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## ENVIRONMENTAL PROTECTION TECHNOLOGIES IN HOTEL ENERGY SYSTEMS: PRIORITISING ENERGY EFFICIENCY IN POST-WAR RECOVERY

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**Abstract.** *This article develops an integrated conceptual framework for post-war hotel energy reconstruction grounded in the synergistic application of the Build Back Better principle and the Energy Efficiency First doctrine. In conditions of large-scale infrastructure destruction, hotels represent energy-intensive assets whose rebuilding creates a critical opportunity to prevent carbon lock-in and accelerate low-carbon transition pathways. The study applies structured conceptual and thematic synthesis of international scientific literature and policy documents to systematise technological, architectural, digital and governance dimensions of resilient energy architecture.*

*The paper argues that reconstruction must prioritise intrinsic energy demand reduction through high-performance envelopes, passive design strategies and efficient HVAC systems before expanding supply capacity. Renewable integration, electrification and decentralised generation should follow minimised demand profiles. The proposed model demonstrates that aligning EE1st sequencing with resilience objectives generates reduced lifecycle consumption, enhanced energy security, lower emissions and improved operational continuity in post-war recovery contexts.*

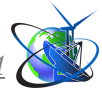
**Keywords:** *hotel energy systems; post-war reconstruction; Build Back Better; Energy Efficiency First; sustainable infrastructure; resilient energy architecture; renewable integration.*

### Introduction

The hospitality industry, encompassing hotels and related accommodation facilities, plays a vital role in global and national economies by contributing to employment, revenue generation and regional development.

In Ukraine, prior to the full-scale Russian invasion in 2022, the sector demonstrated gradual modernization and integration into European tourism markets, yet it continued to face structural challenges related to aging infrastructure and insufficient energy performance. The war has caused extensive destruction of buildings, energy networks and logistical systems, leaving numerous hotels damaged or inoperable and intensifying energy insecurity through grid instability, supply interruptions and increased operational risks.

Post-war recovery creates not only a need for reconstruction but also a strategic

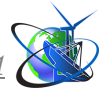


opportunity to redesign hotel infrastructure according to resilience and sustainability principles. The Build Back Better paradigm shifts the focus from simple restoration to structural transformation, embedding environmental protection technologies and decentralised energy solutions into rebuilding strategies. In parallel, the Energy Efficiency First doctrine prioritises demand reduction before supply expansion, ensuring that reconstruction efforts minimise long-term operational costs, enhance energy autonomy and reduce carbon intensity. For the hotel sector, this implies integrating high-performance building envelopes, electrified heating and cooling systems, on-site renewable generation, storage technologies and digitalised energy management platforms within a unified architectural concept [1, 2].

Ukraine's energy transition agenda further reinforces this direction by aligning national recovery priorities with European decarbonisation trajectories and climate commitments. Strengthened building regulations, progressive energy performance standards and the gradual introduction of nearly zero-energy building requirements redefine the technical baseline for both new construction and major renovation. Within the hospitality sector, these regulatory shifts necessitate systemic redesign rather than fragmented upgrades, encouraging lifecycle-oriented planning, integrated system modelling and adaptive energy management capable of functioning under disrupted grid conditions [3, 4].

However, reconstruction in post-conflict environments requires more than regulatory compliance or technological adoption in isolation. Fragmented implementation, limited capital availability and damaged infrastructure create systemic constraints that demand coordinated architectural, engineering and governance solutions. A resilient hotel energy architecture must therefore combine decentralised renewable systems, hybrid backup configurations, intelligent monitoring and demand-response mechanisms within a coherent multi-level framework that connects strategic policy objectives with operational execution. Such an approach enables hotels not only to restore functionality but to operate as semi-autonomous energy units capable of withstanding future shocks.

**Purpose of the Article** is to develop an integrated conceptual framework for post-



war resilient energy architecture in hotel buildings based on the synergistic application of the Build Back Better principle and the Energy Efficiency First doctrine. The study systematises strategic, managerial and technological dimensions of energy reconstruction in the hospitality sector to ensure long-term energy efficiency, operational resilience and low-carbon transition. It provides a transferable methodological basis for designing reconstructed hotel energy systems that prioritise demand minimisation, resource optimisation and adaptive capacity under conditions of infrastructural disruption and energy insecurity.

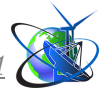
**Statement of the main results.** This study is based on a structured conceptual and analytical research design appropriate for a review article focused on post-war hotel energy reconstruction. The methodological approach relies on systematic synthesis of peer-reviewed scientific literature and international institutional documents addressing energy efficiency, resilient reconstruction, renewable integration and building energy systems [1-5].

The materials analysed include publications indexed in international scientific databases and policy documents from recognised global institutions such as the International Energy Agency, the European Commission and the United Nations system. Sources were selected based on relevance to core analytical domains:

- The Build Back Better principle in infrastructure recovery;
- The Energy Efficiency First doctrine in energy planning.

The literature was examined through thematic analysis, enabling identification of recurring structural, technological, digital and governance dimensions relevant to hotel energy reconstruction.

The “Build Back Better” (BBB) principle emerged within disaster risk reduction and resilient recovery policy frameworks and has progressively evolved into a strategic doctrine for infrastructure modernisation after large-scale destruction. Initially articulated in the context of post-tsunami and post-earthquake recovery, the concept emphasises that reconstruction should not merely restore pre-disaster conditions but improve structural, environmental and institutional performance beyond the previous baseline. In energy-intensive sectors such as hospitality, the BBB principle acquires



additional significance because hotels operate as complex socio-technical systems combining building envelopes, mechanical equipment, digital control platforms and service-intensive operations [13; 14].

Post-war reconstruction differs from conventional renovation due to the scale of damage, disruption of supply chains, grid instability and institutional uncertainty. Under such conditions, rebuilding hotels presents a unique opportunity to integrate low-carbon technologies, advanced efficiency standards and resilient energy configurations from the outset rather than through incremental retrofits. International recovery research demonstrates that integrating resilience and sustainability into reconstruction reduces long-term operational costs and carbon emissions while enhancing systemic stability [5].

In the hospitality sector, energy demand is typically dominated by heating, ventilation, air conditioning (HVAC), domestic hot water, lighting and auxiliary services. Studies indicate that HVAC systems alone can account for 40–60% of total hotel energy consumption, depending on climatic conditions [15].

Therefore, applying BBB in hotel energy reconstruction implies a structural transformation rather than cosmetic rebuilding. It entails embedding energy efficiency, decentralised renewable generation and digital optimisation into the architectural and operational core of reconstructed facilities.

The theoretical integration of BBB with sustainability transitions theory further reinforces the argument that post-war reconstruction can serve as a “window of opportunity” for accelerating decarbonisation pathways. Large-scale disruption destabilises incumbent energy regimes, allowing innovative configurations such as near-zero energy buildings (nZEB), heat pumps and smart energy management systems to replace outdated fossil-dependent systems.

Within the BBB framework, structural interventions form the foundation of long-term energy performance. Unlike operational optimisation, which adjusts system behaviour, structural measures redefine the building’s intrinsic energy demand profile (Table 1).

**Table 1 – Structural Energy Measures within the BBB Framework**

Structural Measure	Technical Description	Post-War Relevance	Documented Impact
nZEB Envelope	High-performance insulation, airtightness, triple glazing	Reduces heating/cooling loads from baseline	30–50% demand reduction
Heat Pump Systems	Electrified heating/cooling with high COP	Enables fossil fuel substitution	20–40% efficiency gain
Passive Design	Orientation, shading, natural ventilation	Reduces cooling intensity in warm climates	10–25% load reduction
Thermal Energy Storage	Phase change materials or water-based storage	Stabilises grid during outages	Load shifting up to 15%

*Author's development*

The data synthesised above indicate that structural upgrades implemented during reconstruction provide significantly higher energy savings than incremental retrofits. For example, EU case studies of post-disaster rebuilding in Italy and Germany show that integrating nZEB envelopes during reconstruction achieved up to 45% lower primary energy consumption compared to pre-damage baselines [15].

BBB in post-war hotel reconstruction requires systemic integration of decentralised renewable technologies. Unlike pre-war centralised grid dependency, resilient reconstruction favours hybrid systems combining photovoltaic (PV) generation, battery storage and grid interconnection (Table 2) [13, 15].

**Table 2 – Renewable Integration Options in Reconstructed Hotels**

Technology	Functional Role	Resilience Contribution	Emission Reduction Potential
Rooftop PV	On-site electricity generation	Reduces grid dependency	15–35% CO <sub>2</sub> reduction
Battery Storage	Backup power and peak shaving	Ensures operation during outages	Improves load stability
Solar Thermal	Domestic hot water supply	Reduces electricity/gas demand	10–20% thermal savings
Hybrid Microgrid	Integrated PV + storage + grid	Enables island mode	Enhances disaster resilience

*Author's development*



Beyond physical infrastructure, BBB requires digital transformation of hotel energy systems. Advanced energy management systems (EMS), Internet of Things (IoT) monitoring and predictive analytics enable continuous optimization [8, 10].

Digital twins are particularly relevant in post-war contexts because they allow simulation of reconstruction scenarios before capital investment decisions. This reduces financial risk and ensures alignment with long-term decarbonisation targets.

The BBB principle becomes most effective when aligned with the Energy Efficiency First (EE1st) doctrine, which prioritises demand reduction before expanding supply infrastructure. In hotel reconstruction, this means that structural efficiency improvements precede renewable capacity expansion [4, 5].

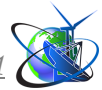
The Energy Efficiency First (EE1st) doctrine has emerged as a strategic principle within European and international energy policy frameworks, asserting that demand-side measures should be prioritised whenever they are more cost-effective or socially beneficial than supply-side expansion [1–3].

Unlike conventional energy planning approaches that expand generation capacity to meet projected demand, EE1st reverses the logic by first minimising demand through structural, technological and behavioural efficiency interventions.

In post-war reconstruction contexts, where infrastructure damage, fiscal constraints and energy insecurity coexist, EE1st provides a rational prioritisation framework. Rather than reconstructing hotels according to pre-war consumption patterns, the doctrine requires a systematic reassessment of intrinsic energy needs, technological options and lifecycle performance. This shift is particularly relevant in the hospitality sector, which is characterised by high energy intensity due to continuous operation, comfort requirements and service diversity.

The regulatory institutionalisation of EE1st in the European Union under the Energy Efficiency Directive establishes efficiency as a planning criterion across energy systems, buildings and infrastructure investment [1].

In reconstruction settings, applying EE1st ensures that scarce financial resources are allocated to measures delivering the highest long-term energy and carbon reduction returns.



From a systems perspective, EE1st aligns with integrated resource planning theory, which evaluates supply and demand measures within a unified analytical framework. In post-war hotel reconstruction, this implies that rebuilding should not automatically restore previous HVAC capacities, boiler systems, or grid connections without reassessing demand reduction potential.

Disruption caused by war creates a structural break that enables redesign of building typologies, service models and technological configurations. According to sustainability transition theory, such moments of systemic disturbance provide opportunities to accelerate low-carbon pathways. EE1st leverages this disruption by embedding energy minimisation at the earliest stages of architectural and engineering design [18].

The doctrine further integrates lifecycle cost analysis, recognising that efficiency investments frequently produce lower total cost of ownership compared to expanded energy supply. For hotels, where energy expenditures represent a substantial share of operational costs, this lifecycle approach enhances both environmental and financial resilience.

The first operational layer of EE1st concerns structural demand reduction. This involves minimising heating, cooling, lighting and hot water loads before integrating renewable generation or expanding electrical infrastructure (Table 3) [15, 19].

**Table 3 – Structural Demand Reduction Measures under EE1st**

Measure	Functional Objective	Demand Reduction Range	Lifecycle Benefit
High-performance envelope	Reduce thermal transmission losses	30–50% heating/cooling demand	Lower peak load and equipment size
Airtightness optimisation	Prevent uncontrolled infiltration	10–20% energy savings	Improved indoor comfort
Passive solar design	Utilise orientation and shading	10–25% cooling load reduction	Reduced mechanical dependency
LED and adaptive lighting	Minimise lighting load	50–70% lighting energy reduction	Reduced maintenance cost

*Author's development*

While structural measures redefine baseline demand, EE1st also encompasses



operational optimisation. Intelligent energy management systems ensure that actual consumption aligns with theoretical efficiency potential.

Digitalisation strengthens EE1st by ensuring that structural efficiency gains are not offset by rebound effects. For example, predictive control systems reduce simultaneous heating and cooling, a common inefficiency in large hotels [20].

In reconstruction environments, financial resources are constrained and capital must be allocated strategically. EE1st supports cost-effective prioritisation by ranking interventions according to marginal abatement cost and lifecycle savings [1, 5].

Scientific modelling within European hospitality retrofits indicates that envelope improvements and high-efficiency HVAC systems often exhibit payback periods of 5–10 years, after which operational savings exceed initial capital expenditure [2]. In contrast, expanding renewable generation without prior demand reduction can result in oversized systems and longer payback horizons.

By reducing peak demand, EE1st also decreases required transformer capacity, grid upgrades and backup generation investments. Therefore, the doctrine contributes to systemic financial optimisation beyond individual building boundaries.

Post-war reconstruction frequently coincides with energy supply instability. EE1st mitigates vulnerability by reducing overall dependence on external energy inputs. Lower demand translates into smaller exposure to fuel price volatility and import risks.

The effectiveness of EE1st depends on institutional embedding. Policy instruments such as minimum energy performance standards, mandatory energy audits and conditional recovery financing create regulatory incentives for prioritising efficiency [1–3].

While BBB emphasises resilience and systemic improvement, EE1st provides methodological sequencing. BBB defines the objective of superior reconstruction, whereas EE1st defines the priority order of interventions.

In practice, this integration implies that reconstruction begins with envelope optimisation and load reduction, followed by electrification and renewable integration. Such sequencing prevents carbon lock-in and ensures long-term compatibility with net-



zero strategies.

Applying EE1st in post-war hotel reconstruction produces multidimensional outcomes. Environmentally, it reduces greenhouse gas emissions through structural demand minimisation. Economically, it improves lifecycle cost efficiency. Institutionally, it strengthens planning coherence.

Longitudinal analyses indicate that efficiency-led rebuilding produces more stable energy expenditure trajectories over 20–30 years compared to supply-led reconstruction. This stability is particularly critical in fragile post-conflict economies.

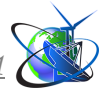
Post-war hotel reconstruction requires a systemic framework capable of integrating structural efficiency, renewable energy deployment, digital optimisation and institutional governance within a unified architecture. Fragmented interventions – implemented independently at building, technological, or policy levels – risk suboptimal performance, technological lock-in and financial inefficiency. Therefore, an integrated conceptual model is necessary to coordinate the sequencing and interaction of energy measures in reconstructed hospitality facilities.

The proposed Post-War Resilient Energy Architecture (PW-REA) conceptual model synthesises the Build Back Better principle and the Energy Efficiency First doctrine into a multilayered energy design structure. This model is grounded in systems theory, which conceptualises buildings as socio-technical energy nodes interacting with grids, markets and regulatory institutions. In post-war contexts, such systems must simultaneously address resilience, decarbonisation, affordability and operational continuity.

The model defines the hotel as a hybrid energy system comprising four interdependent layers:

1. Structural energy demand layer;
2. Technological conversion and supply layer;
3. Digital optimisation layer;
4. Governance and regulatory alignment layer.

These layers operate within clearly defined system boundaries, extending from the building envelope to grid interconnection and emergency islanding capability.



International resilience frameworks emphasise that reconstruction must consider interdependencies between physical infrastructure and institutional governance to ensure long-term sustainability (Table 4) [5].

**Table 4 – Structural Layer Components within the Integrated Model**

Component	Functional Objective	Resilience Contribution	Emission Reduction Impact
nZEB Envelope	Minimise thermal losses	Reduces dependence on external supply	30–50% primary energy reduction
Passive Cooling & Shading	Reduce solar heat gains	Maintains indoor comfort during outages	10–25% cooling load reduction
High-efficiency Glazing	Control thermal transmission	Stabilises internal temperature	15–30% heat loss reduction
Thermal Mass & Storage	Buffer temperature fluctuations	Enhances emergency resilience	Load shifting capacity

*Author's development*

Within the integrated architecture, structural demand reduction precedes energy supply expansion, in accordance with EE1st. Lower intrinsic demand reduces required HVAC system capacity and renewable generation size, thereby preventing capital oversizing.

The Technological Conversion and Supply Layer constitute the core infrastructural component of the integrated Post War Resilient Energy Architecture. It encompasses energy generation conversion storage and distribution systems that determine the operational autonomy and carbon intensity of reconstructed hotels. Decentralised configurations allow partial energy self sufficiency thereby mitigating exposure to external infrastructure disruptions (Table 5).

To operationalise the integrated architecture, measurable indicators must be established. These include:

- Primary energy consumption per square metre;
- Renewable energy share (%);
- Carbon intensity (kg CO<sub>2</sub>/m<sup>2</sup>);
- Backup autonomy duration (hours);
- Peak load reduction (%).



The architecture reduces lifecycle energy demand, enhances operational continuity during supply disruptions, mitigates carbon lock-in and aligns hospitality infrastructure with global climate objectives. Moreover, by embedding governance mechanisms and performance monitoring, it ensures that reconstruction investments generate durable environmental and economic value.

**Table 5 – Supply and Conversion Technologies**

Technology	Functional Role	Reconstruction Relevance	Carbon Reduction Potential
Heat Pumps	Electrified heating and cooling	Replaces fossil boilers	20–40% efficiency gain
Rooftop Photovoltaics	On-site electricity generation	Reduces grid vulnerability	15–35% CO <sub>2</sub> reduction
Battery Storage	Backup and peak shaving	Enables island mode	Enhances energy security
Hybrid Microgrid	Integrated PV + storage + grid	Supports partial autonomy	Improves system reliability

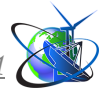
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### Conclusion

Post-war reconstruction of hotel infrastructure constitutes a decisive strategic moment when long-term energy trajectories are determined. The analysis confirms that reconstruction phases offer a unique opportunity to realign hotel energy systems with decarbonisation objectives, resilience standards and efficiency-oriented planning principles.

Integrating the Build Back Better principle into hotel energy reconstruction ensures that resilience is embedded not only in structural durability but also in energy performance. High-performance building envelopes, electrified heating and cooling systems, decentralised renewable generation and hybrid microgrids strengthen operational continuity under conditions of grid instability and supply uncertainty. This resilience dimension extends beyond environmental gains, reinforcing economic stability, risk mitigation and emergency preparedness in post-conflict regions.

The Energy Efficiency First doctrine provides the methodological sequencing required for effective reconstruction. By prioritising intrinsic demand reduction before

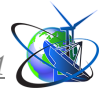


expanding supply capacity, EE1st prevents technological oversizing, reduces capital misallocation and lowers long-term operational expenditures. Structural efficiency improvements decrease peak loads, optimise system design and enhance compatibility with renewable integration.

Overall, post-war hotel energy reconstruction should be conceptualised as a multidimensional transformation process rather than a purely technical rebuilding task. The combined application of Build Back Better and Energy Efficiency First establishes a resilient, low-carbon and future-oriented energy architecture capable of supporting sustainable recovery and long-term climate alignment.

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