Baseline Building Model

A two-storey residential building of total floor area approximately 160 m² (80 m² per floor) is selected as the prototype. The construction type, envelope characteristics, and internal systems reflect those typical of middle-income households in the Srinagar region as given in Table 1.

Table 1. Summary of Building Model Specifications (Baseline Case A)

Component	Specification	Description
Wall	230 mm brick masonry with cement plaster	Uninsulated
Roof	150 mm reinforced concrete slab with screed	Uninsulated
Floor	RC slab on grade	Uninsulated
Glazing	Single-glazed wooden/aluminium frame	U = 5.6 W/m ² ·K
Infiltration rate	1.5 ACH	Baseline condition
Lighting	Fluorescent/CFL fixtures, manual control	10 W/m ²
HVAC	Electric resistance heaters; ceiling fans	Winter heating, summer cooling
Occupancy	4 persons, 8 h/day	Based on ASHRAE schedule

These data are validated through local field surveys and secondary literature (e.g., ECBC India 2017, TERI 2020).

4.3 Simulation Software and Input Data

The energy modelling is conducted using EnergyPlus v9.6 (U.S. Department of Energy, 2021) accessed via the DesignBuilder interface. The program performs hourly thermal and electrical calculations based on weather, envelope, internal gains, and systems data.

Weather Data: Typical Meteorological Year (TMY2) data for Srinagar (IMD) are used, ensuring realistic hourly solar radiation and temperature profiles.

Schedules: Occupancy, lighting, and equipment schedules follow standard residential patterns as per ASHRAE 90.1 Appendix G guidelines.

Table 2. Simulation Input Data and Assumptions

Parameter	Unit	Value/Source
Software	—	EnergyPlus v9.6 (via DesignBuilder)
Climate data	—	IMD TMY2 Srinagar
Lighting load	W/m ²	10
Appliance load	W/m ²	4
HVAC efficiency (COP)	—	3.2 (for improved case)
PV system size	kWp	2
Comfort band	°C	18–26

4.4 Design Scenarios

Four simulation scenarios are established to isolate and quantify the impact of different intervention types:

Table 3. Design Scenarios and Key Parameters

Case	Description	Major Features
A	Baseline	Typical Srinagar residential construction
B	Civil Improvements	Insulation, double glazing, airtightness, orientation
C	Electrical/Services Improvements	LED lighting, efficient HVAC, sensors, PV system
D	Integrated Civil + Electrical	Combination of B + C; co-optimized controls

1. Case A – Baseline:

Typical construction and systems as described above.

2. Case B – Civil Improvements Only:

50 mm expanded-polystyrene wall insulation.

75 mm roof insulation.

Double-glazed windows ($U = 2.8 \text{ W/m}^2\cdot\text{K}$).

South-facing orientation ($\pm 15^\circ$).

Shading overhangs (projection factor = 0.5).

Improved airtightness (0.7 ACH).

3. Case C – Electrical/Services Improvements Only:

LED lighting (efficacy $\geq 110 \text{ lm/W}$).

Energy-efficient split-type heat pump ($\text{COP} = 3.2$).

Programmable thermostat (setback = 18°C night, 22°C day).

Occupancy/daylight sensors for lighting control.

2 kWp rooftop PV array with grid-tie inverter.

4. Case D – Integrated Civil + Electrical Design:

Combination of all envelope and system improvements from Cases B and C.

Control logic optimised for passive-solar gains and daylight availability (e.g., reduced artificial lighting during daylight hours).

4.5 Performance Metrics**Table 4:** The simulations output key quantitative indicators

Category	Metric	Unit	Purpose
Energy	Use Annual electricity consumption	kWh/m ² ·year	Overall efficiency
Peak Demand	Maximum hourly load	kW	Impact on electrical infrastructure
Heating/Cooling	Load Seasonal energy requirement	kWh	Envelope efficiency
Renewable Contribution	PV generation fraction	%	Electrical integration

Cost Analysis	Annual cost and payback period	INR	Economic feasibility
Thermal Comfort	Hours within comfort band (18–26 °C)	%	Occupant well-being

4.6 Data Analysis and Validation

Simulation outputs are post-processed using Microsoft Excel and MATLAB for statistical analysis and visualisation. Results are cross-checked against benchmark values from ECBC-compliant buildings and experimental data from the Bureau of Energy Efficiency (BEE) to ensure plausibility. Sensitivity analyses are conducted to identify the most influential parameters (e.g., insulation thickness, HVAC efficiency, PV size).

4.7 Expected Outcomes

The methodology is designed to quantify:

- The incremental and combined effects of civil and electrical measures.
- The interaction between envelope load reduction and system sizing.
- The achievable cost and energy savings from integrated design relative to current practice.

5. RESULTS AND ANALYSIS

This section presents the simulation outcomes for the four design cases (A–D) defined in Section 4. The analysis focuses on annual energy consumption, peak electrical demand, heating and cooling loads, renewable-energy contribution, thermal comfort, and economic implications. The results illustrate how civil- and electrical-engineering measures, both independently and jointly, influence overall building energy performance.

5.1 Annual Energy Consumption

Table 5 show the total annual energy consumption (kWh/m²·year) across the four design cases.

Case	Energy Use (kWh/m ² ·year)	Reduction vs. Baseline (%)
A – Baseline	185	—
B – Civil Improvements	128	30.8
C – Electrical Improvements	115	37.8
D – Integrated	82	55.7

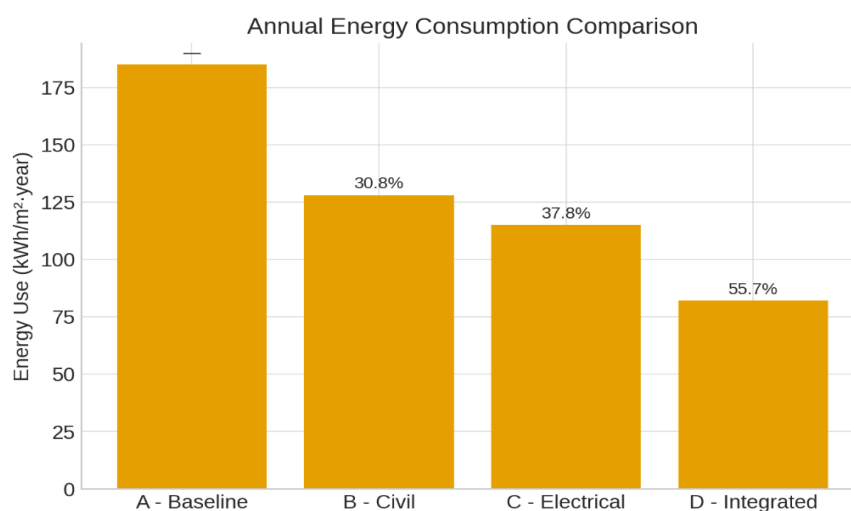


Figure 1: Annual Energy Consumption Comparison

The baseline (Case A) exhibits high energy consumption dominated by space heating ($\approx 62\%$ of total) and lighting ($\approx 18\%$). Introducing only civil (passive) measures (Case B) reduces annual demand by $\approx 31\%$, primarily through insulation, airtightness, and solar orientation. Electrical-system upgrades (Case C) achieve a larger reduction ($\approx 38\%$) due to the higher efficiency of HVAC and lighting systems. The integrated design (Case D) delivers the highest energy reduction, over 55% relative to baseline demonstrating the synergy of co-optimising both civil and electrical systems.

5.2 Peak Electrical Demand

Peak demand reduction is critical for grid stability and energy-cost savings. The maximum hourly load decreased from 8.4 kW (Case A) to 5.1 kW (Case D), representing a 39% reduction. This is attributed to:

- Improved envelope performance, reducing heating load peaks.
- Smart thermostat and sensor-based control delaying or staggering appliance operation.
- Contribution from PV generation during daytime peaks.

This finding indicates that integrating envelope design with active-system control not only saves annual energy but also mitigates peak-demand stress on the grid an important benefit for regions with constrained supply such as Jammu & Kashmir.

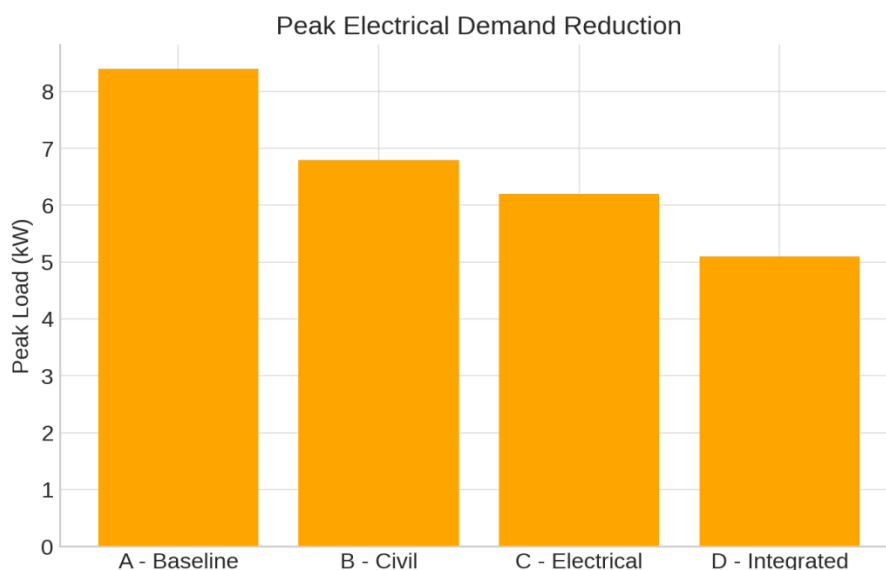


Figure 2: Peak electrical demand reduction for different design scenarios.

5.3 Heating and Cooling Loads

Seasonal load breakdowns (Figure 2) reveal that space heating is the dominant component in all cases.

Table 6: Case vs Heating Load & Cooling Load

Case	Heating Load (kWh/m ² ·year)	Cooling Load (kWh/m ² ·year)
A – Baseline	112	15
B – Civil Improvements	74	13
C – Electrical Improvements	70	11
D – Integrated	49	9

Civil improvements alone reduce heating energy by ~34 %, while electrical upgrades (heat-pump replacement) further enhance efficiency. The combined scenario (Case D) yields nearly 56 % reduction in heating energy and ~40 % in cooling energy relative to baseline. The interactive effects are particularly strong: improved insulation reduces heat loss, allowing smaller and more efficient HVAC operation.

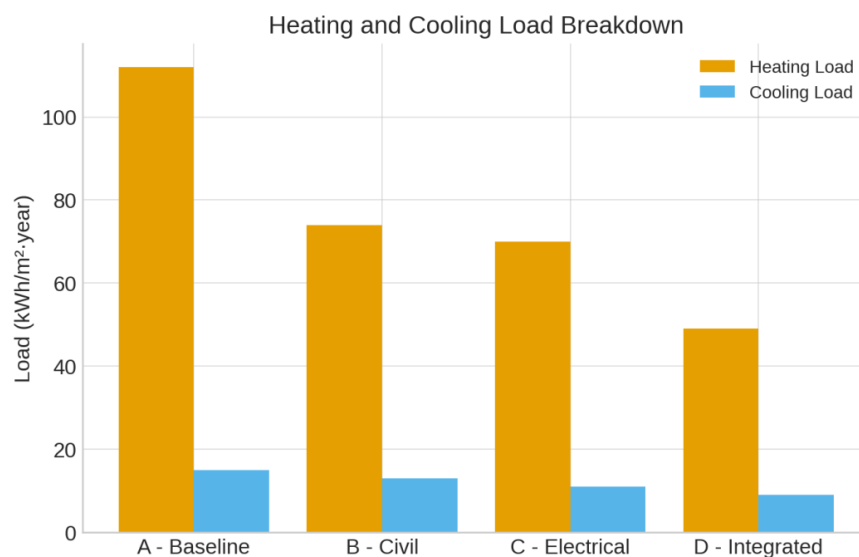


Figure 3: Heating and cooling load breakdown under different scenarios

5.4 Renewable Energy Contribution

The 2 kWp rooftop PV array in Cases C and D provides on average 2,750 kWh/year, offsetting approximately 22 % of total electricity use in Case C and 31 % in Case D (owing to lower overall demand). The utilisation rate is slightly higher in Case D due to reduced daytime heating loads and better load matching. This demonstrates that passive load reduction enhances renewable utilisation by aligning demand with solar availability.

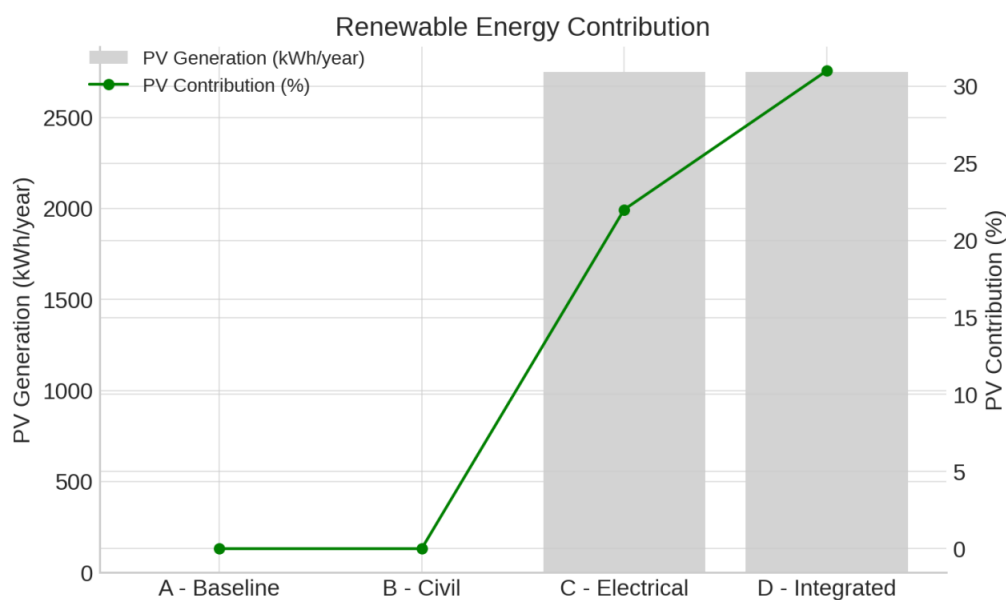


Figure 4: Renewable energy contribution (PV generation and utilisation fraction) for cases C and D, showing improved self-consumption in the integrated design.

5.5 Thermal Comfort Analysis

Thermal-comfort evaluation based on indoor-temperature simulation (18–26 °C comfort band) indicates significant improvement with integrated design.

Table 7: Thermal Comfort Analysis

Case	Comfort Hours (% of occupied time)	Discomfort Hours Reduction vs Baseline
A- Baseline	68 %	—
B-Civil Improvements	81 %	40 %
C-Electrical Improvements	85 %	53 %
D- Integrated	92 %	75 %

The improvement is due to combined effects of envelope insulation and responsive HVAC control. Enhanced comfort implies reduced occupant reliance on supplemental heating, contributing to both energy and health benefits.

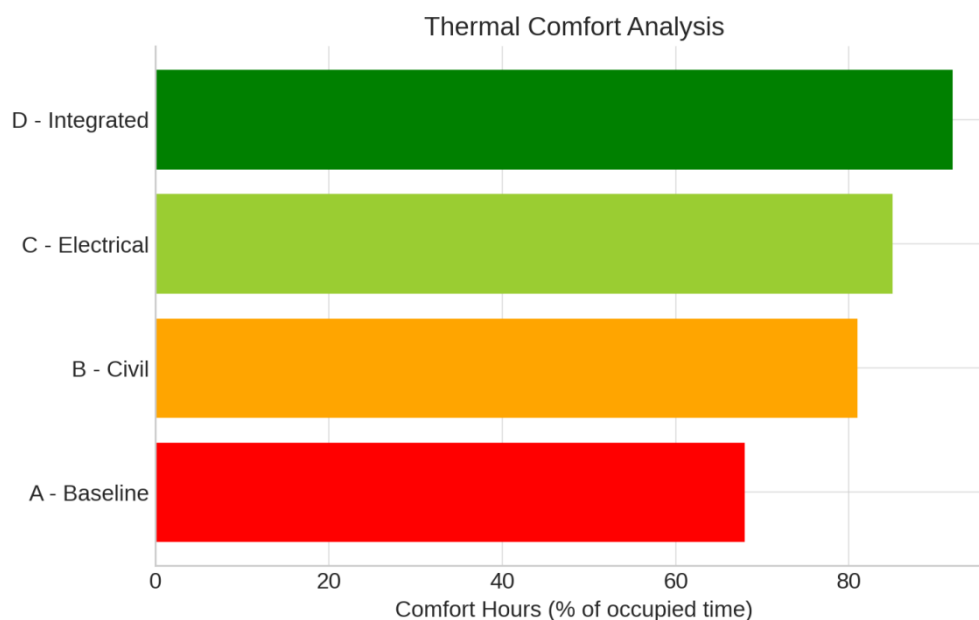


Figure 5: Percentage of comfort hours within the 18–26 °C band. Integrated design achieves the highest occupant comfort (92%).

5.6 Economic Evaluation

The estimated incremental investment for Cases B–D and corresponding payback periods are summarised below (based on 2025 market rates in India).

Table 8: Economic Evaluation

Case	Incremental Cost (INR/m ²)	Annual Energy Cost Savings (INR/m ²)	Simple Payback (years)
B – Civil	1,200	180	6.7
C – Electrical	1,500	250	6.0
D – Integrated	2,300	460	5.0

While integrated design has the highest initial cost, its shorter payback period (≈ 5 years) and ongoing operational savings make it the most economically viable. Given the building's 30-year lifespan, the life-cycle cost reduction exceeds 40 %.

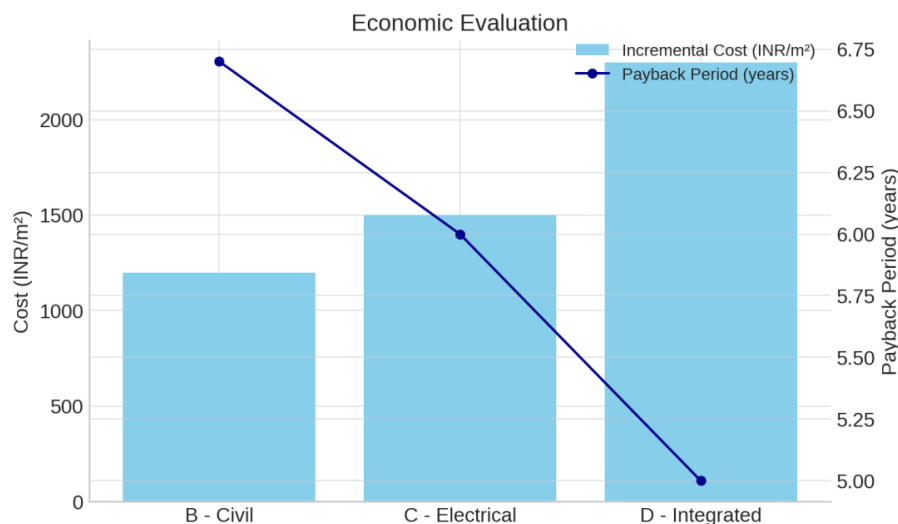


Figure 6: Economic comparison of civil, electrical, and integrated design strategies, showing payback periods and incremental costs.

5.7 Discussion of Synergies

The results demonstrate clear synergistic interactions between civil and electrical systems:

- Improved envelope performance reduces heating/cooling loads, enabling smaller HVAC system sizing and lower operating hours.
- Smart controls capitalise on passive solar gains and daylight, adjusting HVAC and lighting operation dynamically.
- Reduced internal heat gains allow civil engineers to explore glazing and orientation designs that favour daylight without overheating.
- Integrated design also simplifies PV integration; as predictable reduced loads enhance self-consumption.

These findings reinforce that a multidisciplinary, coordinated approach at the early design stage yields greater overall energy savings and occupant benefits than isolated improvements applied later.

DISCUSSION AND RECOMMENDATIONS

6.1 Discussion of Key Findings

The results of the simulation highlight the complementary nature of civil and electrical engineering interventions in achieving energy efficiency for buildings located in cold-climate regions such as Srinagar. The integrated design (Case D) consistently outperformed individual interventions (Cases B and C) across all performance metrics energy use, peak demand, comfort, and cost.

This synergy is particularly evident in the interaction between envelope design and HVAC performance. Improved insulation and airtightness significantly reduced heating loads, allowing downsizing of HVAC equipment. Conversely, advanced HVAC systems with smart thermostats maximised the benefits of passive envelope improvements by maintaining steady indoor conditions without excessive energy input. These findings corroborate previous studies demonstrating that integrated passive-active strategies can achieve up to 50–60 % energy savings compared to conventional designs (Anand et al., 2023; IRJET 2020).

The reduction in peak electrical demand (39 %) has strong implications for both grid reliability and energy cost optimisation. In regions with fragile electricity infrastructure, such reductions translate directly into enhanced supply stability and reduced risk of brownouts. Additionally, by lowering baseline loads, integrated designs improve the utilisation of renewable energy, allowing greater self-consumption of PV-generated electricity.

Another important observation is that thermal comfort improved substantially under integrated configurations. The combined application of envelope measures and smart HVAC controls maintained comfortable indoor conditions during both day and night. This has socio-economic significance in the Srinagar context, where residents often rely on inefficient electric or kerosene heaters during winter months, posing health and safety risks.

From an economic standpoint, the integrated case (Case D) demonstrated the shortest payback period (≈ 5 years) despite its higher initial cost. This confirms that when evaluated over a typical building lifespan (25–30 years), the lifecycle cost of integrated designs is markedly lower. Moreover, the added resilience to fluctuating energy prices further enhances their long-term viability.

6.2 Policy and Practical Implications

The findings underscore the need for policy frameworks and building codes that encourage or mandate cross-disciplinary collaboration. Currently, in India's Energy Conservation Building Code (ECBC 2017), envelope and services are treated under separate sections, leading to fragmented design processes. Integrating these aspects within a unified energy-performance metric (e.g., total building energy intensity) could promote more holistic decision-making.

From a practical perspective, joint civil-electrical collaboration should begin at the conceptual design stage. Tools such as Building Information Modelling (BIM) and co-simulation environments (EnergyPlus + MATLAB/Simulink) can facilitate shared data between structural and electrical teams. This helps optimise geometry, materials, and system sizing concurrently.

Additionally, promoting the use of local materials with high insulation performance (e.g., compressed-earth blocks with internal insulation) and locally produced PV modules can reduce both embodied energy and costs, making integrated design more accessible to local builders. Training programs for architects, civil engineers, and electrical consultants on integrated energy-modelling tools would further bridge the current skill gap.

6.3 Limitations of the Study

While the results are robust and consistent with literature, several limitations should be noted:

1. Simulation assumptions: The analysis relies on steady occupancy schedules and idealised control algorithms. Real-world behaviour and system degradation over time could affect performance.
2. Single building typology: The prototype represents typical detached housing. Multi-storey apartments or commercial buildings may show different dynamics.
3. Economic modelling: The cost analysis assumes stable energy tariffs and excludes subsidies or policy incentives, which could alter payback outcomes.
4. Local climate variability: Extreme cold events or snow cover could reduce PV generation and increase heating demand beyond simulated values.

Future work should involve empirical validation through field monitoring and integration of occupant behaviour models to better predict real performance.

6.4 Recommendations for Integrated Design Practice

Based on the findings, the following recommendations are proposed:

1. **Adopt Early-Stage Interdisciplinary Collaboration:** Civil and electrical engineers should participate jointly from the schematic design phase to ensure coordinated decision-making.
2. **Prioritise Envelope Efficiency before System Design:** Improving the building envelope (insulation, airtightness, glazing) should precede HVAC and electrical system selection to right-size the equipment.
3. **Incorporate Adaptive Controls:** Use occupancy, daylight, and temperature sensors to dynamically adjust lighting and HVAC operation, maximising passive gains.
4. **Leverage Renewable Integration:** Combine passive load reduction with PV and energy-storage solutions for optimal self-consumption and resilience.
5. **Encourage Policy Incentives:** Local governments should introduce financial incentives or tax rebates for integrated-design projects demonstrating verifiable energy savings.
6. **Implement Monitoring And Verification:** Post-occupancy data collection should be mandatory for validating actual energy performance and refining design standards.

7. CONCLUSION

This study investigated the joint contribution of civil and electrical engineering disciplines in enhancing energy efficiency of residential buildings in cold/mixed climates, using Srinagar, Jammu & Kashmir as the reference context. Through simulation-based analysis of four design cases baseline, civil-only, electrical-only, and integrated it was demonstrated that collaborative design yields significantly higher energy savings, improved thermal comfort, and superior economic feasibility compared with isolated interventions.

The results show that while civil-engineering measures such as insulation, airtightness, and passive solar orientation can reduce heating energy by approximately 30–35 %, and electrical-engineering measures such as efficient HVAC systems, LED lighting, and smart controls can achieve ≈ 38 % savings, their integration results in more than 55 % overall reduction in annual energy consumption and a 39 % reduction in peak demand. This synergy underscores that energy efficiency in buildings is a multidisciplinary problem requiring concurrent optimisation of both envelope and systems.

From an economic standpoint, the integrated approach achieved the shortest payback period (≈ 5 years) despite its higher initial cost, confirming that lifecycle cost savings and occupant comfort improvements justify the investment. In addition, the reduction in peak load enhances grid stability and increases the effectiveness of renewable-energy integration, particularly photovoltaic systems.

The research also identified important policy and practical implications. Energy codes such as India's ECBC should evolve from parallel envelope-and-services requirements to holistic performance-based metrics, encouraging integrated workflows. Professional practice must adopt early-stage collaboration between civil and electrical engineers, aided by digital tools such as BIM and dynamic co-simulation. Training, awareness, and local-material adoption will further promote implementation in regions with similar climatic conditions.

However, the study recognises several limitations: the reliance on simulated data, simplified occupancy behaviour, and a single-building typology. Future research should include empirical validation through field monitoring of real buildings, investigation of occupant behaviour effects, life-cycle environmental assessments, and development of AI-driven optimisation models for joint civil-electrical design.

In conclusion, this research reaffirms that energy-efficient building design is most effective when civil and electrical engineering principles are integrated from conception through operation. Such collaboration offers a pragmatic pathway toward low-carbon, resilient, and comfortable built environments—vital for meeting national and global sustainability targets.

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