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A Proposed Project-Based Policy Framework for the **Greater Irbid Municipality** (GIM) to Integrate Algorithmic Analysis of Building Envelope Design for Energy-Efficient Residential Development in Irbid, Jordan into Actionable Local Regulations.

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A Proposed Project-Based Policy Framework for the Greater Irbid Municipality (GIM) to Integrate Algorithmic Analysis of Building Envelope Design for Energy-Efficient Residential Development in Irbid, Jordan into Actionable Local Regulations

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PREFACE

Achieving the 2030 Agenda requires more than translating global goals into national targets — it demands that sustainable development be rooted in the realities, needs, and capacities of local territories. Local and regional governments are indispensable actors in this process: they deliver essential services, address inequalities on the ground, and turn policy commitments into concrete actions. Yet this critical role is only fully effective when backed by strong evidence, meaningful knowledge exchange, and coherent governance across levels.

The Local2030 Knowledge and Scientific Network (KSN) was established within the UN Local2030 Coalition precisely to respond to this need. As a dynamic global platform, KSN connects young researchers, policymakers, community leaders, and practitioners around a shared mission: to harness science for sustainable development with local impact. It does so by aligning academic inquiry with the specific priorities of local development stakeholders, while amplifying research findings as inputs to SDG-related global processes.

Central to this approach is the understanding that research must not only be produced — it must be translated into policy and action. KSN promotes a more dynamic and responsive model of academia, one that co-creates scalable solutions rooted in scientific evidence and community priorities, and that empowers local actors with the skills, tools, and institutional support needed to engage in evidence-based decision-making and influence policy. Through its Country Pilots — sponsored by the Italian government and implemented by UN-Habitat and the Centro Studi di Politica Internazionale (CeSPI ETS) — and Innovation Labs, the network operationalizes this vision by connecting universities and students with local policymakers, enabling interdisciplinary collaboration and capacity-building in territories across Africa, Asia, and Latin America and the Caribbean.

Action-research is the methodological backbone of this work. Territories are engaged not as passive subjects of study, but as spaces for experimentation and learning, where sustained interaction between researchers, local governments, civil society, and communities drives learning, adaptation, and co-creation. By combining quantitative and qualitative methods — data analysis, spatial assessments, stakeholder engagement, and participatory approaches — this process generates a comprehensive and grounded understanding of local dynamics, inequalities, and development opportunities.

This policy paper is the result of that process. It reflects the outcome of collaboration between academic research, territorial analysis, and multi-stakeholder dialogue, in

the spirit of the KSN's core objective: translating research into policy and action. Its aim is to offer context-sensitive analysis and practical policy recommendations that can inform SDG localization at the local level — bridging the gap between global agendas and the communities that will ultimately determine their success.

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LIST OF ABBREVIATIONS

BIM	Building Information Modelling
EUI	Energy Use Intensity
EPBD	Energy Performance of Buildings Directive
GIM	Greater Irbid Municipality
HVAC	Heating, Ventilation, and Air Conditioning
KPI	Key Performance Indicator
M&E	Monitoring and Evaluation
MENA	Middle East and North Africa
MPWH	Ministry of Public Works and Housing
R-value	Thermal Resistance Value
SDG	Sustainable Development Goal
SHGC	Solar Heat Gain Coefficient
U-value	Thermal Transmittance
UN	United Nations
WWR	Window-to-Wall Ratio

EXECUTIVE SUMMARY

Policy problem

Greater Irbid Municipality faces rising residential energy demand driven by rapid urban growth and thermally inefficient building envelope practices. Existing municipal regulations emphasize zoning controls but lack enforceable performance-based energy standards.

Analytical evidence

Computational simulations demonstrate that optimized envelope parameters, including window-to-wall ratio, insulation performance, and glazing properties, can reduce residential cooling loads by up to 14% and overall energy use intensity by measurable margins without altering land-use regulations.

Priority policy actions

- Adopt quantitative building envelope performance thresholds.
- Integrate performance compliance into the municipal permit review process.
- Launch a pilot implementation programme targeting new residential developments.

Implementation logic

The reform embeds performance verification within existing municipal workflows, ensuring feasibility and administrative continuity while aligning with national energy strategy objectives.

Relevance for concept note development

The proposed pilot provides a scalable model for municipal-level energy governance reform, suitable for external technical assistance and climate-focused funding partnerships.

1. STRATEGIC CONTEXT

Jordan is a highly import-dependent country, relying on external sources for approximately 95% of its primary energy needs [1, 2]. Rapid population growth, urban expansion, and increasing housing demand, particularly in northern cities such as Irbid, have intensified pressure on the residential energy sector. Residential buildings account for the largest share of electricity consumption in Jordan, with heating and cooling loads representing the dominant portion of household energy expenditure and greenhouse gas emissions.

Irbid, as the second-largest city and the most densely populated governorate in Jordan [3], is a vital testing ground for policy interventions which align urban development with energy performance and climate change targets. While current national building regulations provide general outlines on construction practices, local municipal policies focus primarily on building codes such as zoning, setbacks, and building heights, with limited standards for building envelope design and performance.

The building envelope refers to the physical boundary separating indoor and outdoor environments, including external walls, roofs, windows, glazing systems, and insulation layers. It regulates heat transfer, solar radiation, air infiltration, and daylight penetration, thereby directly influencing heating and cooling demand. In climates such as Irbid's semi-arid conditions, poorly insulated walls, excessive window-to-wall ratios (WWR), and inefficient glazing significantly increase cooling loads and long-term electricity consumption.

International experience demonstrates that envelope-focused regulations can substantially reduce residential energy demand. The European Union's Energy Performance of Buildings Directive (EPBD) requires minimum thermal performance standards for walls, roofs, and windows [5]. In California, Building Energy Standards mandate maximum glazing ratios and insulation thresholds are mandated to control cooling demand [6, 7]. Similarly, countries in the Gulf region, such as the United Arab Emirates, through the Estidama Pearl Rating System, integrate envelope performance requirements into building approvals to address hot-climate energy loads [7].

The absence of similarly quantified, enforceable envelope standards at the municipal level in Irbid represents a missed opportunity to reduce energy demand through passive, design-based strategies before reliance on mechanical systems. Embedding envelope performance standards into municipal codes, cities can institutionalize passive energy efficiency at the design stage, ensuring long-term

reductions in operational demand without increasing urban density or altering land-use patterns.

This policy paper translates the results of a computational architectural approach into an actionable project-based policy framework. It proposes that the Greater Irbid Municipality integrate algorithmic analysis of building envelope performance standards into local regulations.

2. POLICY RATIONALE AND PROBLEM DEFINITION

2.1 Housing, energy, and climate pressures in Jordan

Jordan is a Middle Eastern country with limited domestic fossil fuel resources and a high level of energy dependency, importing approximately 95% of its energy demand. This structural reliance puts national and municipal energy systems at risk of global fuel price volatility and supply disruptions, creating significant economic and planning uncertainties for local authorities. At the municipal level, these challenges translate into increasing energy costs for urban infrastructure and housing.

Within this national context, Greater Irbid Municipality faces compounded demographic pressures driven by sustained population growth and migration inflows. In 2020, Irbid Governorate's population reached approximately 2,003,800 residents, representing 18.5% of Jordan's total population, making it the second most populous governorate after Amman. With an estimated population density of 1,275 persons per km², it is the most densely populated governorate in the country [3, 8, 9]. Over recent decades, Irbid has expanded from a small urban footprint of 0.28 km² in the late 19th century to more than 359 km², reflecting accelerated urban expansion. Migration flows, including refugee arrivals from neighbouring countries, have further intensified housing demand. These demographic dynamics have significantly increased residential construction activity and, consequently, energy demand for heating and cooling in the building sector.

The residential sector accounts for approximately 46% of total electricity consumption in Jordan, with nearly 57% of this consumption attributable to heating and cooling [10, 11]. This highlights the vital role of building design and envelope performance in shaping local energy demand. For municipalities such as Greater Irbid, enhancing building envelope energy performance represents one of the most effective approaches to reducing electricity consumption and decreasing pressure on the national grid.

However, around 85% of Jordan's electricity generation remains dependent on fossil fuels, resulting in increased greenhouse gas emissions and higher household energy

bills [12-14]. Municipalities should therefore play a critical role as implementation agents of local energy and climate goals. Enforcing local building codes, especially those focusing on building envelope efficiency, thermal performance, and environmentally sound design, is critical to reducing residential building energy consumption and supporting Jordan's commitments to energy security, climate mitigation, and sustainable urban development.

The policy challenge is not merely technical but institutional: current municipal regulations lack quantitative performance criteria to guide architects and developers toward energy-efficient building envelope design. This policy paper therefore proposes a municipal regulatory reform centred on integrating building envelope energy performance standards into local building approval processes. Specifically, it recommends the adoption of enforceable, climate-responsive thresholds for key envelope parameters, such as window-to-wall ratio (WWR), insulation performance, and glazing properties, using scientific simulation results as the evidentiary basis for regulation. By institutionalizing building envelope performance as a mandatory design requirement, the proposed reform shifts municipal oversight from purely dimensional controls toward performance-based energy governance.

Although Jordan has established national thermal insulation requirements and issued a Green Building Guide, these instruments are not systematically enforced at the municipal level. Consequently, envelope-related design decisions are often left to individual developers without quantitative performance benchmarks. This has led to inconsistent building performance, higher electricity bills for residents, and increased emissions from fossil fuel-based power generation.

The core issue is not a lack of technical knowledge, but the absence of locally grounded, evidence-based regulatory thresholds that can be realistically implemented and monitored by municipalities. This policy paper addresses this gap by leveraging computational simulation results that quantify how envelope parameters affect energy use intensity (EUI) in Irbid's residential buildings. Institutionally, these benchmarks should be incorporated by the Greater Irbid Municipality into the building permit review process. During the design submission stage, architects would be required to demonstrate compliance with predefined envelope performance criteria either through simplified simulation outputs or standardized performance checklists. Municipal engineers and planning officers would verify compliance as part of routine plan review, similar to current zoning and setback verification procedures. In this way, computational simulation becomes not a post-design academic exercise, but a pre-construction regulatory tool embedded within existing municipal workflows.

3. RESEARCH-BASED EVIDENCE AND ANALYTICAL FOUNDATION

The analytical foundation of this policy paper is based on a UN-supported scientific study that applies a computational architecture approach to evaluate building envelope performance in Irbid's residential context. Unlike conventional post-design energy assessments, this approach integrates parametric analysis into early design stages, enabling systematic exploration of multiple envelope configurations and their energy implications.

A representative Type B residential apartment, reflecting the most prevalent housing category in Irbid, was selected as the baseline model. Using Building Information Modelling (BIM) tools, the apartment geometry and construction assemblies were digitized and linked to parametric design software (Rhino/Grasshopper). This enabled controlled variation of envelope parameters, including wall insulation materials, window-to-wall ratios (WWR), and glazing types.

Energy performance simulations were conducted using cloud-based energy modelling software under Jordanian climatic conditions. The simulations quantified energy use intensity (EUI) as well as heating and cooling loads for each envelope scenario. Importantly, the analysis demonstrated that envelope variables operate as an interconnected system rather than isolated components. For example, increased glazing ratios amplified cooling demand unless compensated by improved insulation or high-performance glazing.

The results demonstrate that optimized envelope configurations can measurably reduce residential energy demand without altering building form, density, or land-use parameters. For example, the simulations show that increasing the window-to-wall ratio (WWR) from 10% to 40% leads to a 9.2% increase in energy use intensity (EUI), a 20% rise in heating loads, and up to a 30% increase in cooling loads. Conversely, upgrading wall insulation and optimizing glazing properties reduced overall EUI by approximately 4% and cooling loads by up to 14%, depending on the configuration. These quantified reductions indicate that meaningful energy savings can be achieved through targeted regulatory adjustments to envelope parameters rather than large-scale urban restructuring.

Key parameters evaluated included:

- Wall insulation materials and thicknesses
- Window-to-wall ratio (WWR)
- Glazing type and thermal properties

The underlying UN research paper applied a computational architecture approach using BIM-based modelling, parametric design tools (Rhino/Grasshopper), and cloud-based energy simulation software (Cove Tool). A representative Type B residential apartment – typical of Irbid's dominant housing typology – was analysed under multiple envelope scenarios.

The simulations demonstrated that envelope parameters interact dynamically rather than independently. Optimized combinations of insulation, glazing, and WWR resulted in substantial reductions in heating and cooling loads, leading to lower EUI values and improved thermal comfort. These findings provide a strong empirical basis for introducing performance-oriented municipal regulations.

4. STRATEGIC RELEVANCE AND ALIGNMENT WITH THE SUSTAINABLE DEVELOPMENT GOALS

The proposed policy framework is strategically aligned with international and national sustainability agendas by translating quantified building energy performance evidence into actionable municipal regulation. Grounded in computational analysis of Irbid's dominant residential typology, the framework advances the Sustainable Development Goals not at a conceptual level, but through measurable, enforceable interventions within the residential building sector.

4.1 Alignment with SDG 7: affordable and clean energy

This policy framework directly supports SDG 7 by targeting the residential sector, which constitutes the largest share of electricity consumption in Jordan and is primarily driven by heating and cooling demand. The research demonstrates that envelope-related design decisions, particularly window-to-wall ratio (WWR), insulation type and thickness, and glazing performance, have a statistically significant impact on energy use intensity (EUI) under Irbid's semi-arid climate conditions. By institutionalizing optimized envelope performance thresholds within municipal building regulations, the policy reduces operational energy demand at the source, rather than relying on post-occupancy or technology-dependent solutions.

At the household level, this approach translates into long-term reductions in electricity bills, mitigating energy cost burdens that are exacerbated by Jordan's heavy reliance on imported fossil fuels. At the national level, cumulative reductions in residential electricity demand contribute to lower energy imports, easing fiscal pressure on the energy sector and enhancing energy security. By prioritizing passive design strategies over high-cost mechanical systems, the framework ensures that energy efficiency gains remain economically accessible, particularly for middle and lower-income households.

4.2 Alignment with SDG 13: climate action

The framework also advances SDG 13 by directly linking municipal building regulations to emissions mitigation outcomes. As approximately 85% of Jordan's electricity is generated from fossil fuels [12-14], reductions in residential energy demand lead to proportional decreases in greenhouse gas emissions. The research quantifies how optimized envelope configurations reduce cooling-dominated energy loads, which are expected to intensify under future climate warming scenarios in northern Jordan.

By embedding climate-responsive envelope standards into the early stages of building approval, the policy shifts climate action from voluntary design practice to mandatory regulatory compliance. This approach strengthens urban climate resilience by ensuring that new housing stock is inherently better adapted to rising temperatures, increased cooling demand, and long-term climatic variability, thereby reducing future retrofit needs and lock-in effects associated with inefficient construction.

4.3 SDG localization and municipal governance

At the municipal level, the proposed policy framework exemplifies SDG localization by operationalizing global sustainability targets through locally enforceable building regulations. Rather than treating the SDGs as aspirational objectives, the framework translates them into quantitative performance benchmarks aligned with Irbid's climatic conditions, construction practices, and regulatory capacities. This strengthens the role of the Greater Irbid Municipality as a key intermediary between national commitments and on-the-ground implementation.

Moreover, the framework complements existing national strategies on energy efficiency, thermal insulation, and climate resilience by addressing a critical implementation gap at the municipal scale. While national policies provide overarching guidance, their effectiveness depends on local enforcement mechanisms. By equipping GIM with evidence-based regulatory tools derived from locally calibrated simulations, the policy enhances vertical policy coherence between national energy strategies and municipal planning instruments.

4.4 Strategic value

Collectively, this alignment positions the proposed intervention as a high-impact, low-cost policy mechanism that simultaneously advances energy affordability, climate mitigation, and institutional capacity building. By anchoring SDG 7 and SDG 13 within municipal building regulations, the framework ensures that sustainability objectives are systematically integrated into everyday development decisions, supporting a more resilient, energy-efficient, and climate-responsive urban housing sector in Irbid.

5. PROPOSED INTERVENTION LOGIC (THEORY OF CHANGE)

5.1 Problem

Residential energy consumption in Irbid is structurally high due to the widespread use of thermally inefficient building envelopes combined with limited municipal enforcement of quantitative energy performance requirements. Current municipal building regulations emphasize zoning controls, such as plot coverage, setbacks, and height, while offering minimal enforceable guidance on envelope parameters such as window-to-wall ratio (WWR), insulation performance, and glazing properties. As demonstrated by the computational simulations in this study, unrestricted façade glazing, suboptimal insulation thicknesses, and non-optimized glazing specifications significantly increase heating and cooling loads under Irbid's semi-arid climate conditions.

This regulatory gap leads to long-term consequences, including elevated household energy bills, increased peak electricity demand, higher dependence on imported fossil fuels, and reduced thermal comfort, disproportionately affecting middle and low-income households.

5.2 Inputs

5.2.1 Computational research evidence

The study provides quantitative, locally calibrated thresholds for envelope performance, linking WWR, insulation type and thickness, and glazing characteristics directly to energy use intensity (EUI) and heating and cooling loads for Irbid's dominant residential typology. This evidence moves beyond generic energy-efficiency principles by offering climate-specific and market-realistic benchmarks applicable to municipal regulatory frameworks.

5.2.2 Municipal regulatory authority

The Greater Irbid Municipality (GIM) holds the institutional mandate to revise

building approval requirements, integrate performance criteria into permitting processes, and condition construction approvals on compliance with updated envelope standards. This authority enables the translation of technical findings into enforceable regulatory instruments.

5.2.3 Existing technical capacity within GIM

Municipal planning and engineering departments already conduct plan review, inspections, and compliance checks. With targeted capacity building, this existing structure can absorb and operationalize quantitative envelope performance criteria without requiring the creation of new institutions.

5.3 Activities

Draft and adopt amendments to municipal building regulations incorporating quantitative envelope performance thresholds (e.g., maximum WWR limits, minimum insulation values, glazing performance criteria).

Develop standardized compliance documentation templates requiring architects to submit envelope performance calculations or simplified simulation outputs during the building permit application stage.

Train municipal engineers and planning officers on interpreting envelope performance indicators (R-values, U-values, SHGC, EUI thresholds) and verifying compliance during plan review.

Pilot the revised standards on selected residential permit applications to test administrative feasibility and refine enforcement procedures before city-wide implementation.

Publish technical guidance documents for architects and developers outlining compliance pathways and example envelope configurations aligned with regulatory requirements.

5.4 Outputs

The immediate outputs of the intervention include revised municipal building regulations that explicitly reference envelope performance criteria alongside conventional planning controls, and standardized envelope performance benchmarks applicable to residential developments, providing designers and developers with predictable and transparent requirements during early design

stages. These outputs institutionalize evidence-based decision-making within GIM's regulatory framework.

5.5 Outcomes

In the medium term, the intervention is expected to result in reduced residential energy consumption, particularly for heating and cooling, as new residential buildings comply with optimized envelope standards, and improved indoor thermal comfort resulting from reduced heat gains and losses, thereby enhancing occupant well-being without increasing operational energy demand.

5.6 Impact

At the city scale, the intervention contributes to enhanced energy security by lowering electricity demand in a city heavily dependent on imported energy; improved energy affordability through reduced long-term household energy expenditures; and increased climate resilience as buildings become better adapted to rising temperatures and climate variability.

Collectively, this intervention supports SDG 7 by improving energy efficiency in the residential sector and SDG 13 by reducing emissions associated with fossil fuel-based electricity generation, while strengthening the role of GIM as a key actor in localizing global sustainability goals.

6. PROPOSED POLICY MEASURES

To operationalize the research findings and translate computational evidence into enforceable action, this policy framework proposes a set of interlinked municipal measures targeting building envelope performance in new residential developments. These measures are designed to be evidence-based, locally calibrated, and institutionally feasible within the regulatory mandate of the Greater Irbid Municipality, while allowing flexibility for designers and developers.

6.1 Municipal envelope performance standards

The first policy measure proposes the introduction of quantitative envelope performance standards within municipal building regulations. Based on the computational analysis conducted in this study, envelope parameters, particularly window-to-wall ratio (WWR), insulation type and thickness, and glazing properties, have a measurable and significant impact on residential energy demand in Irbid's semi-arid climate.

Accordingly, the municipality should establish maximum allowable WWR ranges for residential buildings, differentiated by housing typology where relevant. The research demonstrates that increases in WWR beyond moderate thresholds result in disproportionate increases in cooling loads, indicating the need for regulatory limits to prevent long-term energy inefficiency.

In parallel, municipal regulations should require minimum insulation performance levels, expressed in thermal resistance (R-value) or equivalent metrics, calibrated to local climate conditions and construction practices. Rather than mandating specific materials, the regulation should define minimum performance thresholds that can be met using locally available insulation systems, ensuring both technical feasibility and market compatibility.

6.2 Performance-based compliance approach

To avoid overly rigid or prescriptive regulations, the policy adopts a performance-based compliance model. Under this approach, architects and developers retain

design flexibility, provided that the proposed building envelope meets or exceeds defined energy performance benchmarks.

This model shifts regulatory emphasis from specifying construction methods to verifying energy outcomes, such as maximum allowable energy use intensity (EUI) or heating and cooling load thresholds. The computational methodology demonstrated in the research supports this approach by showing how envelope parameters can be evaluated quantitatively at early design stages.

Performance-based compliance encourages architectural innovation while ensuring that energy efficiency objectives are achieved. It also reduces resistance from the private sector, as developers are not constrained to a single construction solution, but are instead guided by clear and measurable performance targets.

6.3 Digital review and simulation support

To support effective implementation, the policy recommends integrating simplified digital simulation tools into the municipal permit review process, particularly for medium and large-scale residential projects. While full-scale energy modelling may not be feasible for all applications, simplified or template-based simulation workflows can be used to verify compliance with envelope performance standards.

The research demonstrates the value of computational workflows in linking design parameters with energy outcomes. Adapting this approach for municipal use through standardized digital checklists, simplified simulation inputs, or pre-approved envelope configurations can significantly enhance regulatory effectiveness without overburdening municipal staff.

This measure also supports transparent and objective decision-making, reducing reliance on subjective interpretation during plan review and strengthening consistency across permitting cases.

6.4 Capacity building and awareness

Regulatory reform alone is insufficient without corresponding investment in institutional capacity and stakeholder awareness. This policy therefore prioritizes targeted capacity building for municipal engineers, planners, and inspectors to ensure effective interpretation, evaluation, and enforcement of envelope performance standards.

Training programmes should focus on:

- Understanding envelope performance metrics (e.g., WWR, R-values, glazing properties).
- Interpreting basic energy simulation outputs.
- Applying performance-based criteria during plan review and site inspection.

In parallel, the municipality should develop clear guidance documents for architects, engineers, and developers. These documents would translate regulatory requirements into practical design guidance, illustrating compliant envelope configurations, recommended performance ranges, and common compliance pathways based on local construction practices.

Such guidance reduces uncertainty for the private sector, accelerates permit approvals, and fosters a shared understanding of energy-efficient design objectives across stakeholders.

6.5 Policy coherence and implementation value

Collectively, these measures form a coherent regulatory package that balances technical rigour with institutional feasibility. By embedding envelope performance standards into municipal regulations, enabling performance-based compliance, supporting digital review processes, and strengthening technical capacity, the proposed policy framework ensures that energy efficiency objectives are systematically integrated into residential development in Irbid.

This approach directly addresses the implementation gap identified in the research, where national energy-efficiency guidance exists but lacks consistent municipal enforcement, thereby transforming computational research outcomes into durable, scalable, and locally enforceable policy instruments.

7. STAKEHOLDER MAPPING AND GOVERNANCE ARRANGEMENTS

Effective implementation of the proposed envelope performance policy requires a coordinated multi-level governance structure that clearly defines stakeholder roles, responsibilities, and channels of interaction. Given that building energy performance is shaped by decisions made across regulatory, technical, and market domains, the success of this framework depends on structured collaboration between municipal authorities, national institutions, the private sector, academia, and end users.

7.1 Greater Irbid Municipality: regulatory authority and implementation lead

The Greater Irbid Municipality serves as the primary regulatory authority and the central actor responsible for translating policy objectives into enforceable local instruments. GIM's role includes integrating envelope performance standards into municipal building regulations, overseeing compliance during permit review, and ensuring enforcement during construction and inspection phases.

By embedding quantitative performance thresholds into its regulatory framework, GIM can directly influence the energy efficiency of new housing stock and act as the key conduit for localizing national energy and climate objectives.

7.2 Ministry of Public Works and Housing: national policy alignment

The Ministry of Public Works and Housing plays a critical coordination and alignment role, ensuring consistency between municipal regulations and national building codes, energy efficiency strategies, and climate commitments. Through formal coordination mechanisms, the Ministry can facilitate harmonization between national standards and municipal enforcement practices by issuing technical circulars that authorize municipalities to adopt locally calibrated envelope performance thresholds consistent with national insulation requirements, establishing joint technical committees to review and align regulatory amendments,

and integrating municipal envelope standards into national building code guidance documents. Periodic reporting and compliance monitoring frameworks can further ensure that municipal enforcement practices remain consistent with national energy efficiency strategies.

7.3 Architects and developers: primary implementers

Architects, engineers, and developers are the frontline implementers of the proposed policy framework. Their design choices directly determine envelope performance outcomes, including WWR, insulation levels, and glazing specifications. A performance-based compliance approach enables these stakeholders to maintain design flexibility while meeting defined energy performance benchmarks.

Clear municipal guidelines and predictable regulatory requirements reduce uncertainty for the private sector, encourage early-stage integration of energy efficiency considerations, and help avoid costly design revisions.

7.4 Academic institutions: technical support and monitoring

Academic institutions play a strategic role as technical advisors and knowledge partners. Drawing on computational design and energy simulation expertise, universities and research centres can support municipalities by refining performance benchmarks, validating simulation methodologies, and assisting with the development of guidance documents and training programmes. Academic involvement ensures that municipal regulations remain evidence-based, locally calibrated, and adaptable to evolving climate data and construction practices.

7.5 Residents: end beneficiaries

Residents are the ultimate beneficiaries of improved envelope performance, experiencing reduced electricity bills, enhanced indoor thermal comfort, and increased resilience to extreme weather conditions. By prioritizing passive envelope strategies rather than technology-intensive solutions, the policy framework ensures that benefits accrue across income groups, supporting affordability and reducing energy vulnerability at the household level.

7.6 Multi-level governance and policy coherence

The proposed regulatory reform is designed to complement – not replace – existing national building and energy frameworks. At the national level, Jordan has established thermal insulation requirements and articulated energy efficiency priorities within the Jordan Energy Strategy (2020–2030). However, these national instruments provide broad technical guidance without specifying climate-calibrated envelope performance thresholds tailored to municipal housing typologies.

The municipal reform in Irbid operationalizes these national objectives by translating them into locally enforceable standards within the building permit process. Regulatory amendments at the municipal level would be reviewed in coordination with the Ministry of Public Works and Housing, maintaining legal compatibility with national building codes. This vertical integration allows Irbid to act as an implementation arm of national energy policy, strengthening alignment between municipal enforcement practices and Jordan's broader energy security and climate mitigation objectives.

8. RISK ASSESSMENT AND MITIGATION

The implementation of municipal envelope performance standards involves regulatory, institutional, and market-related risks that must be proactively managed to ensure policy effectiveness and long-term sustainability.

8.1 Risk 1: resistance from developers due to perceived cost increases

A primary risk is resistance from developers and contractors who may perceive enhanced envelope performance requirements as increasing upfront construction costs. In Irbid's residential market, where affordability and speed of construction are often prioritized, stricter envelope standards may initially be viewed as a regulatory burden rather than a value-enhancing measure. However, the computational analysis demonstrate that optimized envelope design – particularly controlled window-to-wall ratios, improved insulation performance, and appropriate glazing selection – leads to measurable reductions in heating and cooling loads and overall energy use intensity. These reductions translate into lower operational energy costs over the building lifecycle, offsetting modest increases in initial construction expenditure.

8.1.1 Mitigation strategy

The policy proposes implementing pilot residential projects that apply the proposed envelope standards and document their performance over time. These pilots can generate local, evidence-based comparisons of construction costs versus operational savings, demonstrating lifecycle cost benefits to developers, homeowners, and financiers.

8.2 Risk 2: limited technical capacity within municipal institutions

A second critical risk relates to the technical capacity of municipal staff to interpret, evaluate, and enforce performance-based envelope standards. Municipal planning and engineering departments are traditionally oriented toward zoning compliance and dimensional checks rather than quantitative energy performance assessment.

Without adequate capacity, there is a risk of inconsistent enforcement, delays in permit review, or reduced regulatory credibility.

8.2.1 Mitigation strategy

This risk can be mitigated through targeted capacity-building programmes and phased implementation. Initial phases may focus on simplified performance indicators (e.g., maximum WWR ranges, minimum insulation values) that can be verified using standardized checklists, before gradually integrating simplified digital simulation tools for larger or more complex projects.

Training workshops for municipal engineers and planners, supported by academic institutions and technical experts, can strengthen internal capacity while minimizing disruption to existing workflows. A phased rollout allows institutional learning, reduces implementation pressure, and ensures that enforcement capacity evolves in parallel with regulatory complexity.

8.3 Risk management and adaptive implementation

By explicitly identifying and addressing these risks, the proposed policy framework adopts a preventive and adaptive implementation approach. Linking regulatory reform with pilot projects, capacity development, and incremental enforcement reduces institutional and market resistance while enhancing long-term compliance and policy durability.

9. MONITORING AND EVALUATION FRAMEWORK

Monitoring and evaluation (M&E) are essential to ensure that the proposed policy measures translate into measurable energy and climate outcomes. The M&E framework should remain practical, data-driven, and aligned with existing administrative processes.

Key performance indicators (KPIs) may include:

- Average reduction in residential energy use intensity (EUI) for newly permitted buildings.
- Percentage of new residential permits complying with envelope performance benchmarks.
- Estimated reduction in annual heating and cooling loads per dwelling.
- Household electricity cost savings attributable to improved envelope performance.

Data sources can include building permit documentation, simplified simulation outputs submitted during the approval process, and aggregated electricity consumption data provided by utility companies. Academic institutions and research centres may support periodic evaluation studies to validate long-term impacts.

The introduction of pilot districts or phased implementation zones within Irbid can further support adaptive learning, allowing municipal authorities to refine standards before broader scaling.

10. RESOURCE MOBILIZATION AND FINANCING CONSIDERATIONS

While this policy paper does not propose a detailed budget, implementation can be supported through a combination of municipal resources, national programmes, and international cooperation mechanisms. Potential financing modalities include:

- Integration with national energy efficiency and climate action programmes.
- Technical assistance grants from international development partners.
- Public-private partnerships supporting capacity building and digital permitting tools.

The policy framework aligns with donor priorities related to SDG localization, climate mitigation, and urban resilience, enhancing its eligibility for external support.

11. PATHWAY TO PILOT IMPLEMENTATION

The proposed regulatory reform is designed to transition from policy recommendation to pilot implementation within the Greater Irbid Municipality. As a first phase, a pilot program can be launched targeting newly submitted Type B residential developments. The pilot would test the integration of envelope performance thresholds into the municipal permitting process, including submission templates, compliance checklists, and staff training. Performance monitoring would track compliance rates, projected energy reductions, and administrative feasibility. Lessons learned from the pilot phase would inform refinement prior to city-wide adoption and potential replication in other Jordanian municipalities.

12. POTENTIAL FUNDING AND PARTNERSHIP OPPORTUNITIES

The proposed pilot aligns closely with the priorities of international development partners focusing on SDG localization, climate mitigation, and energy efficiency in urban systems. Potential funding partners may include multilateral climate funds, urban resilience initiatives, bilateral development agencies supporting municipal governance reform, and international cooperation programmes focused on energy transition in the MENA region. Technical assistance could support digital permitting tools, staff training, and pilot evaluation.

13. ECONOMIC VALUE OF ENVELOPE PERFORMANCE MEASURES

Integrating building envelope performance measures, such as enhanced wall insulation layers, optimized window-to-wall ratios, and high-performance glazing, may result in modest increases of initial construction costs. These additional costs are primarily associated with improved insulation materials and energy-efficient glazing systems. However, the long-term operational benefits significantly outweigh these upfront investments. The computational simulations conducted in this research demonstrate that optimized envelope configurations can reduce cooling loads by up to 14% and lower overall energy use intensity (EUI), leading directly to reduced household electricity consumption.

In a climate such as Irbid's, where residential electricity demand is largely driven by heating and cooling needs, these reductions translate into lower monthly electricity bills for households and reduced pressure on the national energy system. While estimating precise lifecycle cost savings remains challenging due to fluctuations in construction material prices, inflation, and changes in energy tariffs, the quantified energy reductions provide a reliable proxy for economic benefits. Consequently, even modest improvements in envelope performance can produce cumulative financial savings for residents over the building's lifespan while simultaneously reducing greenhouse gas emissions associated with fossil fuel-based electricity generation.

14. POLICY RECOMMENDATIONS FOR DECISION-MAKERS

To translate research findings into actionable and scalable regulatory reform, the following policy recommendations are proposed for municipal and national decision-makers. These recommendations emphasize practicality, evidence-based governance, and alignment with existing institutional capacities.

14.1 Adopt evidence-based envelope performance thresholds at the municipal level

Decision-makers are encouraged to formally adopt quantitative building envelope performance thresholds within municipal building regulations. The computational analysis demonstrates that parameters such as window-to-wall ratio (WWR), insulation performance, and glazing properties have a direct and measurable impact on residential energy demand under Irbid's climatic conditions.

By embedding locally calibrated thresholds into municipal codes, authorities can move beyond generic or advisory guidance and establish enforceable standards that shape energy performance outcomes at the design stage.

14.2 Integrate computational tools into early-stage planning and permitting

Municipal authorities should integrate simplified computational and simulation-based tools into early-stage planning and permitting processes, particularly for medium and large-scale residential developments. As demonstrated in the research, early-stage evaluation of envelope performance enables informed decision-making before architectural and construction choices become fixed.

Rather than requiring advanced modelling for all projects, decision-makers can adopt tiered or simplified digital workflows, such as standardized templates or pre-

approved envelope configurations, that support objective performance verification while remaining administratively feasible.

14.3 Pilot the framework in Irbid prior to national scaling

It is recommended that the proposed policy framework be piloted within the Greater Irbid Municipality before broader national adoption. Irbid represents a suitable testing ground due to its rapid residential growth, high energy demand, and dominance of standardized housing typologies.

Piloting allows decision-makers to evaluate regulatory feasibility, market response, institutional capacity, and real-world energy performance outcomes under local conditions. Lessons learned from implementation can then inform refinements prior to scaling the framework to other municipalities.

14.4 Strategic value for policymakers

Collectively, these recommendations offer a low-risk, high-impact pathway for improving residential energy efficiency through municipal governance. By combining evidence-based thresholds, early-stage computational evaluation, and phased implementation, decision-makers can institutionalize sustainable building practices, reduce long-term energy demand, and strengthen alignment between national energy strategies and local urban development processes.

15. CONCLUSION

Embedding computationally informed building envelope standards into municipal regulations represents a low-cost, high-impact strategy for addressing Jordan's energy and climate challenges. By acting at the design stage, where long-term energy performance is determined, municipalities such as Irbid can significantly reduce residential energy demand, improve household affordability, and contribute to national climate commitments.

This policy paper demonstrates that scientific research, when translated into regulatory language and institutional mechanisms, can serve as a powerful tool for sustainable urban governance. The proposed framework positions the Greater Irbid Municipality not only as a regulator, but as an active agent in SDG implementation and climate-responsive urban development. With appropriate scaling and coordination, this approach can inform national policy reform and serve as a replicable model for other Jordanian cities.

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